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ATPL GROUND TRAINING SERIES

BOOK NINE
EASA FIRST EDITION
REVISED FOR NPA 29

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Introduction

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ATPL Book 9 Meteorology

I Introduction

Chapter

1

The Atmosphere

A Definition of Meteorology

"The branch of science dealing with the earth's atmosphere and the physical processes occurring in it."

Reasons for Studying Meteorology

- To understand the physical processes in the atmosphere
- To understand the meteorological hazards, their effect on aircraft and how to minimize the risks posed by those hazards
- To identify the weather information that is required for each flight
- To interpret actual and forecast weather conditions from the documentation provided
- To analyse and evaluate weather information before flight and in-flight
- To devise solutions to problems presented by weather conditions

Weather is the one factor in modern aviation over which man has no control; a knowledge of meteorology will at least enable the aviator to anticipate some of the difficulties which weather may cause.

Weather-influenced Accidents to UK Transport Aircraft

Table 1 Transport aircraft accidents, 1975 - 94

All accidents

	Aeroplanes			Rotorcraft			All aircraft		
Year	Total	WI	Per cent	Total	WI	Per cent	Total	WI	Per cent
1975-79	52	17	32.69	9	4	44.44	61	21	34.43
1980-84	67	20	29.85	20	7	35.00	87	27	31.03
1985-89	95	22	23.16	20	3	15.00	115	25	21.74
1990-94	216*	25	11.58*	20	6	30.00	236*	31	13.13*
1975-94	430	84	19.53	69	20	28.98	499	104	20.84

* Includes ramp and other minor ground accidents, hence low percentage figures.
WI: Weather-influenced

Accidents excluding selected ramp and other occurrences

	Aeroplanes			Rotorcraft			All aircraft		
Year	Total	WI	Per cent	Total	WI	Per cent	Total	WI	Per cent
1975-79	52	17	32.69	9	4	44.44	61	21	34.43
1980-84	67	20	29.85	20	7	35.00	87	27	31.03
1985-89	78	22	28.20	20	3	15.00	98	25	25.51
1990-94	101	25	24.75	20	6	30.00	121	31	25.62
1975-94	298	84	28.18	69	20	28.98	367	104	28.34

WI: Weather-influenced

Table 2 Weather-influenced accidents to transport aircraft by element of weather, 1975 - 94

	All Accidents		Fatal Accidents	
Element	No.	Percentage of total	No.	Percentage of total
Visibility	22	21.1	10	66.7
Icing/snow	22	21.1	3	20.0
Wind and turbulence	45	43.3	2	13.3
Rain/wet runway	12	11.5	0	0
Lightning	3	2.9	0	0
All cases	104	100	15	100

For this course a knowledge of advanced physics is not required, but a knowledge of the elementary laws of motion, heating, cooling, condensation and evaporation will be useful.

A Definition of the Atmosphere

"The spheroidal gaseous envelope surrounding a heavenly body."

The Constituents of the Atmosphere (By Volume)

Nitrogen	78.09%	Argon	0.93%
Oxygen	20.95%	Carbon Dioxide	0.03%

Plus traces of:

Neon	Nitrous Oxide	Helium	Nitrogen Dioxide
Krypton	Carbon Monoxide	Xenon	Sulphur Dioxide
Hydrogen	Ammonia	Methane	Iodine and Ozone

Also present are solid particles and, in particular, water vapour which, from a meteorological point of view, is the most important gas in the atmosphere.

The proportions of the constituents remain constant up to a height of at least 60 km (except for ozone), but above this the mixing processes associated with the lower levels of the atmosphere no longer exist and gravitational separation of the gases occurs. Although the trace of ozone in the atmosphere is important as a shield against ultraviolet radiation, if the whole of the layer of ozone were brought down to sea level it would only be 3 mm thick.

Properties of the Earth's Atmosphere

The earth's atmosphere varies vertically and horizontally in:

- Pressure.
- Temperature.
- Density.
- Humidity.

The earth's atmosphere is fluid, supports life only at lower levels and is a poor conductor.

The Structure of the Atmosphere

- **The Troposphere:**
  - is the lowest layer of the earth's atmosphere where temperature decreases with an increase in height.
  - consists of ¾ of the total atmosphere in weight.
  - contains almost all the weather.

- **The Stratosphere** is the layer above the troposphere where temperature initially remains constant to an average height of 20 km then increases to reach a temperature of -2.5°C at a height of 47 km, then above 51 km temperature starts to decrease again. The reason for the increase is the action of ultraviolet radiation in the formation of ozone. The boundary between the stratosphere and the next layer, the mesosphere is known as the stratopause. The average height of the stratopause is 50 km in temperate latitudes.

- **The Tropopause**:
  - This marks the boundary between the troposphere and the stratosphere and is where temperature ceases to fall with an increase in height. (Practically taken as the height where the temperature fall is less than 0.65°C per 100 m (2°C per 1000 ft.)

  - The height of the tropopause is controlled by the temperature of the air near the surface. The warmer the air, the higher the tropopause. The colder the air, the lower the tropopause. Therefore, temperature variations due to latitude, season, land and sea, will all cause varying heights of the tropopause. There are two locations where the tropopause abruptly changes height or "folds". These are at approximately 40° and 60° latitude. The average height of the tropopause at the Equator is 16-18 km with an average temperature of -75°C to -80°C, and at the poles 8 km with an average temperature of -40°C to -50°C. The average value at 50°N is 11 km (36 090 ft) with a temperature of -56.5°C.

  - The temperature of the tropopause is controlled by its height. The higher it is, the colder the temperature at the tropopause. The lower it is, the warmer the temperature at the tropopause. The temperature at the tropopause can be as high as -40°C over the poles and as low as -80°C over the Equator.

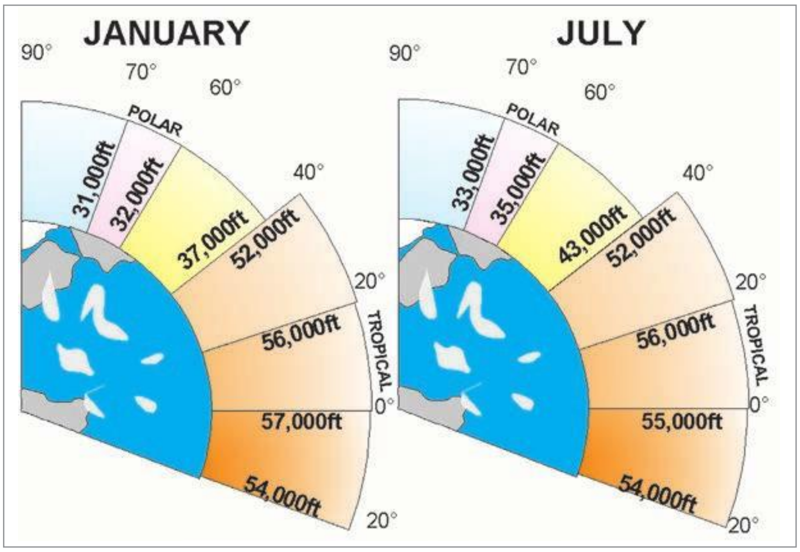


Figure 1.1 The mean height of the tropopause at the Greenwich Meridian

The Significance of Tropopause Height

The significance of the tropopause height is that it usually marks:

- the maximum height of significant cloud.
- the presence of jet streams.
- the presence of Clear Air Turbulence (CAT). It is now referred to as TURB.
- the maximum wind speed.
- the upper limit of most of the weather

Temperatures

Temperature in the troposphere increases from the poles to the Equator.

Temperature in the lower stratosphere increases from the Equator to the poles in summer but reaches max temperature in mid latitudes in winter.

Atmospheric Hazards

As aircraft operating altitudes increase, so concentrations of OZONE and COSMIC RADIATION become of greater importance to the aviator.

Above 50 000 ft, normal concentrations of ozone exceed tolerable limits and air needs to be filtered before entering the cabin. The heat of the compressor system will assist in the breaking down of the ozone to an acceptable level.

Cosmic radiation is not normally hazardous, but at times of solar flare activity a lower flight level may be necessary.

Advances in meteorological forecasting and communications should result in pilots receiving prompt and accurate information regarding high altitude hazards, but it is important that they should be aware of these hazards and prepared to take the necessary re-planning action.

The International Standard Atmosphere (ISA)

Because temperature and pressure vary with time and position, both horizontally and vertically, it is necessary, in aviation, to have a standard set of conditions to give a common datum for:

- the calibration of aircraft pressure instruments
- the design and testing of aircraft.

The standard atmosphere now used in aviation is the ICAO International Standard Atmosphere (ISA). ISA defines an 'average' atmosphere from -5 km (-16 400 ft) to 80 km (262 464 ft). For practical purposes we just need to look at the ISA between mean sea level and 20 km.

The ICAO International Standard Atmosphere (ISA) is:

- a MSL temperature of +15° Celsius,
- a MSL pressure of 1013.25 hectopascals (hPa),
- a MSL density of 1225 grams / cubic metre,
- a lapse rate of 0.65°C/100 m (1.98°C/1000 ft) up to 11 km (36 090 ft),
- a constant temperature of -56.5°C up to 20 km (65 617 ft),
- an increase of temperature 0.1°C/100 m (0.3° C/1000 ft), up to 32 km (104 987 ft).

Note: *Practically we use a lapse rate of 2°/1000 ft for calculations up to the Tropopause.*

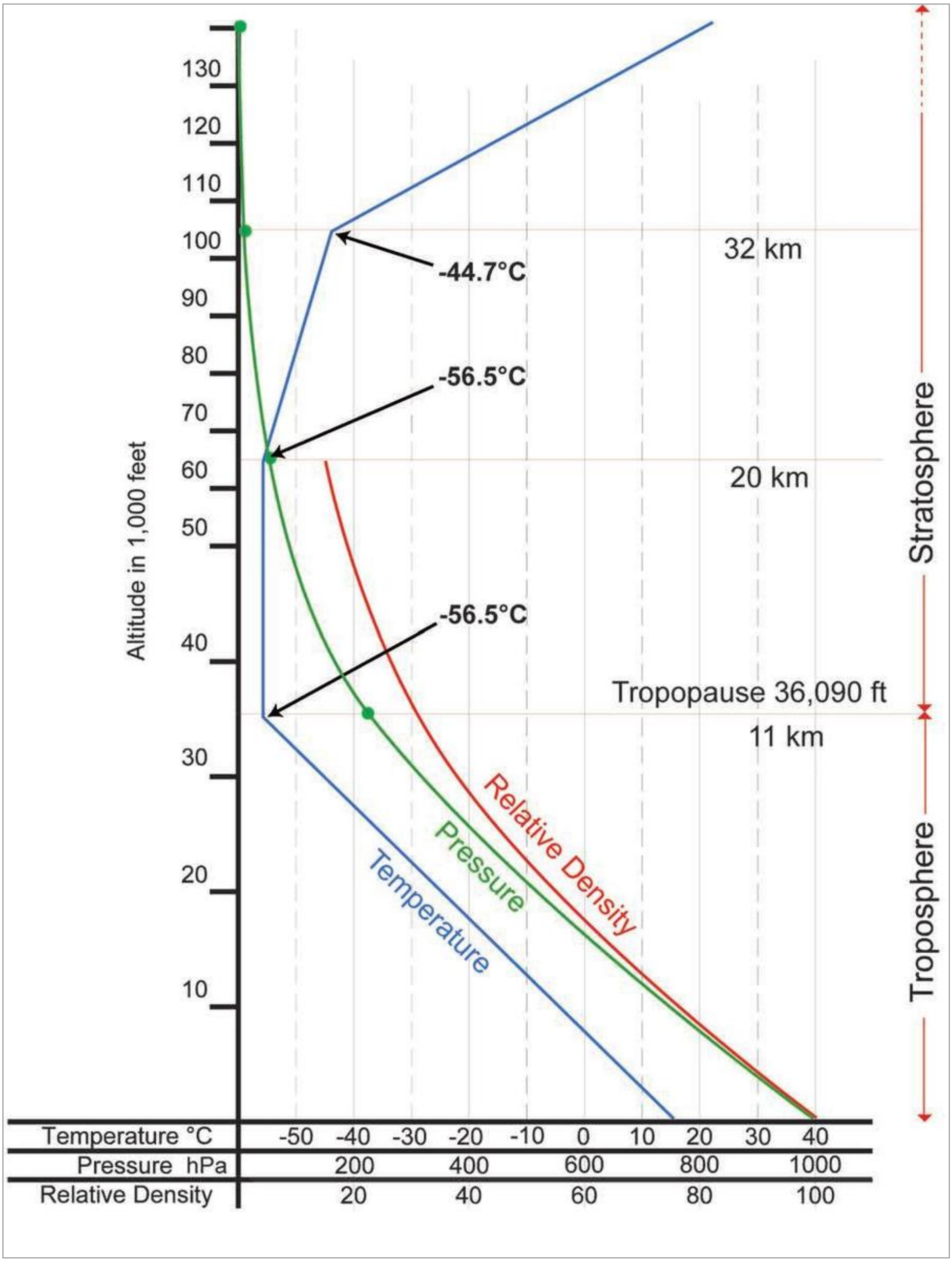


Figure 1.2 The International Standard Atmosphere (ISA).

ISA Deviation

To determine true altitude and for the assessment of performance data it is necessary to determine the temperature deviation from the ISA at any specified altitude. To do this we firstly need to determine what the ISA temperature is at a specified altitude, then calculate the deviation from the ISA.

The ISA temperature at a particular pressure altitude is found by reducing the MSL temperature by 2°C for each 1000 ft above 1013 hPa datum:

ISA Temperature = 15 - 2× altitude (in 1000 ft)

e.g. find the ISA temperature at 18 000 ft:

ISA temperature = 15 - 2 × 18 = -21°C

Note: *Remember the temperature is isothermal above 36 000 ft (11 km) in the ISA at -57°C.*

Now to find the deviation from ISA we subtract the ISA temperature from the actual temperature:

ISA Deviation = actual temperature - ISA temperature

So if the actual temperature at 18 000 ft is -27°C, then the deviation is:

ISA Deviation = -27 - (-21) = -6°

For the temperatures below, calculate the ISA deviations:

Height (ft)	Temperature (°C)	ISA Temperature	ISA Deviation
1500	+28		
17 500	-18		
24 000	-35		
37 000	-45		
9500	-5		
5000	+15		
31 000	-50		
57 000	-67		

If the limiting deviation for your aircraft at an airfield 5000 ft AMSL is ISA +10, what is the maximum temp at which you can operate?

If the deviation at 3500 ft is +12, what is the ambient temperature?

(Answers on page 14)

The ICAO International Standard Atmosphere

Height (km)	Height (ft)	Temp (°C)	Pressure (hPa)	Height Change (per hPa)	Density (%)
32.00	104 987	-44.7	8.9		1.1
30.48	100 000	-46.2	11.1		1.4
27.43	90 000	-49.2	17.3		2.2
24.38	80 000	-52.2	28.0		3.6
21.34	70 000	-55.2	44.9		5.8
20.00	65 620	-56.5	56.7		7.2
15.24	50 000	-56.5	116.6		15.3
13.71	45 000	-56.5	148.2		19.5
11.78	38 662	-56.5	200	103 ft	26.3
11.00	36 090	-56.5	228.2	91 ft	29.7
9.16	30 065	-44.4	300	73 ft	36.8
5.51	18 289	-21.2	500	48 ft	56.4
3.05	10 000	-4.8	696.8	37 ft	73.8
3.01	9882	-4.6	700	36 ft	74.1
1.46	4781	+5.5	850	31 ft	87.3
0	0	+15	1013.25	27 ft	100

Note: *The above height change figures show how the pressure against height change equation is modified as altitude changes but the figures offered only relate to ISA conditions of Temperature and Pressure. We can assess changes outside these conditions by using the following formula:*

$$H = \frac{96 \times T}{P}$$

where H = height change per hPa in feet
T = Actual Absolute Temperature at that level in kelvin (K)
P = Actual Pressure in hPa

Note: *this formula is only valid for calculating the height change per hPa change in pressure at a specified altitude; it cannot be used to calculate a change in height between two pressure levels, nor the change in pressure between two altitudes.*

Questions

1. **How does the height of the tropopause normally vary with latitude in the Northern Hemisphere?**

    a. It decreases from south to north
    b. It increases from south to north
    c. It remains constant from north to south
    d. It remains constant throughout the year

2. **What, approximately, is the average height of the tropopause over the Equator?**

    a. 8 km
    b. 16 km
    c. 11 km
    d. 50 km

3. **In the International Standard Atmosphere the decrease in temperature with height below 11 km is:**

    a. 0.5°C/100 m
    b. 0.6°C/100 m
    c. 0.65°/100 m
    d. 1°C/100 m

4. **The 200 hPa pressure altitude level can vary in height. In temperate regions which of the following average heights is applicable?**

    a. FL390
    b. FL300
    c. FL100
    d. FL50

5. **The temperature at FL110 is -12°C. What will the temperature be at FL140 if the ICAO standard lapse rate is applied?**

    a. -6°C
    b. -18°C
    c. -9°C
    d. -15°C

6. **At a certain position the temperature on the 300 hPa chart is -54°C, and according to the significant weather chart the tropopause is at FL330. What is the most likely temperature at FL350?**

    a. -48°C
    b. -60°C
    c. -56.5°C
    d. -64°C

7. **What is the boundary between the troposphere and the stratosphere called?**

    a. Ionosphere
    b. Stratosphere
    c. Atmosphere
    d. Tropopause

8. Which constant pressure altitude chart is standard for 4781 ft pressure level (FL50)?

a. 500 hPa
b. 300 hPa
c. 850 hPa
d. 700 hPa

9. An outside air temperature of -30°C is measured whilst cruising at FL200. What is the temperature deviation from the ISA at this level?

a. 5°C colder than ISA
b. 5°C warmer than ISA
c. 10°C colder than ISA
d. 10°C warmer than ISA

10. What is the most likely temperature at the tropical tropopause?

a. -56.5°C
b. -75°C
c. -40°C
d. -25°C

11. Which one of the following statements applies to the tropopause?

a. It is, by definition, an isothermal layer
b. It indicates a strong temperature lapse rate
c. It is, by definition a temperature inversion
d. It separates the troposphere from the stratosphere

12. In the lower part of the stratosphere the temperature:

a. is almost constant
b. decreases with altitude
c. increases with altitude
d. increases at first and decreases afterwards

13. What is the approximate composition of the dry air by volume in the troposphere?

a. 10% oxygen, 89% nitrogen and the rest other gases
b. 88% oxygen, 9% nitrogen and the rest other gases
c. 50% oxygen, 40% nitrogen and the rest other gases
d. 21% oxygen, 78% nitrogen and the rest other gases

14. How does temperature vary with increasing altitude in the ICAO standard atmosphere below the tropopause?

a. Remains constant
b. Decreases
c. Increases
d. At first it increases and higher up it decreases

15. **How would you characterize an air temperature of -15°C at the 700 hPa level over western Europe?**
    a. Within +/-5°C of ISA
    b. 20°C below standard
    c. Low
    d. High

16. **If you are flying at FL300 in an air mass that is 15°C warmer than a standard atmosphere what is the outside temperature likely to be?**
    a. -15°C
    b. -30°C
    c. -45°C
    d. -60°C

17. **If you are flying at FL140 and the outside temperature is -8°C at what altitude will the freezing level be?**
    a. FL75
    b. FL100
    c. FL130
    d. FL180

18. **What is the most important constituent in the atmosphere from a weather standpoint?**
    a. Carbon dioxide
    b. Oxygen
    c. Water vapour
    d. Methane

19. **The average height of the tropopause at a latitude of 50° is about:**
    a. 8 km
    b. 11 km
    c. 14 km
    d. 16 km

20. **Between mean sea level and a height of 20 km the lowest temperature in the international standard atmosphere (ISA) is:**
    a. -273°C
    b. -44.7°C
    c. -56.5°C
    d. -100°C

21. **The international standard atmosphere (ISA) assumes that the temperature will reduce at a rate of:**
    a. 1.98°C per 1000 feet up to 36 090 feet after which it remains constant to 65 617 feet
    b. 1.98°C per 1000 feet up to 36 090 feet and then will rise at 0.3°C per 1000 feet up to 65 617 feet when it will remain constant
    c. 2°C per 1000 feet up to 65 617 feet after which it will remain constant to 104 987 feet
    d. 2°C per 1000 feet up to 36 090 feet and will then increase at 0.3°C per 1000 feet up to 65 617 feet

22. In the mid-latitudes the stratosphere extends on average from:

a. 0 to 11 km
b. 11 to 50 km
c. 50 to 85 km
d. 11 to 20 km

23. In relation to the total weight of the atmosphere, the weight of the atmosphere between mean sea level and a height of 5500 m is approximately:

a. 1%
b. 25%
c. 50%
d. 99%

24. A temperature of +15°C is recorded at an altitude of 500 metres above mean sea level. If the vertical temperature gradient is that of a standard atmosphere, what will be the temperature at the summit of a mountain 2500 metres above mean sea level?

a. 0°C
b. +2°C
c. +4°C
d. -2°C

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	b	c	a	b	b	d	c	a	b	d	a

13	14	15	16	17	18	19	20	21	22	23	24
d	b	c	b	b	c	b	c	a	b	c	b

Answers to Questions on page 8

Height (ft)	Temperature (°C)	ISA Temperature	ISA Deviation
1500	+28	+12	+16
17 500	-18	-20	+2
24 000	-35	-33	-2
37 000	-45	-57	+12
9500	-5	-4	-1
5000	+15	+5	+10
31 000	-50	-47	-3
57 000	-67	-57	-10

Max temperature = +15°C
Ambient temperature = +20°C

Chapter

2

Pressure

2 Pressure

Introduction

Variations in pressure have long been associated with changes in the weather - the 'falling glass' usually indicating the approach of bad weather. The Handbook of Aviation Meteorology makes the statement:

"The study of atmospheric pressure may be said to form the foundations of the science of meteorology."

Atmospheric Pressure

Atmospheric pressure is the force per unit area exerted by the atmosphere on any surface in contact with it. If pressure is considered as the weight of a column of air of unit cross-sectional area above a surface, then it can be seen from the diagram that the pressure (weight of the column above) at the upper surface will be less than that at the lower surface.

Thus atmospheric pressure will decrease with an increase in height.

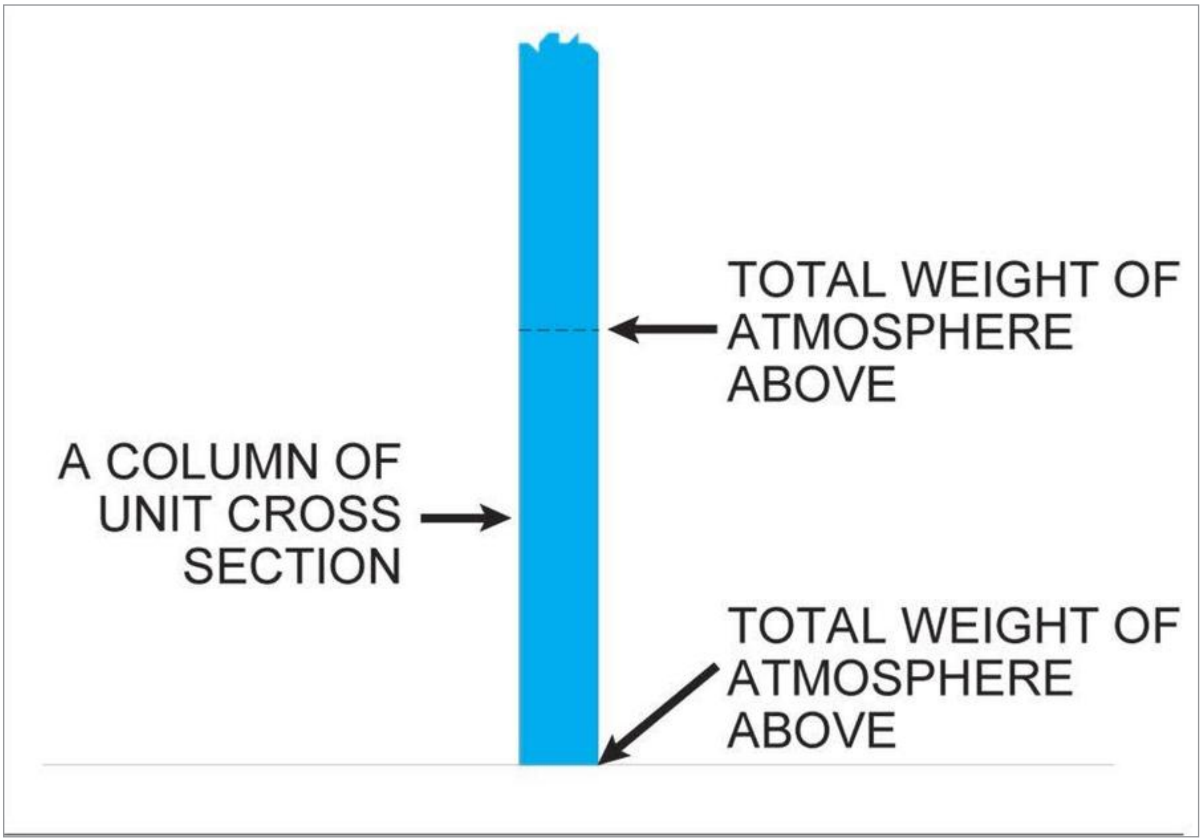


Figure 2.1 The Weight of the Atmosphere on the Surface of the Earth

Units of Measurement

The standard unit of force is the NEWTON (N) and an average for atmospheric pressure at sea level is 101 325 newtons per square metre (pascals). For simplicity this is expressed as 1013.25 hectopascals (hPa) because the earlier system of measurement was millibars (mb) and 1 hPa = 1 mb. In some countries millibars are still used. Other units which are still in use are related to the height of a column of mercury in a barometer in inches or millimetres (see overleaf).

Note: *mean sea level pressure in the ISA is 29.92 inches or 760 mm of mercury.*

Mercury Barometer

The basic instrument used for the measurement of atmospheric pressure is the mercury barometer. The atmospheric pressure is measured by the height of a column of mercury, and this height can be read in terms of any of the units shown above. The USA still uses inches of mercury as their measurement of atmospheric pressure.

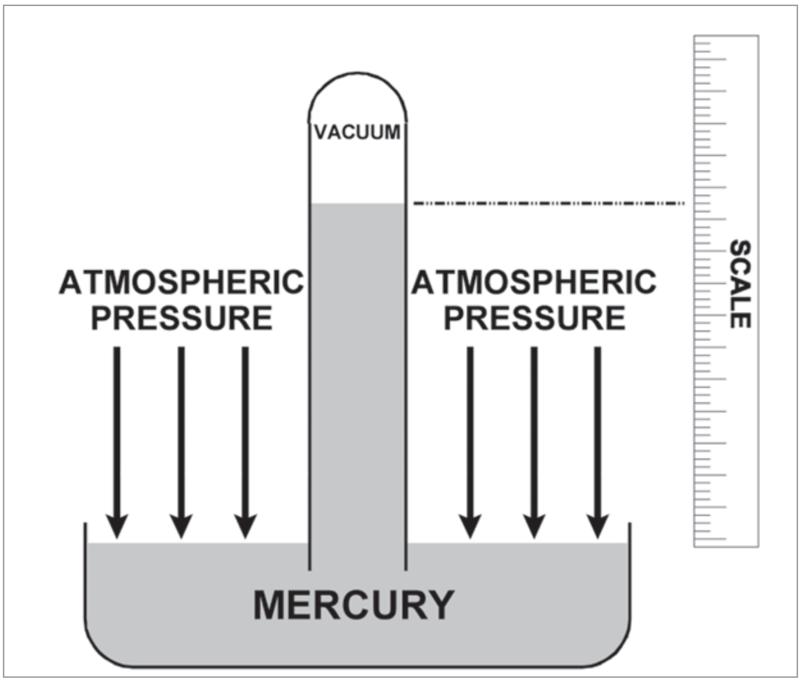


Figure 2.2 A Mercury Barometer

Aneroid Barometer.

A more compact means of measuring atmospheric pressure is the Aneroid Barometer. It consists of partially evacuated capsules, which respond to changes in pressure by expanding and contracting, and a system of levers, these changes of pressure being indicated by a pointer moving over a scale.

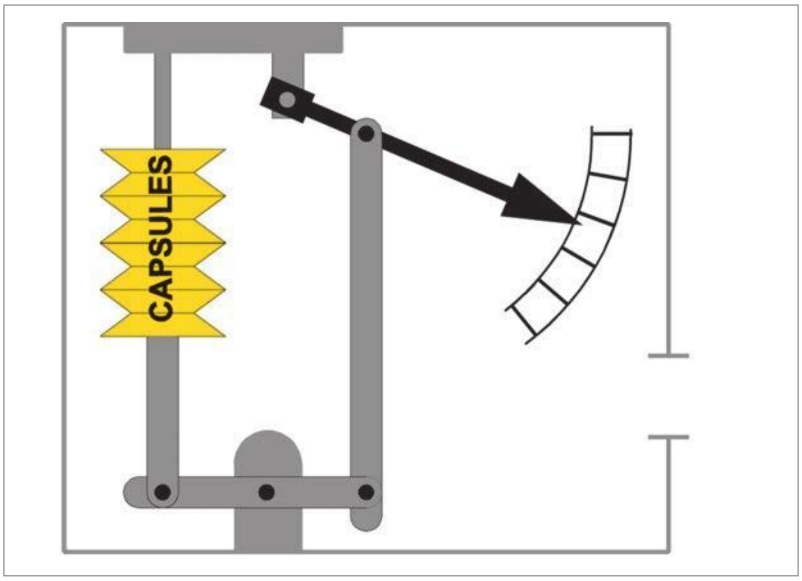


Figure 2.3 An Aneroid Barometer

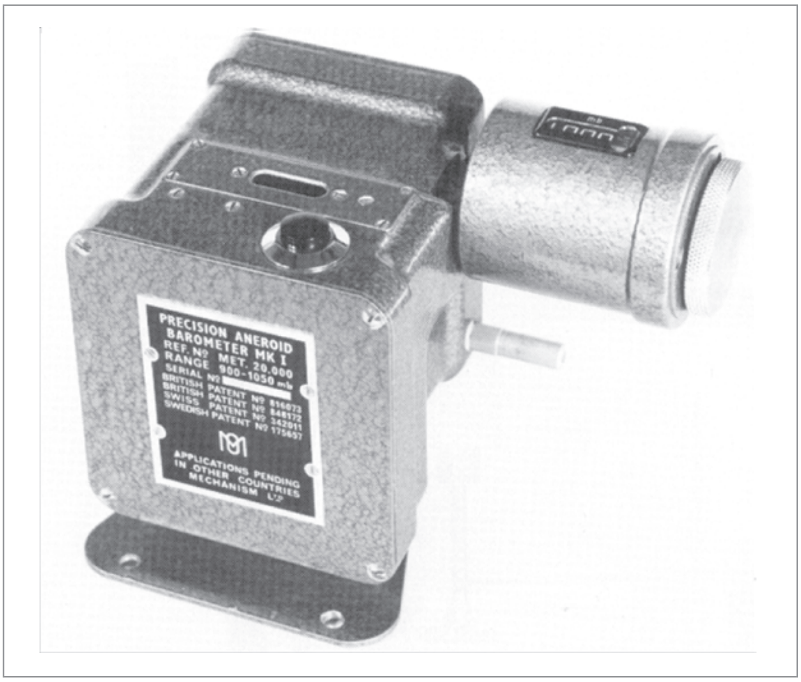


Figure 2.4 Met Office Aneroid Barometer

The Barograph

To enable a continuous record of pressure changes to be made, a paper covered rotating drum is substituted for the scale and the instrument then becomes a barograph. This instrument is used by the meteorologist to measure what is known as pressure tendency, the rise and fall of pressure over a period of time. Pressure tendency is an important forecasting tool.

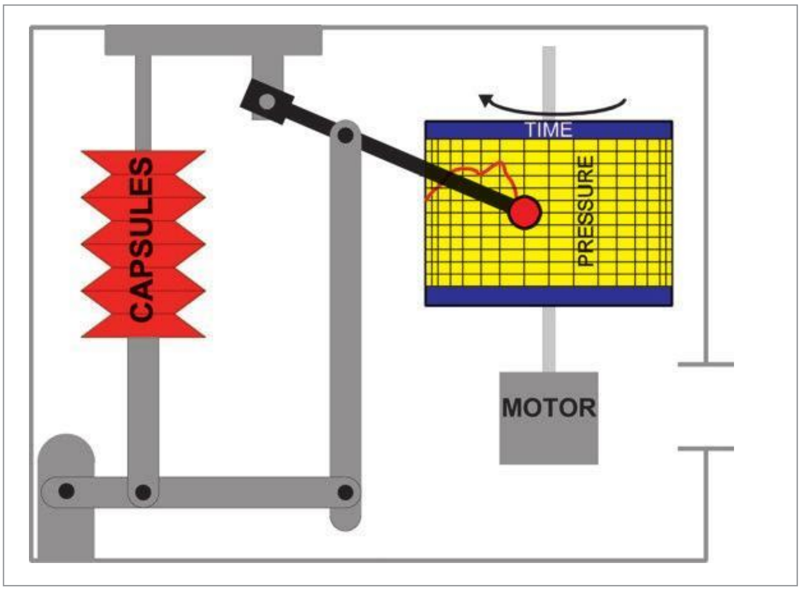


Figure 2.5 A Barograph

Variations of Pressure

Height

With an increase in height, the weight of air overlying the surface will reduce. Therefore pressure will fall with height. The rate of change of pressure with height (the barometric lapse rate) reduces as altitude increase (see table on *page 9*), or the height change per hPa increases as altitude increases

However, temperature has a dramatic effect on the pressure change with height, i.e. the pressure lapse rate. Warm air will cause pressure to fall slowly with height, i.e. decreasing the pressure lapse rate, whereas cold air will cause pressure to fall rapidly with height, i.e. increasing the pressure lapse rate. Therefore we would expect the pressure at any given height to be higher over warm air and lower over cold air. The effect of temperature on the rate of change of pressure with height is an important fact which we will return to in altimetry and upper winds.

Shown below is how temperature affects the height difference with a 1 hPa change in pressure. These values have been derived from the formula described in the chapter on the atmosphere.

$$H = \frac{96T}{P}$$

ISA
27 feet at MSL
50 feet at 20 000 ft
100 feet at 40 000 ft

Diurnal Variation

There is a change in pressure during the day which although small (about 1 hPa in temperate latitudes, can be as much as 3 hPa in the tropics) would need to be taken into account when considering pressure tendency as an indication of changing weather. The variation is shown in *Figure 2.6*.

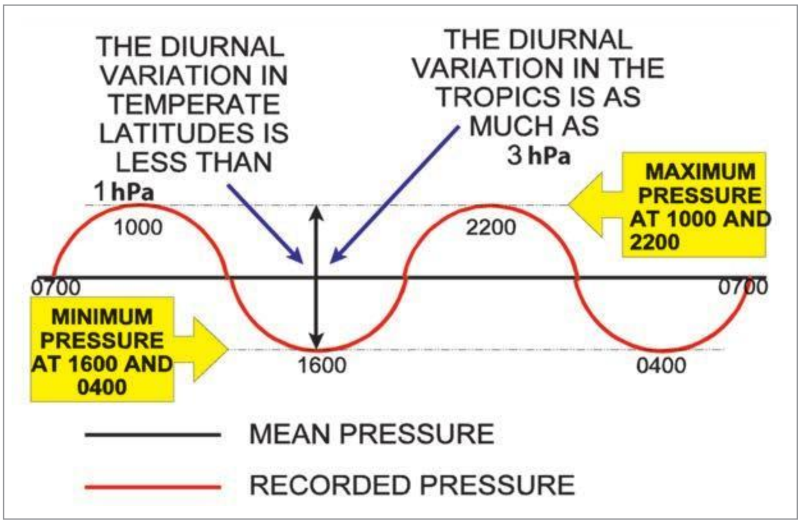


Figure 2.6 Diurnal Variation

The variation is difficult to explain, but is probably due to a natural oscillation of the atmosphere having a period of about 12 hours, this oscillation being maintained by the 24 hour variation of temperature.

Types of Pressure

QFE

The atmospheric pressure measured at the aerodrome reference point. With QFE set on the altimeter the altimeter will read zero feet when the aircraft is on the aerodrome.

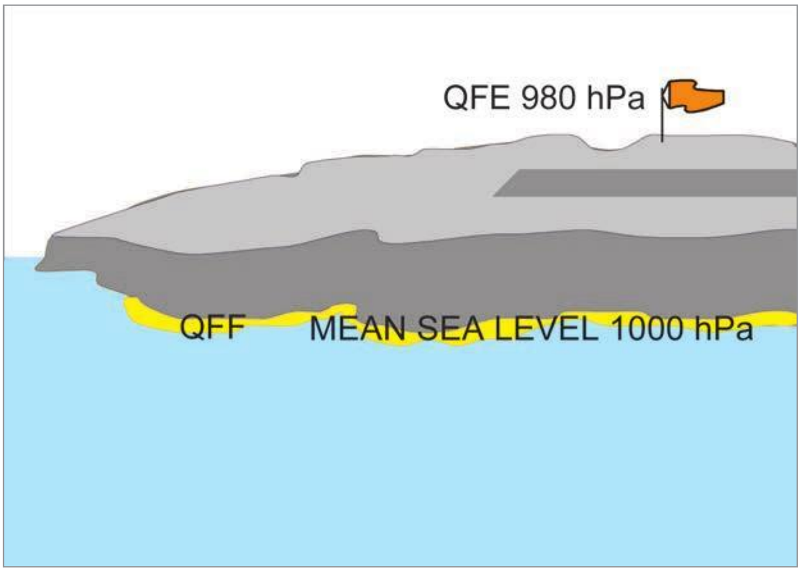


Figure 2.7 QFE

QNH

This is the barometric pressure at the airfield (QFE), converted to mean sea level (MSL) using the ISA temperature at the airfield and the ISA pressure lapse rate. This will provide a pressure which does not account for any temperature deviation away from ISA. The correction to be made to the surface pressure will depend solely upon the height of the airfield AMSL. QNH is always a whole number without any decimal places and is always rounded down. When on the aerodrome with QNH set the altimeter will read aerodrome elevation.

QFF

Because temperature affects the change of pressure over height QNH is not a true mean sea level pressure (unless ISA conditions exist). The forecaster needs to know the true mean sea level pressure in order to construct accurate analysis charts and to help with the forecasting of future changes.

The meteorological offices, therefore, convert QFE to MSL using the actual temperature and assuming isothermal conditions between the aerodrome and MSL. This pressure is known as QFF and, because of the differential rate of change of pressure over height at different temperatures, may differ from QNH.

We can determine, from the formula above, that at temperatures below ISA we have a relatively small height change per 1 hPa change in pressure and a relatively large change at temperatures above ISA.

Example 1: What is the relationship between QFF and QNH at Oxford (270 ft AMSL) if the QNH is 1020 hPa and the temperature ISA +10°?

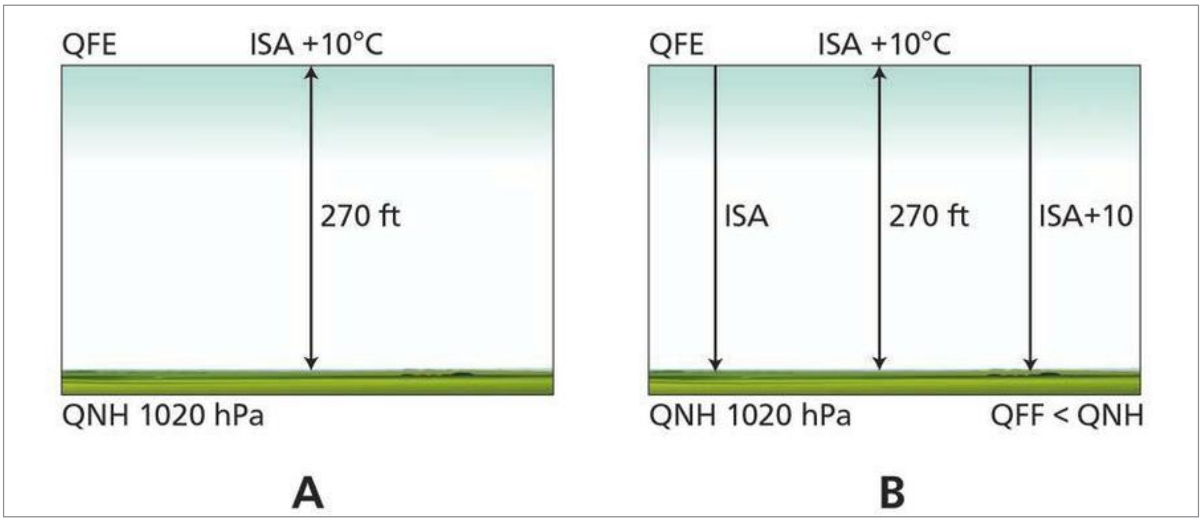


Figure 2.8

The QNH is calculated using the ISA temperature and the QFF using the actual temperature. Since the actual temperature is warmer than ISA the change in pressure over 270 ft will be greater in the ISA than in the actual conditions. As we are above MSL this means that the QNH will be greater than the QFF.

Example 2: What is the relationship between QFF and QNH at an aerodrome 69 m below MSL if the QNH is 1005 hPa and the temperature is ISA-10°?

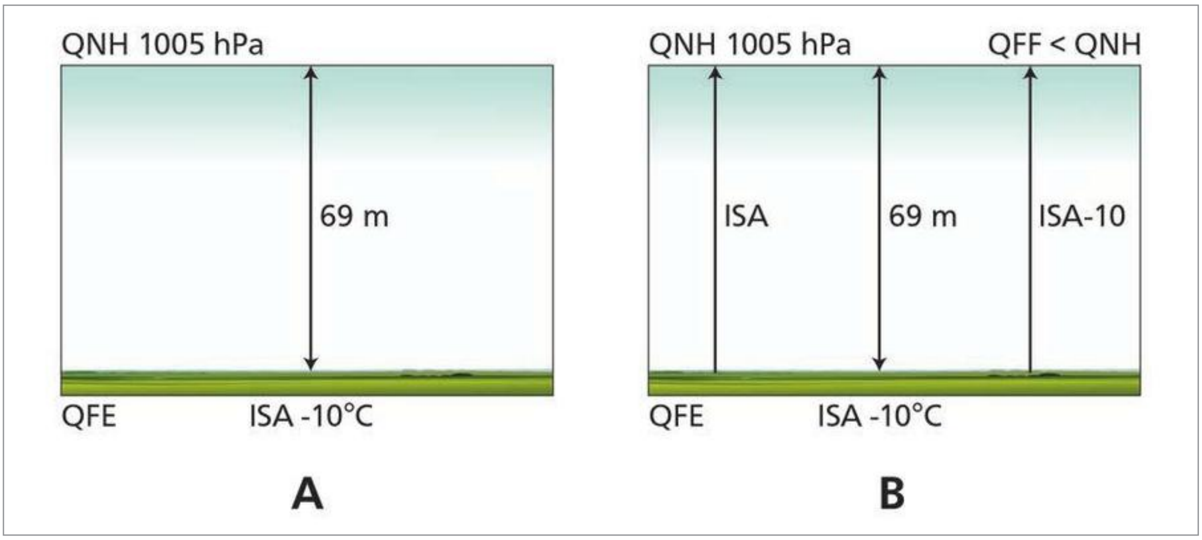


Figure 2.9

This time the change in pressure is greater for the calculation of QFF than for the QNH. As we are reducing pressure this time it means the QNH will once again be greater than the QFF.

We can use similar arguments to show that at an aerodrome AMSL with a temperature colder than ISA or at an aerodrome below MSL with a temperature greater than ISA the QFF will be greater than the QNH. This is summarized overleaf:

Summary

ISA

+ - QNH < QFF	+ + QNH > QFF	
		MSL
- - QNH > QFF	- + QNH < QFF	

Same sign, above mean sea level and warmer than ISA (+,+) or below mean sea level and colder than ISA (-,-) then QNH is greater than QFF. Otherwise the QFF is greater than the QNH.

Stations AT MSL	Regardless of temperature	QNH = QFF (=QFE)

The normal range of mean sea level pressure (QFF) extends from 950 to 1050 hPa. The lowest recorded mean sea level pressure is 870 hPa in the eye of Typhoon Tip in the Western Pacific in 1979. The lowest recorded in the North Atlantic is 882 hPa in the eye of Hurricane Wilma in 2005. The highest mean sea level pressure was 1085.7 hPa recorded in winter in Siberia in 2001.

Pressure Definitions

QFE	The pressure measured at the aerodrome reference point.
QFF	QFE converted to mean sea level using the actual temperature.
QNH	QFE converted to mean sea level using the ISA.
ISOBAR	A line joining places of the same atmospheric pressure (usually MSL pressure QFF).

Standard Pressure Setting (SPS) 1013 hPa

Analysis Charts

Isobars on analysis charts are corrected mean sea level pressures (QFF) and are drawn at a spacing which is dependent on the scale of the chart.

On larger area charts the spacing may be expanded to 4 or more hectopascals but this will be stated on the chart.

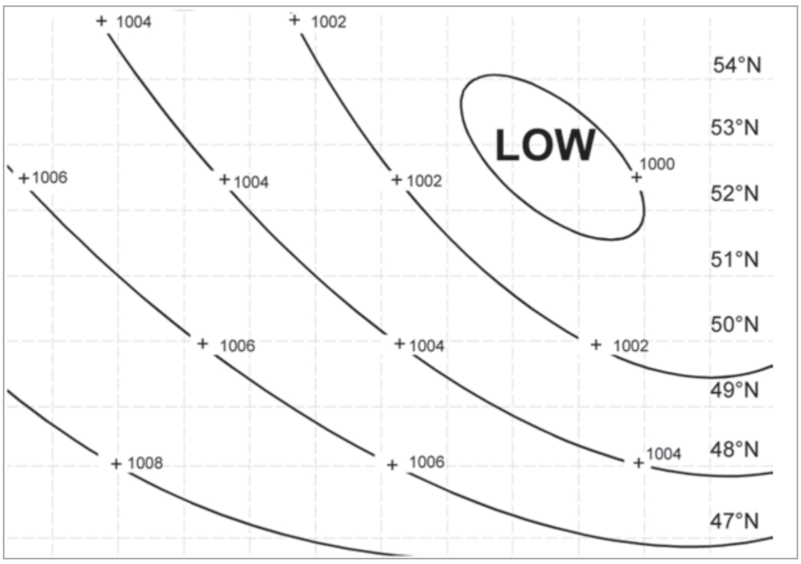


Figure 2.10 Isobars on an Analysis Chart

Questions

1. **The barometric pressure at the airfield datum point is known as:**

   a. QFF
   b. QNH
   c. QFE
   d. Standard Pressure

2. **The instrument that gives a continuous printed reading and record of the atmospheric pressure is:**

   a. barometer
   b. hygrometer
   c. anemograph
   d. barograph

3. **The pressure of the atmosphere:**

   a. decreases at an increasing rate as height increases
   b. decreases at a constant rate as height increases
   c. decreases at a decreasing rate as height increases
   d. decreases at a constant rate up to the tropopause and then remains constant

4. **When considering the actual tropopause which statement is correct?**

   a. It is low over the poles and high over the Equator
   b. It is high over the poles and low over the Equator
   c. It is the same height of 36 090 ft all over the world
   d. It is at a constant altitude of 26 000'

5. **Atmospheric pressure may be defined as:**

   a. the weight of the atmosphere exerted on any surface with which it is in contact
   b. the weight of the atmosphere at standard sea level
   c. the force per unit area exerted by the atmosphere on any surface with which it is in contact
   d. a pressure exerted by the atmosphere of 1013.2 hPa

6. **The QFF is the atmospheric pressure:**

   a. at the place where the reading is taken
   b. corrected for temperature difference from standard and adjusted to MSL assuming standard atmospheric conditions exist
   c. at a place where the reading is taken corrected to MSL taking into account the prevailing temperature conditions
   d. as measured by a barometer at the aerodrome reference point

7. **The pressure of 1013 hPa is known as:**

   a. standard pressure setting
   b. QNH
   c. QFE
   d. QFF

8. The aircraft altimeter will read zero at aerodrome level with which pressure setting set on the altimeter subscale:

a. QFF
b. QNH
c. SPS
d. QFE

9. The aerodrome QFE is:

a. the reading on the altimeter on an aerodrome when the aerodrome barometric pressure is set on the subscale
b. the reading on the altimeter on touchdown at an aerodrome when 1013 is set on the subscale
c. the reading on the altimeter on an aerodrome when the sea level barometric pressure is set on the subscale
d. the aerodrome barometric pressure

10. When an altimeter subscale is set to the aerodrome QFE, the altimeter reads:

a. the elevation of the aerodrome at the aerodrome reference point
b. zero at the aerodrome reference point
c. the pressure altitude at the aerodrome reference point
d. the appropriate altitude of the aircraft

11. The aerodrome QNH is the aerodrome barometric pressure:

a. corrected to mean sea level assuming standard atmospheric conditions exist
b. corrected to mean sea level, assuming isothermal conditions exist
c. corrected for temperature and adjusted to MSL assuming standard atmosphere conditions exist
d. corrected to MSL using ambient temperature

12. A line drawn on a chart joining places having the same barometric pressure at the same level and at the same time is:

a. an isotherm
b. an isallobar
c. a contour
d. an isobar

13. An isobar on a meteorological chart joins all places having the same:

a. QFE
b. QFF
c. QNH
d. standard pressure

14. Pressure will __________ with increase of height and will be about ___________ at 10 000 ft and ____________ at 30 000 ft.

a.	Increase	800 hPa	400 hPa
b.	Decrease	700 hPa	300 hPa
c.	Increase	200 hPa	800 hPa
d.	Decrease	500 hPa	200 hPa

15. **An airfield in England is 100 m above sea level, QFF is 1030 hPa, temperature at the surface is -15°C. What is the value of QNH?**

a. Impossible to determine
b. Less than 1030 hPa
c. Same as QFF
d. More than 1030 hPa

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	d	c	a	c	c	a	d	d	b	a	d

13	14	15
b	b	b

Chapter

3

Density

3 Density

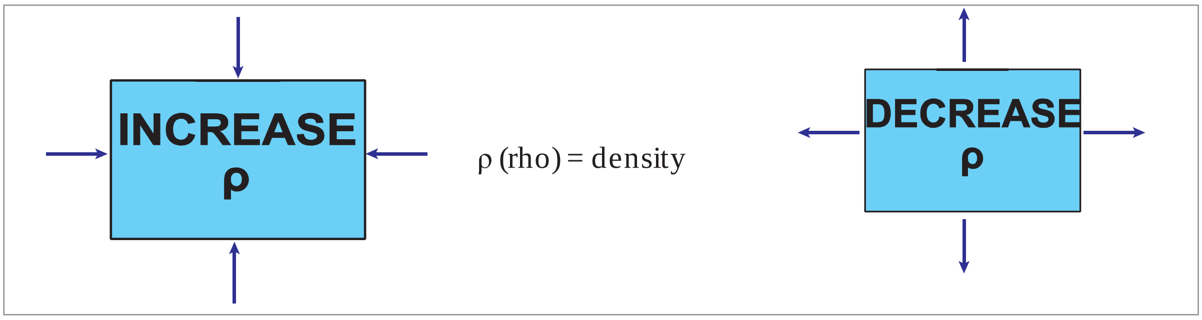
Introduction

Density may be defined as **mass per unit volume** and may be expressed as:

- Grams per cubic metre.
- A percentage of the standard surface density - **relative density.**
- The altitude in the standard atmosphere to which the observed density corresponds - **density altitude.**

Effect of Changes of Pressure on Density

As pressure is increased, the air will be compressed which reduces the volume and increases the density. Likewise, if pressure is decreased, the air will expand which will increase the volume and decrease the density.



We can therefore say that:

DENSITY IS DIRECTLY PROPORTIONAL TO PRESSURE.

In the atmosphere density can be decreased by raising the volume of air to a greater height since we know that pressure decreases with an increase in altitude. Similarly, density can be increased by lowering the volume of air to a lower height.

Effect of Change of Temperature on Density

If a volume of air is heated it will expand and the mass of air contained in **unit volume** will be less. Thus density will **decrease** with an **increase** in temperature and we can say:

DENSITY IS INVERSELY PROPORTIONAL TO TEMPERATURE.

Effect of Changes in Humidity on Density

The molecular mass of water is less than that of nitrogen and oxygen. If we increase the amount of water vapour in a fixed volume of air, then we are replacing the heavier nitrogen and oxygen molecules with the lighter water molecules so the total mass of that volume will decrease and hence the density will decrease.

DENSITY IS INVERSELY PROPORTIONAL TO WATER VAPOUR CONTENT

Effect of Change of Altitude on Density

In the troposphere as altitude increases both temperature and pressure decrease but, although they have opposite effects on density, the effect of pressure is much greater than the effect of temperature so density **decreases as altitude increases**.

(In the ISA ρ = 100% at sea level, 50% at 20 000 ft, 25% at 40 000 ft and 10% at 60 000 ft)

Density will change by 1% for a 3 degree change in temperature or a 10 hPa change in pressure.

Effect of Change of Latitude on Density

At the surface as latitude increases temperature decreases so density will increase as we move from the Equator towards the poles. At the Equator the surface temperatures are high so the rate of change of pressure with height is relatively low compared to the poles where temperatures are low and the change of pressure with height is relatively high. This means that at, say, 50 000 ft the pressure over the Equator will be relatively high compared to the pressure at 50 000 ft over the poles. The temperatures are lower at 50 000 ft at the Equator than at the poles which means that the density at 50 000 ft at the poles will be less than at 50 000 ft at the Equator. So we can summarize the change of density as follows:

- at the surface density increases as latitude increases
- at about 26 000 ft density remains constant with an increase in latitude.
- above 26 000 ft density decreases with an increase in latitude. (Maximum deviation from standard occurs at about 50 000 ft.)

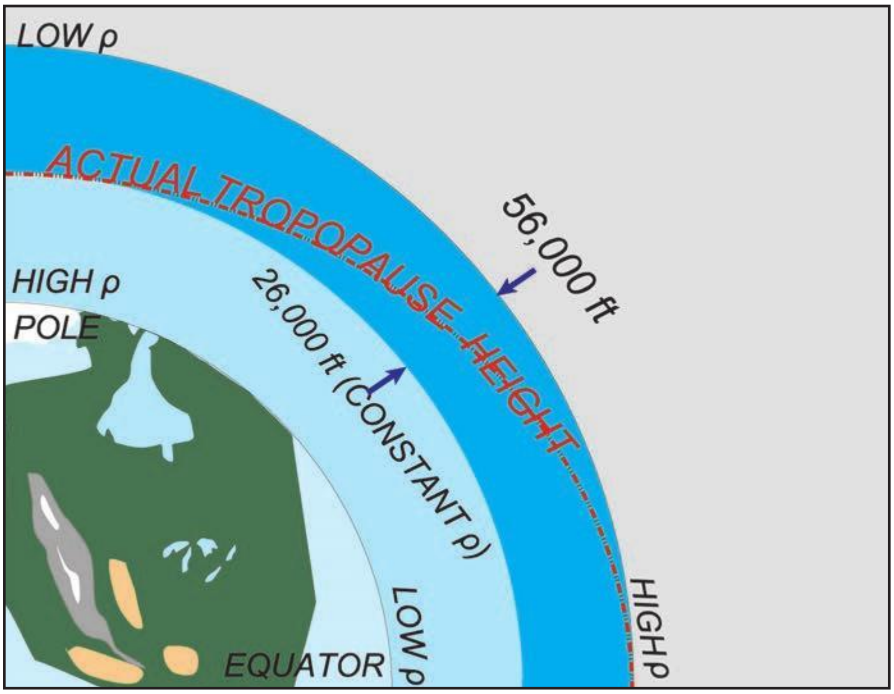


Figure 3.1 The Effect of Latitude on Density

Effect of Changes in Density on Aircraft Operations

a) Accuracy of aircraft instruments - Mach meters, ASIs.

b) Aircraft and engine performance - low density will reduce lift, increase take-off run, reduce maximum take-off weight.

$$(L = C_L \tfrac{1}{2}\rho V^2 S)$$

Where	L	=	Lift
	C_L	=	Coefficient of Lift
	ρ	=	Density
	V	=	TAS
	S	=	Wing area

Airfields affected would be:

• **High**	Denver	Nairobi	Sana'a
• **Hot**	Bahrain	Khartoum	Singapore

c) Humidity generally has a small effect on density (humidity reduces density), but must be taken into account at moist tropical airfields, e.g. Bahrain, Singapore.

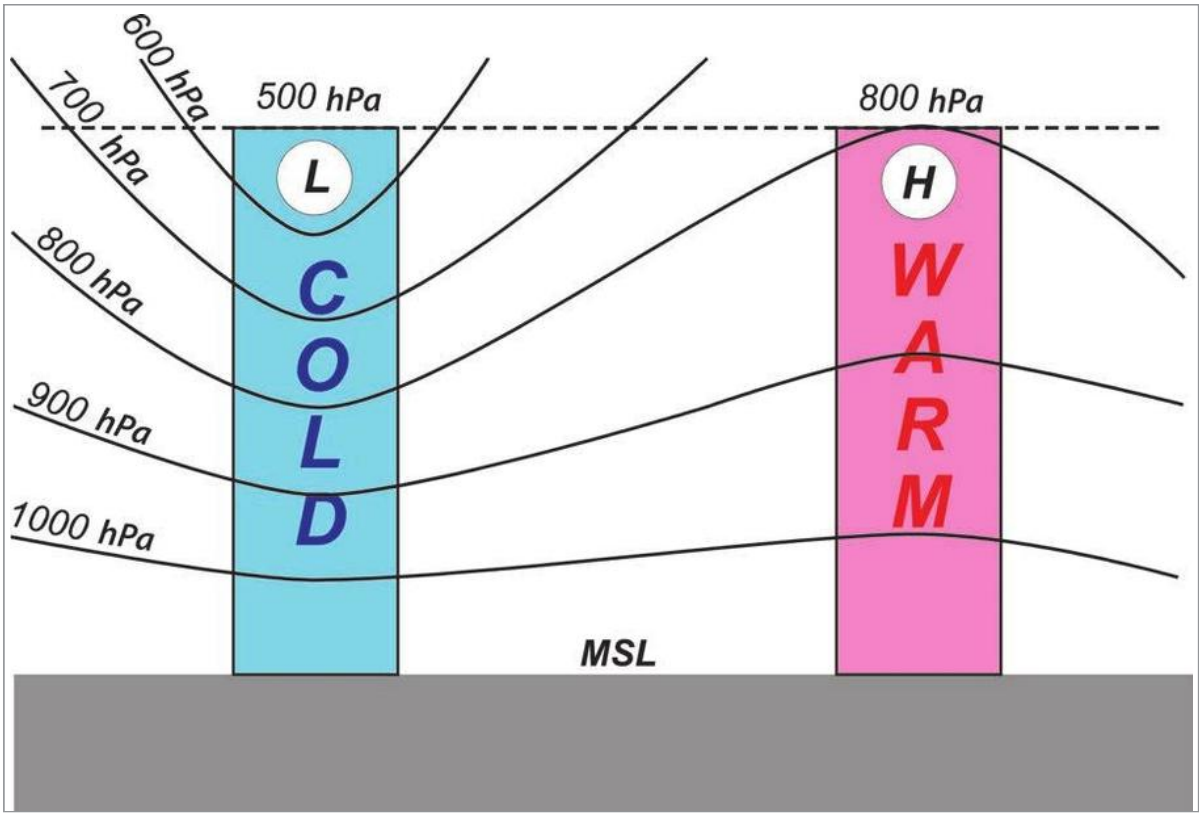


Figure 3.2 An Illustration of Pressure Decrease with Height in air masses with Different Temperatures and therefore Different Densities

3 Density

Questions

1. **Consider the following statements relative to air density and select the one which is correct:**

 a. Because air density increases with decrease of temperature, air density must increase with increase of height in the International Standard Atmosphere (ISA)
 b. At any given surface temperature the air density will be greater in anticyclonic conditions than it will be when the MSL pressure is lower
 c. Air density increases with increase of relative humidity
 d. The effect of change of temperature on the air density is much greater than the effect of change of atmospheric pressure

2. **The tropopause in mid latitudes is:**

 a. lower in summer with a lower temperature
 b. lower in winter with a higher temperature
 c. lower in summer with a higher temperature
 d. lower in winter with a lower temperature

3. **Generally as altitude increases:**

 a. temperature decreases and density increases
 b. temperature, pressure and density decreases
 c. temperature and pressure increase and density decreases
 d. temperature decreases and pressure density increases

4. **In the troposphere:**

 a. over cold air, the pressure is higher at upper levels than at similar levels over warm air
 b. over cold air, the pressure is lower at upper levels than at similar levels over warm air
 c. over warm air, the pressure is lower at upper levels than at similar levels over warm air
 d. the upper level pressure depends solely on the relative humidity below

5. **Density at the surface will be low when:**

 a. pressure is high and temperature is high
 b. pressure is high and temperature is low
 c. pressure is low and temperature is low
 d. pressure is low and temperature is high

6. **Which of the following combinations will give the lowest air density?**

 a. Low pressure, low humidity, low temperature
 b. High pressure, high temperature, high humidity
 c. High pressure, low temperature, low humidity
 d. Low pressure, high humidity, high temperature

Answers

1	2	3	4	5	6
b	b	b	b	d	d

Chapter 4

Pressure Systems

Introduction

Isobars can form patterns, which when they are recognized, can help us forecast the weather. These patterns are called pressure distribution systems. They include:

- Depressions, or lows.
- Anticyclones, or highs.
- Troughs.
- Ridges.
- Cols.

Buys Ballot's Law

In the 19th century the Dutch scientist and meteorologist, Buys Ballot, produced a law based on the observation of wind direction and pressure systems.

Buys Ballot's Law states that:

If an observer stands with his back to the wind in the Northern Hemisphere then the low pressure is on his left. (In the Southern Hemisphere low pressure is to the right.)

This law will prove to be a useful tool in both the study of wind and altimetry.

Advection

Advection is a meteorological term for horizontal movement of air.

Depressions

A depression is a region of comparatively low pressure shown by more or less circular and concentric isobars surrounding the centre, where pressure is lowest. A depression is sometimes called a **low** or a cyclone. In Europe the term cyclone is usually reserved for tropical revolving storms. However, the term cyclonic circulation implies a low pressure system.

Buys Ballots' law tells us that the wind will move around a low pressure system in an anti-clockwise direction in the Northern Hemisphere.

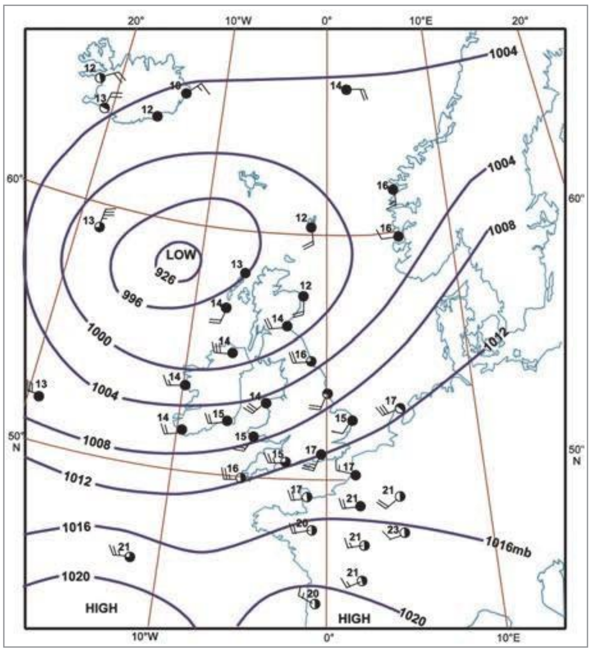


Figure 4.1 A Depression in the Northern Hemisphere

There are two types of depression, frontal (large scale) found in our temperate latitudes and non-frontal (small scale) depressions which can occur virtually anywhere.

In a depression air is converging at the surface, rising from the surface to medium to high altitude (convection) then diverging at medium to high altitude.

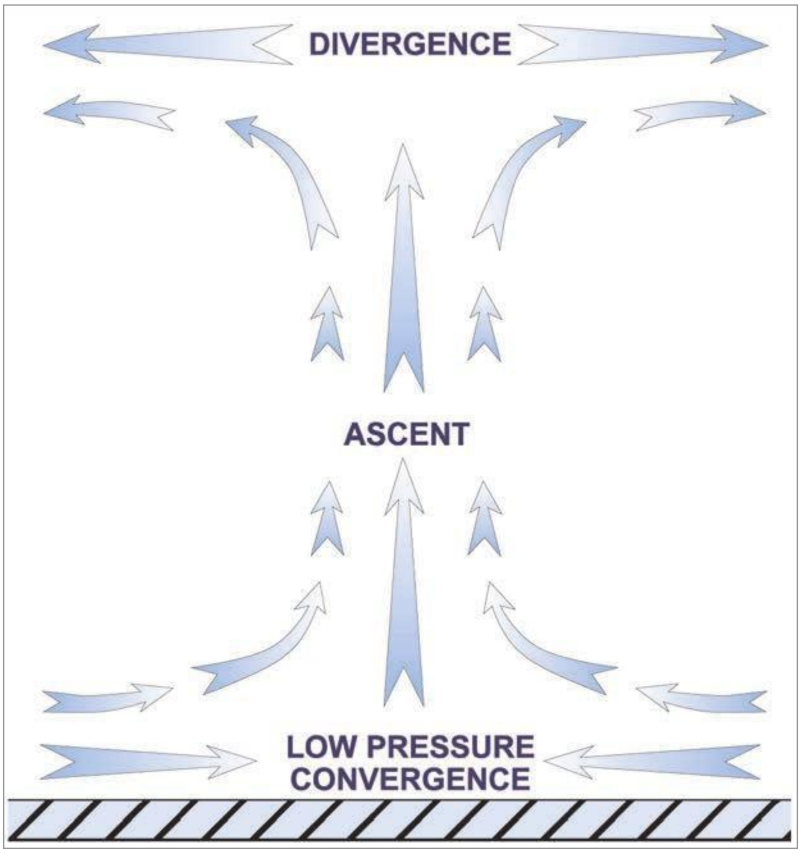


Figure 4.2 Vertical Cross-section

Frontal depressions are known as **Polar Front Depressions** and form, in temperate latitudes, in both the Northern and Southern Hemispheres when warm, moist sub-tropical air masses meet cold polar air masses. These depressions move from west to east and eventually, in the Northern Hemisphere, lose their identity over the North American or Eurasian land masses. In the N. Atlantic these depressions originate in the central to western Atlantic and move rapidly eastward, eventually losing their identity over the steppes of central Asia. An example of a polar front depression is centred over Greenland/Iceland on the analysis chart on the next page.

Non-frontal depressions are usually formed by surface heating when they are known as thermal depressions. They occur over land in summer as a result of strong surface heating. They also occur over the warm sub-tropical oceans where they are known as tropical cyclones. In winter they occur over sea areas in cold polar or arctic air masses. The different types of depressions and their formation will be discussed in later chapters. On the analysis chart thermal depressions (labelled TD) are seen over the Black Sea and the Mediterranean Sea, formed in the cold air coming out of central Asia

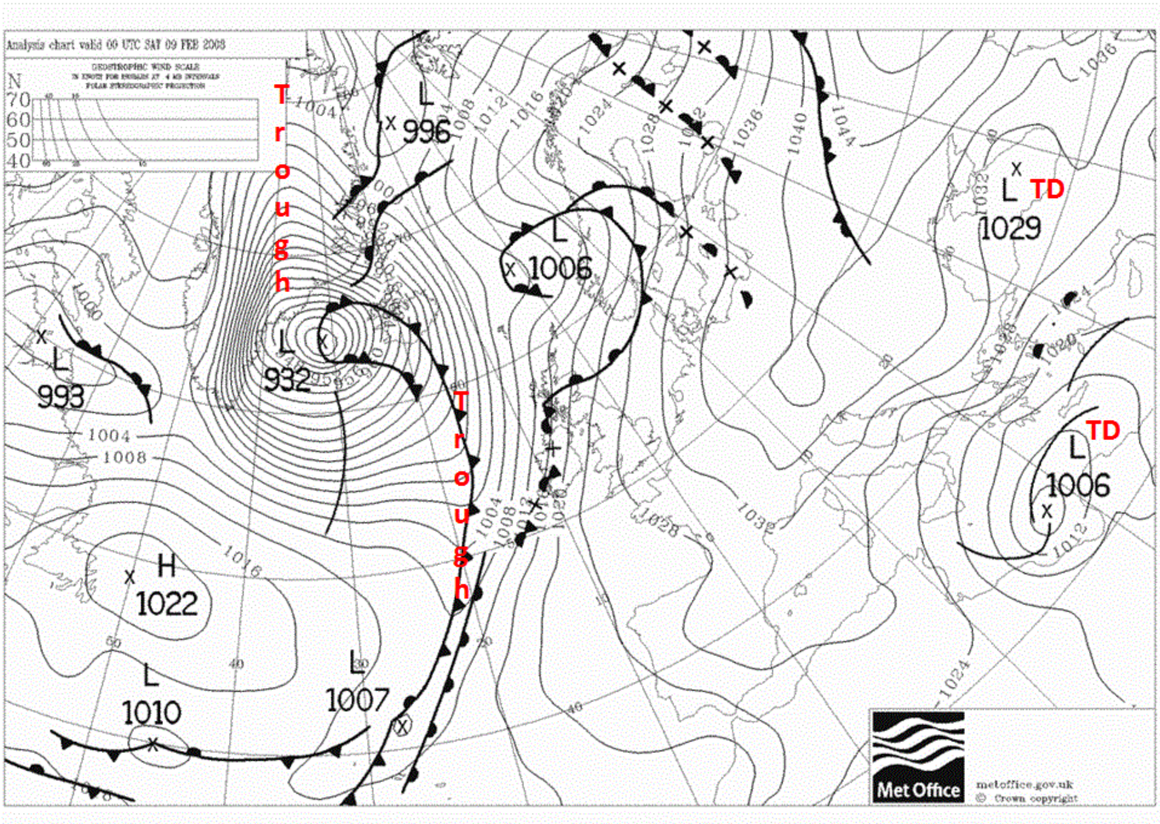


Figure 4.3

Troughs

A trough is an extension of a low pressure system. On the analysis chart there are two troughs associated with the polar front depression centred over Greenland/Iceland. One extending north across Greenland is a non-frontal trough. The other extending southward is a frontal trough formed along the cold front. Troughs are very often associated with the fronts of polar front depressions. The weather associated with a trough will be similar to that of a depression.

Depression Weather

Cloud extensive and may extend from low altitude to the tropopause

Precipitation may be continuous/intermittent precipitation or showers and intensity can range from light to heavy dependent on the type of depression

Visibility Poor in precipitation, otherwise good due to ascending air.

Temperature dependent on type of depression and time of year. For example, a frontal depression coming into Europe from the Atlantic in winter will bring warmer air, but in summer will bring cooler air.

Winds Winds are usually strong - the deeper the depression and the closer the isobars, the stronger the wind.

Anticyclones

An anticyclone or high is a region of relatively high pressure shown by more or less circular isobars similar to a depression but with higher pressure at the centre.

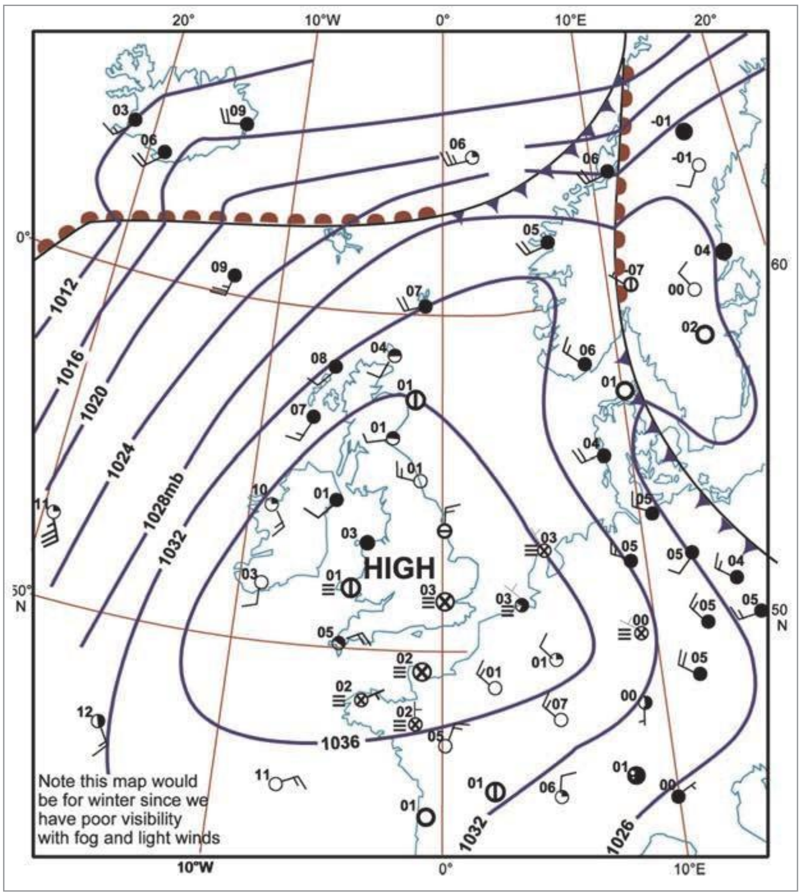


Figure 4.4 An Anticyclone in the Northern Hemisphere

Isobars are more widely spaced than with depressions. There are five types of anticyclone, **warm**, **cold**, **temporary cold, ridges (or wedges)** and **blocking**. Within an anticyclone, at high altitude we have air converging, then descent of air within the anticyclone (subsidence) and divergence at the surface.

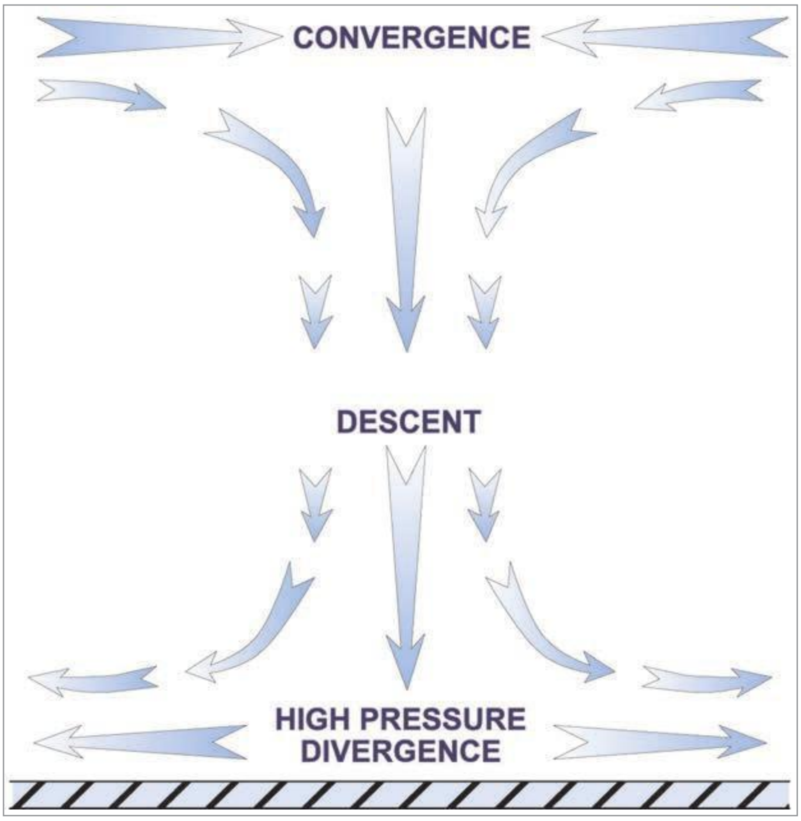


Figure 4.5 Vertical Cross-section

Cold anticyclones occur as permanent features at the poles and as seasonal features over continental land masses in the winter. In simple terms the air at the surface is cooled thereby increasing its density and drawing more air down from above hence increasing the surface pressure.

Warm Anticyclones

To understand the formation of warm anticyclones we need to look at the global circulation of air. In the 19th century a British scientist, George Hadley, proposed a global circulation based on hot air rising at the Equator then flowing up to the poles at the tropopause, descending at the poles and flowing back to the Equator at the surface. This model was not quite correct because in our temperate latitudes pressure is predominantly low because of the large scale frontal depressions. An American scientist, William Ferrel, proposed a modification to Hadley's model introducing the

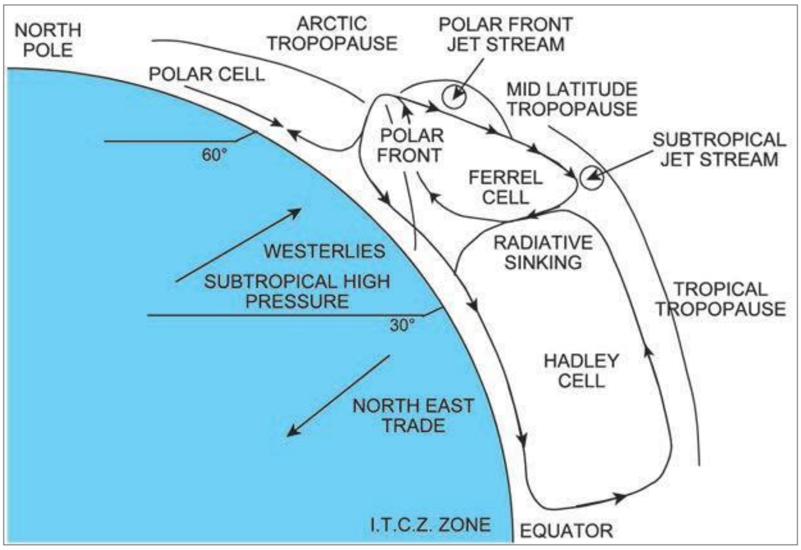


Figure 4.6 Hadley Cell, Polar Front, and Associated Wind-Flows.

modification arising because of the low pressure systems in temperate latitudes. This gives the three circulation cells, the Hadley cell between the Equator and the subtropics, the Ferrel cell between the subtropics and temperate latitudes and the Polar cell between temperate latitudes and the poles.

This circulation means that we have, at the tropopause, air flowing outwards from the Equator towards the poles and from temperate latitudes towards the Equator. This creates an excess of air at the tropopause in subtropical regions which is forced to descend, hence creating the subtropical high pressure systems which are permanent features over the subtropical oceans, for example the Azores high in the N. Atlantic.

Ridges

Ridges of high pressure are indicated by isobars extending outwards from an anticyclone and always rounded, never V-shaped as seen in a trough.

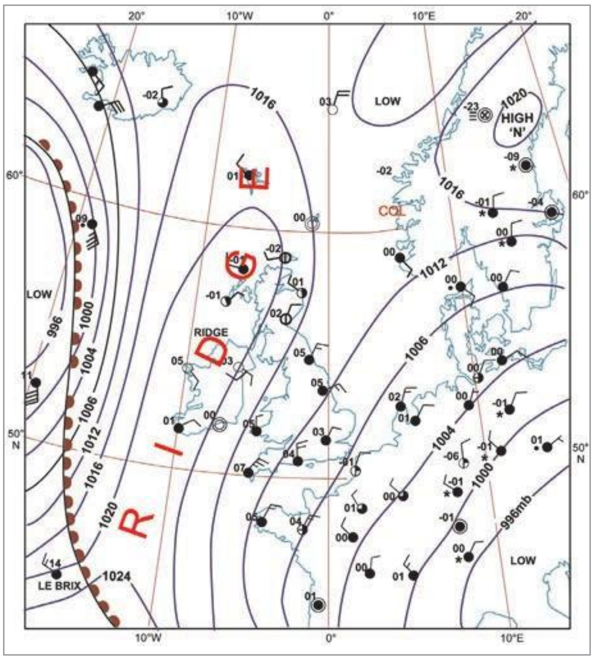


Figure 4.7 A Ridge of High Pressure.

Temporary Cold Anticyclones

A temporary cold anticyclone is a ridge of high pressure found in the cold air between two frontal depressions. Because the depressions are moving rapidly the influence of these anticyclones will be experienced for up to a maximum of about 24 hours.

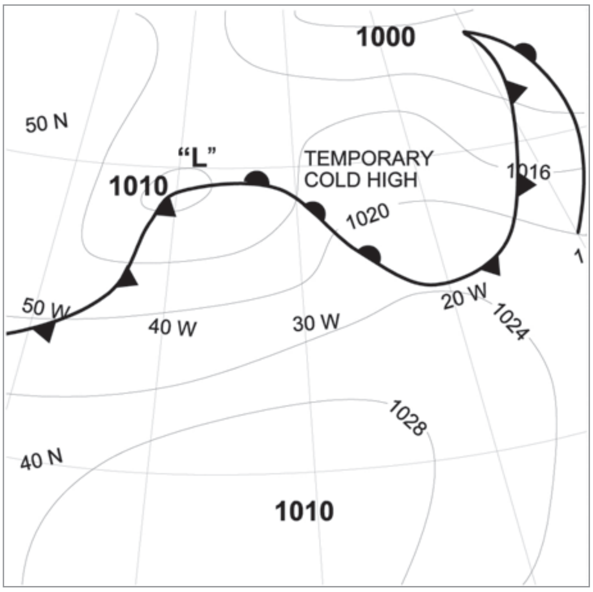


Figure 4.8 A Temporary Cold Anticyclone.

Blocking Anticyclones

A blocking anticyclone is one which prevents the usual eastward movement of frontal depressions, forcing these depressions to take up northerly tracks in the Northern Hemisphere. These anticyclones are usually extensions of the warm subtropical anticyclones. They can persist for weeks giving (usually) warm dry weather in summer and gloomy overcast conditions in winter with a possibility of drizzle. Over Europe in winter they may be extensions of the Siberian high giving (usually) cold clear conditions.

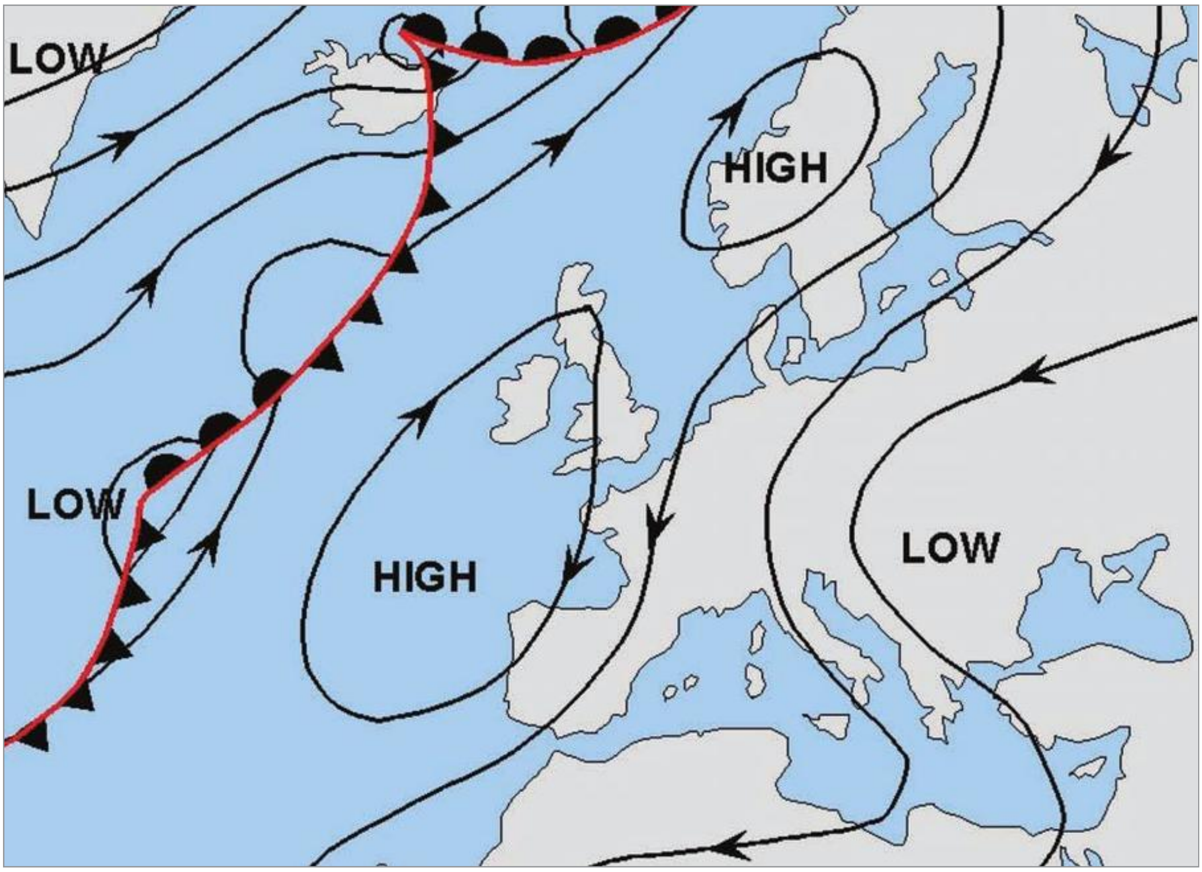


Figure 4.9 High from Azores to Scandinavia.

Anticyclonic Weather

SUMMER (and cold anticyclones in winter):

Cloud None except on the edge of the anticyclone.
Precipitation None.
Visibility Generally moderate with haze
Temperature Dependent on type.
Winds Light.

WINTER (warm anticyclones):

Cloud Extensive stratus with a low base and limited vertical extent.
Precipitation Possibly drizzle.
Visibility Generally moderate to poor with mist and fog likely
Temperature Relatively warm.
Winds Light.

Cols

Cols are regions of almost level pressure between two highs and two lows. It is an area of **stagnation** as illustrated in *Figure 4.10* and *Figure 4.11*.

Col Weather

Col weather is normally settled, but is dependent on changing pressure.

In autumn and winter cols produce poor visibility and fog, whilst in summer thunderstorms are common. *Figure 4.11* is an example of a weather forecast for a day when a col influenced the weather over the UK.

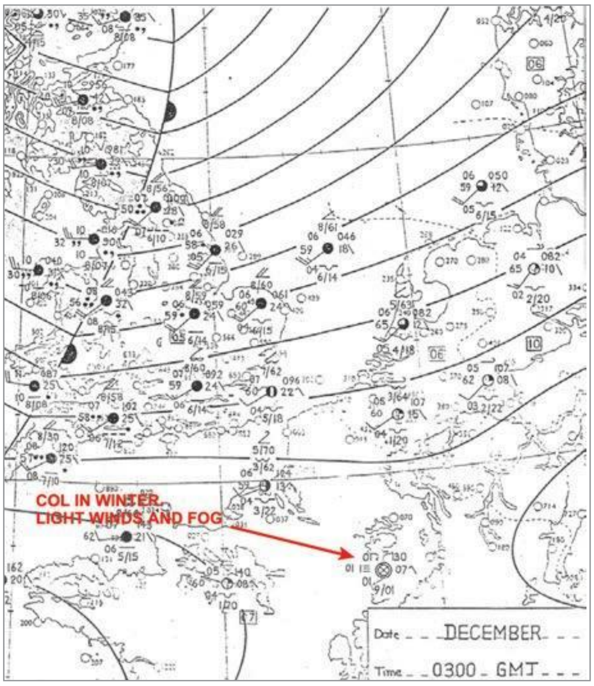
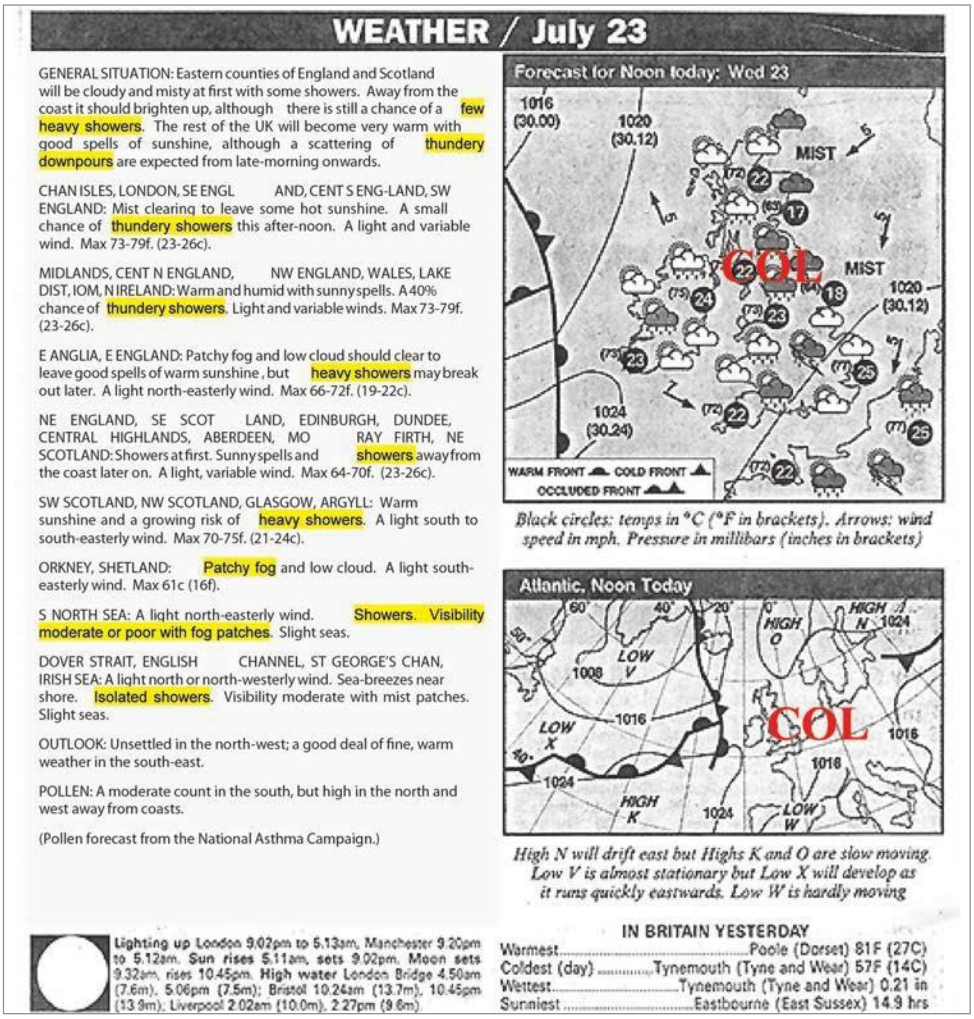


Figure 4.10 A Col.



WEATHER / July 23

GENERAL SITUATION: Eastern counties of England and Scotland will be cloudy and misty at first with some showers. Away from the coast it should brighten up, although there is still a chance of a few heavy showers. The rest of the UK will become very warm with good spells of sunshine, although a scattering of thundery downpours are expected from late-morning onwards.

CHAN ISLES, LONDON, SE ENGLAND, CENT S ENGLAND, SW ENGLAND: Mist clearing to leave some hot sunshine. A small chance of thundery showers this after-noon. A light and variable wind. Max 73-79f. (23-26c).

MIDLANDS, CENT N ENGLAND, NW ENGLAND, WALES, LAKE DIST, IOM, N IRELAND: Warm and humid with sunny spells. A 40% chance of thundery showers. Light and variable winds. Max 73-79f. (23-26c).

E ANGLIA, E ENGLAND: Patchy fog and low cloud should clear to leave good spells of warm sunshine, but heavy showers may break out later. A light north-easterly wind. Max 66-72f. (19-22c).

NE ENGLAND, SE SCOTLAND, EDINBURGH, DUNDEE, CENTRAL HIGHLANDS, ABERDEEN, MORAY FIRTH, NE SCOTLAND: Showers at first. Sunny spells and showers away from the coast later on. A light, variable wind. Max 64-70f. (23-26c).

SW SCOTLAND, NW SCOTLAND, GLASGOW, ARGYLL: Warm sunshine and a growing risk of heavy showers. A light south to south-easterly wind. Max 70-75f. (21-24c).

ORKNEY, SHETLAND: Patchy fog and low cloud. A light south-easterly wind. Max 61c (16f).

S NORTH SEA: A light north-easterly wind. Showers. Visibility moderate or poor with fog patches. Slight seas.

DOVER STRAIT, ENGLISH CHANNEL, ST GEORGE'S CHAN, IRISH SEA: A light north or north-westerly wind. Sea-breezes near shore. Isolated showers. Visibility moderate with mist patches. Slight seas.

OUTLOOK: Unsettled in the north-west; a good deal of fine, warm weather in the south-east.

POLLEN: A moderate count in the south, but high in the north and west away from coasts.

(Pollen forecast from the National Asthma Campaign.)

Forecast for Noon today: Wed 23

Black circles: temps in °C (°F in brackets). Arrows: wind speed in mph. Pressure in millibars (inches in brackets)

Atlantic, Noon Today

High N will drift east but Highs K and O are slow moving. Low V is almost stationary but Low X will develop as it runs quickly eastwards. Low W is hardly moving

Lighting up London 9.02pm to 5.13am, Manchester 9.20pm to 5.12am. Sun rises 5.11am, sets 9.02pm. Moon sets 9.32am, rises 10.45pm. High water London Bridge 4.50am (7.6m), 5.06pm (7.5m); Bristol 10.24am (13.7m), 10.45pm (13.9m); Liverpool 2.02am (10.0m), 2.27pm (9.6m)

IN BRITAIN YESTERDAY

Warmest .... Poole (Dorset) 81F (27C)
Coldest (day) .... Tynemouth (Tyne and Wear) 57F (14C)
Wettest .... Tynemouth (Tyne and Wear) 0.21 in
Sunniest .... Eastbourne (East Sussex) 14.9 hrs

Figure 4.11 Col Weather.

Pressure Systems Movement

Frontal depressions tend to move rapidly. The movement of non-frontal depressions depends on type and location; they may remain relatively static or move at moderate speeds. Anticyclones tend to be slow moving and will persist in more or less the same location for long periods. Cols tend to be static.

Movement of the systems is the key to accurate forecasting.

The figures below show the movement of weather over a period of four successive days.

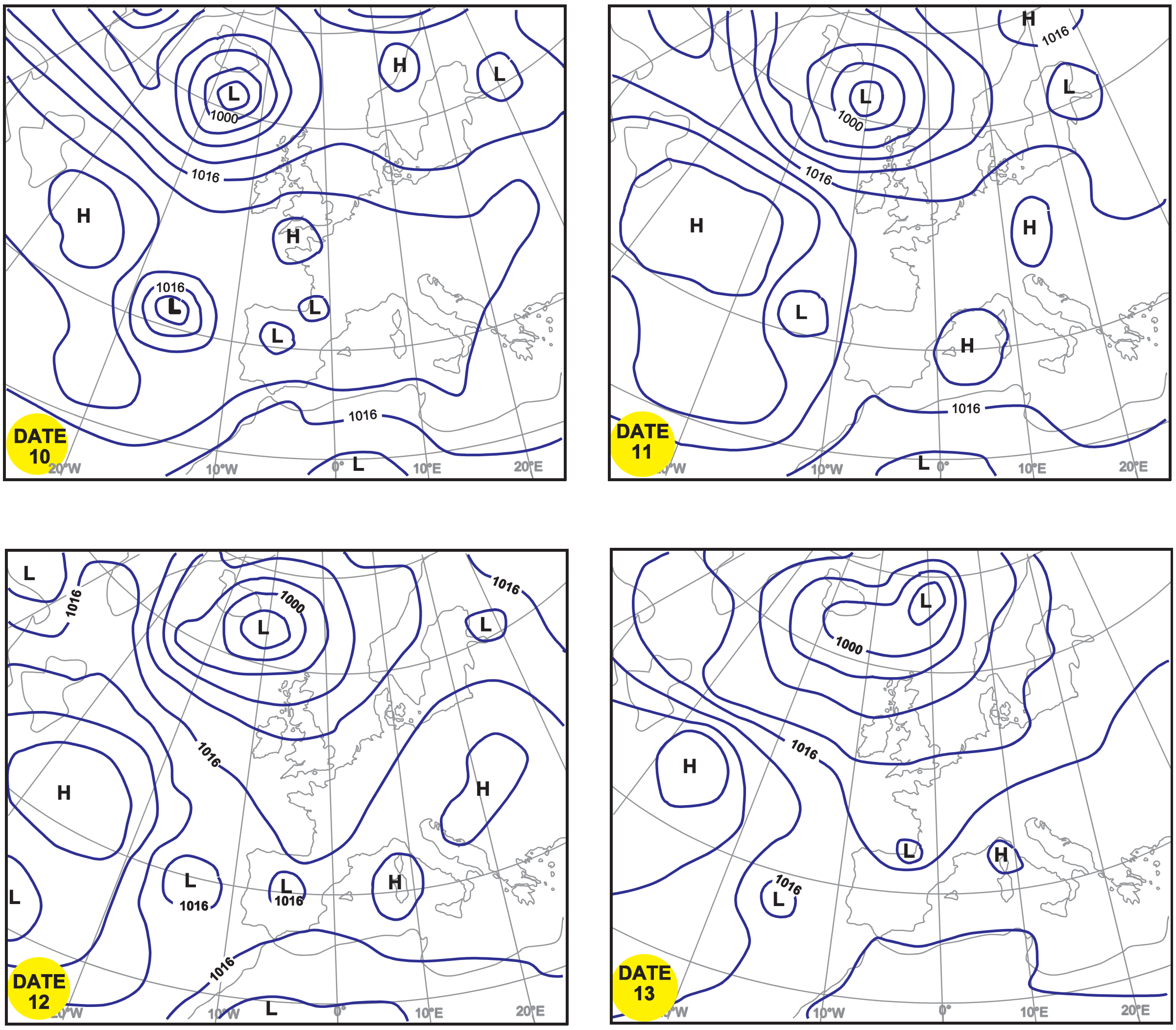


Figure 4.12 Maintenance of Shape.

Terminology

Depressions will **fill up** or **decay** as pressure **rises.**

Depressions will **deepen** as pressure **falls.**

Frontal depressions move rapidly, their average lifetime is 10 to 14 days.

Anticyclones will **build up** as pressure **rises.**

Anticyclones will **weaken** or **collapse** as pressure **falls.**

Anticyclones are generally slow moving and may persist for long periods.

Cols may last up to a few days before being replaced by other pressure systems.

Questions

1. A steep pressure gradient is characterized by:

a. isobars close together, strengthened wind
b. isobars far apart, decreased wind
c. isobars close together, temperature increasing
d. isobars far apart, temperature decreasing

2. QNH at Timbuktu (200 m AMSL) is 1015 hPa. What is the QFE? (Assume 1 hPa = 8 m)

a. 1000 hPa
b. 990 hPa
c. 1020 hPa
d. 995 hPa

3. In temperate latitudes in summer what conditions would you expect in the centre of a high pressure system?

a. Thunderstorms
b. Calm winds, haze
c. Showers
d. Dense cloud

4. If the pressure level surface bulges upwards, the pressure system is a:

a. cold low
b. warm low
c. cold high
d. warm high

5. The QNH at an airfield 200 m AMSL is 1009 hPa; air temperature is 10°C lower than standard. What is the QFF?

a. Not possible to give a definite answer
b. Less than 1009 hPa
c. 1009 hPa
d. More than 1009 hPa

6. QNH is defined as:

a. the pressure at MSL obtained using the standard atmosphere
b. the pressure at MSL obtained using the actual conditions
c. QFE reduced to MSL using the actual conditions
d. QFE reduced to MSL using the standard atmosphere

7. Landing at an airfield with QNH set the pressure altimeter reads:

a. zero feet on landing only if ISA conditions prevail
b. zero
c. the elevation of the airfield if ISA conditions prevail
d. the elevation of the airfield

8. **Airfield is 69 metres below sea level, QFF is 1030 hPa, temperature is ISA -10°C. What is the QNH?**

a. Impossible to tell
b. Less than 1030 hPa
c. 1030 hPa
d. More than 1030 hPa

9. **What is the vertical movement of air relating to a trough?**

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Converging and ascending

10. **What is the vertical movement of air relating to a ridge?**

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Ascending and converging

11. **What is subsidence?**

a. Horizontal motion of air
b. Vertical down draught of air
c. Vertical up draught of air
d. Adiabatic cooling

12. **Aerodrome at MSL, QNH is 1022 hPa. QFF is:**

a. greater than 1022 hPa
b. less than 1022 hPa
c. same as QNH
d. cannot tell without temperature information

13. **Air at the upper levels of the atmosphere is diverging. What would you expect at the surface?**

a. Rise in pressure with clouds dissipating
b. Rise in pressure with clouds forming
c. Fall in pressure with cloud dissipating
d. Fall in pressure with cloud forming

14. **Subsidence would be described as:**

a. vertical ascension of air
b. horizontal movement of air
c. the same as convection
d. vertical down flow of air

15. **You are flying at FL170. The pressure level which is closest to you is the:**

a. 300 hPa
b. 700 hPa
c. 500 hPa
d. 850 hPa

16. **On a surface weather chart, isobars are lines of:**

a. QNH
b. QFE
c. QFF
d. QNE

17. **At FL60 what pressure chart would you use?**

a. 700 hPa
b. 500 hPa
c. 800 hPa
d. 1000 hPa

18. **(For this question use Annex B) A ridge is indicated by letter:**

a. D
b. A
c. B
d. C

19. **(For this question use Annex A) Which of the following best describes Zone D?**

a. Ridge of high pressure
b. Anticyclone
c. Trough of low pressure
d. Col

20. **(For this question use Annex A) Which of the following best describes Zone C?**

a. Trough of low pressure
b. Depression
c. Ridge of high pressure
d. Anticyclone

21. **(For this question use Annex B) Which of the following best describes Zone A?**

a. Col
b. Ridge of High Pressure
c. Depression
d. Trough of low pressure

22. **(For this question use Annex B) Which of the following best describes Zone B?**

    a. Ridge of high pressure
    b. Depression
    c. Anticyclone
    d. Col

23. **(For this question Annex C) The pressure system at position A is a:**

    a. trough of low pressure
    b. anticyclone
    c. col
    d. secondary low

24. **(For this question use Annex C) The pressure system located in area "B" is a**

    a. Ridge of high pressure
    b. col
    c. trough of low pressure
    d. depression

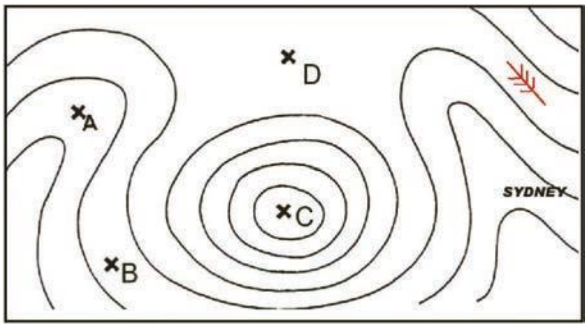
25. **At which average height can the 500 hPa pressure level be expected in moderate latitudes?**

    a. 12.2 km
    b. 3 km
    c. 5.5 km
    d. 9.0 km

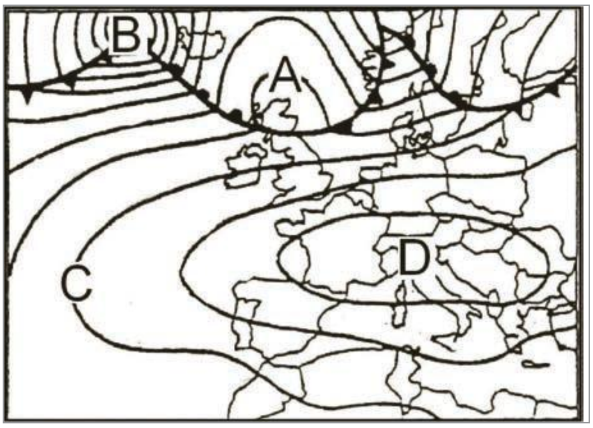
26. **The average pressure found at a height of 1620 m in mid latitudes would be:**

    a. 350 hPa
    b. 400 hPa
    c. 850 hPa
    d. 950 hPa

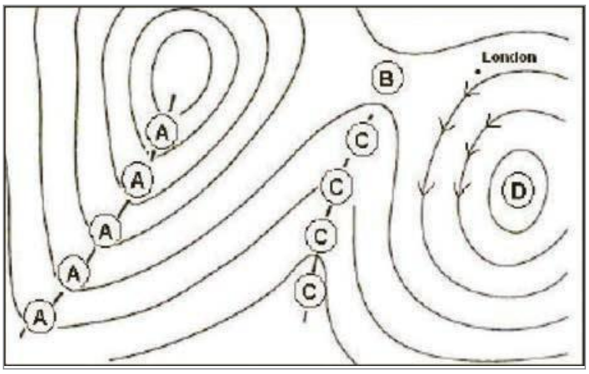
Annex A



Annex B



Annex C



Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	b	b	d	d	d	d	d	d	a	b	c

13	14	15	16	17	18	19	20	21	22	23	24
d	d	c	c	c	b	d	d	b	b	a	b

25	26
c	c

Chapter

5

Temperature

Introduction

One of the important variables in the atmosphere is temperature. The study of temperature variation, both horizontally and vertically has considerable significance in the study of meteorology.

Measurement

There are three scales which may be used to measure temperature though only Celsius and Kelvin are used in meteorology. The figures show the melting point of ice and the boiling point of water (at standard pressure) in each scale.

- The FAHRENHEIT scale: +32 and +212 degrees.
- The CELSIUS (or Centigrade) scale: 0 and +100 degrees.
- The KELVIN (or Absolute) scale: +273 and +373 Kelvin.

Conversion factors:

$$°C = \frac{5}{9} \times (°F - 32)$$

$$°F = \frac{9}{5} \times °C + 32$$

$$K = °C + 273$$

Instruments

The standard means of measurement on the ground is a mercury thermometer placed in a **Stevenson Screen.** Electrical resistance thermometers may be used where the screen is not readily accessible to the observer.

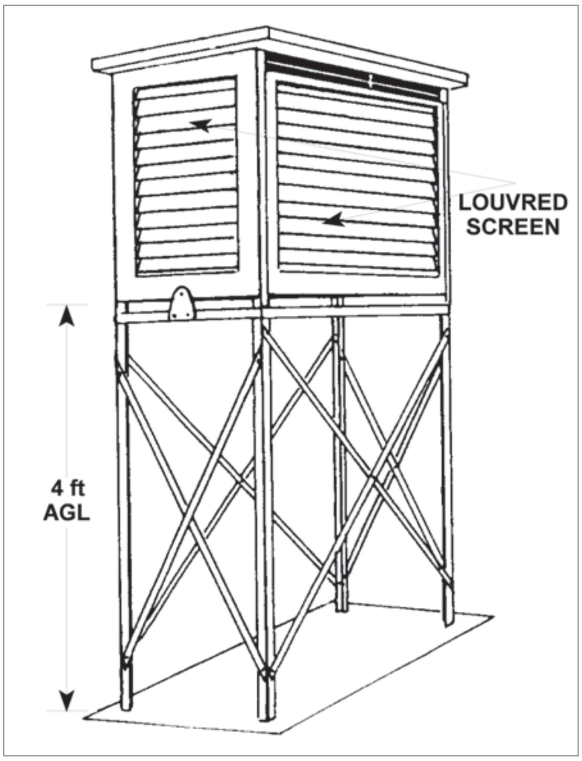


Figure 5.1 The Stevenson Screen

A Thermograph (similar in its output to a barograph) will also be found inside the screen. The Stevenson screen is a louvred box 4 feet (1.22 m) above the ground. This screen, shown in *Figure 5.1*, is used worldwide.

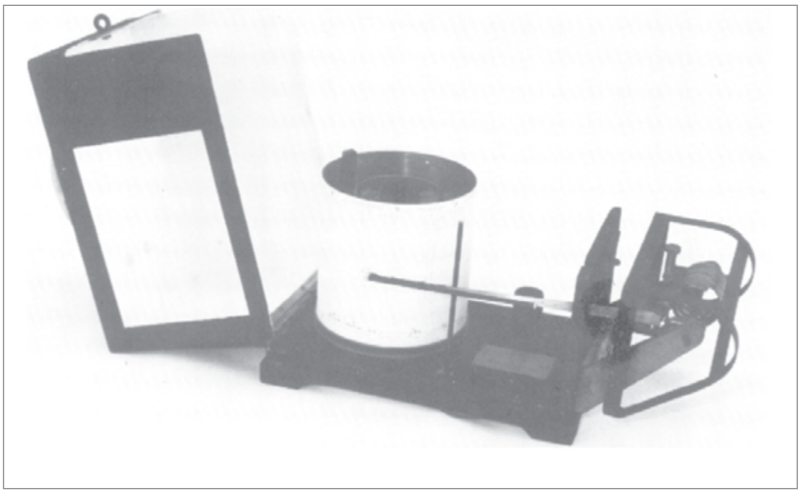


Figure 5.2 Thermograph

Upper air temperature (and pressure and humidity) are measured using a **Radiosonde**, shown in *Figure 5.3*, - a device transmitting continuous readings whilst being carried aloft beneath a balloon. Rate of climb is 1200 fpm and maximum ceiling between 65 000 and 115 000 ft. Earlier devices were tracked using radar to determine position and to determine wind speed. Modern systems use GPS to provide a 3D position to send with the data.

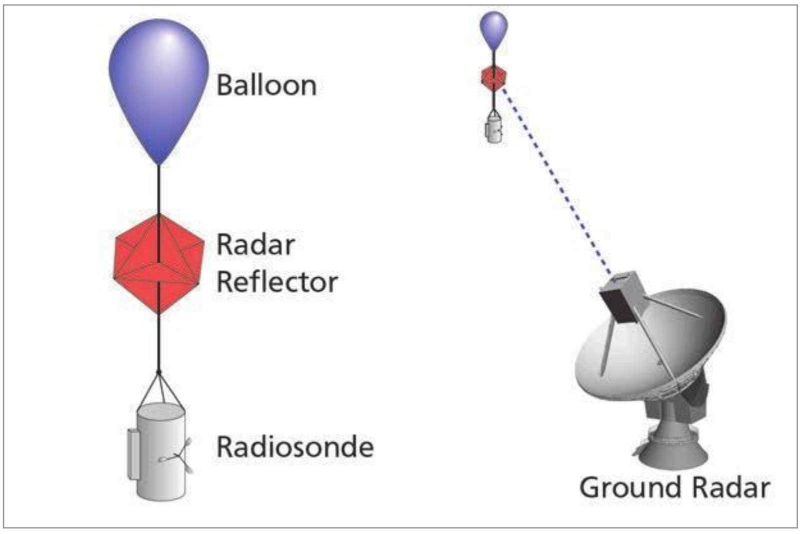


Figure 5.3 A Radiosonde

Aircraft readings, though often the only way in which atmospheric temperature may be measured over the oceans and other areas far away from meteorological stations, are not as accurate as they are affected by compressibility and lag. The electrical thermometer will give a digital readout of temperature and this can be automatically calibrated and transmitted on some modern aircraft.

Figure 5.4 Electrical Thermometer

Heating of the Troposphere

The main source of heat for the troposphere is the sun.

- **Solar Radiation.** Radiation from the sun is of **Short wave-length** (λ) and passes through the troposphere almost without heating it at all.

  λ = 0.15 - 4 microns (micron = μ = 10^{-6} m)

  Some solar radiation is reflected back to the upper air from cloud tops and from water surfaces on the earth. The rest of this radiation heats the earth's surface. The process whereby the **surface** is heated by solar radiation is called **insolation.**

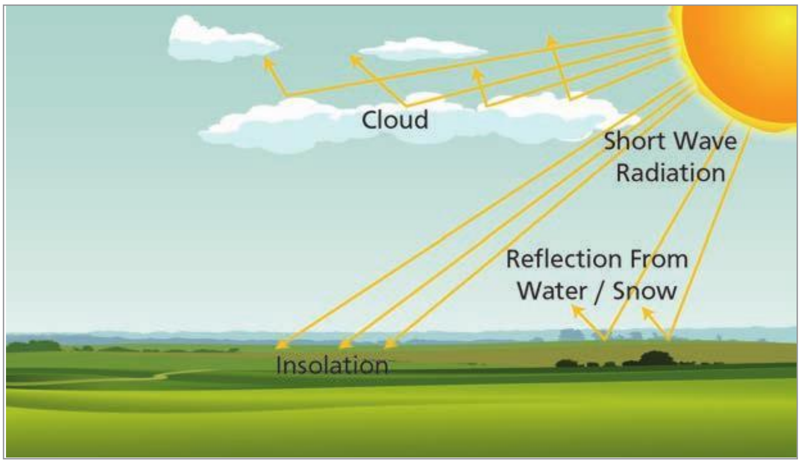


Figure 5.5 Solar Radiation

There are four processes which heat the troposphere:

- **Terrestrial Radiation.**

  The earth radiates heat at all times. It is relatively **long wave** radiation λ = 4 to 80 microns, peaking at 10 m.

  This radiation is absorbed by the so-called greenhouse gases giving rise to the lapse rate in the troposphere, principally water vapour, carbon dioxide and methane. The increase in the amount of carbon dioxide in the troposphere is one of the factors contributing to global warming. (Note: the global warming phenomenon is much more complex than this.)

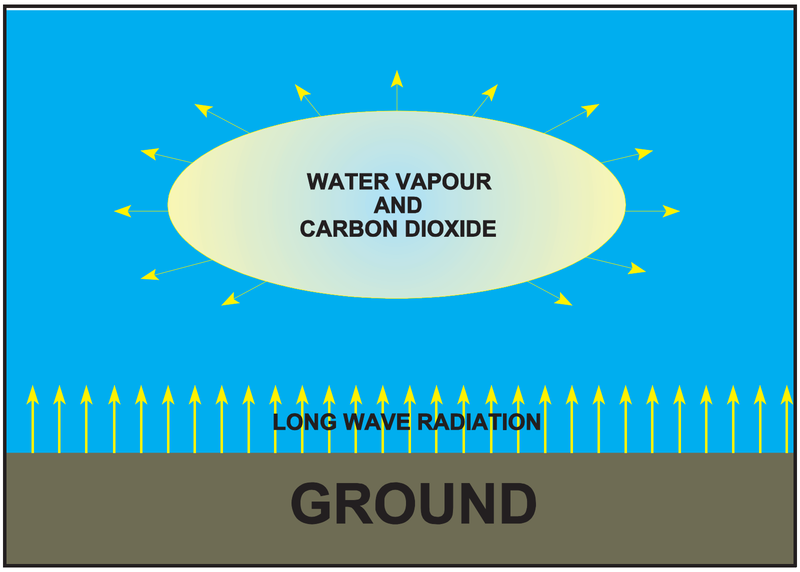


Figure 5.6 Terrestrial Radiation

- **Conduction.** Air lying in contact with the earth's surface by day will be heated by **conduction**. At night air in contact with the earth's surface will be cooled by conduction. Because of the air's poor conductivity, the air at a higher level will remain at the same temperature as during the day and an **inversion** will result.

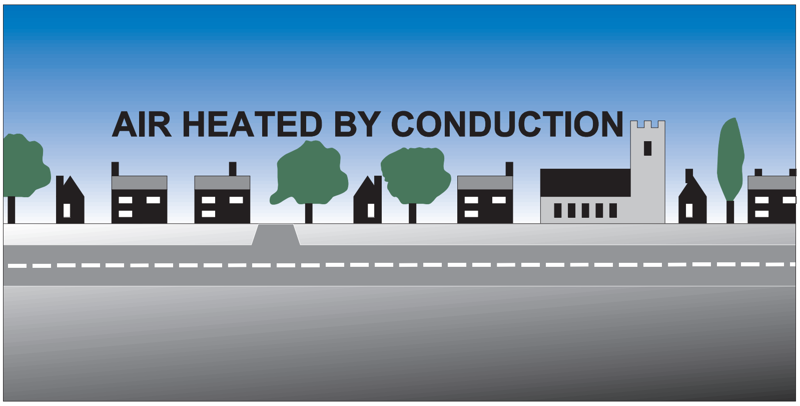


Figure 5.7 Conduction

- **Convection.** Air heated by conduction will be less dense and will therefore rise. This will produce up currents called **thermals** or **convection currents.** These will take the warm air to higher levels in the troposphere. This and terrestrial radiation are the two main processes heating the troposphere.

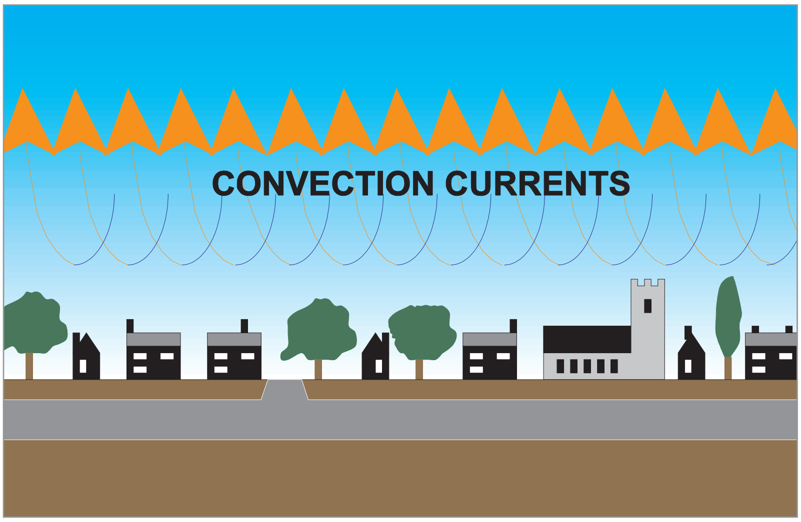


Figure 5.8 Convection Currents

- **Condensation.** As the air is lifted it will cool by the **adiabatic** process and the water vapour in the air will **condense** out as visible droplets forming cloud. As this occurs **latent heat** will be released by the water vapour and this will add to the heating of the troposphere.

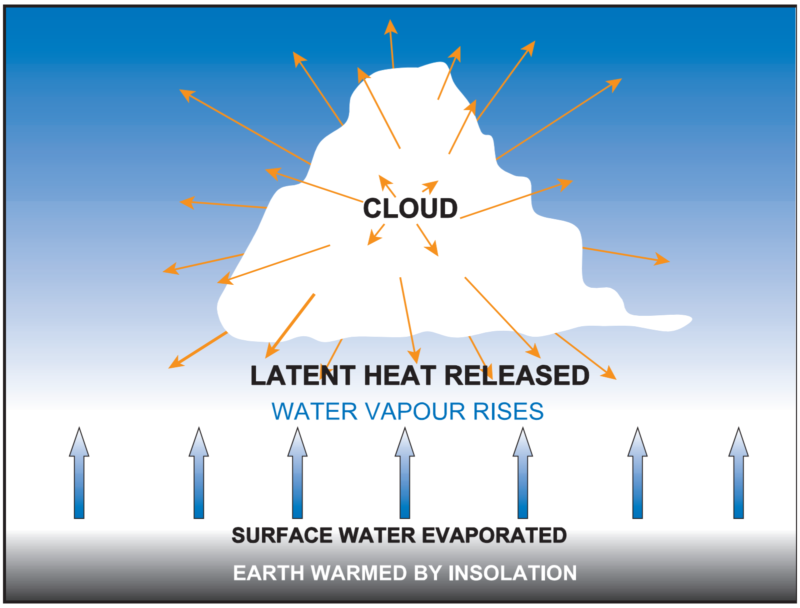


Figure 5.9 Latent Heat being released through Condensation

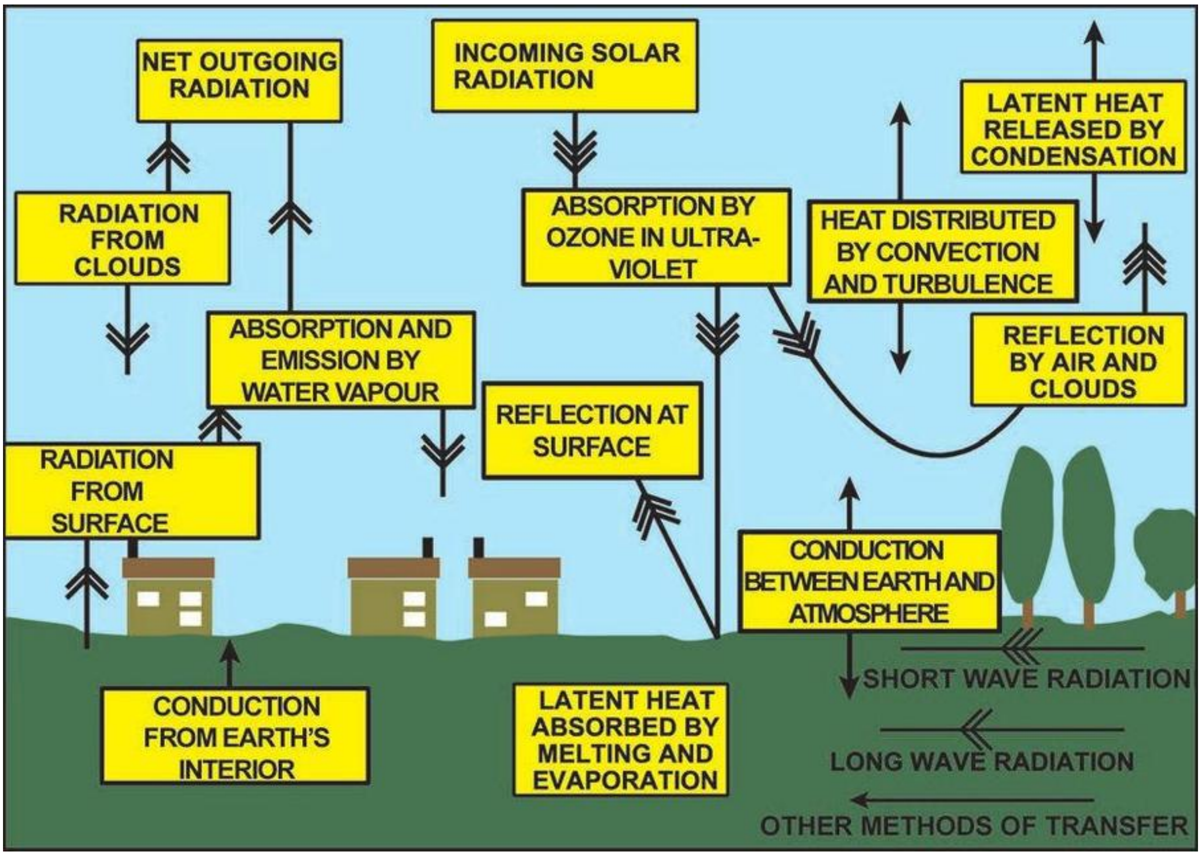


Figure 5.10 Heat Processes in the Atmosphere

Temperature Variation with Height

We have seen that although our source of heat is the sun, because of the troposphere's virtual transparency to insolation, it is in fact heated (by long wave IR) from the surface upwards.

Thus as we move further and further from the surface we would expect the heating effects to diminish.

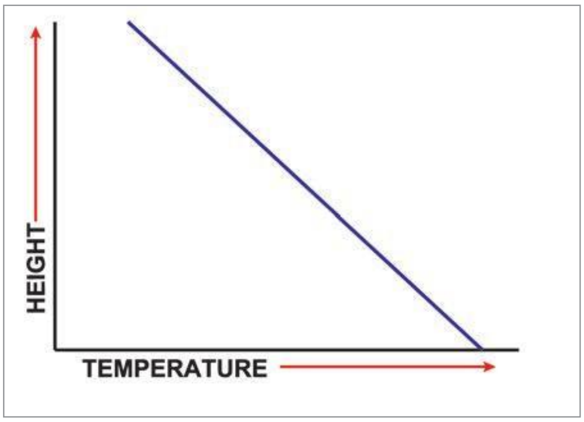


Figure 5.11 Temperature Variation with Height

Lapse Rate

The rate at which temperature falls with an increase in height is called the **Lapse Rate.** An ideal uniform atmosphere would show a constant lapse rate rather like the ISA, which is 0.65°C/100 m (1.98°C (2°) per 1000 ft.)

Isotherm

If temperature remains constant with height it is called an isothermal layer.

Inversions

Where the temperature **increases** with an increase in height, then we have what is called an **inversion.** We have already seen that at night we can expect an inversion above the surface, but this can occur in many different ways.

Radiation, on a night of clear skies, will also result in a temperature inversion above the surface. This is called a Radiation Inversion.

When we look at cloud formation, we shall see that because of **turbulence** in the layer closest to the surface we can have an inversion at a height of 2 or 3 thousand feet.

Quite often, at the **tropopause** instead of the temperature remaining constant, it may show a slight rise for a few thousand feet.

At the **higher levels of the stratosphere**, temperature will show an increase with height (in ISA from 20 km to 32 km the temperature increases at 1°C per km).

In a **high pressure** system, air descends at the centre. As the air **descends** it will be heated **adiabatically** (more of this later) and will be warmer than the air at a lower level. This is called a Subsidence Inversion.

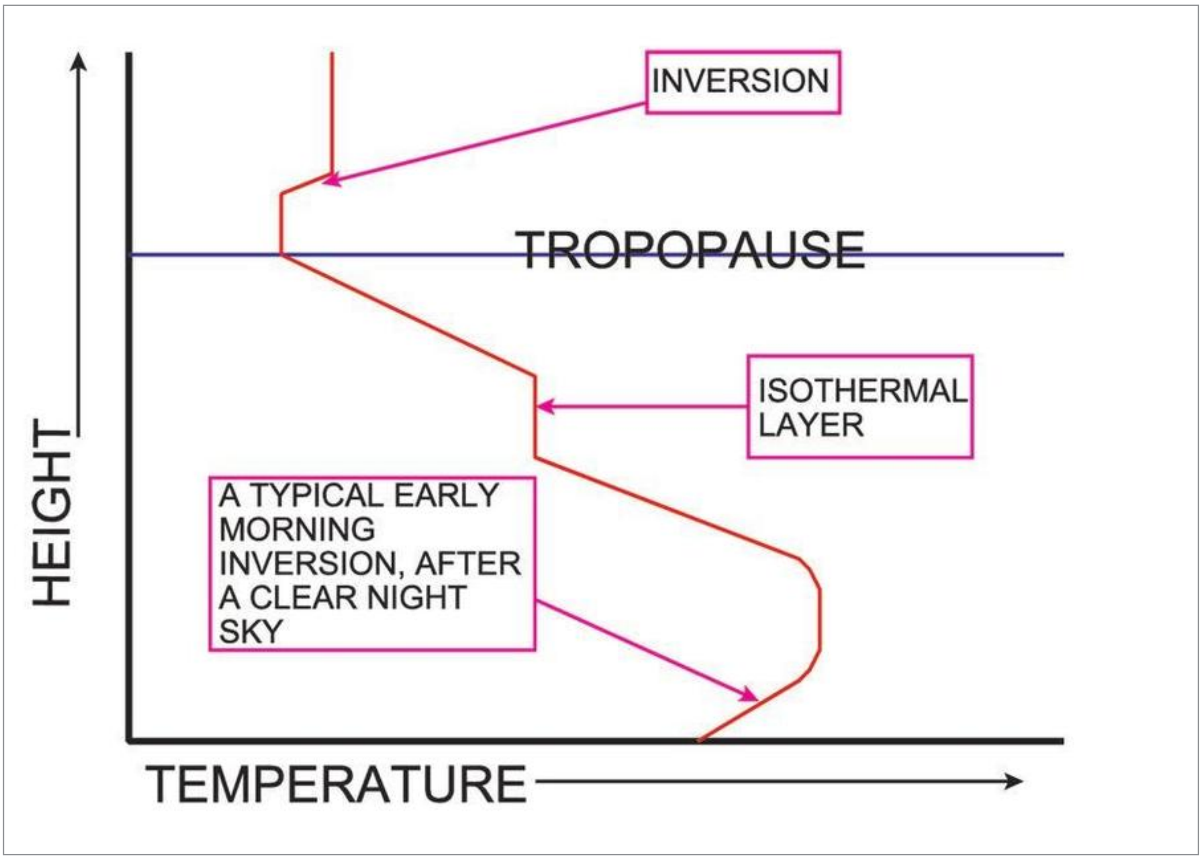


Figure 5.12 Inversions

Surface Temperature

The surface air temperature measured in a Stevenson screen is subject to considerable variations: Latitude Effect, Seasonal Effect, Diurnal Variation and multiple effects due to cloud and wind.

The Angular Elevation of the Sun

- **Latitude Effect.** At the Equator only a small area is heated by the sun's radiation and therefore will be subject to the greatest heat/unit area. At the poles the sun's rays will cover a larger area and there will be the least heat/unit area.

- The actual distance of polar regions from the sun is only fractionally more than that from the Equator, and the effect may be ignored.

- **Seasonal Effect.** The Vernal (Spring) and autumnal equinoxes occur about 21 March and 21 September respectively. Then the sun is directly over the Equator and maximum heating will occur there. About 21 June the sun reaches its most northerly latitude (Summer Solstice for the Northern Hemisphere) and maximum heating will occur in the Northern Hemisphere. But the land (and sea) continues to heat up and maximum temperatures are found around late July or early August in temperate latitudes. Around 21 December the sun reaches its most southerly latitude (Winter Solstice for the Northern Hemisphere) and minimum heating occurs. But the land (and sea) continues to cool down and minimum temperatures are experienced around late January or early February in temperate latitudes.

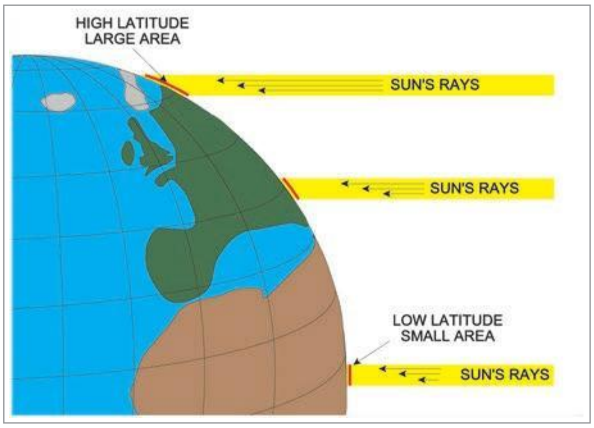


Figure 5.13 The Effect of Latitude

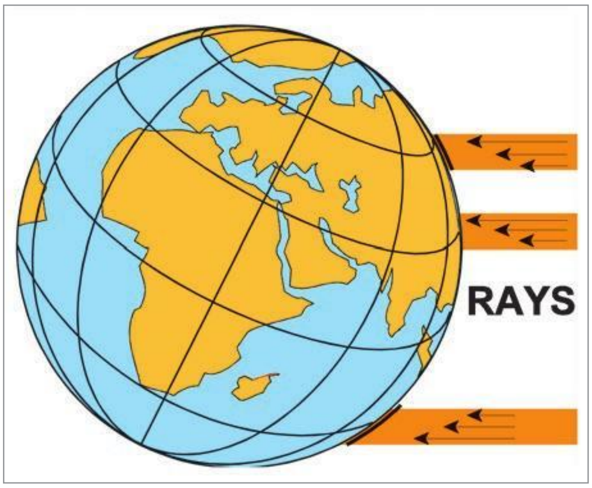


Figure 5.14 The Seasonal Effect

Diurnal Variation - (Note: This Assumes Clear Skies and Light Winds and No Change in Air Mass)

- The sun is at its highest elevation at noon, but for two to three hours after this time, the earth is receiving more solar radiation than it is giving up as terrestrial radiation. A balance between incoming and outgoing radiation is reached on average at 1500 local time when maximum temperatures can be expected.

  Note: the actual time of maximum temperature varies with latitude and time of year, earlier in winter later in summer, but 1500 local time is a good average for temperate latitudes.

- From 15:00 onwards, the temperature falls continuously until a little after sunrise. The lowest temperature occurs at about sunrise plus 30 minutes when once again we get a balance between incoming and outgoing radiation.

- Diurnal Variation (DV) is greatest with clear skies and little wind. DV varies with a number of factors, but in temperate latitudes is about +/- 6 degrees about the mean.

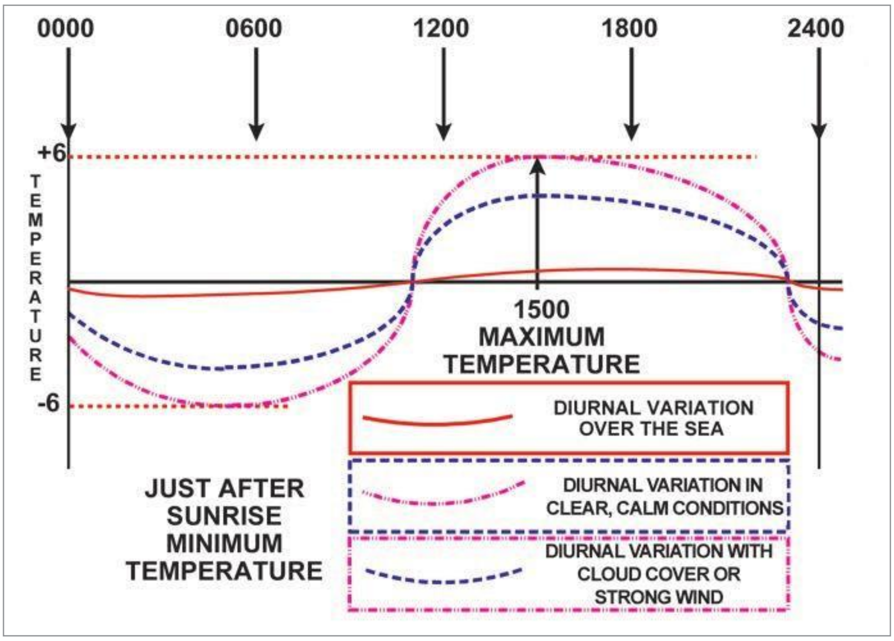


Figure 5.15 Diurnal Variation

- **Cloud cover by day.** By day some of the solar radiation is reflected back by the cloud tops and maximum temperature (T Max) is reduced.

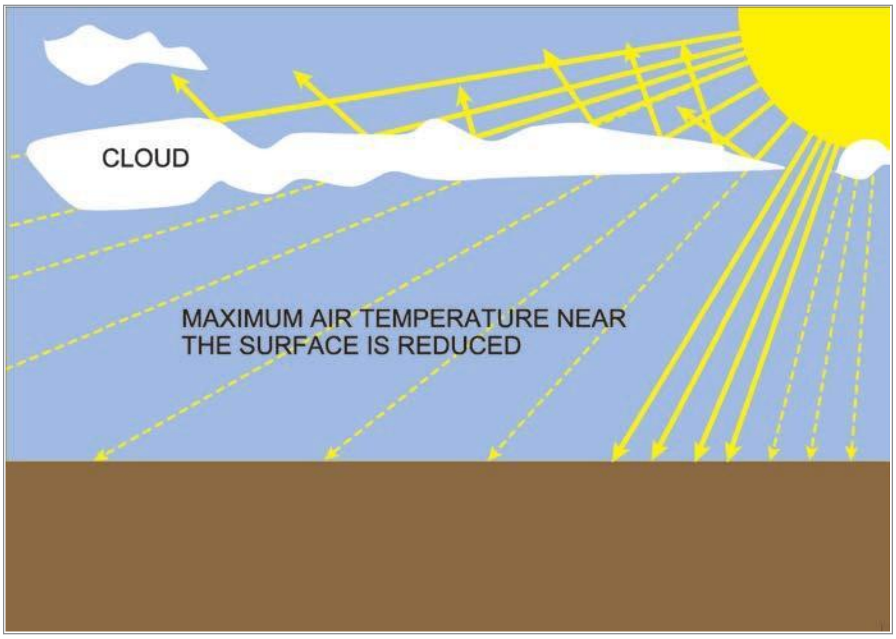


Figure 5.16 Cloud Cover by Day

- **Cloud cover by night.** By night terrestrial radiation is absorbed and radiated back to the earth's surface from the clouds. T min is **increased.**

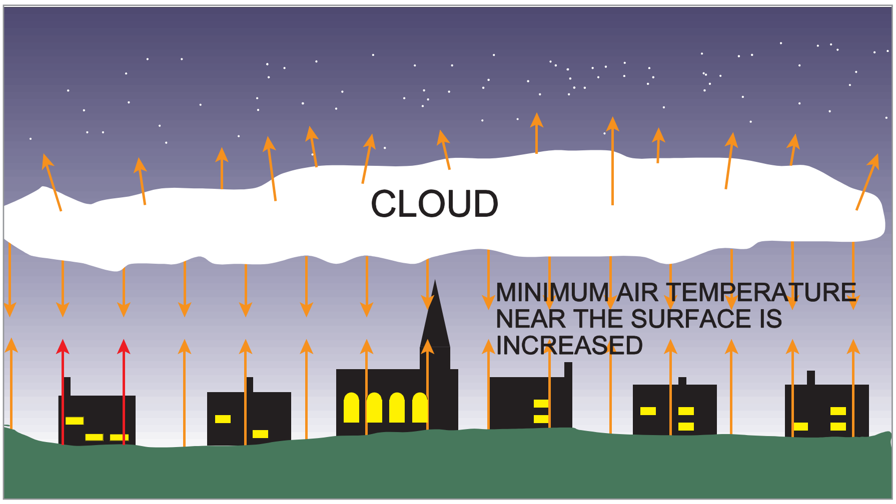


Figure 5.17 Cloud Cover by Night

- **Effect of wind by day.** By day wind will cause turbulent mixing of the warm air at the surface with cold air above, **reducing** T max. Wind will also reduce the time the air is in contact with the warm ground.

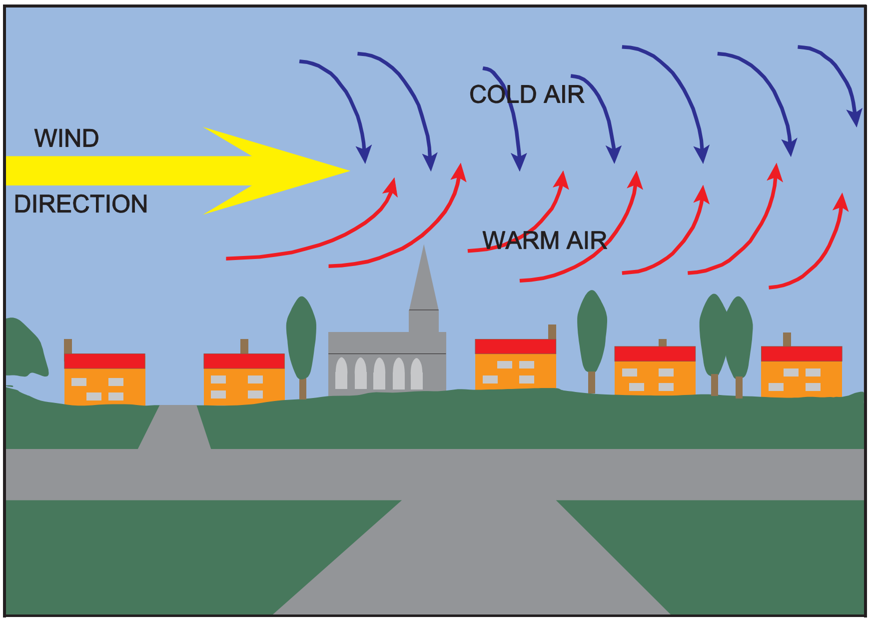


Figure 5.18 The Effect of Wind by Day

- **Effect of wind by night.** By night there will normally be an inversion above the surface and wind will cause cold air to be turbulently mixed with warm air above thus **increasing** T min.

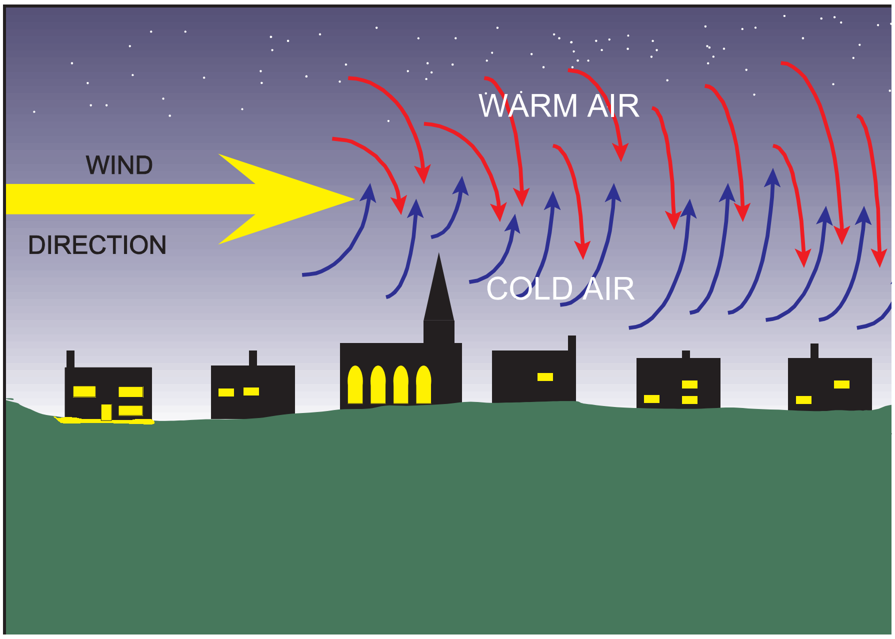


Figure 5.19 The Effect of Wind by Night

In summary, wind or cloud cover will cause T max to be reduced and T min to be increased. Therefore DV will be **reduced.**

- **DV over sea.** As the **Specific Heat** (SH) of water is unity, compared to other substances whose SH is much less, and as the temperature rise is **inversely proportional** to the **Specific Heat**, the diurnal temperature variation over the sea is small, generally less than 1°C.

Nature of the Surface

- **Sea.** The sea takes a long time to heat (and cool) and as we have seen has a very small DV.

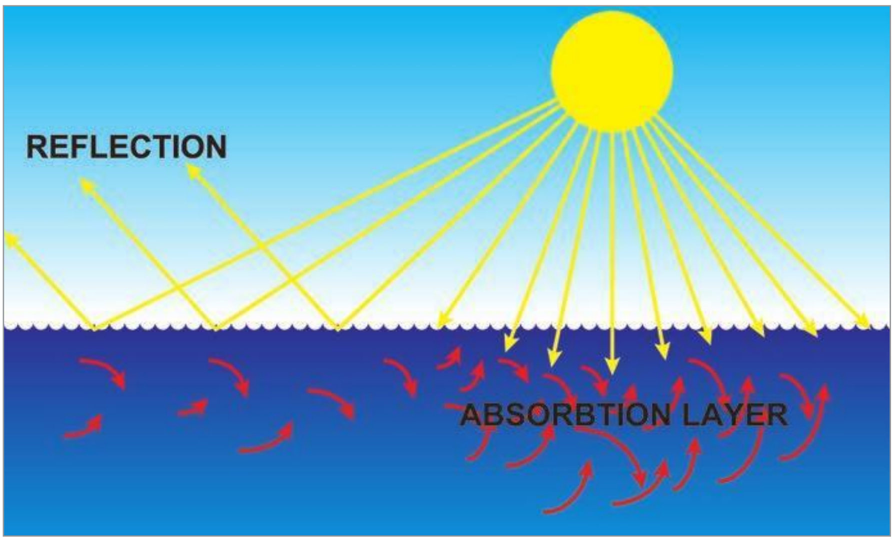


Figure 5.20 Diurnal Variation Over the Sea

The difference in DV values between land and sea is the cause of sea breezes. The minimal DV of sea temperature is the reason why the most common form of fog, radiation fog, never forms over the sea.

When the angular elevation of the sun is low, much solar radiation is reflected back to the atmosphere.

- **Land.** Bare rock, sand, dry soil, tarred roads and concrete runways attain a higher temperature by insolation than woods, lakes, grasslands and wet soil.

The temperature difference between air above concrete runways and adjacent grass can be as much as 4 degrees. Higher temperature surfaces provide strong up currents called thermals or convection currents.

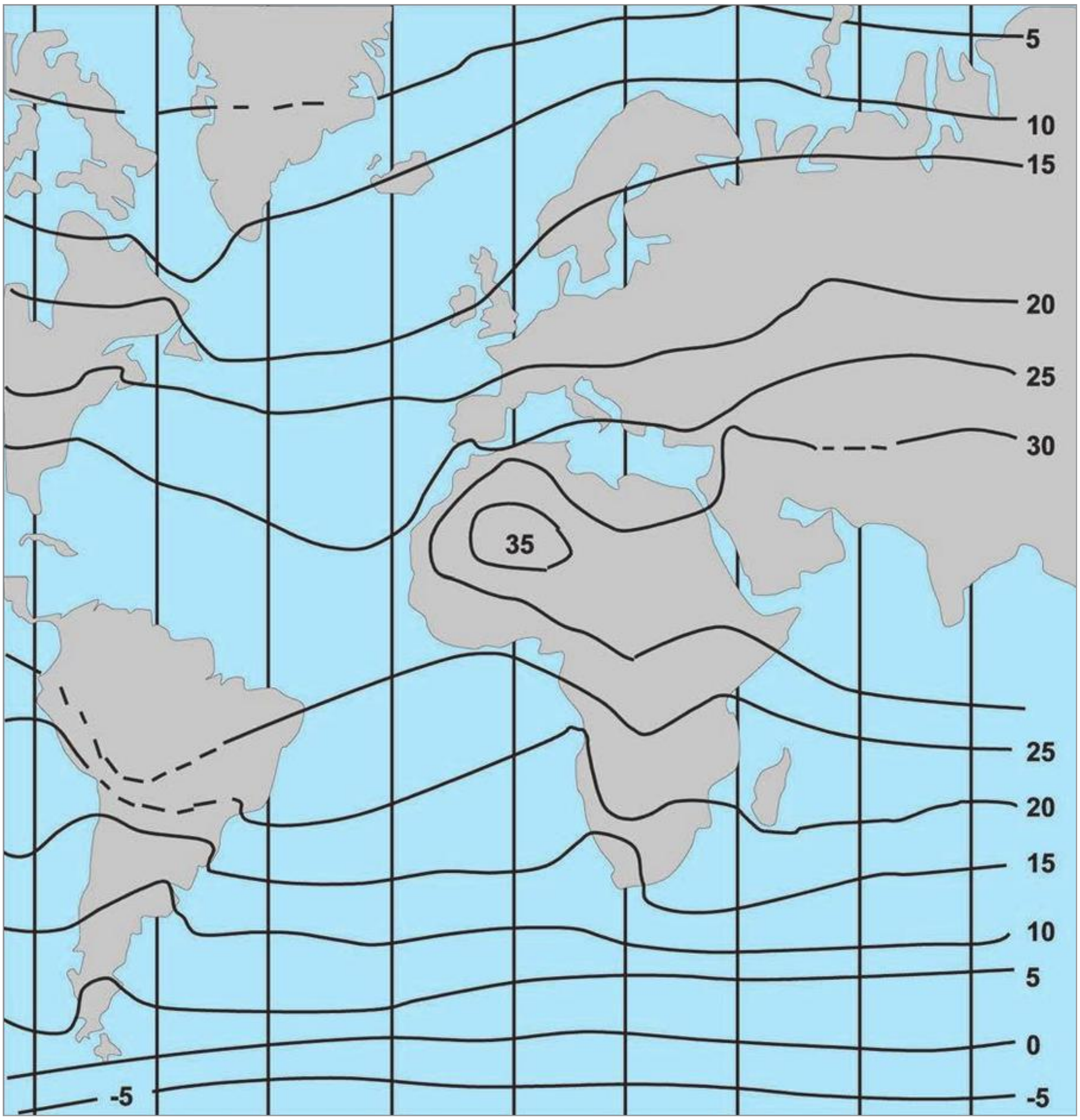


Figure 5.21 July Average Temperatures

In *Figure 5.21* we may note that the sea temperature remains "cool" in July in the Northern Hemisphere but the desert land areas of Africa and neighbouring Asia get very warm. Air over snow covered surfaces is very cold. Some 80% of solar radiation is reflected from snow surfaces.

Snow **does not** prevent the earth from radiating its heat. Hence surface air temperatures over snow will become colder day by day. Temperatures in Siberia can reach -72°C after a long cold winter. This very cold air results in high density and the development of anticyclones.

Location

- **Over Land.** Air in a valley will tend to be more static than air in an exposed position. Therefore by night the air is in contact with the ground for a longer time and the air temperature is lower than on a hill. Additionally, in a valley, cold air tends to sink from the hills above at night, again causing lower temperatures. It is for these reasons that mist and fog tend to form firstly in valleys.

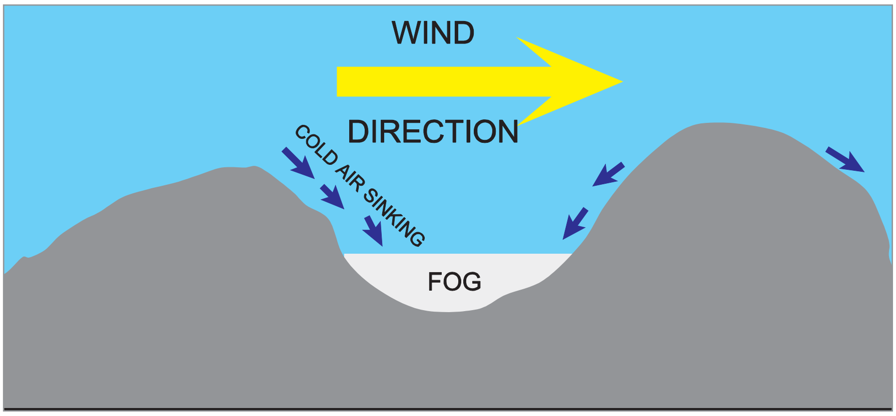


Figure 5.22 Location Effect

- **Over Oceans.** The fact that seas tend to have a very small DV of temperature has been stated above. On a wide scale this means that in winter the sea is warmer than the land and thus there is a widespread movement of air from land to sea (monsoon effect). There is an opposite tendency in summer.

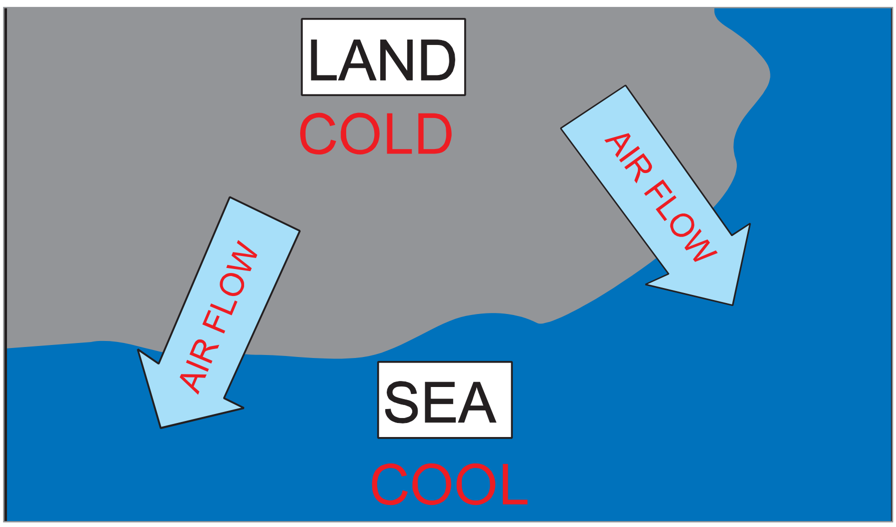


Figure 5.23 Relative Airflow in Winter

Origin of Air Supply

Air tends to retain its temperature and humidity for a considerable time, therefore air from high latitudes will bring lower temperatures to UK. A southerly wind, however, will normally provide an increase in temperature.

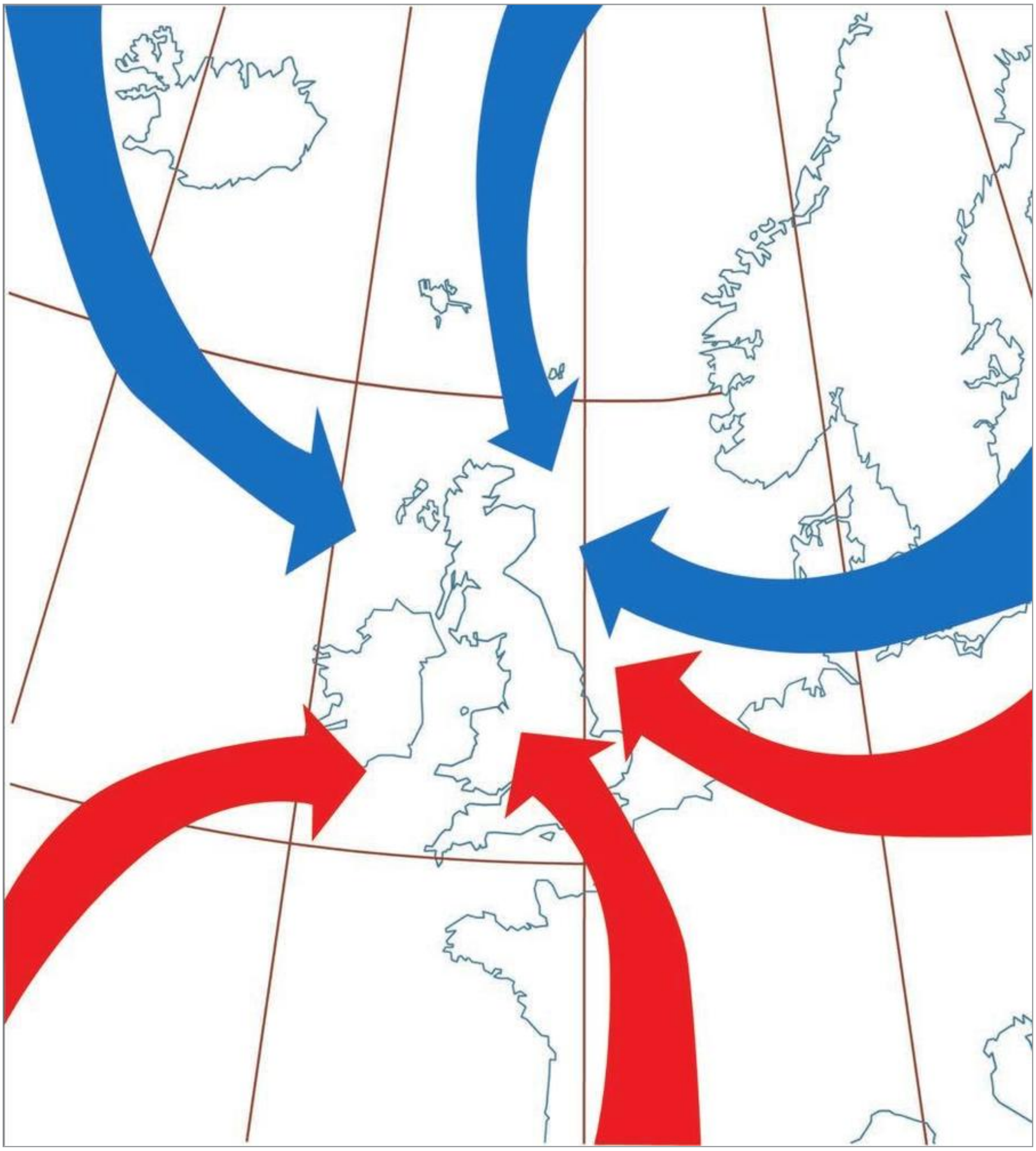


Figure 5.24 Origin of Air Supply

Questions

1. The measurement of surface temperature is made:

a. at ground level
b. at approximately 10 metres from ground level
c. at approximately 4 feet above ground level
d. at approximately 4 metres above ground level

2. The purpose of a "Stevenson screen" is to:

a. maintain a moist atmosphere so that the wet bulb thermometer can function correctly
b. prevent the mercury freezing in the low winter temperatures
c. protect the thermometer from wind, weather and from direct sunshine
d. keep the wet and dry bulb thermometers away from surface extremes of temperature

3. If temperature remains constant with an increase in altitude there is:

a. an inversion
b. an inversion aloft
c. uniform lapse rate
d. an isothermal layer

4. The surface of the earth is heated by:

a. convection
b. conduction
c. long wave solar radiation
d. short wave solar radiation

5. Cloud cover will reduce diurnal variation of temperature because:

a. incoming solar radiation is reflected back to space and outgoing terrestrial radiation is reflected back to earth
b. incoming solar radiation is re-radiated back to space and atmospheric heating by convection will stop at the level of the cloud layer
c. the cloud stops the sun's rays getting through to the earth and also reduces outgoing conduction
d. incoming solar radiation is reflected back to space and outgoing terrestrial radiation is re-radiated from the cloud layer back to the surface

6. Diurnal variation of the surface temperature will:

a. be unaffected by a change of wind speed
b. decrease as wind speed increases
c. increase as wind speed increases
d. be at a minimum in calm conditions

7. **Which of the following surfaces is likely to produce a higher than average diurnal variation of temperature:**

a. rock or concrete
b. water
c. snow
d. vegetation

8. **Most accurate temperatures above ground level are obtained by:**

a. tephigram
b. aircraft reports
c. temperature probe
d. radiosonde

9. **The method by which energy is transferred from one body to another by contact is called:**

a. radiation
b. convection
c. conduction
d. latent heat

10. **The diurnal variation of temperature is:**

a. greater over the sea than overland
b. less over desert areas then over temperate grassland
c. reduced anywhere by the presence of cloud
d. increased anywhere as wind speed increases

11. **The troposphere is heated largely by:**

a. absorption of the sun's short wave radiation
b. radiation of heat from cloud tops and the earth's surface
c. absorption by ozone of the sun's short wave radiation
d. conduction from the surface, convection and the release of latent heat

12. **An inversion is one in which:**

a. there is no horizontal gradient of temperature
b. there is no change of temperature with height
c. there is an increase of temperature as height increases
d. there is a decrease of temperature as height increases

13. **The sun gives out________ amount of energy with _________ wavelengths. The earth gives out relatively___________ amounts of energy with relatively___________ wavelengths:**

a. large, large, small, small
b. small, small, large, large
c. large, large, small, large
d. large, small, small, large

14. With a clear night sky, the temperature change with height by early morning is most likely to show:

a. a steady lapse rate averaging 2°C per 1000 ft
b. a stable lapse rate of 1°C per 1000 ft
c. an inversion above the surface with an isothermal layer above
d. an inversion from near the surface and a 2°C per 1000 ft lapse rate above

15. Over continents and oceans, the relative temperature conditions are:

a. warmer in winter over land, colder in summer over sea
b. colder in winter over land, warmer in winter over sea
c. cold in winter over land and sea
d. warmer in summer over land and sea

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	c	d	d	d	b	a	d	c	c	d	c

13	14	15
d	d	b

Chapter

6

Humidity

Definition of Latent Heat

The latent heat of a substance is the heat absorbed or released without change of temperature when the substance changes state. Latent heat differs according to the state of the substance. When ice changes to water or water vapour, or water changes to water vapour, latent heat is **absorbed**.

When water vapour changes to water or ice, or water changes to ice, latent heat is **released**.

Evaporation

Evaporation is the change of state from **liquid** to **vapour**. Latent heat is **absorbed**.

Evaporation can occur at any temperature. For a particular temperature there is a particular amount of water per unit volume that the air can hold. When this maximum is reached, evaporation will cease.

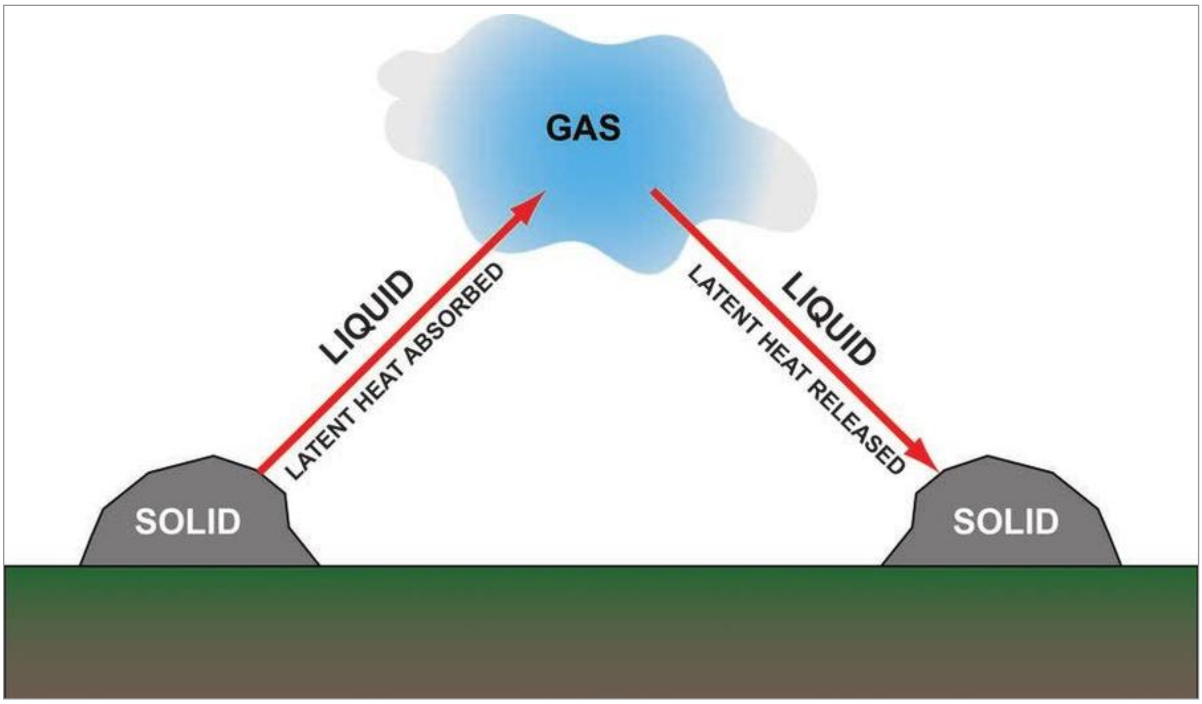


Figure 6.1 The Change of State from Solid to Liquid to Gas and Back Again.

Saturation

Air becomes saturated by adding more water vapour to it. Alternatively, as warm air can hold more water vapour than cold, saturation can be achieved by **cooling** the air.

Air is saturated if it contains the maximum amount of water vapour that it can hold at that temperature. If **saturated** air is cooled, **condensation** will occur.

Condensation

Condensation is the change of state from **vapour to liquid**. Latent heat is **released**. Condensation causes cloud and fog to form. Condensation will require minute impurities or particles called **hygroscopic or condensation nuclei;** these are usually present in abundance in the troposphere.

Freezing

If the water droplet is cooled below zero, then it may change state again to **ice**. The process is called **freezing**. Freezing requires the presence of **freezing nuclei**; these are less common in the troposphere than condensation nuclei, so it is possible to have water droplets in the atmosphere with temperatures below 0°C. These are known as supercooled water droplets and give us the icing hazard discussed in Chapter 16.

Melting

The opposite change of state, from solid to liquid, is called **melting**. (There is no **superfrozen** state).

Sublimation

Sublimation is the change of state directly from **water vapour** to **ice** without water droplets being formed. Latent heat is **released.** This process is also known as **deposition.**

The change of state from ice directly to **water vapour** is also called sublimation.

Humidity Measurement

- **Absolute Humidity** is the weight of water vapour in unit volume of air. Absolute Humidity is usually expressed in g/m^3 .

- **Humidity Mixing Ratio (HMR)** is the weight of water vapour contained in unit mass of dry air. The Humidity Mixing Ratio is usually expressed in g/kg. In unsaturated air, HMR remains constant during ascent while temperature and pressure decreases.

- **Saturation Mixing Ratio (SMR)** is the maximum amount of water vapour a unit mass of dry air can hold at a specified temperature.

- **Relative Humidity (RH).**

The ratio $\frac{\text{HMR}}{\text{SMR}} \times 100\%$

or more simply, the amount of water vapour present in a volume of air divided by the maximum amount of water vapour which that volume could hold at that temperature expressed as a percentage.

RH 100% = SATURATION

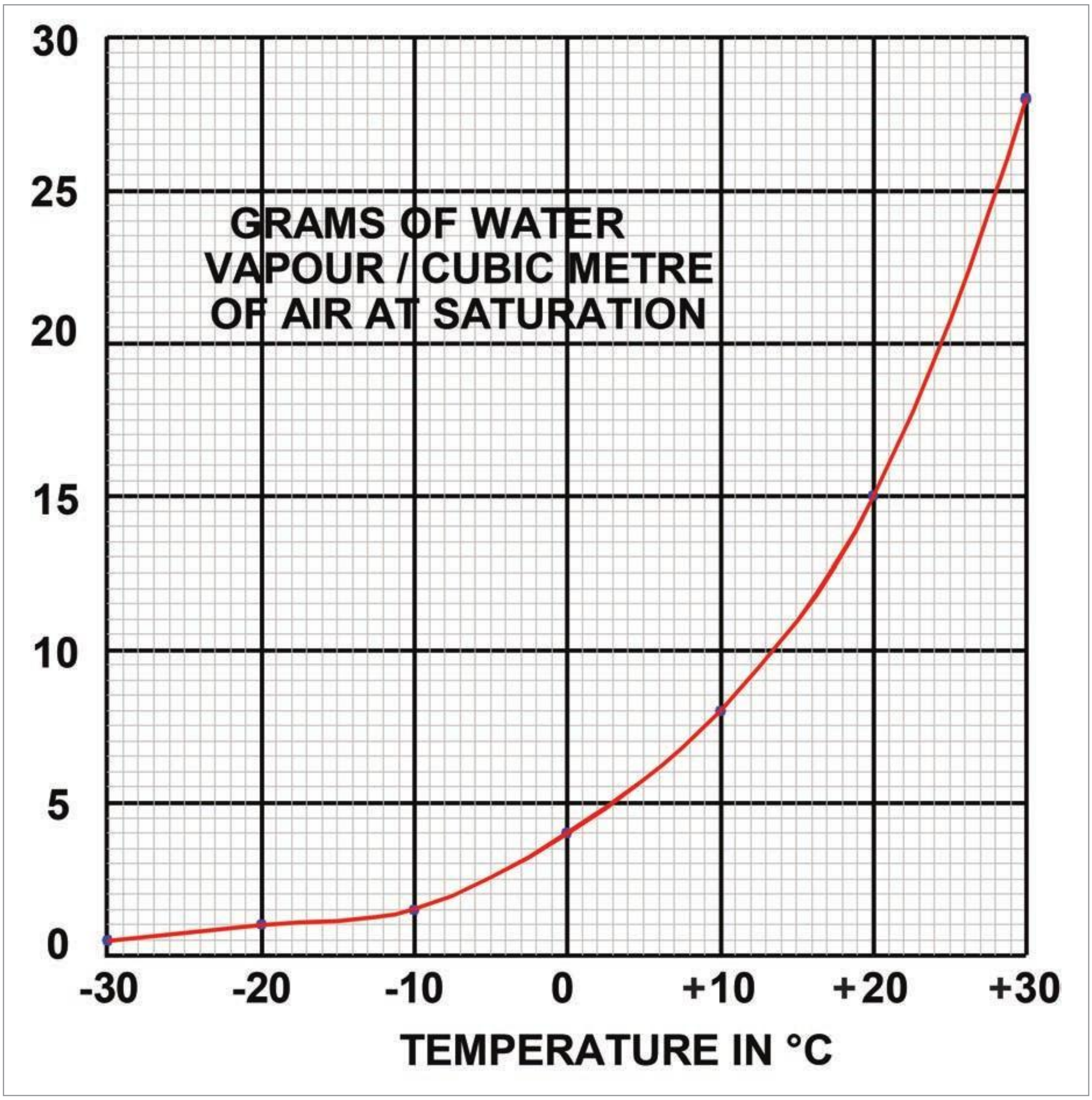


Figure 6.2 The Amount of Water Vapour the Air can Hold when Saturated at Different Temperatures

Bergeron Theory

This is more accurately the (Wegener)-Bergeron-Findeissen theory, named after the 3 scientists who discovered the relationship. *Figure 6.3*, next page, shows the partial pressure of water vapour at saturation for temperatures from -30°C to +40°C. As we already know, the maximum amount of water vapour the air can hold and hence the partial water vapour pressure at saturation decreases as temperature decreases.

The small sub-diagram shows that at temperatures below 0°C the partial pressure at saturation for the formation of water is greater than the partial pressure for the formation of ice. This means that the air becomes saturated for the formation of ice before it becomes saturated for the formation of water. In other words at temperatures below zero the water vapour will go directly to the solid state without first going through the liquid state (the converse also applies). This may be stated as: **"the saturation vapour pressure over water is greater than over ice"**.

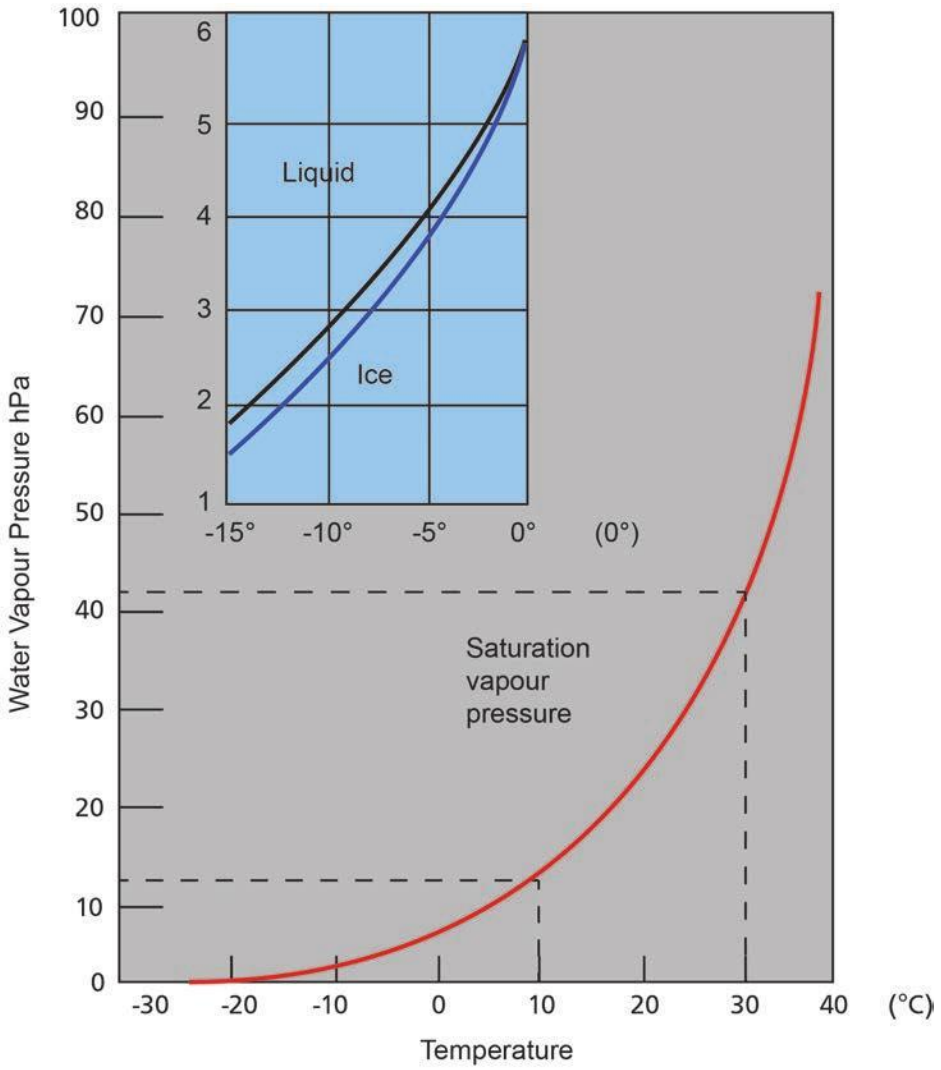


Figure 6.3

The table shows the same effect in terms of relative humidity for water and ice, for example, at -10°C when the air is saturated for the formation of ice the relative humidity for water is 91%. The effect of this is that when supercooled water droplets exist (at temperatures below 0°C), the water droplets will evaporate saturating the air (for the formation of ice) and the water vapour will now sublime out as ice. This effect is important in the formation of precipitation in clouds when the temperature is below 0°C and in the formation of fog.

RELATIVE HUMIDITY AT SATURATION FOR ICE		
Temperature	RH for water	RH for ice
0°C	100%	100%
-05°C	95%	100%
-10°C	91%	100%
-15°C	87%	100%
-20°C	83%	100%

Measurement of Humidity

Atmospheric humidity is measured using a **dry bulb and wet bulb hygrometer** or **psychrometer** or an **electrical hygrometer**. The dry bulb and wet bulb hygrometer or psychrometer comprises two thermometers. The dry bulb thermometer gives the ambient temperature. The wet bulb thermometer has, around its bulb, a muslin cloth the other end of which is in a reservoir of distilled water. The water rises up the muslin and evaporates drawing heat from the bulb and hence reducing its temperature. So the wet bulb thermometer gives the lowest temperature to which the air can be cooled by the evaporation of water. The rate at which the water evaporates depends on the relative humidity. With high relative humidity the rate of evaporation will be slow so the wet bulb temperature will be relatively high. Conversely if the air is dry the evaporation will be rapid and the wet bulb temperature will be much lower than the dry bulb temperature.

Dry-bulb and Wet-bulb Hygrometer or Psychrometer

- If air is dry, water will evaporate from the muslin covering the wet bulb and latent heat will lower the temperature.
- If air is saturated, no evaporation will occur and thermometers will read the same.
- **Dew point, relative humidity** and **HMR** are read from tables or slide rule by entering with the two temperatures obtained.

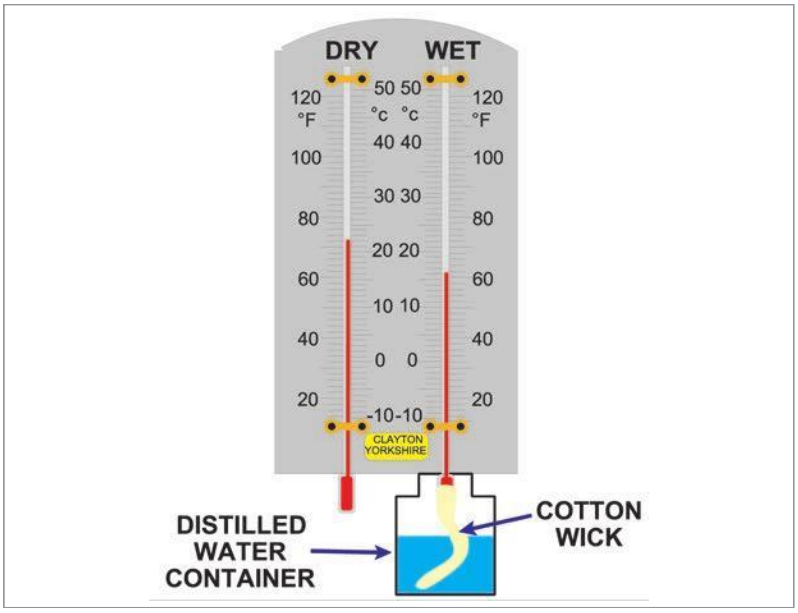


Figure 6.4 Dry-Bulb and Wet-Bulb Hygrometer or Psychrometer

Dew Point Temperature

Dew point (DP) is the temperature to which air must be cooled at constant pressure for saturation to occur.

Note that the **dew point** temperature is not the same as the **wet bulb** temperature (except at saturation).
The dew point has a lapse rate of 0.5°C/1000 ft
Wet bulb = dry bulb (= dew point) – 100% RH (saturation)

Diurnal Variation of Humidity

By day, as the temperature increases, RH will **decrease** because the maximum amount of water vapour air can hold increases as the temperature rises.

After 1500 hrs, the temperature will start to fall and the maximum amount of water vapour the air can hold will fall and thus the RH will **increase**. The higher RH at night is the reason for the formation of **mist** and **fog** after dark in autumn and winter.

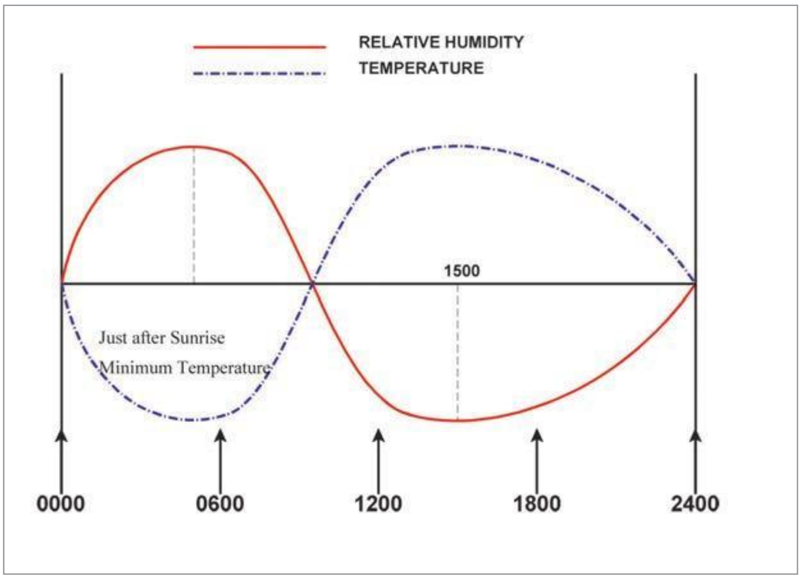


Figure 6.5 Diurnal Variation of Humidity

RH is maximum approximately 30 minutes after sunrise when the temperature is minimum.

Figure 6.6 shows a graph of relative humidity at RAF Waddington over a number of years. The maximum and minimum times and the sinusoidal curve confirm *Figure 6.5*.

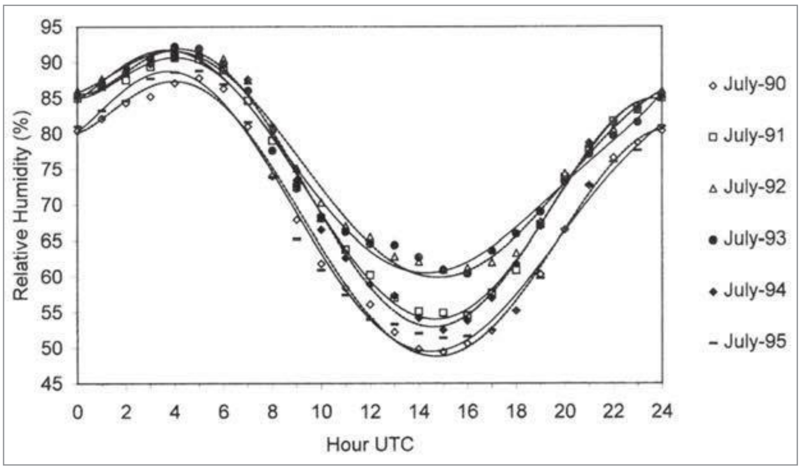


Figure 6.6

By definition:
Saturated Air: RH=100%
Dry Air: RH<100%
E.g. RH=99.9% - Dry Air

Questions

1. **Throughout the 24 hours of a day the Relative Humidity can be expected to:**

   a. increase during the day and decrease at night
   b. stay reasonably constant throughout the 24 hours
   c. reduce during the day and increase at night
   d. only change with a change of air mass

2. **During a night with a clear sky, surface temperature will ____________ RH will______________ and dew point will___________.**

   a. fall, rise, rise
   b. rise, rise, fall
   c. fall, rise, remain the same
   d. fall, fall, remain the same

3. **A change of state directly from a solid to a vapour or vice versa is:**

   a. insolation
   b. condensation
   c. evaporation
   d. sublimation

4. **The instrument used for measuring the humidity of air is a:**

   a. hydrometer
   b. hygrometer
   c. wet bulb thermometer
   d. hygroscope

5. **The process of change of state from a gas to a liquid is:**

   a. evaporation in which latent heat is absorbed
   b. evaporation in which latent heat is released
   c. condensation in which latent heat is absorbed
   d. condensation in which latent heat is released

6. **The process of change of state from a liquid to a gas is:**

   a. condensation in which latent heat is released
   b. evaporation in which latent heat is released
   c. condensation in which latent heat is absorbed
   d. evaporation in which latent heat is absorbed

7. **Air is classified as dry or saturated according to its relative humidity. If the relative humidity were 95% the air would be classified as:**

   a. conditionally saturated
   b. partially saturated
   c. saturated
   d. dry

8. **On a wet bulb thermometer in an unsaturated atmosphere there will be a reduction of temperature below that of the dry bulb thermometer because:**

a. heat is absorbed during the process of condensation
b. heat is released during the process of condensation
c. heat is absorbed by the thermometer during the process of evaporation
d. heat is released from the thermometer during the process of evaporation

9. **Relative humidity is:**

a. air temperature over wet bulb temperature × 100
b. air temperature over dew point temperature × 100
c. the actual amount of water vapour in a sample of air over the maximum amount of water vapour that the sample can contain × 100
d. the maximum amount of water vapour that a sample of air can contain over the actual amount of water vapour the sample does contain × 100

10. **Absolute humidity is:**

a. the number of water droplets in a given quantity of air
b. the amount of water vapour that a given quantity of air holds
c. the maximum amount of water vapour that a given quantity of air can hold
d. the maximum number of water droplets that a given quantity of air can hold

11. **Wet bulb temperature would normally be lower than the dry bulb temperature because:**

a. condensation causes a release of latent heat
b. evaporation causes cooling
c. latent heat is absorbed by the bulb thermometer
d. of condensation on the muslin wick of the bulb

12. **The wet bulb temperature:**

a. is measured using a hydrometer
b. is the minimum temperature to which a thermometer bulb can be cooled by the evaporation of water
c. measures the dew point of the air
d. is the minimum temperature reached by the surface of the earth as measured by a thermometer placed 1.2 metres above the ground

13. **Which one of the following statements relating to atmospheric humidity is correct?**

a. If the air temperature falls then the absolute humidity must increase
b. The absolute humidity is the mass of water vapour contained in unit volume of air
c. The diurnal variation of dew point temperature is greatest when skies are clear at night
d. The dew point temperature is the temperature indicated by the wet bulb thermometer

14. When condensation takes place, the higher the temperature, the __________the amount of latent heat___________:

a. lesser; released
b. greater; absorbed
c. greater; released
d. lesser; absorbed

15. When water vapour changes to ice:

a. latent heat is absorbed
b. specific heat is released
c. latent heat is released
d. specific heat is absorbed

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	c	d	b	d	d	d	d	c	b	b	b

13	14	15
b	c	c

Chapter

7

Adiabatics and Stability

Adiabatic Temperature Changes

An adiabatic temperature change occurs when a gas is compressed or expanded with no external exchange of heat.

We can experience this in everyday life. When we use a manual pump to inflate a bicycle tyre we observe that the tyre valve gets hot. The reason for this is that the compression of the air in the pump raises its temperature and this heat is transferred to the valve as the air passes through.

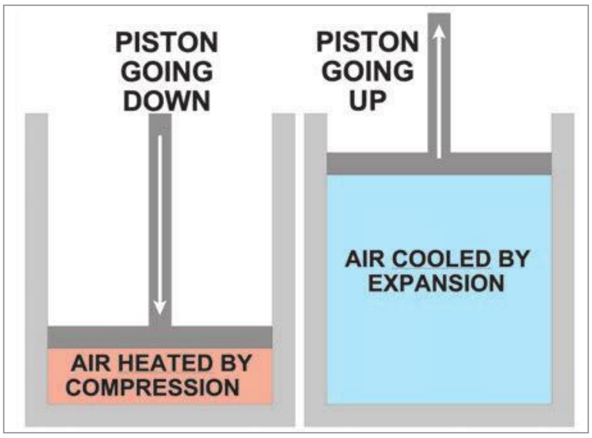


Figure 7.1

The opposite effect is observed when a carbon dioxide (CO_2) fire extinguisher is discharged. The CO_2 is under very high pressure in the cylinder, when the release handle is operated the gas expands rapidly as it exits the cylinder cooling as it does so. (In fact the expansion is so great that the fall in temperature is such that we risk frost burns if we hold the horn.)

In each case the temperature has changed because of the expansion or compression of the gas; no heat has been added from or removed to external sources.

In the atmosphere pressure decreases as altitude increases so if a parcel of air is forced to rise it will expand as it rises and hence will cool by the adiabatic process. Similarly if a parcel of air is forced to descend it will become compressed and hence heat up, again by the adiabatic process.

The Dry Adiabatic Lapse Rate - DALR

The Dry Adiabatic Lapse Rate (DALR) is the lapse rate for rising **dry** (i.e. unsaturated) air. It has a constant value of 1°C/100 m (about 3°C/1000 ft) as illustrated in *Figure 7.2*.

The Saturated Adiabatic Lapse Rate - SALR

Saturated air, when forced to rise will also cool, but as it cools condensation will take place, releasing latent heat which slows the rate at which the air cools. The Saturated Adiabatic Lapse Rate (SALR) is the lapse rate for rising air which is **saturated** (RH 100%) and has an **average** value in temperate latitudes near the ground of 0.6°C/100 m (1.8°C/1000 ft), as seen in *Figure 7.3*.

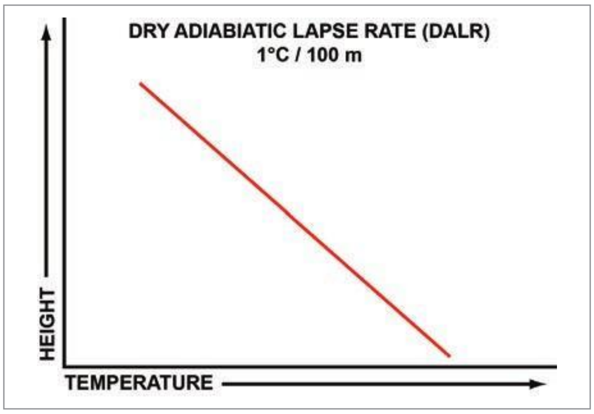


Figure 7.2

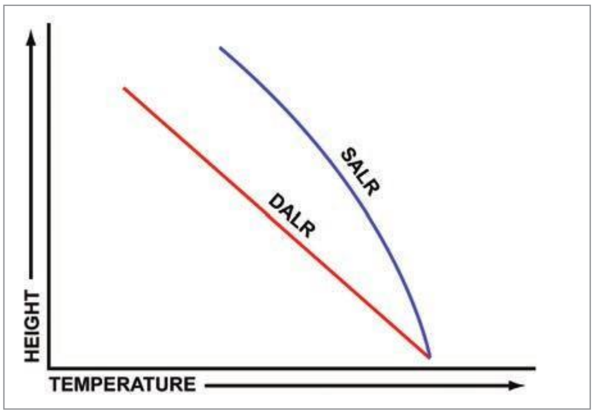


Figure 7.3

Variation of the SALR with Temperature

The amount of water vapour the air can hold is directly proportional to temperature. At high temperatures the air can hold large amounts of water vapour so that when it cools a much greater amount condenses releasing a lot of latent heat thus slowing the cooling process even more. Conversely, at low temperature the air holds a relatively small amount of water vapour, so little latent heat is released to slow the rate of cooling.

Hence the SALR increases as latitude and/or altitude increase, tending towards DALR at high altitude and high latitude.

The difference between DALR and SALR is shown in *Figure 7.4*.

A comparison between SALRs at different latitudes is shown below.

Zone	DALR °C / 100 m	TEMP	SALR °C / 100 m
Polar Low Level; High Alt All Latitudes	1	Cold	>0.6
Mid Latitudes Low Level	1	Med	0.6
Equatorial Latitudes Low Level	1	Warm	<0.6

Figure 7.4 SALR Differences

The Environmental Lapse Rate (ELR)

The ELR is the actual temperature profile of the troposphere as measured by radiosonde ascents. It varies with time and position.

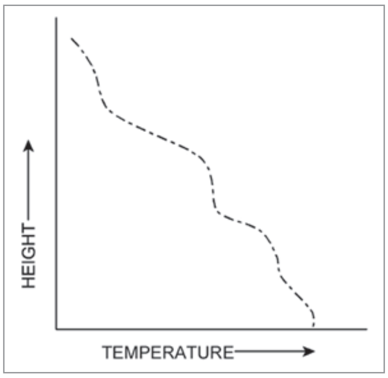


Figure 7.5 Variable ELR

Stability

Stability can be defined as being resistance to change. When dealing with atmospheric stability we are looking at what happens to air in vertical motion. If a parcel of air is forced to rise, for example over a mountain, when it gets to the top of the mountain there are 3 things it can do. It may return to its original height, it may continue rising or it may remain at the height of the summit. In the first case, in terms of the vertical position, the air is where it started so before and after are the same so we have a stable situation. In the second case we have continual change and hence instability. The third situation is a neutral or indifferent case, since the parcel of air is remaining where it was moved.

Atmospheric stability is determined by comparing the ELR with the DALR and the SALR.

Absolute Instability

Let us imagine a hill, 300 m high. A radiosonde ascent gives the ELR over the first few hundred metres as 1.2°C/100 m so the environmental temperature at a height of 300 m is +16.4°C (see diagram).

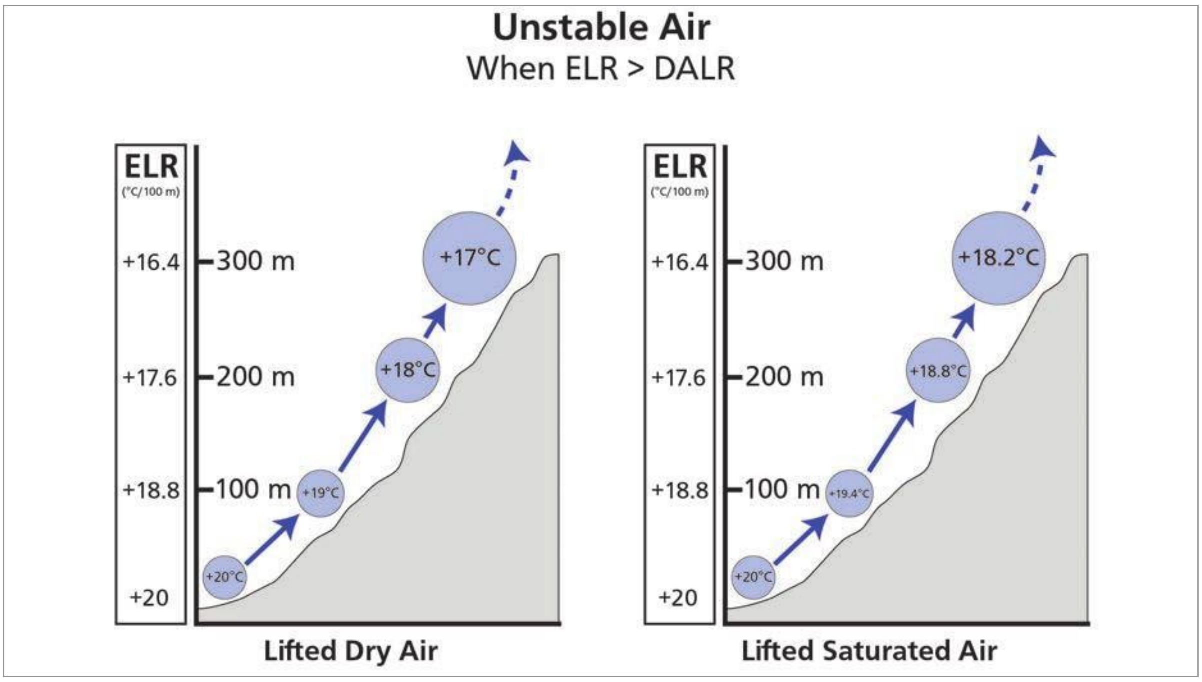


Figure 7.6

The wind blows a parcel of unsaturated air up the hill and that air cools adiabatically at rate of 1.0°C/100 m and at 300 m has cooled to 17°C. This air is now warmer than the environment and hence less dense so will continue to rise. This is an unstable situation.
Now the wind blows a parcel of saturated air up the hill which cools at 0.6°C/100 m, cooling to a temperature of 18.2°C at 300 m. This air is also warmer than the environment and will also continue to rise and is hence unstable.

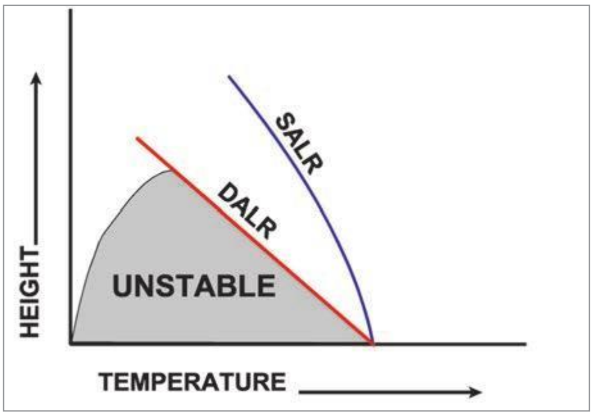


Figure 7.7

In this scenario when the ELR is greater than the DALR, the air is unstable for both dry and saturated air. We call this situation absolute instability.

ELR > DALR: ABSOLUTE INSTABILITY

Absolute Stability

Let us now take the same situation except that the radiosonde ascent shows a lapse rate of 0.4°C/100 m, giving an environmental temperature at 300 m of 18.8°C.

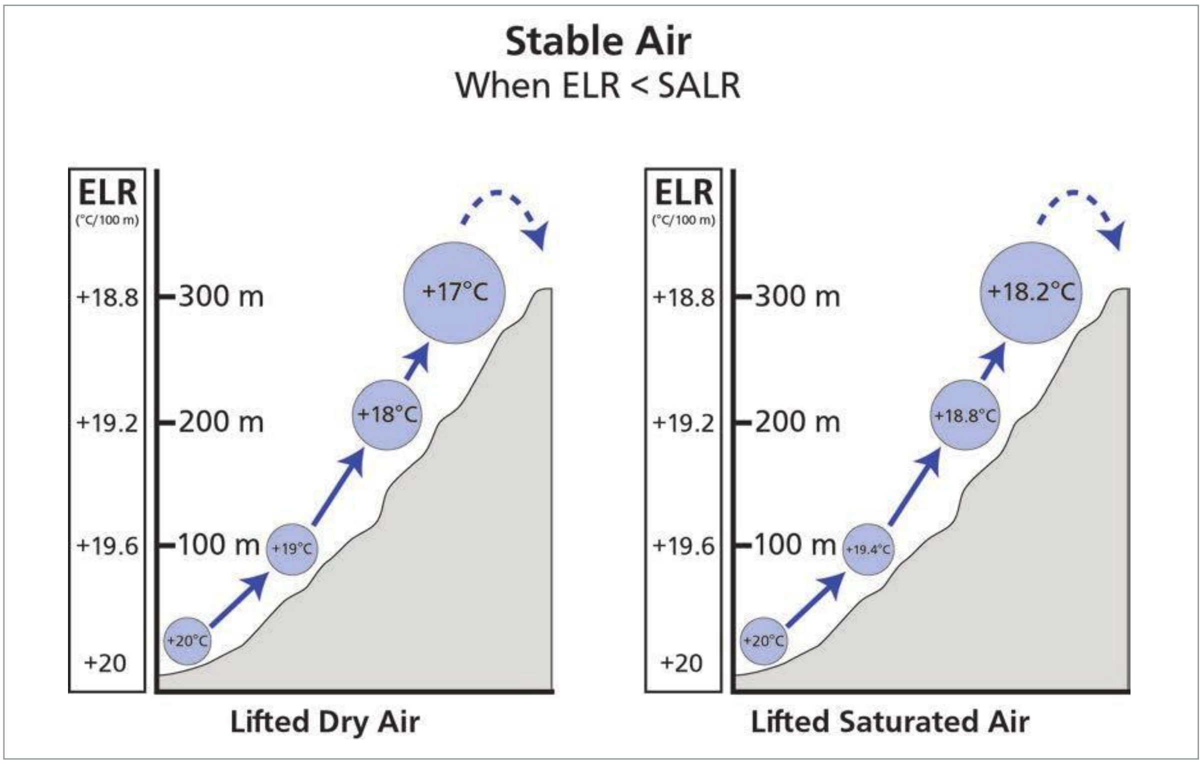


Figure 7.8

Once again the parcel of dry air is blown up the hill cooling adiabatically to 17°C. This parcel of air is now cooler and therefore denser than the environment and will now descend on the opposite side of the hill to its starting position. Now we have a stable situation.

The saturated air as it is blown up the hill will cool to 18.2°C and it too will be colder than the environment and will roll down the other side of the hill.

This time we have stable conditions for both dry and saturated air which we term absolute stability.

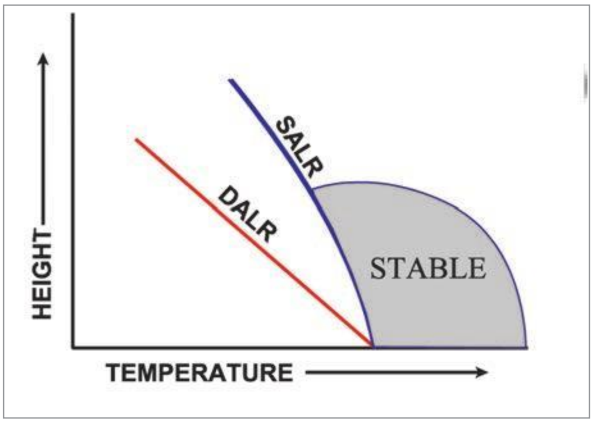


Figure 7.9

ELR < SALR: ABSOLUTE STABILITY

Conditional Instability

Now we will look at what happens when the radiosonde ascent shows an average lapse rate of 0.8°C/100 m over the first few hundred metres giving an environmental temperature of 17.6°C at a height of 300 m.

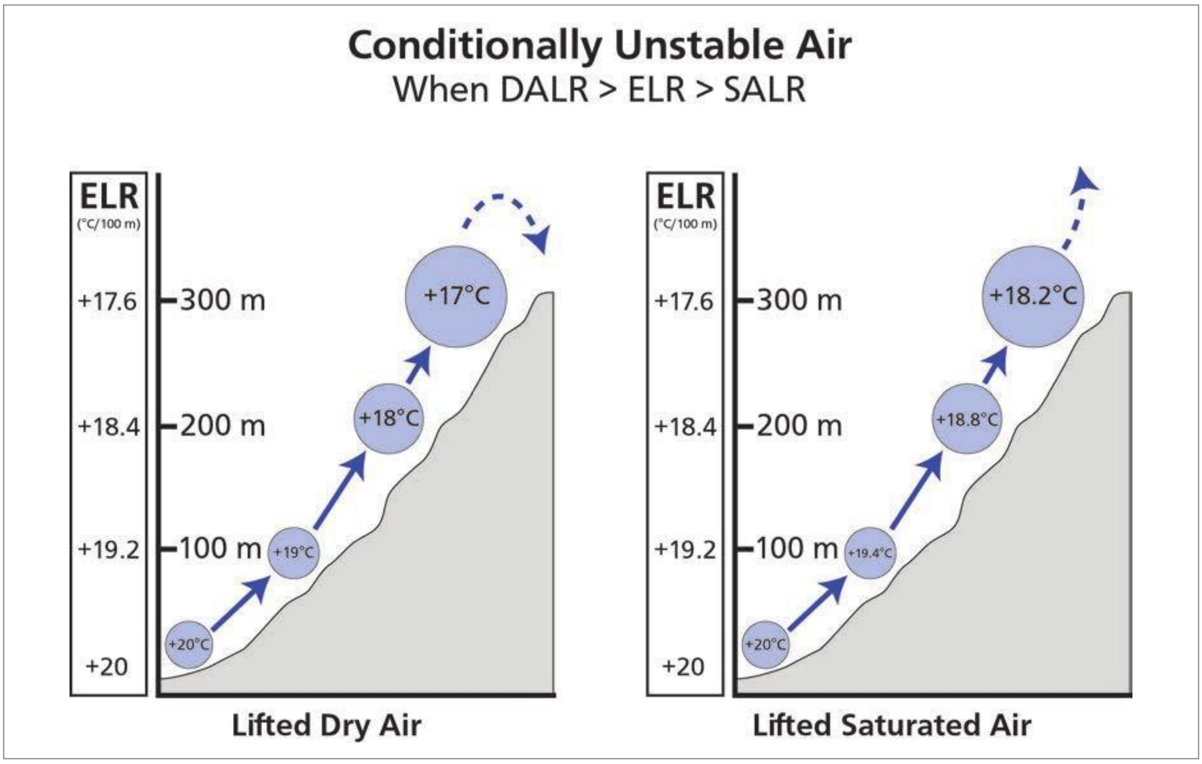


Figure 7.10

The parcel of dry air is blown up the hill and cools as before to 17°C. This air is now colder than the environment and will descend on the other side of the hill, the stable condition.

The saturated air will cool to 18.2°C as it is blown up the hill. Now the saturated air is warmer than the environment and will continue to rise, the unstable condition.

The stability of the air is now dependent on whether the air is saturated or unsaturated. This state is known as conditional instability, where the atmosphere is stable for unsaturated (dry) air and unstable for saturated air.

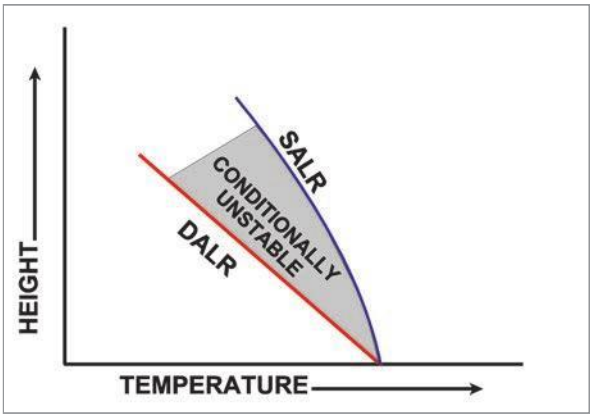


Figure 7.11

DALR > ELR >SALR: CONDITIONAL INSTABILITY

Note: *The term 'conditional stability' is not a meteorological term and, if seen in the answer to an examination question, can be confidently deleted as an incorrect answer.*

Neutral Stability

If the ELR is the same as the DALR then the temperature at 300 m will be 17°C.

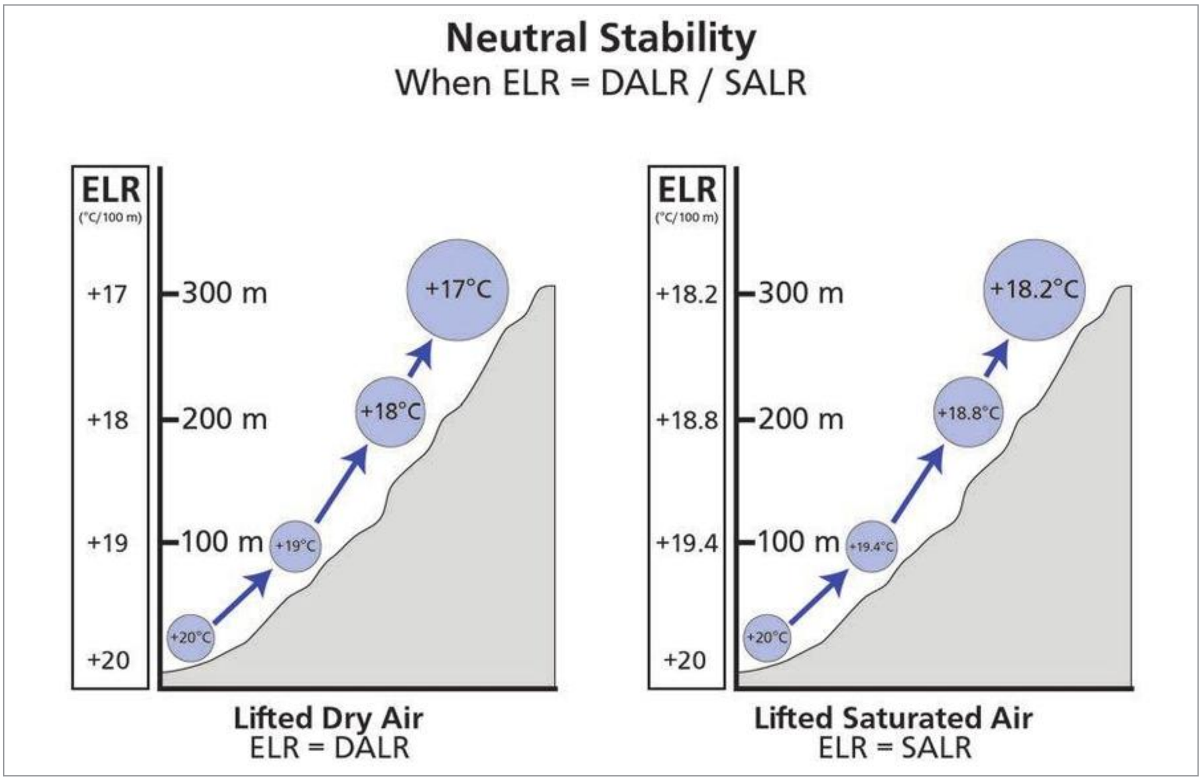


Figure 7.12

The unsaturated air blown up the hill will cool to 17°C as it rises. The uplifted air now has the same temperature and hence density as the environment, so it will now remain at 300 m. This situation is known as neutral (or indifferent) stability for unsaturated (dry) air.

A similar argument holds for saturated air, however this is less likely since the value of the SALR is a function of both temperature and pressure and is more complex.

ELR = DALR: NEUTRAL STABILITY, for unsaturated (dry) air

(ELR = SALR: NEUTRAL STABILITY, for saturated air)

Stability Summary

THE RELATIONSHIP BETWEEN THE ELR AND THE DALR AND SALR DETERMINES STABILITY

When ELR < SALR we have absolute stability.

Stable Weather: Clear skies

Moderate to poor visibility

Light turbulence (except at any inversion and in mountain waves – see chapter on turbulence)

OR

Stratiform cloud

Possibly fog, especially in winter

Continuous or intermittent light precipitation

- The clouds which form in stable air tend to be small in vertical extent and large in horizontal extent - layer clouds. Layer clouds may include stratocumulus as shown in *Figure 7.13*. which is identified by its well defined shape, whereas stratus is ill defined in shape but can cover equally large areas.

Figure 7.13 Stratocumulus

When ELR > DALR we have absolute instability.

Unstable Weather: Cumuliform clouds

Moderate to heavy showers

Potential for moderate to heavy precipitation

Good visibility except in showers

- The clouds which form in unstable air tend to be large in vertical extent and small in horizontal extent - heap clouds.

Figure 7.14 Cumulus of moderate to strong vertical development

Examples

Assuming a constant lapse rate in the layer between 2000 ft and 5000 ft and ignoring the effects of pressure change, what is the state of stability when:

	TEMP AT 2000′	TEMP AT 5000′	RH	STABILITY STATE
1	+7°	+1°	60%	
2	+15°	+9°	100%	
3	+12°	+9°	100%	
4	+16°	+2°	75%	
5	+11°	+5°	100%	
6	+11°	+8°	100%	
7	0°	-9°	88%	
8	+11°	+4°	50%	
9	+15°	+3°	98%	
10	+5°	0°	100%	
11	+10°	+10°	90%	
12	+10°	+15°	100%	

What else is unusual about the environment with regard to questions 11 and 12?

Answers on page 102.

Questions

1. If the ELR is 0.65°C / 100 m, the layer is:

a. atmosphere is conditionally stable
b. atmosphere is stable
c. atmosphere is unstable
d. atmosphere is stable when dry

2. ELR is 1°C / 100 m, the layer is:

a. neutral when dry
b. absolute stability
c. absolute instability
d. conditional stability

3. Why does air cool as it rises?

a It expands
b. It contracts
c. The air is colder at higher latitudes
d. The air is colder at higher altitudes

4. From which of the following can the stability of the atmosphere be determined?

a. Surface pressure
b. Surface temperature
c. DALR
d. ELR

5. When the upper part of a layer of warm air is advected:

a. Stability increases within the layer
b. Stability decreases within the layer
c. Wind speed will always decrease with increase in height in the Northern Hemisphere
d. Wind will back with increase in height in the Northern Hemisphere

6. The temperature at the surface is 15°C, the temperature at 1000 m is 13°C. The atmosphere is:

a. unstable
b. conditionally unstable
c. stable
d. cannot tell

7. Which of the following gives conditionally unstable conditions?

a. 1°C / 100 m
b. 0.65°C / 100 m
c. 0.49°C / 100 m
d. None of the above

8. **A mass of unsaturated air is forced to rise till just under the condensation level. It then settles back to its original position. What happens to the temperature?**

a. Temp. is greater than before
b. Temp. stays the same
c. Temp. is less than before
d. It depends on QFE

9. **What happens to the stability of the atmosphere in an inversion? (Temp increasing with height)**

a. Absolutely stable
b. Unstable
c. Conditionally stable
d. Conditionally unstable

10. **What happens to stability of the atmosphere in an isothermal layer? (Temp constant with height)**

a. Absolutely stable
b. Unstable
c. Conditionally stable
d. Conditionally unstable

11. **What is the effect of a strong low level inversion?**

a. Good visibility
b. Calm conditions
c. Turbulence
d. Unstable conditions

12. **A layer of air can be:**

a. conditional; unstable when unsaturated and stable when saturated
b. conditional; unstable when saturated and stable when unsaturated
c. neutrally stable when saturated and unstable when unsaturated
d. all of the above

13. **What happens to the temperature of a saturated air mass when forced to descend?**

a. It heats up more than dry because of expansion
b. It heats up less than dry because of evaporation
c. It heats up more than dry because of sublimation
d. It heats up less than dry because of latent heat released during condensation

14. **In still air a lapse rate of 1.2°C / 100 m refers to:**

a. DALR
b. SALR
c. ELR
d. ALR

15. **What happens to the temperature of a saturated air mass when descending?**

a. It heats up more than dry because of expansion
b. It heats up less than dry because of evaporation
c. It heats up more than dry because of compression
d. It heats up less than dry because of latent heat released during condensation

16. **The DALR is:**

a. variable with time
b. fixed
c. variable with latitude
d. variable with temperature

17. **An environment cooling at more than 1°C / 100 m is said to be:**

a. conditionally stable
b. conditionally unstable
c. unstable
d. stable

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	a	a	d	a	c	b	b	a	a	c	b

13	14	15	16	17
b	c	b	b	c

Answers to Questions on Page 96

Question	Answer
1.	Stable
2.	Unstable
3.	Stable
4.	Unstable
5.	Unstable
6.	Stable
7.	Neutral
8.	Stable
9.	Unstable
10.	Stable
11.	Stable (isothermal)
12.	Stable (inversion)

Chapter 8

Turbulence

8 Turbulence

Introduction

A dictionary definition of turbulence is a 'disturbed state' and so from the aviation point of view this would mean disturbed or rough air. There are different ways in which this turbulence is caused and also different parts of the atmosphere where it occurs.

Windshear

Windshear is the sudden change in speed and/or direction of the wind including vertical currents. These changes affect the energy of the aircraft and that change in energy is felt inside the aircraft as turbulence

Vertical Windshear: change in speed and/or direction with change of height, measured in knots per 100 feet.

Horizontal Windshear: change in speed and/or direction in the horizontal plane, measured in knots per 1000 feet.

Locations

Turbulence occurs:

- In the **friction layer**.
- In **clouds -** This will be discussed in detail in the chapters on clouds and thunderstorms.
- In **clear air.**

The Friction Layer

The friction layer is the lower part of the atmosphere extending from the surface to a height of 2000 ft to 3000 ft above the surface. The depth of the friction layer depends on:

- The roughness of the terrain. The rougher the surface the greater the strength of the (vertical) deflection and hence the greater the height to which it will penetrate.
- The wind speed. The higher the speed the greater will be the deflection.
- The stability of the layer. Stable conditions will resist vertical movement and hence limit the depth.

Within the friction layer there are 2 sources of turbulence:

- Convection from thermal currents
- Frictional or mechanical turbulence

By day the presence of thermal currents will tend to reduce low level stability and hence increase the depth of the friction layer, whereas at night there is only mechanical turbulence so the stability will tend to increase because of the surface cooling and the depth of the friction layer will reduce.

At night the surface cooling, particularly with clear skies, can lead to the formation of low level inversions. Now vertical mixing is inhibited and the surface frictional effect is enhanced. This means that below an inversion the wind speed will be light with a significantly different direction to the much stronger wind above the inversion. Hence Windshear will occur at the inversion. An aircraft climbing (or descending) through the inversion will experience a rapid change in speed and direction giving, possibly, moderate to severe turbulence. This and other low level effects are discussed in the Aeronautical Information Circular (AIC) at the end of this chapter.

Thermal Turbulence

Insolation gives rise to convection currents. The intensity of these currents depends on the heating of the surface. Surfaces like rock and concrete heat rapidly and give rise to strong vertical currents, whereas grass and wooded areas will only heat slowly and create weak convection currents. So flight within the friction layer on a sunny day will be affected by variable speed vertical currents and hence windshear giving turbulence.

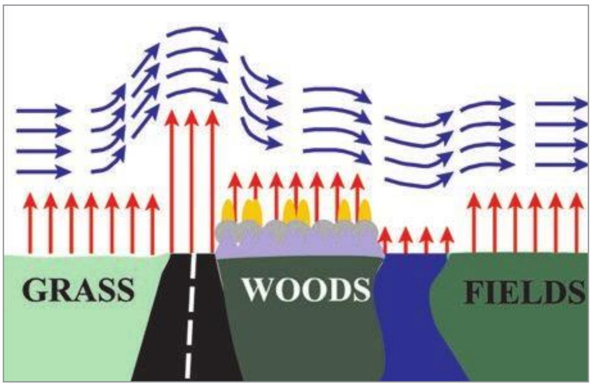


Figure 8.1 Thermal Turbulence

Thermal turbulence is greatest around 1500 hrs on clear sunny days. There is no thermal turbulence over the sea.

Mechanical Turbulence

This is caused by physical obstructions to the normal flow of air such as hills, mountains, coasts, trees and buildings.

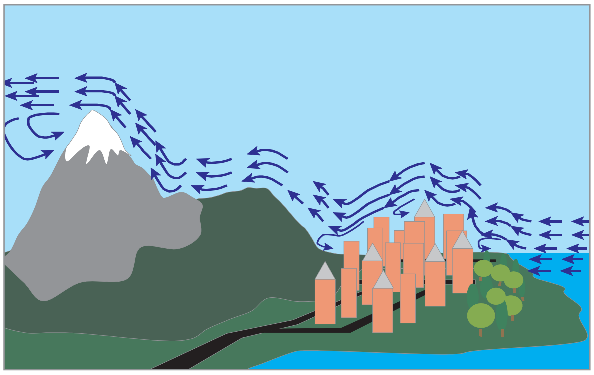


Figure 8.2 Mechanical Turbulence

Mountain Waves (MTW)

Mountain waves may also be referred to as standing waves or lee waves. These occur when the following conditions exist:

- The wind direction is perpendicular to the mountain range (+/-30°) without significant change in direction as altitude increases
- The wind speed at the summits is at least 15 kt with speed increasing as altitude increases
- A marked layer of stability around the altitude of the summits, e.g. an isothermal layer or inversion, with less stable air above and below

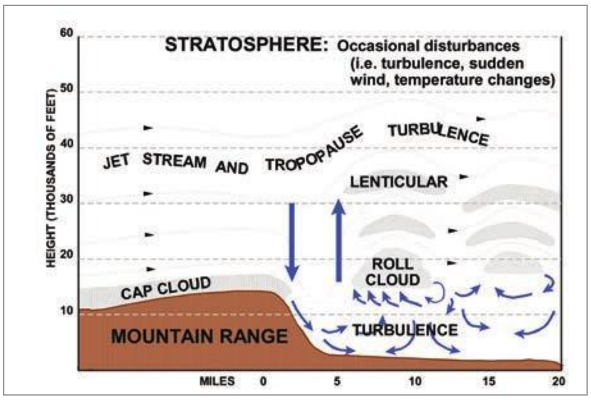


Figure 8.3 Conditions necessary for the formation of mountain waves

The resultant waves can extend for hundreds of miles downwind of the range if suitable conditions prevail. The waves may extend well above the tropopause and the wave form may be seen in cirrus clouds high in the troposphere and also in noctilucent clouds which occur at altitudes around 250 000 ft in the upper mesosphere.

Turbulence Effects of Mountain Waves

Most severe turbulence can occur in the **Rotor Zone** lying beneath the crests of lee waves and is often marked by **Roll Clouds.** The most powerful rotor lies beneath the first wave crest (one wavelength downwind). Flight in waves can be smooth, but severe turbulence may occur. Occasionally violent turbulence will occur, due to wave 'breaking'.

Normal turbulence associated with flight across jet streams is frequently greatly increased when the jet passes over mountainous areas, particularly when mountain waves are present.

It has been found that turbulence caused in the troposphere due to mountain waves may continue well into the stratosphere. An aircraft flying close to its ceiling on these occasions might find itself in serious difficulty.

Visual Recognition Features of Mountain Waves

Provided there is sufficient moisture in the atmosphere, distinctive clouds are formed with mountain waves and these provide useful warning of the presence of such waves. The clouds are:

- **Lenticular**, or lens shaped clouds which form on the crests of the waves. They may appear above the mountain tops and in the crests of the waves downwind. They may be found up to, and possibly above, the tropopause. **Ragged edges** indicate turbulence.

- **Rotor**, or roll-clouds occur under the crests of strong waves downwind of the ridge. The strongest rotor is normally formed in the first wave downwind and will be level or slightly above the ridge crest.

- **Cap** clouds form on the ridge and strong winds may sweep the cloud down the lee slopes.

Note:

- The characteristic clouds above may be obscured by other clouds and the presence of standing waves may thus not be evidenced.

- If the air is dry, clouds may not form at all, even though mountain waves are present.

Action to Avoid the Worst Effects of Mountain Waves

- Read the Met. Forecast.

- Arrange to cross mountain ranges at 90 degrees.

- Fly at the recommended turbulence penetration speed.

- Do not fly parallel to and just downwind of the range at any altitude.

- Avoid flight through or near the rotor zone.

- Avoid flight levels within 5000 ft of stable layer where severe turbulence is most likely.
- Allow a height clearance above highest ground at least equal to the height of that ground above local terrain.
- Avoid low altitude flight towards the mountain range **from the lee side**. Aircraft height variations will be out of phase with waves and downdraughts will be hazardous.
- Avoid high altitude flight on the lee side of the mountain range **downwind.** Buffet margin at high level may be small, and speed of approaching standing waves will be high, with subsequently greater loads applied to the airframe.
- Be prepared for icing in cloud.

Rotor Streaming

If the winds approaching a mountain range are strong only at lower levels and fall off or reverse direction at higher levels, **Rotor Streaming** may result. This comprises violent rotors moving downwind from the ridge. Unlike the stationary rotors described above, these rotors travel downwind after forming on the lee slopes, *Figure 8.4* shows rotor streaming.

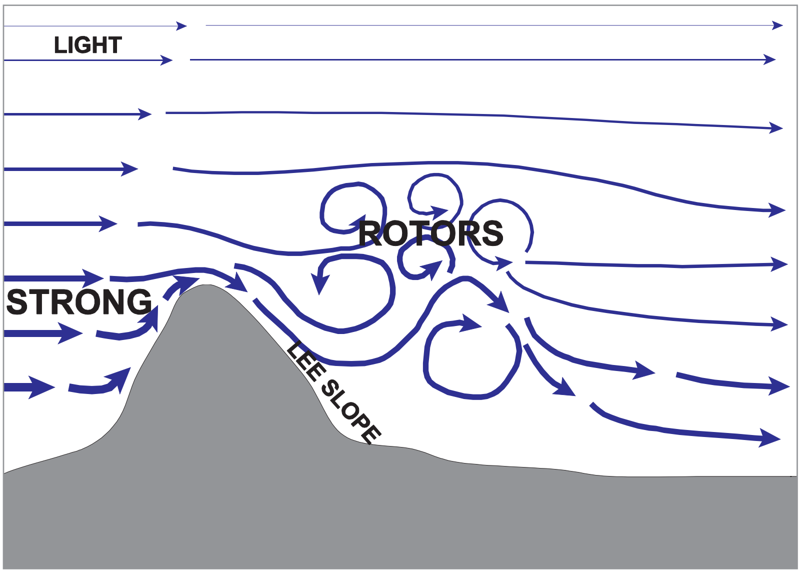


Figure 8.4 Rotor Streaming

Jet Streams

Jetstreams are narrow fast moving currents of air which occur just below the tropopause and will be discussed in detail in the chapter on upper winds. Generally the associated turbulence is found on the cold air side of the Jet Stream just below the core where the greatest windshear occurs, with a secondary area above the core extending into the stratosphere as the winds rapidly decrease in strength. The turbulence will be more severe with curved jets, developing and rapidly moving jets and in mountainous areas, particularly when mountain waves are present.

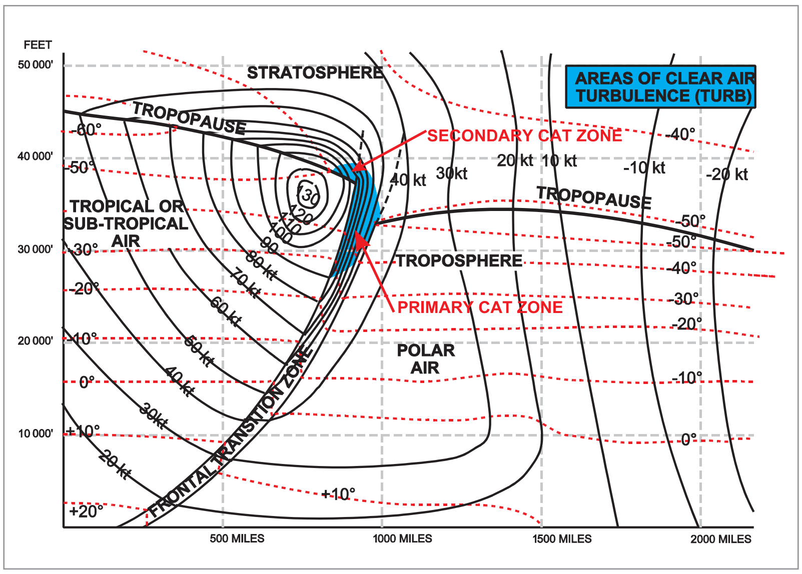


Figure 8.5 A Vertical Cross-section Through a Jet stream

If turbulence is encountered at high altitude as well as reducing speed to the rough air penetration speed the pilot should also descend. At high altitude the margins to high and low speed buffet may be quite small and the effect of the turbulence may put the aircraft into high or low speed stall. Descent will increase these margins thus enhancing the aircraft safety.

Cumulonimbus Clouds

Cumulonimbus (CB) clouds and their associated hazards will be discussed in detail in later chapters. Turbulence will be found within CB with strong vertical currents. These vertical currents cause air to be drawn in from around the cloud creating turbulence and the energy of the air rising in the cloud is transmitted to above the cloud creating turbulence. Below the cloud the inflow and outflow of air creates severe turbulence at low altitude and the possibility of microbursts (or downbursts) create a potentially fatal hazard. The hazard of these microbursts is discussed in the AIC at the end of this chapter.

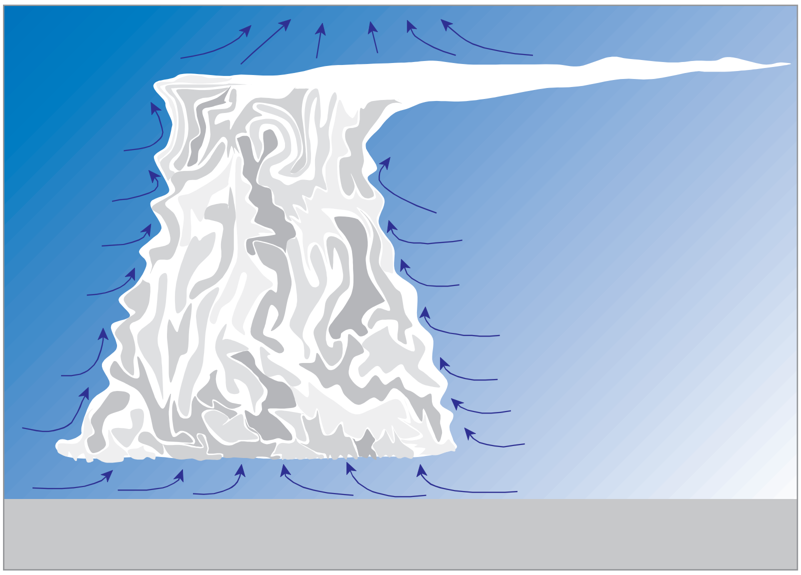


Figure 8.6 Turbulence Surrounding Cumulonimbus Clouds

Turbulence around Upper Level Troughs and Ridges

Since upper level winds are stronger than those at the surface, the sharp changes in wind direction at upper level troughs are likely to produce considerable **horizontal windshear** and consequent disturbance which may be experienced as Clear Air Turbulence (CAT).

As upper level ridges tend to be more gently curved than troughs, the direction changes and consequent turbulence will be less severe.

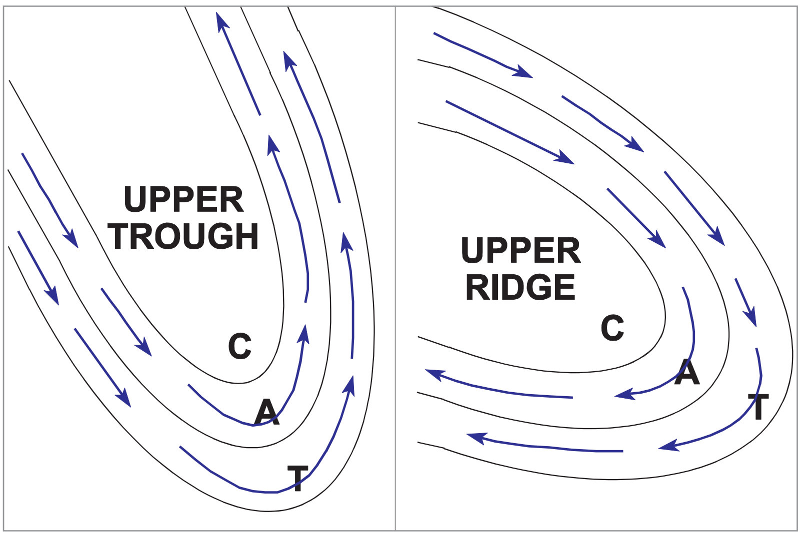


Figure 8.7 Turbulence Produced at Upper Troughs and Ridges

Turbulence Reporting Criteria

Turbulence remains an important operational factor at all levels but particularly above FL150. The best information on turbulence is obtained from pilots' Special Aircraft Observations; all pilots encountering turbulence are requested to report time, location, level, intensity and aircraft type to the ATS Unit with whom they are in radio contact. High level turbulence (normally above FL150 not associated with cumuliform cloud, including thunderstorms) should be reported as TURB, preceded by the appropriate intensity or preceded by Light or Moderate Chop. (Note: EASA still refer to clear air turbulence as CAT.)

Table 3.5.6.1 - TURB and other Turbulence Criteria Table		
Incidence: **Occasional** - less than 1/3 to 2/3 **Intermittent** - 1/3 to 2/3 **Continuous** - more than 2/3		
Intensity	Aircraft Reaction (transport size aircraft)	Reaction Inside Aircraft
Light	Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw). IAS fluctuates 5 - 15 kt. (<0.5 g at the aircraft's centre of gravity) Report as '**Light Turbulence**'. or; turbulence that causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude. No IAS fluctuations. Report as 'Light Chop'.	Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered in walking.
Moderate	Turbulence that is similar to light Turbulence but of greater intensity. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times. IAS fluctuates 15 - 25 kt. (0.5 - 1.0g at the aircraft's centre of gravity). Report as '**Moderate Turbulence**'. or; turbulence that is similar to Light Chop but of greater intensity. It causes rapid bumps or jolts without appreciable changes in altitude or attitude. IAS may fluctuate slightly. Report as '**Moderate Chop**'.	Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are dislodged. Food service and walking are difficult.
Severe	Turbulence that causes large, abrupt changes in altitude and/or attitude. Aircraft may be momentarily out of control. IAS fluctuates more than 25 kt. (>1.0 g at the aircraft's centre of gravity). Report as '**Severe Turbulence**'.	Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking impossible.
Note 1: Pilots should report location(s), time(s) (UTC., incidence, intensity, whether in or near clouds, altitude(s) and type of aircraft. All locations should be readily identifiable. Turbulence reports should be made when moderate/severe turbulence is encountered, or on request. Example: (a) Over Pole hill 1230 intermittent Severe Turbulence in cloud, FL 310, B747. (b) From 50 miles north of Glasgow to 30 miles west of Heathrow 1210, occasional moderate Chop TURB, FL 330, MD80. Note 2: The UK does not use the term 'Extreme' in relation to turbulence.		

Low Altitude Windshear

Vertical Windshear

Vertical windshear is change in wind velocity with height. It is typically measured in knots per 100 ft.

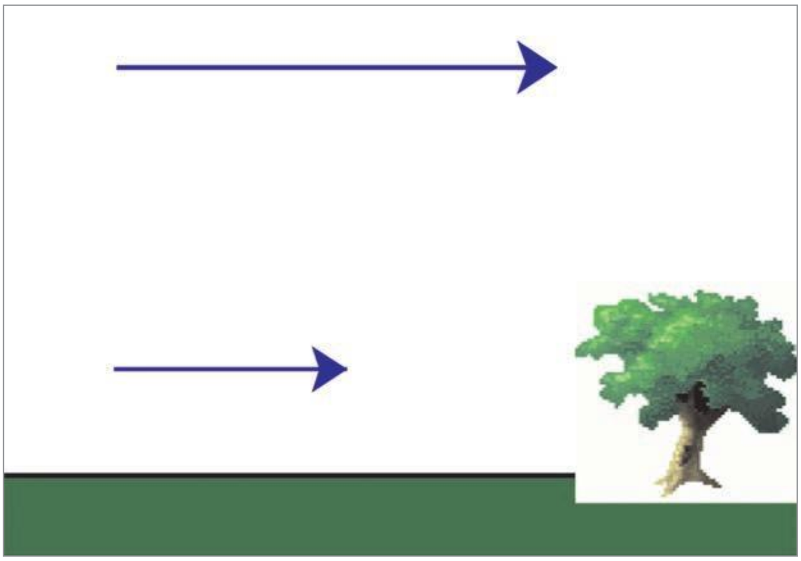


Figure 8.8 Vertical Windshear

Horizontal Windshear

Horizontal windshear is change in wind velocity with horizontal distance. It is typically measured in knots per 1000 ft.

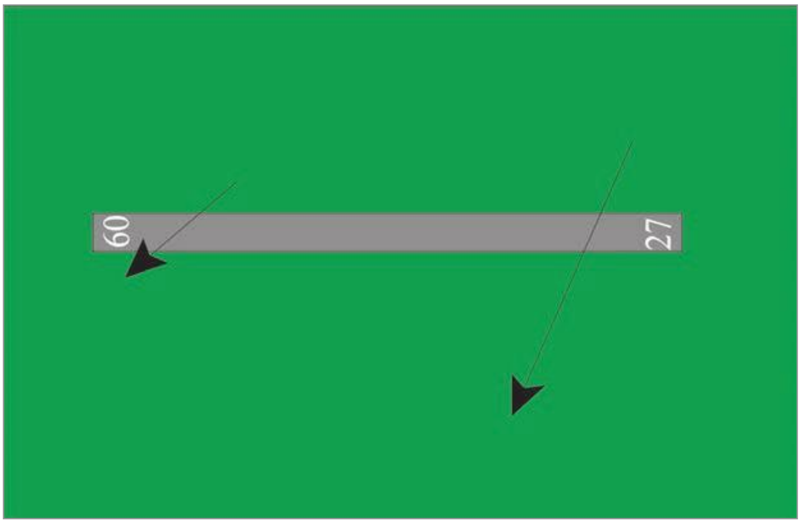


Figure 8.9 Horizontal Windshear

The remainder of this chapter consists of a UK Civil Aviation Authority Aeronautical Information Circular covering low altitude windshear. Some of this material has already been covered, but those parts which are new should be highlighted.

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LOW ALTITUDE WINDSHEAR

1 Introduction

1.1 This Circular has been produced to provide an understanding of the nature of windshear, and an appreciation of its dangers. Guidance on how best to avoid windshear and how an aircraft may have to be handled during a windshear encounter is also included. It should be noted that research and experiment continues to take place in relation to the phenomenon, nevertheless, windshear encounters still continue to be cited as a primary or contributory cause of accidents and incidents. Although aircraft flying in United Kingdom airspace can experience windshear events, the severity of such encounters and the intensity of the probable causative events are often much less than that experienced elsewhere in the world. Windshear has been the direct cause of accidents; it is not a phenomenon to be treated lightly. Pilots and operators are therefore urged to understand the phenomenon and if planning to fly to destinations or areas where severe weather, turbulence or windshear is known or likely to occur, to obtain appropriate briefings, training and instruction. This circular is written for guidance only, all suggestions regarding flying techniques and similar procedures in this document do not supersede appropriate operations or flight manual instructions.

2 Definitions

2.1 In discussing windshear, it is not easy to find a definition that will satisfy both meteorologist and pilot. **As a consequence, it is possible to find circumstances where an alert has been issued concerning windshear, but where the meteorological understanding of the event differs from that expected by the flight crew.** Thus it is important if operating to areas where windshear can be a regular phenomenon that flight crews fully understand that which is being forecast. At its simplest, windshear can be described as a change in wind direction and/or speed including both downdraughts and updraughts.

2.2 The definitions of windshear used in this circular are:

(a) Windshear:

Variations in the wind vector along the flight path of an aircraft with a pattern, intensity and duration that will displace an aircraft **abruptly** from its intended flight path such that **substantial control input and action is required** to correct it.

(b) Low altitude windshear:

Windshear along the final approach path or along the runway and along the take-off and initial climb-out flight paths.

2.3 Additional qualifying conditions/descriptions related to windshear:

(a) Vertical windshear:

The change of horizontal wind vector with height, as might be determined by two or more anemometers at different heights on a mast.

(b) Horizontal windshear:

The change of the horizontal wind vector with horizontal distance, as might be determined by two or more anemometers mounted at the same height along a runway.

(c) Updraught or downdraught shear:

The changes in the vertical component of wind vector with horizontal distance.

2.4 If the basic windshear definition in paragraph 2.2 (a) is set aside, it can be seen that the additional definitions and qualifying statements allow for changes in wind vector which could include the relatively minor or benign. Notwithstanding these possible (academic) variations in description, this circular is concerned with the basic definition, in particular, the emphasis on **abrupt** displacement of an aircraft from the desired flight path, at low altitude, together with the necessity for **substantial control action** to counteract it. Windshear is therefore highly dynamic which can be extremely uncomfortable and frightening; to think of windshear as an aggravated form of wind gradient is unwise. Windshear can strike suddenly and with devastating effect beyond the recovery powers of both experienced pilots flying the most modern and powerful aircraft. **Thus the first and most vital defence is avoidance; this should be taken to be the recurrent theme of the rest of this circular.**

3 Meteorological Background

3.1 Among the most potent examples of windshear are those associated with thunderstorms, however, windshear can also be experienced in association with other meteorological features such as the passage of a front, a marked temperature inversion, a low level jet (wind maximum) or a turbulent boundary layer. Topography or buildings can create substantial local windshear effects that can be considerably more than might be expected from the average strength of a prevailing wind.

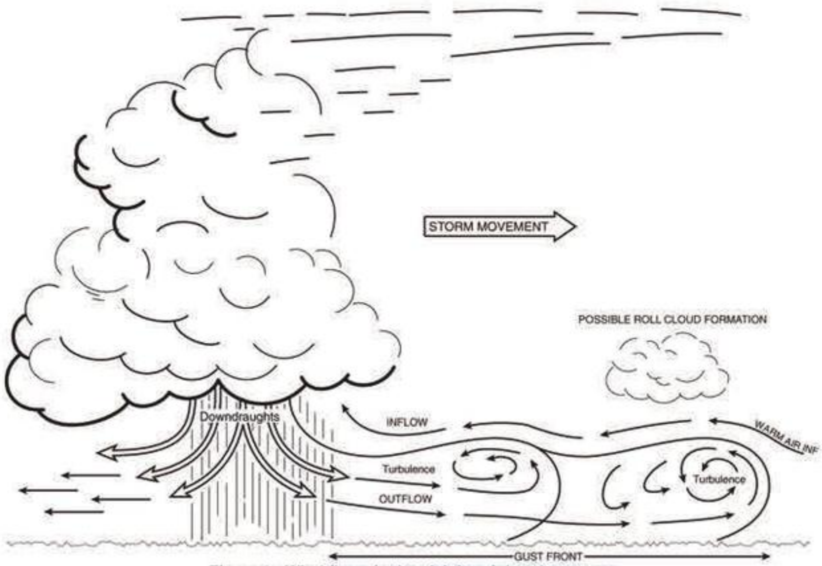

Figure 1 : Wind flows in the vicinity of thunderstorms

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3.2 Thunderstorms

3.2.1 The principles of thunderstorm formation are already covered in AIC 81/2004 (Pink 66). For the purposes of this Circular it is sufficient to remark that thunderstorms are violent events, unpredictable, and associated with turbulence, windshear, lightning and precipitation as separate or joint hazards. Shears will occur, and draughts can strike from all angles. The assessment of the aircraft's actual angle of attack in relation to some of the wind flows will be difficult to judge and in consequence the closeness of the aircraft to the stall will be harder to gauge. In relation to low altitude windshear there are features of thunderstorms which merit further description:

(a) **Gust Front:** Some thunderstorms may have a well-defined area of cold air flowing out from a downdraught, but tending to lead the storm along its line of movement. This is labelled a "gust front" (see Figure 1) and may extend some distance (up to 30 km) from the storm centre and affect the area from the surface up to 6000 ft. If the storm is part of an organised line of storms, the gust front may extend an even greater distance from the centre line of the storms. 'Gust fronts' manifest themselves as regions of great turbulence with a potential for vertical shears between out-flowing cold air as it undercuts warmer air. The leading edge of the 'gust front' could be encountered without warning, although roll cloud effects can be associated with it.

(b) **Microburst:** A microburst is a highly concentrated and powerful downdraught of air, typically less that 5 km across, which lasts for about 1 to 5 minutes. (It should be noted that the word 'microburst' is also associated with a phenomenon called 'gap flow microburst', associated with topographical effects and strong winds and is a very strong horizontal shear effect with the energy loss effect on the aircraft as shown in Figure 2). Microbursts associated with thunderstorms have proved to be a most lethal form of windshear giving downdraught speeds of 60 kt or more. As this vertical shaft of air approaches the ground it will 'splay out' and lose its vertical speed component, nevertheless, vertical (downward) components have been recorded as low as 300 ft with surface wind differences of as much as 90 kt. Although these figures are extreme examples they do illustrate that a microburst should not be treated lightly. Microbursts have been well documented in the United States but could easily be found elsewhere in association with thunderstorm activity. Microbursts can be 'wet' or 'dry', ie associated with or without precipitation. The 'dry' microbursts will therefore be difficult to detect on weather radar, but are often associated with high-based cumulus, alto-cumulus or the cirrus cloud overhang from a cumulonimbus cloud. In each case when precipitation falls from the clouds (indicated by 'virga') it evaporates in the dry air beneath the cloud. This evaporation process requires energy, which further cools the falling air thus enhancing the speed of the downdraught. A 'wet' microburst is associated with intense precipitation that falls in shafts below a cumulonimbus cloud.

2

3.3 **Frontal Passage**

3.3.1 Fronts vary in strength and normally only well-developed active fronts, with narrow surface frontal zones and with marked temperature differences between the two air masses are likely to carry a windshear risk. Weather charts showing sharp changes in wind direction across the front, temperature differences of 5°C or more, or a speed of frontal advance in the region of 30 kt or more may indicate a potential windshear hazard. Frontal windshear is also a hazard as the following incident illustrates. A twin-jet aircraft was about to land in the UK and was caught by the passage of a cold front. In 10 seconds, the wind changed such that a 10 kt crosswind from the left (with a slight tail wind) changed to an 8 kt crosswind from the right coupled with a 14 kt head wind. A missed approach, from very low level was carried out as directional control became difficult. The actual numerical values of wind speed change in this actual incident may appear less than dramatic to some readers, however, the control difficulties experienced during this incident were considerable. Similar wind **velocity** changes, with an aircraft at critical phases of flight will always be hazardous.

3.4 **Inversions**

3.4.1 A change in wind strength is nearly always present in the boundary layer, ie close to the ground. This is frequently described as 'windshear' but as this normally involves a gradual change in strength with which pilots will be most familiar, it does not fit the definition already given in this circular. A proper windshear hazard can exist, however, when an unexpectedly strong vertical change develops. This is often associated with the following situations:

(a) A low level jet (more accurately referred to as a low level wind maximum) can form just below the top of, or sometimes within, a strong radiation inversion which may develop at night under clear skies. Other low level jets may develop in association with a surface front, particularly ahead of cold fronts.

(b) On occasions, low-level inversions may develop and decouple a relatively strong upper flow from layers of stagnant or slow moving air near the surface. Shear effects may be pronounced across the interface.

4 The Effects of Windshear on an Aircraft in Flight

4.1 Windshear will affect aircraft in many different ways and during an encounter the situation will be constantly changing, especially during the more dynamic encounters. Conventional thought, in the past, has suggested that such encounters are associated only with thunderstorms; however, there is evidence to show that equally dynamic encounters can be expected with other windshear causes. Particular types of aircraft will vary in their reaction to a given shear; a light high wing piston-engined aircraft may react in a totally different way to a heavy four-engined swept wing jet aircraft. The notes and diagrams that follow describe stylised windshears and the progressive effects that can occur. Windshear can be encountered at any height and the effects will be similar. If the windshear event is at low-level it can be a great hazard and it is this that must be borne in mind in relation to the described effects.

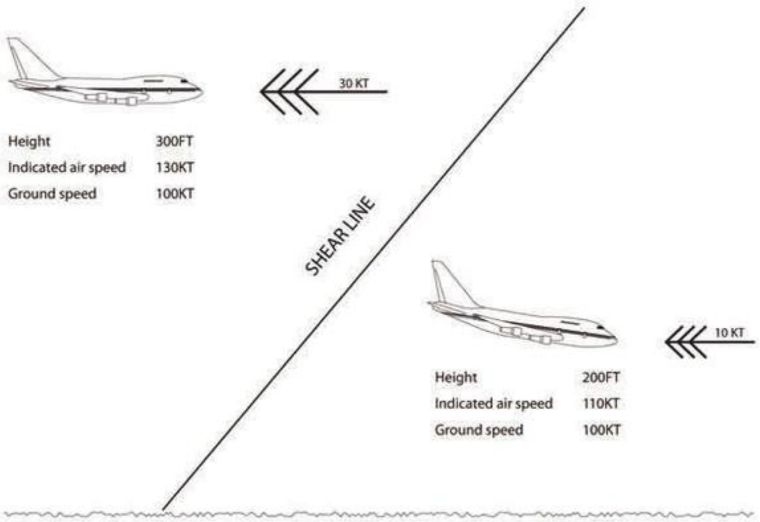

Figure 2 : Effect of loss of headwind - Energy Loss

4.2 To understand the effects of windshear it is important to note the relationship of an aircraft to two reference points. One reference point is the ground below the aircraft and the other is the air mass in which the aircraft is moving. In a windshear encounter it is not only the magnitude of the change of the wind vector, but the rate at which it occurs. For example, an aeroplane at 1000 ft above ground level (agl) may have a head wind component of some 30 kt, but the aerodrome surface report shows this as a 10 kt component close to the runway. That 20 kt difference in wind strength may taper off evenly from 1000 ft to touchdown with no changes in direction; thus its effect and relationship to the aircraft will be that of a reasonable wind gradient with height with which all pilots will be familiar. On the other hand, if the 20 kt difference still exists at 300 ft, it will be obvious that the change, when it occurs, is going to be far more sudden and its effect more marked. Windshear, from the definition, implies a narrow borderline, and the 20 kt of wind strength may be lost over a short vertical distance. If this strength is lost over 100 ft the effect will be as shown in the diagram, with the concomitant loss of aircraft energy.

3

4.3 The reverse effect will occur when an aeroplane is taking off through such a shear line. In this case however, the gain in energy would be beneficial with aircraft gaining some additional 20 kt of airspeed in a short distance. However, this could potentially produce some handling difficulties, particularly if the aircraft was approaching a flap limiting speed (for example) as the shear line was crossed.

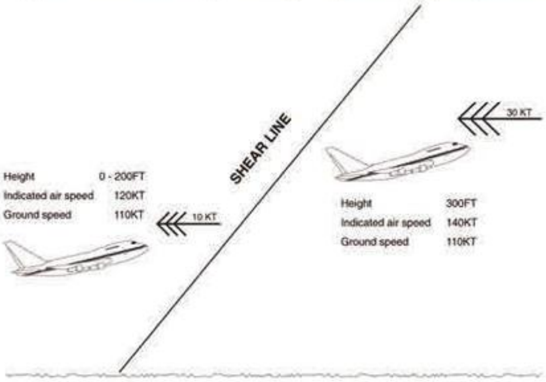

Figure 3 : Effect of Increased headwind - Energy Gain

4.4 In an encounter with a downdraught, the relative airflow across the aircraft's wing will change direction. Normally, an aircraft could be expected to be flying into a head wind and as the downdraught is encountered, this head wind will reduce markedly, thus reducing the energy of the aircraft. In the downdraught itself, the relative airflow across the wing will change as shown in the diagram below. Its effect will be to effectively decrease the angle of attack of the wing, which will be counteracted by the pilot manoeuvring the aircraft in response to the downburst effect, ie increasing the angle of attack. This might be beneficial in terms of increased lift. However, if the wing is already at steep attack angle (eg during an approach), any subsequent changes in airflow may result in the aircraft being very close to the stall.

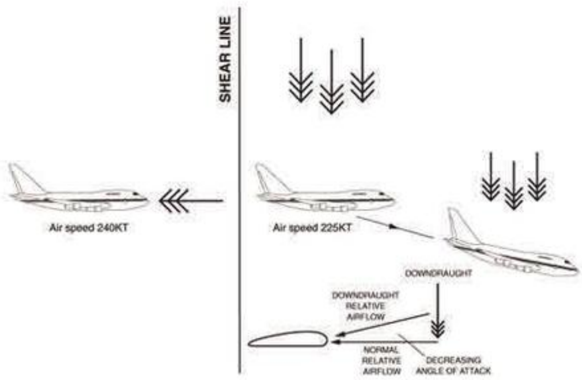

Figure 4 : Effect of downdraught - Energy Loss

4.5 Another version of a windshear event is that occasioned by an encounter with a microburst. Classically, a microburst, as illustrated below, is associated with thunderstorm or similar convective activity associated with areas of heavy rain. However, the term 'microburst' is also associated, in some locations, with very severe windshear warnings, possibly without associated convective activity. (See paragraph 3.6 (c)). **Therefore, if 'microburst' warnings are given, flight crew should be fully aware of which phenomenon they are being warned about and take appropriate action.**

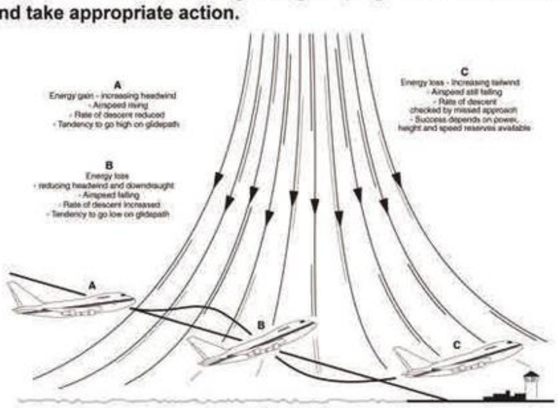

Figure 5 : Microburst effects

4

4.6 The likely sequence of events during a classic (convective activity) microburst encounter is a combination of the previous events as follows. Approaching the airfield, using the aircraft weather radar, an area of strong radar returns may be observed in the vicinity of the final approach path. This may alert the pilot to the possible dangers, particularly if this is also associated with earlier meteorological forecasts. The recommended course of action would be to initiate a go-around at this early stage in the approach and hold off until the activity moved on. Some airfields may even prohibit approaches during conditions when microburst activity is anticipated. If after the initiation of the go-around, an encounter with the microburst occurred at this stage, the extra energy of the aircraft and possible increased height should ensure that no untoward events occur.

4.7 If, however, the aircraft were to continue its approach into the microburst, the sequence of probable events is as shown in the diagram. A successful go-around will depend, obviously, on the strength of the microburst, its position in relation to the approach path; the aircraft power reserves available and the rate at which they can be increased to give maximum thrust to counteract the energy loss of downdraught and increasing tail wind. The dynamic events will probably be associated with severe buffeting, heavy rain, thick cloud and probably blinding flashes of lightning, and external noise occasioned by heavy rain or hail on the aircraft skin.

4.8 A microburst encounter during take-off could be equally as hazardous notwithstanding the fact that during take-off an aircraft is already developing high thrust and is less constrained by the need to hold a precise glide path. Whilst the initial increase in head wind may improve lift and thus rate of climb, the transition to downdraught and then tail wind may totally negate this increase and the airspeed of the aircraft, possibly still close to the ground may be further reduced. A heavy aircraft, with small reserves of power may not be able to fly through the encounter successfully.

5 Techniques to Counter the Effects of Windshear

5.1 It should now be apparent that windshear can vary enormously in its impact and effect. There is as yet no international agreement on ways of grading windshears, but clearly some shears will be more severe and more dangerous than others. If the definition used by this circular is borne in mind, a windshear encounter is expected to result in **abrupt** changes to the desired flight path requiring **considerable control action** to effect recovery. Thus, if avoidance has failed, any further actions must anticipate the worst effects, bearing in mind that the shear itself will probably be invisible to the crew.

5.2 If the meteorological situation has been carefully studied in advance of flight and updated with latest reports during flight, the possibility of windshear should have already been identified. Strong winds at a destination, particularly where topography is warned as having an effect, or a forecast of thunderstorms, particularly if reinforced, near the destination, with weather radar or visible evidence should trigger a mental 'Windshear Alert'. At this point the prudent decision would be to divert, following company procedures in the case of AOC operators.

5.3 If an approach must be attempted in such conditions, crews should consider a few basic measures to anticipate a windshear encounter. One such measure is to increase the approach speed, however, if a shear event does not materialise, the increased approach speed may then cause problems near the threshold, particularly at airfields with short runways. If an encounter with shear does occur, its overall effect will be to de-stabilise an approach, and any thrust reduction taken to counter an initial extra head wind, may have to be quickly changed to a thrust increase if the head component is removed or reversed. Actions to counter a loss of airspeed close to the ground include:

(a) Briskly increase power (to full go-around if felt necessary);

(b) Raise the nose to check descent;

(c) Co-ordinate power and pitch;

(d) Be prepared to carry out a missed approach rather than risk a landing from a de-stabilised approach.

5.4 The actions required to counter the effect of a downburst or microburst on the approach or during take-off will require more stringent measures. Again, it should be emphasised that if such phenomena are either forecast or suspected, the most sensible course of action would be to delay the take-off or landing, or if airborne to divert to another airfield. In the absence of specific aircraft flight manual or operations manual guidance which must be followed, some **suggested** techniques for dealing with a microburst encounter on an approach are given below:

(a) The presence of thunderstorms should be known and obvious, so that any increase in airspeed caused by the increasing head wind should be seen as the precursor to a downburst or microburst encounter. Any hope, therefore, of a stabilised approach should be abandoned and a missed approach is the recommended action - the technique is to make this as safe as possible;

(b) The initial rise in airspeed and the rise above the approach path should be seen as a bonus and capitalised upon. Without hesitation, the power should be increased to that required for a go-around, whilst being prepared to further increase it to maximum, if necessary, and an appropriate pitch angle, consistent with a missed approach should be selected. Typically, this will be in the region of 15° and this should be held against the buffeting and turbulence that will undoubtedly occur;

(c) The initial 'bonus' of speed and rate of climb may now be rapidly eroded as the downdraught is encountered. Airspeed may now be lost and the aircraft may now begin to descend again despite the high power and pitch angle. It may be impossible to gauge the angle of attack, so there is a possibility that stall warnings may be triggered; in such cases the pitch angle may need to be relaxed slightly;

(d) The point at which the tail wind starts to be encountered may be the most critical. The rate of descent may lessen, but the airspeed may continue to fall and any height loss may now be close to ground obstacle clearance margins. Maximum thrust will by now have been applied and if there is now a risk of hitting the ground or an obstacle it may be necessary to raise the nose until stall warnings start to be triggered and to hold this attitude until the aircraft starts to escape from the effects.

5

5.5 The likely effects of windshear on take-off have already been discussed in paragraph 4.3. When there is a possibility of shear, without a clear forecast, it may be possible to use a longer runway, preferably pointing away from an area of potential threat. However, this must not be a 'spur of the moment' action and any such decision will need to have been pre-planned taking into account all necessary factors including runway length and obstacle clearances. The high power setting and high pitch angle after rotation may put the aircraft in a reasonable situation should an encounter now occur, however, if it has not been fully thought out there may be unexpected handling and performance difficulties. However, the aircraft will still be low, with a small safety margin. At that point, maximum power should be selected (if it is not already); noise abatement procedures should be ignored and the high pitch attitude (consistent with any stall warnings) should be maintained. Notwithstanding the above, the safest and recommended course of action would be to delay take-off until the possibility of windshear has diminished.

5.6 The vital actions for downburst/microburst encounter in both approach and take-off cases are:

(a) Early **recognition** and **committal** to the appropriate action;

(b) Follow operations manual or aircraft flight manual techniques;

(c) Use maximum power available as soon as possible;

(d) Adopt an appropriate pitch angle and try and hold it; do not 'chase' airspeed.

(e) Be guided by stall warnings when holding or increasing pitch, easing the back pressure as required to attain or hold a lower pitch attitude if necessary. (In many aircraft types optimum performance is very close to the point of onset of stall warning. It is important, however, not to go beyond the point of onset as it is then not possible for the pilot to know how deeply into the warning the aircraft is).

5.7 It is not possible to be prescriptive in relation to the 'best' technique to use as these will vary between aircraft, and may be documented in appropriate manuals, but could be expected to follow the broad guidelines above. Some of the responses required of the pilot and the attitude and trim forces to be used may sometimes appear to be counter-intuitive. Therefore, the best advice would be to use a windshear training programme, coupled with dedicated simulator exercises to practice the techniques. Any such training should **emphasise** the fact that windshears are to be avoided. The knowledge thus gained and any techniques practiced should serve to make the survival of an inadvertent encounter more possible and not encourage pilots to think that windshears can be tackled with impunity.

6 Windshear Warning and Reporting

6.1 Windshear warning is provided in the following ways:

(a) Meteorological warning;

(b) ATS warning;

(c) Pilot warnings;

(d) On board pre-encounter warnings.

6.2 Warning of windshear from meteorological sources may start at the pre-flight briefing stage and pinpoint the possibility of frontal or inversion shear. Any forecast of thunderstorm activity should alert pilots to the possibility of downdraught or microburst activity. If the planned destination is one where topographical features are known to cause shear hazards, the direction and strength of forecast winds should be noted carefully and compared with published information. In the United Kingdom, windshear warnings are provided in ATIS broadcasts at London (Heathrow) and Belfast (Aldergrove) if the following conditions exist:

(a) The mean surface wind exceeds 20 kt;

(b) The vector difference between the mean surface wind and the gradient wind at about 2000 ft exceeds 40 kt;

(c) Thunderstorms or heavy showers are within about 5 nm of the airfields.

The warnings are broadcast as 'Windshear Forecasts', and if reinforced by pilot (aircraft) reports, the alert becomes 'Windshear forecast and reported'. (See UK AIP GEN 3-5-4 for more information).

6.3 In other parts of the world, windshear warnings can be based not just on meteorological forecasts but on actual observed conditions using, for example, a series of anemometers around an airfield. With such systems, the measured differences in wind velocity between anemometers are used in conjunction with computer programmes and recorded data to produce warnings. Terminal Doppler Weather Radars (TDWR) are also used to measure wind velocities and these can also be configured to produce warnings. **However, a note of caution is necessary**. It will have been noted that no universal standard exists regarding the grading of the severity of windshear, nor is there a universal standard regarding windshear warnings. Furthermore, the term 'microburst' is not always used to describe the classic thunderstorm associated event. 'Microburst' is also used to alert crews to the possibility of a shear event from wind over 30 kt. In this context, it is not a microburst in the sense as shown in Figure 5 (and the associated text). In addition, some locations use a 'Maximum intensity, first encounter' rule, in warnings. This results in warnings as follows:

'Windshear warning, 25 kt, 3 nm final'

This could be interpreted as 'expect an encounter of 25 kt at 3 nm on final approach'. This is incorrect. The correct interpretation (as a result of maximum intensity, first encounter) is:

'Expect encounter(s) with windshear somewhere between 3 nm and touchdown with a maximum intensity of 25 kt'

It should be noted in this context that an aircraft belonging to a UK airline experienced such events with a maximum intensity in the region of 35 (or more) kt ie an encounter with a 'gap-flow microburst' at an approximate height of 150 ft on an approach. From all the available evidence, it would appear that the loss of an aircraft, crew and passengers was very narrowly avoided.

6.4 Pilot reports of windshear encounters are important sources of information to warn other pilots of the danger. The UK AIP (GEN 3-5-21) contains guidance on windshear reporting, which for convenience is repeated below. In this context it should be noted that similar entries in the AIPs of other States may be slightly different and may require the use of different terminology or phraseology.

'Windshear Reporting Criteria

Pilots using navigation systems providing direct wind velocity readout should report the wind and altitude/height above and below the shear layer, and its location. Other pilots should report the loss or gain of airspeed and/or the presence of up or down draughts or a significant change in cross wind effect, the altitude/height and location, their phase of flight and aircraft type. Pilots not able to report windshear in these specific terms should do so in terms of its effect on the aircraft, the altitude/height and location and aircraft type, for example, 'Abrupt windshear at 500 ft QFE on finals, maximum thrust required, B747'. Pilots encountering windshear are requested to make a report even if windshear has previously been forecast or reported'.

6.5 As yet, no perfect on-board system is available for general use and trials continue in this respect. Some aircraft are fitted with predictive windshear warning system, but in most cases the pilot will not receive much advance warning of the presence of windshear. Airborne weather radar may give some clues, however, it must be remembered that most weather radars do not detect turbulence; they only detect precipitation. Warning that an aircraft is about to experience windshear may therefore come from a variety of sources, and in this context it is probably important to ensure that the more sophisticated modern aircraft are configured for a possible encounter in such a way that give the most warning and assistance to the pilot. Guidance for the best configuration to use will come from the manufacturer and it is this that should be used. For less well-appointed aircraft, early clues may come from the airspeed and vertical speed indicators; flight directors may be misleading when a windshear recovery is flown; again manufacturers' guidance should be sought. Finally, although visual clues may have assisted in the early prediction of a windshear event, they will not necessarily be available during an event and its recovery. Similarly, physiological sensations should also be ignored and flight conducted purely by reference to appropriate instruments.

7 Conclusions

7.1 Most pilots will experience changes in wind speed of some form or other; hopefully few will experience windshear as defined in this circular when considerable control inputs will be required to overcome the abrupt changes that the shear encounter has caused. There are no sure and absolute ways of determining the severity of an encounter; therefore the best advice must be to avoid them. If an encounter does occur the generic advice in this circular together with further training and knowledge should help to alleviate the effects.

Recognise – that windshear is a hazard

and

Recognise – the signs that may indicate its presence

Avoid – windshear by delay or diversion

Prepare – for an inadvertent encounter by a 'speed margin' if 'energy loss' is expected

Recover – know the techniques recommended for your aircraft and use them without hesitation if windshear is encountered

Report – immediately to ATC controlling the airfield at which the incident occurred (see paragraph 6.4) **and** using the Mandatory Occurrence Reporting Scheme, to the Civil Aviation Authority.

This Circular is issued for information, guidance and necessary action.

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Questions

1. Maximum turbulence associated with the mountain waves is likely to be:

a. two wavelengths downwind and just above the surface
b. approximately one wavelength downwind of, and approximately level with, the top of the ridge
c. just below the tropopause above the ridge
d. down the lee side of the ridge and along the surface

2. For the formation of mountain waves, the wind above the level of the ridge should:

a. decrease or even reverse direction
b. increase initially then decrease
c. increase with little change in direction
d. increase and then reverse in direction

3. When flying in IMC in a region close to a range of hills 2000 ft high, in stable air and with wind direction at right angles to the axis of the range of hills, which of the following is probably the most dangerous practice:

a. flying towards the hills, into the wind, at flight level 65
b. flying parallel to the hills on the downwind side at flight level 40
c. flying towards the hills downwind at flight level 55
d. flying parallel to the hills on the upwind side at flight level 40

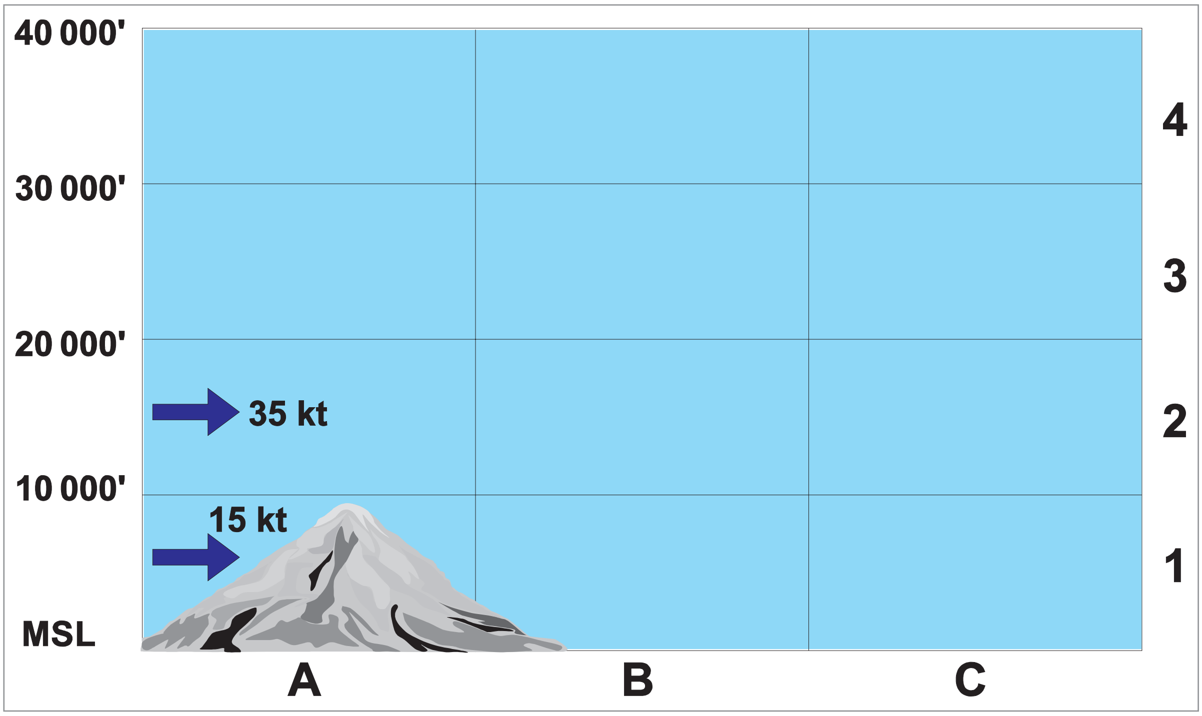
4. Which of the following statements referring to jet streams is correct?

a. Turbulence associated with jet streams is probably associated with the rapid windshear in the vicinity of the jet
b. The maximum wind speed in a jet stream increases with increase of height up to the tropopause and remains constant thereafter
c. The core of a jet stream is usually located just below the tropopause in the colder air mass
d. The rate of change of wind speed at any given level is usually greatest on the warmer side of the jet

Continued Overleaf

Refer to the diagram (Appendix A) below, for questions 5-8, assuming mountain waves are present.

Appendix A



5. The wind at square A3 is likely to be:

a. 35 kt
b. 50 kt
c. 25 kt
d. light

6. The wind at ABC 4 may be:

a. 50 kt
b. 40 kt
c. 35 kt
d. a jet stream

7. Flight conditions at B1 are likely to be:

a. smooth
b. turbulent
c. turbulent in breaking wave crests
d. turbulent due to marked up and down currents

8. The most extreme turbulence can occur:

a. at B1
b. at A2
c. at ABC 4
d. at B2, 3, 4 and at C2, 3, 4

9. **The significance of lenticular cloud is:**

a. there may be mountain waves present and there will be severe turbulence
b. there are mountain waves present but they may not give severe turbulence
c. a Föhn wind can be expected with no turbulence
d. a katabatic wind is present which may lead to fog in the valleys

10. **A mountain range is aligned in an east/west direction. Select the conditions from the table below that will give rise to mountain waves:**

	2000 ft	5000 ft	10 000 ft
a.	020/40	020/30	020/50
b.	170/20	190/40	210/60
c.	270/15	270/20	270/40
d.	090/20	090/40	090/60

11. **For mountain waves to form, the wind direction must be near perpendicular to a ridge or range of mountains and the speed must:**

a. decrease with height within a stable layer above the hill
b. increase with height within an unstable layer above the hill
c. decrease with height within an unstable layer above the hill
d. increase with height within a stable layer above the hill

12. **A north/south mountain range, height 10 000 ft is producing marked mountain waves. The greatest potential danger exists for an aircraft flying:**

a. on the windward side of the ridge
b. at FL350 over and parallel to the ridge
c. towards the ridge from the lee side at FL140
d. above a line of clouds parallel to the ridge on the lee side at FL25

13. **Clear air turbulence, in association with a polar front jet stream in the Northern Hemisphere, is more severe:**

a. underneath the jet core
b. in the centre of the jet core
c. looking downstream on the right hand side
d. looking downstream on the left hand side

14. **Mountain waves can occur:**

a. up to a maximum of 5000 ft above the mountains and 50 NM to 100 NM downwind
b. up to mountain height only and 50 NM to 100 NM downwind
c. above the mountain and downwind up to a maximum height at the tropopause and 50 NM to 100 NM downwind.
d. in the stratosphere and troposphere

15. Clear air turbulence (CAT) should be reported whenever it is experienced. What should be reported if crew and passengers feel a definite strain against their seat or shoulder straps, food service and walking is difficult and loose objects become dislodged?

a. Light TURB
b. Extreme TURB
c. Severe TURB
d. Moderate TURB

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	c	b	a	b	d	d	a	b	b	d	d

13	14	15
d	d	d

Chapter

9

Altimetry

Altimetry

The Altimeter

An altimeter is an instrument which measures pressure and causes a needle to move across a dial. The dial is calibrated in feet rather than pressure as we know that pressure decreases as altitude increases.

The instrument is calibrated in accordance with the ICAO International Standard Atmosphere so that all altimeters will read the same altitude for the same pressure. (See previous notes on the need for the ISA.)

In addition, altimeters have a means of adjusting the needle setting to take changes in the surface atmospheric pressure into account.

Figure 9.1 shows how the altimeter reading will change with a change in pressure.

In *Figure 9.2* section A, the pressure at the airfield, which is at sea level, is 1010 hPa. The altimeter reads zero feet.

In section B, the pressure at the airfield has fallen to 1000 hPa and the altimeter, rather than showing a decrease in pressure, shows an increase in height.

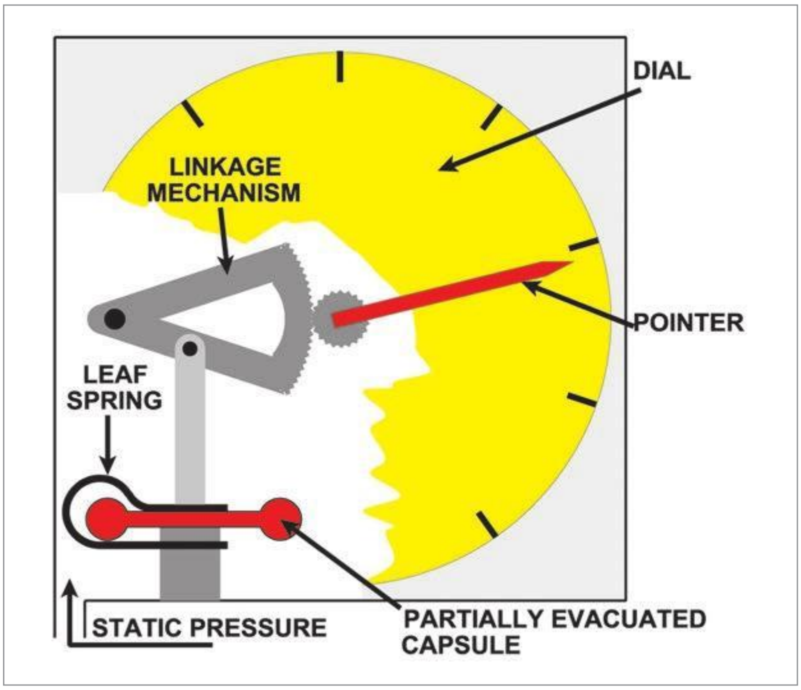


Figure 9.1 Simple altimeter

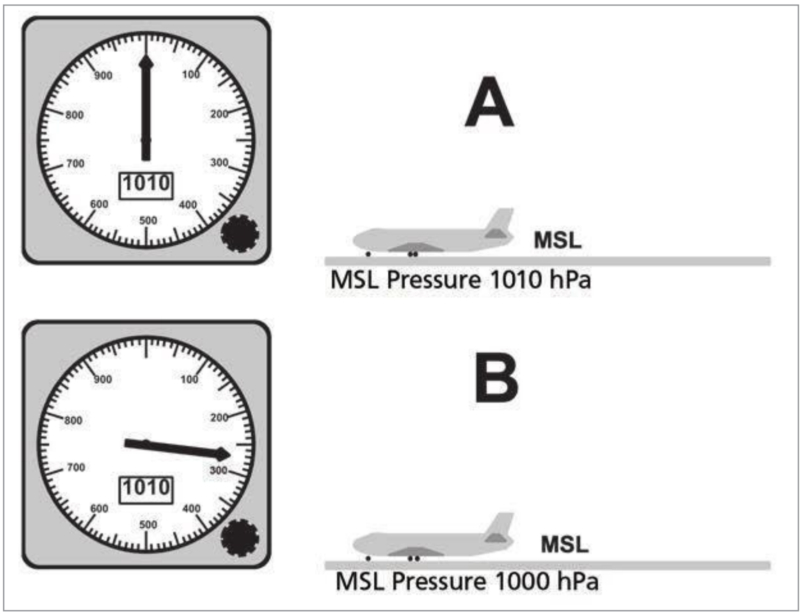


Figure 9.2 The altimeter responding to changes in pressure

- When flying at a constant indicated altitude, outside air pressure must remain the same. To achieve this we must fly along a pressure level. However, when we fly to an area of lower pressure, these pressure lines will dip, consequently our true altitude will decrease. Conversely when flying into a region of higher pressure, the pressure lines will rise and our true altitude will increase.

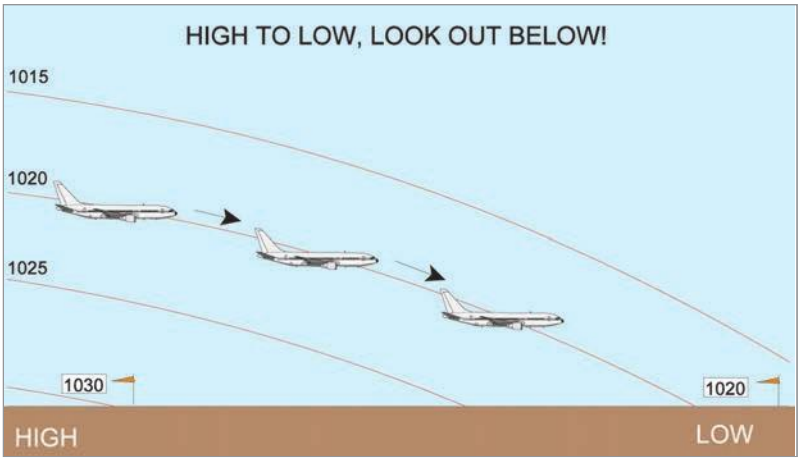


Figure 9.3

HIGHER PRESSURE; TRUE ALTITUDE > INDICATED ALTITUDE
LOWER PRESSURE; TRUE ALTITUDE < INDICATED ALTITUDE

- Varying temperatures within the atmosphere have significant effects on the pressure and the shape of the pressure lines. Cold air will tend to compact and lower pressure lines whilst warm air will expand and raise pressure lines. Using *Figure 9.4* you can see that when flying to a colder area at a constant indicated altitude your true altitude decreases. Conversely, when flying into warmer region your true altitude will increase.

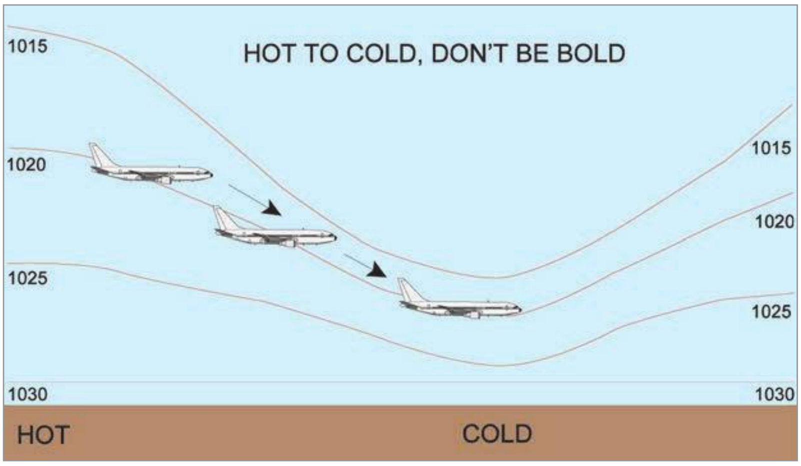


Figure 9.4

COLDER THAN ISA; TRUE ALTITUDE < INDICATED ALTITUDE
WARMER THAN ISA; TRUE ALTITUDE > INDICATED ALTITUDE

- There is a need to be able to reset the altimeter to take account of the fall in pressure. Consequently, if the altimeter is reset when the pressure changes, the altimeter will read correctly. We may, by altering the altimeter subscale setting, set QFE, QNH or SPS for use when we fly to ensure more accurate readings.

Altimeter Settings

QFE

The pressure measured at the aerodrome datum. With QFE set on the altimeter, the altimeter will read zero when the aircraft is on the surface of the aerodrome. When airborne, with QFE set, the altimeter reads the approximate height above the aerodrome. QFE is always rounded down to the nearest hectopascal.

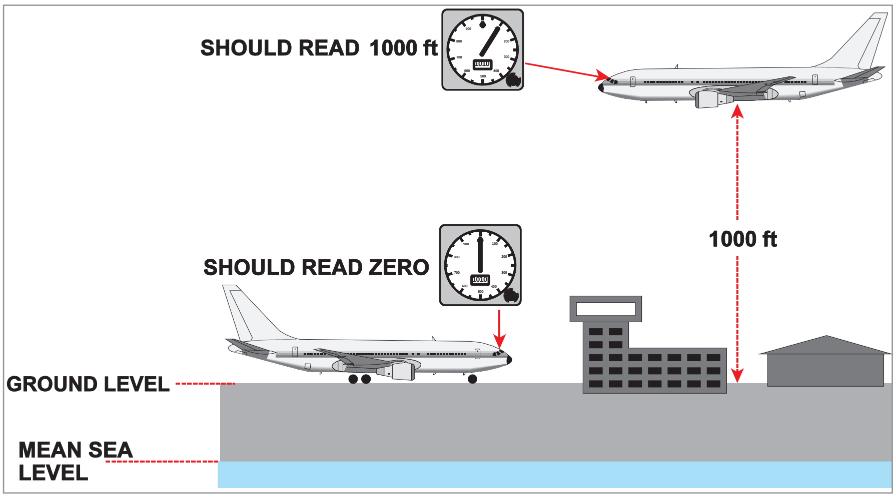


Figure 9.5 Airfield Pressure - QFE.

QNH

QFE converted to mean sea level using the ISA. With QNH set the altimeter will read aerodrome elevation when on the surface of the aerodrome. When airborne it will read the approximate altitude of the aircraft.

Note: QNH is always rounded down to the nearest integer.

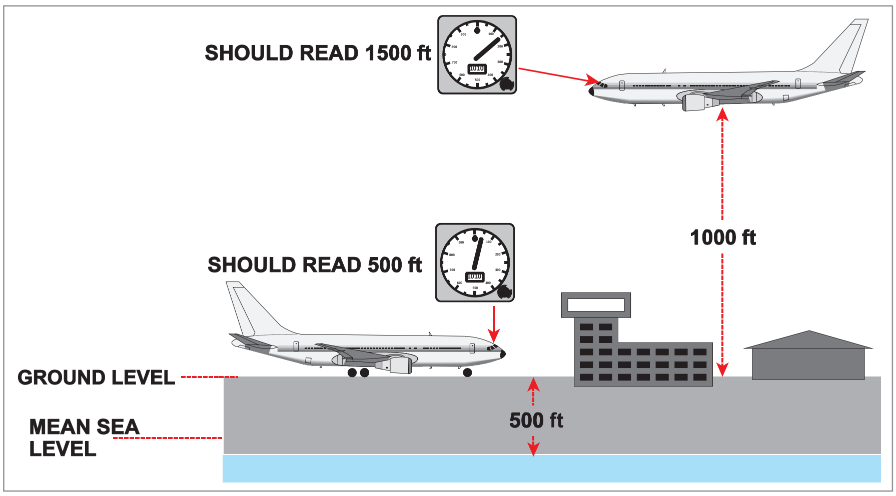


Figure 9.6 Mean Sea Level Pressure - QNH.

Forecast QNH

The lowest forecast QNH within an area, forecast for one hour ahead. The altimeter will be in error, but as the setting is the **lowest** forecast, the actual pressure will always be higher, or at least equal to the forecast QNH, and the altimeter will read **low** (or safe) or the correct altitude. *(See Figure 9.7)*.

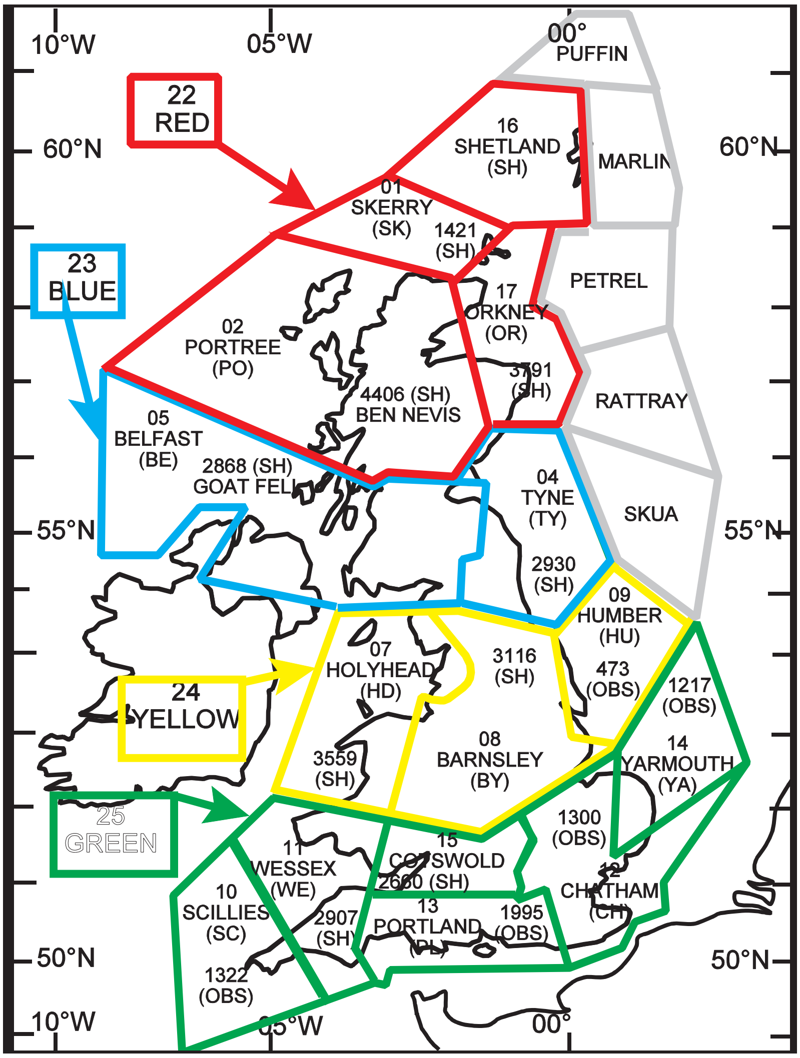


Figure 9.7 Altimeter Setting Regions

	FO UK 70	EGRR	110600				
	FO QNH						
VALIDITY PERIOD	00708	01992	02995	03003	04007	05001	REGION NUMBER
	07011	08011	09011	10014	11014	12019	
	13020	14015	15017	16987	17998	18989	R.P.S
	19998	20004	21981	22987	23001	24011	
	25014						

Note: The Cotswold area where Kidlington is situated is No.15 on the above decode table.

SPS (Standard Pressure Setting) If the standard pressure of 1013 hPa is set on the altimeter, the instrument will read what is known as **pressure altitude** height in the Standard Atmosphere. This is the altimeter setting used when flying above the transition altitude.

Terminology

Altitude Vertical distance above mean sea level.

Height Vertical distance of a level or point measured from a specific datum, e.g. above aerodrome surface.

Elevation Vertical distance of a fixed object above mean sea level (e.g. aerodrome or obstacle.

Flight Level Surface of constant atmospheric pressure measured from the 1013 hPa datum used for vertical separation by specified pressure intervals (usually 500 or 1000 ft). Flight Level is measured in hundreds of feet.

e.g. FL350 = 35 000 ft.

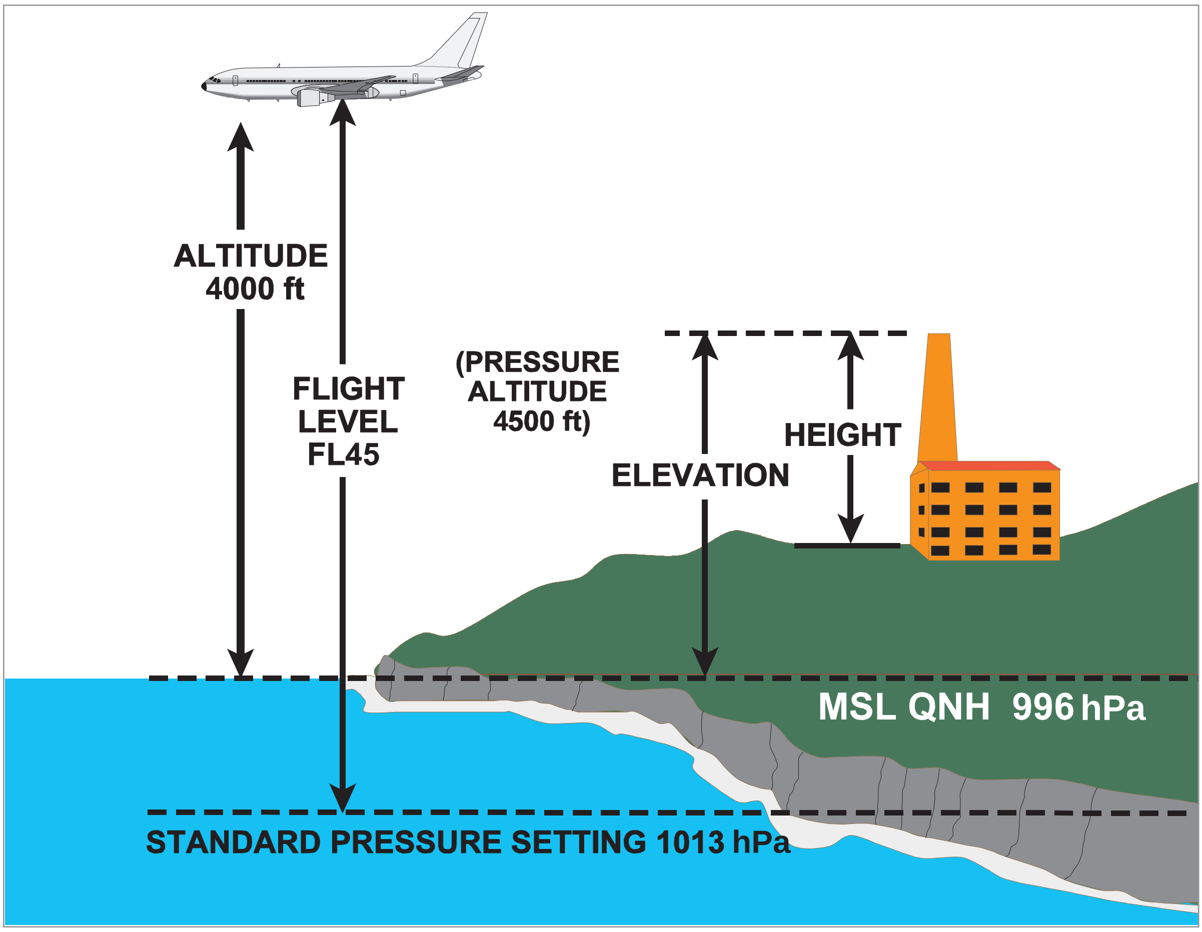


Figure 9.8 Altimetry Terminology

Altimeter Errors

Apart from instrument errors, there are two errors of interest meteorologically. They are:

- **Barometric Error** - Errors caused by setting a pressure on the subscale other than the correct one. For calculations a height of 27 ft per hPa is used in all the meteorology syllabus altimetry questions to determine the difference between indicated and true height/altitude.

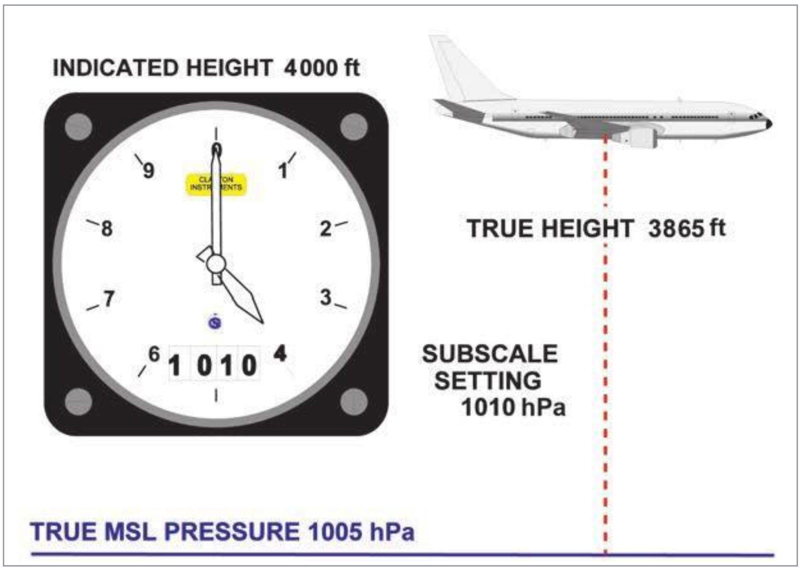


Figure 9.9 Barometric Error

- **Temperature error** - The altimeter is calibrated in accordance with the ICAO ISA. If the temperature is other than that in the ISA, the altimeter will be in error. Corrected altitude is calculated by using a navigational computer, or a correction table. HI-LO-HI will still apply.

Altimeter Temperature Error Correction

- Pressure altimeters are calibrated to indicate true altitude under ISA conditions. Any deviation from ISA will result in erroneous readings, except that the altimeter will read the correct elevation of the airfield regardless of temperature when the aircraft is on the ground with QNH set.

- When temperatures are **lower** than ISA an aircraft's true altitude will be **lower** than the altimeter reading.

- The error is proportional to the difference between actual and ISA temperature, and the vertical distance of the aircraft above the altimeter setting datum.

- The height correction is 4 feet per degree Celsius deviation from ISA per 1000 feet.
  Note: the calculation must be made over the indicated height difference from the datum for the pressure setting.

- **For example:** When making an approach to an aerodrome at mean sea level in Siberia in January the decision height is 200 ft. What is the true height when the indicated height is 200 ft if the temperature is -50°C?

Error = 4×(-65) × 0.2 = -52 ft

Hence the true height is 148 ft!

This is clearly unacceptable so when carrying out an aerodrome or runway approach in temperatures colder than standard the indicated decision height/altitude or minimum descent height/altitude must be increased in accordance with the following table to ensure safe operation.

ISA TEMP DEVIATION °C	HEIGHT ABOVE TOUCHDOWN OR HEIGHT ABOVE AERODROME IN FEET								
	200	300	400	500	600	700	800	900	1000
-15	12	18	24	30	36	42	48	54	60
-25	20	30	40	50	60	70	80	90	100
-35	28	42	56	70	84	98	112	126	140
-45	36	54	72	90	108	126	144	162	180
-55	44	66	88	110	132	154	176	198	220
-65	52	78	104	130	156	182	208	234	260

With temperatures colder than standard consideration must be given to the effect of temperature on terrain clearance.

For example:

A flight is planned at FL180 over Mont Blanc (elevation 15 782 ft). The mean sea level pressure is 983 hPa, from an aerodrome at mean sea level, and the temperature of the air up to the summit is 25°C colder than ISA. Determine the true altitude of the aircraft at Mont Blanc and hence the terrain clearance. *Figure 9.10*.

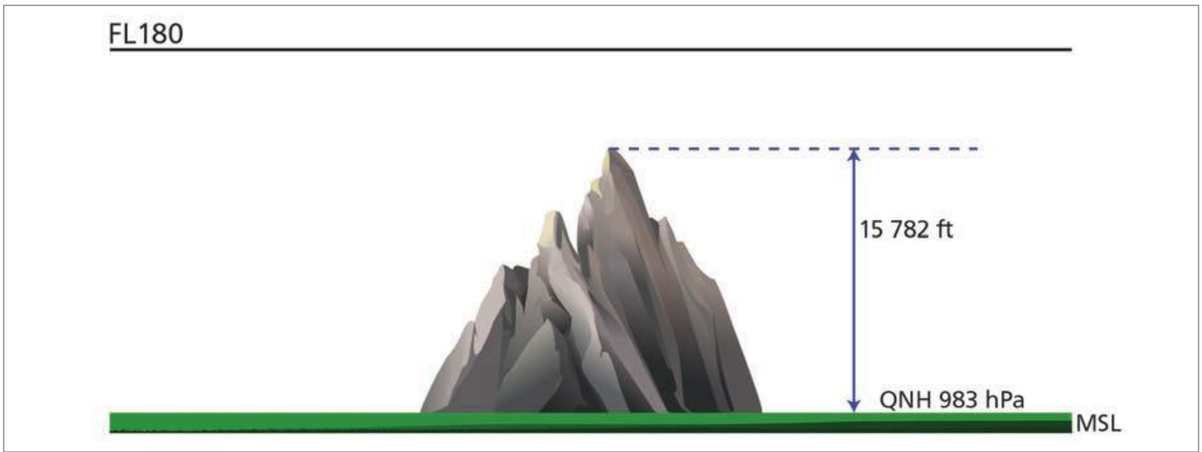


Figure 9.10

The indicated altitude is 18 000 ft above the 1013 hPa datum; the height correction for the 30 hPa pressure difference is:

30 × 27 = 810 feet so the corrected altitude is 17 190 ft. *Figure 9.11.*

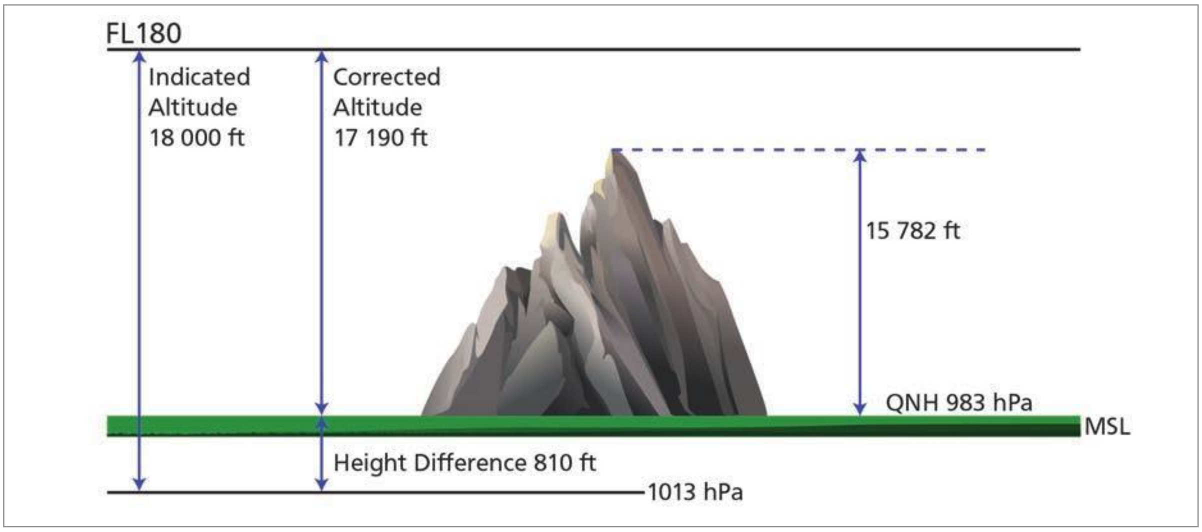


Figure 9.11

The height correction for the temperature deviation from ISA is:

4 × (- 25) × 18 = -1800 ft

Hence the true altitude of the aircraft is 15 390 ft. *Figure 9.12*.

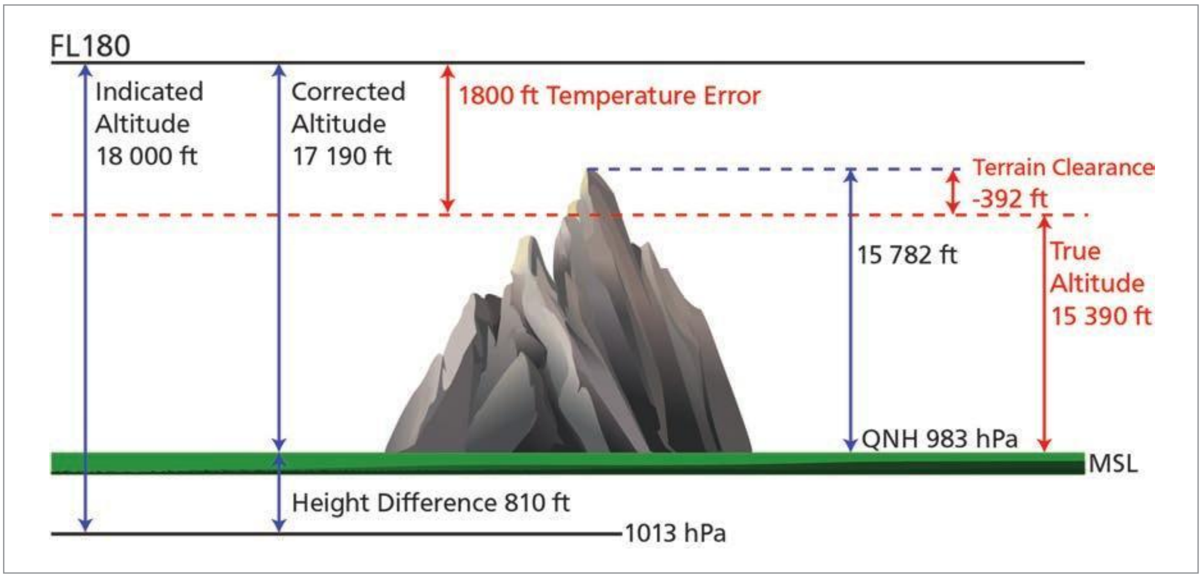


Figure 9.12

But Mont Blanc is 15 872 ft high so if we do not do something about it we will hit the mountain 392 feet below the summit. To simplify the calculation use the formula:

true altitude = indicated altitude + (indicated altitude/1000 × ISA deviation × 4) + 27(actual pressure - pressure setting)

So in winter, particularly if flying close to safety altitude, the effect of temperature on true altitude must be taken into account.

For all of the following questions assume that 1 hPa = 27 ft.

1. **An aircraft is at an airfield with an elevation of 350 ft. The altimeter setting is 1002, but the actual QNH is 993. What is the altimeter reading?**
2. **An aircraft is on an airfield, elevation 190 ft and has an altimeter reading of 70 ft with a setting of 1005. What is the actual QNH?.**
3. **What is the altimeter reading if the setting is 978, the QNH 993 and the airfield elevation 770 ft?**
4. **The regional pressure setting is 1012, the altimeter setting is 1022 and the indicated altitude is 4100 ft. Ahead is some high ground shown on the map as being at 3700 ft. Will the aircraft clear the high ground, and if so, by how much?**

(Answers on *page 137*)

Minimum Safe Flight Level

Minimum safe flight level is the minimum indicated pressure altitude (using SPS 1013 hPa) that will ensure the aircraft is not lower than the safety attitude for each section of the route.

When route planning we must ensure that on all sections of the route the selected flight level is at or above the safety altitude for that section. This means that we have to take account of both expected minimum pressure (QNH) and minimum temperature for each section of the route.

For example: on a section of a route the safety altitude is 8300 ft, the forecast QNH is 983 hPa and the temperature is ISA -30°, determine the minimum safe flight level for that section of the route. *Figure 9.13.*

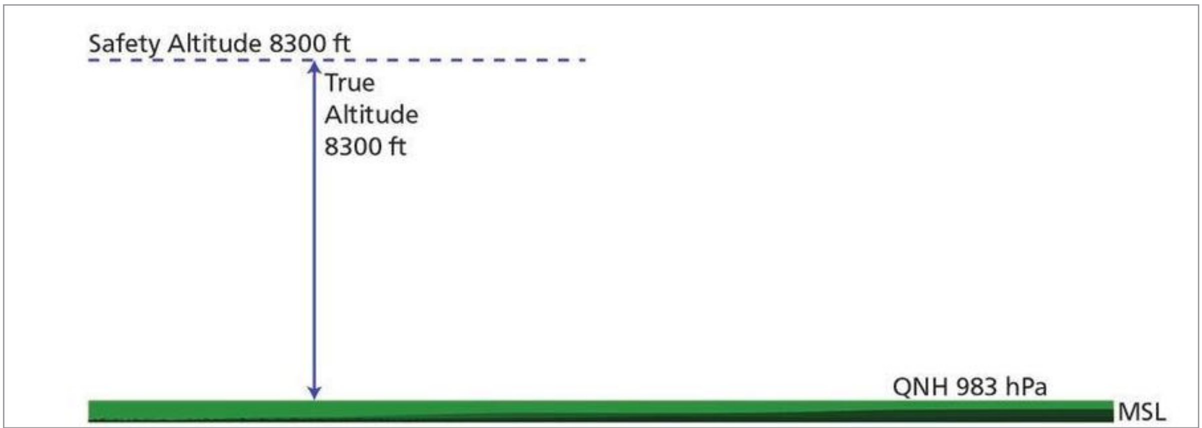


Figure 9.13

The correction for pressure difference is 30 × 27 = 810 ft, giving a minimum indicated pressure altitude of 9110 ft. The temperature correction is 4 × (-30) × 9 = -1080 ft so the minimum indicated pressure altitude required is 10 190 ft. *Figure 9.14.*

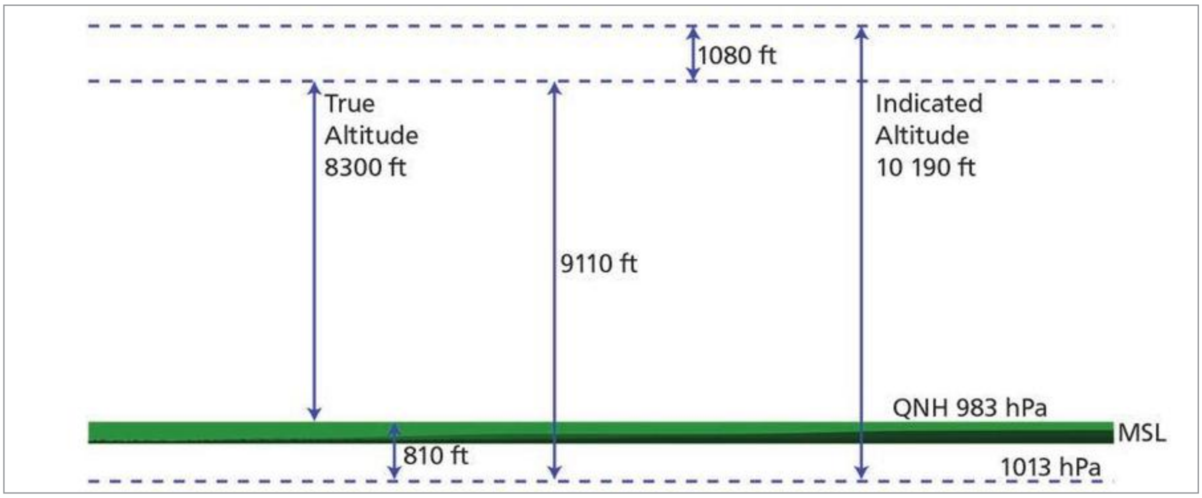


Figure 9.14

This is now rounded up to 10 500 ft (FL105) or 11 000 ft (FL110) dependent of the status of the flight and the type of airspace through which the flight is to be made.

Fill in the blank spaces in the following examples.

Assume 1 hPa = 27 ft

QNH	ALTIMETER SETTING	TRUE ALTITUDE	ALTIMETER READING
1012	1010	4060	
1015	1010		5000
	1010	641	560
1020	1013		10 500
999	1013		8500
1015		46	125
1017	1027	3300	
1012		270	0
	993	405	0
1025	1015	4760	

Transition Altitude

The altitude at or below which the vertical position of an aircraft is controlled by reference to altitude (QNH).

Transition Level

The lowest **flight level** (1013) available for use above the **transition altitude.**

Transition Layer

The airspace between the **transition altitude** and the **transition level.**

Answers to Questions on page 135 and page 136

1. 593 ft

2. 1010 hPa

3. 365 ft

4. Yes, by 130 ft

QNH	ALTIMETER SETTING	TRUE ALTITUDE	ALTIMETER READING
1012	1010	4060	4006
1015	1010	5135	5000
1013	1010	641	560
1020	1013	10 689	10 500
999	1013	8122	8500
1015	1018	46	125
1017	1027	3300	3570
1012	1002	270	0
1008	993	405	0
1025	1015	4760	4490

Questions

1. **MSA given as 12 000 ft, flying over mountains in temperatures +9°C, QNH set as 1023 (obtained from a nearby airfield). What will the true altitude be when 12 000 ft is reached?**

    a. 11 940
    b. 11 148
    c. 12 210
    d. 12 864

2. **When flying at FL180 in the Southern Hemisphere you experience a left to right crosswind. What is happening to your true altitude if indicated altitude is constant?**

    a. Remains the same
    b. Increasing
    c. Decreasing
    d. Impossible to tell

3. **Flying from Marseilles (QNH 1012) to Palma (QNH 1015) at FL100. You do not reset the altimeter, why would true altitude be the same throughout the flight?**

    a. Not possible to tell
    b. Air at Palma is warmer than air at Marseilles
    c. Air at Marseilles is warmer than air at Palma
    d. Blocked static vent

4. **Which of these would cause your true altitude to decrease with a constant indicated altitude?**

    a. Cold/Low
    b. Hot/Low
    c. Cold/High
    d. Hot/High

5. **An aircraft flying in the Alps on a very cold day, QNH 1013 set in the altimeter, flies level with the summit of the mountains. Altitude from aneroid altimeter reads:**

    a. same as mountain elevation
    b. lower than mountain elevation
    c. higher than mountain elevation
    d. impossible to determine

6. **You are flying in an atmosphere which is warmer than ISA, what might you expect?**

    a. True altitude to be the same as indicated altitude
    b. True altitude to be lower than indicated altitude
    c. True altitude to be the decreasing
    d. True altitude to be higher than indicated altitude

7. The QNH is 1030 hPa and at the transition level you set the SPS. What happens to your indicated altitude (assume 27 ft per 1 hPa)?

a. Drops by 459 ft
b. Rises by 459 ft
c. No change
d. Rises

8. You are flying from Madrid (QNH 1012) to Paris (QNH 1015) at FL80. If your true altitude and indicated altitude remain the same then:

a. the air at Madrid is warmer than Paris
b. the air at Paris is warmer than Madrid
c. the altimeters are incorrect
d. your indicated altitude must be changing

9. If you are flying on a QNH 1009 on very cold day and you circle the top of a peak in the Alps, your altimeter will read:

a. the same as the elevation of the peak
b. lower than the elevation of the peak
c. higher than the elevation of the peak
d. not enough information to tell

10. How do you calculate the lowest usable flight level?

a. Lowest QNH and lowest negative temperature below ISA
b. Lowest QNH and highest negative temperature below ISA
c. Highest QNH and highest temperature above ISA
d. Highest QNH and lowest temperature

11. QNH is 1003. At FL100 true altitude is 10 000 ft. It is:

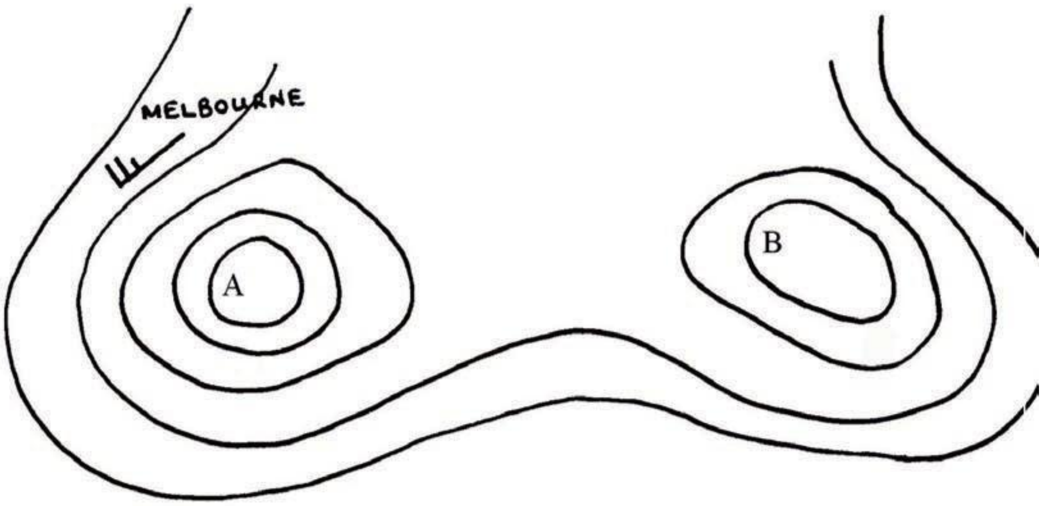
a. warmer than ISA
b. colder than ISA
c. same as ISA
d. cannot tell

12. How is QNH determined from QFE?

a. Using the temperature of the airfield and the elevation of the airfield
b. Using the temperature
c. Using the elevation
d. Using the temperature at MSL and the elevation of the airfield

13. **Using the diagram below you are on a flight from A to B at 1500 ft. Which statement is true?**

a. True altitude at A is greater than B
b. True altitude at B is greater than A
c. True altitude is the same
d. Cannot tell



14. **QFE is 1000 hPa with an airfield elevation of 200 m AMSL. What is QNH? (use 8 m per hPa).**

a. 975 hPa
b. 1025 hPa
c. 1008 hPa
d. 992 hPa

15. **Which of the following is true?**
QNH is:

a. Always more than 1013.25 hPa
b. Always less than 1013.25 hPa
c. Never 1013.25 hPa
d. Can never be above or below 1013 hPa

16. **Flying from Marseilles to Palma you discover your true altitude is increasing, but oddly the QNH is identical at both places. What could be the reason?**

a. Re-check the QNH
b. Re-check the radio altimeter
c. The air at Palma is warmer
d. Palma is lower than Marseilles

17. **QNH is 1030. Aerodrome is 200 m AMSL. What is QFF?**

a. Higher than 1030
b. Lower than 1030
c. Same
d. Not enough info

18. **If an aerodrome is 1500 ft AMSL on QNH 1038, what will the actual height AGL to get to FL75 be?**

a. 6675 ft
b. 8175 ft
c. 8325 ft
d. 5325 ft

19. **Altimeter set to 1023 at aerodrome. On climb to altitude the SPS is set at transition altitude. What will the indication on the altimeter do on resetting to QNH?**

a. Dependent on temperature
b. Decrease
c. Increase
d. Same

20. **What temperature and pressure conditions would be safest to ensure that your flight level clears all the obstacles by the greatest margin?**

a. Cold temp/low pressure
b. Warm temp/high pressure
c. Temp less than or equal to ISA and a QNH less than 1013
d. Temp more than or equal to ISA and a QNH greater than 1013

21. **You are flying from Marseilles (QNH 1012 hPa) to Palma de Mallorca (QNH 1012 hPa) at FL100. You notice that the effective height above MSL (radio altitude) increases constantly. Hence:**

a. one of the QNH values must be wrong
b. you have the altimeters checked, as their indications are obviously wrong
c. the air mass above Palma is warmer than that above Marseilles
d. you have to adjust for a crosswind from the right

22. **You are flying from Marseilles (QNH 1026 hPa) to Palma de Mallorca (QNH 1026 hPa) at FL100. You notice that the effective height above MSL (Radio Altitude) decreases constantly. Hence:**

a. one of the QNH values must be wrong
b. the air mass above Marseilles is warmer than that above Palma
c. you have the altimeters checked, as their indications are obviously wrong
d. you have to adjust for a crosswind from the right

23. **Flying at FL135 above the sea, the radio altimeter indicates a true altitude of 13 500 ft. The local QNH is 1019 hPa. Hence the crossed air mass is, on average:**

a. at ISA standard temperature
b. colder than ISA
c. warmer than ISA
d. there is insufficient information to determine the average temperature deviation

24. **You are flying in the Alps at the same level as the summit on a hot day. What does the altimeter read?**

    a. Same altitude as the summit
    b. Higher altitude as the summit
    c. Lower altitude as the summit
    d. Impossible to tell

25. **An airfield has an elevation of 540 ft with a QNH of 993 hPa. An aircraft descends and lands at the airfield with 1013 hPa set. What will its altimeter read on landing?**

    a. 380 ft
    b. 1080 ft
    c. 0 ft
    d. 540 ft

26. **When is pressure altitude equal to true altitude?**

    a. In standard conditions
    b. When surface pressure is 1013.25 hPa
    c. When the temperature is standard
    d. When the indicated altitude is equal to the pressure altitude

27. **What is the relationship between QFE and QNH at an airport 50 ft below MSL?**

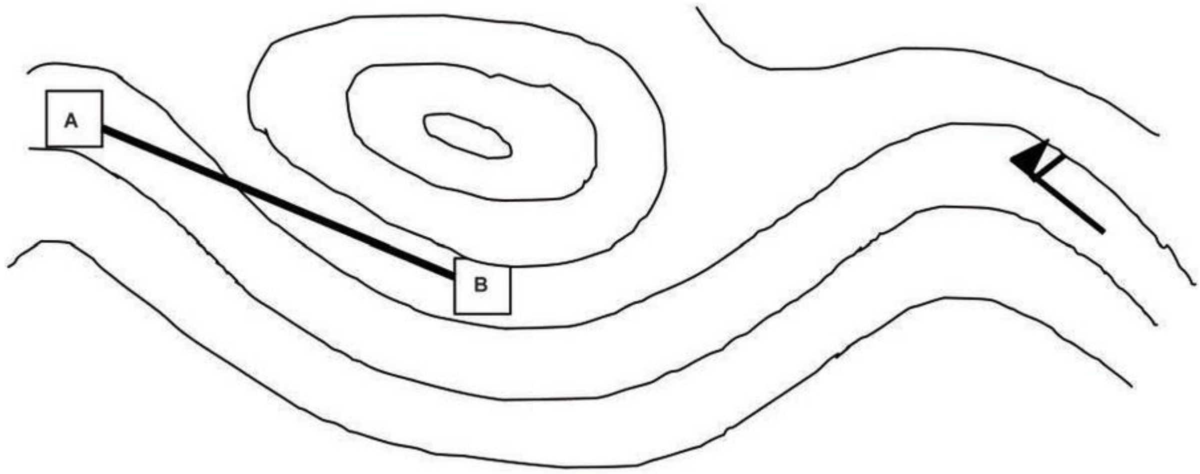
    a. QFE = QNH
    b. QFE < QNH
    c. QFE > QNH
    d. There is no clear relationship

28. **You are flying at FL160 with an OAT of -27°C. QNH is 1003 hPa. What is your true altitude?**

    a. 15 540 ft
    b. 15 090 ft
    c. 16 330 ft
    d. 15 730 ft

29. **Flying from A to B at a constant indicated altitude in the Northern Hemisphere.**

a. True altitude increases
b. Wind is northerly
c. True altitude decreases
d. Wind is southerly



30. **Up to FL180 ISA Deviation is ISA +10°C. What is the actual depth of the layer between FL60 and FL120?**

a. 6000 ft
b. 6240 ft
c. 5760 ft
d. 5700 ft

31. **Up to FL 180 ISA Deviation is ISA -10°C. What is the actual depth of the layer between FL60 and FL120?**

a. 6000 ft
b. 6240 ft
c. 5760 ft
d. 5700 ft

32. **What condition would cause your indicated altitude to be lower than that being actually flown?**

a. Pressure lower than standard
b. Pressure is standard
c. Temperature lower than standard
d. Temperature higher than standard

33. **You fly over the sea at FL90, your true altitude is 9100 ft and QNH is unknown. What can be said about the atmosphere temperature?**

a. QNH is lower than standard
b. It is colder than ISA
c. It is warmer than ISA
d. Nothing, insufficient information

34. **You are flying at FL100 in an air mass that is 15°C colder than ISA. Local QNH is 983 hPa. What would the true altitude be?**

a. 8590 ft
b. 11 410 ft
c. 10 000 ft
d. 10 210 ft

35. **Which statement is true?**

a. QFE is always lower than QNH
b. QNH is always lower than QFE
c. QNH can be equal to QFE
d. QFE can be equal to QFF only

36. **You fly from east to west at the 500 hPa level in the Northern Hemisphere;**

a. if the wind is from the north there will be a gain in altitude
b. if the wind is from the south there is again in altitude
c. if you encounter northerly drift, there is a gain in altitude
d. you fly towards an area of lower pressure, and therefore, experience a loss in altitude

37. **You have landed on an airport elevation 1240 ft and QNH 1008 hPa. Your altimeter subscale is erroneously set to 1013 hPa. The indication on the altimeter will be:**

a. 1200 ft
b. 1375 ft
c. 1105 ft
d. 1280 ft

38. **You are cruising at FL200, OAT is -40°C, sea level pressure is 1033 hPa. Calculate the true altitude.**

a. 20660 ft
b. 21740 ft
c. 18260 ft
d. 19340 ft

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	b	c	a	c	d	a	a	c	a	a	c

13	14	15	16	17	18	19	20	21	22	23	24
b	b	c	c	d	a	c	d	c	b	b	c

25	26	27	28	29	30	31	32	33	34	35	36
b	a	c	b	c	b	c	d	d	a	c	a

37	38
b	d

Chapter

10

Winds

Continued Overleaf

10 *Winds*

Introduction

Wind is air in horizontal motion. **Wind Velocity** (W/V) has both direction **and** speed.

Wind **direction** is always given as the direction **from** which the wind is blowing; this is illustrated in *Figure 10.1*. It is normally given in degrees **true**, but wind direction given to a pilot by ATC will be given in degrees **magnetic**.

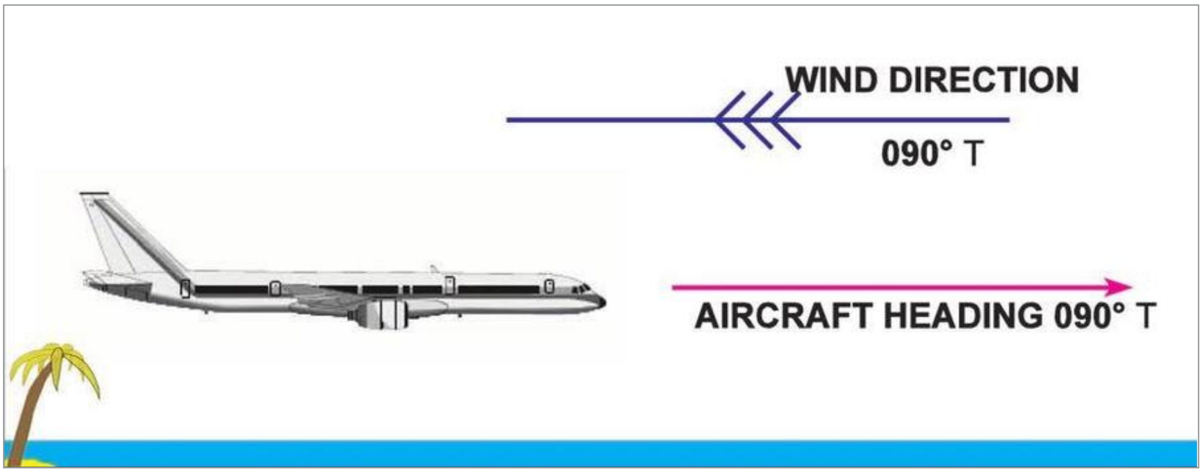


Figure 10.1 Wind direction

Wind speed is usually given in **knots**, but some countries give the speed in **metres per second** (ms^{-1}) and the Met. Office often work internally in kilometres per hour, shown as KMH on reports and forecasts.

On the wind vector the wind direction is from the feathers to the point which indicates the location of the wind. The illustrated wind *Figure 10.2* is 240° (true) at 125 kt. It should be noted that, by convention, the feathers always point towards the low pressure.

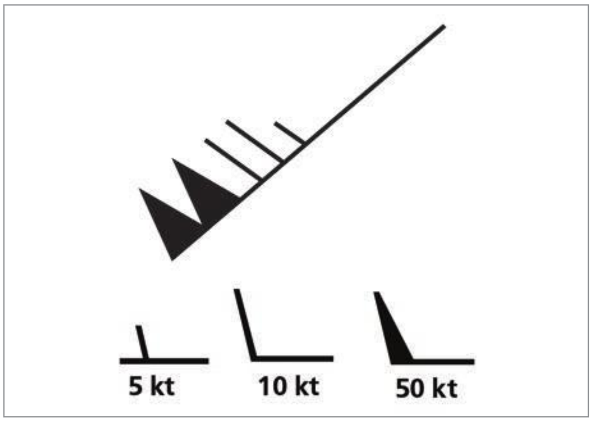


Figure 10.2

Veering is a change of wind direction in a clockwise direction.

Backing is a change of wind direction in an anticlockwise direction. This applies in **both** hemispheres.

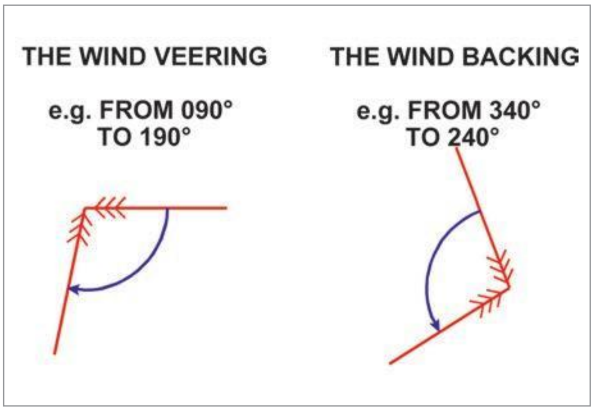


Figure 10.3 The wind veering and backing

Gusts

A **gust** is a sudden increase in wind speed, often with a change in direction lasting less than one minute and it is a local effect. A gust will only be reported or forecast if 10 kt or more above the mean wind speed.

A **lull** is a sudden decrease in wind speed.

Squalls

A squall is a sudden increase in wind speed, often with a change in direction. Lasting for one minute or more and can cover a wide area. It is often associated with **cumulonimbus cloud** and **cold fronts**.

Gale

A gale exists when the sustained wind speed exceeds 33 kt, or gusts exceed 42 kt.

Hurricane

A hurricane force wind exists when sustained wind speed exceeds 63 kt.

Measurement of Winds

Surface wind is measured by a **wind vane** which aligns itself with the wind direction, and an **anemometer** which measures the speed. An anemometer is a set of 3 hemispherical cups which rotate on a shaft with the effect of the wind. The speed of rotation of the shaft is directly proportional to the wind speed. The rotation is used to drive a small generator, the output of which is then displayed on a gauge which is calibrated in knots.

Figure 10.4 A wind vane and anemometer

The ICAO requirement is that the wind vane and anemometer should be positioned 10 m (33 ft) above aerodrome level and located clear of buildings and obstructions which could affect the airflow and hence accuracy. An **anemograph** records wind speed and direction.

Upper winds are measured by GPS tracking of a **radiosonde** and by **aircraft reports**.

Wind

Wind is generated by the pressure differences between high and low pressure systems which give rise to what we call the pressure gradient force (PGF) the change of pressure over distance. The PGF acts directly from high pressure to low pressure.

The spacing of the isobars determines the magnitude of the force, the closer together the isobars the greater the pressure difference and hence the PGF and thus the wind speed.

Buys Ballot's Law tells us that if we stand with our back to the wind in the Northern Hemisphere low pressure is on the left (right in the Southern Hemisphere). This implies that the wind does not flow directly from high pressure to low pressure but parallel to the isobars. Examination of an analysis chart will show that the surface wind does indeed flow nearly parallel to the isobars and we will see that above the friction layer the wind, generally does flow parallel to the isobars. There are two winds that we need to consider:

- **The Geostrophic Wind**
- **The Gradient Wind**

The Geostrophic Wind

As with any theorized wind or model wind, a number of assumptions must be made to reduce the complexity of reality and make the model more simplistic. These are as follows:

- The Geostrophic Wind is said to have only two forces.
- These must be working opposite from each other and in balance.

These two forces are:

Pressure Gradient Force (PGF)

- Pressure Gradient Force, (PGF), is the force that acts from a high pressure to a low pressure.

- We can see the strength of this force by studying the spacing between isobars. Closely spaced isobars would indicate a large pressure gradient force. This is common in low pressure systems. Widely spaced isobars indicate a small pressure gradient force. This is common in high pressure systems.

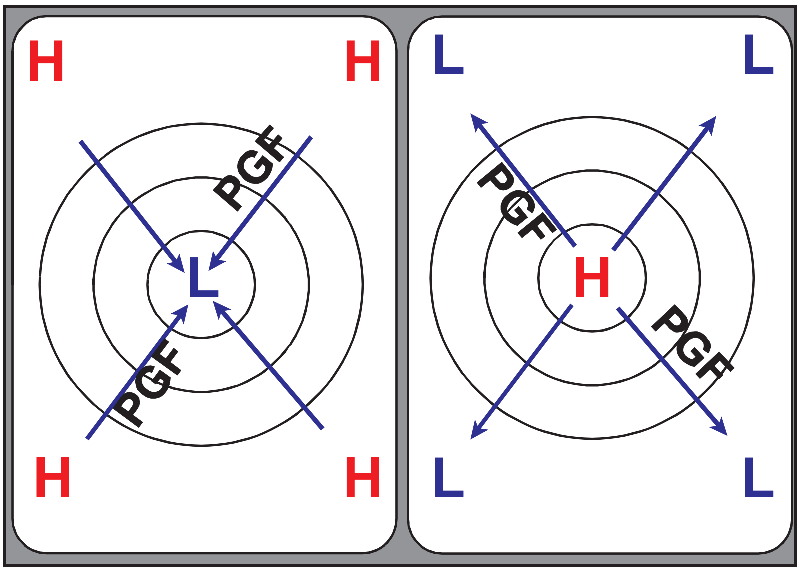


Figure 10.5 Pressure Gradient Force (PGF)

- The Pressure Gradient Force, (PGF), controls the wind speed. A large pressure gradient force would create strong winds, whereas a small pressure gradient force would create light winds. Wind speed is directly proportional to the pressure gradient force.

- The relationship between the isobar spacing, the pressure gradient force and the wind speed can be seen in the Geostrophic Wind Scale (GWS). Using *Figure 10.6*, take the distance between two isobars and reading from left to right, measure the geostrophic wind speed using the geostrophic wind scale shown at the bottom of the diagram. You will notice the wider the spacing of the isobars, the lighter the wind.

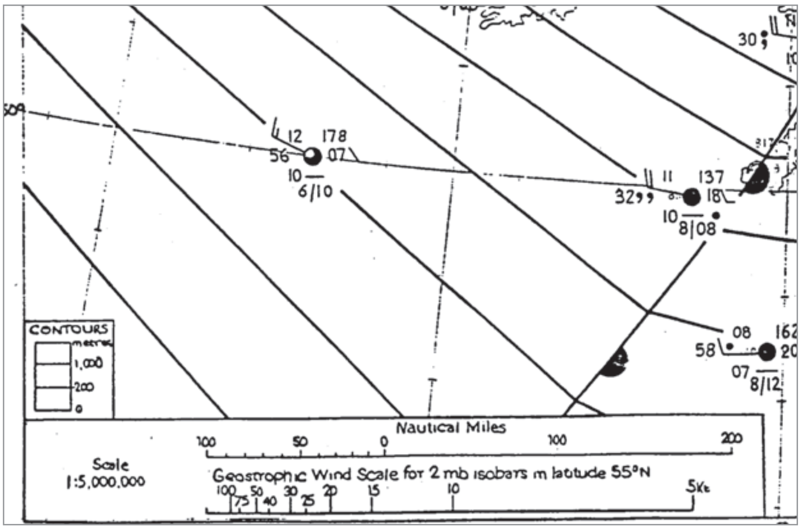


Figure 10.6 Geostrophic wind scale

Coriolis Force (CF)

- Coriolis Force, (CF), is the force caused by the rotation of the earth.

- It acts 90° to the wind direction causing air to turn to the right or veer in the **Northern Hemisphere** and to the **left or back** in the **Southern hemisphere.** CF is **maximum at the poles and minimum at the Equator.**

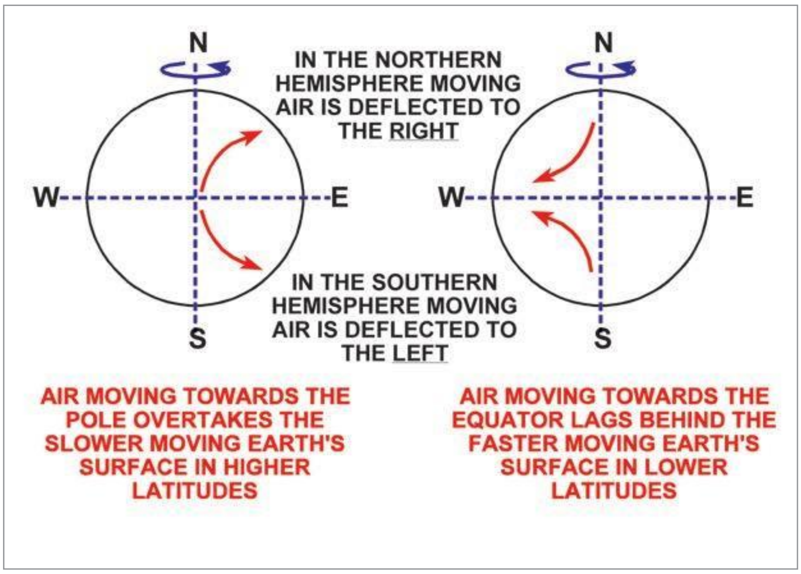


Figure 10.7 An illustration of the Coriolis force

- The Coriolis force is not a true force but is an explanation of the effect the rotation of the earth has on a free moving body not in contact with the earth. It is the combination of 4 factors:

  CF = $2 \Omega \rho V \sin \theta$, where:

  Ω = angular rotation of the earth
  ρ = density
  V = wind speed
  θ = latitude

- It should be noted that the CF is directly proportional to both wind speed and latitude. So an increase in either will result in an increase in the CF.

Geostrophic Wind

- The Geostrophic Wind blows parallel to straight isobars. Therefore the geostrophic wind can only blow in a straight line. If the wind were to follow a curved path, it cannot be considered as a geostrophic wind because there will be additional forces involved, namely the centrifugal or centripetal forces. The gradient wind (which will be discussed later) uses the pressure gradient force, the Coriolis force and the centrifugal force. This is the model for wind which follows a curved path.

- How can we know the direction of the geostrophic wind along the isobar? If you remember from earlier lessons, Buys Ballot's Law told us that in the Northern Hemisphere with your back to the wind, the low pressure is to your left. In the Southern Hemisphere with your back to the wind, the low pressure is on your right. Looking at the diagram below and by using Buys Ballot's Law, we can see a geostrophic wind direction of 180°.

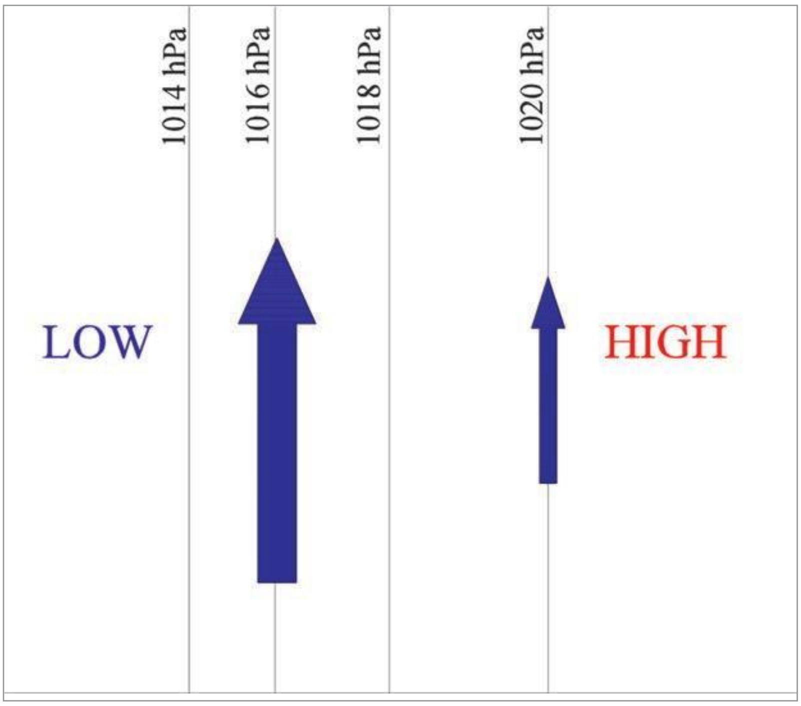


Figure 10.8 Geostrophic wind direction in the Northern Hemisphere

- How can we know the speed of the geostrophic wind? If you remember from earlier, there was a correlation between the isobar spacing, the pressure gradient force and the wind speed. The geostrophic wind scale allowed us to quantify this relationship. Measure the distance perpendicular between the isobars and use that distance on the geostrophic wind scale, reading from left to right.

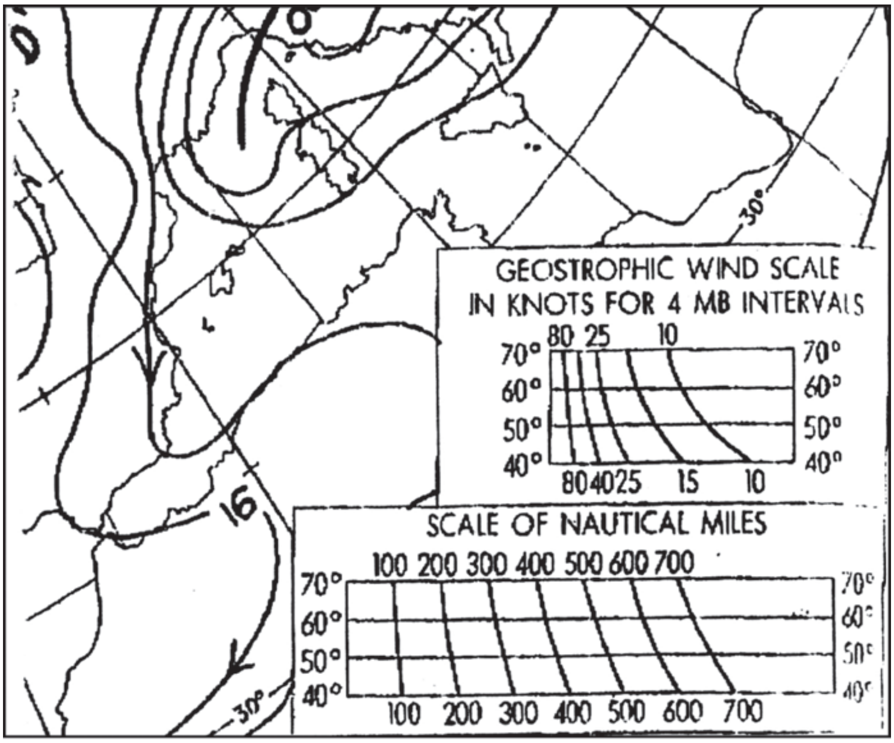


Figure 10.9 Latitude corrected geostrophic wind scale

- The geostrophic wind only blows above the friction layer. Within the friction layer the wind speed is reduced because of surface friction. Therefore the Coriolis force will reduce, causing the two forces to be out of balance. Remember that the friction layer varies depending upon the nature of the surface and the time of the day. Therefore, the height of the geostrophic wind will vary. Generally though it is considered to be between 2000 - 3000 ft.

- With the geostrophic wind the pressure gradient force is equal to the Coriolis force. So, for the same PGF (or isobar spacing) as latitude increases the Coriolis force will remain constant so for the same PGF as latitude increases, sine of latitude also increases and hence the wind speed will decrease. This can be deduced from the geostrophic wind scale on the chart above where a certain isobar spacing at 40°N gives a wind speed of 25 kt. The same isobar spacing at 70°N gives a speed of only 15 kt. (Note, for this type of question the key is “same PGF” or “same isobar spacing”).

$$V = \frac{\text{PGF}}{2\,\Omega\,\rho\,\sin\theta}$$

So the effect of latitude must be accounted for when using the geostrophic wind scale. The diagram below shows the geostrophic wind scale for latitude between 40° and 70°. Notice that the same spacing between the isobars at high latitude gives a slower wind speed when compared to lower latitude. Within 5 degrees of the Equator the CF is close to zero. Within 15 degrees the CF is very small, so that the geostrophic formula is no longer valid.

Construction of the Geostrophic Wind

Look at the diagram below for the Northern Hemisphere. Air is being accelerated towards the low pressure but in doing so, the strength of the Coriolis force is increasing. The wind is being deflected to the right until the two forces are acting opposite from each other and the wind now blows parallel to the isobar. With your back to the wind, the low pressure is on your left.

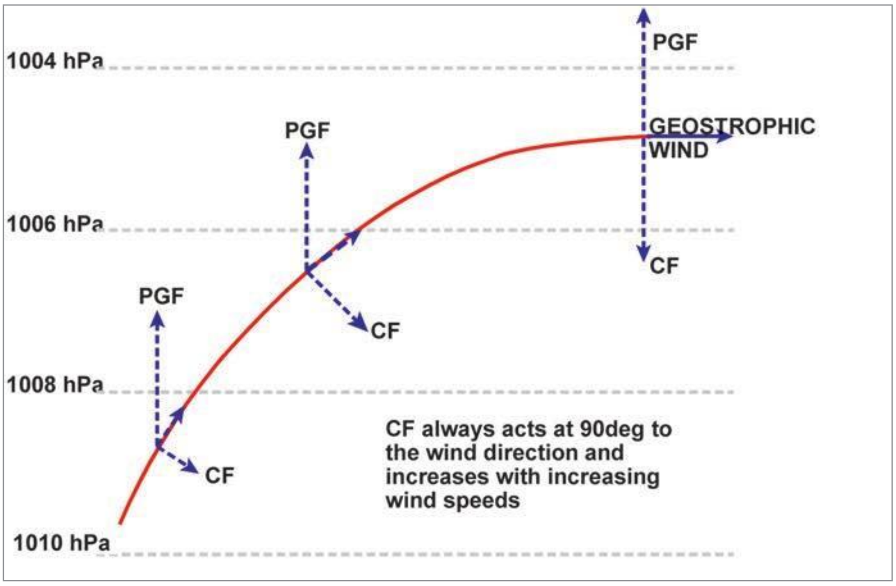


Figure 10.10 The geostrophic wind

Conditions Necessary for the Wind to Be Geostrophic

For the wind to be geostrophic, it has to occur:

- Above the friction layer.
- At a latitude greater than 15 degrees.
- When the pressure situation is not changing rapidly.
- With the isobars straight and parallel.

The geostrophic wind can apply at all heights above the friction layer. However, with an increase in height, the wind speed should increase due to the reduction in density assuming all other factors are unchanged.

The Gradient Wind

The gradient wind occurs when the **isobars are curved**. This brings into play a force which makes the wind follow a curved path parallel to the isobars. The gradient wind then is the wind which blows parallel to curved isobars due to a combination of 3 forces:

- PGF
- CF
- Centrifugal Force

Centrifugal Force

Centrifugal force is the force acting perpendicular to the direction of rotation and away from the centre of rotation.

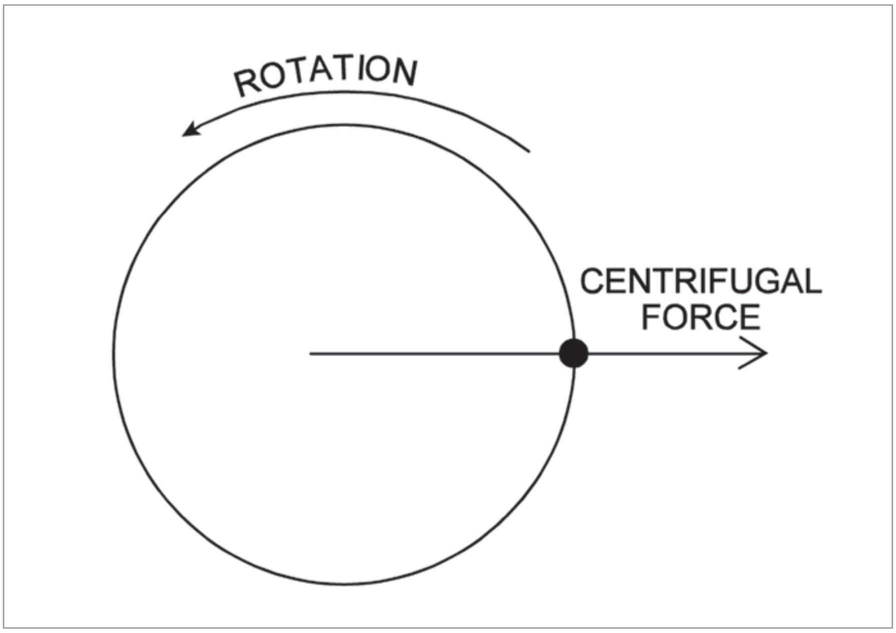


Figure 10.11

Gradient Wind in a Depression

If air is moving steadily around a depression, then the centrifugal force opposes the PGF and therefore reduces the wind speed.

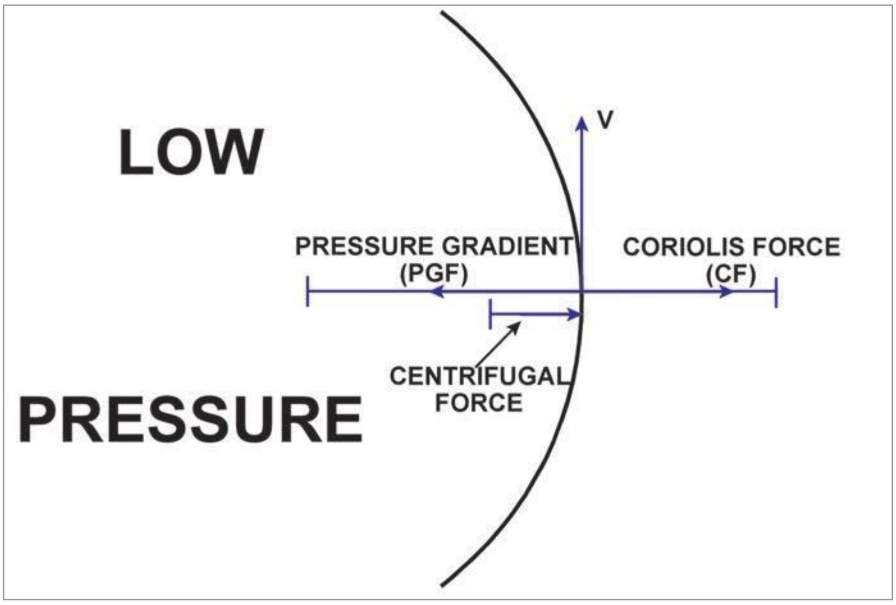


Figure 10.12 Gradient wind speed around a depression (Northern Hemisphere)

The gradient wind speed around a depression is less than the geostrophic wind for the same isobar interval. Hence if the Geostrophic Wind Scale (GWS) is used, it will **overread**.

Gradient Wind in a High

In an anticyclone the centrifugal force is acting in the same direction as the PGF so increases the magnitude of the PGF. Hence the wind speed will be greater than the equivalent geostrophic wind speed.

The gradient wind speed around an anticyclone is **greater** than the geostrophic wind for the same isobar interval. Hence if the Geostrophic Wind Scale (GWS) is used, it will **underread.**

As an example in a system where the radius of curvature of the isobars is 500 NM and the geostrophic wind speed is 40 kt, the speed in a cyclonic system will be 34 kt and in an anticyclonic system 58 kt.

It should be noted that when discussing the gradient wind we are making a comparison of the wind in a low pressure system to the equivalent geostrophic wind and, as a separate argument, comparing the wind in a high pressure system with the equivalent geostrophic wind.

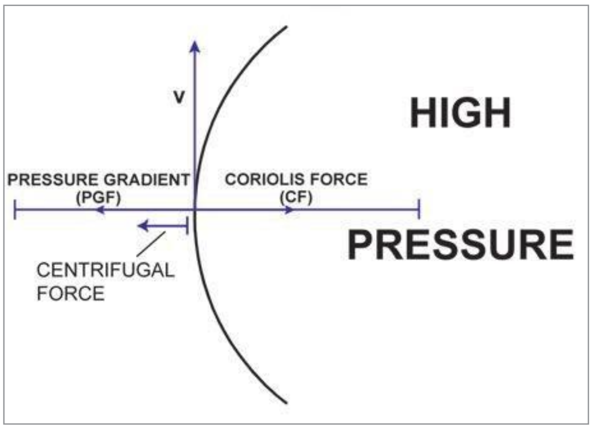


Figure 10.13 Gradient wind speed around a high (Northern Hemisphere)

We are not comparing the wind speed in a low pressure system with the wind speed in a high pressure system.

The Antitriptic Wind

The wind which blows in low latitudes where the CF is very small is called the antitriptic wind.

Winds below 2000 - 3000 ft (1 km).

Friction between moving air and the land surface will reduce wind speed near the ground. This reduction also reduces the CF. This will cause the two forces in the geostrophic wind to be out of balance since now CF is less than PGF. The wind is now called a surface wind.

Since surface friction has reduced the wind velocity, resulting in a reduction in the Coriolis force, the PGF is now more dominant. This causes the wind to blow across the isobars towards the low.

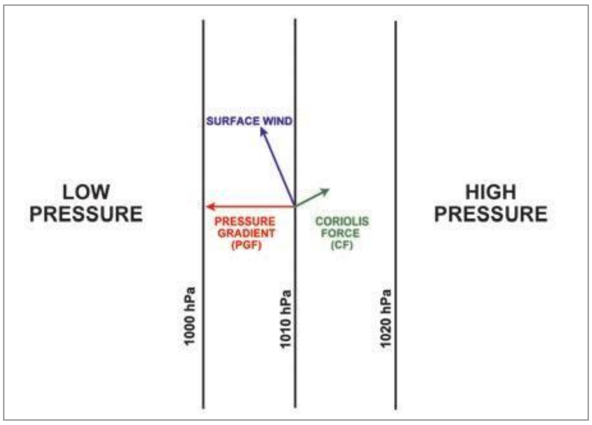


Figure 10.14 The surface winds in the Northern Hemisphere

Rough Rules

- On average in the Northern Hemisphere the surface wind over land is backed by 30 degrees from the geostrophic, or gradient wind direction and its speed is reduced by 50%. In the Southern Hemisphere, because of the opposite effect of the Coriolis force, the surface wind is veered from the 2000 ft wind, but the numerical values are the same.

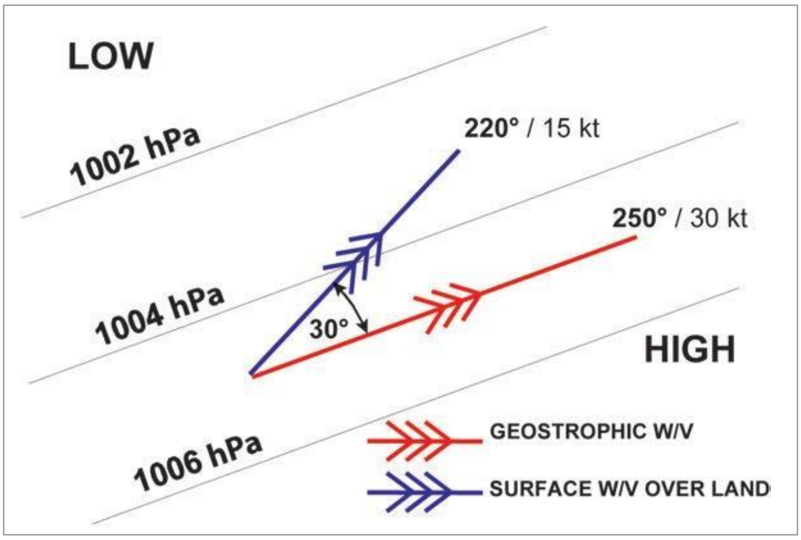


Figure 10.15 An example of rough rules over land in the Northern Hemisphere

- Over the sea friction is very much less and the surface winds are closer to geostrophic values. Surface wind over the sea, in the Northern Hemisphere, is backed by 10 degrees from the geostrophic or gradient wind direction and speed reduced to 70% (surface winds will veer in the Southern Hemisphere).

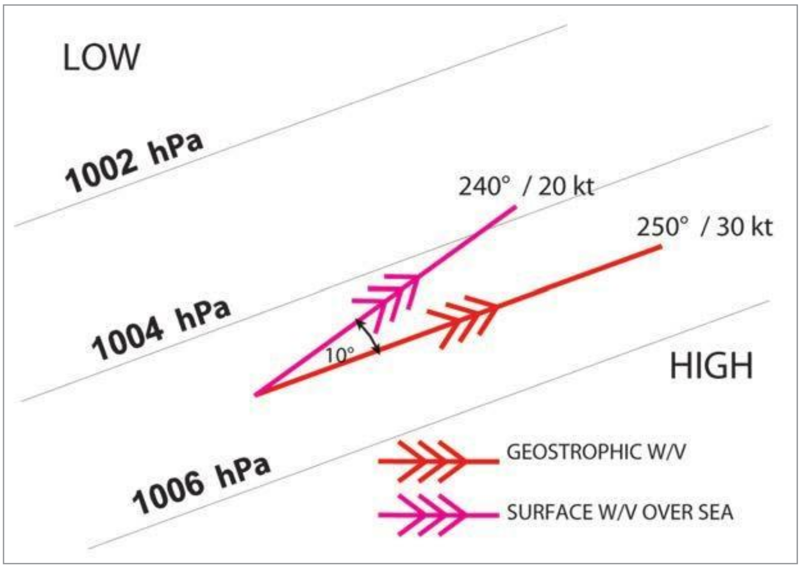


Figure 10.16 An example of rough rules over sea in the Northern Hemisphere

Diurnal Variation of the Surface Wind

There can be a regular change in the surface wind in each 24 hour period. It veers and increases by day reaching maximum strength about 1500 hrs. It backs and decreases thereafter with minimum strength around 30 minutes after sunrise.

This diurnal variation is due to thermal turbulence which mixes the air at the surface with air moving freely above. It is therefore most marked on clear sunny days, and particularly in unstable air masses, with sunny days and clear nights.

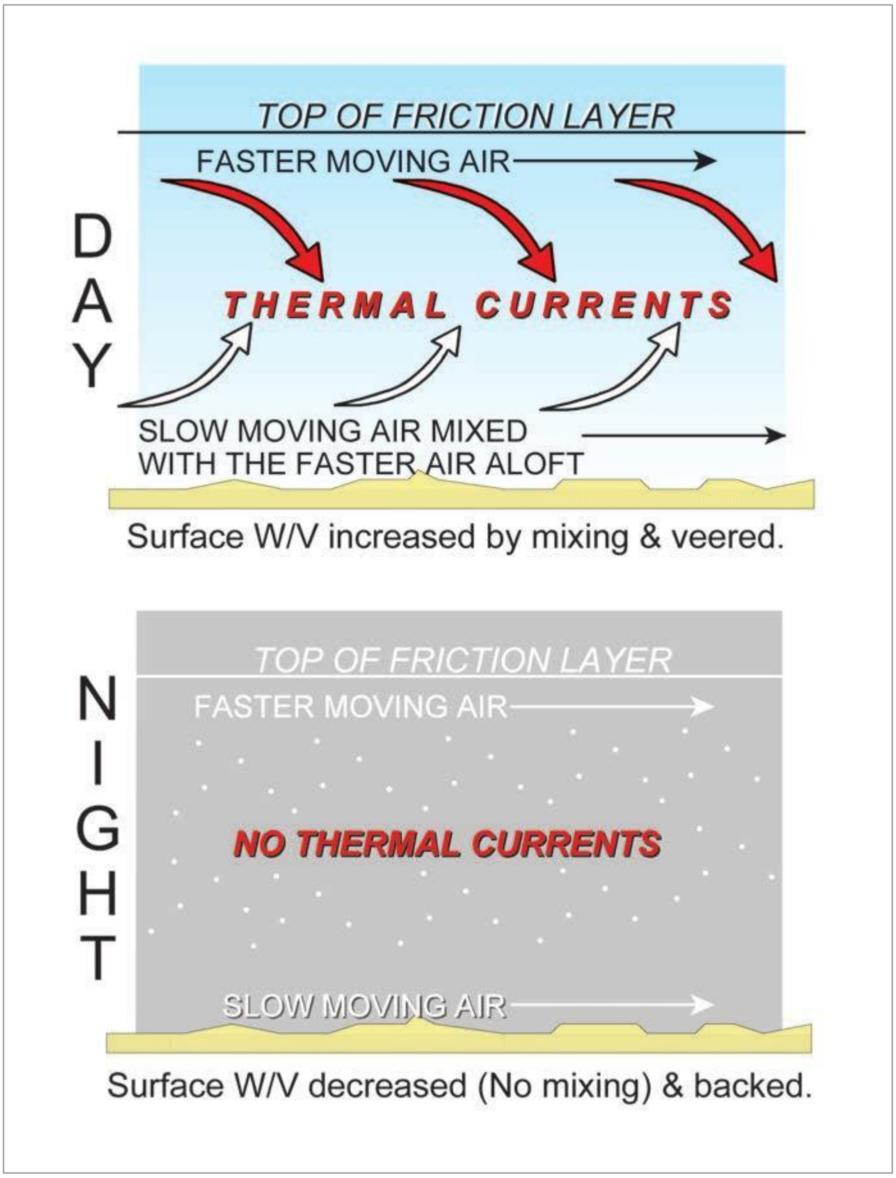


Figure 10.17 Diurnal variation of the surface wind

Diurnal Variation of 1500 ft and Surface Wind Velocity

- *Figure 10.17* and *Figure 10.18* show the effect of diurnal temperature variation on both the 1500 ft W/V and the surface W/V.

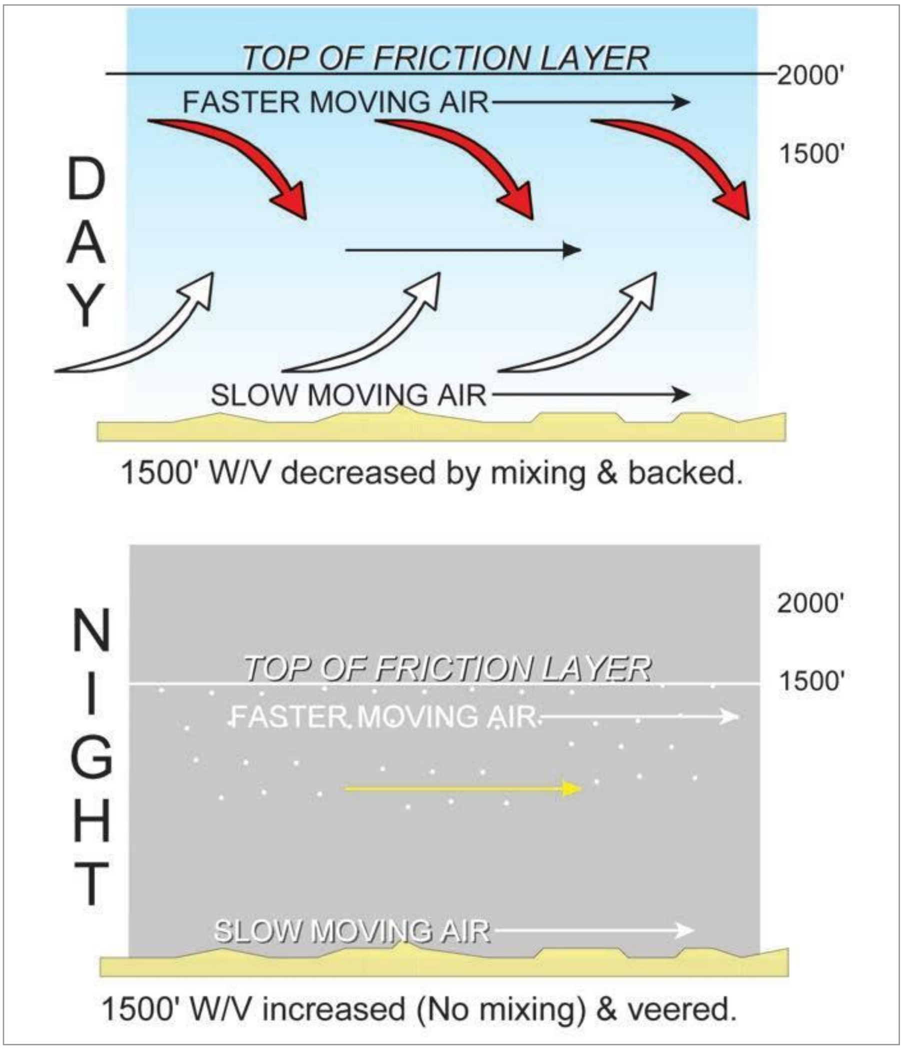


Figure 10.18 Diurnal variation of 1500 ft wind velocity

- **By Day.** Thermal currents are greater on sunny days and at 1500 hours. They will cause interaction between the surface and the top of the friction layer. The 2000 ft W/V will with descent be increasingly affected by the surface friction and will therefore steadily reduce in speed and turn towards the low pressure. (Back in Northern Hemisphere or veer in Southern Hemisphere).

- **By Night.** Thermal currents cease. The top of the friction layer effectively drops below **1500 ft where the W/V will assume 2000 ft direction and speed** thus becoming **faster and veering** (NH). The **surface W/V no longer has interaction with the stronger wind above** and will therefore **decrease and back** (NH). Thus a marked windshear can occur between 1500 ft and the surface, affecting handling for example on an approach.

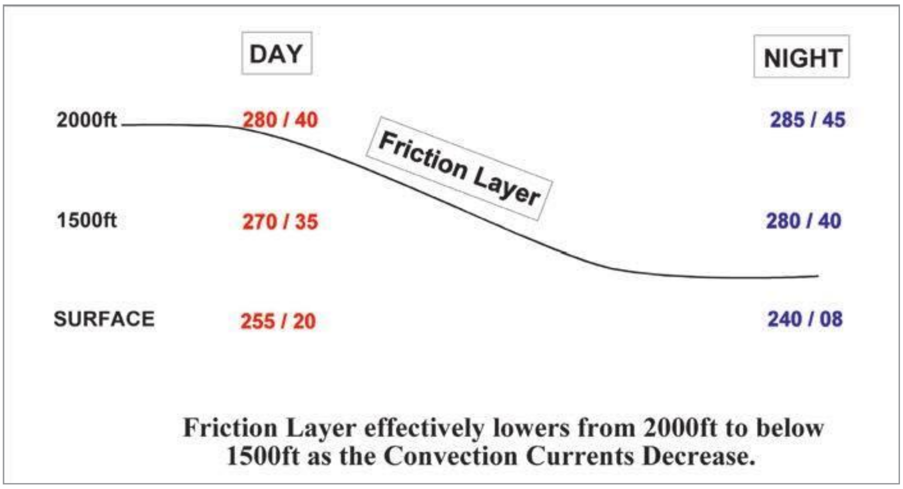


Figure 10.19 Diurnal variation of 1500' and surface wind velocities

- DV of surface wind aids the formation of **radiation** fog at night and early morning, and its dispersal by day.
- Diurnal **effect over the sea is small** because DV of sea temperature is small.

Summary

	DAY	NIGHT
1500 ft	DECREASES BACKS	INCREASES VEERS
SURFACE	INCREASES VEERS	DECREASES BACKS

Figure 10.20 Summary of diurnal variation and surface wind velocities in the Northern Hemisphere

Land and Sea Breezes

Sea breezes. On a sunny day, particularly in an anticyclone with a light PGF, the land will heat quickly.

The air in contact will be warmed and will rise and expand so that pressure at about 1000 ft will be higher than pressure at the same level over the sea. This will cause a drift of air from over the land to over the sea at about 1000 ft. The drift of air will cause the surface pressure over the land to fall, and the surface pressure over the sea to rise.

As a result there will be a flow of air from sea to land - **a sea breeze**.

On average, sea breezes extend 8 to 14 NM either side of the coast and the speed is about 10 kt. In the tropics speed is 15 kt or more and the inland extent is greater.

The direction of the sea breeze is more or less at right angles to the coast, but after some time it will veer under the influence of the Coriolis Force.

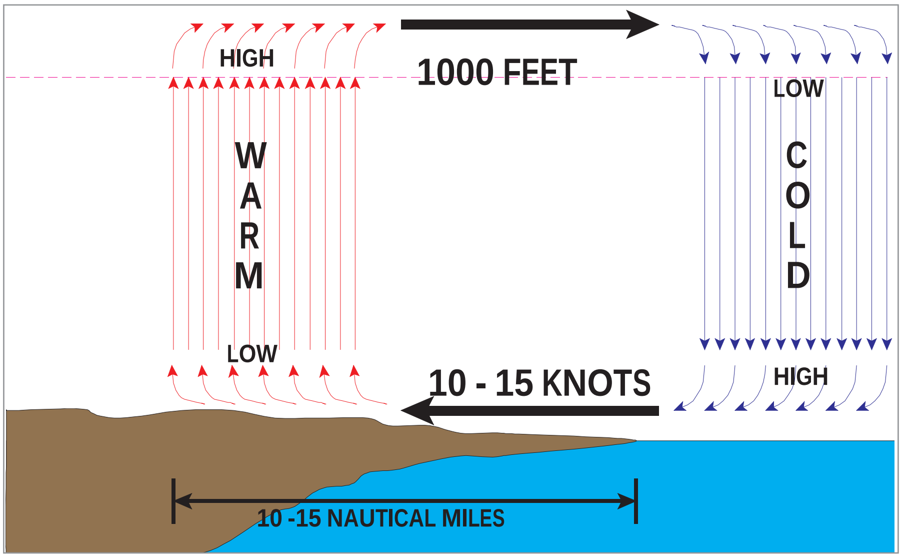


Figure 10.21 The sea breeze

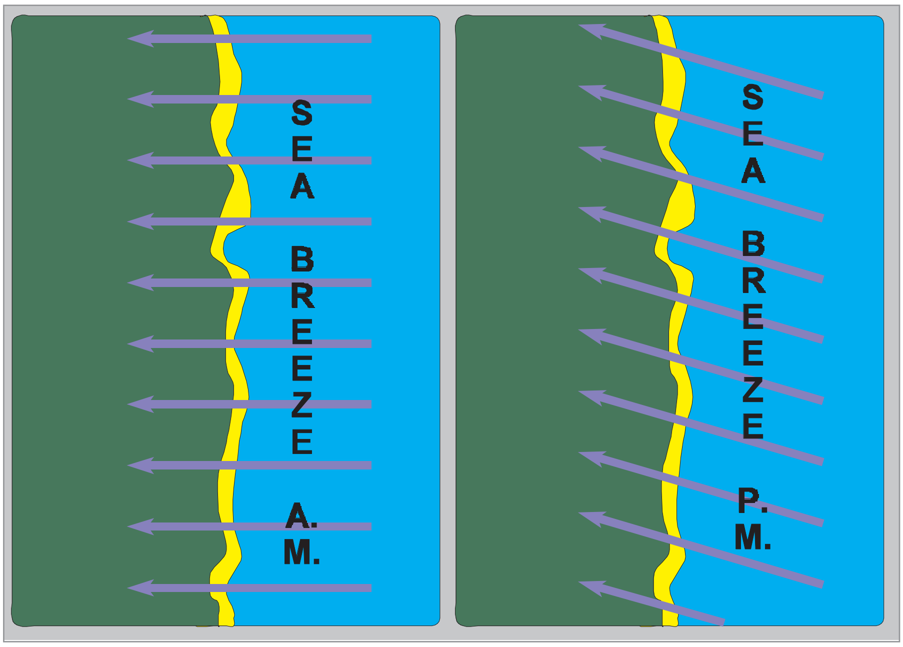


Figure 10.22 The influence of the Coriolis force on sea breezes over time (Northern Hemisphere)

Land breezes. From mid-afternoon the land is starting to cool and this process will accelerate after sunset. Overnight the situation will reverse and pressure will now be higher on land than over the sea as the temperature reduces. This will give rise to a wind now blowing from land to sea, the land breeze. The land breeze can be expected within about 5 NM of the coastline and with a maximum speed of about 5 kt.

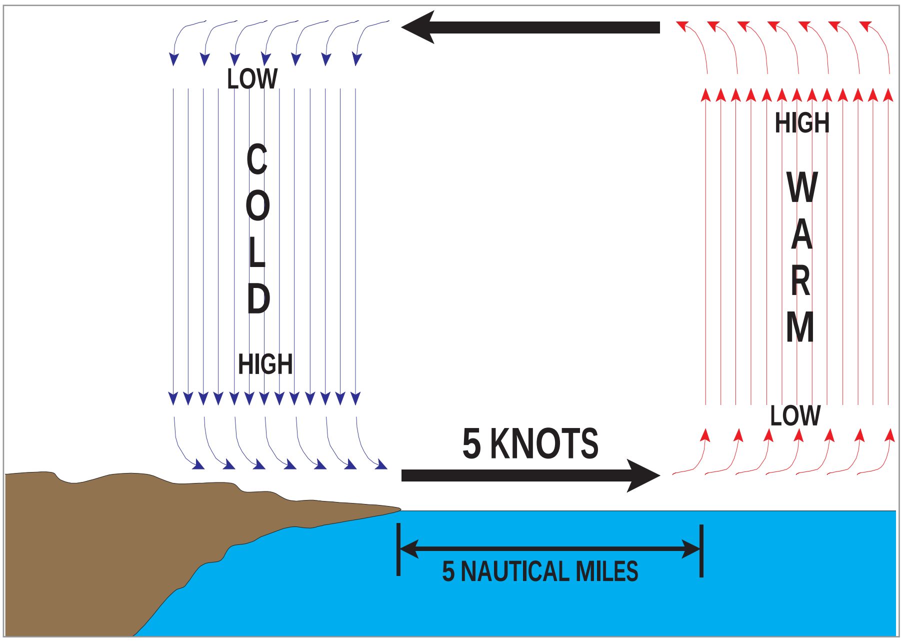


Figure 10.23 The land breeze

Practical Coastal Effects

- The direction of take-off and landing can be reversed with the change from sea to land breeze. This is shown in *Figure 10.24.*

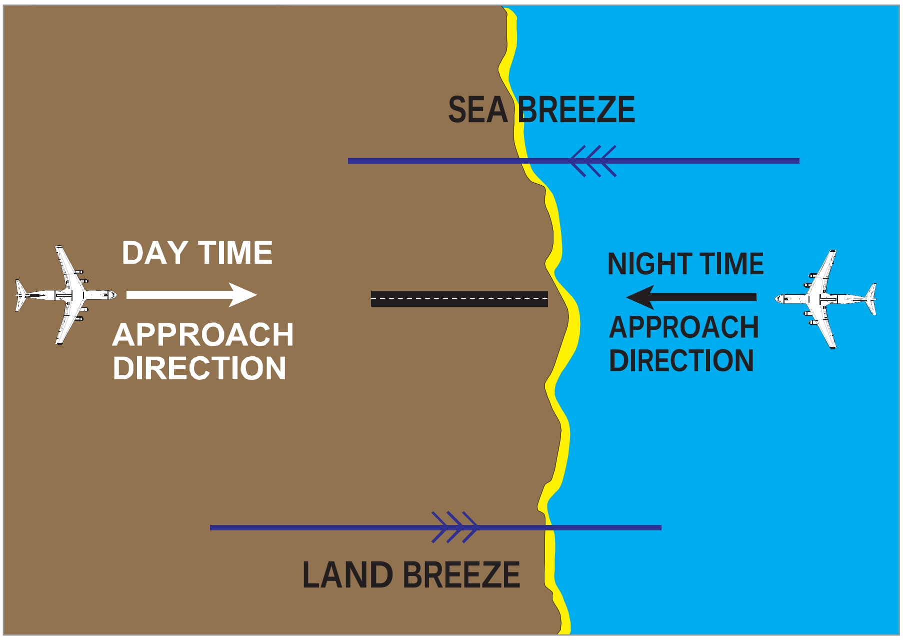


Figure 10.24 Reversal of direction of take-off and landing

- Fog at sea can be blown inland by day to affect coastal airfields. This is illustrated in *Figure 10.25.*

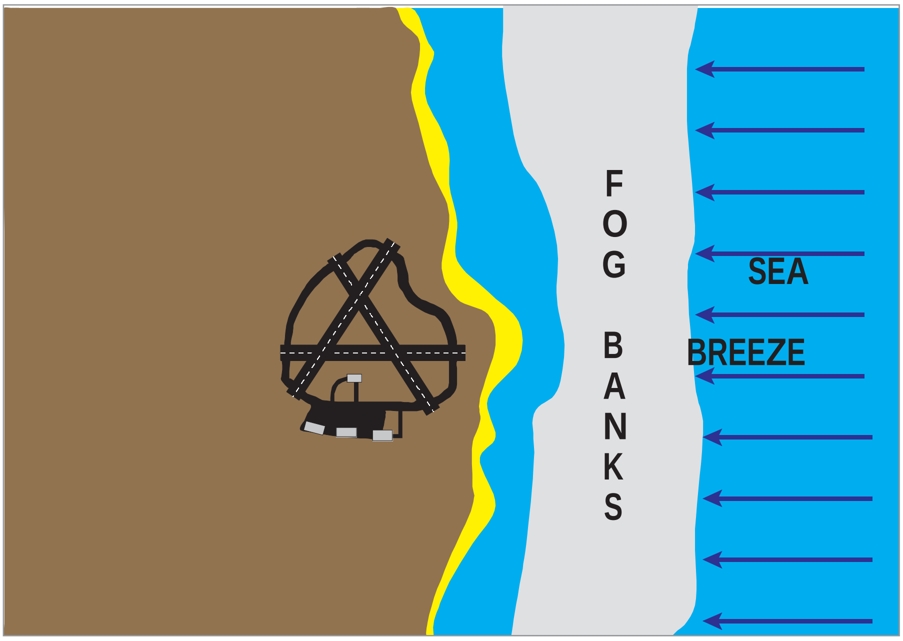


Figure 10.25 Fog being blown inland by the sea breeze

- The lifting of air over land with the sea breeze can cause small clouds to form as shown in *Figure 10.26.* These are a good navigational feature of coastline.

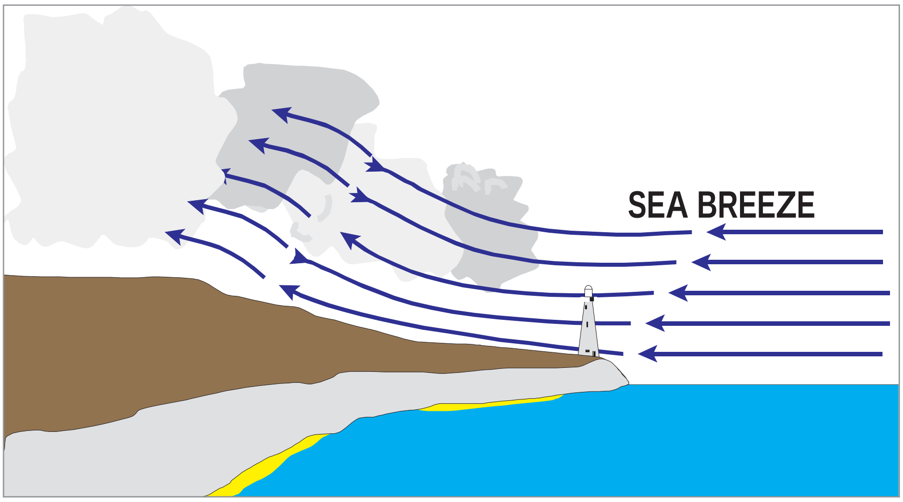


Figure 10.26 Cloud formation over a coastline

Valley or Ravine Winds

A wind blowing against a mountain is impeded. If the barrier is broken by a gap or valley, the wind will blow along the valley at an increased speed due to the restriction. This is illustrated in *Figure 10.27*.

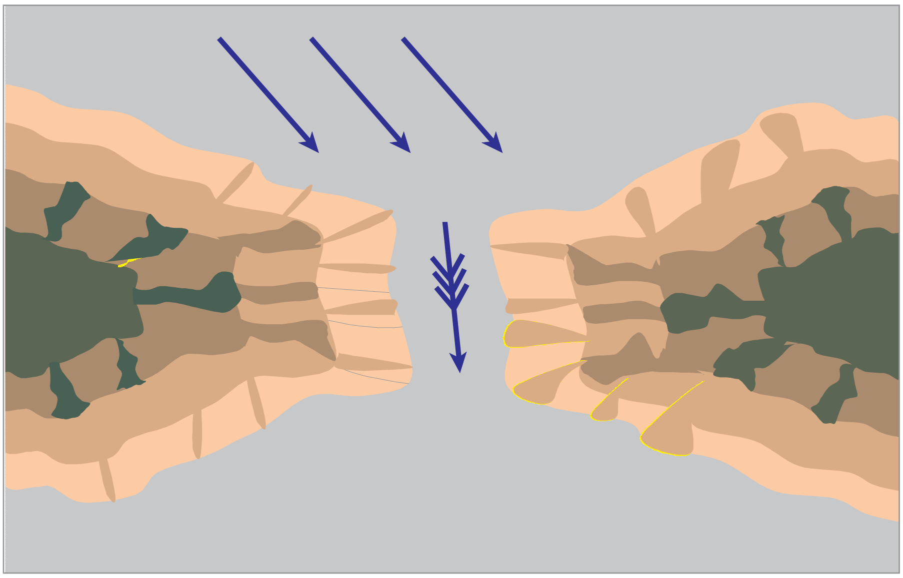


Figure 10.27 A valley or ravine wind

With a valley wind, if there is a relatively small change in the general direction, it is possible for the valley wind to reverse completely as shown in *Figure 10.28*. The combination of high wind speed and rough terrain is likely to give rise to considerable turbulence at low level, landing at airfields in such areas may be difficult.

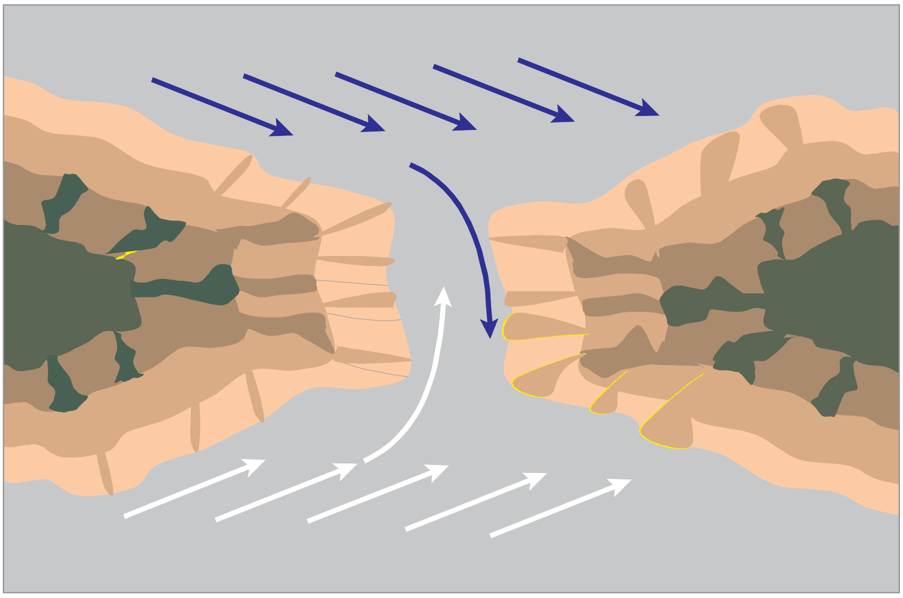


Figure 10.28 Wind direction reversal in a valley or ravine

Examples of valley winds are the **Mistral** (Rhone Valley), (see Chapter 21) **Genovese** (Po Valley), **Kosava** (Danube) and **Vardarac** (Thessalonika). Valley winds also occur in fjords.

Venturi Effect

The increase in speed as the wind flows through a valley will cause the Venturi Effect with the consequent reduction in pressure which will result in the true altitude being less than the indicated altitude. The same effect may be experienced above a mountain range as the wind blows over the range, particularly in stable conditions.

Katabatic Winds

A katabatic wind is caused by a flow of cold air down a hill or mountain side at night.

If the side of the mountain is cooled by radiation, the air in contact is also cooled, it will thus be denser and heavier than the surrounding air and it will therefore flow down the mountain side.

The katabatic effect is most marked if the mountain side is snow covered, if the sky is clear to assist radiation and if the PG is slack. Speeds average 10 kt and the flow of cold air into the valley helps **frost** and **fog** to form. Another effect is that with the sinking of cold air down the slope, the air at higher levels will be warmer and an inversion results. The katabatic effect can also occur by day when relatively warm air comes into contact with snow covered slopes. A katabatic wind is shown in *Figure 10.29.*

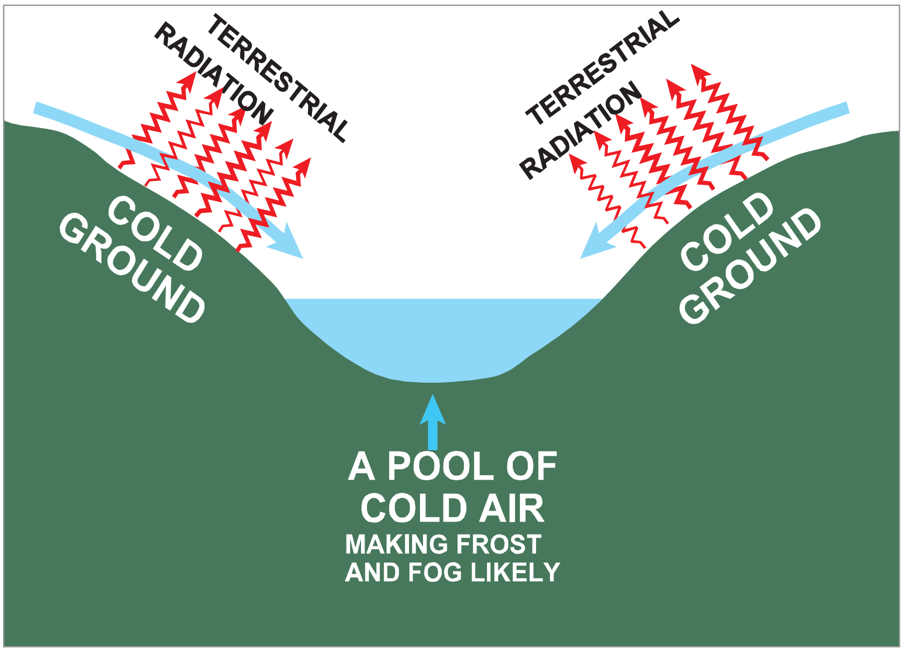


Figure 10.29 Katabatic wind formation

An example of a katabatic wind is the **Bora** in the Northern Adriatic (see Chapter 21).

Anabatic Winds

On a warm sunny day, the slope of a hill will become heated by insolation, particularly if it is a south facing slope.

The air in contact with the ground will be heated by conduction and will rise up the hill. Free cold air will replace the lifted air and so a light wind will blow **up** the hillside. An anabatic wind is a light wind of around 5 kt which blows up a hill or mountain by **day** as illustrated in *Figure 10.30*.

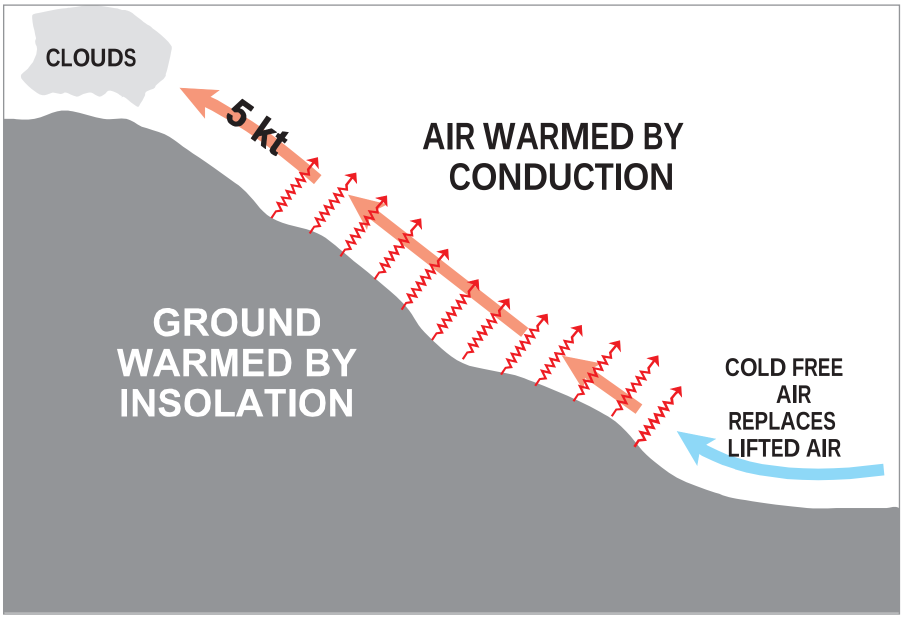


Figure 10.30 Anabatic wind formation

Föhn Winds

The **Föhn Wind** is a warm dry wind which blows on the downwind side of a mountain range. It is a local wind in the Alps. A similar wind on the east of the **Rocky Mountains** in Canada is called the **Chinook** (see Chapter 21). There is also the **Zonda** to the east of the Andes in South America.

When moist air is forced to rise up a mountain in stable conditions it will cool adiabatically at the DALR until saturated when it will continue cooling at the SALR. Precipitation will occur removing water from the air so the dew point will decrease.

When the air descends on the leeward (downwind) side the cloud base will be higher so the air will warm at the DALR over a greater height than it cooled at the SALR on the windward side. Consequently the temperature at the base of the mountain will be greater on the downwind side than it was on the upwind side.

So, on the windward side we can expect low cloud and precipitation whilst on the leeward side we will see clear turbulent conditions.

The result is a warm, dry wind blowing on the downside of the mountain. Temperature increases in excess of 10°C may occur. The presence of a Föhn wind could also indicate the presence of mountain waves.

Föhn winds can occur over the east and west coasts of Scotland when moist winds come over the highlands off the Atlantic Ocean or North Sea.

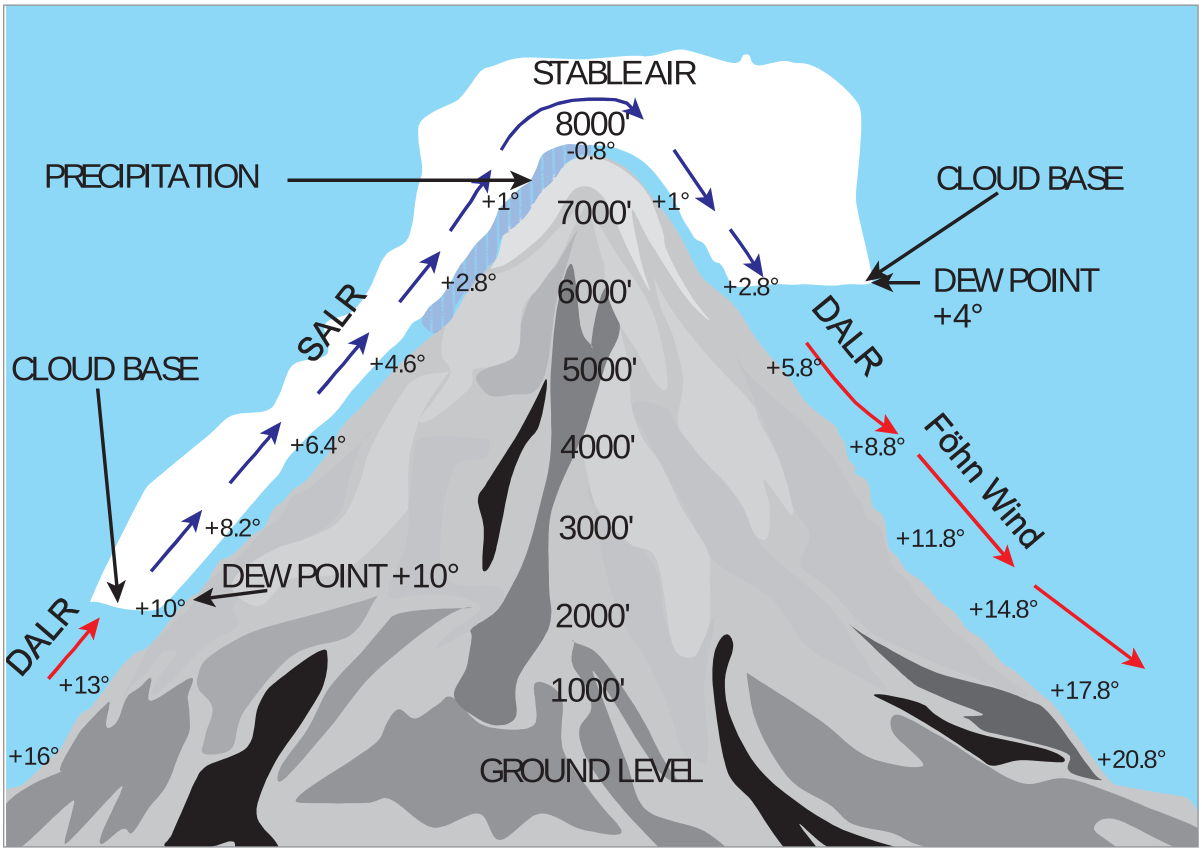


Figure 10.31 The Föhn effect

Questions

1. In central Europe, where are the greatest wind speeds?

a. Tropopause level
b. 5500 m
c. Where the air converges
d. Above the Alps

2. Standing in the Northern Hemisphere, north of a polar frontal depression travelling west to east, the wind will:

a. continually veer
b. continually back
c. back then veer
d. veer then back

3. ATC will only report wind as gusting if:

a. gust speeds exceeds mean speed by >15 kt
b. gusts to over 25 kt
c. gusts exceeds mean speed by 10 kt
d. gusts to over 25 kt

4. What is a land breeze?

a. From land over water at night
b. From land over sea by day
c. From sea over land by night
d. From sea over land by day

5. When heading south in the Southern Hemisphere you experience starboard drift:

a. you are flying towards a lower temperature
b. you are flying away from a lower temperature
c. you are flying towards a low pressure
d. you are flying out of a high

6. What are the factors affecting the geostrophic wind?

a. PGF, ρ, θ, Ω
b. ρ, θ, Ω
c. ρ, θ, PGF
d. ρ, PGF, Ω

7. What is the Bora?

a. Cold katabatic wind over the Adriatic
b. Northerly wind blowing from the Mediterranean
c. Warm anabatic wind blowing to the Mediterranean
d. An anabatic wind in the Rockies

8. **Flying away from an area of low pressure in the Southern Hemisphere at low altitudes, where is the wind coming from?**

   a. Right and slightly on the nose
   b. Left and slightly on the tail
   c. Left and slightly on the nose
   d. Right and slightly on the tail

9. **What causes the geostrophic wind to be stronger than the gradient wind around a low?**

   a. Centrifugal force adds to the gradient force
   b. Centrifugal force opposes the gradient force
   c. Coriolis force adds to the gradient force
   d. Coriolis force opposes the centrifugal force

10. **A METAR for Paris gave the surface wind at 260/20. Wind at 2000 ft is most likely to be:**

   a. 260/15
   b. 210/30
   c. 290/40
   d. 175/15

11. **A large pressure gradient is shown by:**

   a. closely spaced isobars - low temperature
   b. distant spaced isobars - high temperature
   c. close spaced isobars - strong winds
   d. close spaced isobars - light winds

12. **Where would you expect to find the strongest wind on the ground in temperate latitudes?**

   a. In an area of Low pressure
   b. In an area of High pressure
   c. In the warm air between two fronts
   d. In a weak anticyclone

13. **At a coastal airfield, with the runway parallel to the coastline, you are downwind over the sea with the runway to your right. On a warm summer afternoon, what would you expect the wind to be on finals?**

   a. Crosswind from the right
   b. Headwind
   c. Tailwind
   d. Crosswind from the left

14. **What causes wind at low levels?**

   a. Difference in pressure
   b. Rotation of the earth
   c. Frontal systems
   d. Difference in temperature

15. **If flying in the Alps with a Föhn effect from the south:**

a. clouds will be covering the southern passes of the Alps
b. CAT on the northern side
c. wind veering and gusting on the northern side
d. convective weather on the southern passes of the Alps

16. **Comparing the surface wind to the 3000 ft wind:**

a. surface wind veers and is less then the 3000 ft wind
b. surface wind blows along the isobars and is less than the 3000 ft wind
c. surface wind blows across the isobars and is less than the 3000 ft wind
d. both are the same

17. **90 km/h wind in kt is approximately:**

a. 70
b. 60
c. 50
d. 30

18. **The geostrophic wind blows at your flight level in Northern Hemisphere and the true altitude and indicated altitude remain constant. The crosswind is:**

a. from the left
b. from the right
c. no crosswind
d. impossible to determine

19. **With all other things being equal with a high and a low having constantly spaced circular isobars, where is the wind the fastest?**

a. Anticyclonic
b. Cyclonic
c. Where the isobars are closest together
d. Wherever the PGF is greatest

20. **Föhn winds are:**

a. warm katabatic
b. cold katabatic
c. warm descending winds
d. warm anabatic

21. **What is the effect of a mountain valley wind?**

a. It blows down a mountain to a valley at night
b. It blows down a mountain to a valley during the day
c. It blows from a valley up a mountain by day
d. It blows from a valley up a mountain at night

22. **What is the difference between gradient and geostrophic winds?**

a. Difference in temperatures
b. A lot of friction
c. Curved isobars and straight isobars
d. Different latitudes and densities

23. **What prevents air from flowing directly from a high to a low pressure?**

a. Centripetal force
b. Centrifugal force
c. Pressure force
d. Coriolis force

24. **What is the relationship between the 5000 ft wind and the surface wind in the Southern Hemisphere?**

a. Surface winds are veered from the 5000 ft and have the same speed
b. Surface winds are backed from the 5000 ft and have a slower speed
c. Surface winds are veered from the 5000 ft and have a slower speed
d. Surface winds are backed from the 5000 ft and have a faster speed

25. **What is the relationship between the 2000 ft wind and the surface wind in the Northern Hemisphere?**

a. surface winds blow across isobars towards a high
b. surface winds blow parallel to isobars
c. surface winds blow across isobars towards a low
d. surface winds have laminar flow

26. **Wind is caused by:**

a. mixing of fronts
b. horizontal pressure difference
c. earth rotation
d. surface friction

27. **For the same pressure gradient at 50N, 60N and 40N, the geostrophic wind speed is:**

a. greatest at 60N
b. least at 50N
c. greatest at 40N
d. the same at all latitudes

28. **The wind in the Northern Hemisphere at the surface and above the friction layer at 2000 ft would be:**

a. veered at the surface, veered above the friction layer
b. backed at the surface, veered above the friction layer
c. veered at the surface, backed above the friction layer
d. backed at the surface, backed above the friction layer

29. **Where are easterly and westerly jets found?**

a. Northern Hemisphere only
b. Southern Hemisphere only
c. Northern and southern Hemisphere
d. There are no easterly jets

30. **In high pressure systems:**

a. the winds tend to be stronger in the morning
b. the angle between the isobars and the wind direction is greatest in the afternoon
c. the winds tend to be stronger at night
d. the winds tend to be stronger in early afternoon

31. **An aircraft is flying East to West in the Northern Hemisphere. What is happening to its altitude?**

a. Flying into a headwind will decrease altitude
b. If the wind is from the south, it will gain altitude
c. If the wind is from the north, it will gain altitude
d. Tailwind will increase altitude

32. **Where would an anemometer be placed?**

a. Close to station, 2 m above ground
b. On the roof of the station
c. 10 m above aerodrome elevation on a mast
d. Next to the runway, 1 m above ground

33. **Which of the following is an example of a Föhn wind?**

a. Bora
b. Harmattan
c. Chinook
d. Ghibli

34. **Wind at altitude is usually given as .... in ....**

a. true, m/s
b. magnetic, m/s
c. true, kt
d. magnetic, kt

35. **If you fly with left drift in the Northern Hemisphere, what is happening to surface pressure?**

a. Increases
b. Decreases
c. Stays the same
d. Cannot tell

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	b	c	a	b	a	a	c	b	c	c	a

13	14	15	16	17	18	19	20	21	22	23	24
a	a	a	c	c	c	a	c	a	c	d	c

25	26	27	28	29	30	31	32	33	34	35
c	b	c	b	a	d	c	c	c	c	a

Chapter

11

Upper Winds

Introduction

Upper winds are caused by Pressure Gradient Force (PGF), Coriolis Force (CF) and Centrifugal Force in the same way as the wind immediately above the friction layer.

The winds tend to be stronger because the density is less -

$$V = \frac{\text{PGF}}{2\,\Omega\,\rho\,\sin\theta}$$

At 20 000 ft, for the same PGF, the wind speed is double the surface wind speed, since density is half that at the surface.

When flying at higher altitudes the altimeter is set to the standard pressure setting (1013 hPa) so if we are at an indicated altitude of, say, 18 000 ft we are actually flying at the 500 hPa pressure level. Therefore the pressure at 18 000 ft (or any other altitude) is of little interest to us, but the true altitude of the pressure levels becomes important.

Contour Charts - Constant Pressure Charts

A Constant Pressure or Contour Chart is a chart where the pressure is constant everywhere. For example, as shown in *Figure 11.1* we can see that the 1000 hPa pressure level varies with height. These heights are plotted as **contour lines** (also known as isohypses) with the reference being MSL. The heights give us an indication of the distance that a pressure level is from MSL. If the contours are high values (in comparison to other values on the chart) then we can assume a high pressure exists. Conversely if the contours are lower values then we can assume a low pressure.

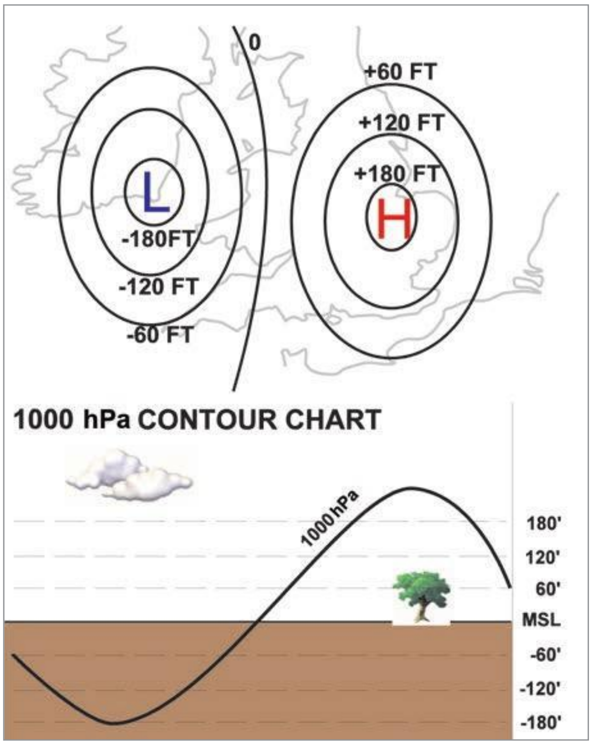


Figure 11.1

These charts provide valuable information to us about how the pressure is changing over a distance. If the contours are closely spaced we can assume a high pressure gradient exists. If we can identify where the low pressure is we can then discover what the strength and direction of the resulting wind will be. Again we can use Buys Ballot's Law so that with our back to the wind in the Northern Hemisphere the lower value contour is on the left, which is effectively a lower pressure. The upper winds will blow parallel to the contour lines (just like surface winds and isobars).

This wind speed is proportional to the distance between the contour lines. The wind that we find from this are for the height of the constant pressure chart, e.g. 500 hPa chart is about 18 000 ft in ISA.

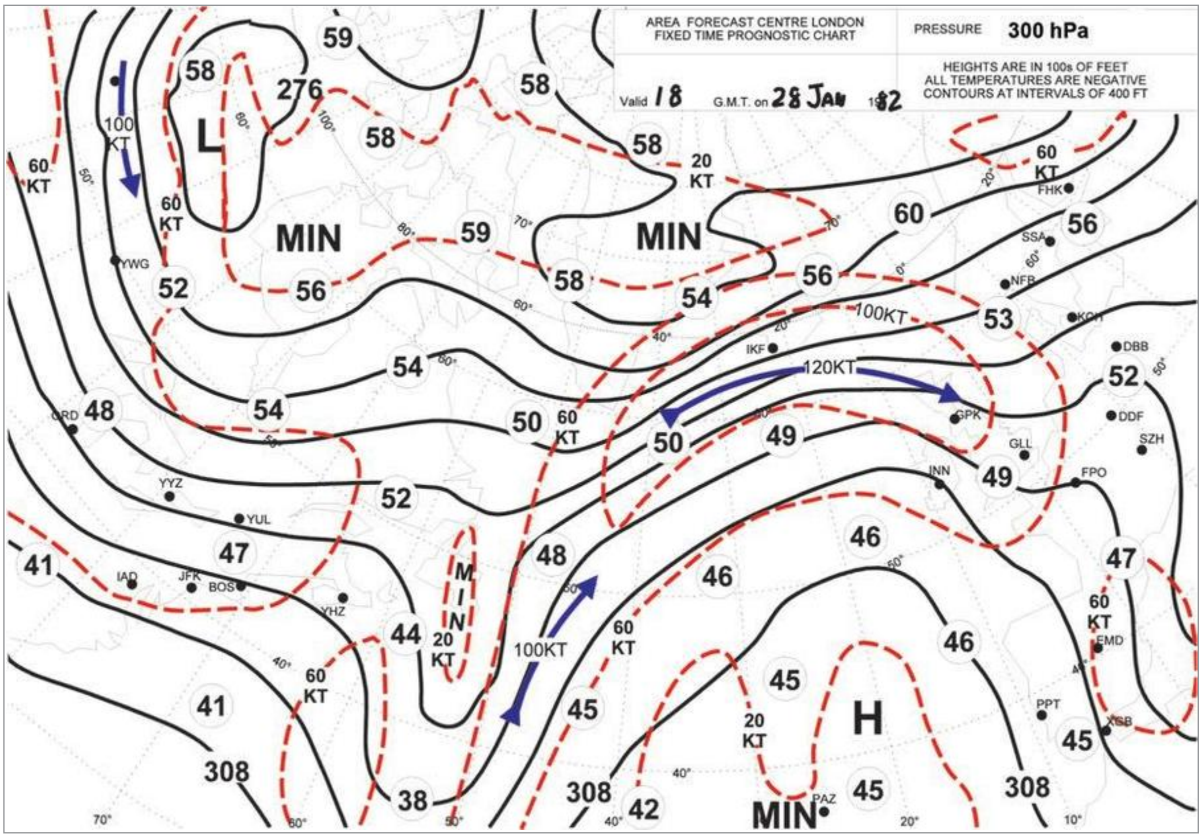


Figure 11.2 300 hPa contour chart

The heights shown on contour charts are heights AMSL.

Charts are provided for:

850 hPa - FL050
700 hPa - FL100
500 hPa - FL180
400 hPa - FL240
300 hPa - FL300
250 hPa - FL340
200 hPa - FL390
150 hPa - FL450
100 hPa - FL530
50 hPa - FL610

but are produced as spot wind and temperature charts (see Chapter 27).

Isotachs

Isotachs are lines joining places of equal wind speed (shown as red dashed lines on *Figure 11.2*).

Thermal Wind

The pressure changes that exist in the upper atmosphere that control our upper winds are directly related to the temperature differences between air masses. *Figure 11.3* shows that the temperature difference between two air masses dictates the pressure we find in the upper atmosphere. Because the pressure differences that produce the upper winds are created by surface temperature differences, the upper winds are referred to as thermal winds.

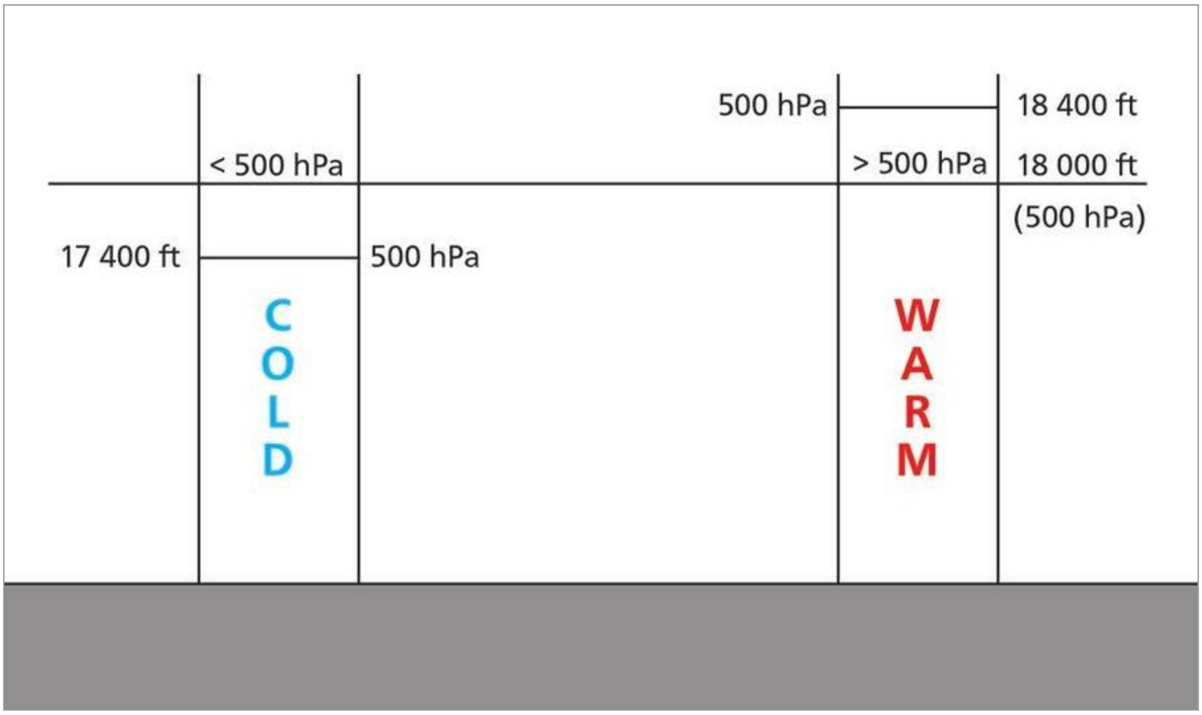


Figure 11.3 Pressure changes at height in air masses of different temperature

Buys Ballot's Law Revisited

In *Figure 11.3*, assuming we are in the Northern Hemisphere, then, from Buys Ballot's law, the wind will be blowing into the diagram. Hence we can now modify Buys Ballot's law: If we stand with our back to the wind in the Northern Hemisphere then low pressure, low temperature or low altitude are on the left. (And on the right in Southern Hemisphere).

We can deduce from this that upper winds will, generally be westerly in both hemispheres. The exceptions to this, and the reasons, will be discussed in jet streams and global climatology.

We can now extend Buys Ballot's Law to cover upper winds. We have seen that low surface temperatures lead to comparatively low pressure at altitude compared to high surface temperatures and this, therefore, gives low altitude for a specified pressure level over cold air and higher altitudes over warm air.

Jet Streams

As we go higher in the troposphere, the density decreases and the temperature effect overwhelms the surface pressure effect, hence winds veer or back to blow perpendicular to the surface temperature gradient as altitude increases which means that upper winds will generally be westerly in both hemispheres. The strongest winds are to be found just below the tropopause and where these winds exceed 60 kt they are termed jet streams. For examination purposes we assume a jet stream to be about 2000 miles long, 200 miles wide and 2 miles deep. This gives a width to length ratio of 1:10, a depth to width ratio of 1:100 and a depth to length ratio of 1:1000. Speeds of in excess 300 kt have been recorded though these are rare.

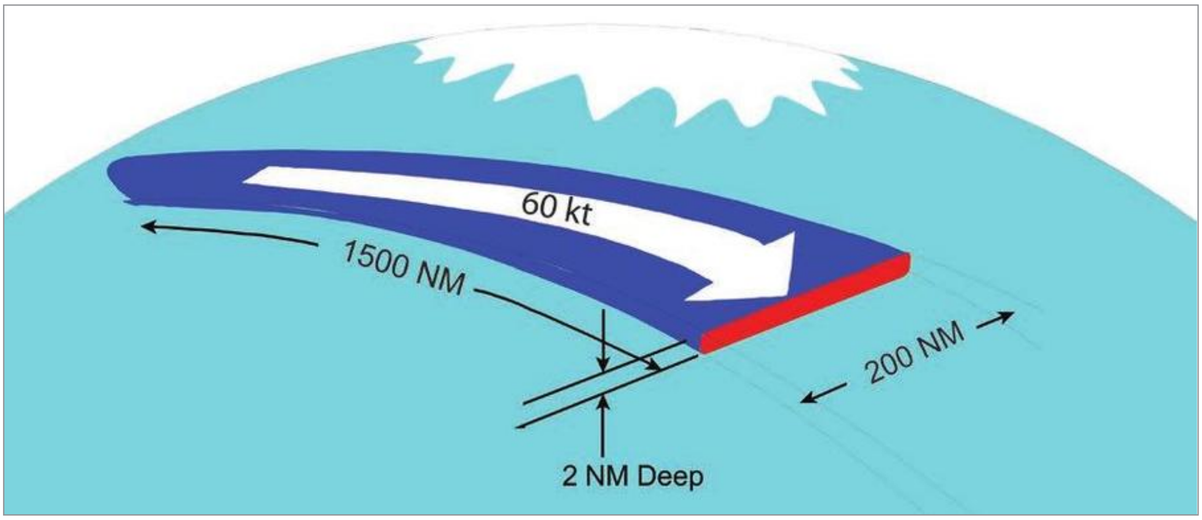


Figure 11.4 Typical jet stream dimensions

Causes

Jet streams are caused by large surface temperature differences, i.e. large thermal components.

Locations

There are two main locations:

- **Subtropical jet streams** form in the area of the subtropical anticyclones. They are more or less permanent but move seasonally with the subtropical highs. In the Northern Hemisphere they occur in the latitude bands 25° to 40° in winter and 40° to 45° in summer, in the Southern Hemisphere they occur between about 25° and 30°. The jet core is at the 200 hPa level.

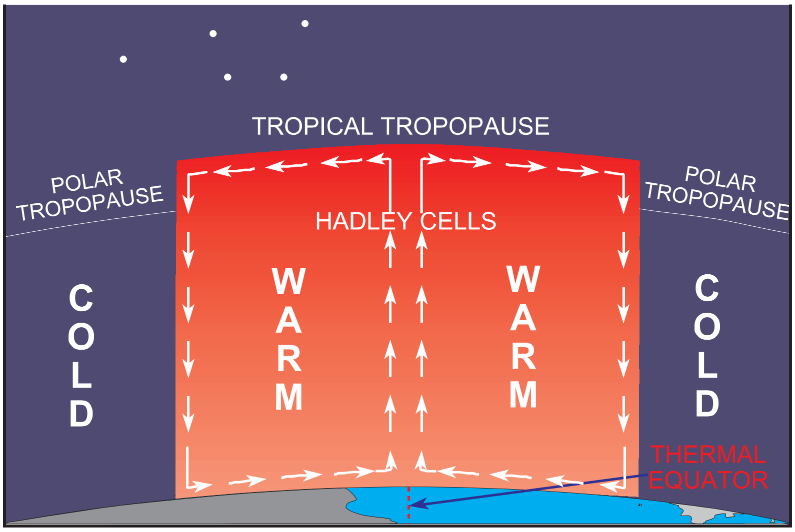


Figure 11.5 Subtropical jet streams

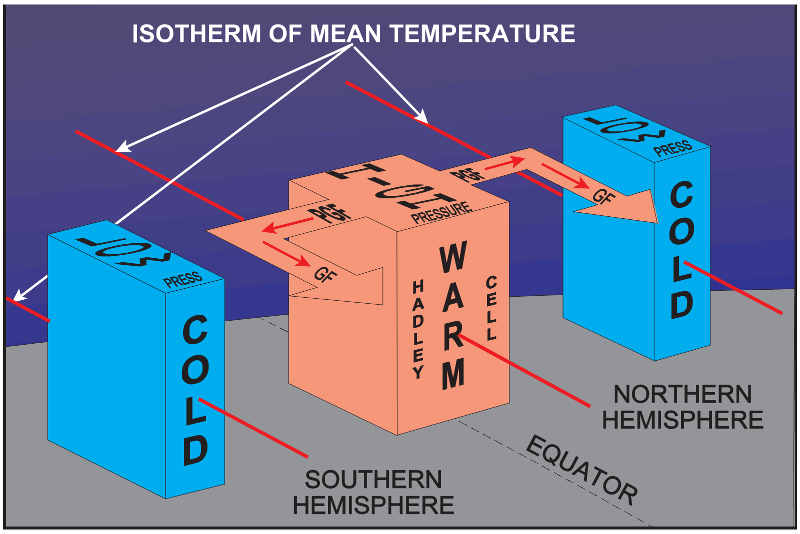


Figure 11.6 Subtropical jet streams

- **Polar front jetstreams** are associated with the polar front depressions and usually lie parallel to the surface position of the warm and cold fronts. They are found between about 40°N and 65°N in the Northern Hemisphere and around 50°S to 55°S in the Southern Hemisphere.

- **Polar Night Jets** occur in higher middle latitudes in mid-winter near the top of the stratosphere (50 hPa level). Direction is **westerly** and speeds average **150 kt.** Speeds of 350 kt have been noted.

- **Tropical Easterly Jet (Equatorial Easterly Jet).** Strong easterlies that occur in the Northern Hemisphere's summer between 10° and 20° North, where the contrast between intensely heated central Asian plateau and the sea further south is greatest. It runs from South China Sea westwards across southern India, Ethiopia and the sub Sahara. Typically heights circa 100 hPa (16 km; 50 000 ft).

- **Arctic Jet stream** found between the boundary of Arctic air and polar air. Typically in winter at around 60° North but in the USA around 45° to 50° North. The core is at approximately 20 000 ft (400 hPa). It is a transient feature found over North America and Northern Eurasia during Arctic air outbreaks.

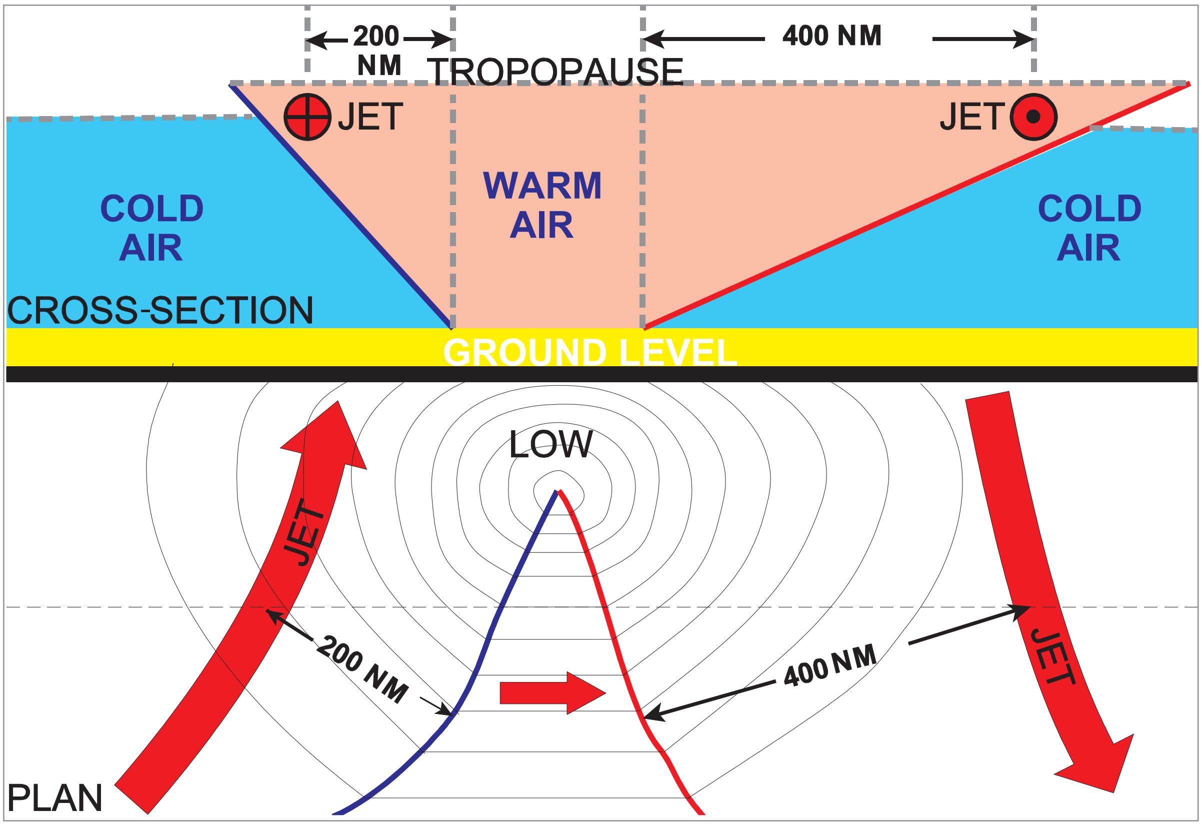


Figure 11.7 Polar front jet streams

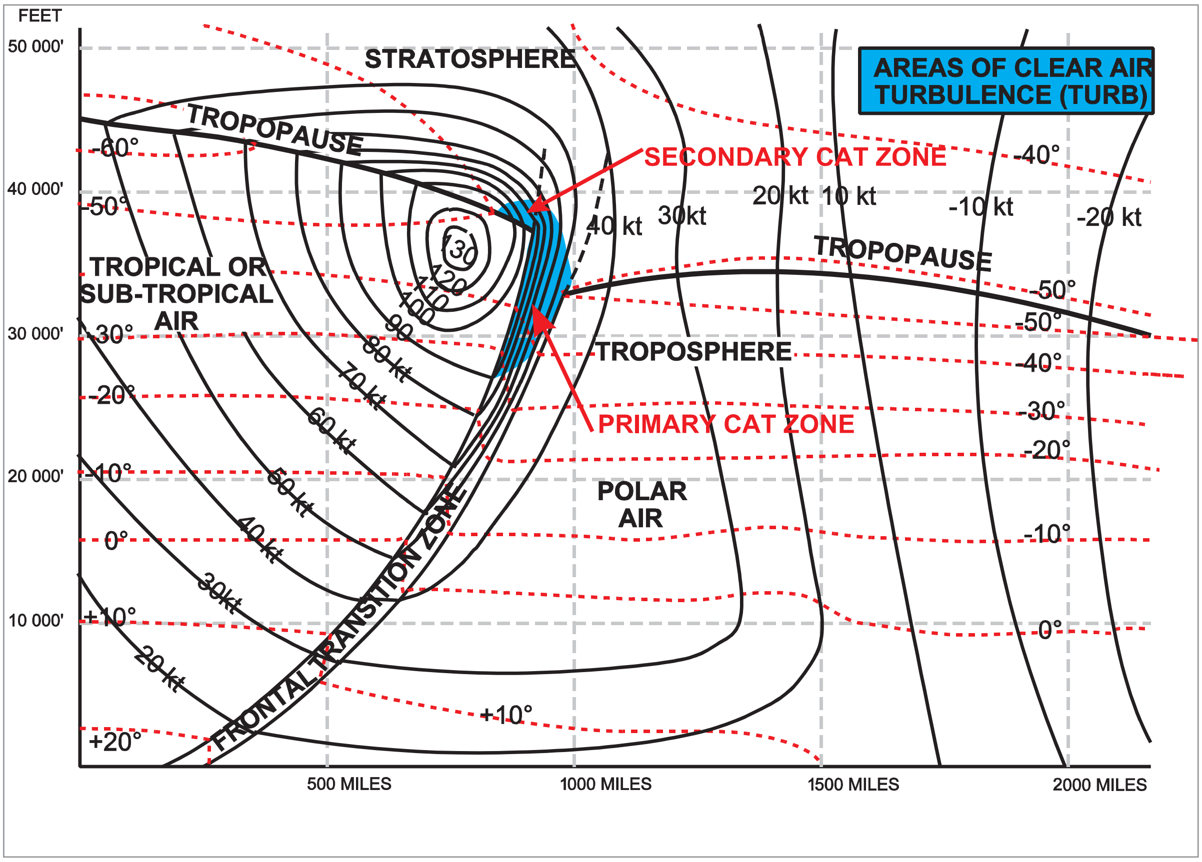


Figure 11.8 A vertical cross-section through a jet stream

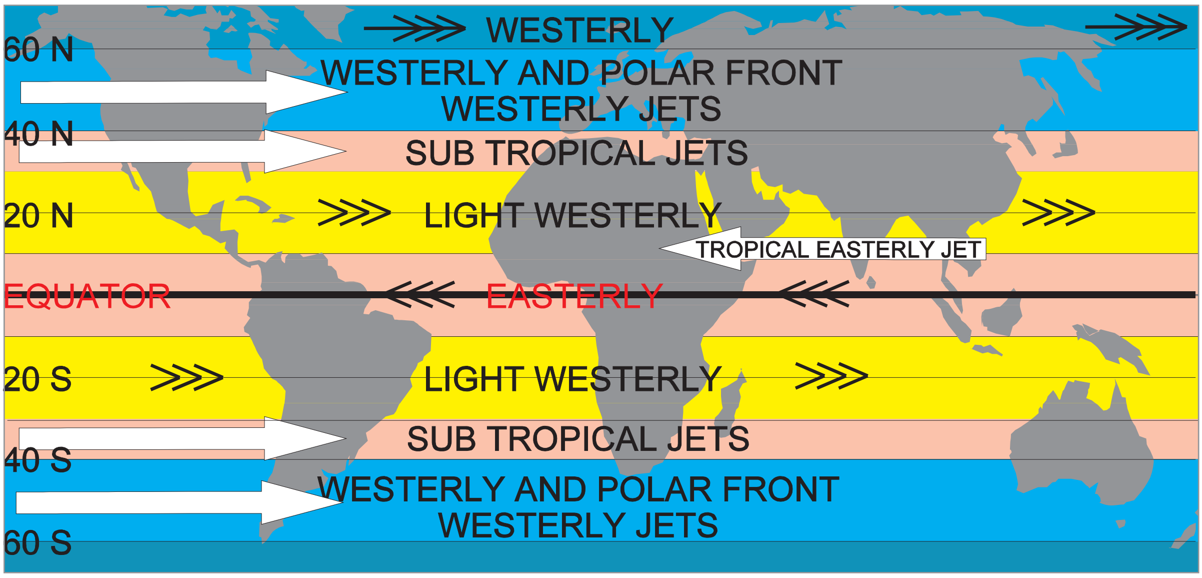


Figure 11.9 Average upper winds - 300 hPa to 200 hPa

Note: *This general disposition of winds will move some 15° south in January and some 15° north in July.*

- Local jets may arise due to local thermal or dynamic circumstances e.g. the Somali, or Findlater jet off East Africa.
- Other jets. 'Jets' as opposed to jet streams may exist as narrow, fast currents of air at low level.

Direction and Speed

The direction of jet streams is generally westerly, maximum speeds occur near the tropopause, 200 kt have been recorded in Europe/N Atlantic and 300 kt in Southeast Asia.

Clear Air Turbulence (TURB)

Clear air turbulence (TURB) occurs around the boundaries of jet streams because of the large horizontal and vertical windshears.

It is strongest near to, or just below, the jet axis on the cold air (low pressure) side with a secondary area above the axis.

Movement

As with most other weather phenomena, jet streams move with the sun.

Subtropical jets, based on Hadley cells, will move north in the northern summer as the heat equator moves north and then south in the northern winter.

Polar front jets in the Northern Hemisphere will move north (and decrease in speed) as the polar front moves north in summer. During the winter the polar front moves south and because of the greater temperature difference, the speed will increase.

Recognition

- From the ground, when the cloud amounts allow, jets may be recognized by wind blown wisps of CIRRUS cloud blowing at right angles to the clouds at lower levels.
- In the air, the presence of a jet will be difficult to see, but temperature differences, increases in wind speed, drift and clear air turbulence are all evidence of jet streams.
- On charts, jets may be picked out quite easily by inspection of upper wind Charts and more graphically perhaps by looking at a Significant Weather Chart.

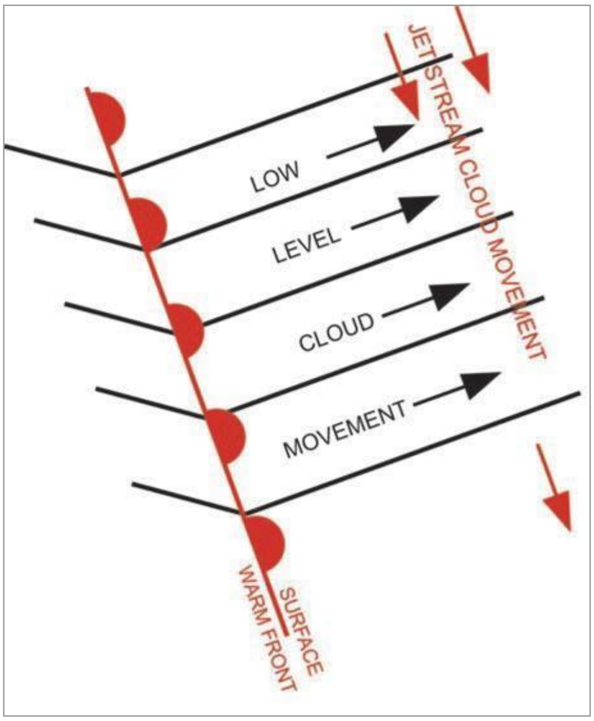


Figure 11.10 Recognition by clouds

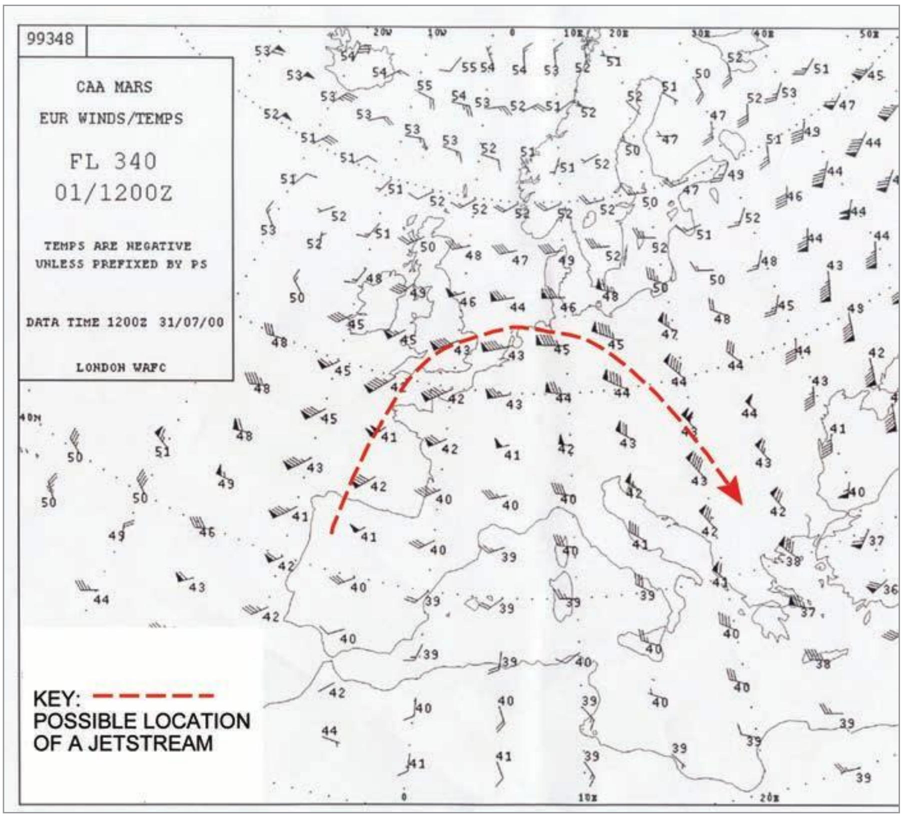


Figure 11.11

Forecasting

The forecasting of jet streams is largely a matter of producing charts from upper air soundings by radiosonde. Thickness charts were mentioned earlier as a means of establishing thermal wind patterns, but for forecasting, meteorologists use contour charts.

In-flight reports of temperature and wind velocities are a useful confirmation of upper air soundings and over oceans (and deserts) are vital supplements.

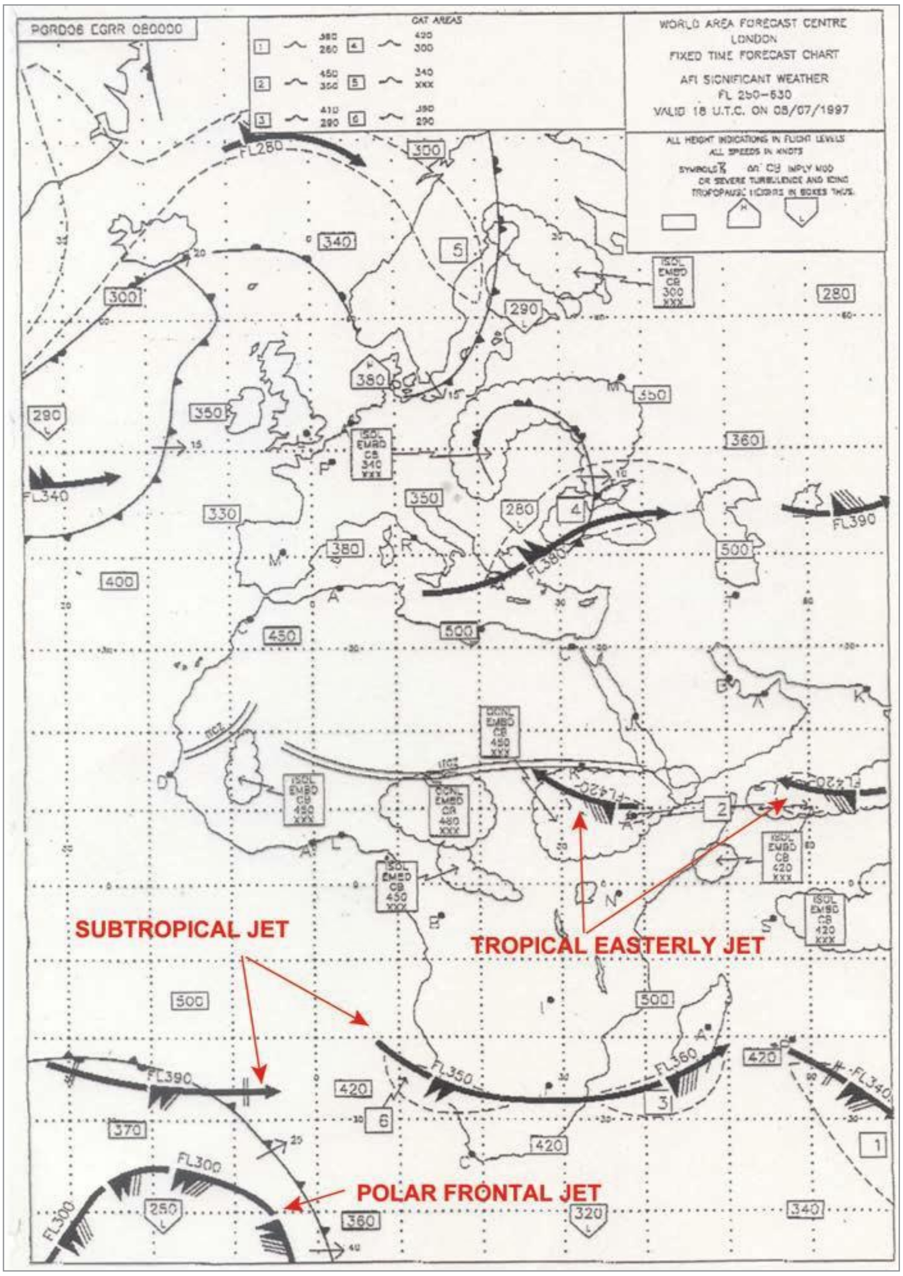


Figure 11.12 Jet Streams on Sig/Wx Chart

Questions

1. **How do you recognize high level jet streams and associated TURB?**

   a. High pressure centre at high level
   b. Streaks of Cirrus
   c. High level dust
   d. Lenticularis

2. **What type of jet stream blows constantly through the Northern Hemisphere?**

   a. Arctic
   b. Equatorial
   c. Polar night
   d. Subtropical

3. **In central Europe, where are the greatest wind speeds?**

   a. Tropopause level
   b. 5500 m
   c. Where the air converges
   d. Above the Alps

4. **The Arctic Jet core is at:**

   a. 20 000 ft
   b. 30 000 ft
   c. 40 000 ft
   d. 50 000 ft

5. **FL180, Northern Hemisphere with a wind from the left, what can you say about temperature with a heading of 360°?**

   a. Not possible to tell without a pressure
   b. Increases from south to north
   c. Increases from north to south
   d. Nothing

6. **When heading south in the Southern Hemisphere you experience starboard drift:**

   a. You are flying towards a lower temperature
   b. You are flying away from a lower temperature
   c. You are flying towards a low pressure
   d. You are flying out of a high

7. **With a polar front jet stream (PFJ), the area with the highest probability of turbulence in the Southern Hemisphere is:**

   a. in the jet core
   b. above the jet core in the boundary of the warm and cold air
   c. looking downstream, on your left hand side
   d. looking downstream, on your right hand side

8. **Contours on a weather chart indicate:**

   a. heights of pressure levels
   b. distance between pressure levels
   c. thickness between pressure levels
   d. height of ground

9. **If an isohypse on a surface pressure chart of 500 hPa shows a figure of 522, this indicates:**

   a. topography of 522 m above MSL
   b. topography of 522 decametres above MSL
   c. pressure is 522 hPa
   d. a low surface pressure

10. **The polar front jet stream in summer compared to winter in the Northern Hemisphere moves:**

   a. north and decreases in strength
   b. north and increases in strength
   c. south and decreases in strength
   d. south and increases in strength

11. **A jet stream with a wind speed of 350 kt is:**

   a. impossible
   b. possible but very rare
   c. possible in polar areas
   d. common

12. **If you fly at right angles to a jet stream and below the jet core in Europe with a decreasing outside air temperature, you will experience:**

   a. increasing headwind
   b. increasing tailwind
   c. wind from the left
   d. wind from the right

13. **On a particular day the PFJ runs north to south in the Northern Hemisphere.**

   a. The temperature gradient runs north to south below the jet core
   b. The temperature gradient runs north to south above the jet core
   c. The polar air is east of the jet above the core
   d. The polar air is below the jet to the east

14. **Flying 2500 ft below core of jet, with temperature increasing in the Southern Hemisphere, where does the wind come from?**

   a. Head
   b. Tail
   c. Left
   d. Right

15. **When flying from south to north in the Southern Hemisphere, you cross over the polar front jet. What happens to the temperature?**

    a. It increases
    b. It decreases
    c. It remains the same
    d. Impossible to determine

16. **The core of a jet stream is located:**

    a. at the level where temperature change with altitude becomes little or nil and the pressure surface is at maximum slope
    b. in the warm air where the pressure surface is horizontal
    c. in the warm air and directly beneath at the surface
    d. in cold air

17. **What is the ratio of height to width in a typical jet stream?**

    a. 1:10
    b. 1:100
    c. 1:1000
    d. 1:10000

18. **When and where does an easterly jet stream occur?**

    a. All year through the Equator
    b. In summer from SE Asia through S. India to Central Africa
    c. In summer from the Middle East through N. Africa and the Mediterranean to S. Spain
    d. In winter in Arctic Russia

19. **From the preflight briefing you know a jet stream is at 31 000 ft whilst you are at FL270. You experience moderate CAT. What would be the best course of action?**

    a. Stay level
    b. Descend
    c. Climb
    d. Reduce speed

20. **What is most different about the equatorial easterly jet stream?**

    a. Its height
    b. Its length
    c. Its direction
    d. Its speed

21. **Where are easterly and westerly jets found?**

    a. Northern Hemisphere only
    b. Southern Hemisphere only
    c. Northern and Southern Hemisphere
    d. There are no easterly jets

22. **Wind at altitude is usually given as .... in ....**

a. true, m/s
b. magnetic, m/s
c. true, kt
d. magnetic, kt

23. **Under which of the following circumstances is the most severe CAT likely to be experienced?**

a. A westerly jet stream at low altitude in the summer
b. A curved jet stream near a deep trough
c. A straight jet stream near a low pressure area
d. A jet stream where there is a large spacing between the isotherms

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	d	a	a	c	b	d	a	b	a	b	c

13	14	15	16	17	18	19	20	21	22	23
d	c	a	a	b	b	b	c	a	c	b

Chapter 12

Clouds

Introduction

Clouds may be regarded as signposts in the sky giving us warning of what the weather is or what it is likely to be. They are also a source of several hazards to aviation:

- Turbulence
- Poor visibility
- Precipitation
- Icing
- Lightning

In view of this it is essential that pilots must be able to recognize the different types of clouds and identify the hazards associated with the clouds. A summary of the properties and hazards associated with the different types of cloud appears at the end of this chapter.

Cloud Amount

Cloud amounts are reported in OKTAS (eighths). It is assumed that the sky is divided into 8 equal parts and the total cloud amount is reported by an assessment of the number of eighths of the sky covered by cloud.

FEW	1 to 2 OKTAS
SCT	3 to 4 OKTAS
BKN	5 to 7 OKTAS
OVC	8 OKTAS

Cloud Base

"That lowest zone in which the type of obscuration perceptibly changes from that corresponding to clear air haze to that corresponding to water droplets or ice crystals." The cloud base is the height of the base of the cloud above ground - above official aerodrome level.

Cloud Ceiling

"The height above aerodrome level of the lowest layer of cloud of more than 4 oktas". (Cloud ceiling is also referred to as main cloud base).

Measurement of Cloud Base

- By day a balloon with a known rate of ascent is released and the time between release and the disappearance of the balloon into cloud is noted. From this cloud base can be calculated.

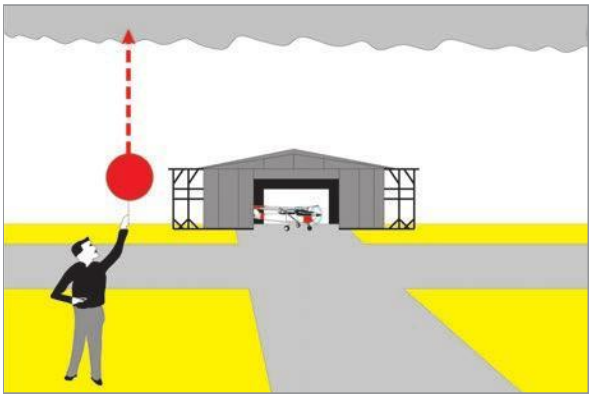


Figure 12.1 Finding the cloud base by releasing a balloon with a known rate of ascent

- By night, an alidade is positioned a known distance from a searchlight and is used to measure the angle above the horizontal of the searchlight glow on the base of the cloud. The height of the cloud base is then calculated by trigonometry.

Figure 12.2 Finding the height of the cloud base using an alidade

The Cloud Base Recorder

A cloud base recorder or ceilometer is a device that uses a laser or other light source to determine the height of a cloud base. There are several types of ceilometers depending on whether a normal light source or a laser light source is used.

- The first type of ceilometer uses a normal light source. There a several versions of such ceilometers. The optical drum ceilometer consists essentially of a projector, a detector, and a recorder. The projector emits an intense beam of light into the sky. The detector, located at a fixed distance from the projector, uses a photoelectric cell to detect the projected light when it is reflected from clouds. In the fixed-beam ceilometer, the light is beamed vertically into the sky by the projector and the detector is aligned at various angles to intercept the reflected light; in the rotating-beam ceilometer, the detector is positioned vertically and the light projected at various angles. In either case, trigonometry is used to determine the altitude of the clouds reflecting the light from a knowledge of the angle at which the light is detected and the distance between the projector and detector. The recorder is calibrated to indicate cloud height directly.

Figure 12.3 A laser ceilometer

- A laser ceilometer consists of a vertically pointing laser and a receiver house in the same instrument assembly, as shown above. It determines the height by measuring the time required for a pulse of light to be scattered back from the cloud base. The laser ceilometer is more accurate and more reliable than the other types of recorders and as such it is the main type of recorder currently in use.

Measurement of Cloud Tops

The height of cloud tops cannot be easily measured. The forecasters can deduce the height from the ELR and SALR but this is not very accurate and the forecasters rely on pilot reports of cloud top height to assist with the forecasting.

Cloud Movement

Meteorological stations measure the movement of clouds by means of a nephoscope. This measures the angular speed of movement of cloud and if the base height is known, the speed of movement may be calculated. A Besson nephoscope is shown on the right.

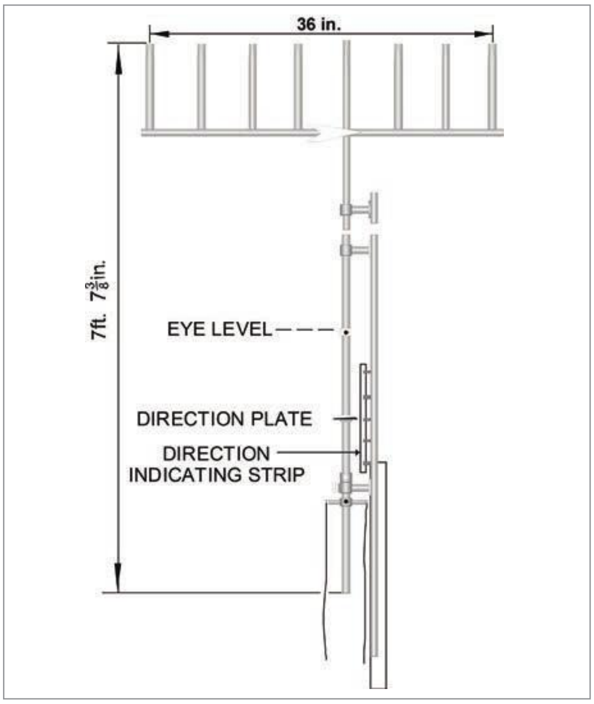


Figure 12.4 Besson nephoscope

Cloud Classification

Classification of cloud type is based, primarily, on the shape, or form of the cloud. The basic forms of cloud are **stratiform, cumuliform** and **cirriform**.

Stratiform cloud is a layered type of cloud of considerable horizontal extent, but little vertical extent. (*See Figure 12.5.*)

Figure 12.5 Stratiform cloud

Cumuliform cloud is heaped cloud, displaying a marked vertical extent, of greater or lesser degree.

Cirriform cloud is a cloud which is fibrous, wispy or hair-like in appearance. This type of cloud is found only at high levels in the troposphere.

Clouds are also identified by reference to the height at which they occur. There are 3 distinct cloud levels within the troposphere.

Cloud Height Bands

Stages	Polar Regions	Temperature Regions	Tropical Regions
High	3-8 km (10 000 - 25 000 ft)	5 - 13 km (16 500 - 45 000 ft)	6 - 18 km (20 000 - 60 000 ft)
Middle	2 - 4 km (6500 - 13 000 ft)	2 - 7 km (6500 - 23 000 ft)	2 - 8km (6500 - 25 000 ft)
Low	From the Earth's surface to 2 km (6500 ft)	From the Earth's surface to 2 km (6500 ft)	From the Earth's surface to 2 km (6500 ft)

- **Low-level clouds** These clouds may be stratus, stratocumulus, cumulus and cumulonimbus. (The prefix nimbo and the suffix nimbus imply "rain bearing".) However, cumulus and cumulonimbus will have significant vertical development and will extend from low-level to higher levels. Cumulonimbus clouds may extend into the lower stratosphere.

- **Medium-level clouds** are found between 6500 ft and 23 000 ft. The names of medium-level clouds are characterized by the prefix "alto-": such as altostratus and altocumulus. Nimbostratus is also classified as a medium level cloud.

- **High-level clouds** The names of high-level clouds are prefixed by "cirro-": cirrostratus, cirrocumulus, and cirrus. (Latin cirrus means curl.)

Figure 12.6

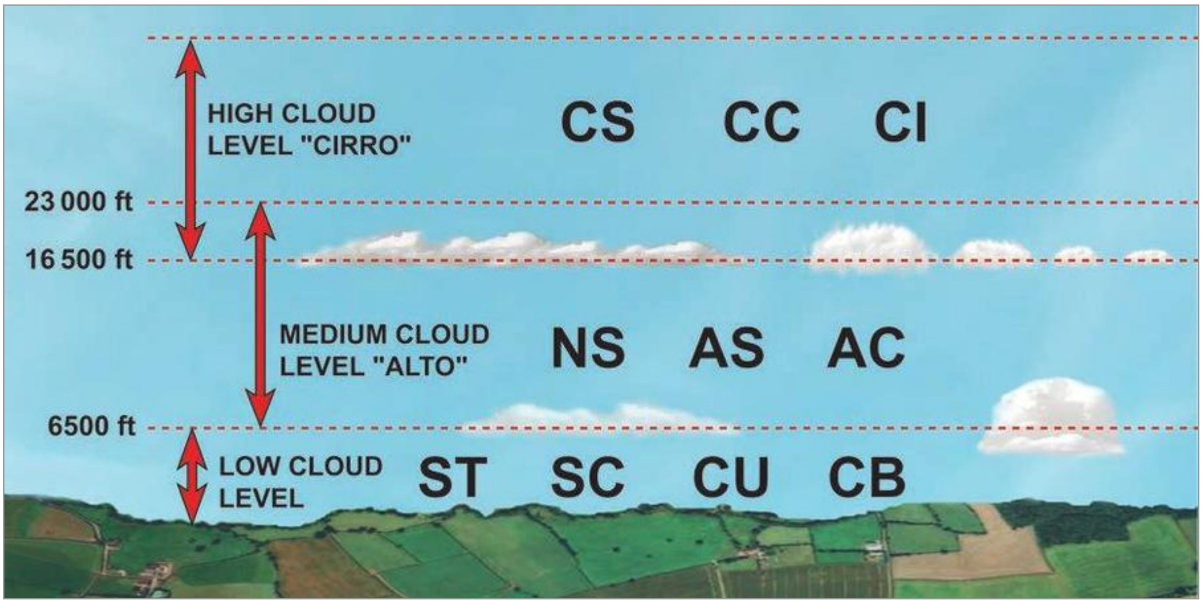


Figure 12.7 Cloud classification

Stratus (St or ST)

Stratus (from Latin stratum, meaning strewn) is generally a grey, layered cloud with a fairly uniform base, which may produce drizzle, or light snow. The vertical extent of stratus cloud may be from a few hundred feet up to several thousand feet. Stratus is usually the lowest of all cloud types. The main hazard associated with stratus is poor visibility and it often covers high ground, concealing hill tops from pilots and producing hill fog for hikers. When stratus is at its thinnest, the sun can be clearly seen through the stratus layer.

Figure 12.8 Stratus

Stratocumulus (Sc or SC)

Stratocumulus cloud is probably the most common form of cloud in the skies of the United Kingdom. It appears grey, or whitish, but usually has distinct dark parts. Stratocumulus can be seen as patches, or in a continuous layer. Stratocumulus is usually no more than 2000 to 3000 ft thick, but may become 5000 to 6000 ft deep in certain conditions. Usually the cloud base is between 1000 ft and 4500 ft.

Figure 12.9 Stratocumulus

Nimbostratus (Ns or NS)

Nimbostratus is a dense, dark-grey, rain-bearing, stratiform cloud, producing extensive and long-lasting continuous or intermittent precipitation. Usually the cloud base is between the surface and 6500 ft above ground level. NS is generally found at the warm front in polar front depressions.

Figure 12.10 Nimbostratus

Cumulus (Cu or CU)

Cumulus cloud is the most common form of convective cloud, being classified as heaped cloud, from Latin cumulare meaning to heap up. For glider pilots, a developing cumulus is regarded as a reliable indication of the presence of thermal upcurrents which, if skilfully exploited, can enable the glider to gain height. Pilots of light aircraft, on the other hand, will note that, on a day when the sky is peppered with fine-weather cumulus flight below cloud base is turbulent, whereas, above the cloud tops, the air is likely to be very smooth.

Figure 12.11 Fair weather cumulus

A developed cumulus cloud is generally dense, with sharp outlines. As it continues to develop vertically, a cumulus cloud forms mounds, domes or towers, of which the upper parts often resemble the head of a cauliflower. The sunlit parts of cumulus clouds are brilliant white, but their bases are relatively dark.

Cumulus clouds of small vertical development can appear benign, but they can grow rapidly, when the atmosphere is unstable, with no upper-air inversion, and may develop into cumulonimbus clouds, with their tops reaching the tropopause. Usually the cloud base is between 1000 ft and 5000 ft but this increases as the surface temperature increases.

Cumulonimbus (Cb or CB)

Cumulonimbus clouds are clouds that the aviator should avoid. Cumulonimbus clouds consist of vigorous convective cloud cells of great vertical extent. The upper parts of a cumulonimbus cloud consist of supercooled water droplets and ice crystals. The base of cumulonimbus clouds is often very dark, with ragged cloud appearing beneath the main cloud cell. Usually the cloud base is between 2000 ft and 5000 ft.

Figure 12.12 Cumulonimbus

The risk of icing and turbulence associated with cumulonimbus is moderate to severe. Within cumulonimbus, very strong upcurrents and downdraughts are continually at play, producing severe precipitation in the form of showers of rain and hail. Other hazards associated with cumulonimbus are lightning and static discharge, which may lead to airframe damage, erroneous instrument readings and squally winds.

Moist unstable air throughout a deep layer of the atmosphere is necessary for the formation of cumulonimbus cloud. A trigger mechanism is also required to kick off the convection process associated with isolated, heat-type cumulonimbus.

Altocumulus (Ac or AC)

Altocumulus takes the form of speckled white or grey cloud. The patches of cloud appear as rounded masses of fibrous or diffuse aspect.

There are two forms of altocumulus which are of particular significance, namely: altocumulus lenticularis and altocumulus castellanus.

Figure 12.13 Altocumulus

Altocumulus lenticularis, also known as lenticular cloud, is found downwind of mountainous or hilly areas, and is indicative of the presence of mountain wave activity. Because of its position downwind of high ground, moderate or even severe turbulence may be associated with the presence of altocumulus lenticularis. However, the air in the lenticular clouds, themselves, is always smooth.

Figure 12.14 Altocumulus Lenticularis.

Figure 12.15 Altocumulus Castellanus.

Altocumulus castellanus is a “bubbly” form of normal altocumulus. The “towers” that form in altocumulus castellanus are like battlements on castles, hence the name. These clouds are significant because they often herald a change to showery, thundery weather and are a feature of summer weather in temperate latitudes.

Cumulonimbus clouds sometimes develop from altocumulus castellanus, when instability is present at medium levels of the troposphere.

Altostratus (As or AS)

Altostratus is a grey or bluish sheet, or layer of cloud, which can be fibrous or uniform in appearance. Sometimes, altostratus covers the whole sky, giving a "ground glass" effect around the sun or moon.

Altostratus can be from around 2000 ft to 8000 ft thick. But despite its thickness, altostratus is not a dense cloud, and the sun is usually perceptible through the cloud layer.

Figure 12.16 Altostratus

Cirrus (Ci or CI)

Cirrus (from Latin cirrus, meaning curl) is the highest of all the cloud types and is composed entirely of ice crystals. Cirrus clouds take the form of white delicate filaments, in patches or narrow bands. They may also be described as fibrous or hair-like. They often herald the approach of a warm front.

Figure 12.17 Cirrus

Cirrostratus (Cs or CS)

Cirrostratus is a transparent, whitish cloud-veil of fibrous or smooth appearance, totally or partially covering the sky.

Cirrostratus is made up of ice crystals, and the presence of CS usually indicates the approach of a warm front. In tropical regions CS is often associated with the presence of tropical revolving storms. CS often produces a halo around the sun or the moon.

Figure 12.18 Cirrostratus

Cirrocumulus (Cc or CC)

Cirrocumulus is probably the cloud which is least often seen in the sky. Cirrocumulus is a thin, white and patchy layer of cloud, with ripples, more or less regularly arranged. Cirrocumulus consists of ice crystals.

Figure 12.19 Cirrocumulus

Stable Air			Unstable Air	
Low	**Medium**	**High**	**Low**	**Medium/High**
0 – 6500 ft	**6500 – 23 000 ft**	**16 500 – Tropopause**	**0 – Tropopause**	**6500 ft –**
Stratus (St): Water droplets No turbulence Light to moderate icing Poor visibility (<30 m) Turbulence cloud Drizzle/light rain	**Nimbostratus (Ns)**:** Water droplets, ice crystals Moderate – severe turbulence Moderate - severe icing Poor visibility (<20 m) Warm front Heavy precipitation	**16 500 – Tropopause** **Cirrus (Ci):** Ice crystals No turbulence No icing Fair visibility (>1000 m) Warm front	**0 – Tropopause** **Cumulus (Cu)***:** Water droplets and ice crystals Moderate to severe turbulence Moderate to severe icing Poor visibility Heavy showers	**6500 ft –** **Altocumulus castellanus (Acc):** Indicative of medium level instability
Stratocumulus (Sc)*: Water droplets Light turbulence Light – moderate Icing Poor visibility (<30 m) Turbulence cloud Drizzle/light rain	**Altostratus (As):** Water droplets, Ice crystals Light to moderate turbulence Light to moderate icing Fair visibility (<1000 m) Warm front Light to moderate rain	**Cirrostratus (Cs):** Ice crystals No turbulence No icing Fair visibility (>1000 m) Warm front	**Cumulonimbus (Cb)***** Water droplets and ice crystals Moderate to severe turbulence Moderate to severe icing Poor visibility Heavy showers	**Altocumulus (Ac):** Water droplets, ice crystals light – moderate turbulence Light – moderate icing Fair visibility (<1000 m)
				Cirrocumulus (Cc): Ice crystals Light turbulence No icing Fair visibility (>1000 m) Warm front

Notes:

*** Orographic uplift can give moderate/severe turbulence and icing in Sc**

**** Stratus Fractus (St Fra)** the ragged cloud found in the precipitation below Ns, caused by the evaporation of the water droplets saturating the air and low level turbulence leading to the formation of the cloud.

*****Stages of Cumulus Development:**

Cumulus Fractus (Cu Fra) small ragged cloud usually forming in the early morning, may also be found in the precipitation zone below Cb

Cumulus Humilis (Cu Hum) also known as **Fair Weather Cu**, small Cu, the next stage of development usually seen early in the morning

Cumulus Mediocris (Cu Med) larger cumulus, distinguished by light upper areas having a cauliflower appearance but very dark underneath (moderate vertical development)

Cumulus Congestus (Cu Con) also known as **Towering Cumulus (TCU)** (strong vertical development)

Cumulonimbus Calvus (Cu Cal) The tops are now rounded but do not have a fibrous appearance and there is no anvil

Cumulonimbus Capillatis (Cb Cap) any Cb having an anvil

Note: By convention, a cumulus cloud is reported as cumulonimbus if accompanied by lightning, thunder, hail or any other precipitation of a showery nature.

Questions

1. What cloud does hail fall from?

a. Cb
b. Ns
c. Cu
d. Ci

2. Flying conditions in Ci cloud and horizontal visibility:

a. less than 500 m vis, light/mod clear icing
b. greater than 1000 m vis, light/mod rime ice
c. less then 500 m vis, no icing
d. greater than 1000 m vis, no icing

3. What is the composition of Ci cloud?

a. Super cooled water droplets
b. Ice crystals
c. Water droplets
d. Smoke particles

4. What cloud types are classified as medium cloud?

a. Ns + Sc
b. Ac + As
c. Cb + St
d. Ci + Cs

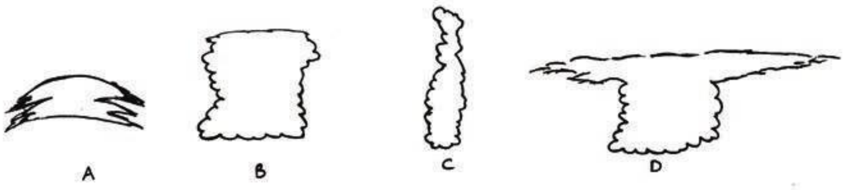
5. What type of cloud is associated with drizzle?

a. St
b. Cb
c. Ci
d. Ac

6. Fair weather cumulus gives an indication of:

a. poor visibility
b. thunderstorms
c. turbulence
d. smooth flying below

7. What best shows Altocumulus Lenticularis?



8. **What are lenticularis clouds a possible indication of?**

a. Mountain waves
b. Instability
c. Developing Cu and Cb
d. Horizontal windshear in the upper atmosphere

9. **In what cloud is icing and turbulence most severe?**

a. Cb
b. Ns
c. Sc
d. Ci

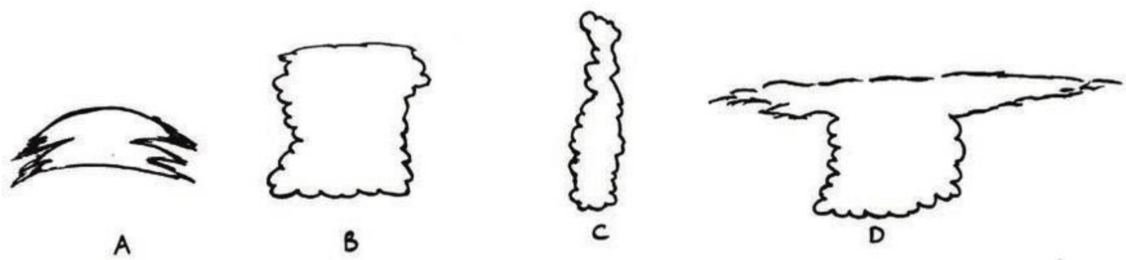
10. **What will snow most likely fall from?**

a. Ns
b. Ci
c. Cs
d. Ac

11. **A plain in Western Europe at 500 m (1600 ft) AMSL is covered with a uniform altocumulus cloud during summer months. At what height AGL is the base of the cloud expected?**

a. 100 - 1500 ft
b. 15000 - 25000 ft
c. 7000 - 15000 ft
d. 1500 - 7000 ft

12. **What best shows Cumulonimbus capillatus?**



13. **Clouds classified as low level are considered to have a base height of:**

a. 500 - 1000 ft
b. 1000 - 2000 ft
c. the surface - 6500 ft
d. 100 - 200 ft

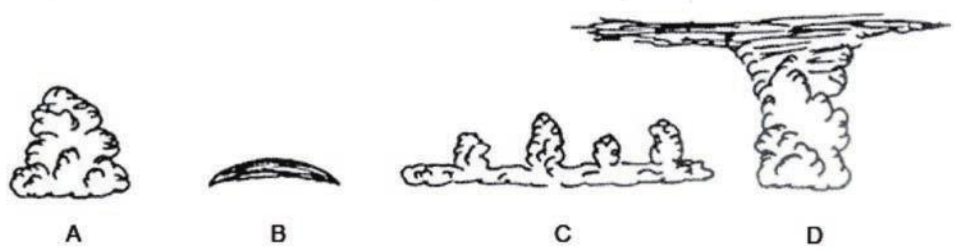
14. In a tropical downpour the visibility is sometimes reduced to:

a. 1000 m
b. 500 m
c. 200 m
d. less than 100 m

15. What type of cloud is usually found at high level?

a. St
b. Ac
c. Cc
d. Ns

16. What best shows Acc?



17. Altostratus is:

a. a low level cloud
b. a medium level cloud
c. a high level cloud
d. a heap type cloud

18. What would be reflected to radar?

a. Fog
b. Hail
c. Cloud
d. Mist

19. Which cloud would you encounter the most intensive rain?

a. Ci
b. Ns
c. St
d. Sc

20. CB cloud in summer contains:

a. water droplets
b. ice crystals
c. water droplets, ice crystals and super cooled water droplets
d. water droplets and ice crystals

21. **Which cloud would produce showers?**

a. NS
b. AS
c. CS
d. CB

22. **When would you mostly likely get fair weather Cu?**

a. 15:00
b. 12:00
c. 17:00
d. 07:00

23. **What type of cloud extends into another level?**

a. As
b. Acc
c. Ns
d. Ci

24. **Ceilometers measure:**

a. RVR
b. cloud height
c. met vis
d. turbulence

25. **Which of the following will indicate medium level instability, possibly leading to thunderstorms?**

a. Halo
b. Altocumulus Castellanus
c. Altocumulus Capillatus
d. Red Cirrus

26. **What is the base of altocumulus in summer?**

a. 0 - 1500’
b. 1500 - 7000’
c. 7000’ - 15 000’
d. 7000’ - 16 500’

27. **When a CC layer lies over a West European plain in summer, with a mean terrain height of 500 m above sea level, the average cloud base could be expected to be:**

a. 0 - 100 ft above ground level
b. 5000 - 15 000 ft above ground level
c. 15 000 - 25 000 ft above ground level
d. 15 000 - 35 000 ft above ground level

28. **Which of the following cloud types can stretch across all three cloud levels (low, medium and high level)?**

a. CI
b. ST
c. AC
d. CB

29. **Which of the following cloud types can stretch across at least two cloud levels?**

a. ST
b. NS
c. CI
d. SC

30. **From which cloud do you get hail?**

a. Sc
b. Cb
c. Ns
d. Ts

31. **If you see Alto Cu Castellanus what does it indicate?**

a. The upper atmosphere is stable
b. Subsistence
c. Instability in the lower atmosphere
d. Middle level instability

32. **To dissipate cloud requires:**

a. subsidence
b. a decrease in temperature
c. an increase pressure
d. convection

33. **Cu is an indication of:**

a. vertical movement of air
b. stability
c. the approach of a warm front
d. the approach of a cold front

34. **Which clouds are evidence of stable air?**

a. St, As
b. Cb, Cc
c. Cu, Ns
d. Cu, Cb

35. **Lack of cloud at low level in a stationary high is due to:**

a. instability
b. rising air
c. sinking air
d. divergence at high level

36. What is the most common freezing precipitation?

a. Freezing pellets
b. Freezing rain and freezing drizzle
c. Freezing graupel
d. Freezing hail and freezing snow

37. From which of the following clouds are you least likely to get precipitation in summer?

a. CS/NS
b. CS/AS
c. CB/CU
d. CU/ST

38. A layer of air cooling at the SALR compared to the DALR would give what kind of cloud?

a. Stratus if saturated
b. Cumulus if saturated
c. No cloud if saturated
d. Convective cloud

39. Over flat dry land what would cause cloud?

a. Orographic uplift
b. Convective uplift during the day
c. Release of latent heat
d. Advection

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	d	b	b	a	c	a	a	a	a	c	d

13	14	15	16	17	18	19	20	21	22	23	24
c	d	c	c	b	b	b	c	d	d	c	b

25	26	27	28	29	30	31	32	33	34	35	36
b	d	d	d	b	b	d	a	a	a	c	b

37	38	39
b	a	b

Chapter

13

Cloud Formation and Precipitation

Vertical Motion

Cloud is formed by air being lifted and cooled adiabatically until the water vapour condenses out as water droplets. The height at which this occurs is called the **condensation level.** It is also the height of the **cloud base**.

The means whereby the initial lifting of the air occurs are as follows:

- Turbulence.
- Orographic Uplift.
- Convection.
- Slow, widespread ascent (frontal uplift).
- Convergence.

Note: *The lifting processes above are strictly all 'convection'; the third process is* ***free convection****, the rest are* ***forced convection****.*

Condensation Level

The condensation level is the height at which the rising air, cooling adiabatically, has cooled to the dew point temperature. Any further ascent and cooling will result in condensation and the formation of cloud. This will be the height of the base of the cloud.

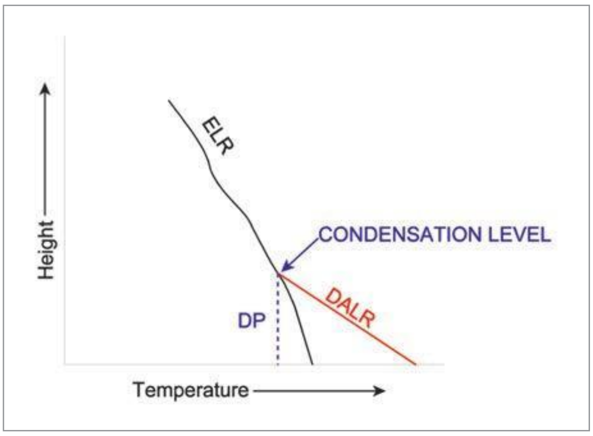


Figure 13.1 Condensation level

Turbulence Cloud

In stable conditions the vertical movement of air is limited and hence the upcurrents created by the surface friction are limited as to the height they can reach. If the rising air reaches dew point before it reaches the top of the friction layer then cloud will form, but since vertical development is restricted the cloud will tend to develop horizontally giving layers of ST/SC. Because ST and SC are formed in these conditions they are known as turbulence cloud. There will normally be an inversion above turbulence cloud.

Orographic Cloud

Air meeting a ridge of high ground will be forced to rise. If the air is sufficiently humid the condensation level will appear below the crest of the ridge & cloud will form.

If the air is **stable** and precipitation occurs, the air will descend on the LEE side and the cloud base will be higher than on the windward side and this will generate warmer surface temperature - the Föhn effect.

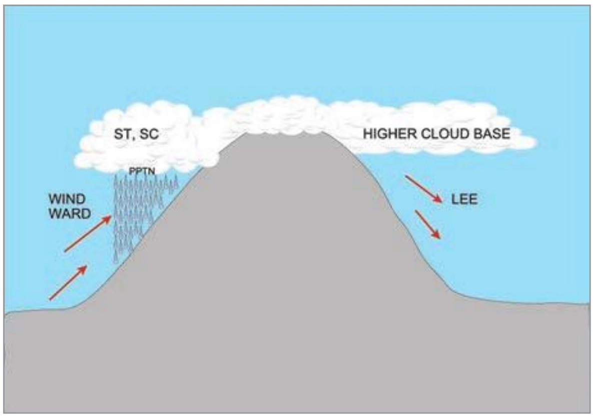


Figure 13.2 Orographic cloud – stable conditions

If the air is dryer, then the cloud base will be above the ridge and **lenticular** cloud would result.

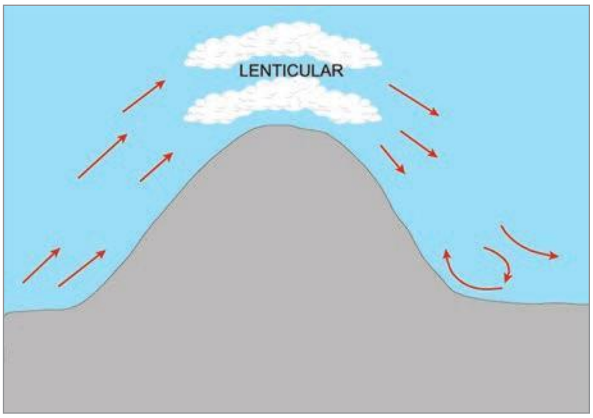


Figure 13.3 Orographic cloud - stable, but dryer

Lifting in **unstable** conditions can produce Cu or Cb clouds and also thunderstorms if there is enough water vapour present.

Strong winds with moist air can cause **convective instability** and Cb and thunderstorms. The Cb can be embedded in other cloud types, eg frontal or Turbulence cloud.

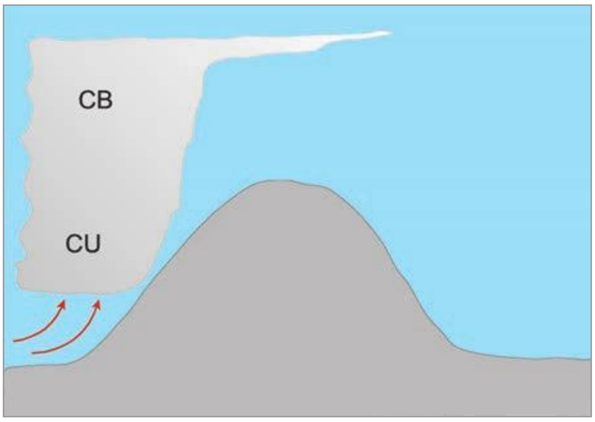


Figure 13.4 Orographic cloud forming in unstable conditions

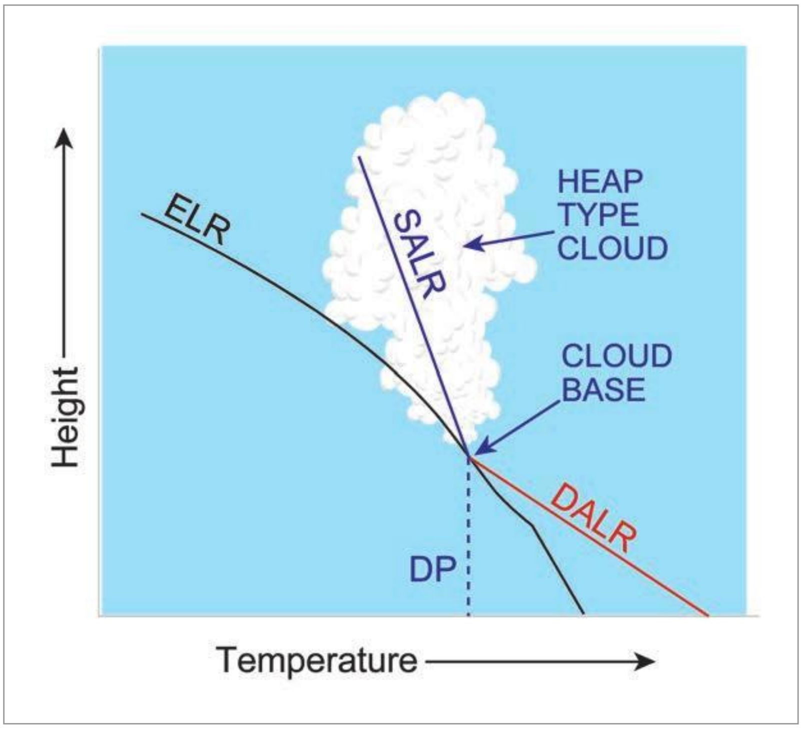


Figure 13.5 Temperature/height diagram

Convection Cloud

Critical Temperature. Before dealing with the formation of convection cloud we must consider the critical, or convective temperature. *Figure 13.6* shows air rising and cooling at the DALR at 0700, 0800 & 0900 hrs. The first two ascents result in the air cooling to the environmental temperature before it reaches dew point. At 0900 the air cools to dew point, cloud forms and the ELR allows the air to continue rising, cooling at the SALR and forming Cu type cloud.

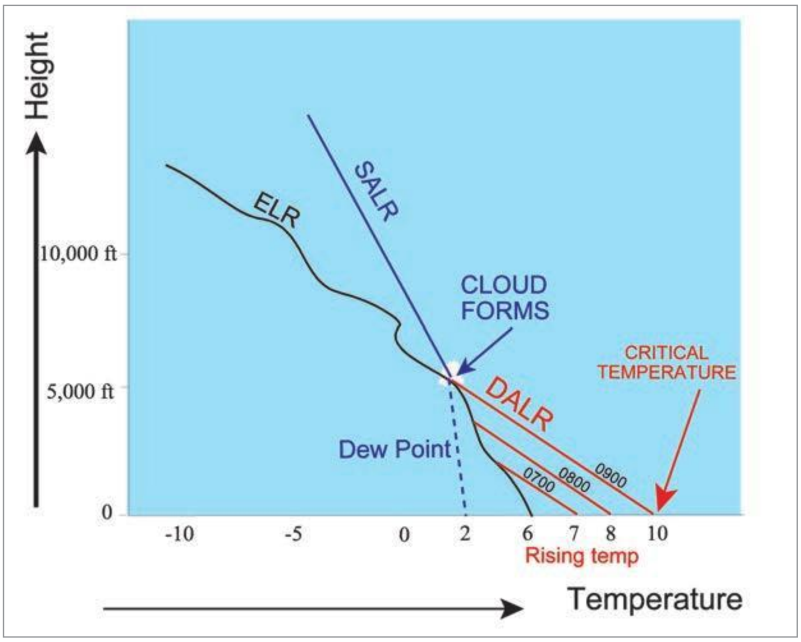


Figure 13.6 Critical temperature

There are two particular cases:

- fair weather Cu, which often forms early in the morning,
- large Cu/Cb, which often occur later in the day.

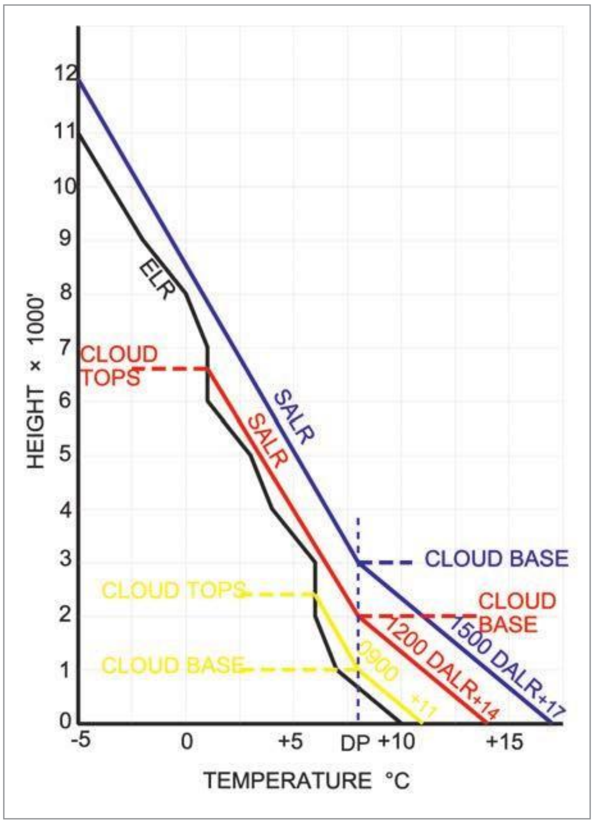


Figure 13.7 The formation of convection cloud

Convection cloud is **heap type**, Cu or Cb. It is isolated, often forming over a place, then being blown away by the wind and further clouds forming over the same place.

The surface air temperature required for the air to be lifted to the condensation level and for cloud to form is called the **critical temperature**.

The cloud base will vary due to the varying temperatures on the ground surfaces. Cloud tops, however, are usually limited by mixing with and evaporating into a drier environment. The tops are then lower than the limit of uplift.

If there is turbulence with the convection, then Sc can form, the Cu being spread out to form the layer cloud.

Pure convection cloud cannot form over the sea but where there is cold air moving over a warm surface the air will become unstable and convection type cloud can form. This movement is called **advection**.

Convection cloud formed over land by surface heating soon **dissipates at night** because insolation stops and the cloud droplets evaporate.

Convective cloud may progress through various cumulus types from humilis, to mediocris, through congestus to calvus. A fully developed Cb may appear as cumulonimbus capillatus.

Widespread Ascent (Frontal Uplift)

At a front there is widespread lifting of air as warm air comes into contact with colder air. Layer type clouds form in the stable air at a **warm front** and heap clouds in the unstable air at a **cold front.**

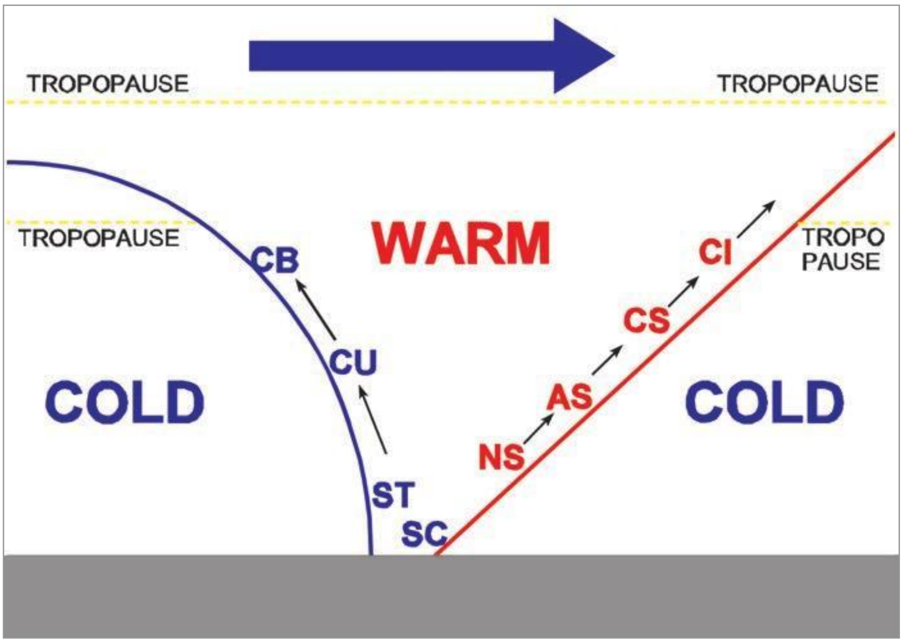


Figure 13.8 The formation of frontal cloud

Convergence Cloud

When there is low pressure there is always convergence at the surface which leads to air being lifted. Thus in depressions and troughs, where there are no actual fronts, cloud formation occurs. See *Figure 13.9.*

With strong convergence at a trough, lifting can cause instability to develop so that the cloud type is Cu or Cb with possible thunderstorms.

This is particularly the case when saturation occurs early, with an average or high ELR.

***Note:** With circular isobars at a non-frontal low, normally only St/Sc cloud will be formed by convergence.*

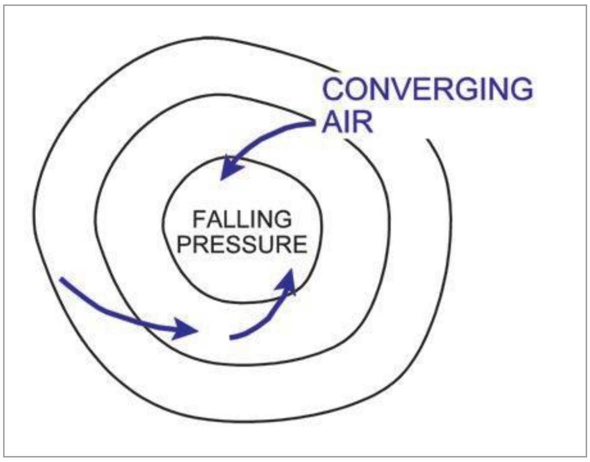


Figure 13.9 Convergence

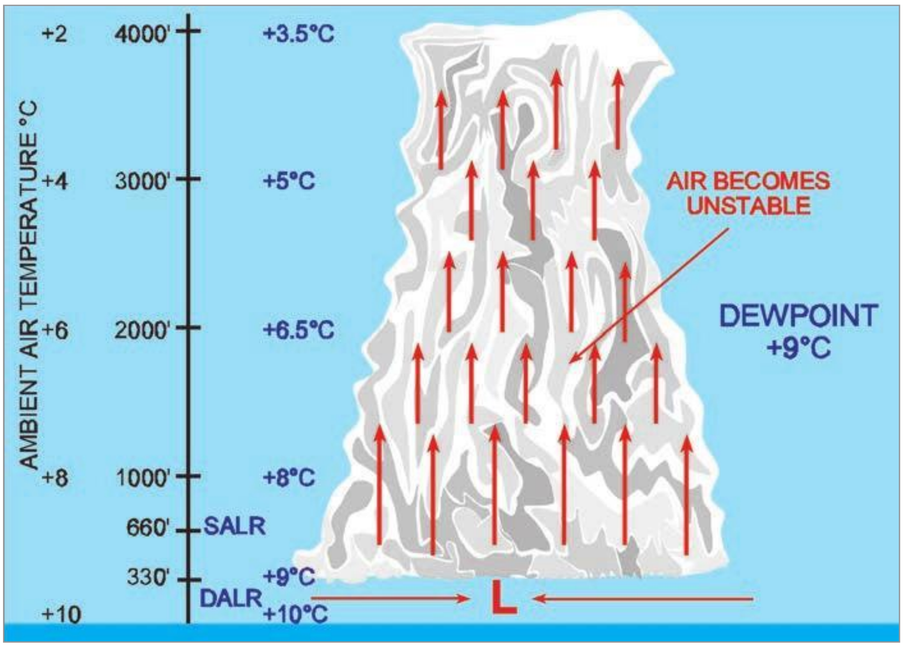


Figure 13.10 cloud formation through convergence

Mountainous Areas

We have seen how orographic lifting produces cloud; in mountainous areas this may be very active and produce extensive cloud and vertical development due to **Convective Instability**. Additionally, this may increase the intensity of precipitation.

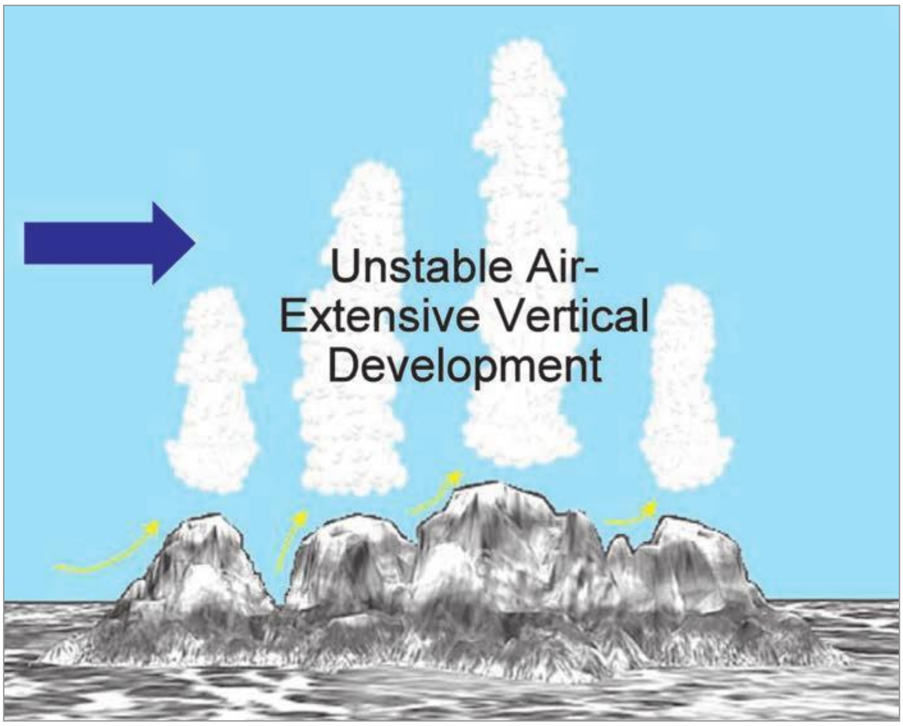


Figure 13.11 Mountainous terrain

Inversions

An inversion in the atmosphere is where temperature rises with an increase in height. This produces extreme stability and must inhibit the formation of cloud. An inversion always exists above turbulence cloud and inversions have a similar effect at ANY altitude.

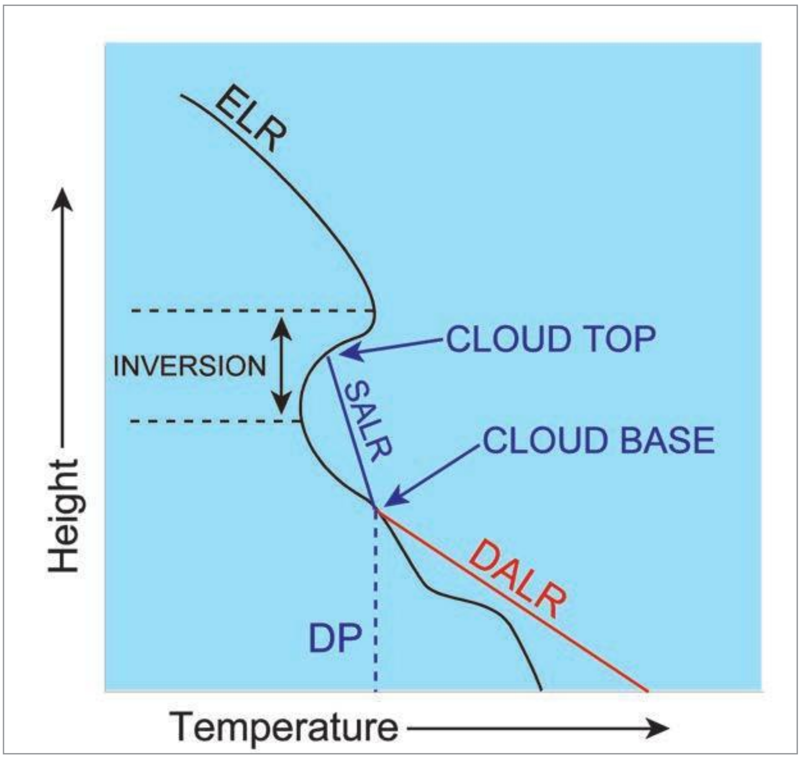


Figure 13.12 Effect of Inversions

Precipitation

Clouds consist of water droplets averaging 0.02 mm in diameter and the rate of fall is negligible. By colliding with other droplets they may increase in size until they are too heavy to be supported by the upcurrents in the cloud and they drop out as precipitation.

There are currently two theories governing the formation of these precipitation drops.

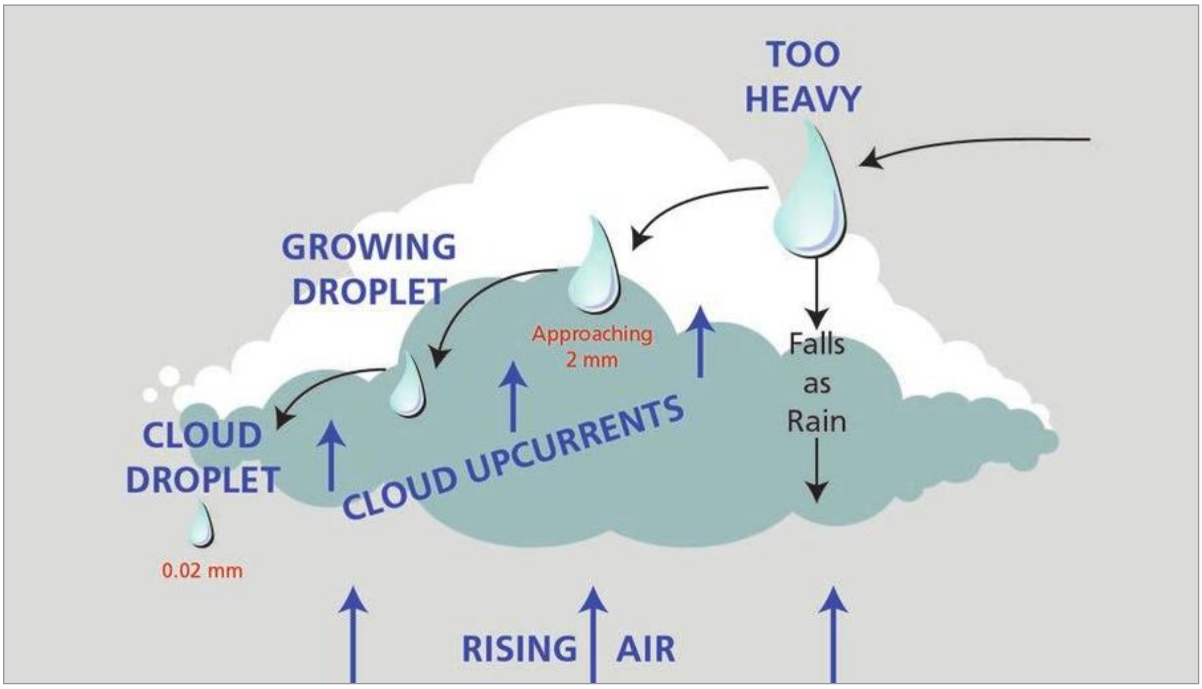


Figure 13.13 Precipitation

Bergeron Theory

The Bergeron theory presumes that at high levels in the cloud, some of the water droplets will turn to ice and will grow in size by **sublimation** of water vapour and collision with supercooled water droplets. The frozen droplets will be much heavier than the existing water droplets and drop out at the bottom of the cloud, either as **snow** or **raindrops,** depending on the temperature.

Coalescence Theory

It is difficult to see how the above can account for summer precipitation where the whole of the cloud is at a temperature above zero and the coalescence theory may provide a better answer. This assumes the presence of a range of droplet sizes, the larger falling faster and uniting with the smaller until eventually the overweight drop falls out as drizzle or rain.

Precipitation Types

• **Drizzle.**	Diameter:	0.2 to 0.5 mm	
,	Visibility:	500 to 3000 m	
	Imperceptible impact.		
• **Rain.**	Diameter:	0.5 to 5.5 mm	
●	Visibility:	3000 to 5.5 km (1000 m in heavy rain)	
	Perceptible impact.		
• **Snow.**	Grains/Needles:	Diameter <1 mm	
✳	Pellets:	Diameter 2-5 mm	
	Flakes:	A collection of crystals greater than 4 mm in diameter. (The lower the temperature, the smaller the size.)	
	Visibility:	Moderate:	1000 m
		Heavy:	50 to 200 m
		Drifting:	(<2 m above the surface) will reduce the above.
		Blowing:	(<2 m above the surface) will GREATLY reduce the above.
• **Hail:**	Diameter:	5 to 50 mm+	
▲	Weight:	Up to 1 kg	
	Growth:	Collision with supercooled water droplets and sublimation / deposition.	

• **Soft Hail or Graupel:** △

Small rounded pellets, only a few mm in diameter.
Fall from wintry, showery cloud.
Early stage of hail growth.

• **Ice Pellets** ◬

Transparent pellets, spherical or irregular.
Diameter <5 mm.
Fall from layered cloud.

Precipitation Summary

Duration

	DESCRIPTION
SHOWERS ▽	Always associated with CONVECTION or HEAP type cloud. Of short duration.
INTERMITTENT ●	Associated with LAYER cloud. Falling 'from time to time', with no marked clearance.
CONTINUOUS ●●	Associated with LAYER cloud. No breaks for 60 minutes +.

Intensity

	RAIN (mm/h)	Snow (cm/h)	Showers (mm/h)
SLIGHT	< 0.5 ●	< 0.5 ∗	< 2 ▽
MODERATE	0.5 TO 4 ● ●	0.5 TO 4 ∗ ∗	2 - 10 ▽
HEAVY	> 4 ● ● ●	> 4 ∗ ∗ ∗	10 - 50 ▽

Cloud

		TYPE	INTENSITY
HEAP (Instability)	Cu Cb	Rain/Snow showers Rain/Snow/Hail showers ● ∗ △	Light to moderate Moderate to heavy
LAYER C: (stability)	Cc Cs	NIL	
	As, St, Ac, Sc	Rain/Snow	Slight
	Ns	Rain/Snow	Moderate to heavy

Rainfall **recorders** are used at some Met. Offices. They will indicate rate of fall (intensity) of precipitation.

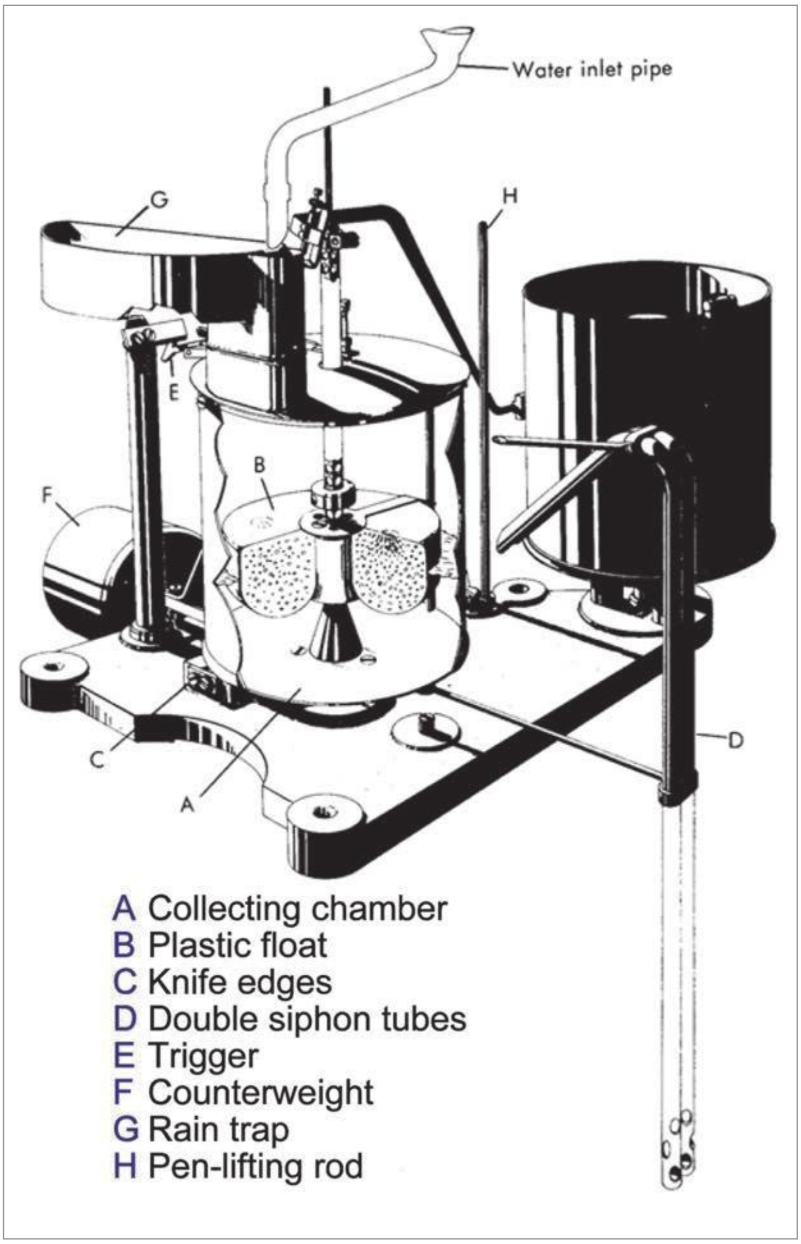


Figure 13.14 Rainfall recorder

Rain **GAUGES** merely measure the amount of precipitation falling at the station. The intensity would have to be estimated, and where visibility is measured a table may be used.

Questions

1. If you observe drizzle falling, the cloud above you is most likely to be:

a. AS
b. CU
c. ST
d. NS

2. Turbulence cloud is usually a sheet of stratus, stratocumulus some 2000 ft thick with a flat top because:

a. the air is usually at low temperatures containing little water vapour
b. turbulence steepens the lapse rate producing an inversion above the friction layer
c. air is not allowed to remain in contact with the surface due to the strong wind thus maintaining cool surface air with warm air above
d. the lapse rate becomes stable in the friction layer, due to turbulent mixing

3. Clouds formed by convection will always:

a. be layer clouds
b. be CU, CB or NS
c. have a rising cloud base and may develop into CB as the day progresses
d. form only in Polar maritime air

4. With reference to anticyclones affecting the UK, which of the following statements is correct?

a. The pressure gradient is greatest towards the centre of the anticyclone
b. Anticyclones are more common in winter than they are in summer. This is why radiation fog is much more frequent in the winter
c. Apart from turbulence cloud, the formation of all other cloud types is unlikely in anticyclonic conditions
d. Warm anticyclones are those which are caused by the extreme air density associated with warmer weather

5. The type of cloud from which continuous moderate or heavy rain is likely to fall is:

a. large cumulus
b. altostratus
c. nimbostratus
d. cumulonimbus

6. The movement of cool moist air over a warmer surface is likely to cause:

a. cumulus or cumulonimbus cloud
b. advection fog
c. nimbostratus cloud
d. altocumulus lenticular cloud

7. Intensity of precipitation is described as either:

a. intermittent, continuous or showery
b. drizzle, rain or snow
c. slight, moderate or heavy
d. intermittent, moderate or heavy

8. The term "shower" implies that:

a. precipitation is in the form of rain and is continuous
b. precipitation is from cumulonimbus cloud and lasts for short periods
c. precipitation is intermittent and is from strato form cloud
d. precipitation is continuous for long periods from cumuloform cloud

9. Precipitation in the form of snow will not reach the surface unless the surface temperature is:

a. less than +4°C
b. less than 0°C
c. less than 45°F
d. less than 30°F

10. The type of precipitation in which visibility is likely to be most reduced is:

a. drizzle
b. snow
c. light rain
d. sleet

11. The type of precipitation usually associated with shallow stratocumulus is:

a. mainly water droplets which can be supercooled if the temperature is low enough
b. ice crystals
c. supercooled water droplets only
d. large water droplets due to the strong up-currents associated with this type of cloud

12. If there are small cumulus in the morning in summer, it is reasonable to forecast later in the day:

a. clear skies
b. St and drizzle
c. CB Cloud
d. haze

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	b	c	c	c	a	c	b	a	b	a	c

Chapter

14

Thunderstorms

Conditions

Thunderstorms (TS) occur in well developed cumulonimbus (Cb) cloud, though not all Cbs produce thunderstorms. They are most likely to occur when there is:

- A lapse rate greater than the SALR through a layer at least 10 000' thick and extending above the freezing level.
- Sufficient water vapour to form and maintain the cloud.
- Trigger * action to produce early saturation, thus enhancing instability.

* The so-called triggers or lifting forces are:

- Convection
- Orographic uplift
- Convergence
- Frontal uplift

Thunderstorms are classified as:

- Air mass type (more common in summer time).
- Frontal type (more common in winter time).

Air Mass Type Thunderstorms

Air mass type thunderstorms are:

- isolated - all triggers except frontal.
- most frequent over land in summer.
- usually formed by day, clear by night.
- formed in **cols** or **weak lows**.

Note Thunderstorms formed by advection can occur day or night, over land or sea or at any time of the year.

Frontal Type Thunderstorms

Frontal thunderstorms are:

- most frequent in winter.
- formed over land or sea, day or night.
- usually formed in a line at a cold front or **occlusion.**
- found in active **depressions** or **troughs.**
- often accompanied by a **line squall.**
- the fastest moving.

Thunderstorm Development (Single Cell)

- **Initial stage.** Several small Cu combine to form a large Cu cell about 5 NM across. There are strong upcurrents of 1000 to 2000 fpm (exceptionally 6000 fpm). Air from the sides and below is drawn in to replace the lifted air, thus causing turbulence. The initial stage lasts about 15 to 20 minutes.

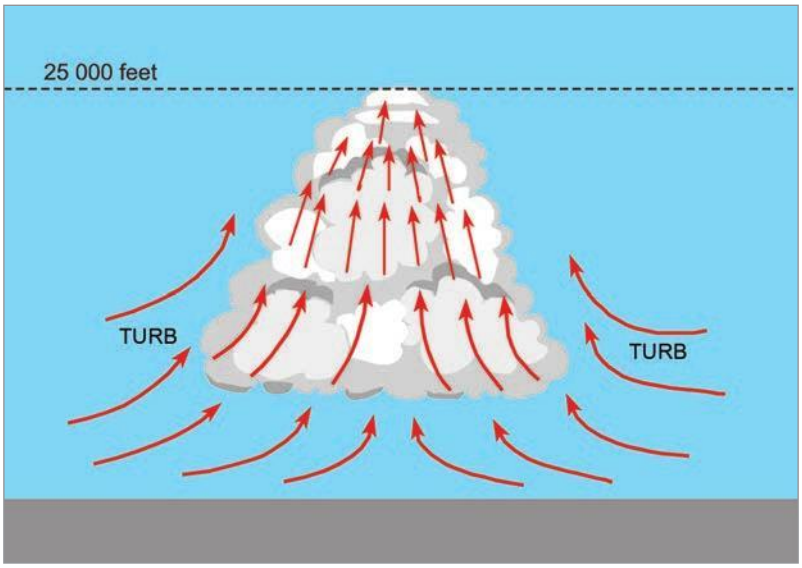


Figure 14.1 The building stage of a thunderstorm

- **Mature stage.** When precipitation occurs, the storm has reached the mature stage. The rain or hail will cause strong down currents of up to 2400 fpm and will also bring cold air to lower levels. These down drafts will warm initially at the SALR causing the air to warm very slowly, thereby staying colder than the surrounding air causing it to sink faster. Another factor aiding these down drafts is that some of the rain will evaporate which will absorb latent heat from the air making it even colder and more dense. The intensity of this can lead to the formation of the GUST FRONT.

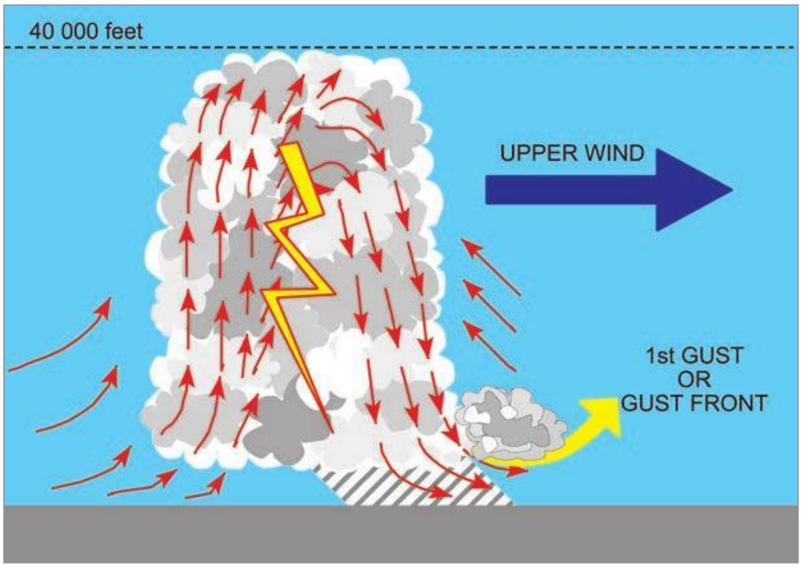


Figure 14.2 The mature stage of thunderstorm development

Up currents remain strong and can be up to 10 000 fpm. Tops may rise at 5000 fpm or more. There can be moderate to severe turbulence in, under, over and all around the cloud.

At the bottom leading edge of the storm there can be a roll of Sc and a strong gust front can be experienced up to 13 to 17 NM (24 to 32 km) ahead of the storm and be up to 6000 feet in depth. Below the cloud a squall and associated windshear can be expected.

Downbursts (microbursts or macrobursts) may occur at this stage. These are discussed later in this chapter.

Rising and falling water droplets will produce a considerable build-up of **static electricity,** usually of positive charge at the top of the cloud and negative at the bottom. The build-ups eventually lead to **lightning** discharge and **thunder.**

A characteristic of the mature stage is the GUST FRONT in advance of the storm produced by the force of the descending air. The gust front may extend 13 to 17 NM (24 to 32 km) ahead of the storm centre.

The mature stage lasts for a further 15 to 20 min.

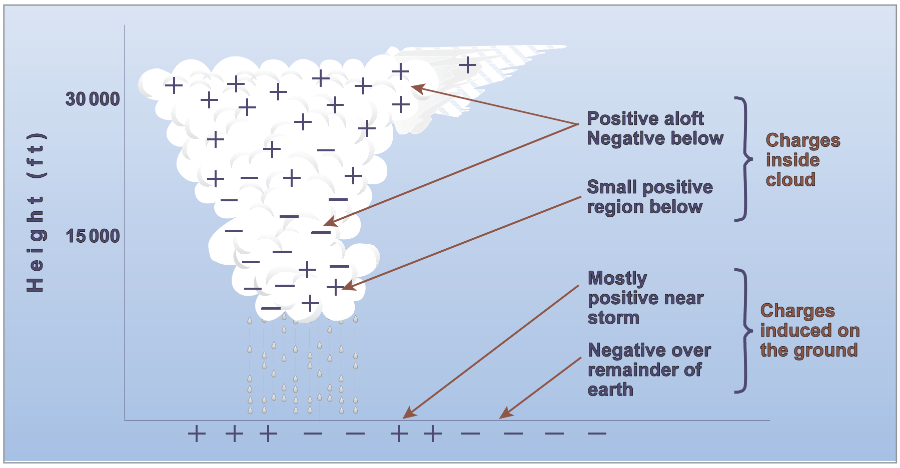


Figure 14.3 Electrostatic charge on a thundercloud

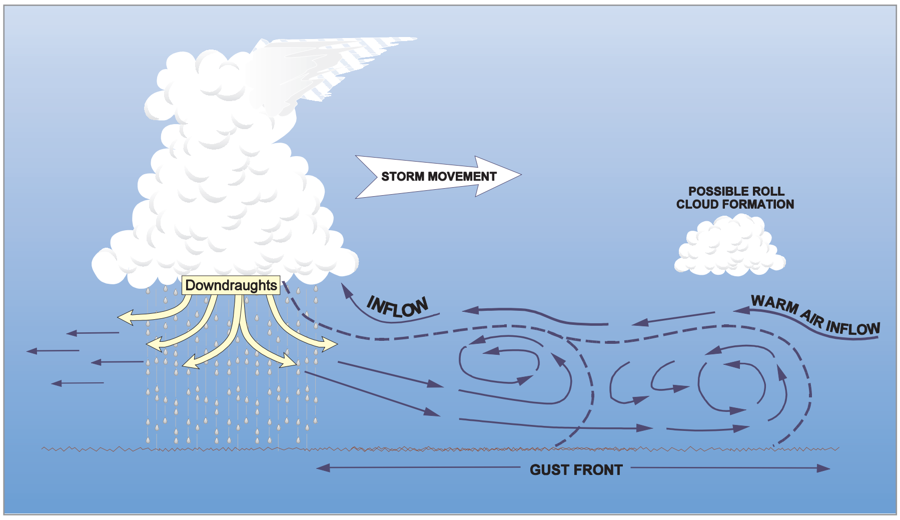


Figure 14.4 Gust front

- **Dissipating stage.** At this stage there is **precipitation**, which is heavy, and **extreme turbulence**. Thunder and lightning may possibly occur at this stage.

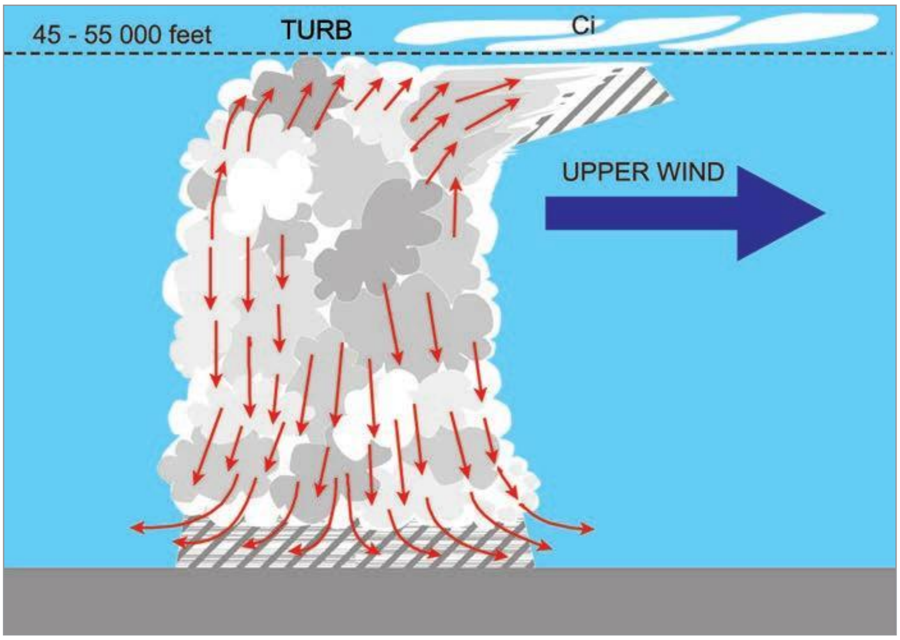


Figure 14.5 The dissipating stage of thunderstorm development

The cloud extends to the tropopause, where it is spread out by the upper wind to form an **anvil**. At these levels the cloud thins to form Ci.

Large variations in static charge in and around the cloud cause discharge in the form of lightning which can appear in the cloud, from the cloud to the ground, or from the cloud to the air alongside.

The dissipating stage lasts for a further 1 1/2 to 2 1/2 hours.

Movement of Thunderstorms

Single cell thunderstorms usually move in the direction of the 10 000 ft (700 hPa) wind, though large storms and newly developed ones may differ from this.

Alignment

Thunderstorm squall lines may occur at and some miles ahead of an active cold front.

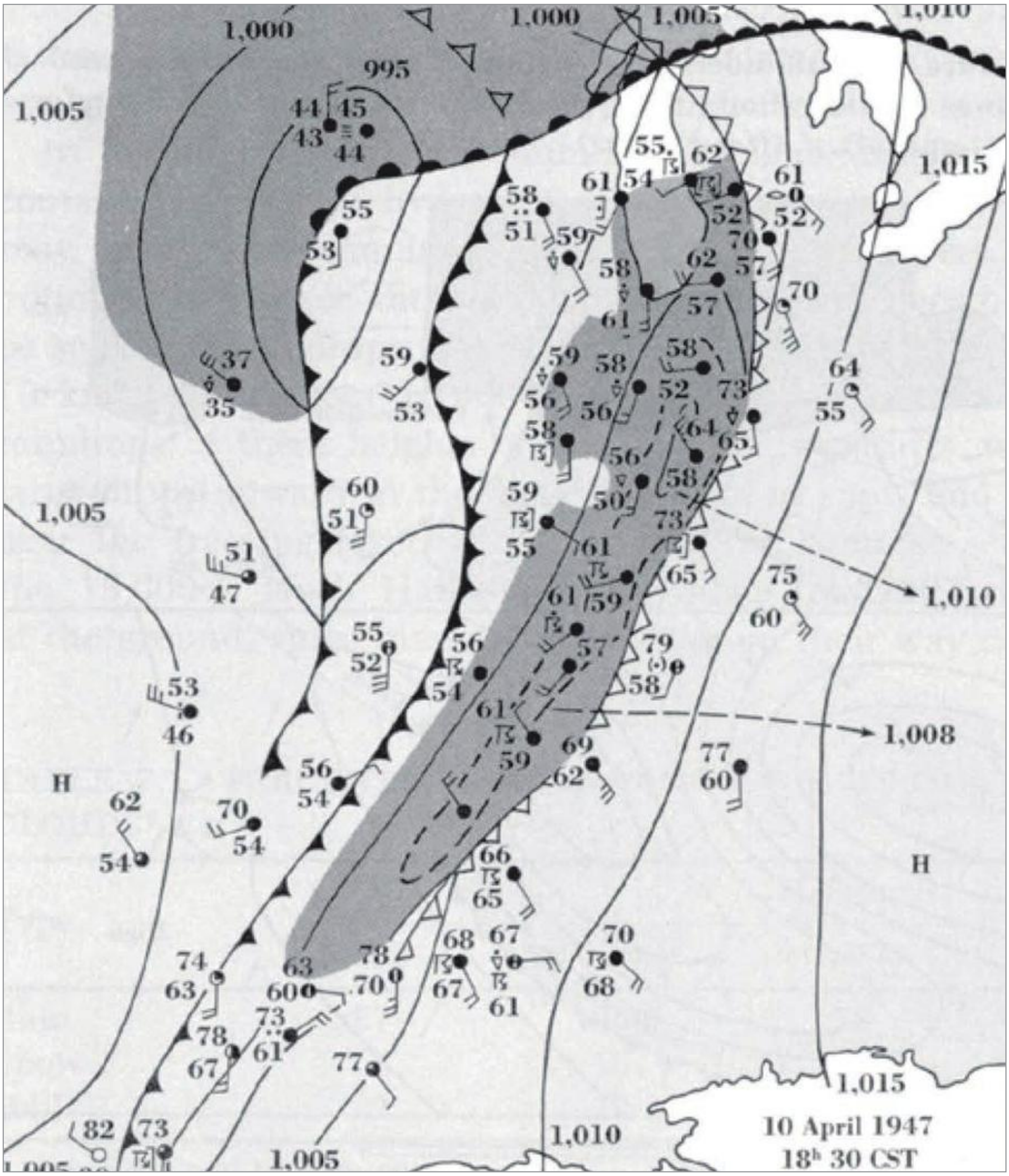


Figure 14.6 Squall line

Forecasting

Forecasting the occurrence of thunderstorms will be largely a matter of assembling the conditions necessary for the formation and the triggers. A combination of these two groups will indicate the probability of thunderstorms. **Satellite photography** and **computer modelling** are used to predict this occurrence.

Supercell Thunderstorms (Severe Local Storms)

- **Initial Stage**
  Conditions necessary to initiate these thunderstorms are:

  - Great depth of instability
  - Strong vertical windshear
  - Stable layer between warm (lower) and cool (upper) air which is eventually broken down by insolation.

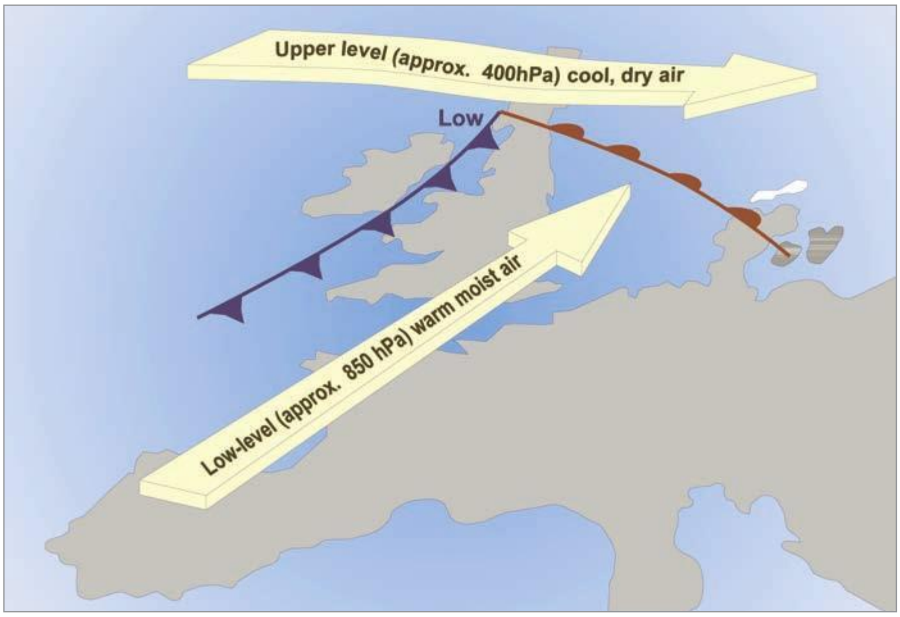


Figure 14.7 Conditions for supercell thunderstorm

- **Mature Stage**
  Characteristics of the mature stage are:
  - Very strong up and downdraughts produced in the one large (super) cell give rise to violent weather and even **tornadoes** (an average of 33 tornadoes per year have occurred in Britain over recent years reminding us that they are not a phenomena restricted to the USA.)
  - The mature stage may last several hours.

- **Movement**
  In the Northern Hemisphere movement is usually about 20° to the right of the 18 000 ft (500 hPa) W/V.

- **Location**
  Supercell thunderstorms are more common over continental land masses than over maritime areas. Thunderstorms over the mid-west states of the USA producing tornadoes are good examples.

Avoidance

The CAA has produced recommended avoidance distances when using weather radar. These are shown below in *Figure 14.8*. It should be noted that the significance of a radar return of given intensity usually increases with altitude. The principle underlying use of airborne weather radar is that strong up currents (which will support strong turbulence) will support large water droplets, which will show a stronger radar return. The diagram at *Figure 14.8* shows a display that can be found on a typical /generic EFIS display.

Figure 14.8 Typical Weather Mode Display

Recommended Thunderstorm Avoidance Ranges Using Airborne Radar

Flight Altitude (ft)	Echo Characteristics			
	Shape	Intensity	Gradient of Intensity*	Rate of Change
0 - 20 000	Avoid by 10 miles echoes with 'hooks', 'fingers', scalloped edges or other protusions from the main storm return.	Avoid by 10 miles echoes with sharp edges or strong intensities.	Avoid by 10 miles echoes with strong gradients of intensity	Avoid by 10 miles echoes showing rapid change of shape, height or intensity.
20 - 25 000	Avoid all echoes by 20 miles.			
25 - 30 000	Avoid all echoes by 20 miles.			
Above 30 000	Avoid all echoes by 20 miles.			
*Applicable to sets with Iso-Echo or a colour display. Iso-Echo produces a hole in a strong echo when the returned signal is above a pre-set value. Where the return around a hole is narrow, there is a strong gradient of intensity.				

Radar

Airborne Weather Radar (CCWR) is Plan Position Indicator (PPI) radar, but ground radar, though mostly PPI, may also use RHI (range-height indicator). CCWR is explained elsewhere in this course, but *Figure 14.9* shows how returns from many radars are combined to produce an area display which will be multicoloured to identify different precipitation intensities.

A Stormscope is a highly sophisticated system that detects, locates and maps areas of electrical discharge activity contained within thunderstorms permitting avoidance of the associated hazards.

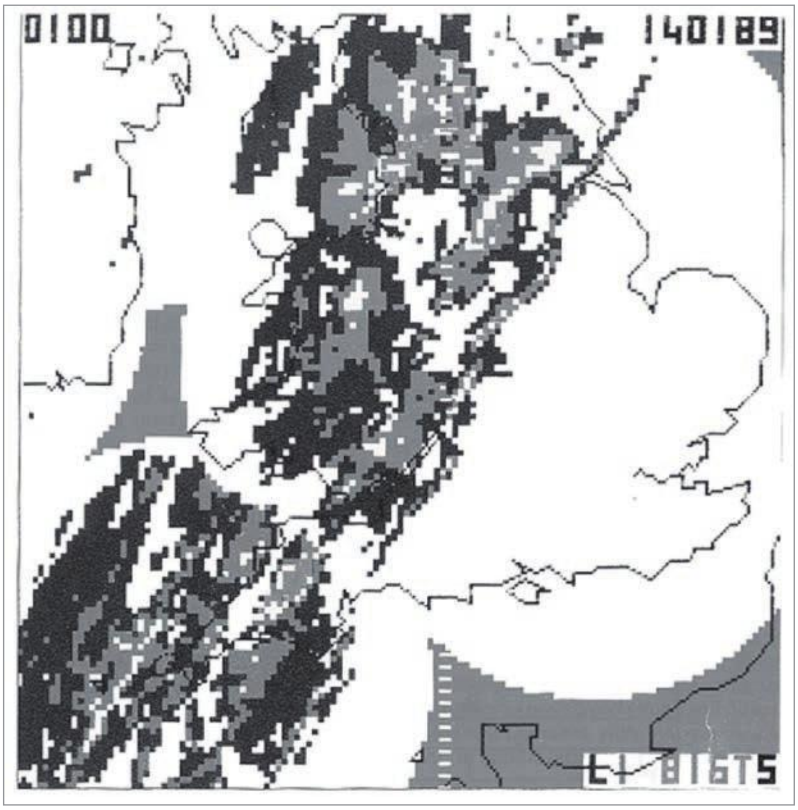


Figure 14.9 Radar Mosaic

Summary of Thunderstorm Hazards

- **Turbulence.** Turbulence can be violent both within cloud and at their sides. Below the cloud, turbulence can be dangerous during take-off and landing and there can be windshear. It is possible for a pilot to overstress the airframe in these conditions.

  Loose articles being thrown about inside the aircraft cabin can injure passengers. Pressure instruments can be in error due to lag.

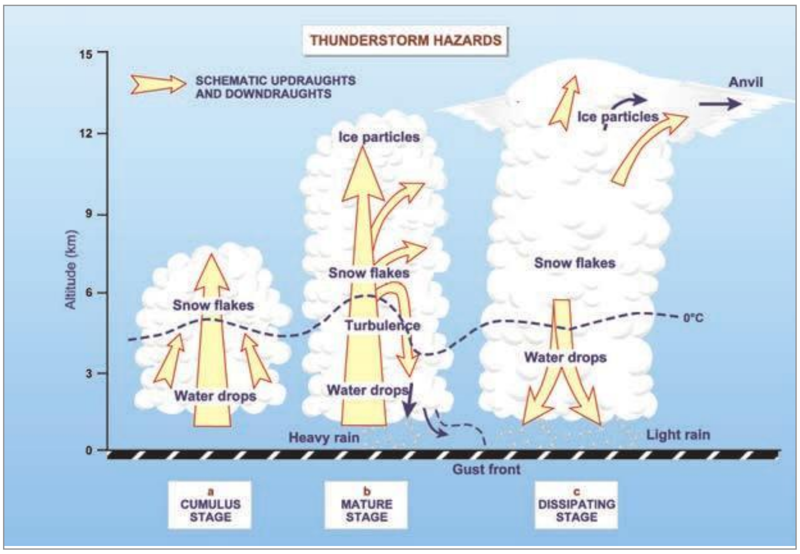


Figure 14.10 Thunderstorm Hazards

- **Hail.** Hail can be met at any height in the cloud, also below the cloud and below the anvil. Severe skin damage to the airframe can occur when the hail is large. Damaging hail can occur up to a height of 45 000 feet.

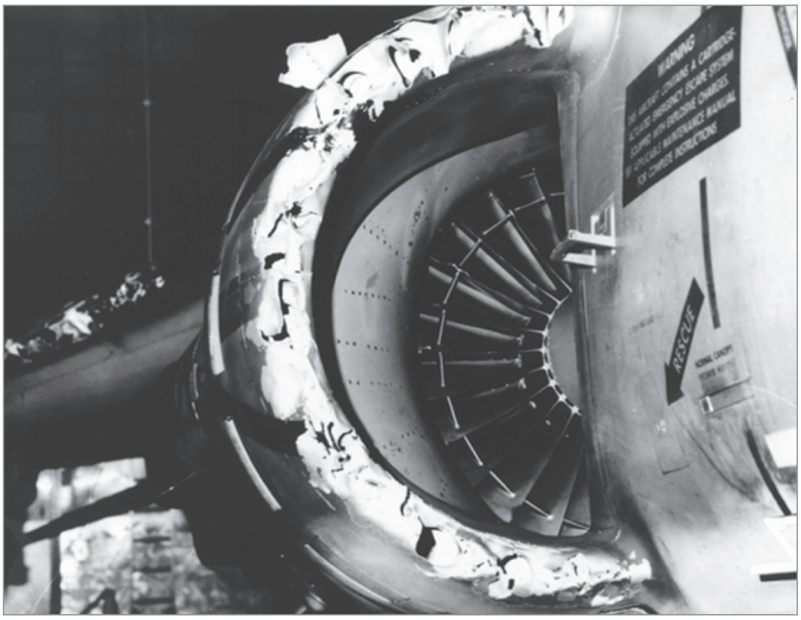


Figure 14.11

- **Icing**. This can occur at all heights in the cloud where the temperature is between 0°C and -45°C. Heavy concentrations of droplets and large droplet size result in severe clear icing.

  Carburettor icing can occur at temperatures between -10°C and +30°C and it can be particularly severe between -2°C and +15°C.

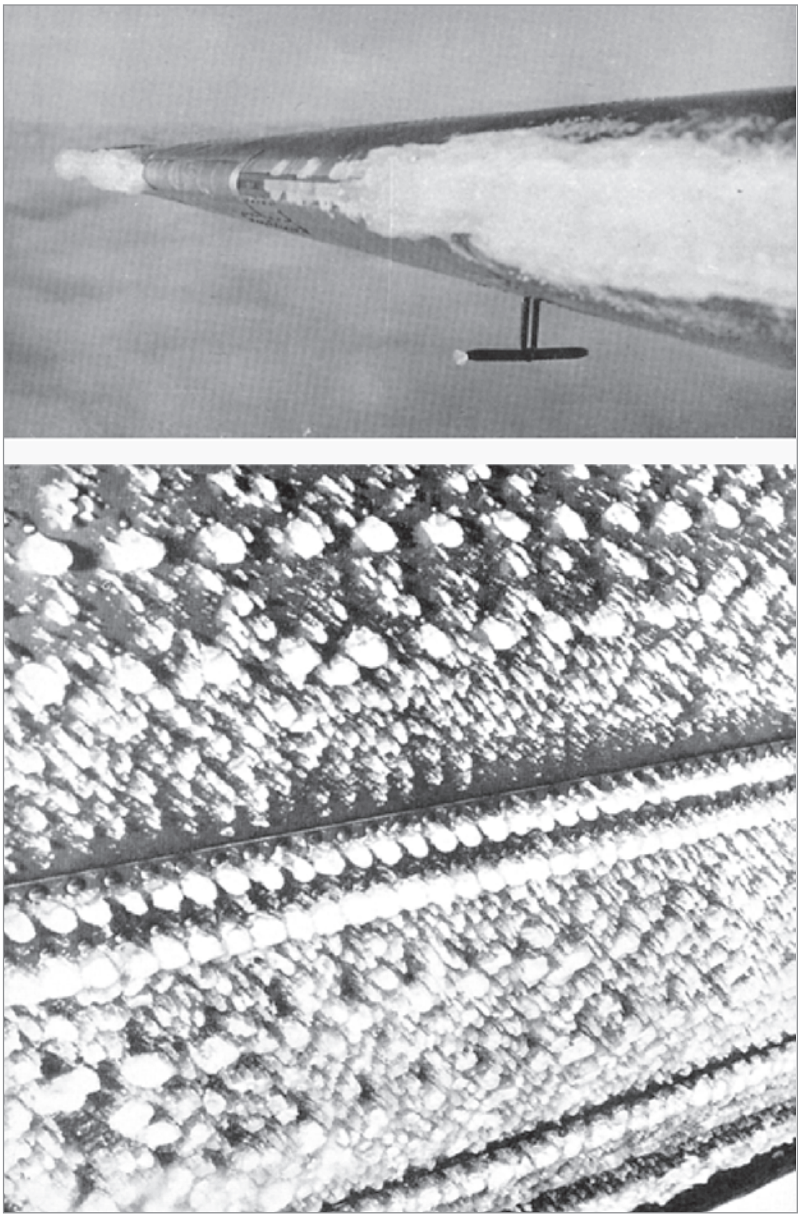


Figure 14.12 Ice accretion on tailplane and underwing

- **Lightning.** Lightning is most likely to occur within about 5000 ft of the freezing level. Temperature between +10°C and -10°C. The main effects of a lightning strike are:

    - Temporary blindness of the pilots
    - Minor airframe damage
    - Magnetic compasses may be seriously affected (errors of 10s of degrees have been recorded) and their information should be used with caution until they can be checked
    - Disruption to electrical equipment

Figure 14.13 Lightning

- **Static.** This causes interference on radio equipment in the LF, MF, HF and VHF frequencies. St Elmo's fire can be caused by static and it results in purple rings of light around the nose, wing tips and propellers.

  This is not a hazard, but it indicates that the air is electrically charged and lightning is probable.

- **Pressure variations.** Local pressure variations covering only a very small region, in or close to, a storm can occur causing QFE/QNH to be in error, so that altimeter readings can be inaccurate by as much as ±1000' at all heights. These, together with gust effects, can cause height errors at low level which can be dangerous.

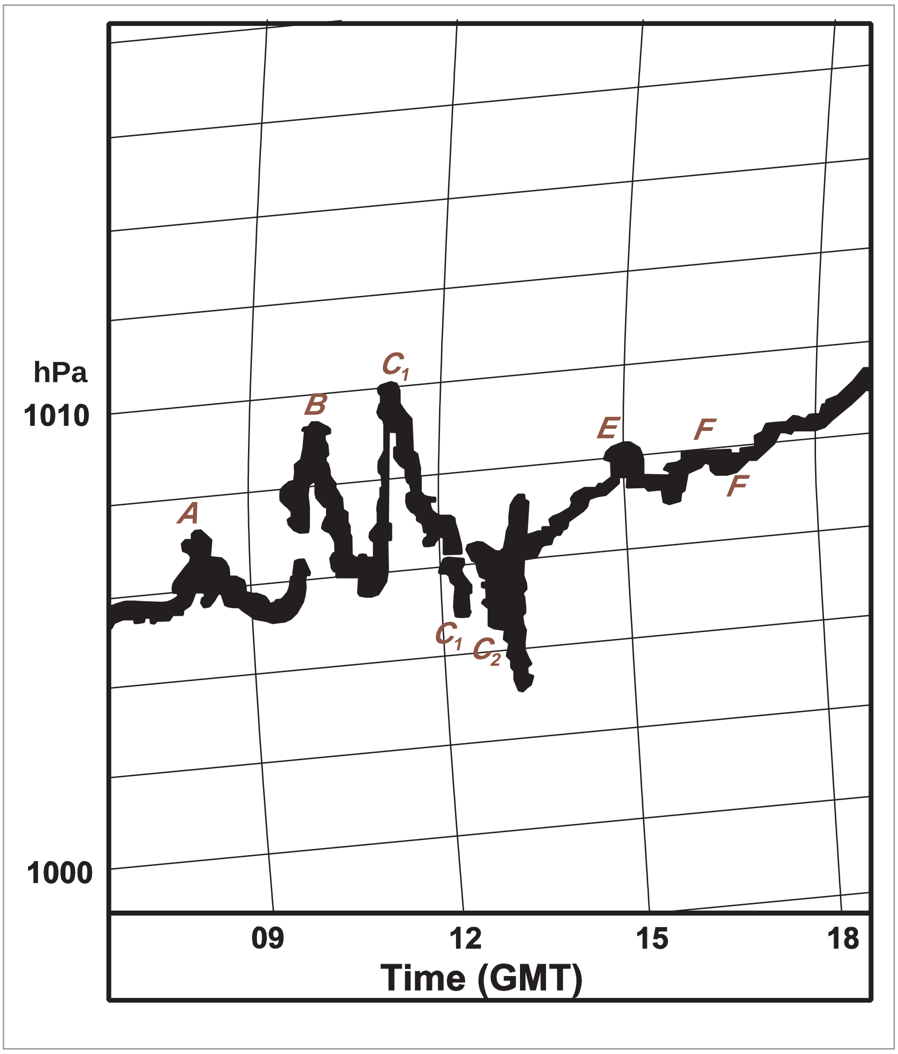


Figure 14.14 Barogram during a thunderstorm pressure variations

VSIs will also be subject to errors. The aircraft should be flown for **ATTITUDE** rather than altitude, though some attitude indicators may not be able to cope with the changes of attitude produced by the severe turbulence likely to be encountered.

- **Microbursts.** These are down currents in the cloud which also move outwards by reaction from the ground, having speeds considerably in excess of 1000 feet per minute downwards (up to 6000 fpm) and 50 kt horizontally. The windshear (headwind to tailwind) may be between 50 & 90 kt. They are largely caused by descending raindrops which cool the surrounding air by evaporation, the higher density accelerating the downdraught still further.

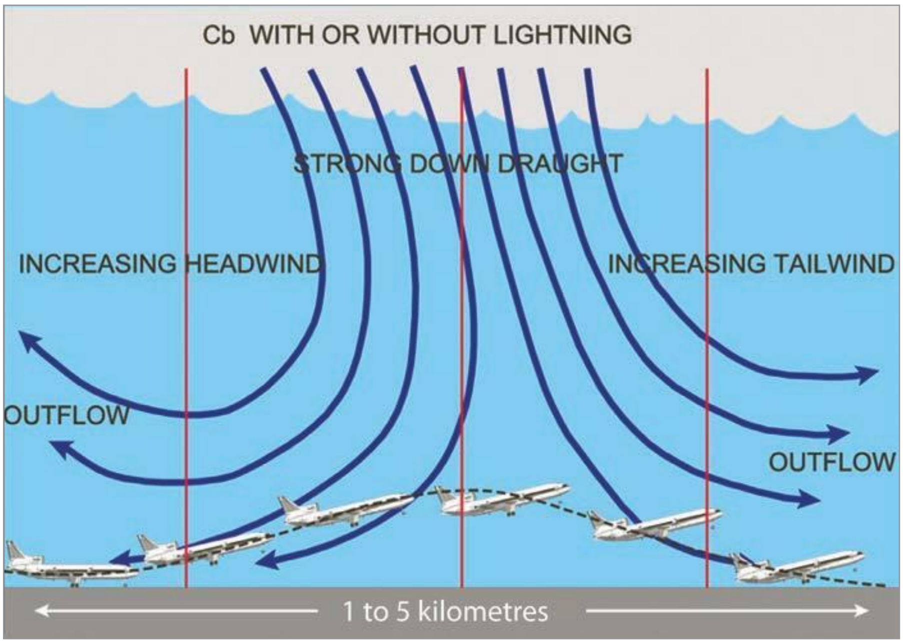


Figure 14.15 Microbursts

They are concentrated in a burst which is up to 4 km in horizontal length and have a lifetime of less than 5 minutes. (A macroburst is a similar event but over a bigger area.)

Microbursts are most likely to occur in summer air mass thunderstorms in low latitude regions where surface conditions are dry. They cause extreme turbulence and severe windshear conditions.

A warning sign is **virga**, which is streaks of precipitation from below the cloud which do not reach the ground.

- **Water ingestion.** If updraught speed approaches or exceeds the terminal velocity of the falling raindrops, the resulting high concentrations of water can exceed the design limits for water ingestion in some turbine engines. The result can be engine flame-out and/or engine structural failure. Water ingestion may also affect pitot heads, even though heaters have been switched on.

- **Tornadoes.** Tornadoes are exclusively associated with CB and large CU clouds. They usually occur as a result of vertical windshear with warm moist air at low altitude and cool dry air coming from a different direction at high altitude. They are very powerful whirlwinds with small horizontal extent and very low pressure in the centre.

  The highest incidence is in the southern states of the USA (tornado alley) in the spring and early summer when very warm air from the Gulf of Mexico, moving north, meets relatively cold air coming from the northwest. This gives massive instability and the windshear required. These tornadoes may have rotational speeds in excess of 200 kt and diameters up to 1 km.

Fortunately in Europe we do not have such volatile conditions. Typically the maximum diameter of a tornado will be 100 to 150 m, but most are considerably smaller than this. They are most likely to be associated with air mass thunderstorms in the summer months and usually occur in the afternoon. When they occur over the sea they appear as water spouts

The Fujita Scale

Dr. Fujita of the University of Chicago has devised a scale based on the damage caused by the tornadoes. It should be noted that the scale is based on the observed damage so different construction standards may result in erroneous assessment of speed.

	Estimated wind speed				
F Scale Number	**kt**	**KMH**	**Relative Frequency**	**Average damage path width**	**Potential Damage**
F0	34-63	64–116	38.9%	10–50	(Gale tornado) Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	64-97	117–180	35.6%	30–150	(Moderate tornado) Moderate damage. The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving vehicles pushed off the roads; attached garages may be destroyed.
F2	98-136	181–253	19.4%	110–250	(Significant tornado) Significant damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; highrise windows broken and blown in; light-object missiles generated.

F3	137-179	254–332	4.9%	200–500	(Severe tornado) Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	180-225	333–418	1.1%	400–900	(Devastating Tornado) Devastating damage. Well-constructed houses levelled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	226-276	419–512	<0.1%	1100 ~	(Incredible Tornado) Incredible damage. Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 m; trees debarked; steel reinforced concrete structures badly damaged.

Dust devils are small whirlwinds usually occurring on hot and sunny afternoons when strong convective currents interact. In dry conditions they will draw up dust off the ground, hence the name. Whilst wind speeds may exceed gale force they have small diameter and will only extend up to a maximum height of around 2000 ft. As with tornadoes dust devils will be hazardous to aircraft and should be avoided.

Questions

1. **The conditions which must exist to allow thunderstorms to develop are:**

    a. a trigger action, a plentiful supply of moisture and a very stable atmosphere
    b. a steep lapse rate, a stable atmosphere through a large vertical extent and a plentiful supply of moisture
    c. a plentiful supply of moisture and a steep lapse rate through a large vertical extent and a trigger action
    d. a steep lapse rate through a large vertical extent, a low relative humidity and a trigger action

2. **When moist air moves across France in the . . . . TS activity is common in southern UK in the . . . .**

    Complete the above statement correctly using one of the following:

    a. winter/morning
    b. summer/late afternoon or evening
    c. winter/late afternoon or evening
    d. summer/morning

3. **Hazards of the mature stage of a TS cell include lightning, turbulence and:**

    a. microburst, windshear and anvil
    b. icing, microburst and windshear
    c. icing, drizzle and microburst
    d. windshear, hail and fog

4. **On a significant weather chart the thunderstorm symbol signifies:**

    a. moderate turbulence and moderate icing
    b. severe turbulence and severe icing
    c. moderate turbulence and severe icing
    d. moderate/severe turbulence and/or moderate/severe icing

5. **Thunderstorms require a trigger action to release the conditional instability. Which of the following would be the least suitable as a trigger?**

    a. Convergence in temperate latitudes
    b. Convergence in tropical latitudes
    c. Subsidence in tropical latitudes
    d. Convection in polar latitudes

6. **During the . . . . stage of a thunderstorm cell, the cloud contains . . . .**
    Complete the above statement correctly using one of the following:

    a. building/up currents and down currents
    b. mature/up currents and down currents
    c. dissipating/up currents and down currents
    d. building/down currents only

7. **The following is unlikely to be a hazard below a thunderstorm:**

   a. severe turbulence
   b. severe icing
   c. windshear
   d. large variations in pressure setting values

8. **Thunderstorms are likely if:**

   a. air is unstable, there is sufficient water vapour and there is trigger action
   b. air is completely stable, there is sufficient water vapour and there is lifting orographically
   c. there is a warm front
   d. there is a col in winter

9. **Hail grows by:**

   a. freezing as it leaves the cloud
   b. up and down progress in CU cloud
   c. collision with supercooled water drops
   d. collision with ice crystals

10. **How long approximately does a cumulonimbus cell take to complete the full cycle from the cumulus (building) to dissipating stage?**

   a. 2-3 hours
   b. 1-2 hours
   c. 4-5 hours
   d. About 1 hour

11. **When approaching at flight level 300 a cumulonimbus cloud with an anvil top, pilots should aim to avoid the cloud by — NM horizontally if avoiding visually, or by — NM horizontally if using cloud avoidance radar. Select the appropriate respective ranges from those given below:**

a.	10	20
b.	15	10
c.	10	15
d.	5	10

12. **A microburst usually lasts for _________ and is about ____________across.**

a.	20 minutes	20 NM
b.	5 minutes	5 km
c.	30 minutes	10 NM
d.	45 minutes	5 NM

13. **Thunderstorms caused by _________are most common in the summer and by ____________in the__________**

a.	lapse rate	air masses	late spring
b.	air masses	frontal activity	winter
c.	cold fronts	air masses	autumn
d.	air masses	frontal activity	summer

14. **When flying through an active CB cloud, lightning strikes are most likely:**

a. above 5000’ and underneath the anvil
b. in the clear air below the cloud in rain
c. in the temperature band between +10°C and –10°C
d. at or about 10 000 ft AMSL

15. **Regarding thunderstorms, the most accurate statement amongst the following is:**

a. there will always be windshear under the cloud
b. the average movement is in accord with the wind at 10 000 ft
c. if the cloud base has a temperature below 0°C then freezing rain will occur
d. the number of lightning flashes is directly proportional to the degree of turbulence

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	b	b	d	c	b	b	a	c	a	c	b

13	14	15
b	c	b

United Kingdom Aeronautical Information Circular

AIC: P 056/2010

12-AUG-2010

Safety

The Effect of Thunderstorms and Associated Turbulence on Aircraft Operations.

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1 Introduction

1.1 This Circular has been produced to provide an understanding of the hazard that thunderstorms and their associated effects can pose to all aircraft operations and replaces the guidance previously published in AIC P 019/2010. It has been published for the information and safety of all pilots.

1.2 This Circular has been written with two-pilot operation of larger aircraft in mind; however, text that has been highlighted by the use of capital letters is of particular relevance to pilots of all aircraft.

1.3 The overarching advice in this Circular is that flight through thunderstorms should be avoided.

2 Thunderstorm Warnings

2.1 Meteorological Watch Offices (MWO) issue SIGMET (Significant Meteorology) warnings of 'Thunderstorms' when significant cumulonimbus clouds likely to produce thunderstorms are forecast and when these thunderstorms are expected to be difficult to detect visually by a pilot. They could be obscured (OBSC TS), embedded in other clouds (EMBD TS) and could possibly be frequent (FRQ TS) or organised along a line (SQL TS). These warnings include information on the location, movement and development of the thunderstorm areas. As it is expected that all pilots will be aware of the additional phenomena associated with thunderstorms, ie hail, severe icing, and severe turbulence (as expanded on in the Annex to this Circular), these forecast details will not be included in the SIGMET text, although heavy hail (HVYGR) could be included. In addition, aircraft commanders are required to send a Special Aircraft Observation when conditions are encountered likely to affect the safety of aircraft. Such a report could then trigger a SIGMET warning. MWOs do not issue SIGMET warnings in relation to isolated or scattered thunderstorms not embedded in cloud layers or concealed by haze (unless prompted by a Special Aircraft Observation). It should therefore be noted that the absence of a SIGMET warning does not necessarily indicate the absence of thunderstorms.

2.2 Aerodrome Warnings are issued by the Meteorological Office for terminal area operations where there is a forecast likelihood of thunderstorms in the immediate vicinity of an aerodrome. Separate windshear warnings may be issued at some aerodromes (notably London Heathrow and Belfast Aldergrove) where a nearby thunderstorm is the criteria for a windshear warning. Elsewhere, the proximity of a thunderstorm will not necessarily result in such a warning, but the probability of windshear is no less. In relation to windshear hazards at low-level your attention is drawn to AIC 84/2008 (Pink 150) - 'Low Altitude Windshear'.

2.3 Details of the criteria for Special Aircraft Observations and the SIGMET service are given in the UK Aeronautical Information Publication at GEN 3.5 paragraph 6.2 and GEN 3.5 paragraph 8 respectively.

3 Procedures and Flying Techniques

3.1 Notwithstanding the advice that follows, gathered from research and operational experience, the first and most basic advice for all pilots is:

Do not treat thunderstorms lightly and whenever possible AVOID them.

3.2 Thunderstorms should be avoided either visually, by the use of radar, or by other methods. If this cannot be achieved, and in the absence of specific aircraft flight manual or operations manual guidance, the following procedures and techniques are recommended.

a. If it is found necessary to penetrate an area of cloud which may contain cumulonimbus clouds:

i. ENSURE THAT CREW MEMBERS' SAFETY BELTS OR HARNESSES ARE FIRMLY FASTENED AND SECURE ANY LOOSE ARTICLES BEFOREHAND. Switch on the seat belt notices and make sure that all passengers are securely strapped in and that loose equipment (eg cabin trolleys and galley containers) are firmly secured. Pilots should remember that turbulence is normally worse in the rear of an aircraft than on the flight deck.

ii. One pilot should control the aircraft with the other continually monitoring all the flight instruments.

iii. SELECT AN ALTITUDE FOR PENETRATION, BEARING IN MIND THE IMPORTANCE OF ENSURING ADEQUATE TERRAIN CLEARANCE IN LIKELY DOWNDRAUGHTS. Investigations have shown that although in some thunderstorms there is very little turbulence at the lower levels, in others there is a great deal; altitude is not necessarily a guide to the degree of turbulence. Increasing height will decrease the buffet margin and up-currents may force the aircraft into buffet owing to an increased angle of attack.

iv. SET THE POWER TO GIVE THE RECOMMENDED SPEED FOR FLIGHT IN TURBULENCE, ADJUST THE TRIM AND NOTE ITS POSITION SO THAT ANY EXCESSIVE CHANGES DUE TO AUTOPILOT OR MACH TRIM OPERATION CAN BE QUICKLY ASSESSED. Turbulence speeds quoted in flight or operations manuals provide a single speed or a speed bracket.

v. CHECK ALL FLIGHT INSTRUMENTS AND ELECTRICAL SUPPLIES.

vi. ENSURE THAT THE PITOT HEATERS ARE SWITCHED ON.

vii. CHECK THE OPERATION OF ALL ANTI-ICING AND DE-ICING EQUIPMENT AND OPERATE ALL THESE SYSTEMS IN ACCORDANCE WITH MANUFACTURER'S OR OPERATOR'S INSTRUCTIONS. The operation of leading edge, expanding boot type de-icers should be delayed until some ice has formed, otherwise their effectiveness will be greatly reduced. IN THE ABSENCE OF SPECIFIC INSTRUCTIONS, ENSURE THAT ALL ANTI-ICING SYSTEMS, INCLUDING WINDSCREEN HEATERS, ARE ON.

viii. DISREGARD ANY RADIO NAVIGATION INDICATIONS SUBJECT TO INTERFERENCE FROM STATIC, eg ADF.

ix. TURN THE COCKPIT LIGHTING FULLY ON AND LOWER THE CREW SEATS AND SUN VISORS TO MINIMISE THE EFFECT OF ANY LIGHTNING FLASHES.

x. FOLLOW THE MANUFACTURER'S OR OPERATOR'S RECOMMENDATIONS ON THE USE OF THE FLIGHT DIRECTOR, AUTOPILOT AND MANOMETRIC LOCKS. If these are not stated, height, Mach, rate of climb or descent, and airspeed locks should be disengaged but the yaw damper(s), if fitted, should remain operative. On many aircraft the autopilot, when engaged in a suitable mode (turbulence or basic attitude modes), is likely to produce lower structural loads than would result from manual flight. However, if major trim movements occur due to the autopilot's automatic trim the autopilot should be disengaged. Note that Mach trim operation may also occur on some aircraft but the Mach trim should remain engaged.

xi. Continue operating, not just monitoring, the weather radar, or other on-board systems, in order to select the safest track for penetration, and to minimise the time of exposure whilst avoiding areas of intense activity.

xii. Be prepared for turbulence, rail, hail, snow, icing, lightning, static discharge and windshear. In turbine-powered aircraft switch on the continuous ignition system (to reduce the possibility of engine flame-out due to water ingestion) ensuring that limitations on its use, if any, are not exceeded. Also see AIC 29/2004 (Pink 64) - 'Engine Malfunction caused by Lightning Strikes'.

xiii. AVOID FLYING OVER THE TOP OF A THUNDERSTORM WHENEVER POSSIBLE. Overflying small convective cells close to large storms should also be avoided, particularly if they are on the upwind side of a large storm, because they may grow very quickly. Similarly, do not contemplate flying beneath the cumulonimbus cloud. In addition to the dangers associated with turbulence, rain, hail, snow or lightning, there may well be low cloud base, poor visibility and possibly low-level windshear.

b. Within the Storm Area:

i. CONTROL THE AIRCRAFT REGARDLESS OF ALL ELSE.

ii. CONCENTRATE ON MAINTAINING A CONSTANT PITCH ATTITUDE APPROPRIATE TO CLIMB, CRUISE OR DESCENT, BY REFERENCE TO THE ATTITUDE INDICATORS, CAREFULLY AVOIDING HARSH OR EXCESSIVE CONTROL MOVEMENTS. DO NOT BE MISLED BY CONFLICTING INDICATIONS ON OTHER INSTRUMENTS. DO NOT ALLOW LARGE ATTITUDE EXCURSIONS IN THE ROLLING PLANE TO PERSIST BECAUSE THESE MAY RESULT IN NOSE DOWN PITCH CHANGES.

iii. MAINTAIN THE ORIGINAL HEADING - IT IS USUALLY THE QUICKEST WAY OUT. DO NOT ATTEMPT ANY TURNS.

iv. DO NOT CORRECT FOR ALTITUDE GAINED OR LOST THROUGH UP AND DOWN DRAUGHTS UNLESS ABSOLUTELY NECESSARY.

v. Maintain the trim settings and avoid changing the power setting except when necessary to restore margins from stall warning or high-speed buffet. The target pitch attitude should not be changed unless the mean IAS differs significantly from the recommended penetration speed.

vi. If trim variations due to the autopilot (auto-trim) are large, the autopilot should be disengaged. However, movement of the Mach trim, where it occurs, is necessary and desirable. Check that the yaw-damper remains engaged.

vii. If negative 'G' is experienced, temporary warnings (eg low oil pressure) may occur. These should be ignored.

viii. ON NO ACCOUNT CLIMB IN AN ATTEMPT TO GET OVER THE TOP OF THE STORM.

c. After a Thunderstorm Encounter - In flight:

i. If hail has been encountered, considerable damage to the airframe, not visible from the cockpit or cabin, may have occurred. Consideration should therefore be given to diverting to a suitable and nearby aerodrome where the aircraft can be inspected for damage. If this damage has occurred to aerodynamically significant areas, eg a nose radome, the increased drag will affect fuel burn. Thus the aircraft, if continuing to its destination, may burn considerably more fuel than expected or planned.

Actual fuel usage should now be monitored very closely, bearing in mind that some FMS calculate 'expected overhead destination' fuel, based on data that assumes normal (planned) conditions and normal (ie fully clean) aircraft aerodynamic states.

ii. If the aircraft has been struck by lightning, treat all magnetic information (eg from direct or remote indicating compasses) with extreme caution. The large electric currents associated with a lightning strike can severely and permanently distort the magnetic field of an aircraft rendering all such information highly inaccurate.

d. Air Traffic Control Considerations:

i. Modern ATC radars in general do not display the build up of weather that may constitute a hazard to aircraft and ATC advice on weather avoidance may, therefore, be limited.

ii. If, as recommended in this Circular, a pilot intends to detour round observed weather when in receipt of an Air Traffic Service that involves ATC responsibility for separation, clearance should first be obtained from ATC so that separation from other aircraft can be maintained. If for any reason the pilot is unable to contact ATC to inform the controller of his/her intended action, any manoeuvre should be limited to the extent necessary to avoid immediate danger and ATC must be informed as soon as possible. In oceanic airspace the weather deviation procedure in PANS-ATM, (ICAO Doc 4444) paragraph 15.2.3 should be followed.

iii. Because of the constraints on airspeed and flight path and the increased workload of the crew when flying in a Terminal Manoeuvring Area, pilots should consider making a diversion from, or delaying entry to, a Terminal Manoeuvring Area if a storm encounter seems probable.

e. Take-off and Landing Problems:

i. The take-off, initial climb, final approach and landing phases of flight present the pilot with additional problems because of the aircraft's proximity to the ground, thus the maintenance of a safe flight path in these phases can be very difficult.

ii. Some operators give advice on the airspeed adjustments to be made to allow for windshear or turbulence (a speed increase of up to 20 knots according to the type of aircraft and the degree of turbulence may be required). The best advice that can be given to the pilot is that, when there are thunderstorms over or near the aerodrome, he/she should delay take-off or, when approaching to land, hold in an unaffected area or divert to a suitable alternate. For further relevant information see AIC 84/2008 (Pink 150) - 'Low Altitude Windshear'.

f. Airworthiness and Maintenance Considerations:

i. Severe weather conditions may cause damage to aircraft and power plant installations, some of which may be invisible to the naked eye. Flight Manuals and Maintenance documents may quantify levels of turbulence which would trigger a maintenance inspection, similar to those that may be applicable to 'heavy landings'. Hail and lightning damage may often be obvious to crews; however, there will be occasions where damage may be restricted to parts of the airframe not normally visible from the ground, or from the cockpit, immediately following a thunderstorm encounter.

ii. In the event that crews believe that an aircraft has been exposed to hail, lightning, turbulence greater than 'moderate', or a heavy landing, they should record the fact(s) in the technical log on arrival to ensure that an appropriate inspection is completed prior to a subsequent release to service. Operators should ensure that procedures in operation manuals for flight crews and maintenance personnel reflect this advice.

g. Light aircraft operators should ensure that their aircraft are adequately secured on the ground when severe thunderstorm activity is forecast.

4 Concluding Remarks

4.1 DO NOT TAKE OFF IF A THUNDERSTORM IS OVERHEAD OR APPROACHING.

4.2 AT DESTINATION HOLD CLEAR IF A THUNDERSTORM IS OVERHEAD OR APPROACHING. DIVERT IF NECESSARY.

4.3 AVOID SEVERE THUNDERSTORMS EVEN AT THE COST OF DIVERSION OR AN INTERMEDIATE LANDING. IF AVOIDANCE IS IMPOSSIBLE, THE PROCEDURES RECOMMENDED IN THE FLIGHT OR OPERATIONS MANUAL OR IN THIS CIRCULAR SHOULD BE FOLLOWED.

4.4 Pilots of turbo-jet swept-wing transport aircraft are advised to ensure that they are fully conversant with the control problems that may be met in turbulence with the type of aircraft they fly.

4.5 AFTER AN ENCOUNTER WITH A THUNDERSTORM CONSIDER REPORTING THE EVENT IN THE AIRCRAFT TECHNICAL LOG. THIS WILL ENSURE THAT A FULL AND PROPER INVESTIGATION OF THE AIRCRAFT OCCURS.

ANNEX

1 Thunderstorms, Flight Hazards and Weather Radar

1.1 A thunderstorm cloud, whether of the air mass or frontal type, usually consists of several self-contained cells, each in a different state of development. It must be stressed that the storm clouds are only the visible part of a turbulent system that extends over a much greater area. New and growing cells can be recognised by their cumuliform shape with clear-cut outline and 'cauliflower' top, while the tops of more mature cells will appear less clear-cut and will frequently be surrounded by fibrous cloud. It is important, however, to remember that the development of cells, which can be very rapid, will not always be seen, even in daylight, since other clouds may obscure the view. In frontal or orographic conditions, for instance, where forced ascent of air may give the impetus required for producing vigorous convection currents, extensive layer cloud structures may obscure a view of the development of Cumulonimbus thunderstorm cells or Altocumulus Castellanus; the latter is cumuliform cloud with a base above 8000 ft and is an indication of middle level instability which often precedes, or is associated with, the development of thunderstorms. Mammatus clouds, udder shaped features seen beneath cumulonimbus clouds, or the associated medium level altocumulus layer clouds (above 8000 ft), or in association with the high-level cirrus anvil cloud (above 20 000 ft), are an indication of strong vertical winds with associated turbulence.

1.2 The most severe thunderstorms require an increase in the general wind speed and a change in direction with height to maintain a release of energy. With no vertical windshear, as the cloud grows and the updraught strengthens, precipitation forms in the upper parts of the cloud. As the precipitation falls towards the ground, it exerts a drag on the updraught, which weakens and the cloud decays. However, for a storm that has the downdraught offset from the updraught, particularly where the updraught is not cut off at the surface by the spreading out of the cold downdraught, it can develop into a self-generating system that can last for hours, independently of any surface heating.

1.3 These up and downdraughts are of comparable intensity, often in close proximity to each other and frequently reach speeds in excess of 3000 ft per minute. Sharp gusts with vertical speeds of 10 000 ft per minute have been measured. The horizontal extent of these vertical draughts may, occasionally, be more than a mile. The top of a developing cell has been observed to rise at more than 5000 ft per minute. When thunderstorms are associated with frontal conditions, areas of 'line squall' activity can extend for more than 100 miles. The vertical extent of storms will vary considerably but it is not uncommon for them to penetrate the tropopause with cloud tops exceeding 40 000 ft in temperate latitudes and 60 000 ft in sub-tropical and tropical regions. Although an individual cell will usually last for less than an hour, a storm system, with new cells developing and old ones decaying, may persist for several hours.

1.4 Areas in which conditions will be favourable for the development of thunderstorms can usually be forecast successfully several hours in advance but it is not possible at present to determine the precise location and distribution of individual storms. Where up-to-date ground weather radar information is available, however, useful information on the expected movement of an individual storm can be forecast for periods of up to an hour or so ahead.

1.5 As a general rule of thumb, in the UK, the movement of a cumulonimbus cloud is in the direction of the 10000 ft (700 hectopoascals) wind, though the tendency for large storms to distort wind fields and the development of new cells will cause variations in this general movement.

1.6 All thunderstorms are potentially dangerous. This considered, there are two facts that should be borne in mind. The first is that a severe storm can occur in practically any geographical area in which thunderstorms are known. The second is that no useful correlation exists between the external visual appearance (or the weather radar appearance) of thunderstorm clouds and the turbulence and hail within them.

2 Flight Hazards

2.1 Turbulence Associated with Thunderstorms

2.1.1 The air movement in thunderstorms, generally referred to as turbulence and composed of draughts (sustained vertical or sloping currents) and gusts (irregular and local variations), can become violent, dangerous and even destructive, reaching a maximum intensity in developing and mature cells. High rates of roll and large pitching motions have been experienced in these storms, as have large vertical displacements of as much as 5000 ft. These extreme variations will, of course, only occur in the most severe conditions. Of equal importance is the fact that eddies, which are felt as gusts, can occur some distance outside a thunderstorm cell. The regions around or between adjacent cells are therefore likely to be turbulent - severely so at times - and severe turbulence is often found 15 to 20 miles downwind of a severe storm core. Conditions at or near the surface in the vicinity of thunderstorms are often rough because, during the mature stage of the cells, the outflow from the base is of a turbulent nature and the air is colder than its environment, producing a miniature cold front often accompanied by heavy precipitation and squally conditions. When this is associated with a line of thunderstorms its effects can be felt as much as 40 miles ahead of them. Take-offs and landings in these circumstances are hazardous. Severe turbulence can also be encountered several thousand feet above the tops of active thunderstorm clouds, particularly when the speed of the wind at this level is high (100 kt or more). It is therefore advisable to avoid flying and in particular not to climb, in these areas.

2.1.2 A thunderstorm cell must be well developed before lightning first occurs but it may continue in the decaying cell. Lightning must not, therefore, be regarded as a reliable guide to the degree of turbulence in a cloud.

2.1.3 Accidents involving loss of control of the aircraft have been caused by flying in and around thunderstorms. In some instances there was structural failure that probably occurred during the attempt to regain control.

2.1.4 Stress requirements for modern transport aircraft are set at a level which experience has shown will rarely be reached. Nevertheless, flight research has indicated that, in the extreme conditions that may exist within thunderstorms, abnormal pilot-induced loads are added to already high gust-loads such that stress limits may be exceeded.

2.1.5 In some instances the correct flying technique is difficult to achieve. Indications are that loss of control, which may follow the use of incorrect techniques, is a more serious hazard than the risk of structural failure due directly to an encounter with turbulence. This is because recovery manoeuvres are likely to subject the aircraft to great stresses that may lead to structural failure or serious deformation.

2.2 Thunderstorm Windshear

2.2.1 Accidents have occurred during the take-off, initial climb and final approach phases of flight, which were probably due in part, if not entirely, to the effect of a rapid variation in wind velocity known as windshear. For further information see AIC 84/2008 (Pink 150) - 'Low

Altitude Windshear'. Unlike the erratic fluctuations caused by gusts, windshear gives rise to airspeed fluctuations of a more sustained nature and is therefore likely to be more dangerous. Gusts are likely to accompany windshear conditions.

2.2.2 Thunderstorms frequently produce windshear and, although it is hazardous at all levels, it is in the lower levels that windshear may have more drastic consequences. Winds caused by the outflow of cold air from the base of a thunderstorm cell have been known to change in shallow layers of a few hundred feet by as much as 80 kt in speed and 90º or more in direction. Due to the effect of inertia, an aircraft in flight will tend to maintain its ground speed and windshear will therefore produce airspeed variations that can be large enough to be extremely dangerous.

2.3 Tornadoes

2.3.1 Tornadoes present a very serious threat to aircraft. A Fokker F-28 flying in cloud at 3000 ft shortly after take-off from Rotterdam was destroyed by a tornado on 6 October 1981. Tornadoes are generally associated with organised severe local storms. They occur frequently in the United States but can also arise in the UK and Europe although they are less common and seldom as violent. There is evidence that tornado circulation may extend throughout the depth of the storm and constitute a hazard to aircraft at all heights.

2.3.2 The most violent thunderstorms draw air into their cloud bases with great vigour. If the incoming air has any initial rotating motion, it often forms an extremely concentrated vortex from the surface well into the cloud. Meteorologists have estimated that wind velocities in such a vortex can exceed 200 kt. Because pressure inside the vortex is quite low, the strong winds gather dust and debris and the low pressure generates a funnel-shaped cloud extending downward from the cumulonimbus base. If the cloud does not reach the surface, it is a 'funnel cloud'; if it touches the land surface, it is a tornado.

2.3.3 Tornadoes occur with both isolated and squall line thunderstorms. An aircraft entering a tornado vortex is almost certain to suffer structural damage. Since the vortex extends well into the cloud, any pilot flying on instruments in a severe thunderstorm could encounter a hidden vortex.

2.3.4 Families of tornadoes have been observed as appendages of the main cloud extending several miles outward from the area of lightning and precipitation. Thus any cloud connected to a severe thunderstorm carries a threat.

2.4 Hail

2.4.1 Notwithstanding all the work that has been done in the field of thunderstorm forecasting, no confirmed or fully reliable method has yet been evolved for recognising a storm that will produce hail. It is safest to assume that hail exists in one part or another of every thunderstorm at some stage in its life. The higher the lapse rate and the greater the moisture content of the air mass, the stronger will be the convective activity which increases the likelihood of the formation of damaging hail. Stability in the upper atmosphere results in the characteristic anvil shape of the spreading-out of the top of the cumulonimbus cloud and strong upper winds will often cause hail to fall from the overhang. Flight beneath the overhang should be avoided.

2.4.2 The maximum size of hailstones which have been found on the ground is around five and a half inches in diameter. It is known that hailstones of four inches in diameter can be encountered at 10 000 ft and damaging hail up to 45 000 ft.

2.4.3 Although hail encounters are usually of short duration, damage to aircraft can be severe. Hail may damage the leading edges and hence reduce the efficiency of the wing. Windscreens or other transparencies may be shattered. In an encounter in the Middle East, hail severely damaged the airframe of a VC-10 that encountered a thunderstorm shortly after take-off. The radome was torn away, denting and damage to the skin occurred in many areas, but there was no evidence of a lightning strike.

2.4.4 Although no fatal accidents to civil aircraft are known to have been attributable entirely to hail damage, hail can be a serious hazard at all altitudes at which civil aircraft operate. Evidence for this comes from a study of military aircraft accidents in the USA, in which aircraft were damaged or destroyed by the combined effect of hail and turbulence and from experience gained through the United States National Severe Storms Project together with individual reports of encounters with hail in normal operations.

2.5 Rain

2.5.1 Water ingestion by turbine engines

2.5.1.1 Turbine engines have a limit on the amount of water they can ingest. Updraughts are present in many thunderstorms, particularly those in the developing stages. If the updraught velocity in the thunderstorm approaches or exceeds the terminal velocity of the falling raindrops, very high concentrations of water may occur. It is possible that these concentrations can be in excess of the quantity of water turbine engines are designed to ingest, which could result in flame out and/or structural failure of one or more engines.

2.5.1.2 At the present time, there is no known operational procedure that can completely eliminate the possibility of engine damage/flame out during massive water ingestion but although the exact mechanism of these water induced engine stalls has not been determined, it is believed that thrust changes may have an adverse effect on engine stall margins.

2.5.1.3 To eliminate the risk of engine damage or flame out by heavy rain, it is essential to avoid severe storms. During an unavoidable encounter with extreme precipitation, the best-known recommendation is to follow the severe turbulence penetration procedure contained in the approved aircraft flight manual, with special emphasis on avoiding thrust changes unless excessive airspeed variations occur. Flight research has revealed that water can exist in large quantities at high altitudes even where the ambient temperature is as low as -30°C. Rain, sometimes heavy, may therefore be encountered and give rise to ice accretion and a possibility of the malfunctioning of pressure instruments. Turbine engine igniters must be switched on.

2.5.2 Heavy precipitation, which occurs in cumulonimbus clouds, may often be seen as shafts of rain below the cloud base. Where this precipitation does not reach the surface, the shafts are known as virga. The evaporation cooling associated with virga may intensify existing downdraughts.

2.6 Icing

2.6.1 Flight must not be initiated or continued into areas where the forecast icing conditions will exceed the icing limitations of the aircraft.

2.6.2 Formation of ice on the airframe must always be considered likely when flight takes place through cloud or rain at a temperature below 0°C. The temperature range favourable for ice accretion in thunderstorms is from 0°C down to -45°C, ie where water droplets can exist in a supercooled state. Below about -30°C, however, a large part of the free water content of the atmosphere normally consists of ice particles or crystals and snowflakes and chances of severe icing at these low temperatures are, therefore, greatly reduced. Conversely, because of downdraughts, the freezing level inside thunderstorm clouds must be assumed to drop to the base of the cloud. Airframe icing can therefore be expected everywhere in a thunderstorm cloud.

2.6.3 In piston engines, loss of power can occur over a wide range of temperatures as a result of the formation of ice in the induction system. Proper use of carburettor heat or other induction anti-icing equipment is therefore essential to prevent or minimise the loss of power.

Furthermore, in clear air of high humidity (ie of the order of 60% or more), which might exist in areas of thunderstorm activity, carburettor ice can easily form.

2.6.4 Where turbine engines are concerned, the danger of flame out must be recognised whenever icing conditions are met. Igniters must therefore be switched on and remain on provided they are cleared for continuous operation. In all circumstances operators' or manufacturers' instructions must be strictly followed to achieve maximum protection.

2.6.5 It must be emphasised that, when flying in thunderstorms, anything more than very light ice accretion adds to the problems related to turbulence because of the increased weight of the aircraft, the disturbance of the normal airflow and the reduced effectiveness of the control surfaces.

2.6.6 Experience has shown that, provided the normal precautions are taken (ie using the anti-icing or de-icing equipment correctly), icing conditions need not be a grave hazard if penetration of a thunderstorm area cannot be avoided. However, failure to recognise or anticipate icing conditions, failure to use the equipment properly, equipment unserviceability or extended flight through a storm area will all considerably increase the risks involved.

2.7 Lightning

2.7.1 Lightning can occur both within and away from cumulonimbus clouds, with discharges taking place either within the cloud, between neighbouring clouds, or commonly between a cloud and the ground and less commonly from the top of a cloud upwards. Most recorded lightning strikes have occurred at levels where the temperature is between +10°C and -10°C, ie within about 5000 ft above or below the freezing level. Some risk also exists outside this band, particularly in the higher levels. Strikes are either electrically positive or negative, although the polarity of the strike is not evident at the time. Positive polarity strikes are likely to be the more severe (ie cause more damage to the aircraft), and recent investigations have shown that the North Sea is an area prone to a higher than normal frequency of positive strikes, although the overall frequency of strikes per flying hour is similar to that in the rest of Europe. The presence of soft hail has been associated with some positive strikes and may thus be indicative of the conditions conducive to a positive strike. For further information regarding lightning and aircraft engines see AIC 29/2004 (Pink 64) - 'Engine Malfunction Caused by Lightning Strikes'.

2.7.2 The brilliant flash, the smell of burning and the accompanying explosive noise may be alarming and distracting to the pilots of an aircraft struck by lightning. The report on a serious accident, in which a large transport aircraft was destroyed, stated that it was due to a lightning strike causing ignition of vapour in the region of fuel tank vents but fatal accidents due to lightning strikes have fortunately been very few and most aircraft receive only superficial damage when struck.

2.7.3 The effect of lightning strikes upon both direct reading magnetic compasses and magnetically slaved compasses can be severe with deviations of many tens of degrees having been recorded. Magnetic compasses should not be relied upon after an aircraft has been struck and should be checked as soon as possible.

2.8 Static Electricity

2.8.1 This phenomenon will generally first be noticed as noise on the High and Medium frequency radio bands and also, to a lesser extent, on VHF receivers. As the static electricity increases in severity, the noise will increase and in extreme cases a visible discharge, known as St Elmo's fire, will be seen on some parts of the aircraft, particularly around the edges of windscreens. Static electricity is not associated only with thunderstorms but such conditions are particularly favourable to its creation. Although it is not normally dangerous, there have been rare incidents when a static discharge has occurred across a windscreen or plastic panel causing it to break.

2.8.2 An understanding of the effect of static electricity on radio equipment is important. It is detrimental to the performance of MF (eg ADF) and HF equipment but has little or no effect upon VHF and UHF. On HF, static may cause the signal-to-noise ratio to be such that communications are impossible. In these conditions navigational aids such as ADF must be used with extreme caution due to the fluctuating or erroneous indications that may occur.

2.9 Instrumental Errors and Limitations

2.9.1 Altimeters and Vertical Speed Indicators

2.9.1.1 Local pressure variations can occur in or very close to a thunderstorm at all heights and this, together with local gusts, may give rise to errors in the indications of altimeters and vertical speed indicators. There is some doubt as to the magnitude of altitude errors but there is evidence that they can be as much as ± 1000 ft. It is essential, for ground clearance purposes, that due allowance is made for such errors when flying in or near thunderstorm areas. Near the surface, periods of heavy rain are an indication of the likelihood of pressure variations and gusts.

2.9.2 Airspeed Indicators

2.9.2.1 Despite the precautions taken in the design of pitot heads, there is still a possibility that very heavy rain may cause an airspeed indicator to give a false indication even when the pitot head heaters are used. If the power which gives the safest speed for penetration has been selected before a storm is entered, no action should be taken to correct for violent or short period airspeed indicator oscillations, provided a reasonably level attitude is maintained.

2.9.3 Attitude Indicators

2.9.3.1 Attitude is indicated by instruments presenting pitch and roll information alone or by other more complex flight directors containing attitude indication amongst other elements.

2.9.3.2 The simple artificial horizons fitted to most aircraft, either as the main attitude indicator or as a standby instrument when remote reading indicators are installed, provide indications of pitch angle up to 85° nose up and down and may have complete freedom in the rolling plane. Except in rare circumstances these instruments give an adequate range of indication but may lack referencing, which would enable the pilot to assess attitude accurately at large angles of pitch or be given maximum assistance in recovery from any unusual attitudes.

2.9.3.3 Pitch referencing is also lacking on the attitude indicators of some flight director presentations. Moreover, their range of indication is much less than 85° up and down, in some cases less than 30°. The presentation of information on these earlier instruments does not give an indication to the pilot of the point at which the aircraft's pitch attitude exceeds the limit of indication of the instrument. These instruments therefore give no guidance as to the progress of recovery from attitudes outside their normal range of indication.

2.9.3.4 The wide variety of instruments which may be encountered makes it essential that pilots are fully aware of the limitations of the particular attitude indicator(s) fitted in the aircraft they fly.

2.9.4 Magnetic Compasses

2.9.4.1 Magnetic compasses are likely to be seriously affected by a lightning strike. They should not be relied upon after an aircraft has been struck and should be checked as soon as possible.

2.10 Use of Weather Radar

2.10.1 Pilots should be in no doubt about the function of airborne weather radar. It is provided principally to enable them to AVOID thunderstorms although they can be of assistance in penetrating areas of storm activity, where avoidance has not been possible. However, pilots should also be aware of the potential for displayed data to be unreliable when used for calculating the safe vertical clearance for the overflight of active storm cells.

2.10.2 Pilots should be familiar with the characteristics and operation of the radar in their aircraft and its limitations. Operators should ensure that their crews are given adequate instructions in relation to the radar equipment fitted to its aircraft, including the operation of the antenna and radar controls and on the adjustment and interpretations of the display.

2.10.3 It should be noted that the subject of airborne weather radar is quite complex and whilst the following notes give a generalised overview, they are no substitute for manufacturers' instructions in relation to specific products.

a. Most modern airborne weather radars operate in the frequency band of 8-12 GHz (ie wavelengths between 2.5 and 4 cm). This band, sometimes known as the 'X' band, was chosen for weather radars as it is highly sensitive to wet precipitation which is a feature of most weather systems that might need to be avoided by pilots. Airborne weather radars do not detect turbulence, although turbulent air, particularly within a thunderstorm, often contains water. In some radars, a change in frequency (a Doppler shift) in the reflected (returned) radar signal caused by moving precipitation is measured and is used to give an indication of likely turbulence.

b. Although wet precipitation is the most reflective of radar signals, other water products will reflect lesser amounts of incident radar energy. In descending order (ie from most to least reflective) these are: wet hail, rain, hail, ice crystals, wet snow, dry hail and dry snow.

c. The intensity of the returned radar signal will also be affected by the range of the aircraft from the precipitation, the amplification of signal (gain) being used by the receiver and the aerial tilt setting.

d. It should be noted that, with weather radars, the significance of radar returns of given intensity usually increases with altitude, but the strength of the echo is not an indication of the strength of any associated turbulence.

e. Radar return intensities may also be misleading because of attenuation resulting from intervening heavy rain. This may lead to serious underestimation of the severity of the rainfall in a large storm and an incorrect assumption of where the heaviest rainfall is likely to be encountered. The echo from that part of an area of rain furthest from the radar will be relatively weaker, and the actual position of the maximum rainfall at the far edge of the storm area will be further away than indicated on the radar display, sometimes by distances up to several miles. Additionally, a storm cell beyond may be completely masked.

f. It should also be noted that, notwithstanding recent research and operational experience, it still seems impossible to use radar to detect with certainty areas where large hailstones exist, because clouds containing rain or hail can produce identical radar pictures. Some operators have claimed success in avoiding hail by keeping well clear of cloud echoes that have scalloped edges or pointed or hooked 'fingers' attached. The best advice is to give radar echoes a wide berth, when detouring storms visually.

g. The high rate of growth of thunderstorms and the danger of flying over or near to the tops of both the main storm and the small convective cells close to it must also be remembered when using weather radar for storm avoidance.

h. Some guidance on the distances by which thunderstorms should be avoided is given in the table below. It is strongly recommended that the decision to avoid a thunderstorm be taken early.

i. Where weather information is available from ATC radar, it should be used to supplement the aircraft's weather radar (but see paragraph 3.2(c) of this Annex).

3 Thunderstorm Avoidance Guidance - Weather Radar

Flight Altitude (ft)	**Echo Characteristics**			
	Shape	**Intensity**	**Gradient of Intensity***	**Rate of Change**
0 - 20000	Avoid by 10 miles echoes with 'hooks', 'fingers', scalloped edges or other protrusions from the main storm return.	Avoid by 10 miles echoes with sharp edges or strong intensities.	Avoid by 10 miles echoes with strong gradients of intensity.	Avoid by 10 miles echoes showing rapid change of shape, height or intensity.
20 - 25000	Avoid all echoes by 20 miles			
25 - 30000	Avoid all echoes by 20 miles			
Above 30000	Avoid all echoes by 20 miles			
* Applicable to sets with Iso-Echo or a colour display. Iso-Echo produces a hole in a strong echo when the returned signal is above a preset value. Where the return around a hole is narrow, there is a strong gradient of intensity.				

3.1 The above avoidance criteria can be simply summarised as: if above 20 000 ft avoid by a minimum of 20 NM; if below avoid by a minimum of 10 NM.

3.2 If storm clouds have to be overflown, always maintain at least 5000 ft vertical separation from cloud tops. It is possible to estimate this separation (using the principle outlined below), but ATC or Met information on the altitude of the tops may also be available for further guidance:

a. To ensure that the optimum radar beam is used for this purpose, it will be necessary to adjust the 'gain' control. One particular weather radar manufacturer recommends that with an aircraft in straight and level flight and the aerial tilt set to zero (ie with the centre of the weather radar beam (ie along the bore-sight) aligned to the horizontal) the gain should be reduced until the 'radar paint' from the clouds just disappears. The gain should then be increased until a 'solid paint' is produced and the gain left at this setting for the required measurement. The range of the nearest part of this 'paint' should then be recorded.

b. The beam should now be raised (by adjusting the aerial tilt upwards) until the return 'disappears'. The tilt angle associated with this disappearance should be recorded. Return the tilt to zero in order to continue to monitor the storm and its development and the separation of the aircraft from it. Then either using data provided by the radar manufacturer (as in a 'look-up' table) or by mental arithmetic the approximate height of the cloud top may be obtained. One method of approximation is as follows:

One half of the notional beam-width as quoted by the radar manufacturer (usually in the region of 3° to 4°) should be subtracted from the recorded angle of tilt. Then using the 1:60 rule, this remainder should be applied to the recorded range of the edge of the return to calculate the height (in nautical miles) that the cloud top is above the aircraft.

Example: In an aircraft at 20 000 ft, with a radar whose notional beam width is 4°, a cloud return at 40 nm is made to 'disappear' at an aerial tilt angle of + 3.5°. 3.5 minus 2 (i.e. ½ the notional beam-width) = 1.5, which, when applied to 40 miles using the 1:60 rule, indicates that the cloud tops are 1 NM (or 6000 ft) above the aircraft. Thus if the cloud is to be overflown with the minimum recommended clearance of 5000 ft, a climb to at least 31 000 ft is indicated. If this course of action is followed, do remember that in the finite time it will take the aircraft to climb and to close this distance, the top of the storm cloud itself, if very active, might easily have ascended to a higher altitude.

c. If the aircraft is not equipped with radar or it is inoperative, avoid by at least 10 miles any storm that by visual inspection is tall, growing rapidly or has an anvil top.

d. Intermittently monitor long ranges on radar to avoid getting into situations where no alternative remains but to penetrate possibly hazardous areas. Unless otherwise instructed by the radar manufacturer, it is usually necessary to adjust both 'gain' and 'tilt' during this monitoring process to ensure that new weather 'targets' are not missed and that active clouds are continually tracked.

e. Avoid flying under a cumulonimbus overhang. If such flight cannot be avoided, tilt antenna full up occasionally to determine, if possible, whether precipitation (which may be hail) exists in or is falling from the overhang.

f. Notwithstanding the principle outlined above, or other guidance provided by radar manufacturers, or by instructors in radar systems, it should always be borne in mind that the result is only an estimate of the height of the storm cloud tops and that the accuracy of the estimate is critically dependent on certain assumptions. These assumptions include radar handling (eg that the beam width in actual use is similar to the quoted notional beam width; and that the tilt control knob has not slipped on the spindle). It should be remembered that weather radars are provided primarily for storm avoidance not penetration or overflight.

4 Use of Information from a Lightning Discharge Monitor

4.1 Instruments are available which indicate and record lightning discharges. However, in a similar manner to that of airborne weather radar they should be used for storm avoidance and not penetration. They work on the principle that in mature thunderstorms, air turbulence has changed the normal distribution of charged particles such that large build-ups of electrical charge occur. Lightning dissipates these buildups. These lightning discharges are detected by the equipment and normally shown on a screen with its centre that of the aircraft. The displayed distance of the discharge from the screen centre is an indication of the strength of the lightning discharge; it is not the actual range of the discharge from the aircraft. The distance calculated uses an algorithm based around the average strength of lightning discharges. Thus, a high power discharge at long range will be displayed at the same distance as a low power discharge at short range.

4.2 Because lightning is more likely to be associated with the most severe turbulence, an area of frequent discharges in a particular direction should be avoided. However, it has been found that the first lightning discharges from recently formed cells (where no discharges have been evident beforehand) may be particularly strong (ie violent). Thus, the lack of an indication of discharge is no guarantee that lightning will not strike. One particular manufacturer recommends that pilots using his equipment should manoeuvre their aircraft such that all discharge clusters are kept at least 25 NM away.

Chapter

15

Visibility

Introduction

Meteorological Optical Range (MOR), or more simply 'met vis' is the greatest horizontal distance at which a dark object can be recognized by an observer with normal eyesight, or at which lights of specified candlepower can be seen by night.

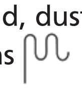
Ground visibility is the visibility of an aerodrome as reported by an accredited observer.

In effect, visibility is a measure of **atmospheric clarity**, or **obscurity**. This can be caused by **water droplets** - cloud, fog, rain, or **solid particles** - sand, dust or smoke, or by a mixture of the two - smog (fog and smoke). Ice, in the form of crystals, hail or snow will also reduce visibility. Poor visibility is usually associated with **stable** conditions, anticyclones, cols, inversions and light winds.

Visibility is generally better **upwind** of towns and industrial areas. The presence of hygroscopic nucleii means that condensation is likely to take place at relative humidities of less than 100%, giving rise to the formation of mist and fog. The various types of reduction in visibility are:

- **Mist.** There is mist if the visibility is 1000 m or more and the relative humidity is greater than 95% with very small water droplets. The upper limit for reporting mist is usually 5000 m, this is discussed under METARs.

- **Fog.** There is fog if the visibility is less than 1000 m and the obscuring agent is water droplets. Relative Humidity (RH) will be near 100%.

- **Haze.** There is haze if the visibility is reduced by extremely small solid particles - sand, dust or smoke. If the visibility is reduced below 1000 m, it is shown on synoptic charts as  . Again, haze is not usually reported when the visibility is more than 5000 m.

Radiation Fog

Radiation fog is caused by radiation of the earth's heat at night, and the conductive cooling of the air in contact with the ground to below dew point.

If there is a light wind, then fog will form, and in calm conditions the result will be the formation of dew.

Conditions necessary for radiation fog to form.

- **Clear sky** - to increase the rate of terrestrial radiation.

- **High relative humidity** - so that a little cooling will be enough to cause saturation and condensation.

- **Light wind** - of 2 - 8 kt to mix the layers of air causing turbulence so that droplets will be kept in suspension and so that warmer air from above can be brought into contact with the cold ground to thicken the fog.

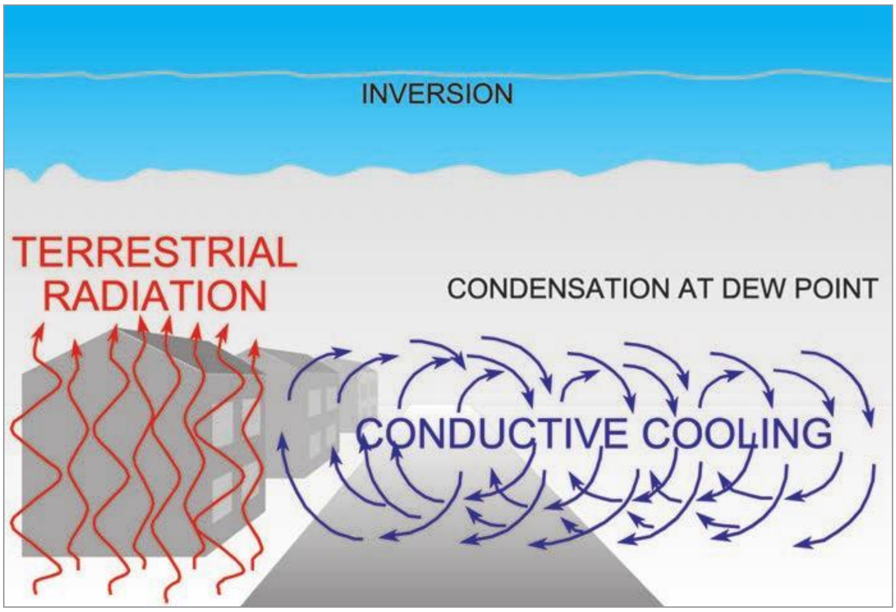


Figure 15.1 Radiation fog

A natural result of the radiative cooling at the surface will be an inversion above the fog layer (usually the friction layer).

Times of occurrence.

- Predominantly in **autumn** and **winter.**
- **Night** and **early morning.** The lowest temperatures are early morning. Additionally, the first insolation provides thermal turbulence and light winds. The latest time at which radiation fog can form is about 30 minutes after sunrise.

Location.

- **Over land** - not over sea because there is little DV of temperature.
- **Firstly in valleys** because of the katabatic effect.
- **In anticyclones, ridges** and **cols.**

Dispersal:

- **By insolation** causing convection which will lift the fog. It will also help to evaporate the lower layers.
- **By a strong wind** lifting the fog to form stratus cloud.

Note: *In the UK, radiation fog usually clears by 1000 - 1100 hours but may persist all day in valleys and in winter.*

Hill (Orographic) Fog

Hill fog is (usually) stratiform cloud (ST, SC) whose base is lower than the summit of the hills. It may be generated when moist stable air is forced to rise over the hills (cap cloud) or by the normal turbulence action producing ST and SC.

Figure 15.2 Hill fog

Advection Fog

Advection fog is formed by the movement of **warm, moist** air over a **cold surface**. The surface can be land or sea.

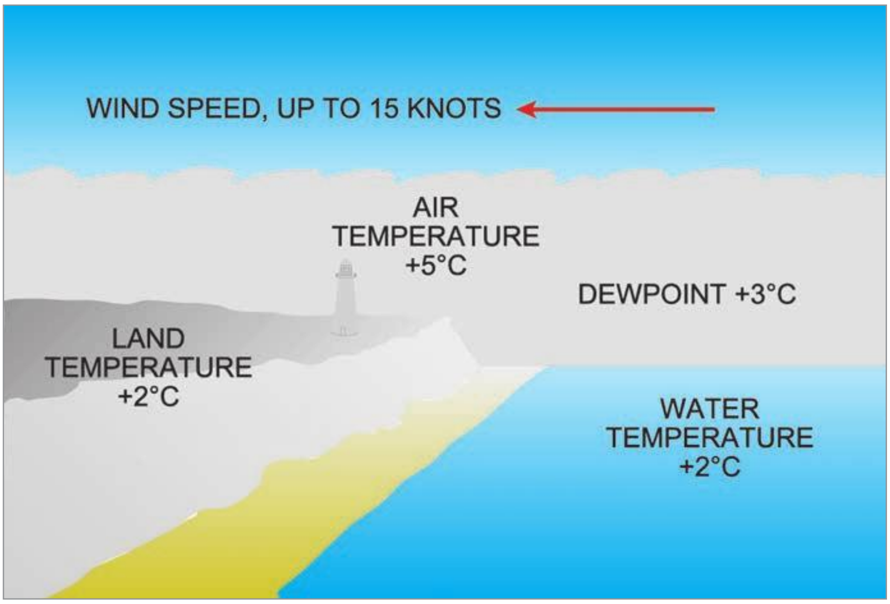


Figure 15.3 The conditions necessary for advection fog to form

Conditions necessary for advection fog to form:

- Winds up to 15 kt to move the air. (May be stronger over sea areas)
- A high RH so that relatively little cooling is required to produce saturation and subsequent condensation.
- A cold surface with a temperature lower than the Dew Point (DP) of the moving air to ensure condensation.

Times of occurrence and location:

- Over **land** areas in **winter** and **early spring.**
- Over **sea** areas in **late spring** and **early summer** but can occur at any time of the year when tropical maritime air moves over sea areas whose temperature is below the dew point of the air.
- Occurs particularly when a SW wind brings **tropical maritime** air to the UK.

Dispersal:

- By a **change of air mass.** (Wind change).
- By a **wind speed greater than 15 kt** which will lift the fog to form stratus cloud.

Special Areas

Nearly all sea fogs are caused by advection. Good examples are the extensive and persistent sea fogs which occur in the region of the **Grand Banks** of **Newfoundland** and around the **Kamchatka Peninsula** in the North Pacific.

In both cases warm air from the south moves over a cold sea current flowing down from the north.

Steaming Fog (Arctic Smoke)

Steaming fog, or as it is sometimes called, Arctic Smoke, occurs over sea in polar regions, e.g. the fjords of Greenland, Iceland and the sea areas of high latitudes. It is caused by **cold air** from a land mass moving over a **warmer sea.** The small amount of evaporation from the sea is enough to cause saturation and condensation but the air itself must be **very stable.**

The fog can be persistent and up to 500 feet thick - may drift inland. Will be dispersed by an increase in wind speed or change of direction. Usually only significant in Arctic regions, but the ‘steam’ may be seen at any latitude when cold air moves over a wet surface.

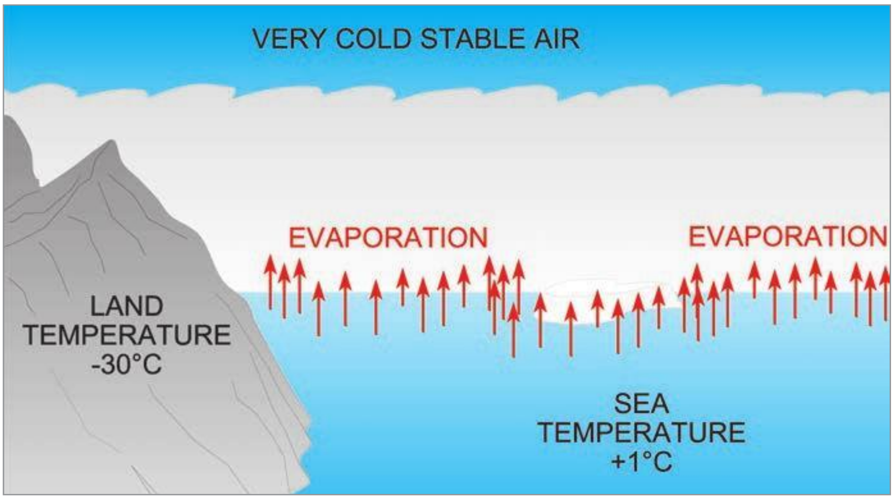


Figure 15.4 The conditions necessary for steaming fog (arctic smoke)

Figure 15.5 Before generation of steaming fog

Figure 15.6 After generation of steaming fog

Frontal Fog

Frontal fog occurs at a warm front or occlusion. The main cause is **precipitation lowering the cloud base to the ground.**

Subsidiary causes are:

- Evaporation of standing water on the ground.
- Mixing of saturated air with non-saturated air below.

The fog can form along a belt up to 200 NM wide which then travels with the front. Can be increased by orographic lifting. Will be dispersed by the passing of the front.

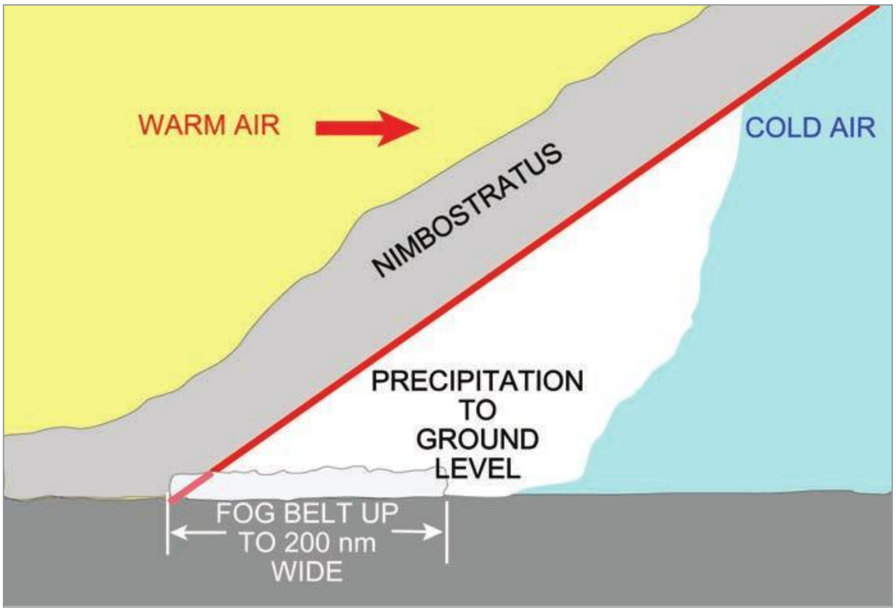


Figure 15.7 Frontal fog

Freezing Fog

The Bergeron theory tells us that, at temperatures below 0°C, the air becomes saturated for the formation of ice before it becomes saturated for the formation of water. Hence water vapour will go directly to the solid state at these temperatures. However, the rarity of freezing nucleii in the atmosphere means that when the dew point is below 0°C condensation will take place producing supercooled water droplets. These droplets will then freeze on contact with a solid object giving hoar frost (or rime ice).

Freezing fog will also occur when the dew point is above 0°C forming fog but the air then cools to a temperature less than 0°C.

Note: *if water vapour is in contact with a solid object at temperatures below 0°C then it will immediately form ice (hoar frost) missing out the liquid state.*

Ice Fog

Ice fog will form in extremely low temperatures (usually below -40°C) when warm moist air is introduced into cold saturated air, typically the results of combustion in car engines.

Condensation and freezing take place almost simultaneously giving a build up of ice crystals in the atmosphere thereby reducing visibility. This is a rare occurrence experienced in northern N. America and northern Eurasia during the winter months.

Visibility Reducers

Apart from very small water droplets, visibility may be reduced by solid particles or precipitation.

Smoke: Smoke consists of solid particles produced by combustion. Conditions will be worse under STABLE (subsiding air) conditions. Smoke may cause widespread reductions, e.g. forest fires in Indonesia.

The reduction will depend upon:

- Rate of production
- Rate of dispersal by wind
- Distance from the smoke source

The particles provide ample **hygroscopic nuclei** for vapour to condense on to, thus increasing the severity of **radiation fog.**

Dust: Dust is a particle less than 0.08 mm in diameter. Because of its lightness, it may be carried high into the atmosphere. The surface wind speed is likely to exceed 15 kt and as the speed increases, so will the height to which the dust will rise.

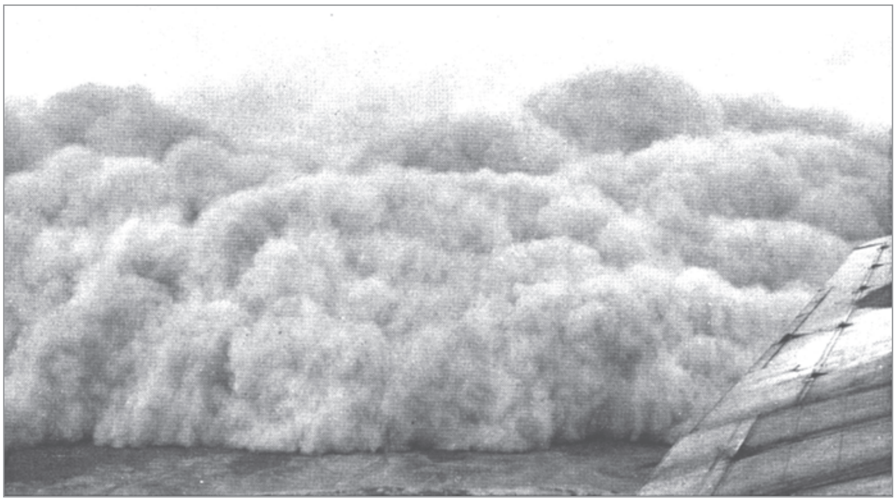


Figure 15.8 Dust storm rising to 11 000 ft (75 miles SSE of Damascus)

Dust storms mainly occur in daylight due to the DV of wind, but simple dust is very small, it may stay in suspension and visibility not improve for a day or so. Examples are the **Khamsin** and **Haboobs**, which will be covered later.

Sand: Sand consists of particles between 0.08 and 0.3 mm in diameter. Wind speed will be 20 kt or more. The greater weight of sand particles means that they will only be carried a few feet above the surface. Again, more a daylight event, due to the DV of wind.

Visibility: In dust storms or sandstorms visibility is likely to be reduced to less than 1000 m.

Precipitation: Reductions in visibility caused by precipitation have already been covered in Chapter 13 Cloud Formation and Precipitation, but to recap, they are:

Drizzle	500 to 3000 m	
Rain	Moderate:	3000 m to 10 km
	Heavy:	< 1000 m
Snow	Moderate	1000 m
	Heavy:	50 to 200 m
	Drifting:	(<2 m above the surface) will reduce the above.
	Blowing:	(2 m above the surface) will GREATLY reduce the above.

Visibility Measurement

- **By day.** Measurements are made by reference to suitable objects at known distances from an observing position.

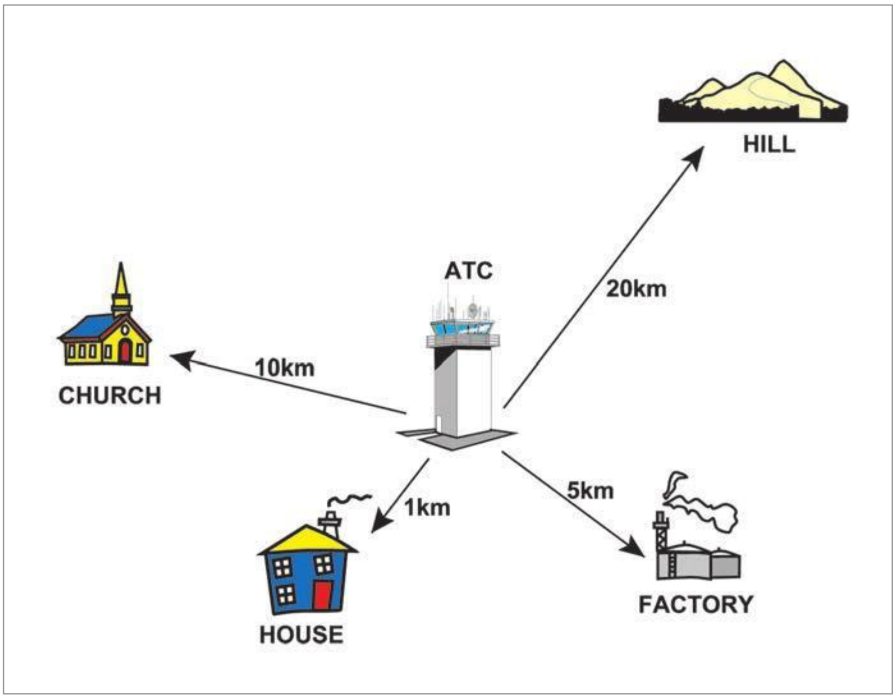


Figure 15.9 Visibility measurement: day

- **By night.** Transmissometers or forward scatter meters are used to measure visibility at night, see below.

Runway Visual Range (RVR)

RVR is the maximum distance that a pilot 15 ft above the runway in the touchdown area can see marker boards by day or runway lights by night when looking in the direction of take-off or landing. The RVR can be assessed by positioning an observer 76 metres from the centre line of the runway in the touchdown area to sight the number of marker board or lights in the appropriate direction. RVR is reported when meteorological optical range (MOR) or (I)RVR falls to less than 1500 m, or when shallow fog is reported or forecast.

The United Kingdom standard RVR reporting incremental scale is 25 m between 0 and 400 m, 50 m between 400 and 800 m, and 100 m above 800 m. If traffic is more or less continuous, readings are taken every 30 minutes, or when a significant change in the normal visibility occurs.

If traffic is light, readings are taken 15 minutes before a take-off or landing. RVR is never forecast. There is no connection between RVR and MOR, but there are factors which may be applied for regulatory purposes (see Air Law Notes). Generally, RVR is greater than MOR.

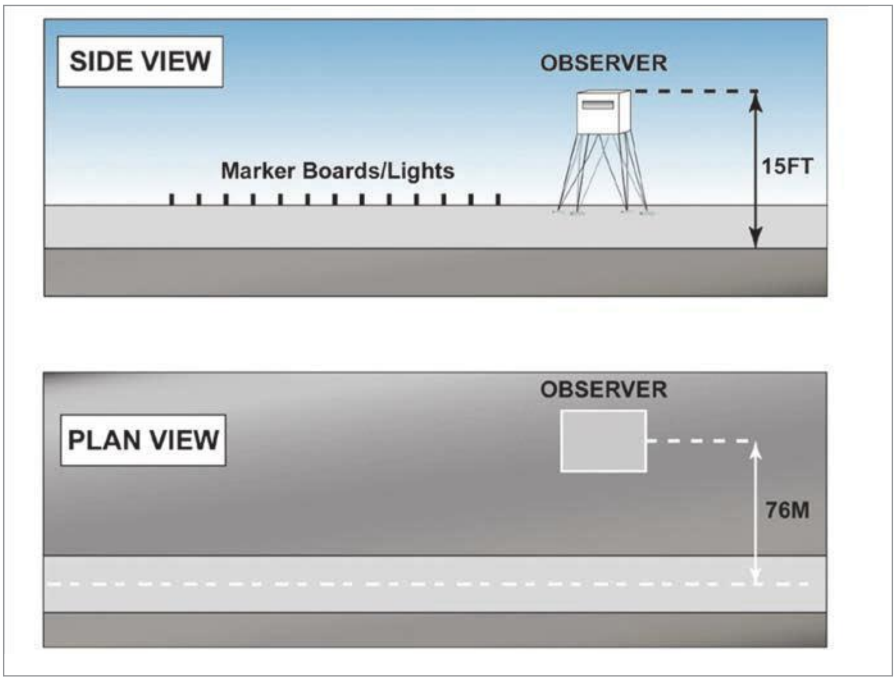


Figure 15.10 Runway visual range

Transmissometer

This is an electronic device where the intensity of a light a distance from a photo-electric cell gives an indication of the equivalent daytime visibility. This has the advantage of a constant measurement of visibility, but the disadvantage is that only a small portion of the atmosphere is being sampled.

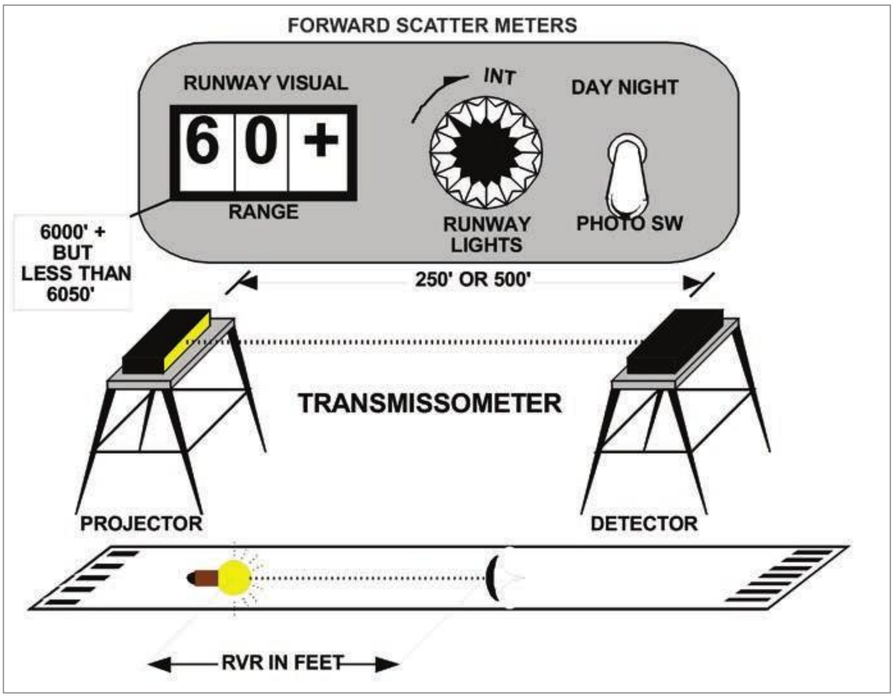


Figure 15.11 A transmissometer

Instrumented Runway Visual Range (IRVR)

Three **Transmissometers** are positioned alongside the runway.

A transmissometer comprises a light source transmitter and photo-electric cell receiver which are separated from each other.

The strength of current in the receiver is dependent on the clarity of the air between the transmitter and the receiver.

IRVR is reported when the normal visibility is 1500 metres or less, or when shallow fog is reported or forecast.

Readings are sent to ATC. Three readings can be given, one each for touch-down zone, mid-point and stop-end, e.g.: R28L / 600 400 550.

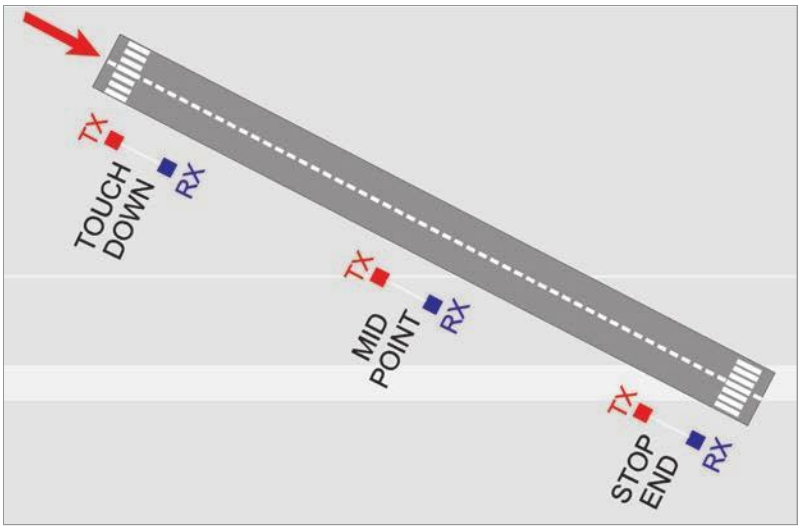


Figure 15.12 Instrumented runway visual range (IRVR)

Forward Scatter Visibility Meters

Transmissometers are being replaced with forward scatter visibility meters. The principle is that a narrow light beam is forward projected from a transmitter. A narrow aperture receiver is set at an angle in the range of 20° to 50° to the transmitter. The receiver measures the amount of scattered light received from the transmitter. This amount will be dependent on the number and type of particles (water droplets, ice crystals or solid particles) which are present in the atmosphere.

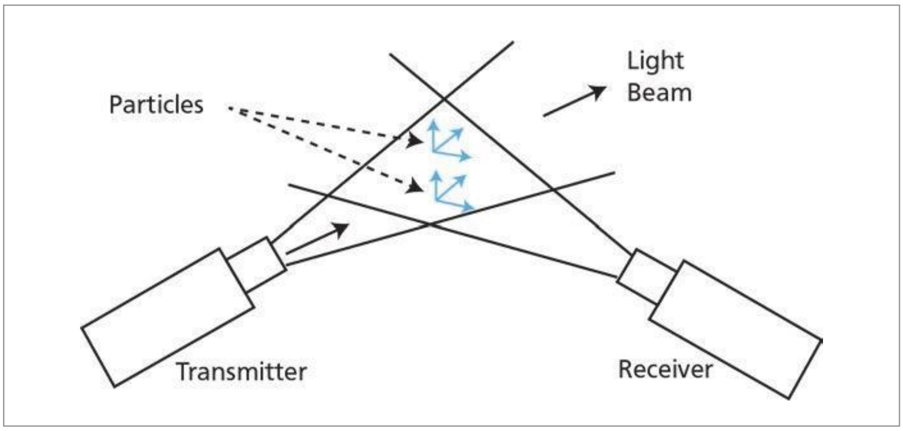


Figure 15.13

By using 3 sensors set at different angles it is possible to determine automatically the substance reducing the visibility and hence calculate an accurate visibility. The forward scatter visibility meters will be sited in similar positions to the transmissometers and they too only determine visibility in the direction of take-off and landing.

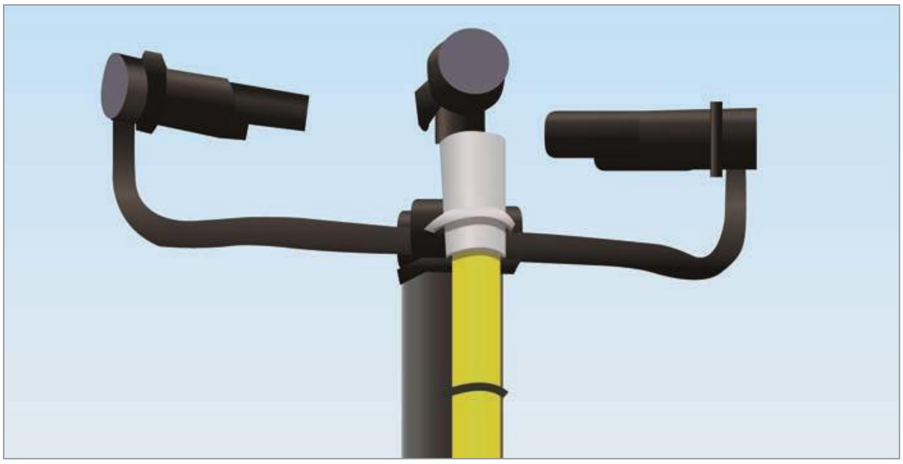


Figure 15.14

Summary of Visibility Effects

- **By day** visibility is generally poor looking **up sun.**
- **By night** visibility is usually better looking **up moon,** because of light reflections from water surfaces, railway lines etc.
- In precipitation visibility is usually worst in **driving snow** and very poor in **drizzle** (because of the large number of small droplets).
- Night visibility is improved if the pilot does not look at bright cockpit lights.

Questions

1. Which of the conditions given below is most likely to lead to the formation of radiation fog?

	Wind speed	Cloud Cover	Temperature	Dew Point
a.	7 kt	8/8 St	12°C	11°C
b.	15 kt	NIL	15°C	14°C
c.	3 kt	1/8 Ci	8°C	7°C
d.	12 kt	NIL	-2°C	-3°C

2. When _______ moist air passes over a surface which is _________ than the dew point of the air, _______fog can form. This occurs over____________

Examine the statement above; the line which contains the correct words in the correct order to complete the statement is:

a.	cool	warmer	radiation	the sea
b.	warm	cooler	radiation	the land only
c.	cool	warmer	frontal	land
d.	warm	cooler	advection	land and sea

3. Radiation fog is most likely at an inland airfield in the UK with a relative humidity of 80% in the ________with ___________and a wind of _______

a.	autumn	clear skies	2-8 knots
b.	spring	6/8 ST& SC	2-10 knots
c.	winter	clear skies	15/20 knots
d.	summer	clear skies	no wind

4. Advection fog is formed when __________air moves over a___________surface and is __________its dew point:

a.	humid	cold	kept above
b.	warm moist	cooler	cooled below
c.	dry	frozen	well below
d.	warm moist	warmer	kept above

5. On a night when radiation fog is forming over most of southern England, the aerodromes likely to be first to experience the fog will be those situated:

a. near the coast with a light onshore wind and clear skies
b. at the bottom of the hill with a light katabatic wind blowing
c. near the coast with a land breeze and cloudy skies
d. at the top of a hill with clear skies and no wind

6. Radiation fog is most likely:

a. with a wind speed up to 15 kt, a clear sky and a high relative humidity
b. with a wind of 2-8 kt, a high density and the summer season
c. in an anticyclone in winter
d. on a hill in autumn

7. **If a station equipped with IRVR equipment reports RVR 1000, this means:**

    a. RVR at touchdown is 1000 metres
    b. RVR at touchdown is 1000 metres and at 'mid point' and 'stop end' the RVR is 800 metres or more
    c. RVR at touchdown is 1000 metres and 'mid point' and 'stop end' equipment is unserviceable
    d. RVR all along the runway is 1000 metres or more

8. **Changes of RVR are reported for increments of:**

    a. 25 m up to 250 m
    b. 25 m up to 200 m
    c. 50 m between 300 m and 800 m
    d. 50 m between 500 m and 800 m

9. **Frontal fog is most likely to:**

    a. form ahead of a vigorous fast moving cold front
    b. form ahead of a warm front
    c. form on a vigorous cold front and last for many hours
    d. form to the rear of a warm front but only last for 1 to 2 hours

10. **Fog may be defined as:**

    a. a reduction of visibility to less than 1000 metres due to the presence of water vapour in the atmosphere
    b. a reduction of visibility to less than 1000 metres due to the presence of water droplets in suspension in the atmosphere
    c. a reduction of visibility to less than 1500 metres due to the presence of water droplets in suspension in the atmosphere
    d. a reduction of visibility to less than 1000 ft due to the presence of water vapour in suspension in the atmosphere

11. **Several types of pressure distribution may be associated with radiation fog but all have one feature in common which is:**

    a. closely spaced isobars
    b. a tight pressure gradient
    c. a slack pressure gradient
    d. a rapidly falling pressure

12. **. . . . . forms when moist air . . . . over a surface which is . . . . than the dew point of the air. Fill in the missing words from the list given below:**

    a. Radiation fog, passes, warmer
    b. Advection fog, settles, cooler
    c. Advection fog, passes, cooler
    d. Radiation fog, settles, warmer

13. **Advection fog:**

    a. only occurs at night and early morning
    b. is most likely with Polar Maritime air
    c. will only clear by insolation
    d. can sometimes last for 24 hours or more in winter

14. In circumstances where there is a clear sky, calm wind and a high relative humidity in autumn:

a. radiation fog is likely over night
b. advection fog will form
c. radiation fog is likely at sunrise after previous mist
d. hill fog can be expected

15. At a station equipped with IRVR, reports are given:

a. every ½ hour
b. when the normal visibility is 1500 m or less
c. when there is mist
d. when there is haze

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	d	a	b	b	c	b	b	b	b	c	c

13	14	15
d	c	b

Chapter 16

Icing

An Introduction to Icing and Its Basic Causes

Airframe icing can cause a serious loss of aircraft performance and this will frequently result in a large increase in fuel consumption and some difficulty with aircraft control.

Icing is difficult to forecast and therefore there is a need for a full understanding of the processes involved.

Ice will form on an airframe if there is:

- Water in a liquid state (supercooled water droplets).
- Ambient air temperature below 0°C (but see hoar frost).
- Airframe temperature below 0°C.

Supercooled Water Droplets (SWD)

A supercooled water droplet is a droplet of water still in the liquid state although its temperature is below 0°C.

If the SWD contains a **freezing nucleus** then the droplet will start to freeze. Mention was made in Chapter 6 of **condensation nuclei**, but as the number of freezing nuclei in the atmosphere is considerably less than these, the state of supercooling is a frequent occurrence.

Supercooled water droplets can exist in clouds at temperatures as low as -40°C. However, when an aircraft strikes a supercooled water droplet, it will start to freeze.

Supercooled water droplet size is dependent on the size of the basic cloud droplet, (controlled by cloud type) and the temperature. As temperature decreases the water droplets evaporate thus reducing their size (the Bergeron process, see Chapter 13).

- Large supercooled water droplets 0°C to -20°C, CU, CB and NS clouds

- Small supercooled water droplets:

    - Upper levels of CU, CB and NS clouds, -20° to -40°C

    - ST, SC, AS and AC clouds 0°C to -40°C

- Below -40°C only very tiny supercooled water droplets can exist.

The Effects of Icing

- **AERODYNAMIC.** Ice tends to form on leading edges, thereby spoiling the aerodynamic shape. The result is **reduced lift, increased drag, increased weight, increased stalling speed** and **increased fuel consumption.**

  Ice, frost or snow of a thickness and roughness similar to coarse sandpaper can reduce lift by 30% and increase drag by 40%.

  It is also possible for pieces of ice to break off other surfaces and to jam between the control surfaces and wings and tail.

- **Weight.** In severe conditions, ice can form at a rate of 1” in 2 minutes.

  There will be a loss of stability due to the weight of ice not being uniform across the airframe.

  This can lead to a displaced C of G. Similar uneven weight of ice on propeller blades can cause severe engine vibration.

  Ice breaking off propellers can cause skin damage.

- **Instrument effects.** Ice can block pressure heads and the readings of ASIs, VSI, altimeters and machmeters can be in error as a result.

- **General.** Windscreens and canopies can be obscured.

  A thin film of ice/frost can cause skin friction.

  Ice in landing gear wells can affect retraction.

  Ice on aerials can cause static interference.

Clear Ice

If a large supercooled water droplet strikes an aircraft, it will start to freeze and this will release **latent heat** . This will delay the freezing process whilst part of the supercooled water droplet will flow back over the impact surface forming **clear ice**.

The amount of a supercooled water droplet that freezes on impact is 1/80th of the droplet for each degree below freezing.

Clear ice is a transparent form of ice formed by **large** supercooled water droplets, and it can be dangerous. There can be much flowback and the ice appears transparent because there is no air trapped under the flowback icing.

The ice will destroy aerofoil shapes and its weight can cause problems of control because the build-up can be uneven. It is illustrated in *Figure 16.1.*

Propeller icing can cause severe vibrations and as the ice adheres strongly, when it breaks off, the pieces can be large and cause skin damage.

Clear ice forms in Ns, Cu and Cb at temperatures from 0 to -20 °C.

This is the most dangerous form of icing because of the speed at which it can build up on the aircraft.

Rime Ice

When the supercooled water droplets are small (at very low temperatures) or when cloud droplets are small, the whole droplet freezes on impact, each droplet sticking to the surface it strikes and becoming solid almost at once.

Air becomes trapped between each frozen droplet, which makes the ice opaque. Rime ice, see *Figure 16.2*, is a **white opaque** deposit with a light texture. It is caused by **small**, supercooled water droplets freezing quickly.

There is little or no flowback. The ice grows out from the leading edges and is compacted by the airstream.

Some loss of aerofoil shape can occur and **air intakes** can be affected.

Rime ice can occur in any cloud where there are small supercooled water droplets; Ns, As, Ac, SC, St and the parts of heap clouds where supercooled water droplets are small.

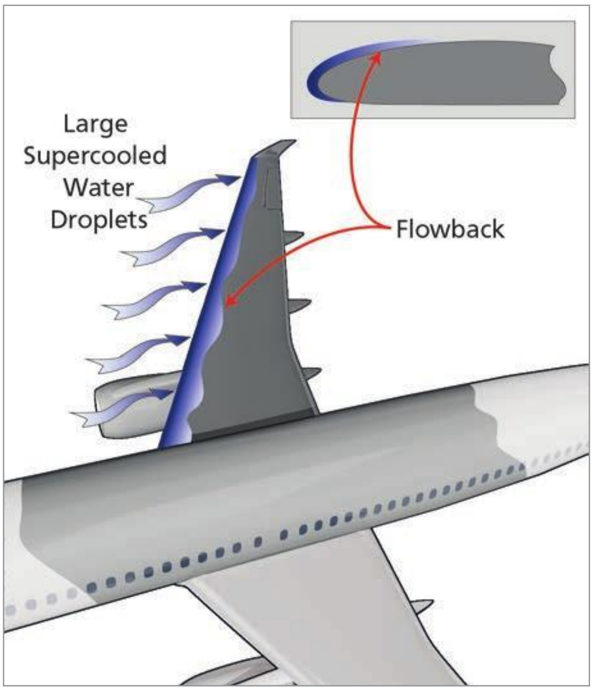


Figure 16.1 The formation of clear ice

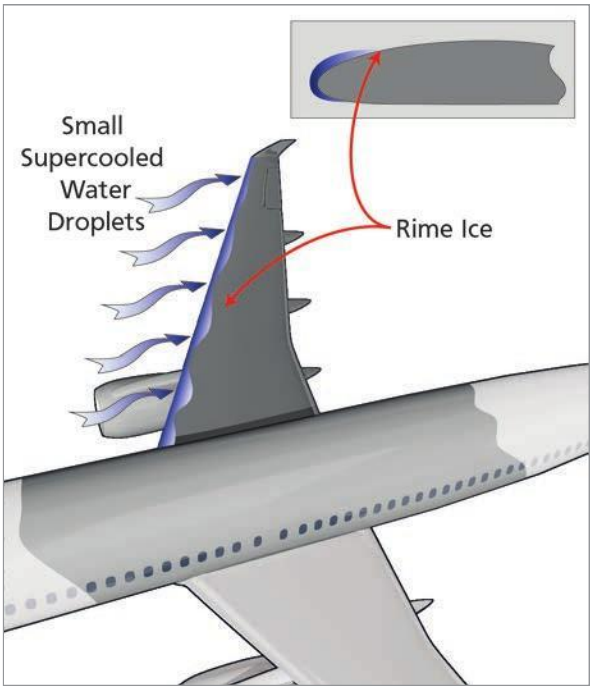


Figure 16.2 The formation of rime ice

Mixed Ice

Very often in cloud, at temperatures between 0° and -20°C we find a mixture of both large and small supercooled water droplets. This produces a build-up of ice on the leading edges from the small droplets and the flowback from the large droplets giving a combination of the worst effects of both clear and rime ice.

Rain Ice

Rain ice occurs in rain which becomes **supercooled** by falling from an **inversion** into air below 0°C.

The rain does not freeze immediately in the air but can impact the aerofoil to form **clear ice** or rime ice.

Rain ice builds up very quickly and a pilot's action should be to turn onto a reciprocal heading immediately.

Rain ice occurs in a narrow range of altitudes at low level, about 1000 ft, ahead of a **warm front** or **occlusion** and is associated particularly with the moderate continuous rain which often falls from **nimbostratus** cloud. This is illustrated in *Figure 16.3.*

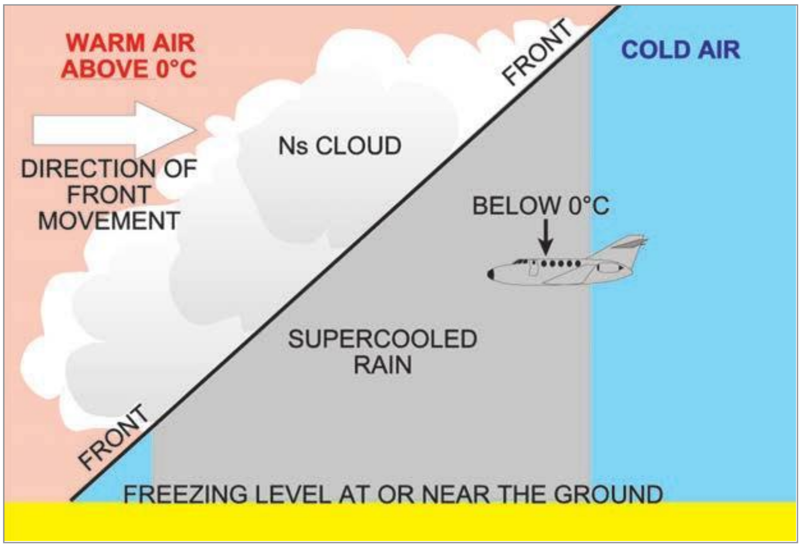


Figure 16.3 Factors affecting the formation of rain ice

Rain ice is rare over the UK, but is common in winter over North America and Central Europe.

Pack Snow

Pack snow is icing which is due to a mixture of supercooled water droplets and **snow.** It can block air intakes and other aircraft openings. Normally the effects are **slight.**

Hoar Frost

Hoar frost is a **white crystal deposit** which appears similar to frost on the ground. It occurs in **clear air**. Hoar frost will form if the airframe temperature is **below** 0°C and the ambient temperature is lowered to saturation level. Water vapour in contact with the airframe is converted to ice crystals without becoming liquid, i.e. **sublimating**. This process requires the presence of another type of ice nucleus, the **sublimation nucleus.** Their composition is usually inorganic, e.g. volcanic dust, clay or soil particles.

There are two situations where hoar frost can occur:

- **on the ground.** This usually occurs at night and is similar to the frost which forms on a car. It must be cleared before take-off because:
    - Skin friction will increase the take-off run.
    - Windscreens will be obscured.
    - Radio interference will be caused by ice on aerials.
- **in flight**. Hoar frost can occur in flight in the following cases:
    - If a **rapid descent** is made from a **very cold** region to a **warm moist** layer.
    - If a climb is made from a temperature **below 0°C** through an **inversion.**

The icing is not severe. The effects can be overcome by flying in a region where the temperature is above 0°C or by flying faster to increase the kinetic heating.

Factors Affecting the Severity of Icing

- **Size of the supercooled water droplets.** This is dependent on cloud type and temperature as follows:

TYPE	DETAILS
MODERATE /HEAVY CLEAR ICE	Supercooled water droplets can only be large in Cu, Cb, Ns and then only when temps are in the general range 0°C to -20°C.
LIGHT/MODERATE RIME ICE	For layer clouds small supercooled water droplets are present from 0°C to -20°C
LIGHT RIME ICE	For layer clouds supercooled water droplets are smaller below -20°C.
RIME ICE	Supercooled water droplets are also small in Cu, Cb and Ns from -20°C to -40°C.

At -40°C and below, supercooled water droplets are very small and icing is usually negligible.

- **Concentration of supercooled water droplets.** The concentration of water droplets is **higher** in **heap** clouds because the up currents are stronger. Hence Cu and Cb clouds have a high concentration of supercooled water droplets and this causes the icing to be moderate to **severe**.

  There is always a **greater** concentration of droplets near the base of the cloud where it is warmest. Icing severity (by cloud types) tends to be:

  - Cu, Cb - Moderate to severe.
  - Ns - Moderate to severe.
  - Sc - Light to moderate, but may be severe in mountainous areas.
  - Ac, As and St - Light
  - Ci, Cs and Cc - Nil or trace

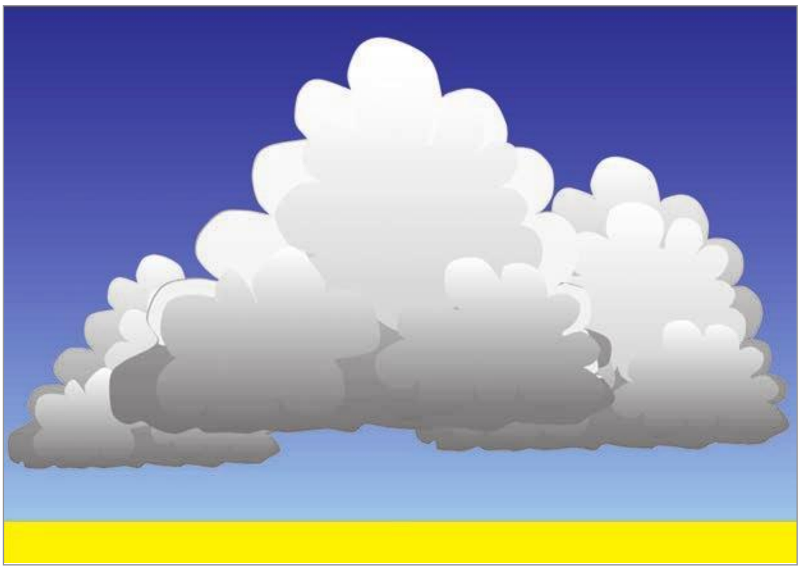


Figure 16.4 The concentration of supercooled water droplets

- **Shape of the aircraft.** *Figure 16.5*. illustrates the air flow around thin and thick wing shapes. **Thin** shapes collect ice more rapidly than **high drag** ones. Thin wings and pressure heads are therefore liable to rapid icing. High speeds also result in a greater ice hazard because the airframe strikes a greater number of supercooled water droplets in unit time. Kinetic heating may cancel this effect. The wing of a small aircraft has a relatively broad cross-section so will accumulate ice relatively slowly. Other parts of the aircraft; tail-plane, undercarriage struts and antenna have relatively narrow cross-sections so will accumulate ice more rapidly. So a small amount of ice on the mainplane could indicate more serious icing elsewhere on the aircraft.

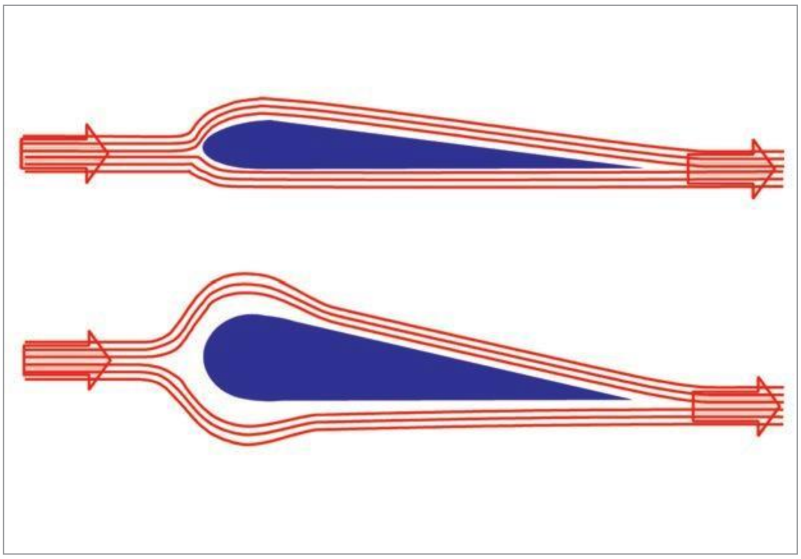


Figure 16.5 Thin wing forms collect ice more rapidly than high drag forms

- **Cloud base temperature.** The higher the temperature, the greater the water vapour content. Condensation first occurs at the base, and there is therefore a greater amount of free water to become ice on an airframe. The free water content at any level in the cloud increases with base temperature.

  Concentration of drops will increase and so will icing severity. An illustration of this is shown in *Figure 16.6*.

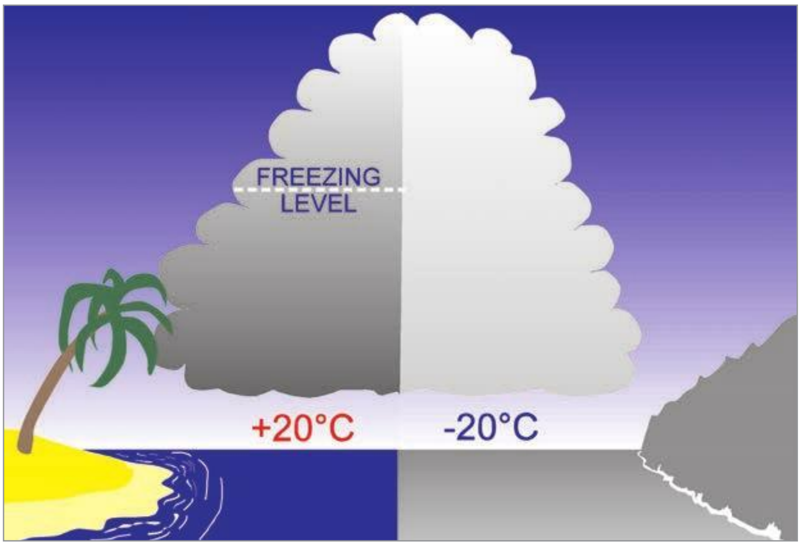


Figure 16.6 The different water vapour content at different temperatures

- **Kinetic heating.** Although a rise of temperature due to kinetic heating to above 0°C may prevent ice accretion, a rise to below 0°C may increase the risk and the severity.

$$\text{Skin Temp} = \text{OAT} + \left[\frac{\text{TAS}}{100}\right]^2$$

Icing Forecasts

Forecasting airframe icing is a matter of forecasting clouds, both by type and vertical extent. The degree of airframe icing is classed as **light, moderate,** or **severe.**

When rain ice is expected, it will be mentioned specifically in the forecast. Forecasts of engine icing are not normally provided.

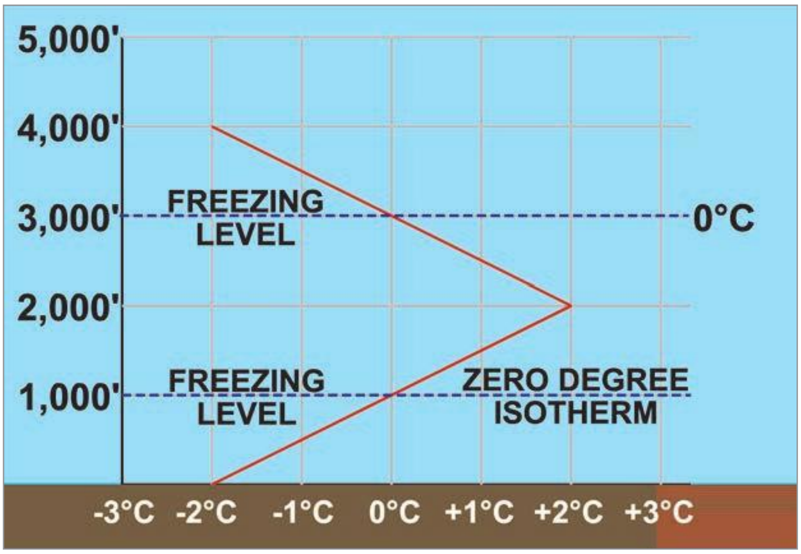


Figure 16.7

Freezing Level

The height where ambient temperature is zero is called the freezing level.

It is usually given in forecasts on an area basis by reference to the height of the **Zero Degree Isotherm**.

With an inversion, two freezing levels are possible.

Freezing levels in the south of the United Kingdom average 11 000 ft in August and 3000 ft in February.

Reporting of Icing

The following extract from the UK Air Pilot is a useful description of the degree of icing encountered in flight.

Airframe Icing

All pilots encountering unforecast icing are requested to report time, location, level, intensity, icing type and aircraft type to the ATS unit with whom they are in radio contact. It should be noted that the following icing intensity criteria are reporting definitions; they are not necessarily the same as forecasting definitions because reporting definitions are related to aircraft type and to the ice protection equipment installed, and do not involve cloud characteristics. For similar reasons, aircraft icing certification criteria might differ from reporting and/or forecasting criteria.

Intensity	Ice Accumulation
Trace	**Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation.** It is not hazardous even though de-icing/anti-icing equipment is not utilized, unless **encountered for more than one hour.**
Light	The rate of accumulation might create a problem if flight in this environment **exceeds one hour. Occasional use of de-icing/anti-icing equipment** removes/prevents accumulation. It does not present a problem if de-icing/anti-icing equipment is used. (ICAO: Less than moderate icing)
Moderate	The rate of accumulation is such that even short encounters become potentially hazardous and **use of de-icing/anti-icing equipment,** or diversion, **is necessary.** (ICAO: conditions in which change of heading and/or altitude may be considered desirable)
Severe	The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. **Immediate diversion is necessary.** (ICAO: conditions in which immediate change of heading and/or altitude is considered essential)

***Rime Ice**: Rough, milky, opaque ice formed by the instantaneous freezing of small supercooled water droplets.

***Clear Ice**: A glossy, clear, or translucent ice formed by the relatively slow freezing of large supercooled water droplets.

Piston Engine Induction Icing

- **Impact icing.** Ice in intake areas caused by **snow, snow** and **rain** mixed or **supercooled water droplets.**

- For turbo-charged (fuel injection) engines, this is the only icing hazard.

- **Fuel icing.** This is caused by water in the fuel freezing in bends in the induction piping.

- **Carburettor icing.** This is caused by:

    - The sudden temperature drop as **latent heat** is absorbed when fuel evaporates.

    - The temperature drop due to the **adiabatic expansion** of the air as it passes through the venturi.

Carburettor icing is most dangerous within a temperature range of -10°C to +25°C, in cloud, fog or precipitation at any power setting.

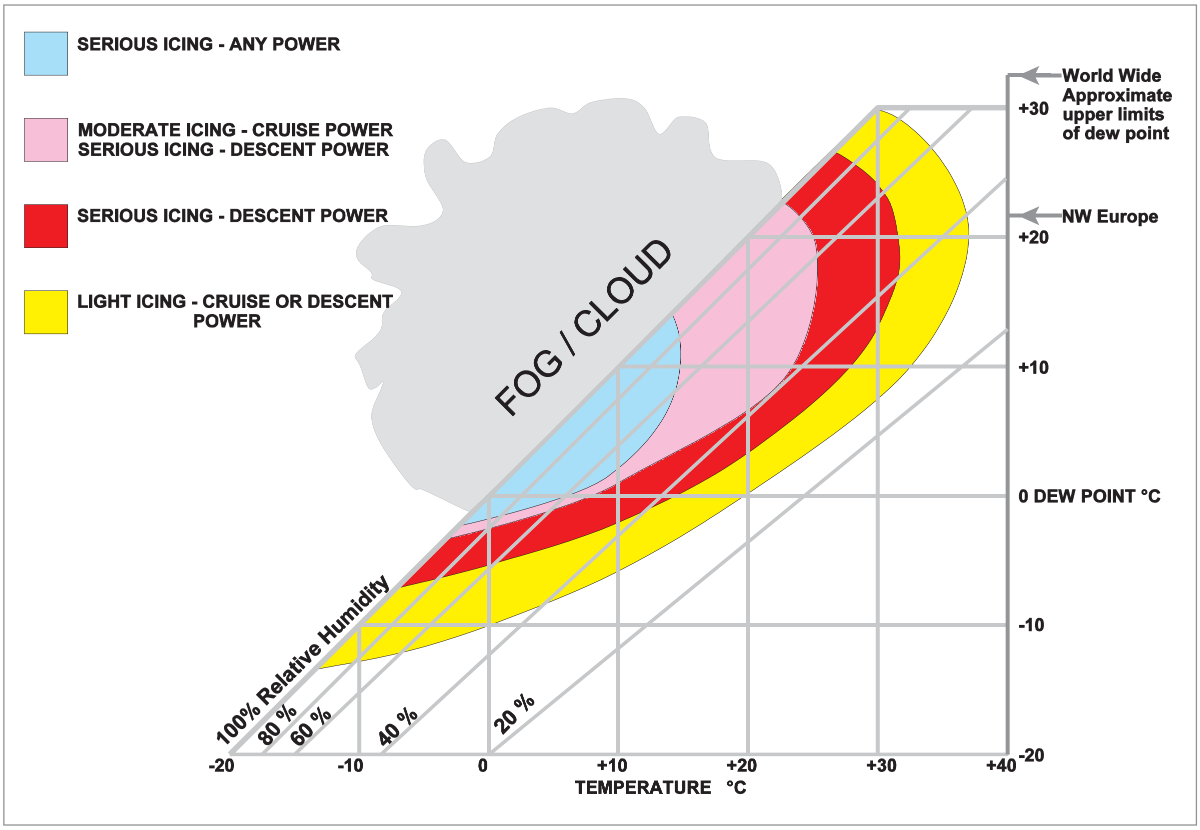


Figure 16.8 The wide range of ambient conditions conducive to the formation of carburettor icing

Jet Engine Icing

Ice may form on intake lips or inlet guide vanes. If this breaks away and enters the engine, blade damage may occur.

Some icing may occur in the early inlet stages, particularly at high engine speeds and low aircraft forward speeds (e.g during the approach), where much adiabatic cooling may occur and temperature reductions of 5°C and more can result.

This icing is particularly prevalent in freezing conditions which are associated with any form of precipitation; as a consequence of this, engine anti-icing **must be selected "ON" when there is precipitation and the indicated outside air temperature is +10°C and below.**

Other Factors Affecting Jet Engine Operation In Icing Conditions

- Engine power indications may be in error if there is ice on engine inlet (P1) pressure probes.

- Engine igniters should be used in potential icing conditions, otherwise engine failure is possible.

- Long flights at very low temperatures may cause fuel freezing and fuel freezing point specification for the aircraft type should be known.

- Clear ice can occur at ambient temperatures above zero when water droplets come into contact with an aircraft whose upper surfaces are at or below zero.

  This low skin temperature can be caused by a very low fuel temperature conducting through the skin.

  This icing can also occur on the ground in high humidity, rain, drizzle or fog. It could then be snow covered and difficult to detect.

  Break up of this ice on take-off can be particularly hazardous to rear engined aircraft.

- Operation of anti-icing or de-icing equipment usually implies a performance penalty.

Questions

1. At temperatures of between 0°C and –10°C clouds will consist of:

a. entirely water droplets
b. entirely ice crystals
c. mostly water vapour
d. mostly supercooled water droplets and a few ice crystals

2. Turbulent clouds are most serious from the icing standpoint because:

a. strong vertical currents mean that a predominance of large supercooled water droplets will be present
b. strong vertical currents mean that a predominance of small supercooled water droplets will be present
c. turbulent clouds produce hail which sticks to the aircraft
d. turbulent clouds indicate a low freezing level

3. Hoar frost forms on an aircraft when:

a. the aircraft suddenly enters a cloud at below freezing temperature
b. the aircraft in subzero clear air suddenly enters a colder region
c. the aircraft in subzero clear air suddenly enters a warmer moist region
d. the aircraft suddenly enters a cloud which is at a higher temperature than the surrounding air

4. Most cases of serious piston engine icing occur in cloud, fog, or precipitation with a temperature range between:

a. -10°C to +25°C
b. -18°C to +5°C
c. -10° C to 0°C
d. -20°C to +15°C

5. Stratus cloud of limited depth at a temperature of -5°C will most likely give:

a. moderate to heavy rime ice
b. moderate to heavy glaze ice
c. light to moderate rime ice
d. light to moderate glaze ice

6. Clear ice forms as a result of:

a. large supercooled water droplets spreading as they freeze
b. ice pellets splattering on the aircraft
c. small supercooled water droplets splashing over the aircraft
d. water vapour freezing to the aircraft

7. **Orographic uplift in stable conditions gives a strong vertical component to air movement thus supporting larger supercooled droplets in orographically formed cloud. Consideration should also be given to the fact that in this cloud:**

a. the 0°C isotherm will be higher
b. the 0°C isotherm will be lower
c. the lapse rate will be isothermal
d. an inversion can be anti-cyclonic

8. **Which of the following conditions is most favourable for the formation of carburettor icing if the aircraft is descending with glide power set?**

	Relative Humidity	Ambient Temperature
a.	25%	+25°C
b.	40%	+20°C
c.	50%	-10°C
d.	30%	-5°C

9. **Flying in large CU at a temperature of -20°C, the amount of each cloud droplet that will freeze on impact with the aircraft will be:**

a. all the droplet
b. ½ of the droplet
c. ¼ of the droplet
d. 20% of the droplet

10. **Carburettor icing is unlikely:**

a. in cloud
b. at temperatures between –10°C and –30°C
c. in clear air
d. when the RH is 40%

11. **Flying 50 NM ahead of a warm front out of cloud at 1000 ft in winter, with an ambient temperature of -8°C, there is a strong risk of:**

a. hoar frost
b. rime icing and carburettor icing
c. structure damage caused by hail
d. clear ice in the form of rain ice

12. **In AS cloud at FL170 and a temperature of -20°C the airframe icing most likely to be experienced is:**

a. moderate clear icing
b. light rime icing
c. hoar frost
d. severe clear icing

13. **Mixed (rime and clear) icing is most likely to be encountered:**

a. in nimbostratus at a temperature of −10°C
b. in stratocumulus cloud at a temperature of −20°C
c. in fair weather cumulus at a temperature of −15°C
d. in towering cumulus at a temperature of −10°C

14. **When considering icing in cloud over high ground compared with icing in other clouds, the effect of orographic lifting is to:**

a. cause the height of the freezing level to fall and increases the intensity of the icing
b. cause the height of the freezing level to rise and increases the severity of the icing
c. cause the free water content of the cloud to increase and the freezing level to rise so reducing the icing risk
d. increase the temperature inside the cloud due to the release of extra latent heat so reducing the icing risk

15. **Kinetic heating will:**

a. increase the risk of icing if it raises the airframe temperature to just below 0°C
b. increase the risk of icing if it raises the airframe temperature to just above 0°C
c. always increase the risk of airframe icing
d. always decrease the risk of airframe icing

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	a	c	a	c	a	b	b	c	b	d	b

13	14	15
a	a	a

Chapter

17

Air Masses

Introduction

An air mass is a large volume of air where the humidity and temperature in the horizontal are more or less constant.

The temperature and humidity properties are obtained by the air remaining roughly stationary over a surface where conditions are generally constant for some length of time - a high pressure area. Therefore at source, all air masses must be **stable.**

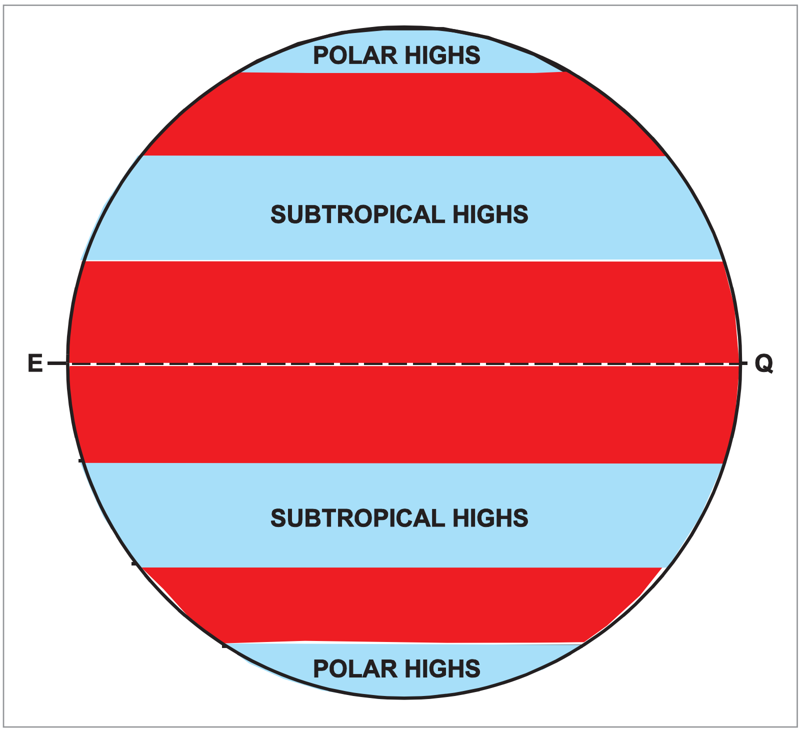


Figure 17.1 General source regions

The basic properties of stability, temperature and humidity can change as an air mass moves over surfaces with different properties. An air mass moving to a warmer area will become heated in the lower layers and should become:

- Unstable.
- Warmer.
- Lower relative humidity.

An air mass moving to a colder region should become:

- More stable.
- Colder in the lower layers.
- Have an increased relative humidity.

Identification

Air masses are identified by temperature/latitude:

- Equatorial.
- Tropical.
- Polar.
- Arctic.

and by humidity or sea/land source:

- Maritime.
- Continental.

Air masses are classified according to moisture content, source or type and temperature using a 3 letter system:

1. First letter: moisture content. c(ontinental) or m(aritime).
2. Second letter: source region or type, E(quatorial), T(ropical), P(olar) and A(rctic).
3. Third letter: temperature, c(old) or w(arm).

Hence the 5 air masses affecting Europe are:

- Arctic maritime, mAc
- Polar maritime, mPc
- Polar continental, cPc
- Tropical maritime, mTw
- Tropical continental, cTw

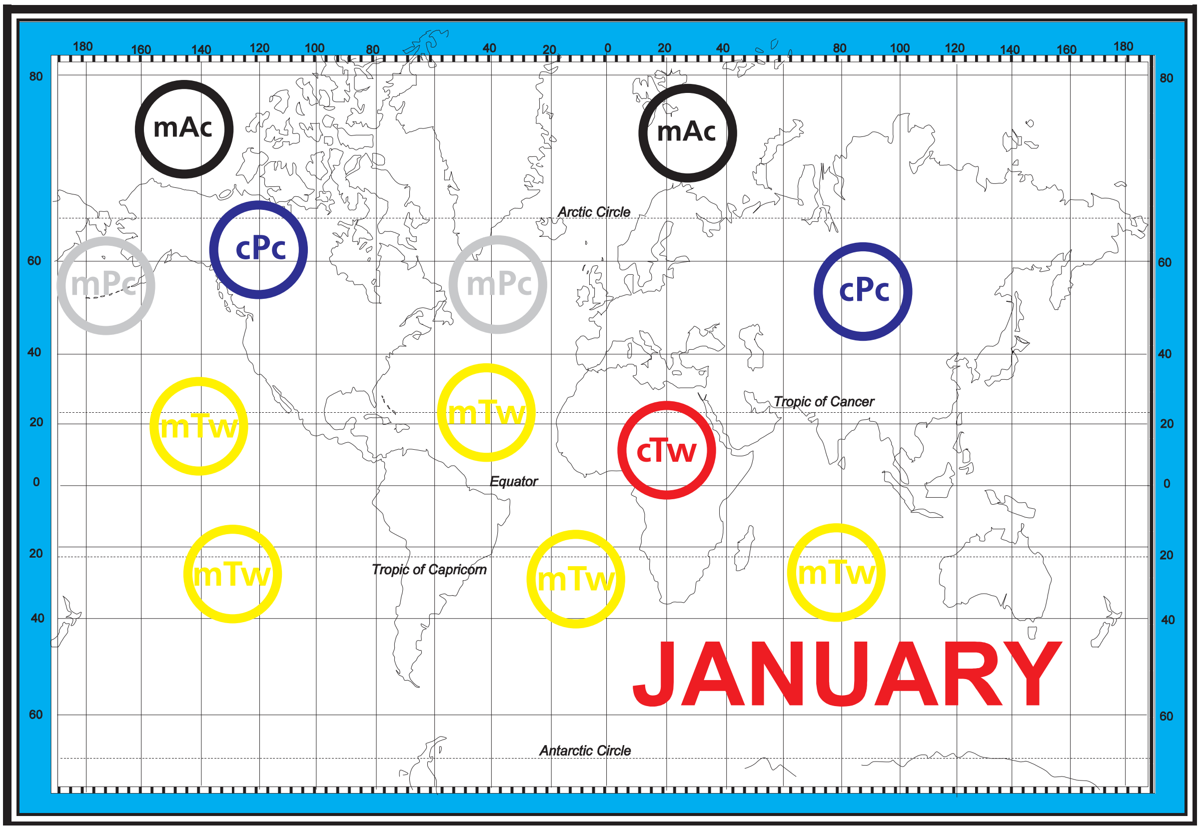


Figure 17.2 Air mass source regions in January

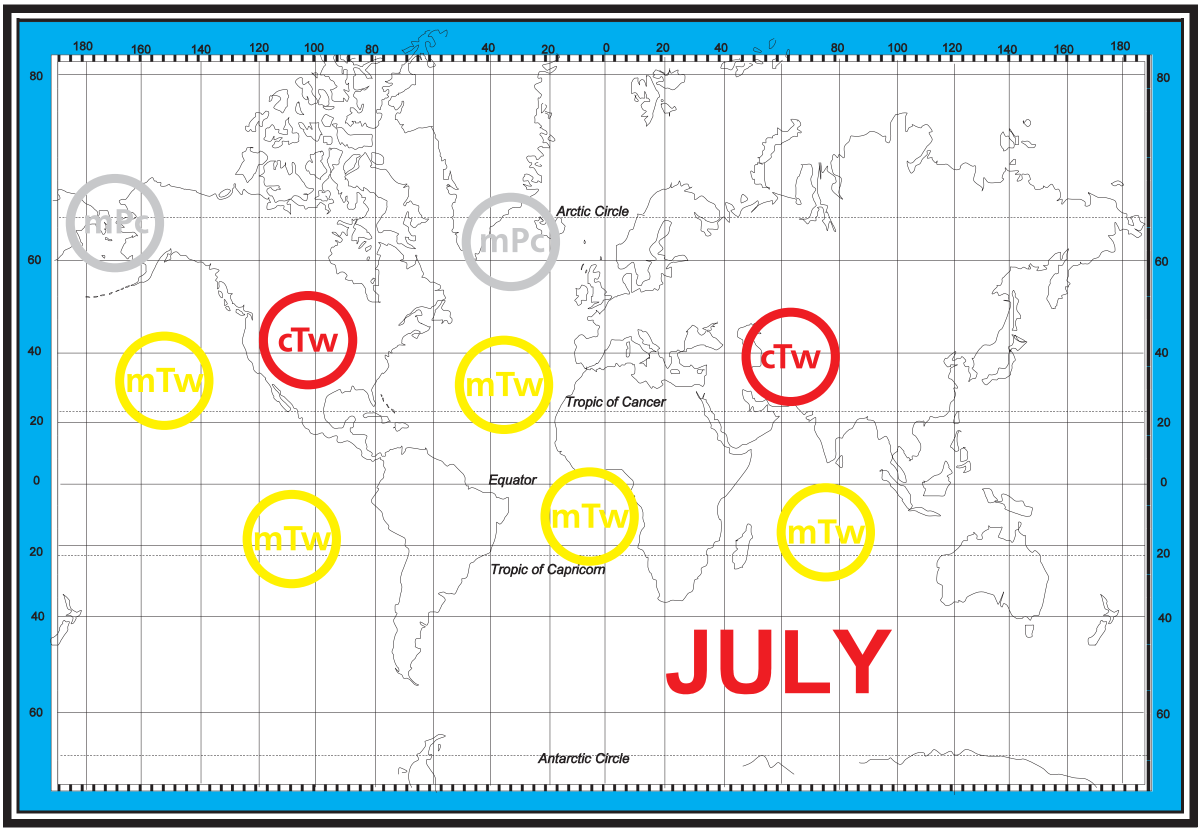


Figure 17.3 Air mass source regions in July

Air Masses Affecting the British Isles and NW Europe

(Air masses affecting this area affect other parts of the world in a similar fashion.)

- **Arctic Maritime (mAc)**

  Source: Polar ice cap, stable very cold and dry. Usually experienced between September and May. During the summer months mAc has characteristics similar to mPc so no distinction is made.

  Weather: relative and absolute humidity increase significantly as the air moves down the Norwegian Sea and the air mass becomes very unstable. Large CU and CB develop giving heavy showers of snow often with blizzard conditions.

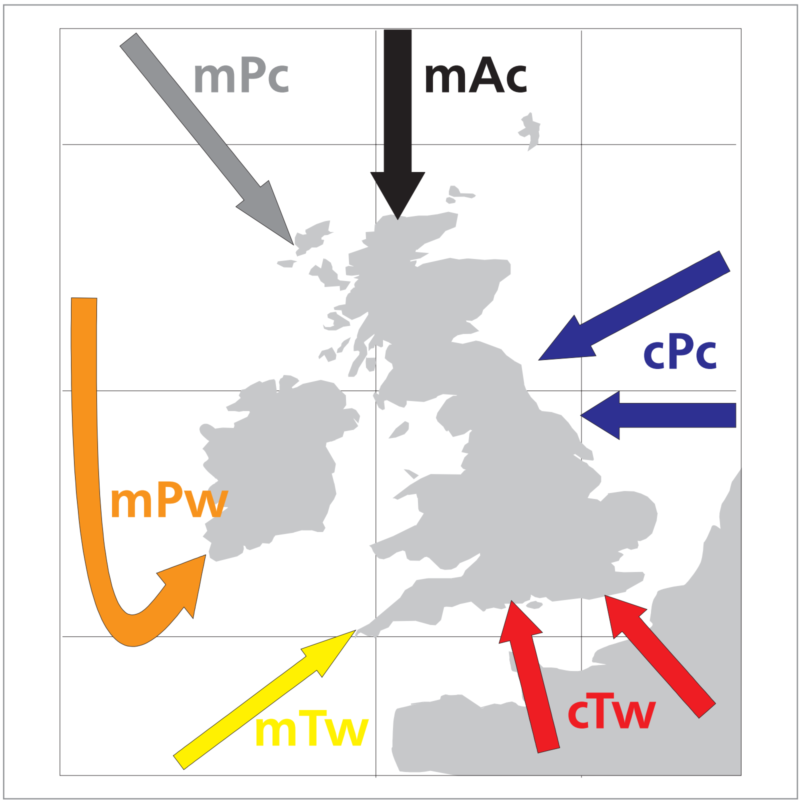


Figure 17.4 Air masses affecting the British Isles

- **Polar Maritime (mPc).**

  Source: Northwest area of North Atlantic: stable, cold, absolute humidity **low**, relative humidity **high**.

  Weather: Cold, moist, NW airflow. On approaching UK becomes unstable giving Cu, Cb, heavy showers, sometimes hail and thunderstorms. Cu, Cb most likely over NW coasts and inland in summer. Visibility good except in showers. Bumpy flying. At night inland the cloud dissipates, the clearing skies causing a low level inversion with stable air below - ideal conditions for radiation fog.

- **Polar Continental (cPc).**

  Source: Siberia (winter only). Stable, very cold and dry.

  Weather:

  - If the airflow is mainly from the E via continental Europe, then very cold, very dry, no cloud, no precipitation. Becomes unstable hence good visibility.

  - If the airflow comes over the Baltic or North Seas the air will become unstable, with large Cu and heavy snow showers on the E coast of Sweden and the UK. Remains very cold. Visibility good except in showers.

- In summer the air mass virtually disappears. However, with high pressure over Scandinavia in early to mid summer, there will be a NE flow over the North Sea to E UK. The air originates as dry, warm and stable. Over the North Sea it becomes moist and cool.

  This results in **Haar** conditions over E coast of N England and Scotland - very low St, drizzle, advection fog, poor visibility.

- **Tropical Continental (cTw).**

  Source: N Africa/SE Europe. Mainly summer, warm, dry, stable.

  Weather: A warm, dry S or SE flow. No cloud or precipitation, warm or very warm. Visibility moderate except in dust haze which can occur.

- **Tropical Maritime (mTw).**

  Source: The Azores anticyclone. Warm, stable, absolute humidity **high**, RH **high.**

  Weather: A warm, moist SW air flow. As the air moves north, the temperature reduces (but remains warm). Stability and RH increase. Low cloud, St and Sc. Drizzle or light precipitation. Visibility poor. Advection fog over sea area late spring, early summer, over land winter, early spring. In high summer insolation and convection break down the stability resulting in clear skies or possibly a few small Cu.

- **Returning Polar Maritime (mPw).**

  This is Polar Maritime air which has moved to the S of the North Atlantic & approaches from the W or SW. In its lower layers tropical maritime conditions are acquired and retained. In the NW Europe summer it will tend to give typical mPc conditions particularly by day. In winter the conditions in NW Europe will tend to be similar to those of an mTw air mass.

  Equatorial (mEw): Equatorial air masses do not affect Europe. The weather associated with equatorial regions will be discussed in Chapters 19 and 20.

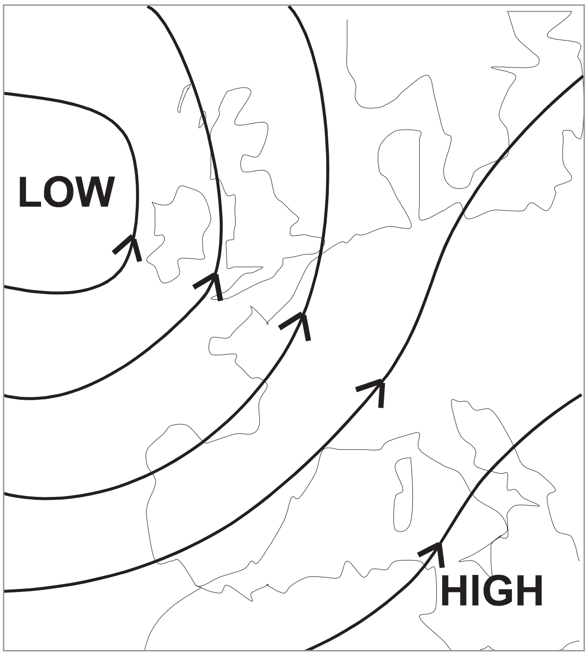


Figure 17.5 Returning polar maritime

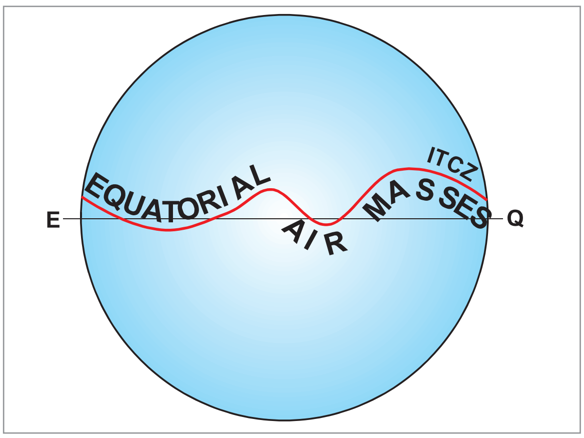


Figure 17.6 Equatorial Air Masses

Other Areas

Polar Maritime (mPc) air also has a source in the other oceans in temperate regions. Tropical Maritime (mTw) air has sources in the other subtropical oceans. Polar Continental (cPc) air has a source in Canada which considerably affects N American weather.

Fronts, An Introduction

A front is a zone or surface of interaction between two air masses of different temperature.

When the two air masses meet, the warmer will rise over the top of the colder because of the difference in density. The frontal surface where they meet is frequently, but not always, active with much cloud and precipitation. The ground position of the frontal surface is shown on synoptic charts.

A front is usually only a few miles wide. If the term ZONE is used, then the region of interaction is much wider (up to 300 NM).

The main global fronts are:

- The Polar Front.
- The Arctic Front.
- The Mediterranean Front.
- The Intertropical Convergence Zone (ITCZ).

The Polar Front

The Polar Front is the boundary between polar and tropical air masses. In the Northern Hemisphere the polar front is found between latitude 35°N and 65°N. In the North Atlantic the front extends from mid-Florida to SW UK in winter and from Newfoundland to NW UK in summer. In the N. Pacific the polar front is found in similar latitudes. In the Southern Hemisphere it is found between about 50°S and 55°S throughout the year.

There are numerous waves on the front which cause depressions which contain their own portions of the polar front.

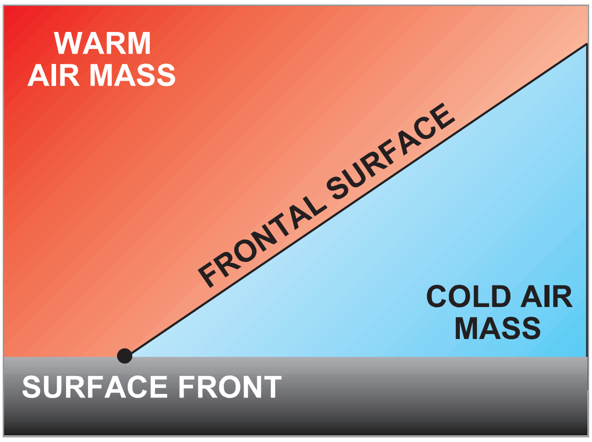


Figure 17.7 Front

The Arctic Front

The Arctic Front is the boundary between the Arctic and the Polar air masses and may have an associated jet stream. It lies at higher latitudes than the polar front but sometimes moves into temperate latitudes (south Greenland to north of Norway) in winter and spring. (See *Figure 17.8 and Figure 17.9*).

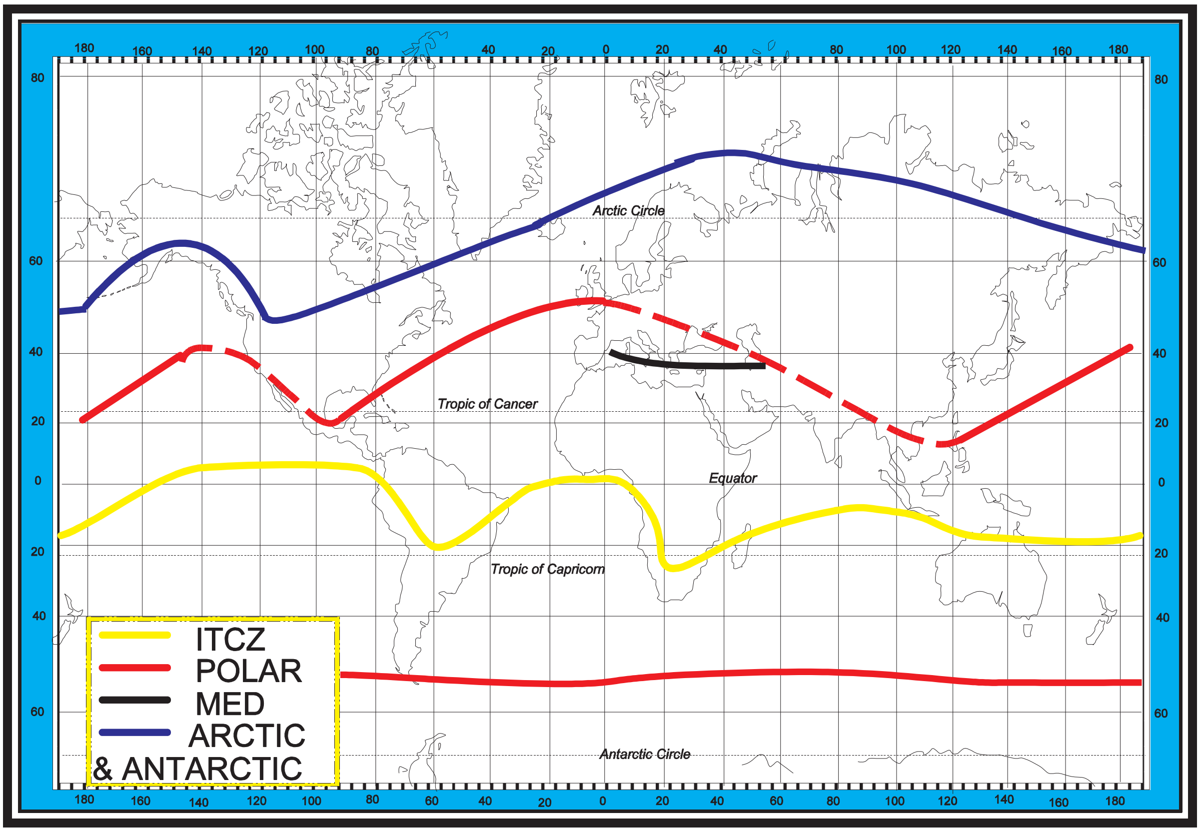


Figure 17.8 Frontal positions in January

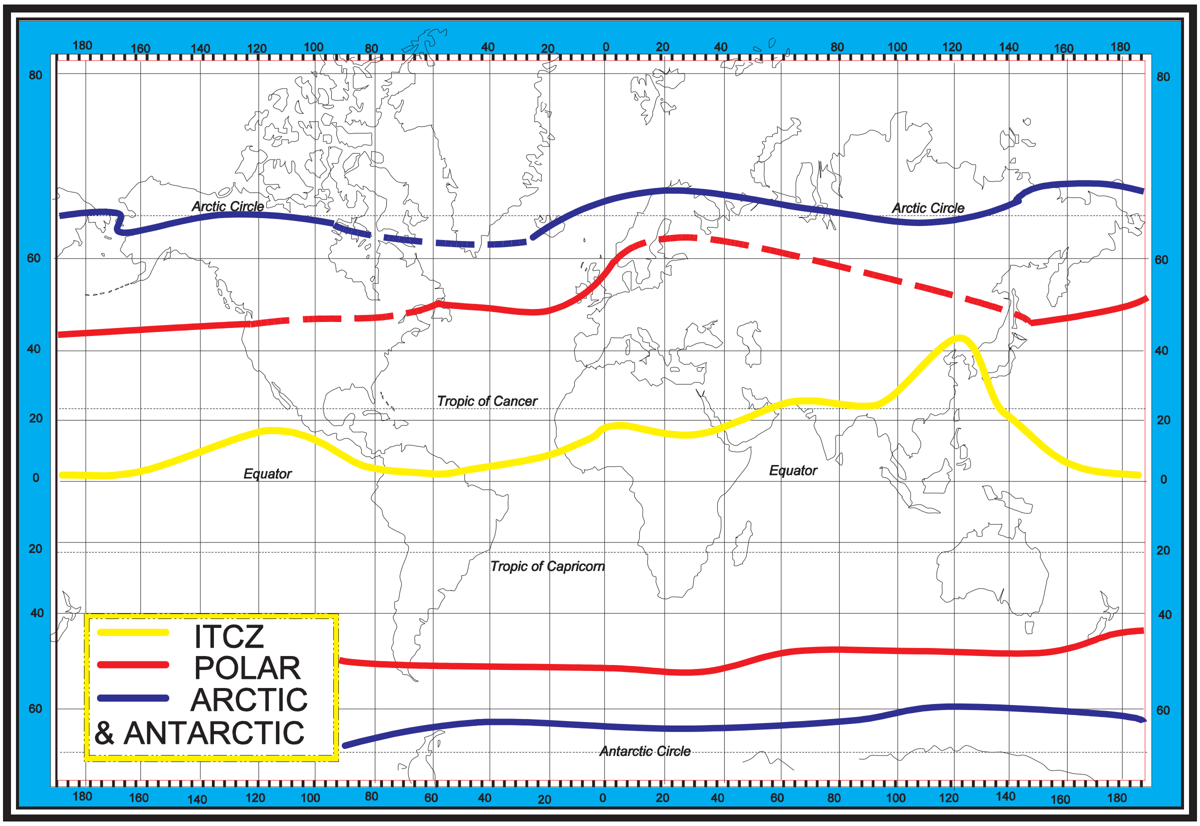


Figure 17.9 Frontal positions in July

The Mediterranean Front

The Mediterranean Front is the boundary between Polar Continental or Maritime air from Europe and Tropical Continental air from North Africa. It extends west to east across the middle of the Mediterranean Sea as far as the Caspian.

The front disappears in summer.

The Intertropical Convergence Zone (ITCZ)

The Intertropical Convergence Zone is the broad zone of separation between the air masses either side of the heat equator. The ITCZ is where the northeast and southeast trade winds converge. Subject to large seasonal movement overland, but much less over the sea. Sometimes known as the **Thermal Equator** or **Equatorial Trough. The ITCZ is discussed in detail in Chapter 20.**

Frontal Factors

Fronts in a locality are named warm or cold, dependent upon whether warm or cold air is replacing the other. All fronts have a slope with height so that in side view the front is a sloping surface.

Whilst fronts are normally associated with convergence and ascending air, giving much cloud and bad weather, it is possible for air masses to flow side by side with little interaction.

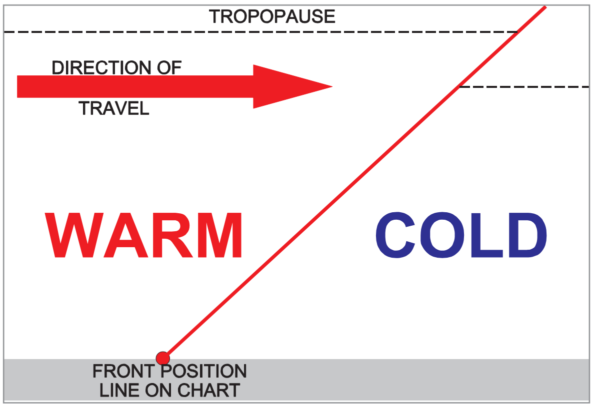


Figure 17.10 Front

The factors concerned are:

a) **Equilibrium**. The Pressure Gradient Force (PGF) is towards the front from both the cold and the warm side then under these conditions the wind would be geostrophic, blowing parallel to the front. The frontal surfaces would be in equilibrium with no tendency for the cold air to undercut the warm.

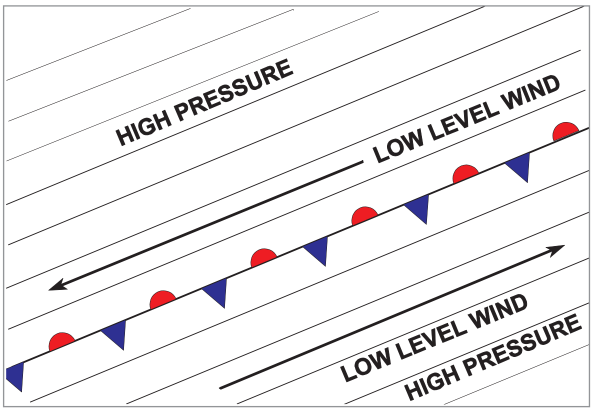


Figure 17.11 Equilibrium - a quasi-stationary front

Figure 17.11 shows the equilibrium state where the polar front is parallel to the isobars with the geostrophic winds being parallel to the front. In this case the front is known as a quasi-stationary front. These fronts are relatively inactive because there is little convergence

b) **Convergence**. There is always convergence in any depression but this will normally be small and give light precipitation and thin cloud only. It follows therefore that there must be unbalancing of the equilibrium, causing lifting and undercutting of the warm air, for extensive cloud to occur together with heavy precipitation.

Unbalancing can be caused by the pressure falling in the depression. This will cause the winds to no longer be geostrophic and there will be a flow of air across the isobars towards the deepening centre.

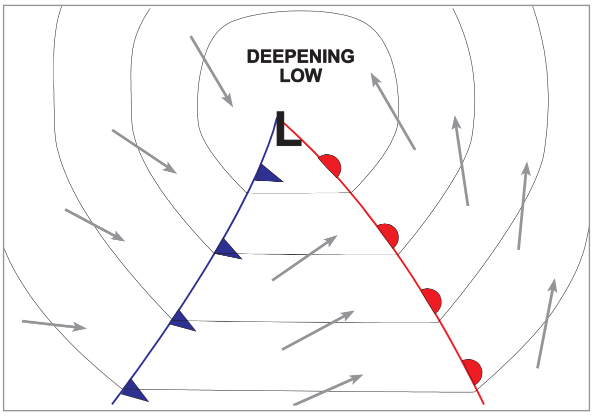


Figure 17.12 Convergence

The Polar Front and Polar Front Depressions

Polar and tropical air masses meet at a boundary which is called the polar front. This front is in temperate latitudes in both hemispheres and its position changes, particularly with the seasons.

The portion of the polar front which particularly affects the British Isles is the Atlantic polar front.

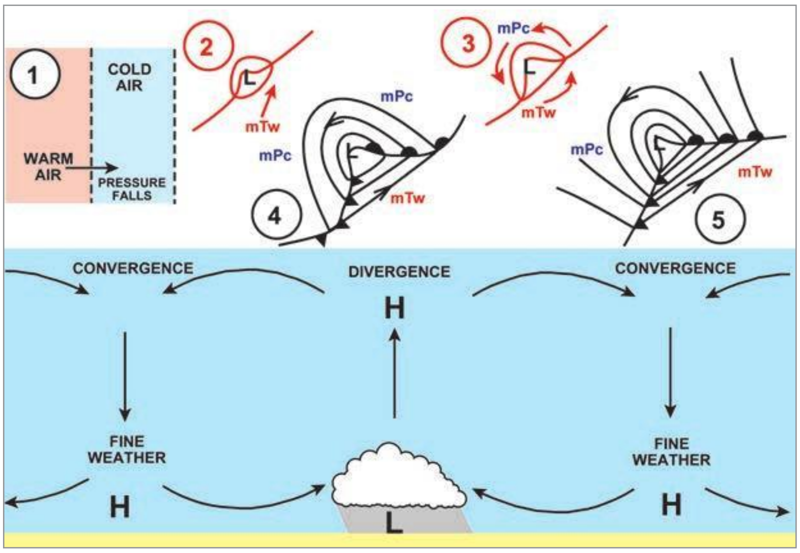


Figure 17.13 The development of polar front depressions

The polar front is important because depressions form on the front and these contain modified portions of the front which provide much of the UK and European bad weather.

Depressions which form on the polar front (PF) are called polar front depressions. They form in families one behind the other. The formation most frequently occurs on the tail of the depression cold front. The portions of the front lying either side of the PF depression are called either warm or cold. Polar front depressions move parallel to the isobars in the warm sector and at a speed equal to the geostrophic wind speed measured between the two central isobars in the warm sector.

Warm Fronts

If warm air is replacing cold air, then the front is called warm. A warm front is shown at *Figure 17.14.*

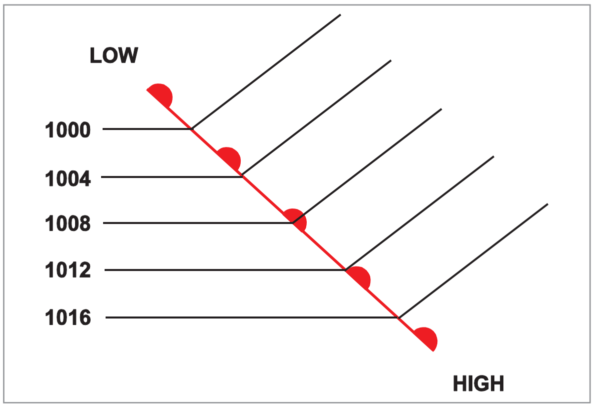


Figure 17.14 Warm front

A warm front has an approximate slope of 1:150 and a side view is as shown in *Figure 17.15.*

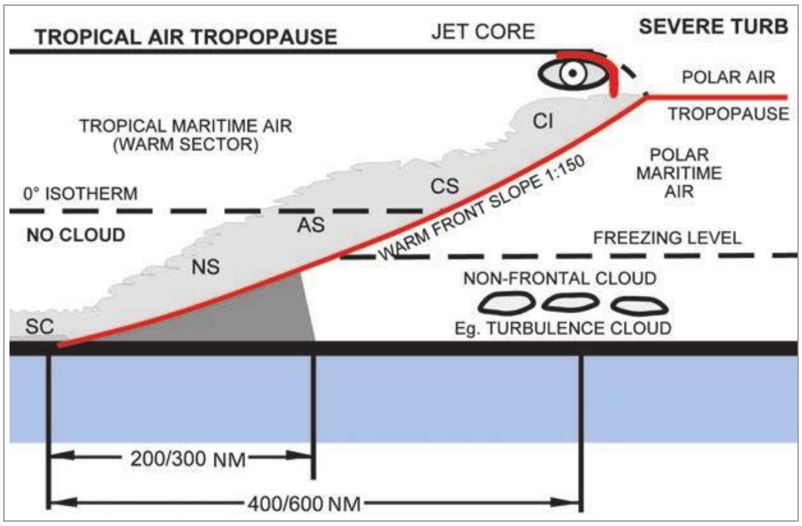


Figure 17.15 Warm front side elevation

The front moves at right angles to itself at a speed equal to 2/3 of the geostrophic interval measured along the front. See *Figure 17.16*.

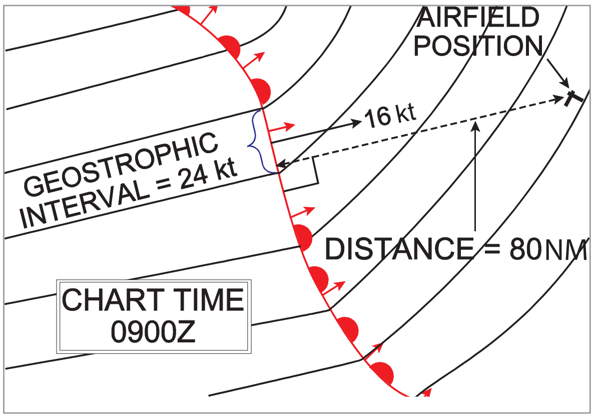


Figure 17.16 Warm front - speed at movement

Cold Fronts

If cold air is replacing warm air, then the front is called a cold front. A cold front on an analysis chart is as shown in *Figure 17.17*

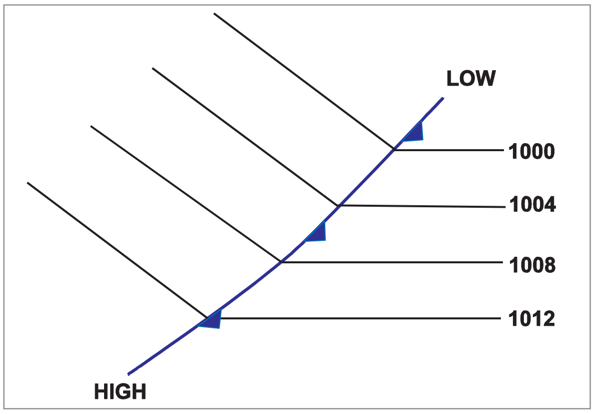


Figure 17.17 A cold front

The slope of a cold front is approximately 1:50 to 1:80 and a side view is shown in *Figure 17.18*. A winter cold front in Europe will usually produce more intense weather and precipitation.

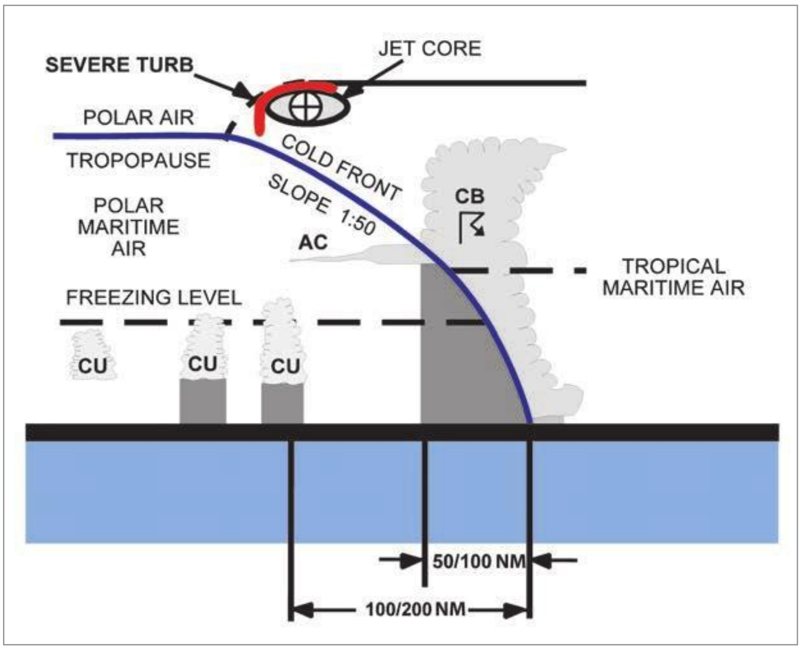


Figure 17.18 Cross -section through a cold front

The front moves at right angles to itself at a speed equal to the geostrophic interval (full) measured along the front. See *Figure 17.19*.

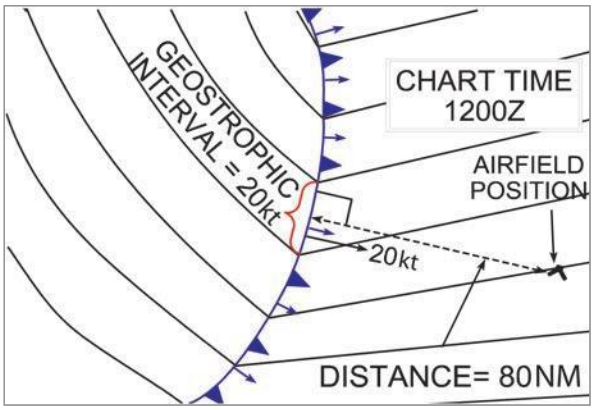


Figure 17.19 Cold front - speed of movement

Quasi-stationary Fronts

When the front has little or no movement it is known as a **quasi-stationary** front. *Figure 17.20* shows such a front on a synoptic chart. Since there is little frontal movement, weather conditions are likely to be comparatively quiet, though longer lasting. The situation can be described as geostrophic as the front is parallel to the isobars.

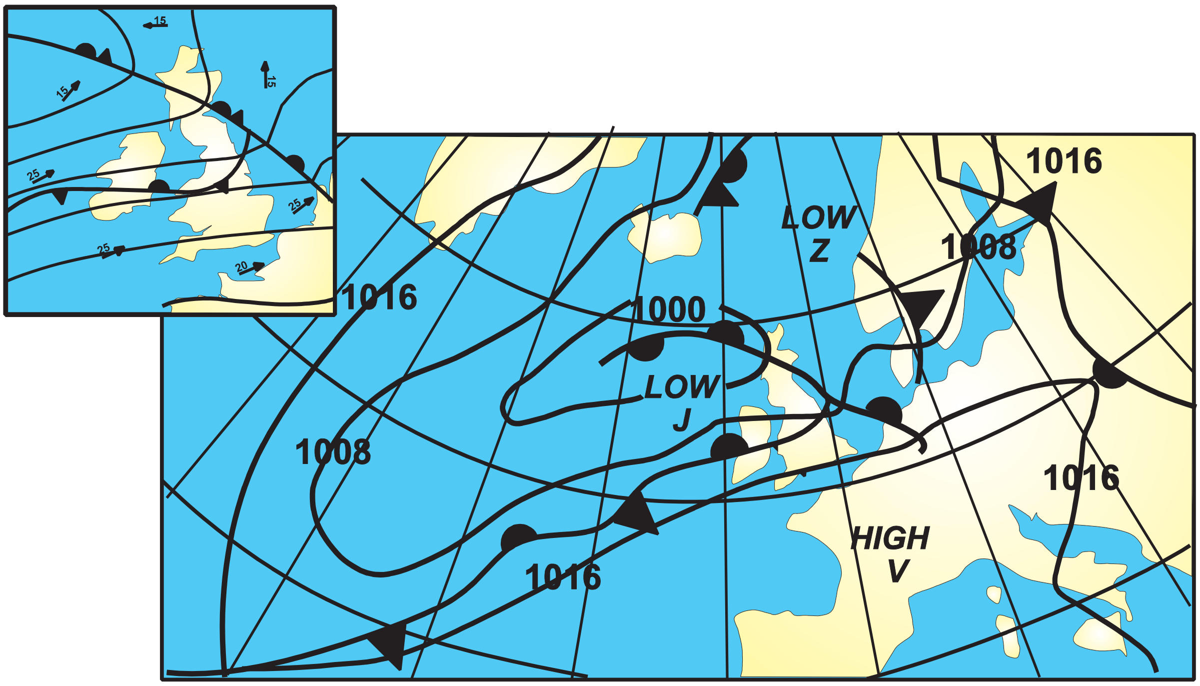


Figure 17.20 A quasi-stationary front

The Warm Sector

The area lying between the two fronts is known, since it is covered by **tropical air**, as the **warm sector**.

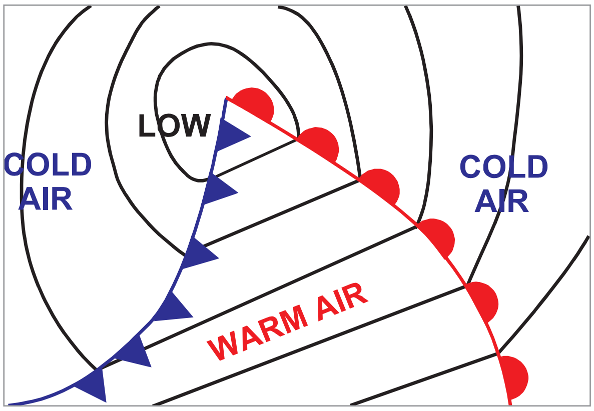


Figure 17.21 The warm sector

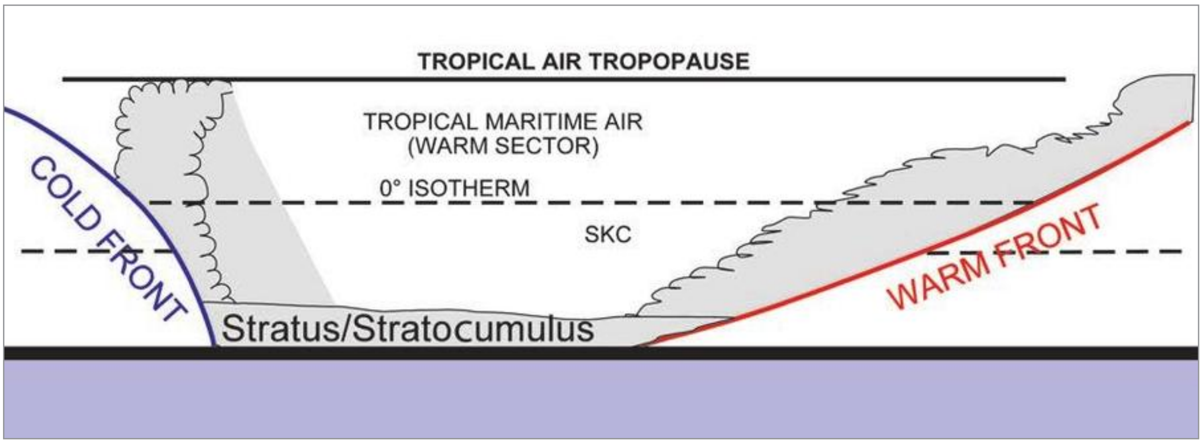


Figure 17.22 The warm sector

The **warm sector** will move as the warm front and cold fronts move and will in fact narrow, as the cold front moves faster than the warm. The **depression** at the tip of the warm sector will move parallel to the isobars in the warm sector at a speed given by the distance between the first and second isobars.

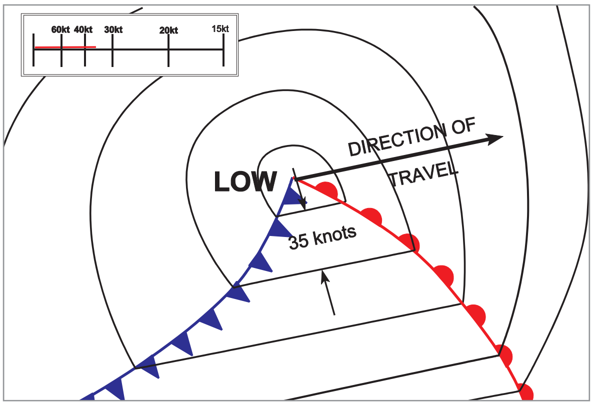


Figure 17.23 Movement of a depression

Weather with the Passage of a Polar Front Depression

- **Ahead of a warm front** (*Figure 17.24*).

Surface W/V	-	Speed increasing, slight backing, usually southerly.
Temperature	-	Steady low.
Dew Point	-	Steady low.
Pressure	-	Steady fall.
Cloud	-	Increasing to 8/8, base lowering, Ci, Cs, As, Ns.
Precipitation	-	Light continuous from As becoming moderate to heavy continuous from Ns.
Visibility	-	Reducing to poor.

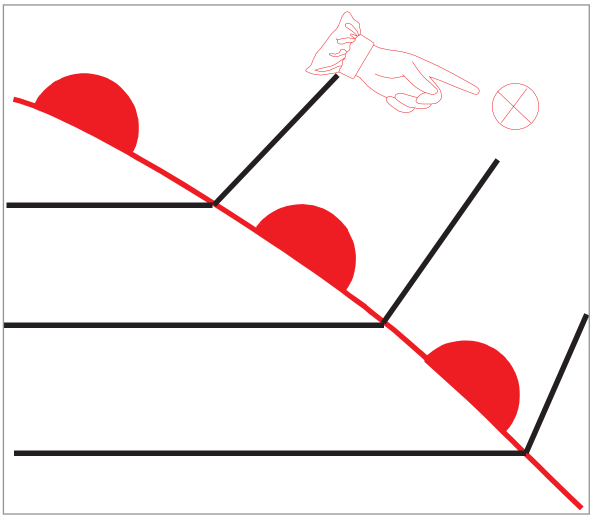


Figure 17.24 Ahead of a Warm Front

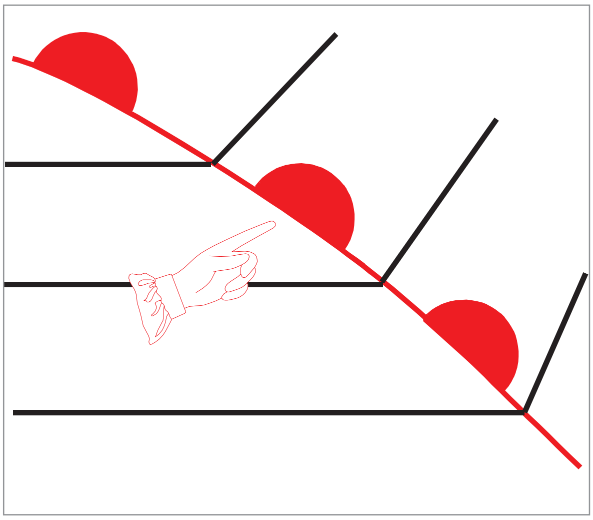


Figure 17.25 At the Warm Front

- **At the warm front.** (*Figure 17.25*)

Surface W/V	-	Sharp veer.
Temperature	-	Sudden rise.
Dew Point	-	Sudden rise.
Pressure	-	Stops falling.
Cloud	-	8/8, base very low, Ns, St.
Precipitation	-	Moderate or heavy continuous.
Visibility	-	Very poor, fog can occur

- **In the warm sector.** (*Figure 17.26*)

Surface W/V	-	Steady, usually from the SW.
Temperature	-	Steady.
Dew Point	-	Steady.
Pressure	-	Slight fall.
Cloud	-	6/8 to 8/8, some large breaks may occur, base low, St, Sc.
Precipitation	-	Light rain, drizzle
Visibility	-	Poor, possibly advection fog in winter.

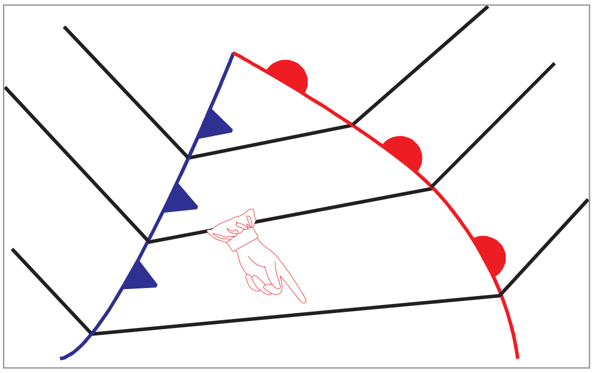


Figure 17.26 In the Warm Sector

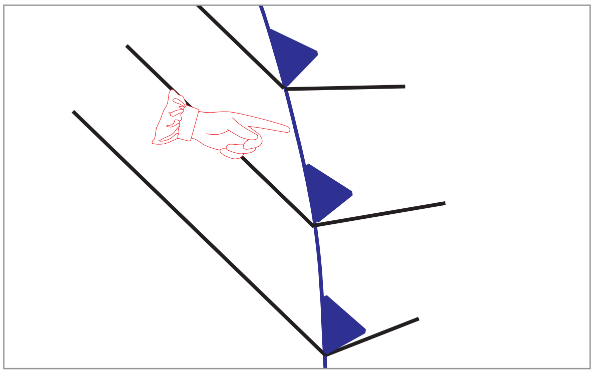


Figure 17.27 At the Cold Front

- **At the cold front.** (*Figure 17.27*)

Surface W/V	-	Sharp veer, gusts and squalls likely.
Temperature	-	Sudden fall.
Dew Point	-	Sudden fall.
Pressure	-	Starts to rise.
Cloud	-	6/8 to 8/8, base low but rising, Cu, CB, sometimes Ns.
Precipitation	-	Heavy rain or snow showers, thunder and hail possible.
Visibility	-	Good, except in precipitation.

- **Behind the cold front** (*Figure 17.28*)

Surface W/V	-	Steady or slight veer to NW.
Temperature	-	Steady low.
Dew Point	-	Steady low.
Pressure	-	Rises slowly.
Cloud	-	6/8, base lifting, Cu, Cb.
Precipitation	-	Showers, heavy at times, hail and TS possible.
Visibility	-	Very good, except in showers.

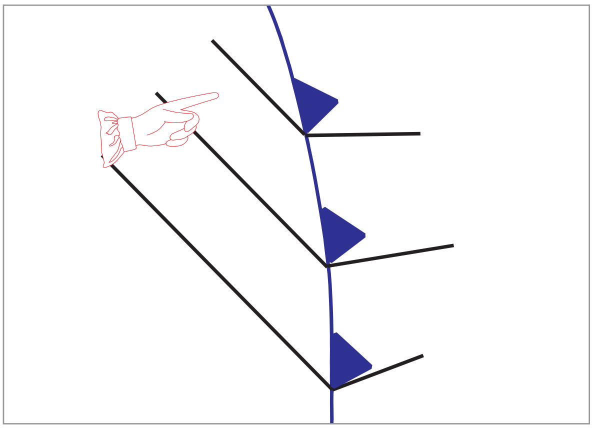


Figure 17.28 Behind the Cold Front

Upper Winds in a Polar Front Depression

At the height of the jet stream (about FL300) the cause is directly related to the temperature gradient so the jet streams generally will be parallel to the fronts. The winds are:

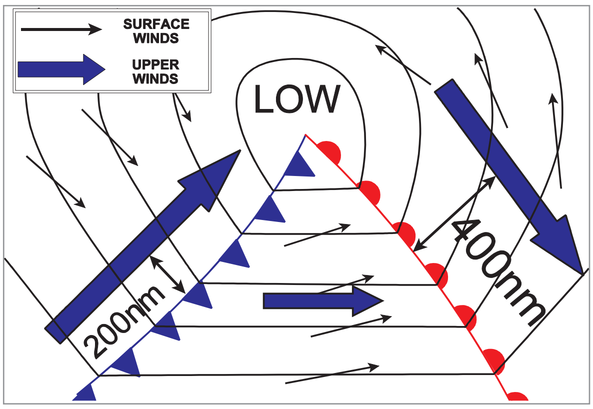


Figure 17.29 The upper winds in a polar front depression

- **Ahead of a warm front.** NW (rapid movement of Ci from the NW is a good indication of a jet stream above). The jet stream will be near the tropopause, parallel to and about 400 NM **ahead** of the surface position of the front in the **warm air.**

- **Above the warm sector.** There will be little change from the geostrophic wind near the surface as regards direction, but the speed will be greater.

- **Behind the cold front.** SW. The jet stream will be near the tropopause, parallel to and about 200 NM **behind** the surface position of the cold front in the **warm air.**

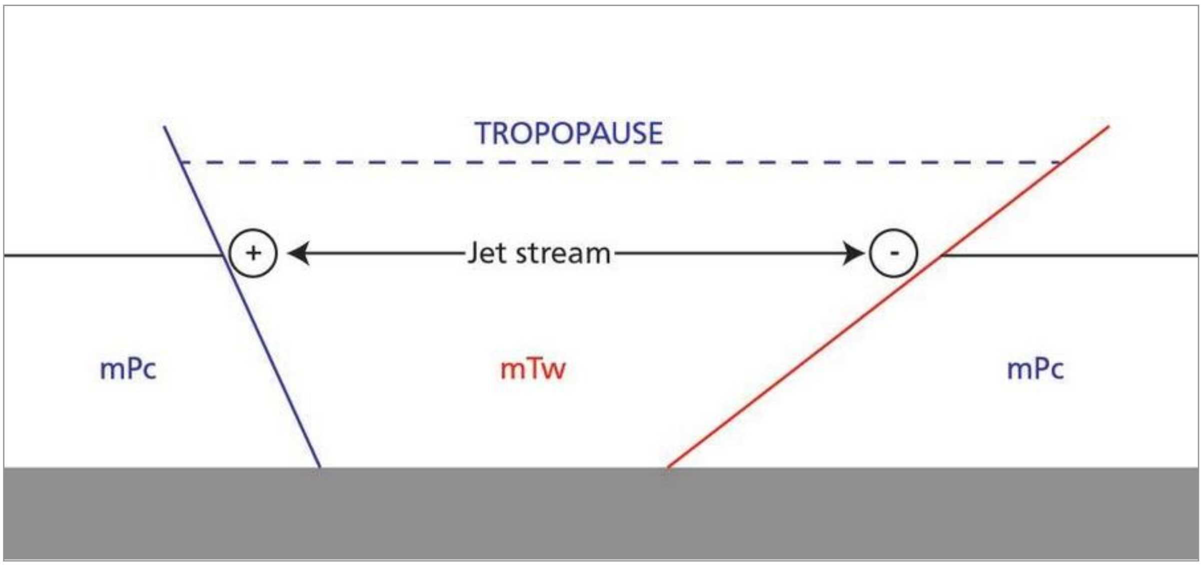


Figure 17.30

Questions

1. **An air mass that has travelled over an ocean is known as:**

    a. continental air and has a high humidity
    b. continental air and has a low humidity
    c. maritime air and has a high humidity
    d. maritime air and has a low humidity

2. **Characteristic weather associated with a mPc air mass transiting the British Isles in summer would include:**

    a. widespread Cu and Cb activity overland during the day
    b. clear quiet settled weather overland by day with good visibility
    c. warm moist conditions with some Sc or Cu and moderate to poor visibility
    d. extensive low stratus cloud giving drizzle to light rain overland by day

3. **If air in transit is heated from below it tends to become more:**

    a. stable
    b. neutrally stable
    c. unstable
    d. none of these

4. **The weather associated with polar maritime air is:**

    a. overcast, moderate drizzle
    b. overcast moderate intermittent rain
    c. broken cloud, light, moderate or heavy rain
    d. broken cloud, moderate continuous rain

5. **Polar maritime air is . . . . and can bring . . . . in the UK in winter but . . . . in summer.**

    Complete the above sentence correctly using one of the following:

    a. very unstable/heavy snow showers/does not arrive
    b. cold and stable/advection fog/rain showers
    c. unstable/intermittent or continuous snow/cool dry weather
    d. unstable/heavy showers/light rain showers

6. **Tropical continental air normally brings to the UK:**

    a. hot dry cloudless weather with a thick haze
    b. warm weather with broken Cu and showers on coasts, visibility very good except in showers
    c. warm dry cloudless weather with very good visibility
    d. hot dry cloudless weather on coasts but Cu building up inland with rain showers, visibility good except in showers

7. **Referring to the area of the North Atlantic, the mean position of the polar front in January is:**

a. from Florida to southwest England
b. from Newfoundland to the north of Scotland
c. from Florida to the north of Scotland
d. from Newfoundland to southwest England

8. **When air from an air mass moves to a lower latitude, it can be expected that:**

a. surface layer air will become warmer, the RH will rise and the air will become unstable
b. surface layer air will become colder, the RH will rise and the air will become more stable
c. surface layer air will become warmer, the RH will fall and the air will become unstable
d. surface layer air will become warmer, the RH will fall and the air will become more stable

9. **In the N. Hemisphere when flying in the troposphere above the surface friction layer in the polar maritime air mass behind the cold front of a fully developed frontal depression:**

a. the wind will tend to veer in direction and increase in speed with progressive increase of altitude
b. the wind will tend to veer in direction with increase of altitude but the speed may remain constant in the lower layers of the atmosphere
c. the wind speed will reduce progressively with increase of altitude until at about 10 000 feet above mean sea level where it will then tend to increase in speed from another direction
d. the wind will tend to back in direction and increase in speed with progressive increase of altitude

10. **The average surface level winds at A3, B3 and C3 in Appendix 'A' are respectively:**

a. easterly, westerly, southwesterly
b. westerly, westerly, southwesterly
c. southwesterly, westerly, northwesterly
d. southwesterly, westerly, northerly

11. **The average upper winds at A1, B1 and C1 in Appendix 'A' are respectively:**

a. easterly, westerly, northwesterly
b. northwesterly, westerly, southwesterly
c. southwesterly, westerly, northwesterly
d. southwesterly, westerly, northerly

12. **It can be expected that the depth of the friction layer over the UK will be:**

a. greater in Polar Maritime air due to the instability and moderate wind
b. greater in Tropical Maritime air due to the warm temperature
c. greater in Polar Continental air due to the very low temperatures
d. greater in Tropical Continental air due to the relatively high temperatures in winter

13. The air masses involved in the development of a polar front depression are:

a. Polar Maritime and Polar Continental
b. Tropical Maritime and Polar Continental
c. Tropical Continental and Polar Maritime
d. Polar Maritime and Tropical Maritime

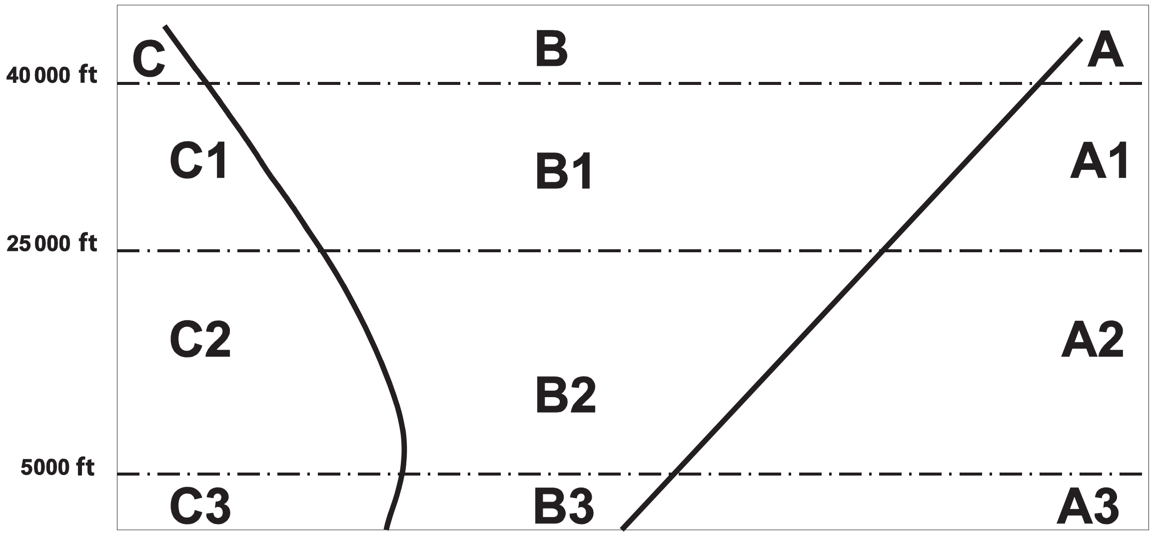
14. When a cold front passes a station in the British Isles:

a. The wind veers and the dew point falls
b. The wind backs and the dew point falls
c. The wind veers and the dew point rises
d. The wind backs and the dew point rises

15. Refer to Appendix B
The air masses indicated in the diagrams by the hand are respectively:

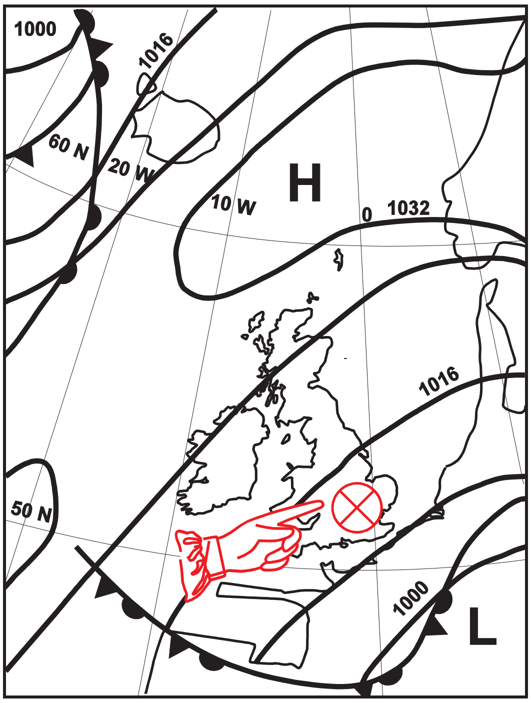
a. Arctic, Tropical Continental, Polar Maritime, Arctic Maritime
b. Polar Continental, Tropical Maritime, Tropical Continental, Arctic
c. Polar Maritime, Tropical Maritime, Polar Continental, Arctic
d. Polar Continental, Polar Maritime, Tropical Maritime, Arctic

Appendix A

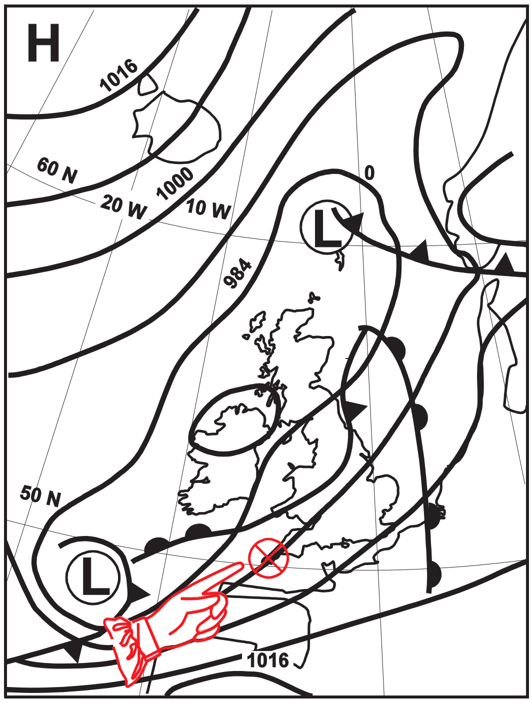


Cross-section through a polar front depression

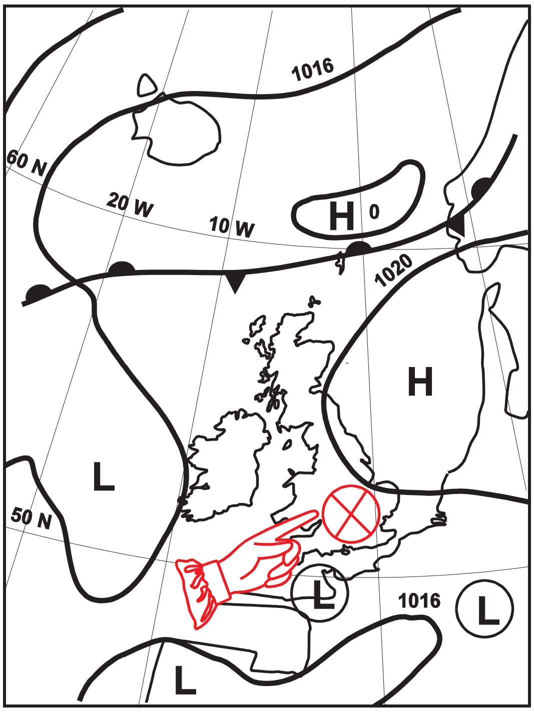
Appendix B



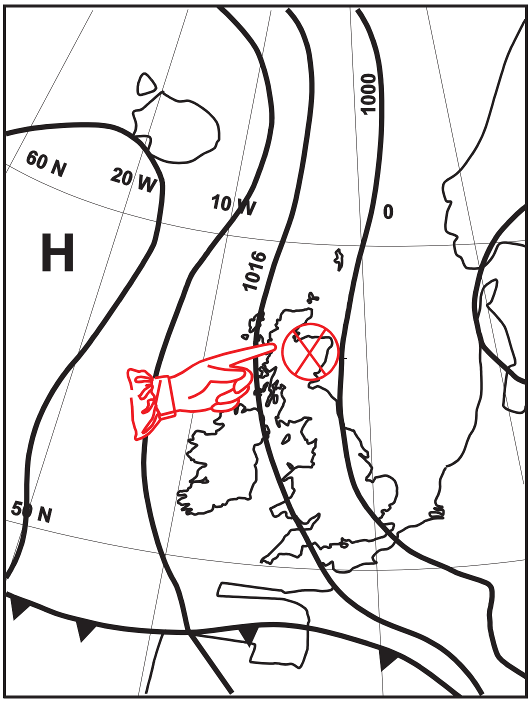
February



March



July



November

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	a	c	c	d	a	a	c	d	c	b	a

13	14	15
d	a	b

Chapter

18

Occlusions

Introduction

As the cold front is moving faster than the warm front the surface position of the cold front will eventually catch up with that of the warm front. When this occurs we have an occlusion. What happens next depends on the temperatures of the air ahead of the warm front and behind the cold front.

The position where the occluded front meets the warm and cold fronts is known as **the point of occlusion** or **triple point**.

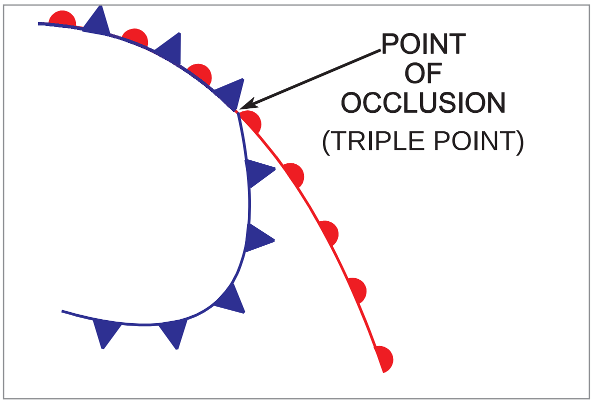


Figure 18.1 An occlusion

Warm (Front) Occlusion

If the air ahead of the warm front is **colder** than the air behind the cold front, then a **warm** occlusion will be formed. With a warm occlusion the cold air behind the cold front rises over colder air ahead of the warm front. This type of occlusion is most likely to occur in the winter months because as the depression approaches the European (or N. American) coast cold continental air is drawn in ahead of the warm front. In plan view the line of the occlusion follows the line of the warm front and the line of the cold front is discontinuous.

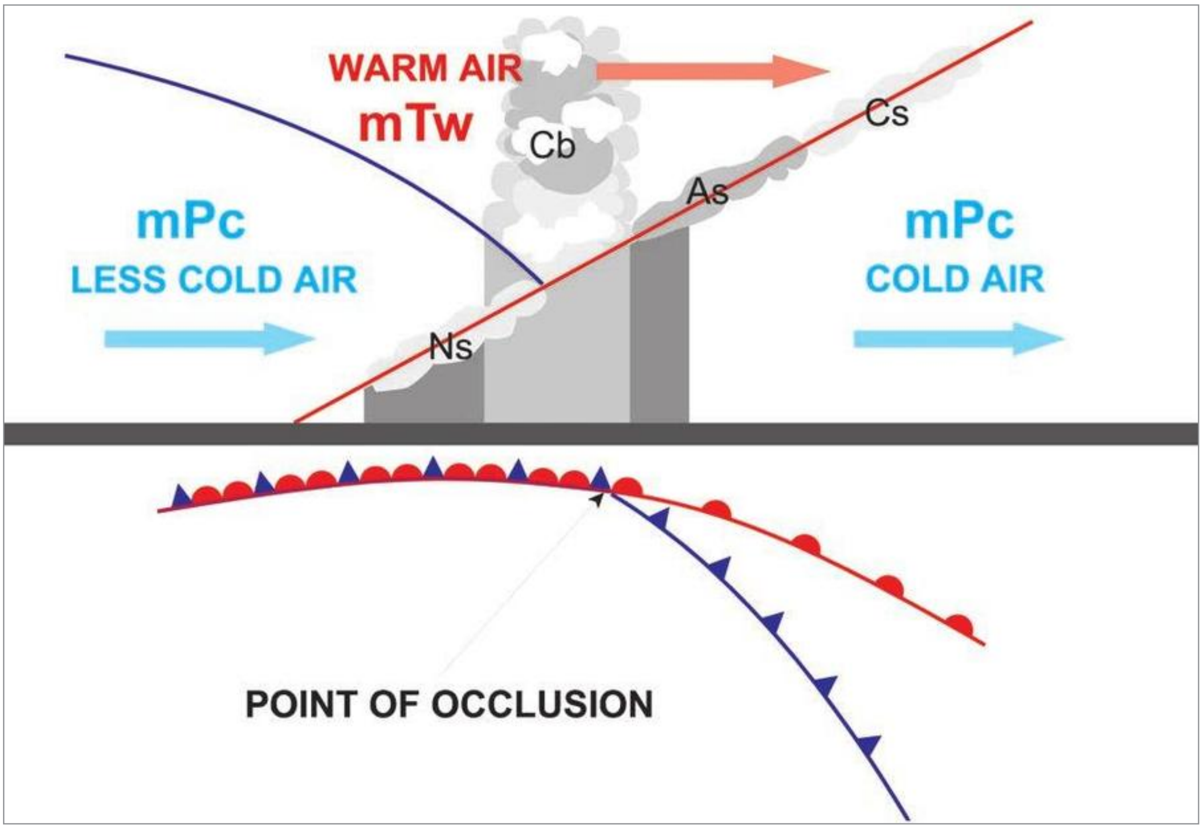


Figure 18.2 A warm occlusion

The warm sector is now raised off the ground and the cumuliform cloud at the cold front is pushed into the stratiform cloud at the warm front, giving the hazard of embedded CB. Most of the precipitation in the warm occlusion occurs ahead of the surface position.

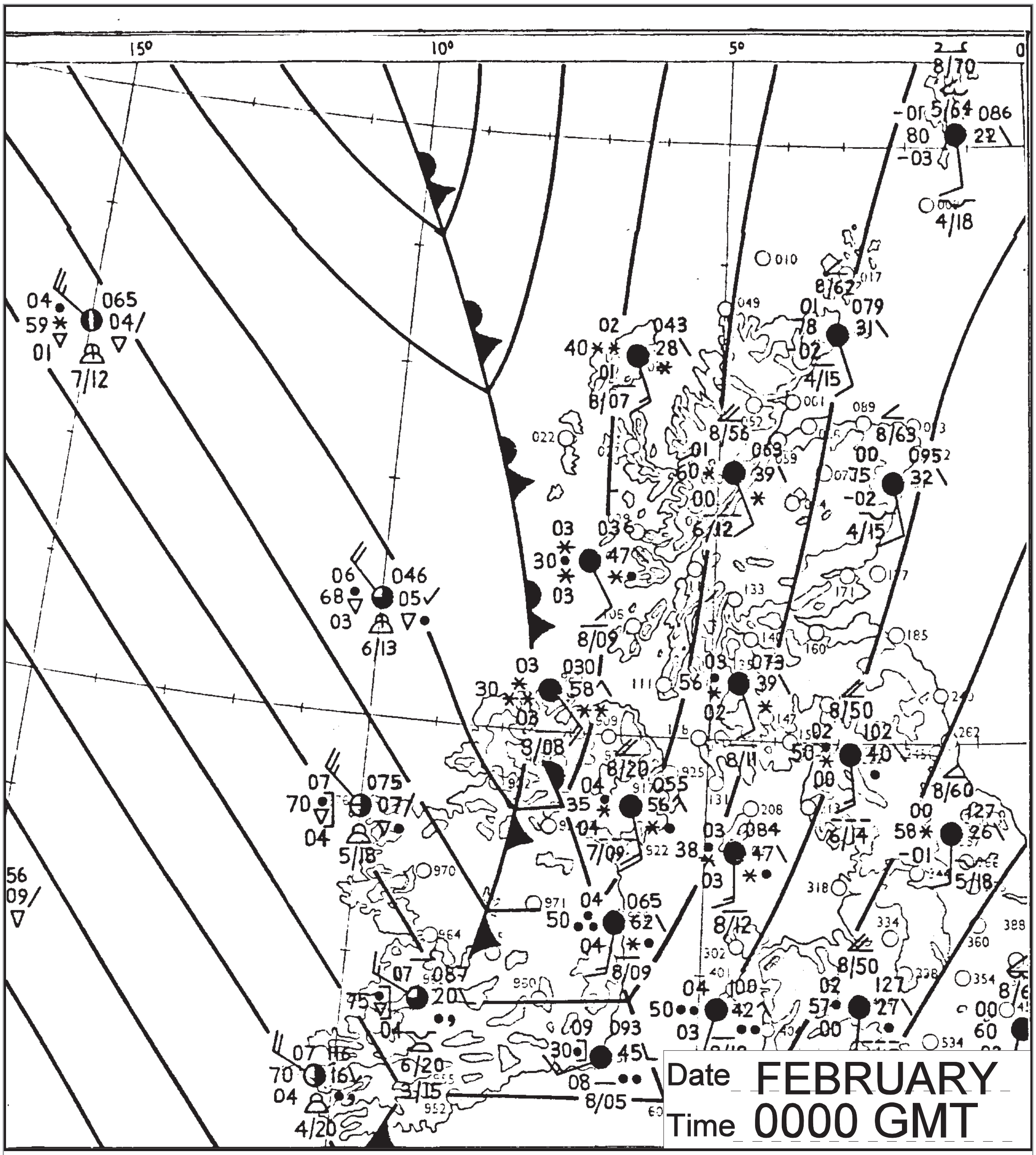


Figure 18.3 A warm occlusion

Figure 18.3 appears to show a cold occlusion but the only way to be certain about the type of occlusion is to check the temperatures ahead of the warm front and behind the cold front.

On *Figure 18.3* at the station circle at 56N010W in the 10 o'clock position is the number "06", this shows a temperature of 6°C at that location. To the east of that position and the occlusion is another station circle (at Tiree) showing a temperature of 3°C. So the air ahead of the occlusion is colder than the air behind so it must be a warm occlusion. Hence the diagram is correctly labelled

Cold (Front) Occlusion

If the air behind the cold front is **colder** than the air ahead of the warm front, then a **cold** occlusion will be formed.

With the cold occlusion cold air behind the cold front undercuts the less cold air ahead of the warm front. This type of occlusion is most likely to occur in the summer months because the continental air being pulled in ahead of the warm front is warmer than the Atlantic air or Pacific behind the cold front. Once again the warm sector is raised off the ground and we have the hazard of embedded CB. Most of the precipitation is behind the surface position of the occlusion.

In plan view the line of a cold occlusion follows the line of the cold front and the line of the warm front is discontinuous.

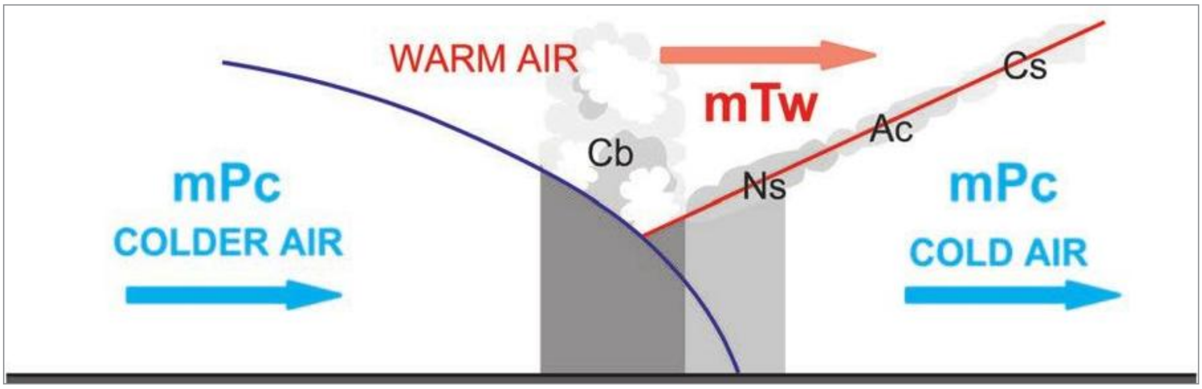


Figure 18.4 A cold occlusion

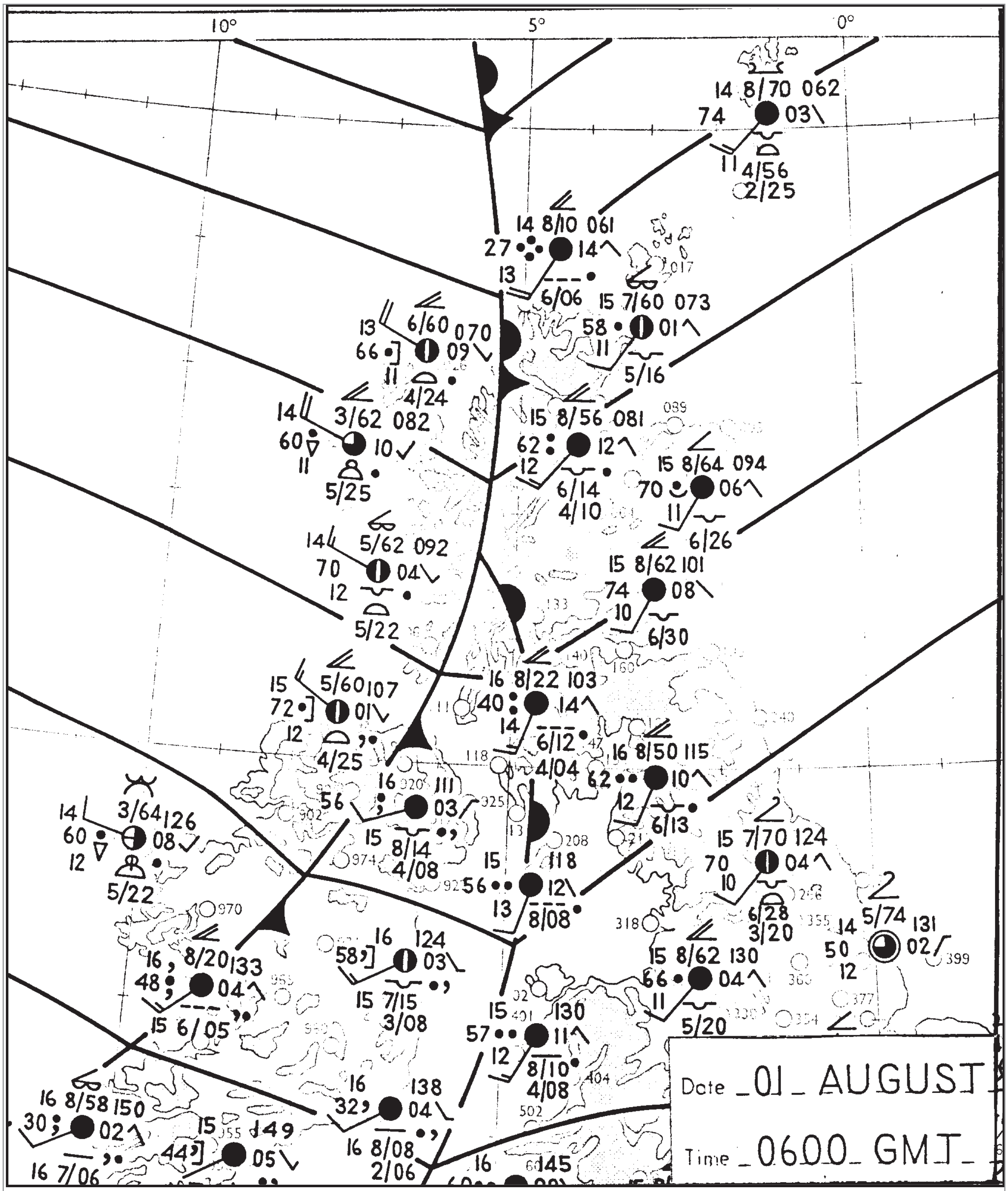


Figure 18.5 A cold occlusion

Occlusion Weather

Weather is usually bad because the normal frontal depression weather is concentrated into a smaller horizontal band and therefore a mixture of clouds can occur, e.g. Cb embedded in Ns. Furthermore, an occlusion forms towards the end of the life cycle of a depression, when it is slow moving and hence the weather can last for a lengthy period of time.

The above situation applies more particularly to the **warm** type occlusion because of the wider precipitation belt and the fact that this type of occlusion is more frequent in European winters because of the effect of Polar Continental air from the east (rain ice is a particular hazard).

Occlusions can become non-active and then produce a little cloud and nothing more as the depression dies.

Back Bent Occlusions

As the occlusion forms, the first point of occlusion is at the depression centre. It gradually moves S and W forming a **back bent** occlusion rather like a loop through the depression centre. This back bent portion is usually some 100 - 200 NM long and gives a belt of rain in the cold air behind the cold front, often of a thundery nature.

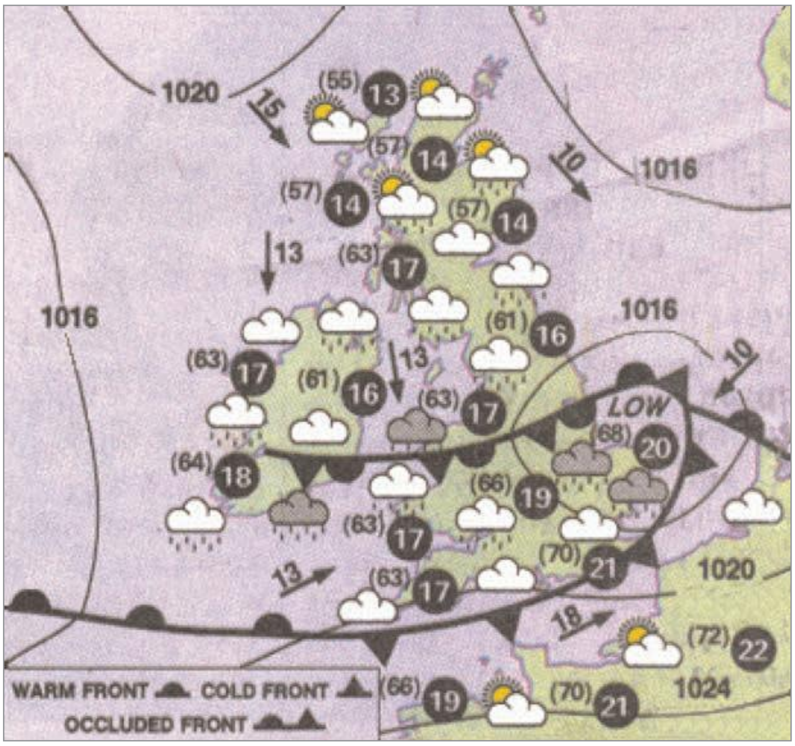


Figure 18.6 A Back Bent Occlusion

Movement

The precise forecasting of weather and movement of the occlusion is difficult. The **point of occlusion** may be plotted for some time ahead by moving the **warm front** and **cold front** of a warm sector depression as described in the last chapter. Where the fronts meet will be the new point of occlusion. *Figure 18.7* shows how this may be done.

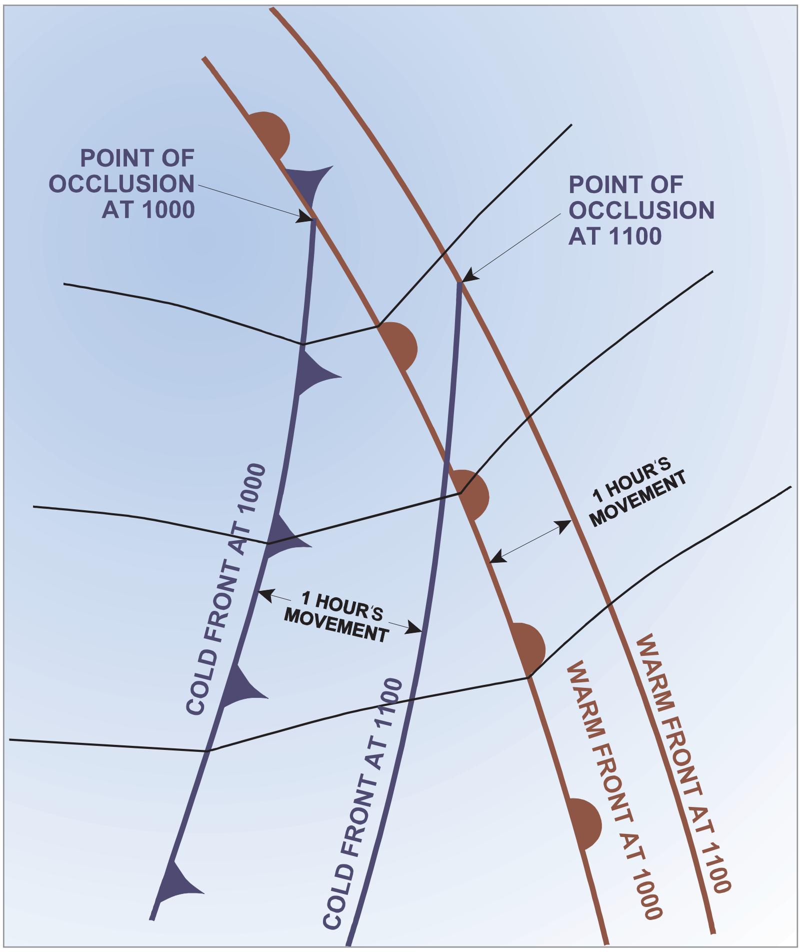


Figure 18.7 Movement of the point of occlusion

Movement of the **depression** itself is much more difficult to predict, but it will curve in an anticlockwise direction (Northern Hemisphere) at a speed dependent upon isobar spacing.

Growth and Decay

Growth of a depression to the time of producing the lowest pressure at the centre is about 4 days. The dying away as the depression fills can take 10 days or more and eventually the depression is absorbed by some other pressure feature.

For the British Isles, the time sequence typically involves:

- Formation and growth near the eastern seaboard of USA or mid-Atlantic.
- Lowest pressure, in central to eastern Atlantic.
- Depression filling over East Europe/Norwegian sea/Scandinavia - frontolysis, and eventually fill and lose their identity in central Asia or the Arctic Ocean.

Families of depressions form along the polar front and most frequently the new members form as secondary depressions at an occlusion point or at the end of a trailing cold front. This latter position particularly applies later in the life of a depression as the cold front crosses a coastline (e.g. the coast of Brittany) or a range of mountains.

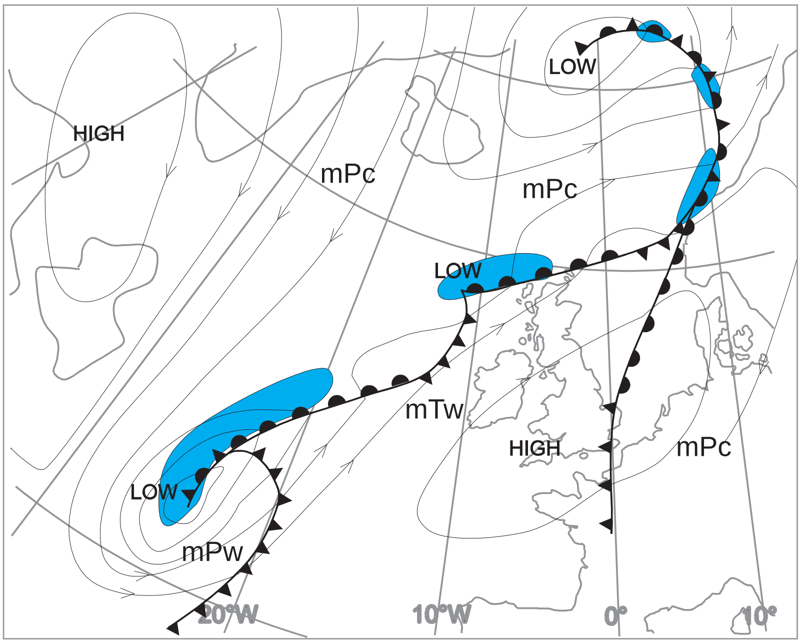


Figure 18.8 A north atlantic polar front

Conclusion

The Handbook of Aviation Meteorology sums up the matter of occlusions thus:

'The characteristics of the occlusion are variable. They may be similar to those of either the warm or cold front (according to type) but are often ill defined'.

Questions

Refer to Appendix A for Questions 1-3:

1. **The cloud in grid square M11 is most likely to be:**

   a. cirrus
   b. nimbostratus
   c. altocumulus
   d. stratus fractus

2. **Precipitation will reach the ground mainly in the area:**

   a. L14 -R14
   b. Q14 -S14
   c. O14 -T14
   d. J14-O14

3. **In grid square M6 the worst cloud conditions for flying could be:**

   a. altrocumulus
   b. cumulonimbus embedded in nimbostratus
   c. cumulonimbus
   d. nimbostratus

4. **Which of the conditions below would lead to the worst icing condition:**

	Size of Drop	Ambient Temp.
a.	2 mm	-30°C
b.	1 mm	-1°C
c.	5 mm	-4°C
d.	3 mm	-12°C

5. **Refer to Appendix 'B'. In a warm occlusion flying at 20 000' where will the most turbulence be found?**

   a. A
   b. B
   c. C
   d. A and C

6. **Refer to Appendix 'C'. Which area will get the most rain at the surface?**

   a. A
   b. B
   c. C
   d. D

7. **Refer to Appendix 'D'. What type of cloud will be found at X?**

   a. CS
   b. NS
   c. SC
   d. CB

8. **Refer to Appendix 'D'. What type of cloud is most likely at Z?**

a. CU
b. CB
c. AS
d. NS

9. **After passage of an occluded front in the Northern Hemisphere:**

	Wind	Temperature	Precipitation
a.	backs	stops falling	continues
b.	veers	drops rapidly	stops abruptly
c.	veers	drops or rises	begins to dry up
d.	backs	rises quickly	increases in strength

10. **With a cold occlusion:**

a. the air ahead of the warm front is colder than the air behind the cold front
b. the warm sector remains on the surface
c. the cloud type is predominately layer with a wide precipitation band
d. there is a risk of CB embedded in NS

Refer to Appendix 'A' for question 11

11. **The front at P14 is:**

a. cold
b. warm
c. warm at an occlusion
d. cold at an occlusion

Refer to Appendix 'B' for questions 12 -14

12. **The relative temperatures at A, B, and C could be respectively:**

a.	+6	+8	+10
b.	+6	+10	+8
c.	+8	+10	+8
d.	+10	+6	+8

13. **Precipitation at the surface underneath B is likely to be:**

a. Light drizzle
b. Continuous moderate
c. Showers, heavy with the possibility of hail
d. Nil

14. **Flight conditions at B are likely to be:**

a. smooth and clear
b. layer clouds with only light turbulence
c. some turbulence in NS with the possibility of embedded CB giving moderate/severe turbulence
d. flight in CU, CB with some turbulence

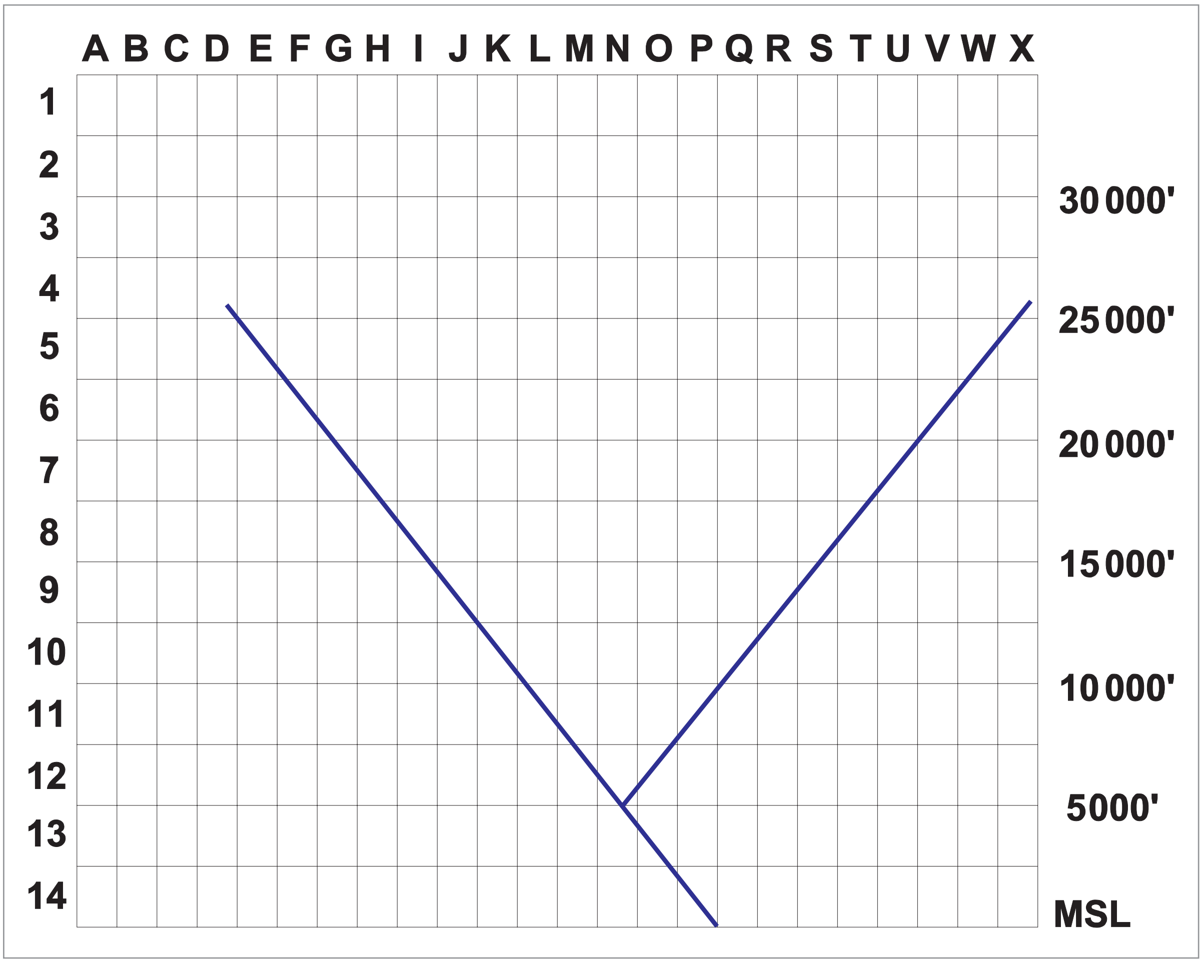
15. When flying from west to east through a cold occlusion (below the warm air) over the North Atlantic you would expect the wind to . . . . and the temperature to . . . .:

a. veer/decrease
b. back/increase
c. back/decrease
d. veer/increase

16. A warm occlusion occurs when:

a. warm air is forcing cool air over cold air
b. cold air is forcing cool air over warm air
c. cool air is forcing warm air over cold air
d. cool air is forcing cold air aloft

Appendix A


A B C D E F G H I J K L M N O P Q R S T U V W X
1
2
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7
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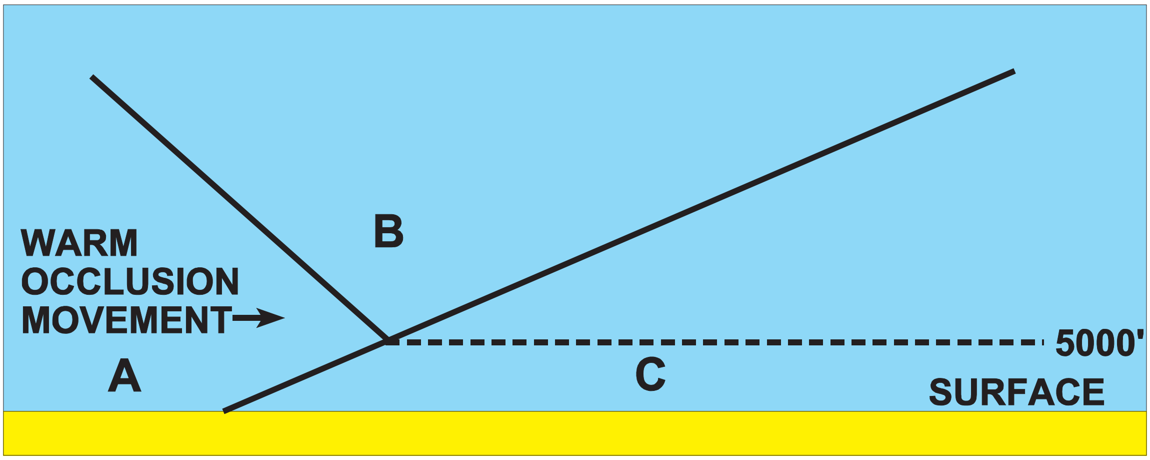
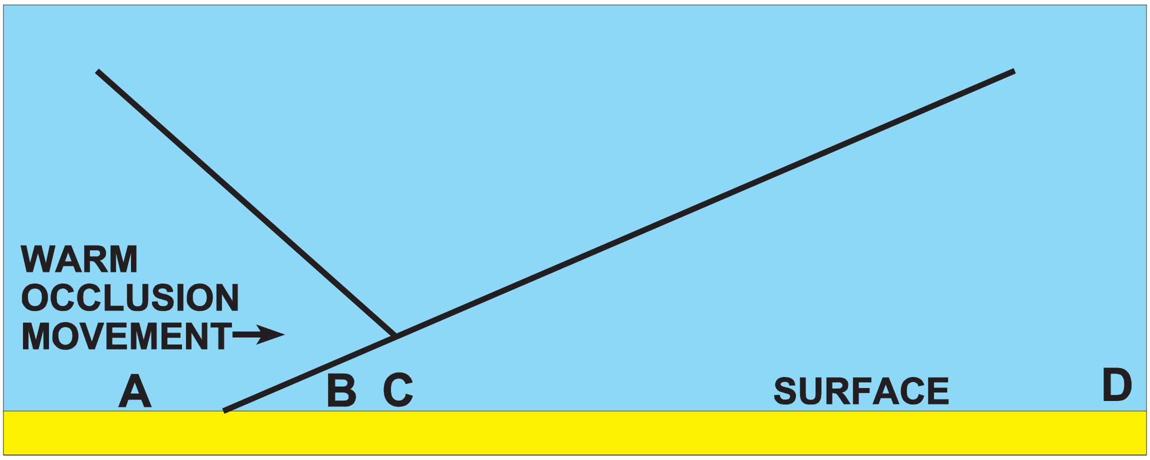
11
12
13
14
30 000'
25 000'
20 000'
15 000'
10 000'
5000'
MSL

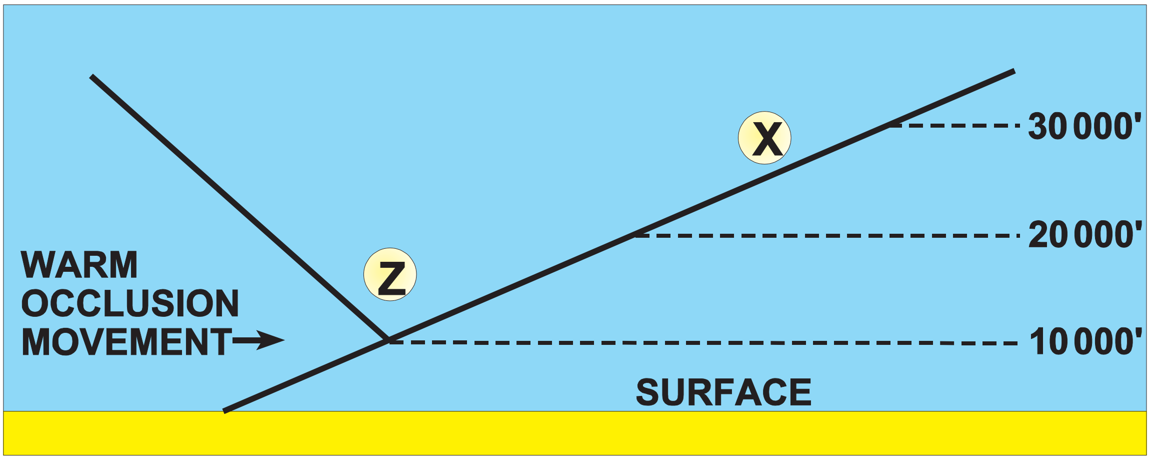
Appendix B, C, D



APPENDIX B



APPENDIX C



APPENDIX D

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	d	b	c	b	c	a	b	c	d	d	d

13	14	15	16
c	c	b	c

Chapter 19

Other Depressions

Introduction

Polar front depressions predominate in temperate latitudes but other types of depression also exist, in temperate and other regions. These include:

- Orographic depressions.
- Thermal depressions.

Orographic (Lee) Depressions

When a flow of air meets a mountain range at a large angle, there is a marked tendency for much of the air to flow around the end of the range instead of flowing over the top. This can cause a comparative lack of air on the downwind (lee) side of the mountains so that low pressure occurs. Orographic depressions formed over N. Italy when a cold front comes from the north into the Alps can produce significant convective weather. This is because the colder air of the front is now coming over the Alps above the warmer air to the south creating very unstable conditions.

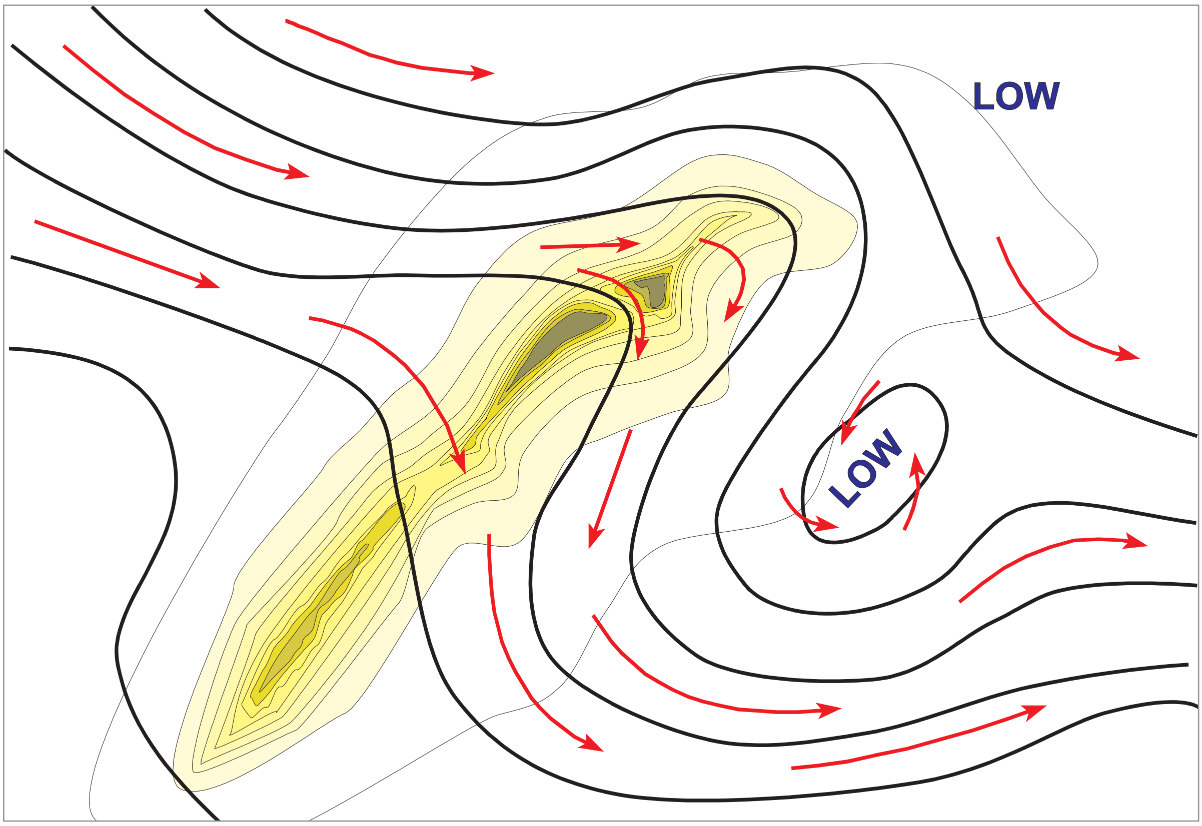


Figure 19.1 Orographic depressions

There are three weather situations:

- If the air is **dry** and **stable,** then any uplift caused by the depression will have little effect and the weather will be **warm, clear** and **dry**. This is the Föhn effect.

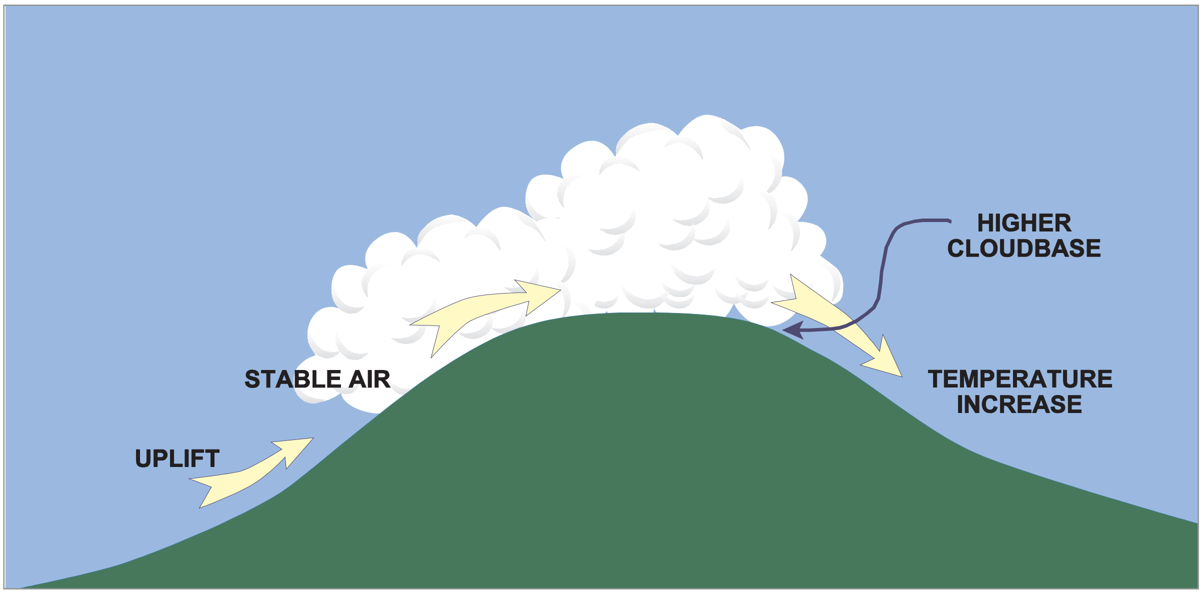


Figure 19.2 Föhn effect

- If the air is **moist,** then the uplift caused as it passes over the depression can ensure that Cu and Cb with **showers** and possibly **thunderstorms** and hail may develop.

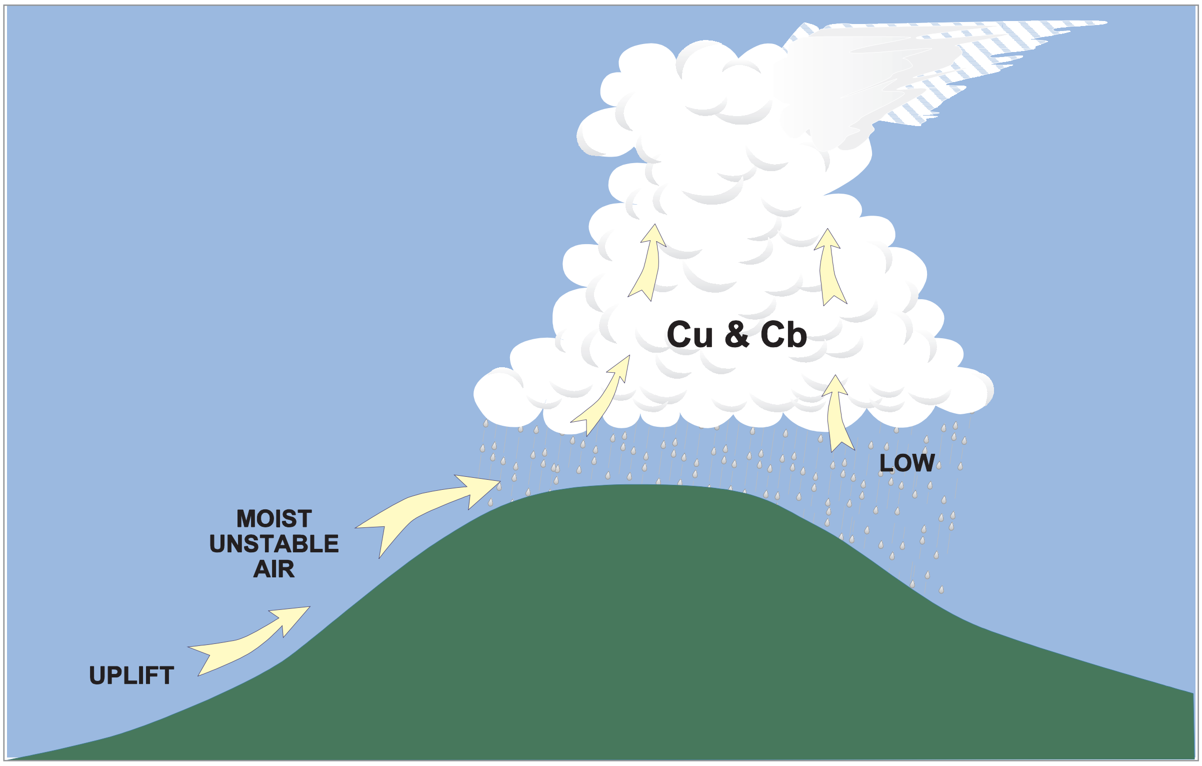


Figure 19.3 Moist, unstable

- Sometimes a **cold front** will approach the mountain range and then much of the cold air will initially be held back by the range. When this unstable air finally breaks over the mountains, lifting will occur with additional lifting from the orographic low.

  The result can be **heavy banks** of Cb, with **line squalls, very heavy showers, thunderstorms, hail** and **poor visibility**.

  A good example of this occurs over the **Alps** in **northern Italy** in winter, the cold front being part of a polar front depression.

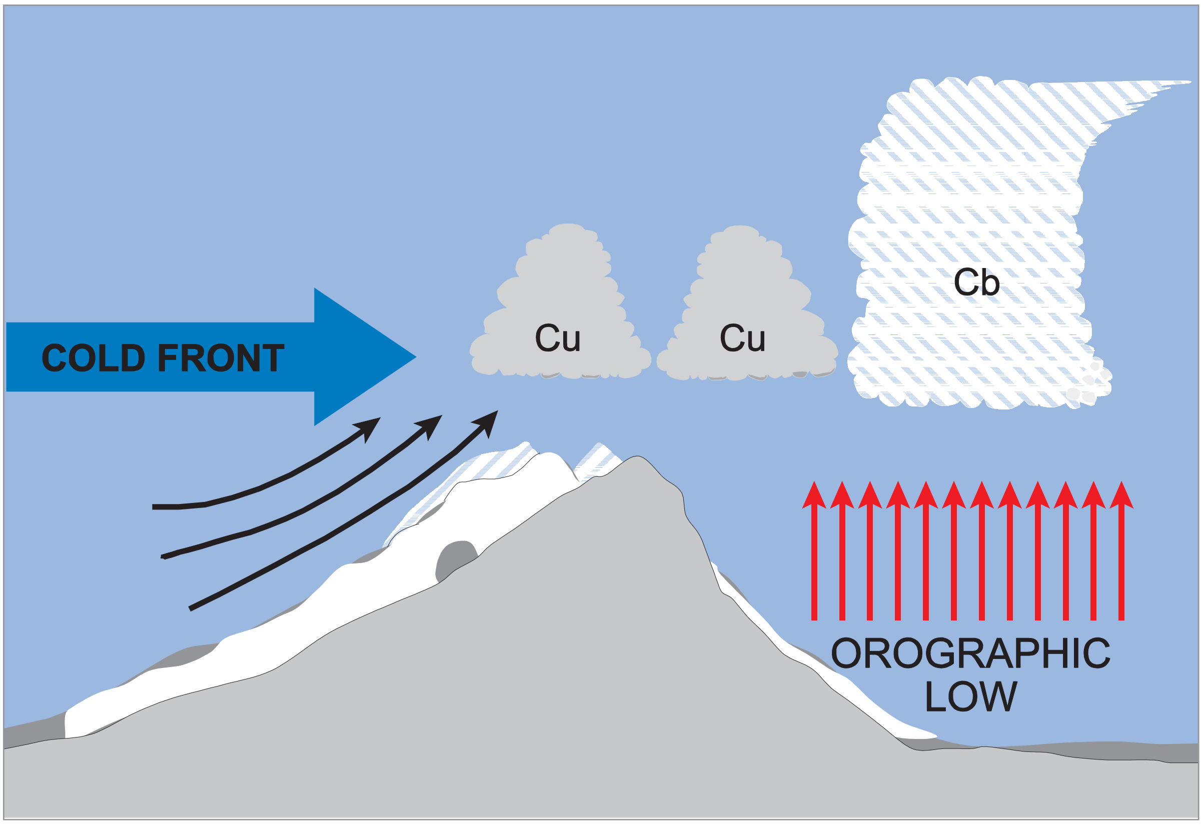


Figure 19.4 The result of a cold front approaching a mountain range

Thermal Depressions

Basic Theory

As the air at the surface is heated, it will expand, causing the pressure surface to be lifted. This higher pressure at height will result in an outflow of air. In turn this will cause a fall in surface pressure and the air will move cyclonically.

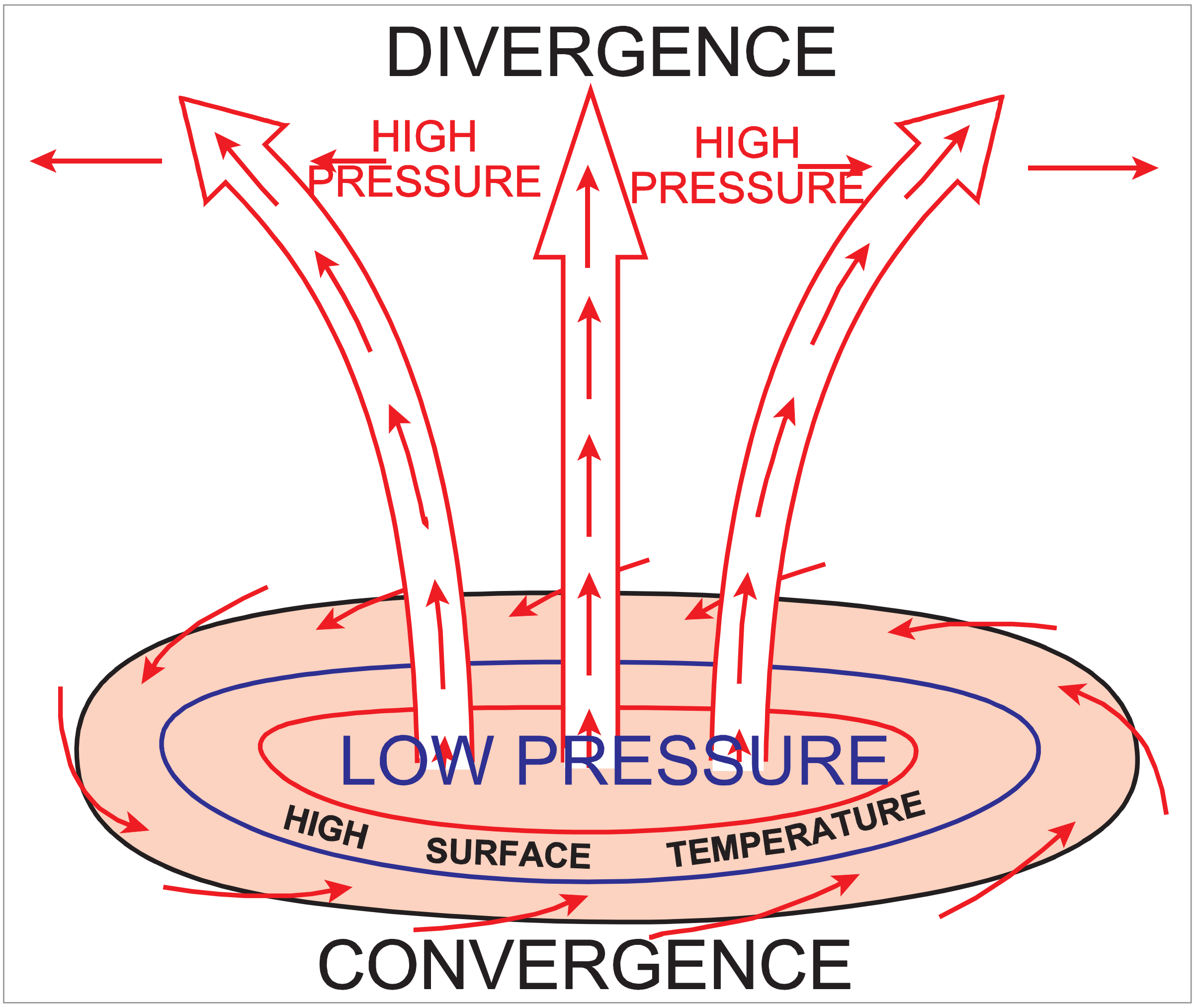


Figure 19.5 Thermal depression theory

The thermal depression often weakens with height because pressure tends to be higher. This can cause upper winds to reverse, but development of a thermal depression in unstable air can be active up to tropopause heights.

Weather.

- Cu, Cb (perhaps hail and thunderstorms).
- Heavy showers.
- Good visibility except in showers.
- Moderate or severe turbulence.

The Monsoon Low

Over large continents in summer a large thermal low develops which controls the circulation of air. The weather pattern is variable, being affected by topography, e.g. the Himalayas, and by the air masses drawn into the circulation.

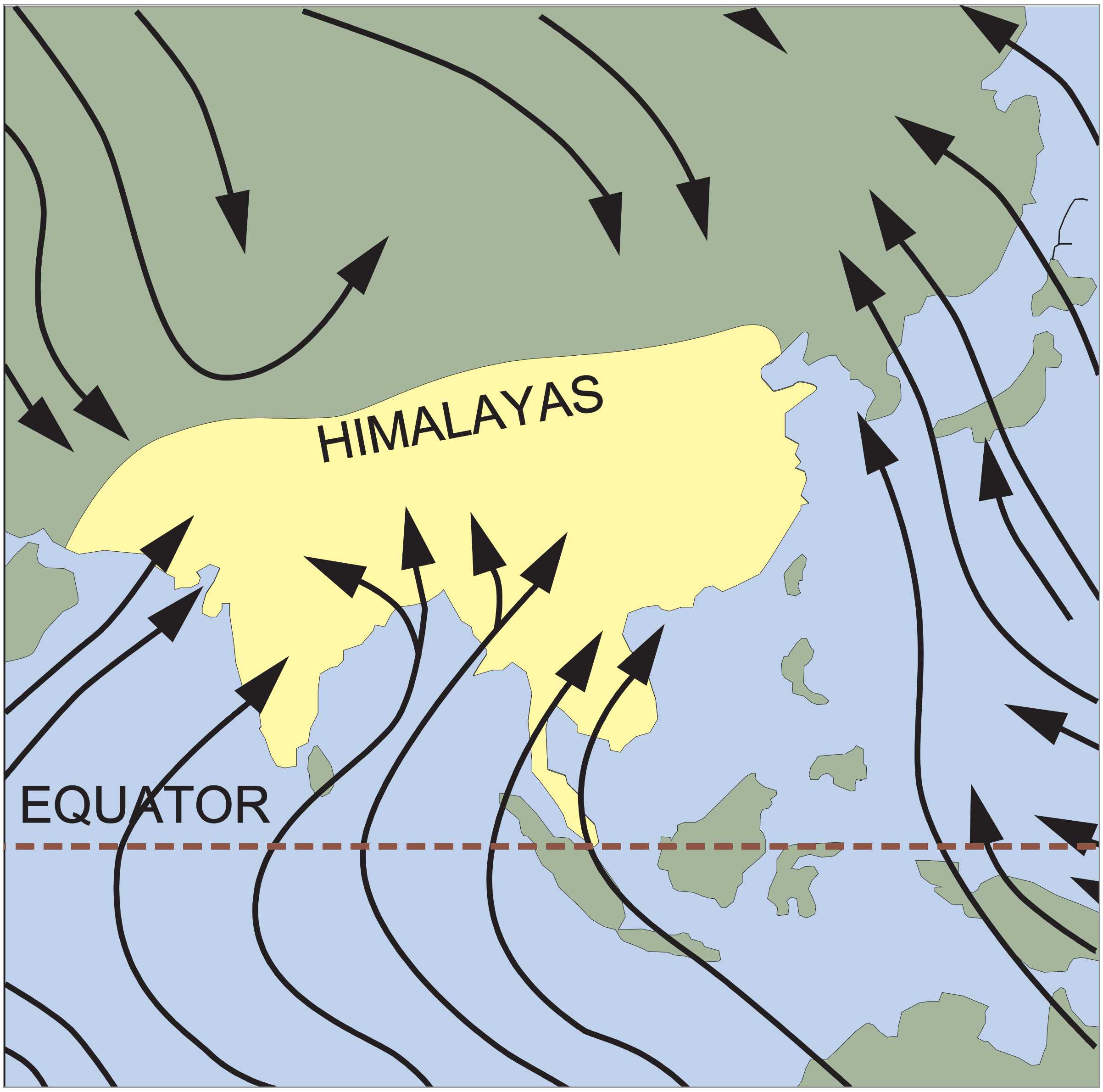


Figure 19.6 Monsoon low

Polar Air Depressions

These thermal lows form when Arctic Maritime air is subject to lifting on a large scale. This usually occurs due to the mAc air moving south over a warmer sea in winter. It gives Cu, Cb, **heavy showers** and sometimes **secondary cold fronts** develop. Do not confuse with polar front depressions which are at the joining point of the Tropical Maritime and Polar air masses.

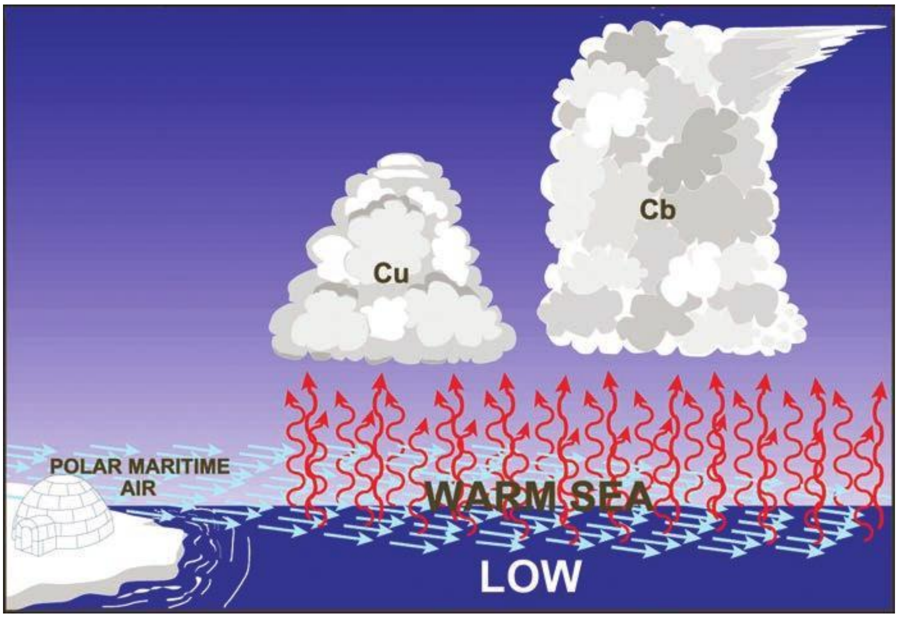


Figure 19.7 The formation of a polar air depression

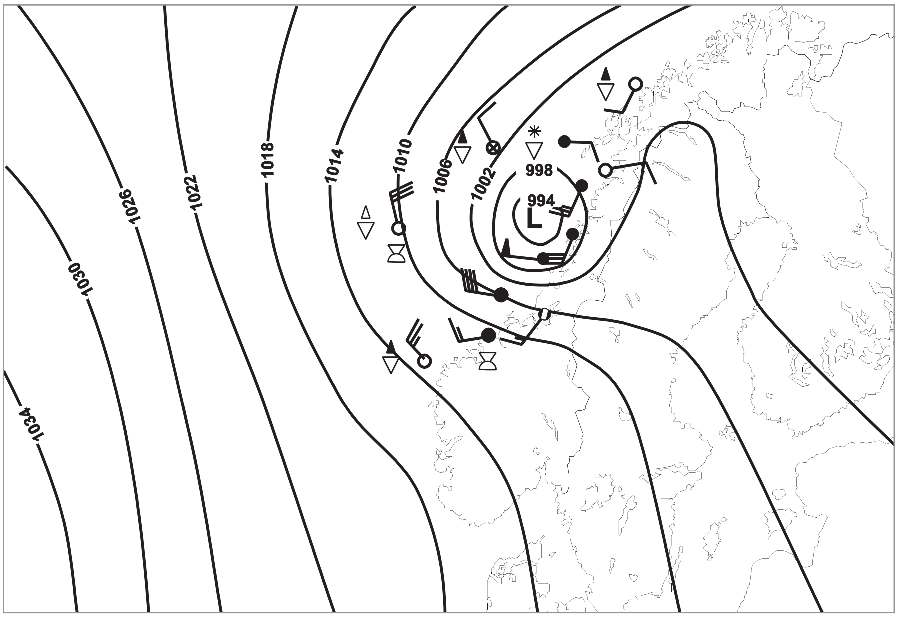


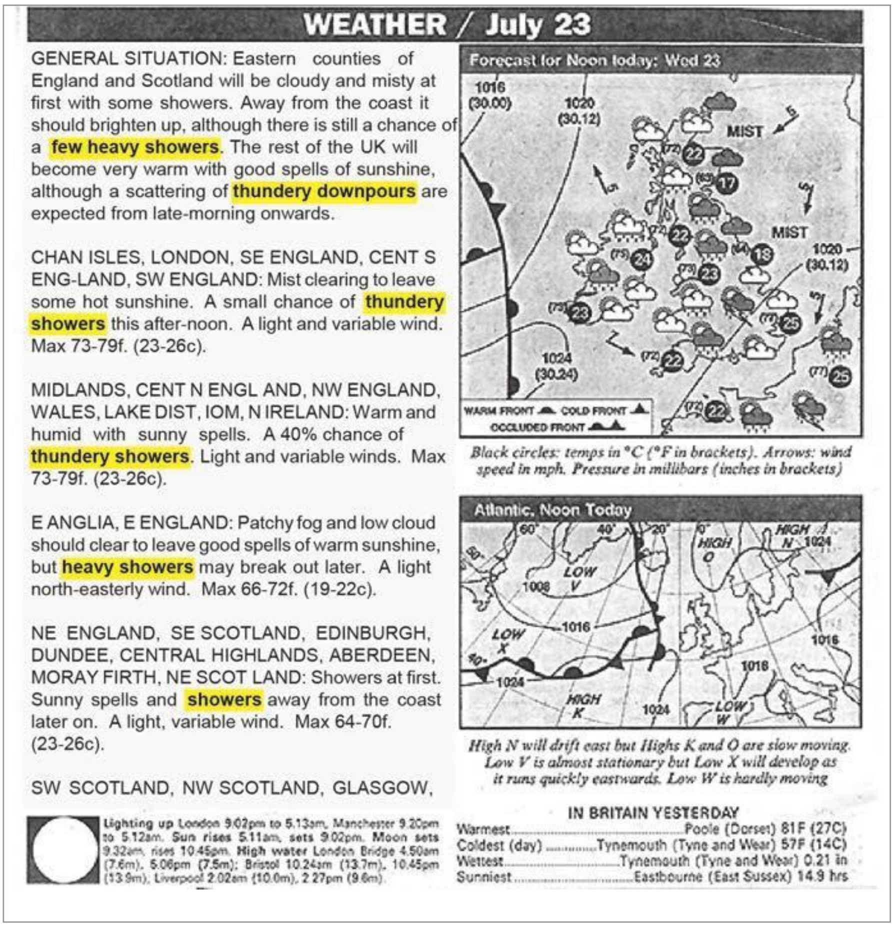
Figure 19.8 A Polar air depression off the Norwegian coast in November

Inland Waters

In winter, thermal lows develop over the **Caspian, Black** and **Mediterranean** Seas. A cold outflow of cPc air from the **Siberian high** flows over the warmer seas. Convection and the development of depressions result. Similar lows develop over the **Great Lakes of North America.**

Thermal Lows Over Land (Summer)

During SUMMER, shallow lows will appear over land due to surface heating. If the air is already UNSTABLE or there are OLD FRONTAL ZONES in the area, thunderstorms, widespread rain or squalls may result. *Figure 19.9* shows such lows over central France producing thunderstorms. They also occur regularly in Summer over the American mid-west, giving heavy thunderstorms.



WEATHER / July 23

GENERAL SITUATION: Eastern counties of England and Scotland will be cloudy and misty at first with some showers. Away from the coast it should brighten up, although there is still a chance of a few heavy showers. The rest of the UK will become very warm with good spells of sunshine, although a scattering of thundery downpours are expected from late-morning onwards.

CHAN ISLES, LONDON, SE ENGLAND, CENT S ENG-LAND, SW ENGLAND: Mist clearing to leave some hot sunshine. A small chance of thundery showers this after-noon. A light and variable wind. Max 73-79f. (23-26c).

MIDLANDS, CENT N ENGL AND, NW ENGLAND, WALES, LAKE DIST, IOM, N IRELAND: Warm and humid with sunny spells. A 40% chance of thundery showers. Light and variable winds. Max 73-79f. (23-26c).

E ANGLIA, E ENGLAND: Patchy fog and low cloud should clear to leave good spells of warm sunshine, but heavy showers may break out later. A light north-easterly wind. Max 66-72f. (19-22c).

NE ENGLAND, SE SCOTLAND, EDINBURGH, DUNDEE, CENTRAL HIGHLANDS, ABERDEEN, MORAY FIRTH, NE SCOT LAND: Showers at first. Sunny spells and showers away from the coast later on. A light, variable wind. Max 64-70f. (23-26c).

SW SCOTLAND, NW SCOTLAND, GLASGOW,

Lighting up London 9.02pm to 5.13am, Manchester 9.20pm to 5.12am. Sun rises 5.11am, sets 9.02pm. Moon sets 9.32am, rises 10.45pm. High water London Bridge 4.50am (7.6m), 5.06pm (7.5m); Bristol 10.24am (13.7m), 10.45pm (13.9m); Liverpool 2.02am (10.0m), 2.27pm (9.6m).

Black circles: temps in °C (°F in brackets). Arrows: wind speed in mph. Pressure in millibars (inches in brackets)

High N will drift east but Highs K and O are slow moving. Low V is almost stationary but Low X will develop as it runs quickly eastwards. Low W is hardly moving

IN BRITAIN YESTERDAY

Warmest	Poole (Dorset) 81F (27C)
Coldest (day)	Tynemouth (Tyne and Wear) 57F (14C)
Wettest	Tynemouth (Tyne and Wear) 0.21 in
Sunniest	Eastbourne (East Sussex) 14.9 hrs

Figure 19.9 Thermal low effect

Tropical Revolving Storms (TRS)

Description

These are thermal depressions that develop over the warm tropical oceans and have sustained wind speeds in excess of 33 kt, they are designated tropical cyclones when the sustained wind speed exceeds 63 kt. They are the most destructive and extensive weather phenomenon which affects our planet. Winds in a tornado may momentarily exceed those of a TRS, but the life cycle of a tornado is primarily measured in minutes. The life cycle of a TRS, however, may be up to about 2 weeks and its size may match that of polar front depressions but has much greater intensity.

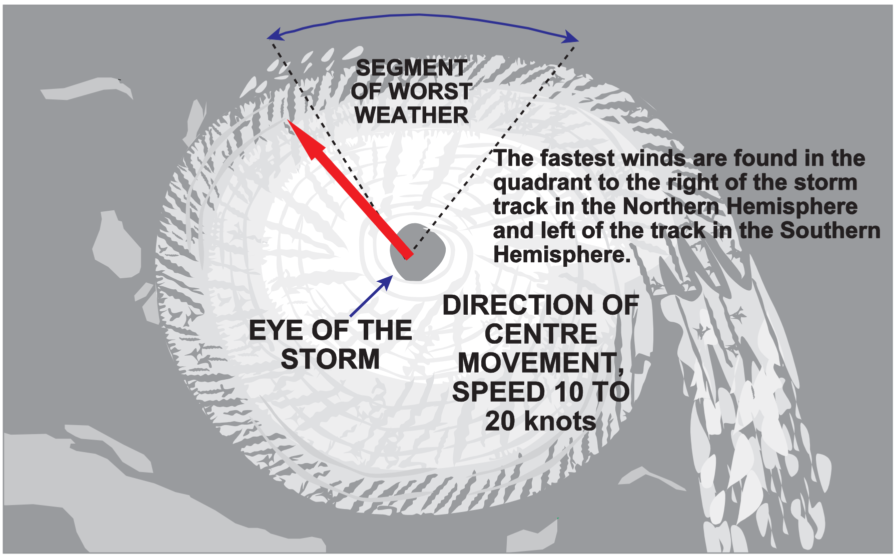


Figure 19.10 The segment of worst weather in a tropical revolving storm.

Formation:

Hurricanes are formed from complexes of thunderstorms, (usually the western side of the oceans). However, these thunderstorms can only grow to hurricane strength with the right conditions of the ocean and the atmosphere. These thunderstorms are most commonly formed in one of two ways. The main way being from the Intertropical Convergence Zone (ITCZ) where the easterly trade winds converge at the Equator creating a band of storms circumnavigating the globe. The second way is from the equatorial easterly atmospheric waves, otherwise known as easterly waves originating in NW Africa (see Chapter 20) These easterly waves give rise to the hurricanes in the N Atlantic and the NE Pacific.

The storms generate their power and energy from the release of large amounts of latent heat from the moisture they have gained over the warm seas. This release of heat causes the air to expand, further reducing the surface pressure. This creates even stronger convergence, which in turn causes more moist air to rise and cool to condensation, aiding the release of greater amounts of latent heat.

Requirements:

- Must be within 5 and 25 latitude. Below 5 Coriolis force is too small, above 25 latitude the sea is usually too cold.

- Ocean temperatures must be greater than 26°C. The higher the ocean temperature the greater the pressure drop within the core. This is the reason why we do not usually have TRS forming in the southern Atlantic because the sea surface temperatures are too low.

- There must be a sufficient depth of warm water (200-300 ft) in the ocean to provide a continual energy source. If the depth of warm water is too shallow the storm would quickly drain the energy from the ocean and cease to develop.

- Very little shear must exist within the atmosphere, otherwise the storm would topple. This also has the effect of increasing the area over which the latent heat is released, thereby reducing the effect it will have on intensifying the storm.

Movement:

The path of a TRS greatly depends upon the wind belt in which it is located. Since most originate from the tropics, it follows then that the TRS will initially be driven westwards by the easterly trade wind belt at around 10 - 20 knots. Eventually the storms will move away from the Equator and increase in strength as a result of increasing Coriolis force. The subtropical highs and prevailing westerlies at these latitudes drive the TRS eastwards. At this stage the TRS have moved to higher latitudes where the seas are now too cold to feed energy into the storm and they will eventually die. If at any time the storm goes over land, the influx of moisture is ceased and again, the storm will die. *Figure 19.13* shows the general movement of TRS around the world.

Stages of Development:

TRS evolve through a life cycle, from birth to death much like that of a thunderstorm. The stages are based upon the organization of the storm and the sustained wind speeds which they create. Not all of the stages will eventually evolve in to a TRS.

Stage 1 **Tropical Depression**

This is designated when the first appearance of a lowered pressure and organized cyclonic circulation in the centre of the thunderstorm complex occurs. A surface pressure chart will reveal at least one closed isobar.

Stage 2 **Tropical Storm**

A tropical depression is designated a tropical storm when the sustained wind speeds exceed 33 kt. It is at this stage when it is assigned a name.

Stage 3 **Tropical Cyclone**

The system is designated a tropical cyclone, hurricane or typhoon, dependent on location, when sustained wind speeds are greater than 63 knots. There is a pronounced rotation around a central core which will eventually form the “eye”.

The Eye:

One of the most recognizable features found within a TRS is the eye. They are found within the centre having a typical diameter of 20 - 50 km. The tightening of the eye is a useful guide that the storm is increasing in strength. It is within the eye that we find the lowest surface pressures, and the calmest conditions. As air is forced up and outward from the storm some of it returns down the centre causing adiabatic heating which evaporates clouds creating the familiar clear column of air which distinguishes the eye itself. The air descending in the eye has cooled at the SALR in the clouds of the eye wall, but is now dry so is warming at the DALR. Hence the air in the eye is warmer than the air in the eye wall.

The Eye Wall:

This is where the most active Cb's are found with the strongest winds and most severe turbulence. In other words the most dangerous part of a tropical revolving storm.

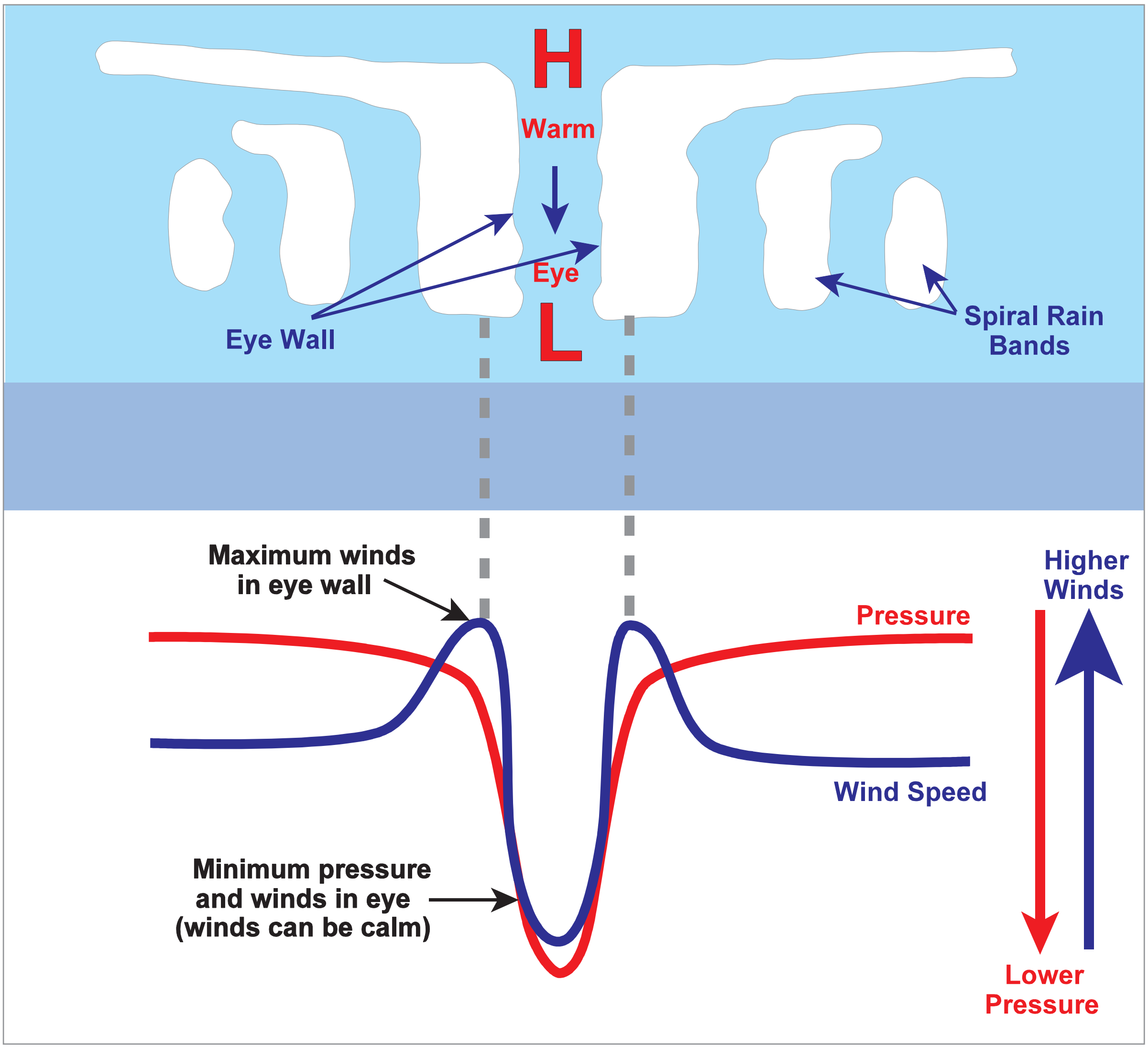


Figure 19.11 Cross-section of a TRS

Names and Nicknames:

TRS are given different names in different parts of the world. *Figure 19.13* shows the names and movements of these storms.

Within each region, and for each storm season, a series of nicknames in alphabetical order is devised, alternating male and female names, e.g. the first storm in this year's season in the Caribbean might be called 'Arthur', the next one 'Betty' and the third one 'Charlie'. Next year the series would start with 'Annie' followed by 'Brian' and so on.

Action to Avoid a Revolving Storm:

- In the Northern Hemisphere, if very high values of starboard drift occur, turn port or starboard until port drift occurs. The aircraft is then heading away from the storm.

- In the Southern Hemisphere, drifts are reversed.

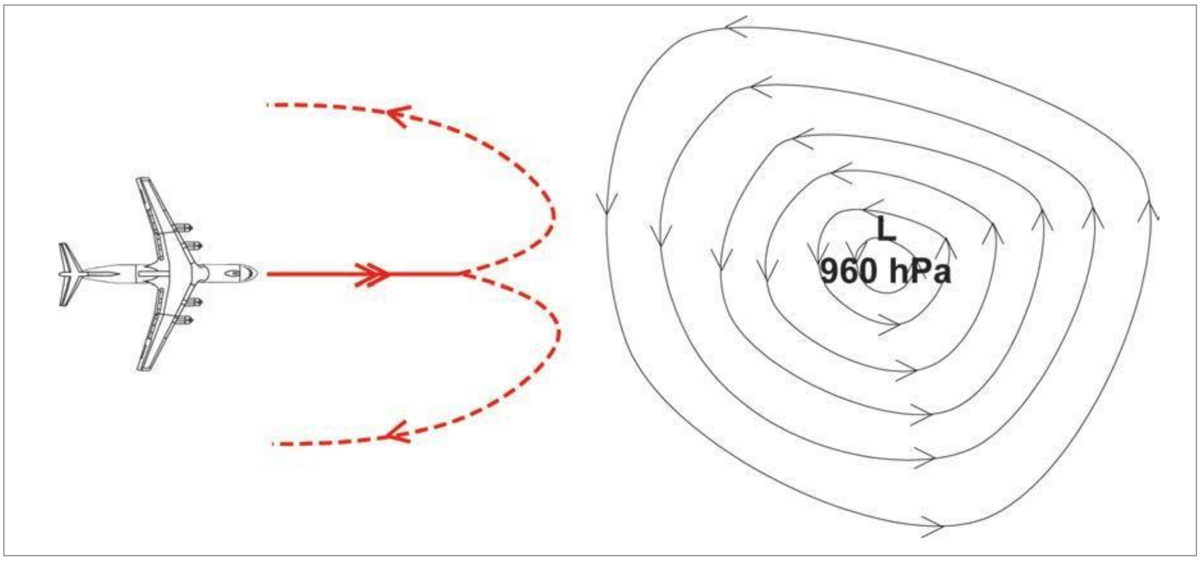


Figure 19.12 Action to Avoid a TRS

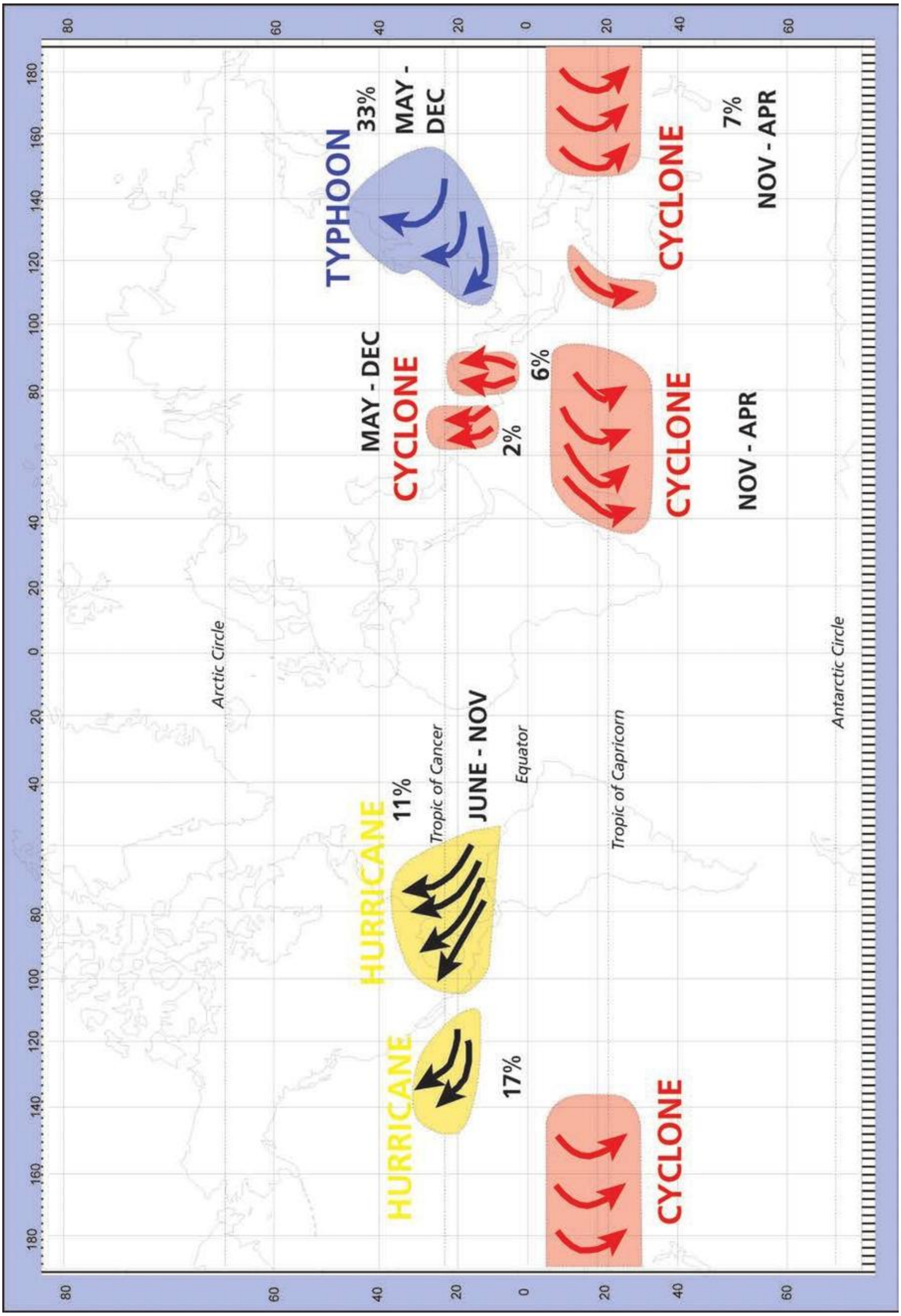


Figure 19.13 Tropical revolving storms

Secondary Depressions

When a small depression is enclosed within the circulation of a larger depression it is called a **secondary.** The isobars need not show a closed centre. Secondaries are particularly associated with frontal depressions and form:

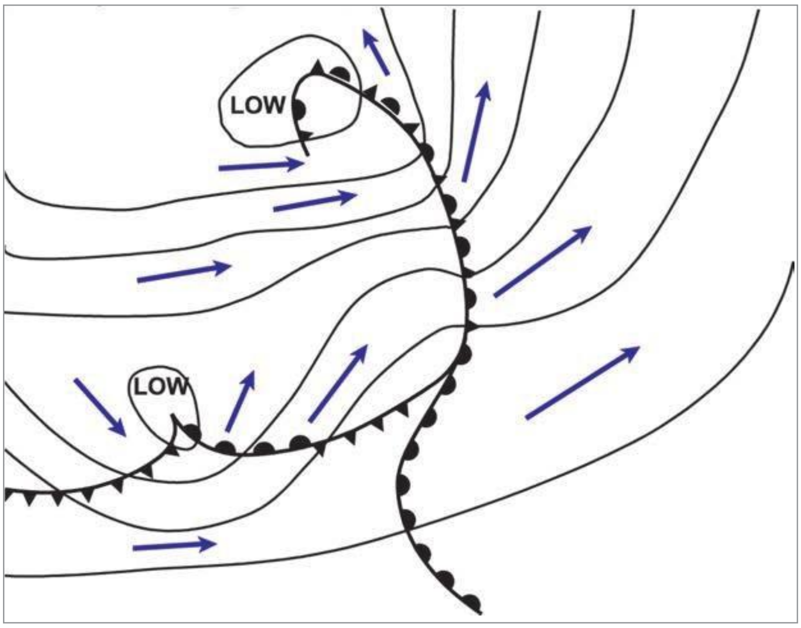


Figure 19.14 A secondary depression on the end of a cold front

- **On a trailing front from an occluded primary.** This secondary may deepen and form the next depression along the PF and equal the size of the primary. At this stage, the depressions tend to rotate around each other, until eventually the primary and the secondary have become the new primary.
- **On a trailing cold front well within the primary circulation**. In this case, it appears only as a disturbance on the front, it moves along it without much development until it eventually becomes absorbed. Although producing little weather of its own, it may delay the movement of the cold front and make forecasting of frontal passage difficult.

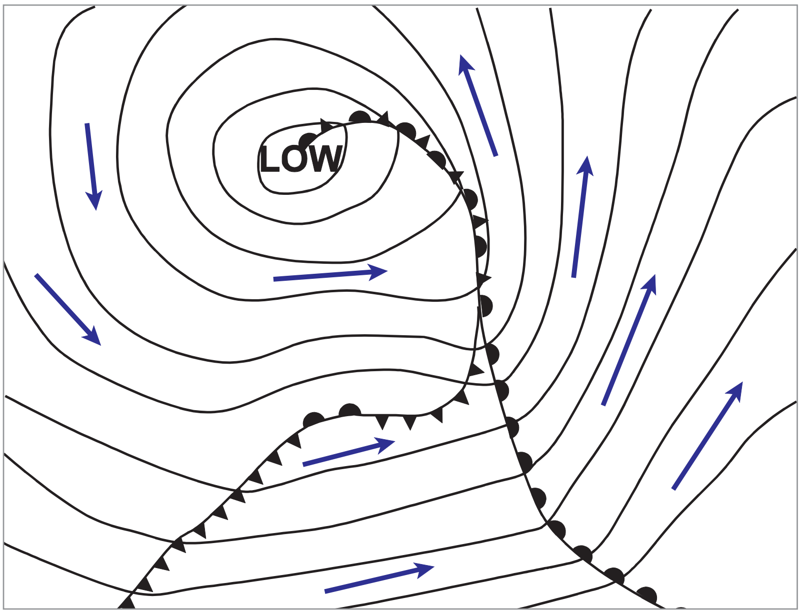


Figure 19.15 A secondary depression within the primary circulation

- **At the tip of the warm sector of a partly occluded depression.** Formed at the Point of Origin or Triple Point, while the primary fills up. Often formed when primary and occluded fronts are held up by a mountain barrier as in **southern Greenland** or **Norway**.

  Secondary depressions move in a cyclonic sense around the primary depression.

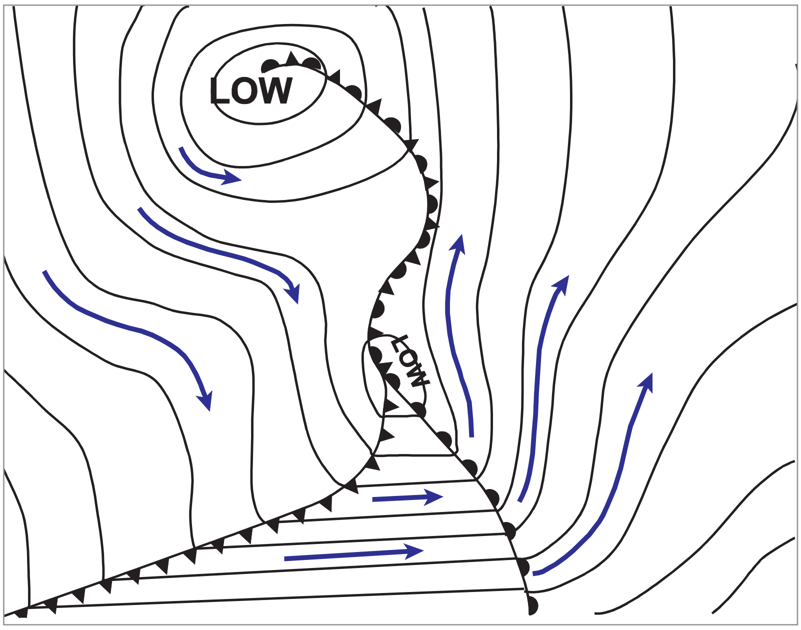


Figure 19.16 A secondary front formed at the tip of a warm sector where fronts have occluded

Cold Air Pools

Cold air pools exist within cold air masses. On *Figure 19.17* the surface pressure is overlaid with a thickness chart which shows the vertical distance between the 1000 hPa and 500 hPa levels. On this presentation the thickness is colour coded with the scale on the right. The thickness is given in decametres (tens of metres) so over the north of the UK the thickness between the 1000 hPa and 500 hPa levels is 524 decametres (5240 metres) or about 17 190 ft, these individual thicknesses are also known as **isohypses**. In the ISA the thickness between these levels is approximately 18 000 ft so this indicates that a cold air pool exists over the UK.

The cold air pools can only be located by examining thickness charts or upper contour charts, where a low thickness or altitude indicates the presence of a cold air pool. They cannot be detected on surface analysis charts. *Figure 19.17* shows the surface pressure distribution which gives no indication of temperatures.

The cold air pools may be quasi-stationary, as the one over NW Greenland, or transitory as those over UK and Novaya Zemlya.

Cold air pools in the NW Atlantic and NW Europe are often found in the polar maritime air behind a cold front and an advecting cold pool would have a cold front at its leading edge. The weather associated with a cold pool will typically be convective especially over land in summer when thunderstorms can be expected.

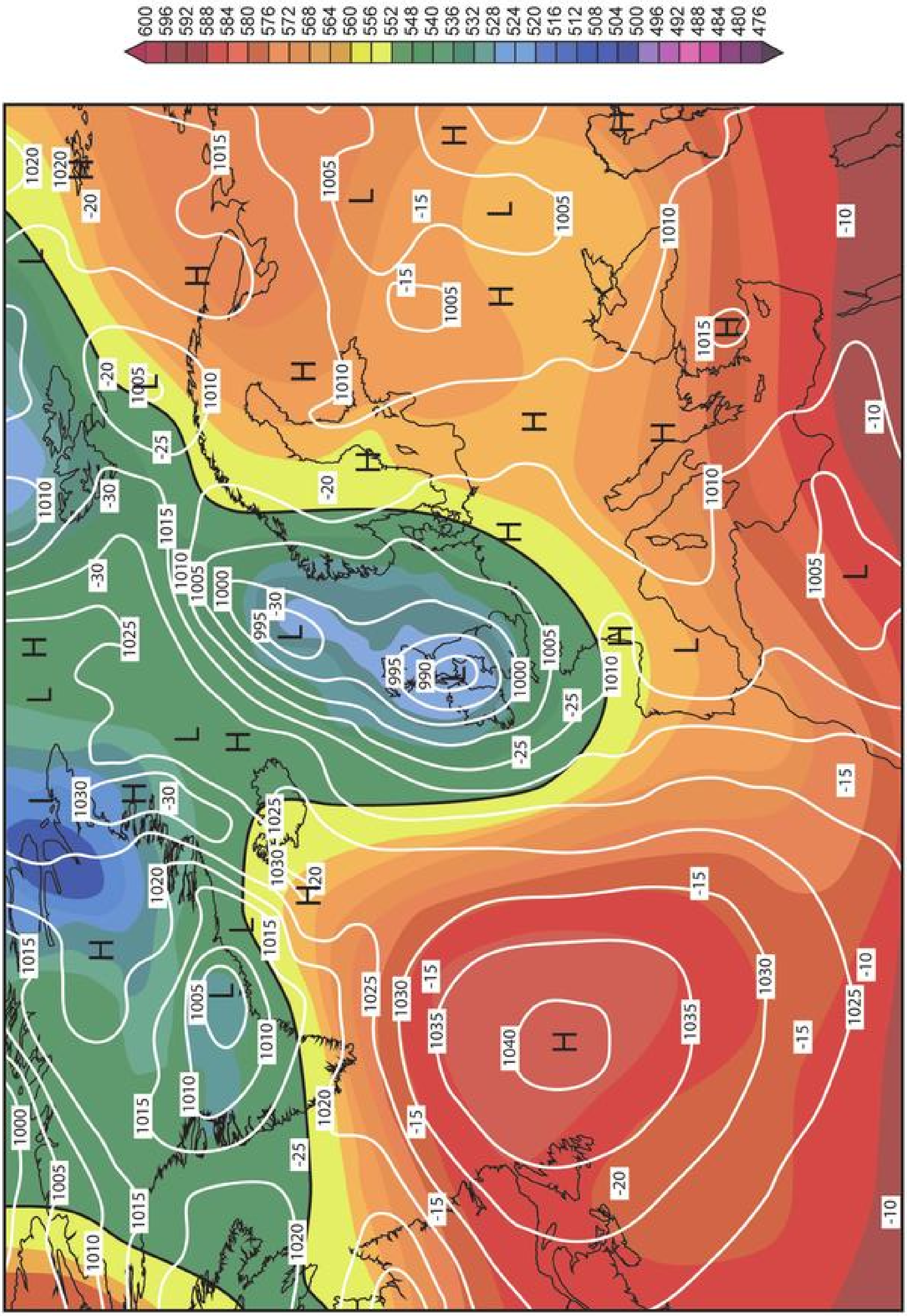


Figure 19.17 Cold Air Pool

Tornadoes

'A violent whirl, generally cyclonic in sense, averaging about 100 m in diameter and with an intense vertical current at the centre, capable of lifting heavy objects into the air.' (Meteorological Glossary).

North American Tornado. The synoptic situations giving rise to tornadoes in the USA are as shown in *Figure 19.18*.

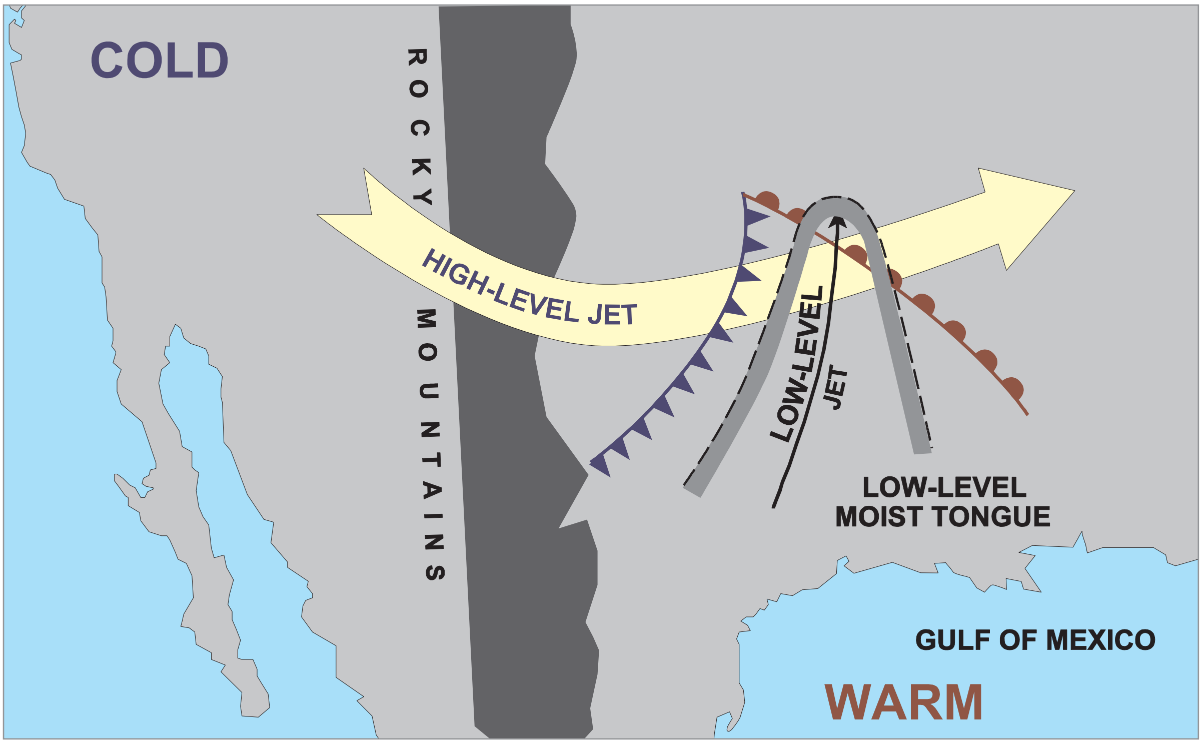


Figure 19.18 Synoptic situation favouring tornadoes

The tornadoes will occur when **cold dry air** from the **northwest** meets **warm moist air** from the **Gulf of Mexico** over the **prairies of central USA** in spring and early summer. 80% of tornadoes occur between 1400 and 2200 with peak incidence at 1700. The precise means of formation of the 'twister' is open to considerable conjecture, but computer modelling and the use of Doppler radars is making prediction more certain. *Figure 19.19* to *Figure 19.22* show how a tornado may form.

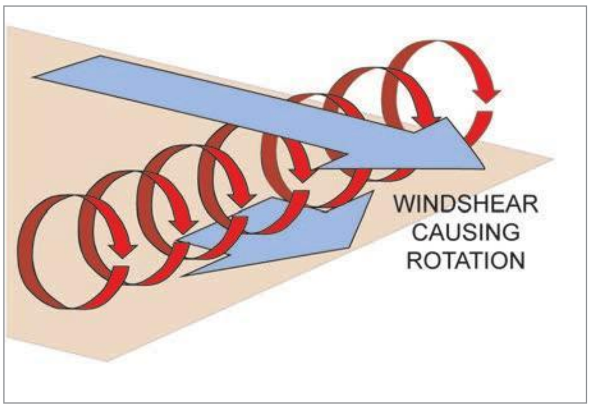


Figure 19.19 Possible causes of tornado formation (a)

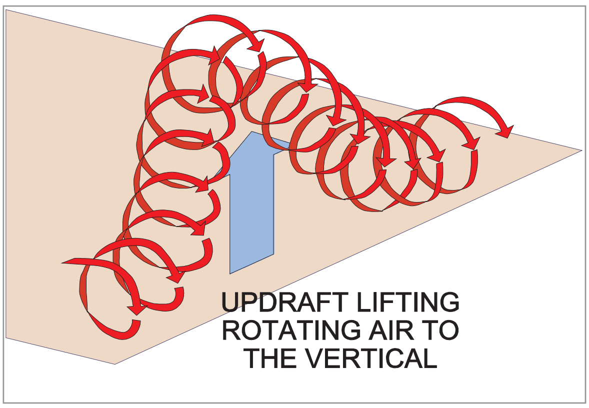


Figure 19.20 Possible causes of tornado formation (b)

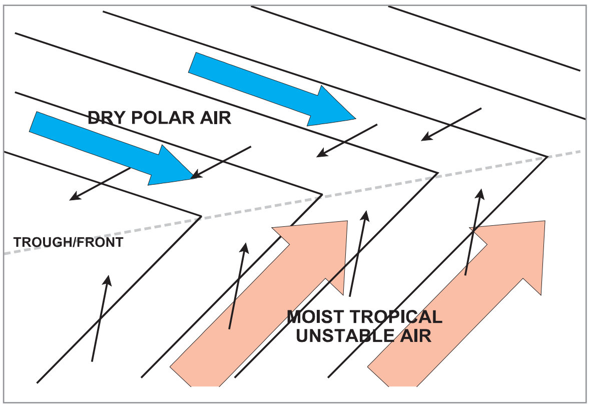


Figure 19.21 Possible causes of tornado formation (c)

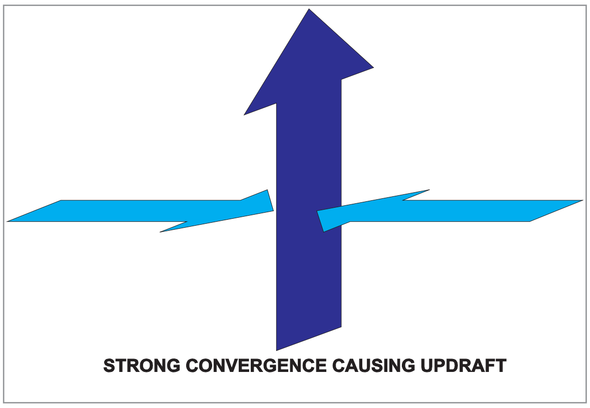


Figure 19.22 Possible causes of tornado formation (d)

Tornadoes are invariably associated with cumulonimbus clouds and in some cases the rotation extends to the top of the storm.

Destructive power of tornadoes lies in the localized reduction in pressure (20 to 200 hPa) leading to structures exploding and the very high (up to 300 kt) wind speeds in the vortex. Tornadoes usually last a matter of minutes, some occasionally last a few hours and move at speeds up to 40 kt. *Figure 19.23* shows the appearance of tornadoes.

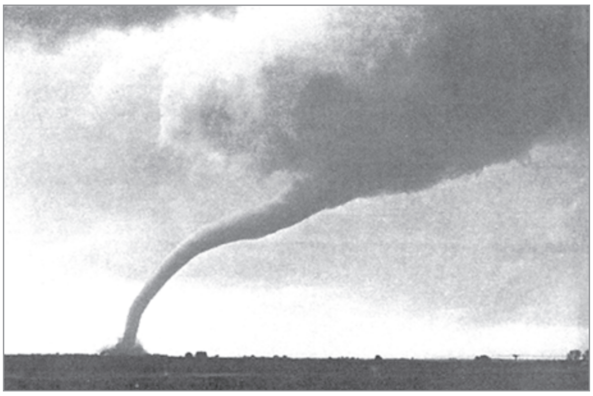


Figure 19.23 A Tornado

Increasing use of Doppler radars which will also measure particle speeds within the vortex is making local tornado warnings more reliable, but still not more than 30 min ahead. Tornadoes develop a typical 'hook' pattern on the radar screen. *Figure 19.24* shows this radar 'signature'.

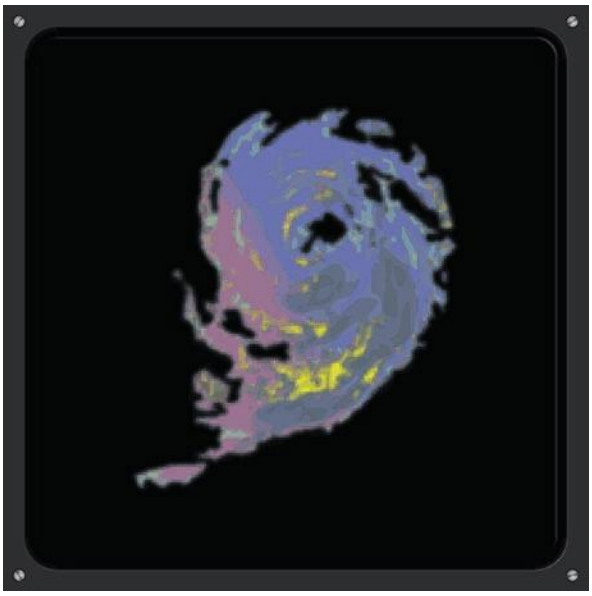


Figure 19.24 Radar scope picture

Within Europe tornadoes are much weaker systems whose maximum diameter is of the order of 100 m - 150 m, but usually much smaller.

See Chapter 14 for more detail on tornadoes.

West African Tornado. West African tornadoes are associated with the passage of the ITCZ through countries bordering the Gulf of Guinea. They are thunderstorm squall lines which form in a line north-south and move from east to west between March and November and are most common from March to May and October to November.

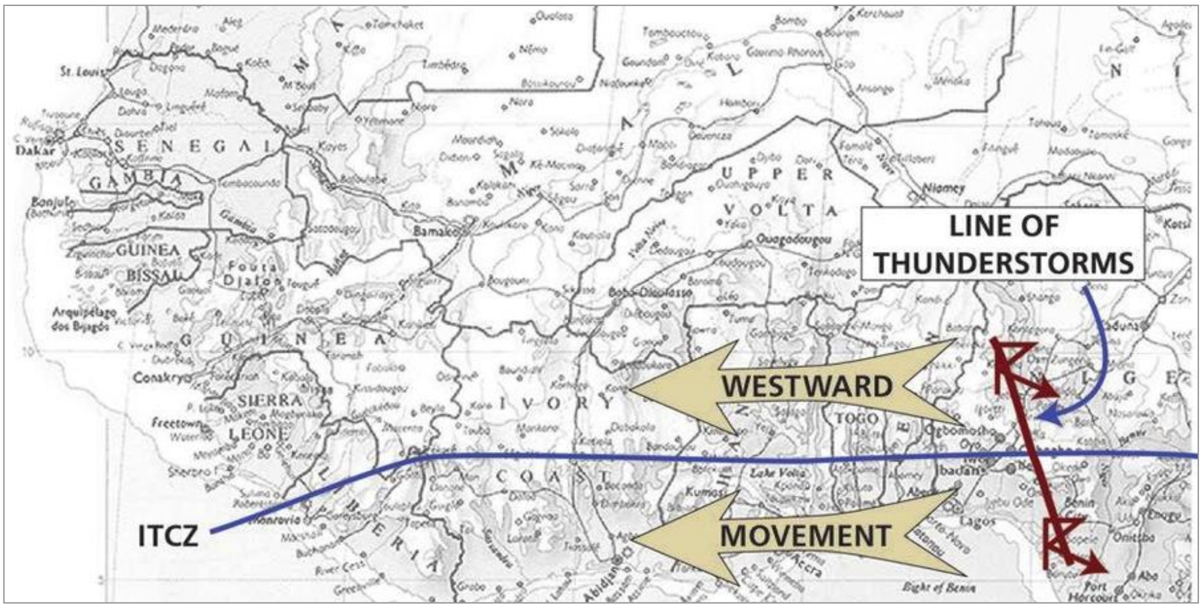


Figure 19.25 West African Tornadoes

Questions

1. A thermal depression is likely to form:

a. over the Iberian peninsular during the summer
b. in the lee of the Alps over northern Italy in winter
c. in association with a marked trough of low pressure over the USA
d. on the trailing edge of a warm sector mid latitude depression

2. Tropical revolving storms usually:

a. form close to one side of the Equator and while moving slowly in a westerly direction, cross over to the other hemisphere
b. move in a westerly direction before recurving towards the Equator
c. move in an easterly direction before recurving towards the nearest pole
d. do not form within 5° of the Equator

3. With reference to tropical revolving storms, which of the following statements is correct?

a. Typhoons are found in the South China sea in January
b. Cyclones occur in the Bay of Bengal in winter
c. Hurricanes in the South Atlantic sometimes affect the east coast of Brazil
d. Hurricanes affect the southeast of the USA in late summer

4. Which of the following statements accurately describes the "West African tornado"?

a. The West African tornado is similar to the North American and European tornadoes
b. It is a line of thunderstorms producing a line squall aligned roughly north/south
c. It is another name for the cyclones that affect the West African coast in summer
d. It is the name given to a line of thunderstorms that lie along the ITCZ but some 200 miles to the south

5. Extensive cloud and precipitation is often associated with a non-frontal thermal depression because of:

a. surface divergence and upper level convergence causing widespread descent of air in the depression
b. surface convergence and upper level divergence causing widespread descent of air in the depression
c. surface convergence and upper level divergence causing widespread ascent of air in the depression
d. surface divergence and upper level convergence causing widespread ascent of air in the depression

6. **In comparison with a primary depression a secondary depression is:**

   a. always more active
   b. sometimes more active
   c. never more active
   d. unlikely to produce gale force winds

7. **A secondary depression would form in association with:**

   a. a polar depression
   b. a col
   c. a summer thermal depression over the Mediterranean or Caspian Sea
   d. a polar front low

8. **Tropical revolving storms:**

   a. are always given a male first name beginning with "A" for the first of the season and thereafter named in alphabetical order of occurrence
   b. have internal wind speeds of 10-20 knots rotating cyclonically round a subsiding clear air core known as the eye
   c. usually have the most severe weather in the quadrant to the right of the track in a hurricane
   d. regenerate after crossing the coast from sea to land

9. **Which of the following are thermal depressions?**

   a. Tropical revolving storms, polar air depressions, tornadoes
   b. The equatorial trough, monsoon lows, some depressions over the central and eastern Mediterranean sea in summer
   c. The equatorial trough, polar air depressions, monsoon lows, orographic lows
   d. The lows forming over flat land in summer, polar air depressions, tropical revolving storms, some of the lows which form over inland seas in winter

10. **A secondary low pressure system rotates around a primary low:**

   a. cyclonically
   b. anticyclonically
   c. into the primary
   d. at a constant distance

11. **Flying conditions in a secondary low pressure system are:**

   a. always more severe than in a primary low
   b. sometimes more severe than in a primary low
   c. less severe than in a primary low
   d. relatively calm

12. **Tropical revolving storms:**

   a. do not occur in the South Atlantic
   b. generally move from east to west before turning towards the Equator
   c. intensify after crossing coasts
   d. occur principally in spring and early summer

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	d	d	b	c	b	d	c	d	a	b	a

Chapter

20

Global Climatology

Introduction

We have now studied the various atmospheric processes associated with weather and how their interaction produces the different types of weather phenomena we experience. Now we turn our attention to weather on a global scale and look at the weather we can expect in different locations. This study is known as **climatology**.

The elements of climatology are **precipitation, temperature, humidity, sunshine** and **wind velocity.**

These elements will be affected differently across the globe by; **latitude, location** (maritime or continental), the circulation of **pressure systems, altitude** and **geography.**

Over the years climatological data has been accumulated to such a degree that weather forecasting on an area basis has become quite accurate and communications have improved to such a degree that weather expected on arrival at a destination (and the weather en route) may easily be obtained. This chapter will deal with climatology on a global basis and its regional and seasonal variations.

Idealized Air Circulation

The general air circulation is a very complicated system of air movements. These movements, while based on the passage of air from high pressure to low and the effect of the rotation of the earth, are complicated by:

- The unequal heating of land and sea together with land and sea disposition.
- Variation in land heating caused by different surfaces.
- The 23½° inclination of the earth's axis which causes movement of the thermal equator.

It is therefore useful to consider an air circulation which ignores these main complications and to use this as a basis for understanding the conditions which actually prevail. The idealized circulation assumes that the earth's surface is covered with sea and that the geographic and thermal equators are coincident. In fact, since the surface of the Southern Hemisphere is largely covered by sea, climatology in that hemisphere very closely follows the idealized case.

Idealized Circulation Weather

With a uniform spherical earth, the temperature would only vary with latitude. Pressure at any given height over the Equator would then be greater than that at any height over the poles. Thus air would drift at height from the Equator to the poles, helping to produce high latitude anticyclones and causing a movement on the surface of air from poles to Equator.

However, this cyclic movement of air would be affected by the rotation of the earth, and the circulation would be modified to that shown in *Figure 20.1*.

Anticyclones, formed by Hadley cells around 30° N and S, and known as subtropical anticyclones, would provide a surface outflow of warm air, some of which would move towards the nearer pole. This air would meet the cold anticyclonic flow from the polar regions, thus providing areas of frontal activity.

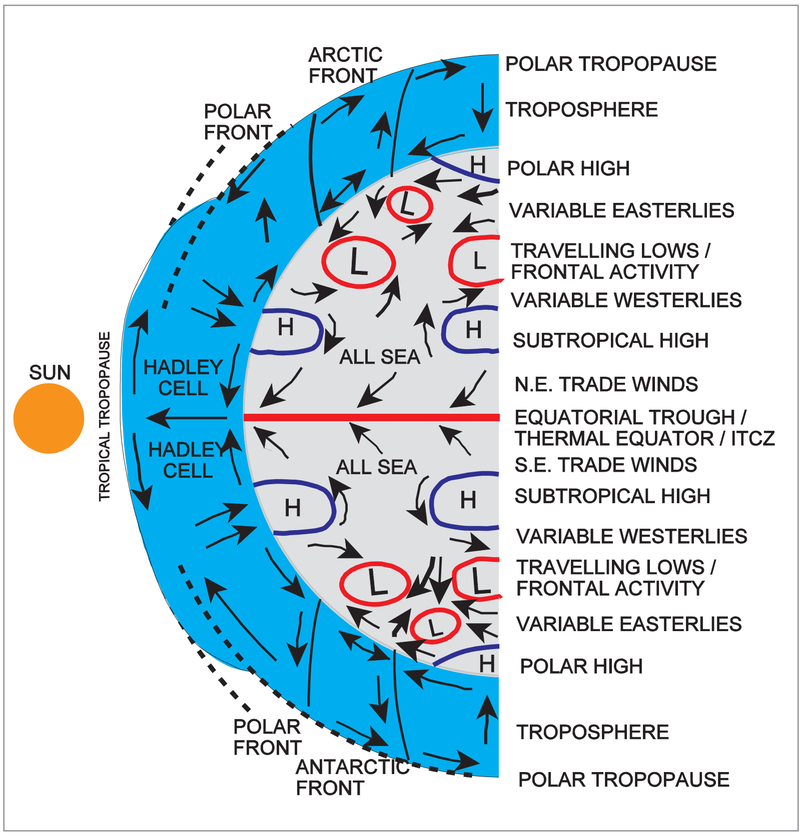


Figure 20.1 Idealized distribution of surface pressure over the earth

The Hadley cell and polar front, with the vertical airflows that cause them, are shown at *Figure 20.2*.

From the subtropical anticyclones in each hemisphere, surface outflow also occurs towards the Equator. This convergence causes rising air and much instability in the equatorial zone, and is known as the Intertropical Convergence Zone (ITCZ).

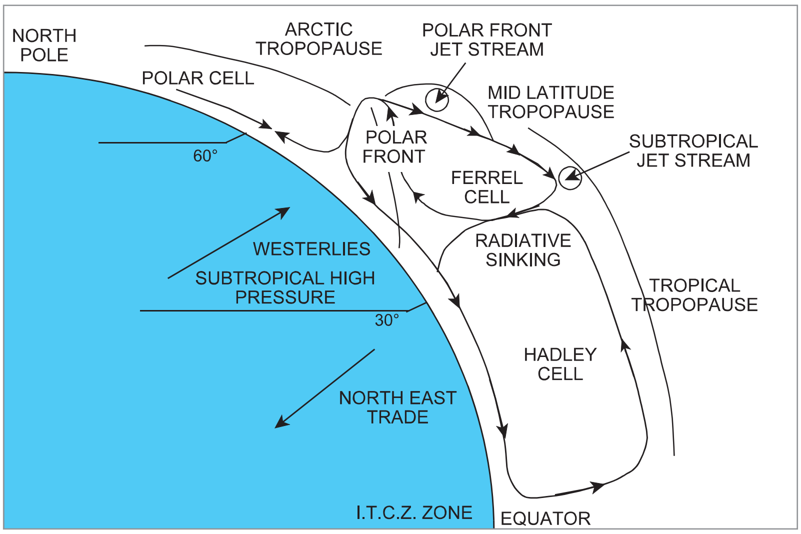


Figure 20.2 Hadley cell, polar front and associated wind-flows

The earth's climatic engine, the airflow pathways of the world, clearly demonstrate how the climatic zones of earth are interrelated. Moisture laden air rises along the ITCZ causing masses of cumulonimbus thunderclouds to develop giving rise to the heavy rains in the tropical regions. Upper air from the Hadley and Ferrel cells, indicated in *Figure 20.2*, meet and are cooled and undergo radiative sinking to produce the Subtropical High Pressure zones at the Earth's surface giving settled weather.

The air streams separate here in the Northern Hemisphere , one flows south as the NE trade winds whilst the other flows north to become temperate latitude westerlies. The flow is mirrored in the Southern Hemisphere.

The polar front is caused by cold air of the polar cell forming a wedge beneath the warmer Ferrel cell. Complex airflow patterns associated with the polar front are responsible for the vagaries in the weather of mid latitudes.

Basic Climatic Zones

The pressure distribution shown above gives us 4 basic climatic zones: (*Figure 20.3*)

- A warm, wet equatorial zone
- Warm, arid subtropical zones
- Cool, wet temperate zones, and
- Cold dry polar zones

To these we can add, in the Northern Hemisphere, a continental area over northern N. America and northern Eurasia.

The tilt of the earth's axis means that these zones will move north in the Northern Hemisphere summer and south in the Southern Hemisphere summer adding 2 transitional zones. (*Figure 20.4*)

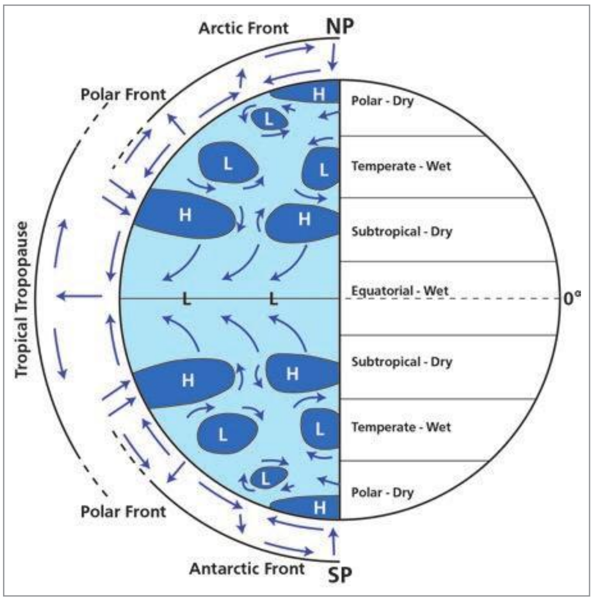


Figure 20.3 World Climatic Zones

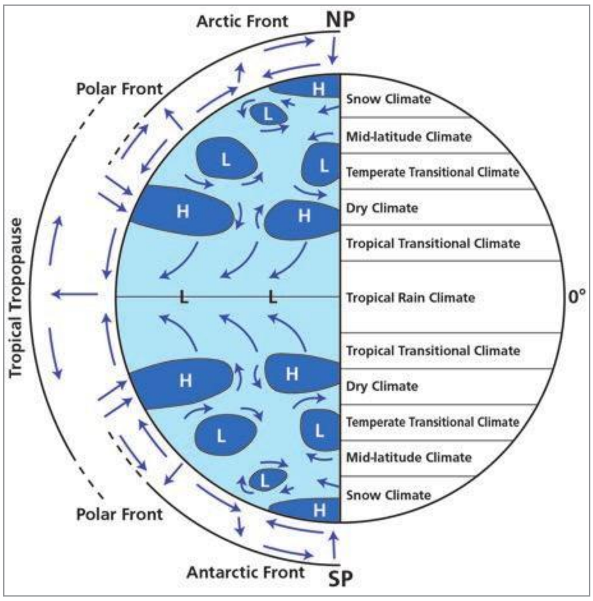


Figure 20.4 World Climatic Zones

Climatic Zones

The climatic zones follow the classification system devised by an Austrian botanist, Wladimir Koeppens. The system was revised in conjunction his student, Rudolph Geiger, around 1918. The system has since been extended to account for some smaller climatic effects, mainly in N. America. Whilst the classification system now runs to some 30 zones and subdivisions of the zones, we are only required to know the 5 basic classes plus the 2 transitional zones. The knowledge required covers the latitudes of the zones and the typical weather expected in the zones.

Koeppens (Koeppens - Geiger) Climate Classification:

Class A: Tropical rain climate, (0°-10°) (formerly known as the equatorial climate)
Average temperature of coldest month >18°C
Average monthly rainfall >60 mm, no dry season
Equatorial regions

Class B: Dry climate, (20°-35°) (formerly known as the arid subtropical climate)
Evaporation and transpiration exceed precipitation, no permanent water courses
Sahara etc.

Class C: Mid latitude climate (warm temperate) (40°-70°) (formerly known as the cool temperate climate)
Summer and winter seasons
Average temperature of coldest month between -3°C and 18°C
NW Europe

Class D: Sub-arctic climate (snowy forest) (50°N-70°N) (formerly known as the boreal climate)
Average temperatures: warmest month >10°, coldest month < -3°C
Northern Eurasia/Canada

Class E: Snow climate (polar) (>70°) (formerly known as the polar climate)
Average temperature: warmest month <10°C
N. Greenland, Antarctica etc.

The two transitional climatic zones are:

Tropical transitional climate (10°-20°) (formerly known as the savannah climate)
Warm dry winter, warm wet summer
NW Africa - Ghana etc

Temperate transitional climate (Mediterranean) (35°-40°) (formerly known as the warm temperate climate)
Warm dry summer, cool wet winter

Summary

The idealized weather described above will be modified by local topography and by the proximity of sea areas. The effect of these on temperature, density and pressure can have a marked effect on local climatology.

Seasonal Effect

Figure 20.1 assumes, apart from an all-sea world, that the sun's sub point encircles the globe along the Equator in all seasons.

In practice, the earth's polar axis is inclined at an angle of 23½° to the plane of the path that the earth travels through space during the year. This path is shown in *Figure 20.5* and it may be seen that, while the sun's sub point is on the Equator at the equinoxes on 21 March and 21

September, it is on the Tropic of Cancer (23½°N) at the solstice of 21 June and on the Tropic of Capricorn (23½°S) at the solstice of 21 December.

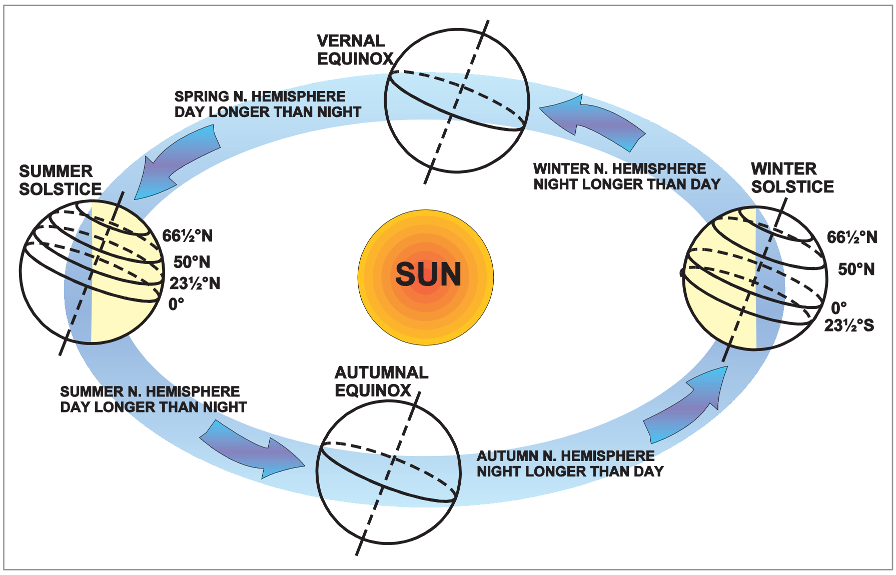


Figure 20.5 The orbital motion of the earth around the sun

Hence when viewed from the earth the sun's sub latitude appears to move southwards from the Tropic of Cancer on 21 June to the Tropic of Capricorn on 21 December then northwards again returning to 23½°N the next June.

It may be noted that above 66½°N (the Arctic Circle) the sun is above the horizon 24 hours a day on 21 June and below the horizon 24 hours a day on 21 December. The reverse is true in the Antarctic.

In the actual world the seasonal movement of the thermal equator can produce tropical rains moving into the summer hemisphere; that is, north in July or south in January. We thus have a transitional region in each hemisphere between the subtropical highs and the equatorial low. Each will be subject to tropical rain in summer and to dry trade wind weather in winter. Near the Equator there will be rain nearly all the time, with maximum rainfall about the time of the equinoxes and minimum at the solstices.

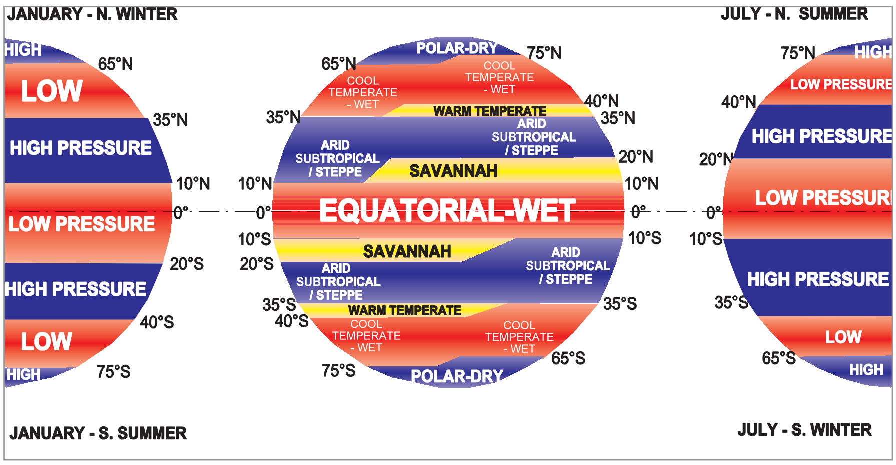


Figure 20.6 Seasonal movement of the world climatic zones

Temperature and Topographical Effects

The surface temperature of an idealized all sea world would cool evenly with latitude increase because the sun's elevation would reduce. In practice this even cooling will be much modified by the presence of land masses, especially in the Northern Hemisphere where the continents of Asia and North America are vast. One effect is that the subtropical anticyclones do sometimes break down due to summertime land heating which lowers pressure. Conversely, continents **outside** the subtropical high belt can experience wintertime land cooling which raises pressure.

In **January** the temperature in **Asia** is exceptionally cold as shown below. The winter cold air over central Asia is due to its distance from the sea, long nights and winter-long terrestrial radiation. It will be held back from India and Pakistan to the south by the Himalayas. In **North America** the cold is further enhanced by the Rocky Mountains which block warm Pacific air while the absence of a barrier to the north allows Arctic air to move south. **North Atlantic** temperatures will remain comparatively high due to the warm water sea current from the Gulf of Mexico. Hence prevailing westerly winds from the Atlantic will warm the adjacent land masses of UK and Western France. **Southern Hemisphere** isotherms will be near the ideal due to the greater sea areas.

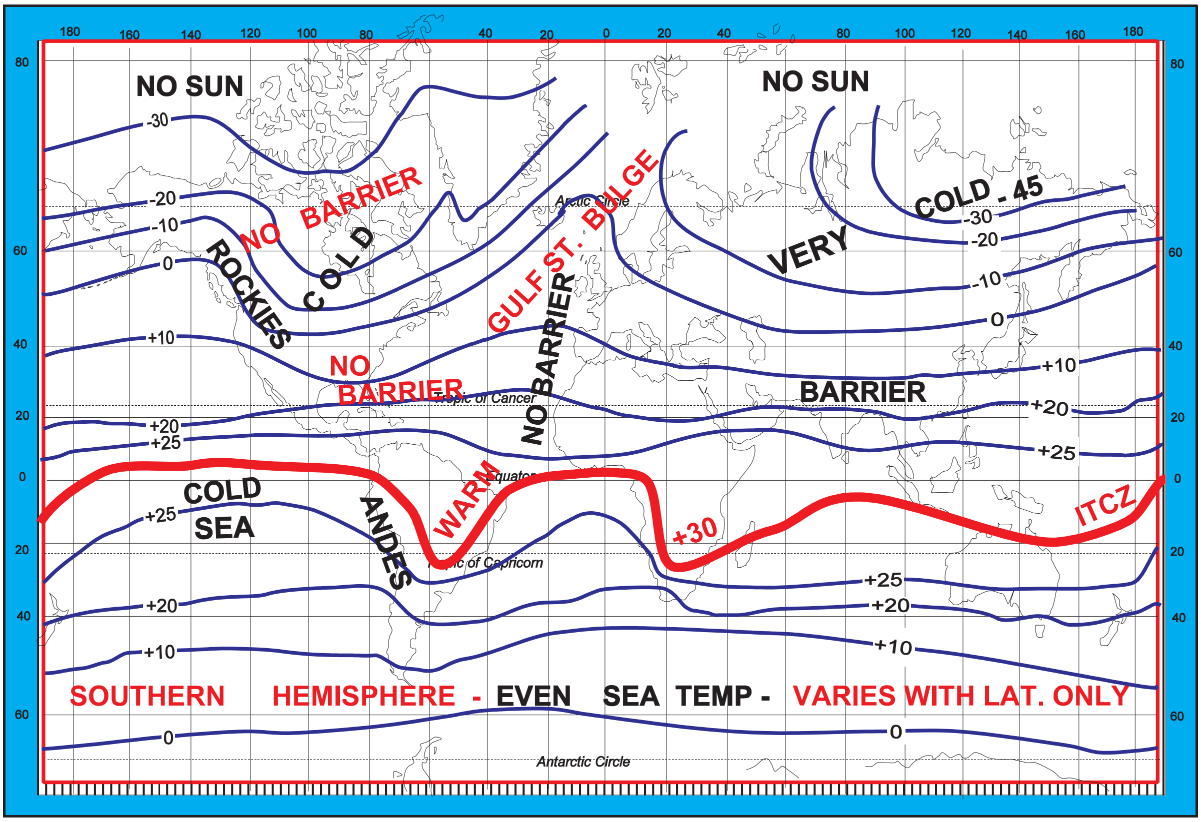


Figure 20.7 Average mean sea level temperatures in degrees celsius in January

In **July,** Central **North America** is warmed by air free to move north from the Gulf of Mexico; the vast area of Asia is warmed by the sun. These continents are now warmer than the Gulf stream-warmed **Atlantic** so that isotherms are reversed, although contrasts are less than in January. In the **Southern Hemisphere** the July winter reflects some seasonal ocean cooling but isotherms still equate approximately with latitude.

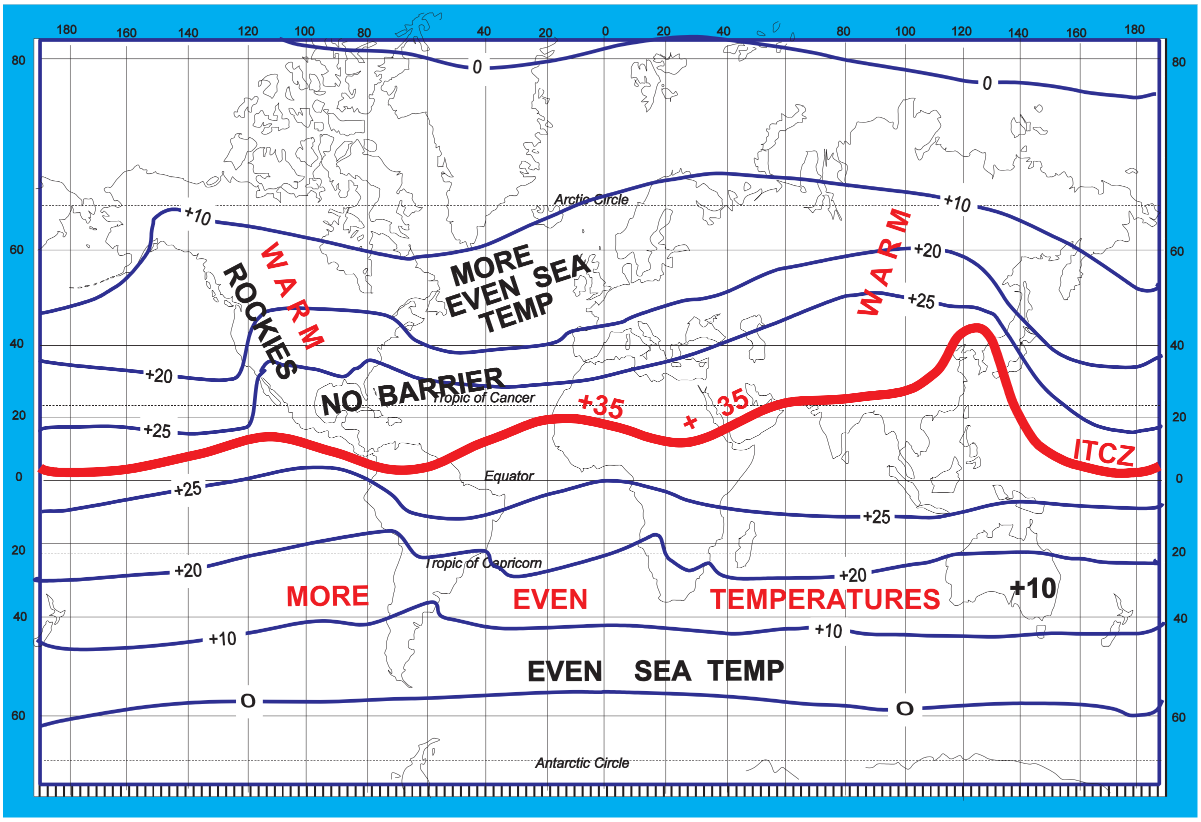


Figure 20.8 Average mean sea level temperatures in degrees celsius in July

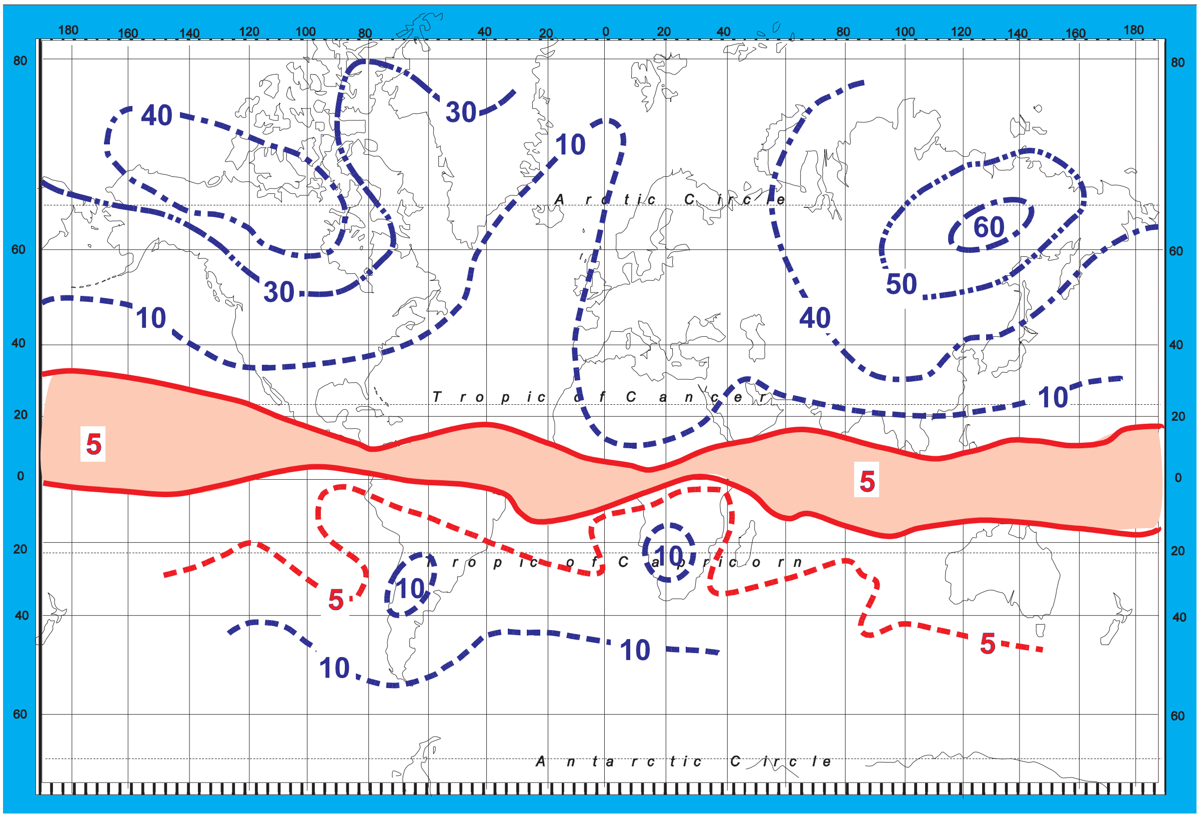


Figure 20.9 Average range of temperature (annual variation)

As distinct from seasonal variation, temperatures will also change daily, but diurnal change will be most in areas over land masses since it is in this circumstance that the sun's heating effect is greatest. The chart below shows the diurnal differences.

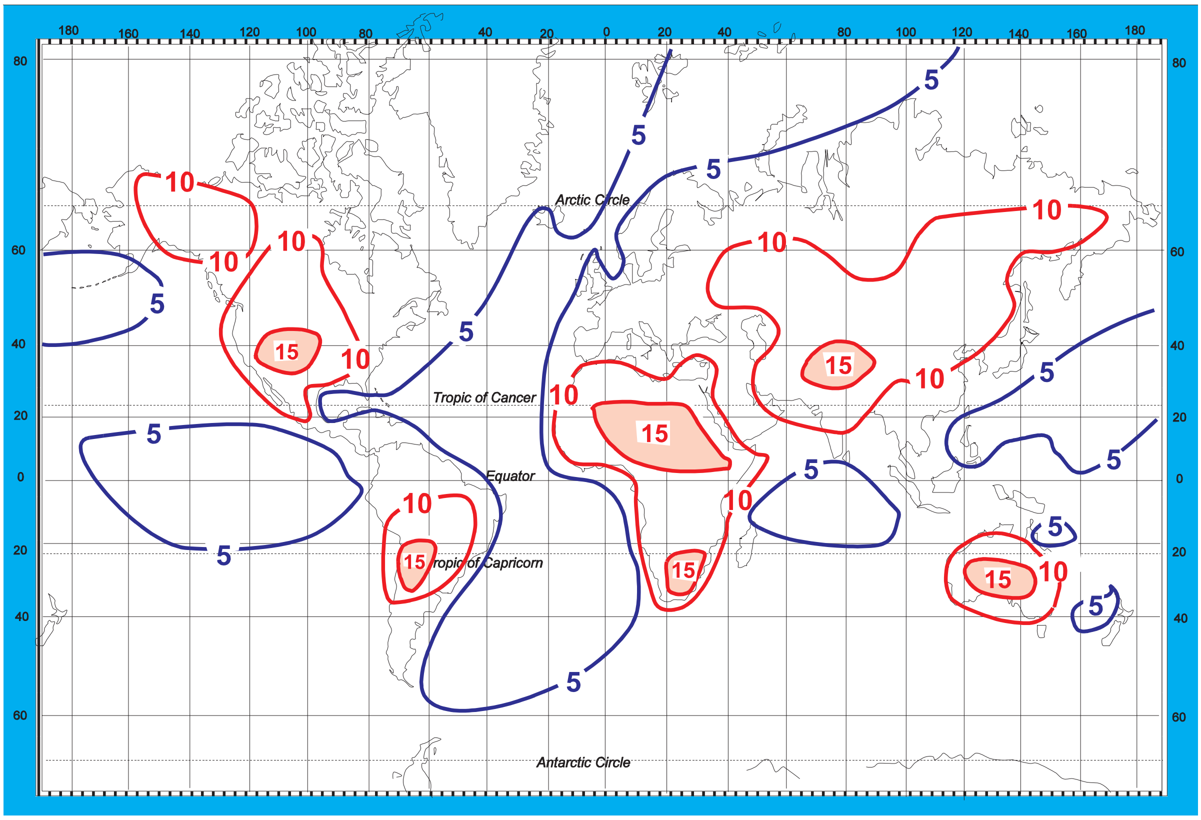


Figure 20.10 Diurnal range of temperature (diurnal variation)

Just as **surface** temperatures change more with departure from the Equator, so will temperatures aloft. At the geographical equator the freezing level is 16 000 ft, although locally as high as 18 000 ft in July when the heat equator lies overland in SE Asia; because of this hail in thunderstorms would melt before reaching Mean Sea Level. Elsewhere in both hemispheres the freezing level change will be seasonally wider but especially so over land areas. The following diagrams show the freezing levels in January and July.

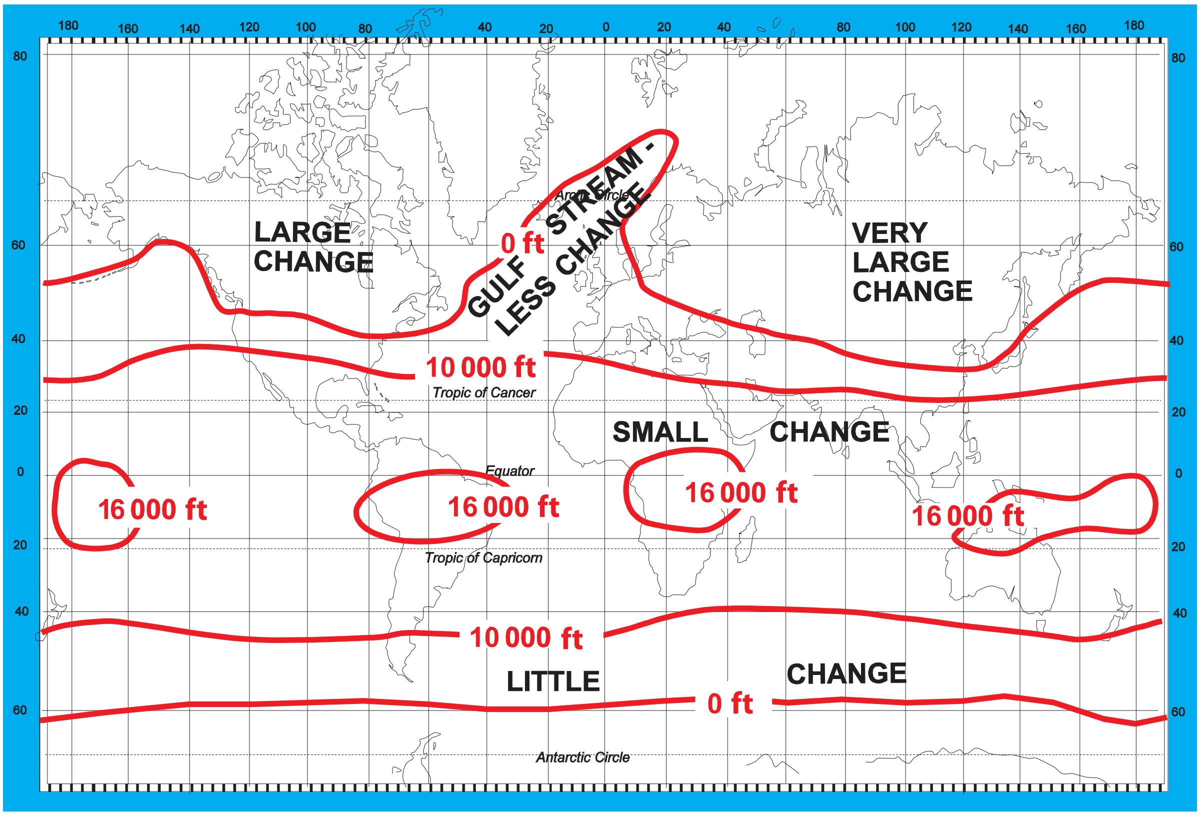


Figure 20.11 Height in feet of freezing level in January

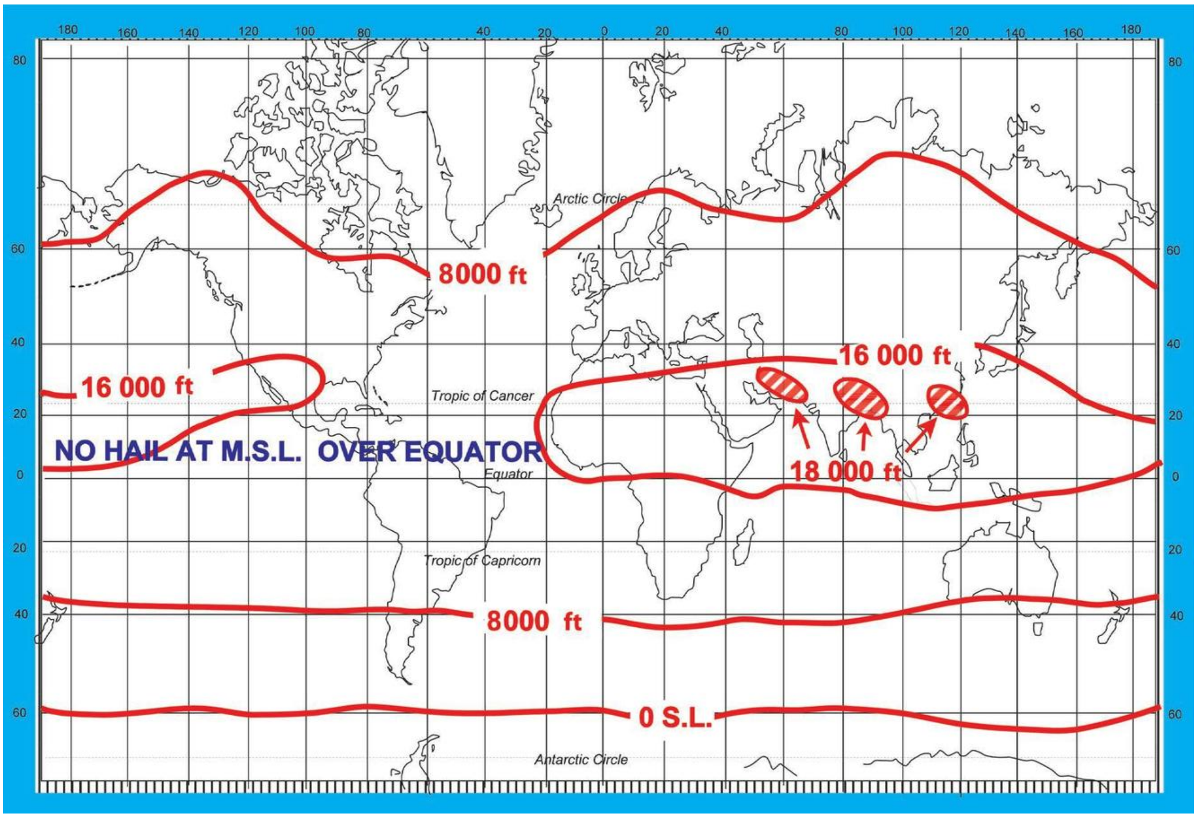


Figure 20.12 Height in feet of freezing level in July

Summary

Topographical temperature variations will affect surface pressure and distort the idealized distribution shown earlier, so that whereas the climatic pressure zones will be maintained over the **oceans**, the pressure patterns **overland**, and hence the winds and weather, will be governed much more by surface temperature changes. This will apply especially to the Northern Hemisphere, where two-thirds of the world's land masses lie.

Relative Humidity

This chart shows how relative humidity varies with latitude and season.

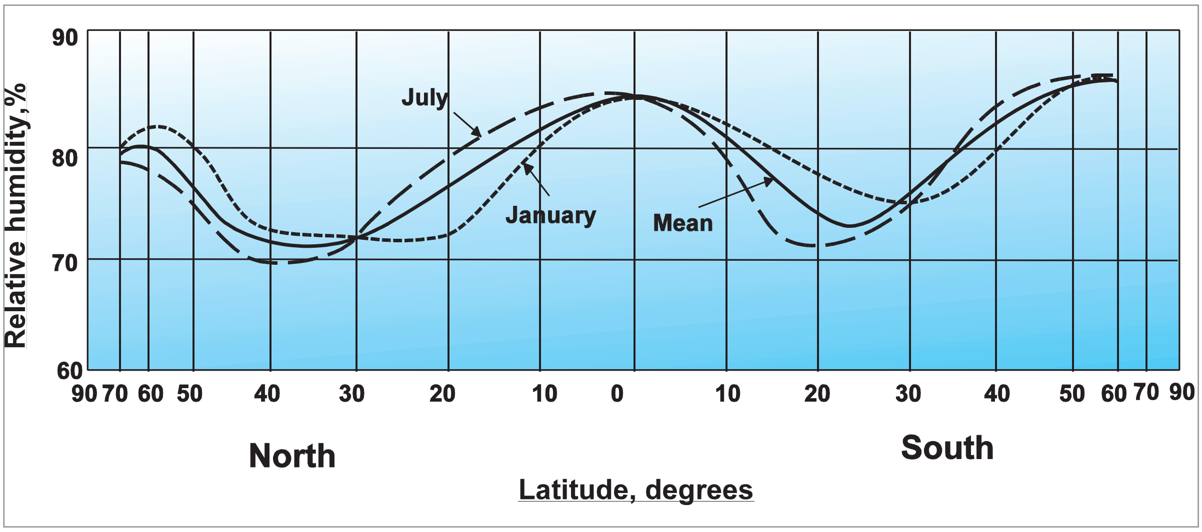


Figure 20.13 Zonal distribution of relative humidity

Pressure

- **JANUARY**
    - In the Southern Hemisphere the pattern is close to the idealized circulation.
    - The **equatorial low pressure zone** lies to the **south** of the Equator.
    - **Subtropical highs** are established over **oceanic areas.**
    - **Cold weather highs** are established over Northern Hemisphere **land masses**.
    - There are significant pressure areas in the region of:

Iceland (**Low**)	1000 hPa	(statistical low)
Aleutians (**Low**)	1000 hPa	(statistical low)
N. Australia (**Low**)	1005 hPa	
Siberia (**High**)	1035 hPa	
N. America (**High**)	1020 hPa	
Azores (**High**)	1020 hPa	
Pacific (**High**)	1020 hPa	

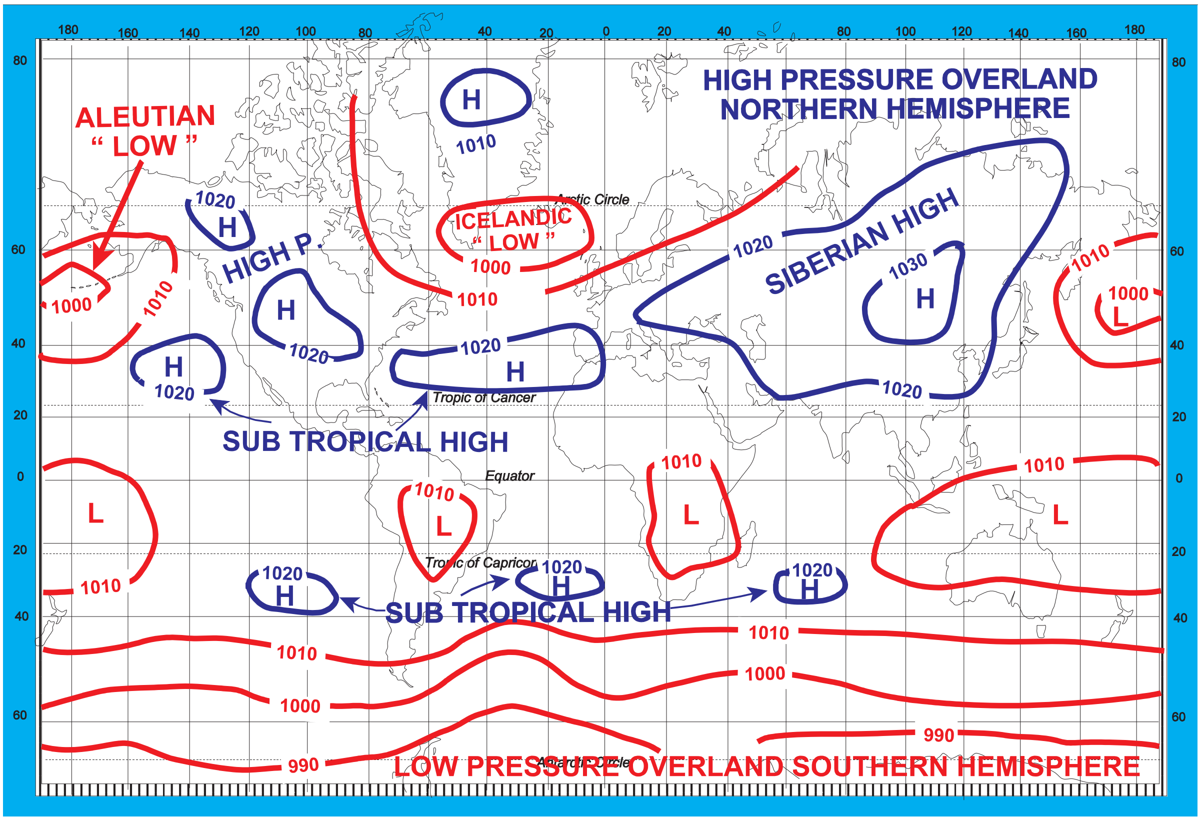


Figure 20.14 Average mean sea level pressures in hectopascals in January

- **JULY**
    - In the Southern Hemisphere the pattern remains close to the ideal. Overland temperatures are colder thus the subtropical high is generally unbroken.
    - The **equatorial low pressure zone** lies to the **north** of the Equator.
    - Where subtropical highs would be expected in the Northern Hemisphere, low pressure areas now form over land masses due to solar heating. Thus the **Siberian High** of January is replaced by the **Baluchistan Low**, centred over Pakistan but affecting all of **Asia. N America** also has low pressure.
    - The **Aleutian** and **N Australia lows** disappear.
    - **Icelandic statistical low** pressure is less deep and is now dispersed into three small areas:

      Off Greenland, the Baltic and Iceland - 1010 hPa
    - The **Azores & Pacific Highs** are dominant at 1025 hPa

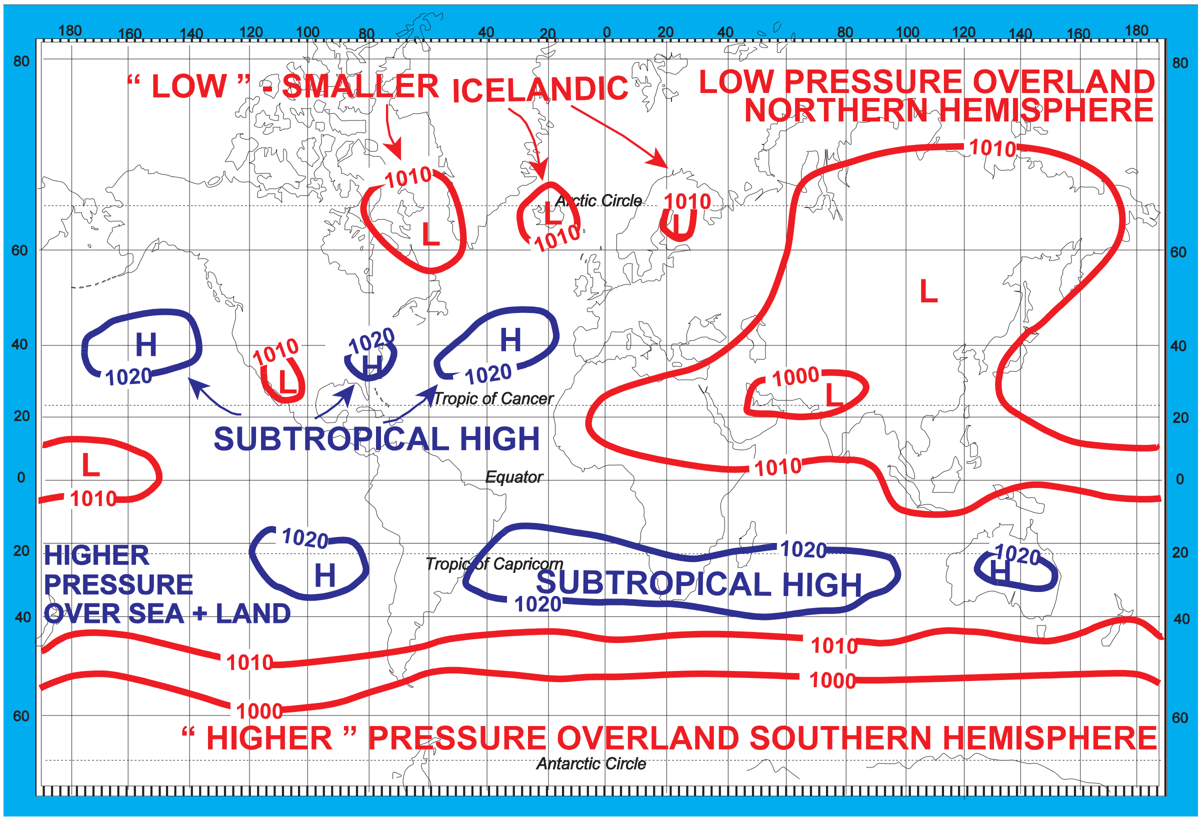


Figure 20.15 Average Mean Sea Level Pressures in hectopascals in July

Surface Winds

The Westerlies of Temperate Latitudes

Westerly winds exist in the region between subtropical highs and temperate lows (40° - 60° degrees latitude). These are caused by the turning effect of geostrophic force (Coriolis) on the **Poleward** outflow from those subtropical highs. In the Northern Hemisphere the westerlies apply mainly over the oceans, with frequent winter gales. During the summer months these westerlies are less constant and less strong. In the Southern Hemisphere these winds are largely uninterrupted by land masses and are consequently strong. They are called **The Roaring Forties** - so called because they blow principally between latitudes forty and fifty South. Weather in this belt comes from rapidly moving depressions; wild weather, strong westerly winds and gales, overcast skies and heavy rain.

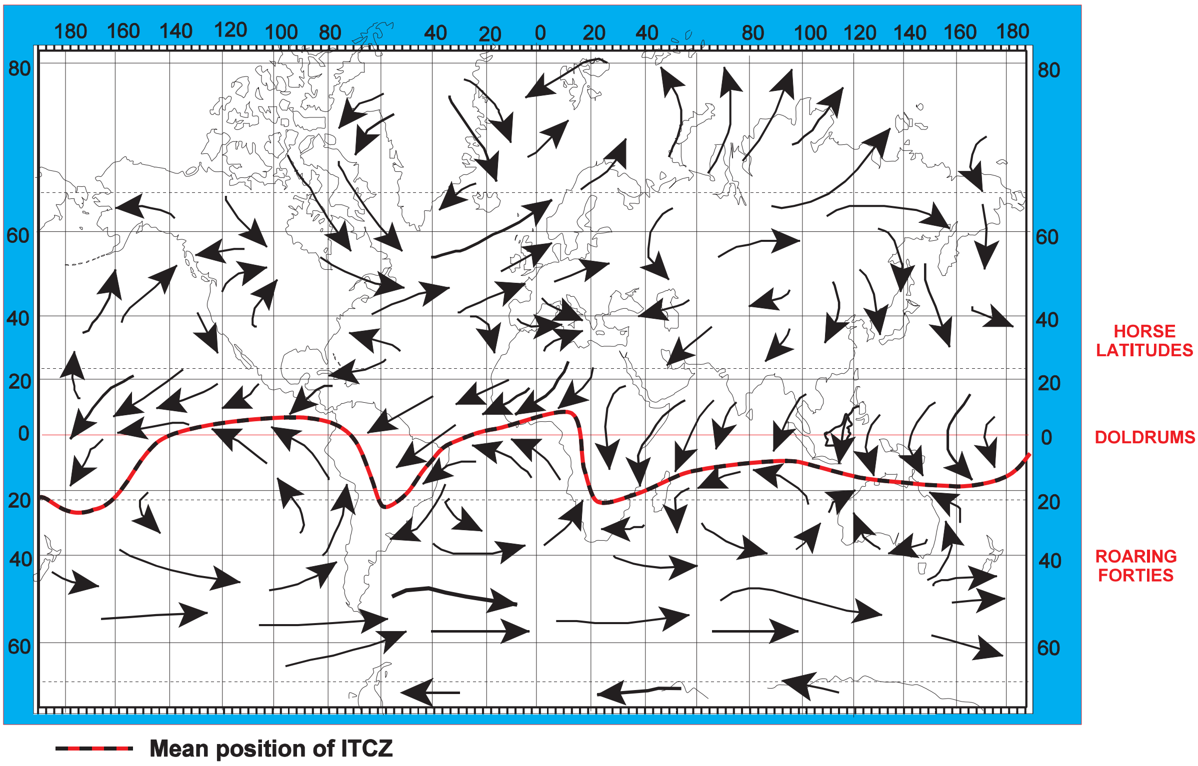


Figure 20.16 Prevailing surface winds in January

Underneath the subtropical high pressure zones the wind speed is relatively slow and sometimes nonexistent. The areas (between 30° - 40°N) have become known as the "Horse Latitudes" from the time when sailors en route to the Americas disposed of their horses off the ships rather than have to feed them when the sailing ships were becalmed.

Trade winds (Tropical Easterlies)

Trade winds are consistent winds converging to the equatorial trough from the subtropical high belt on each side of it. The turning effect of geostrophic force (Coriolis) causes **northeast trades** in the Northern Hemisphere and **southeast trades** in the southern. The trade winds blow towards the **thermal equator** and will therefore **change direction** when crossing the **geographic equator.** NE trades will **back**; SE trades will **veer**. January flow is shown at *Figure 20.16* and July flow at *Figure 20.17*. Fine weather prevails in the poleward and eastern parts of the tropical oceans while towards the west and the Equator unstable conditions will dominate, with cloudy, showery weather.

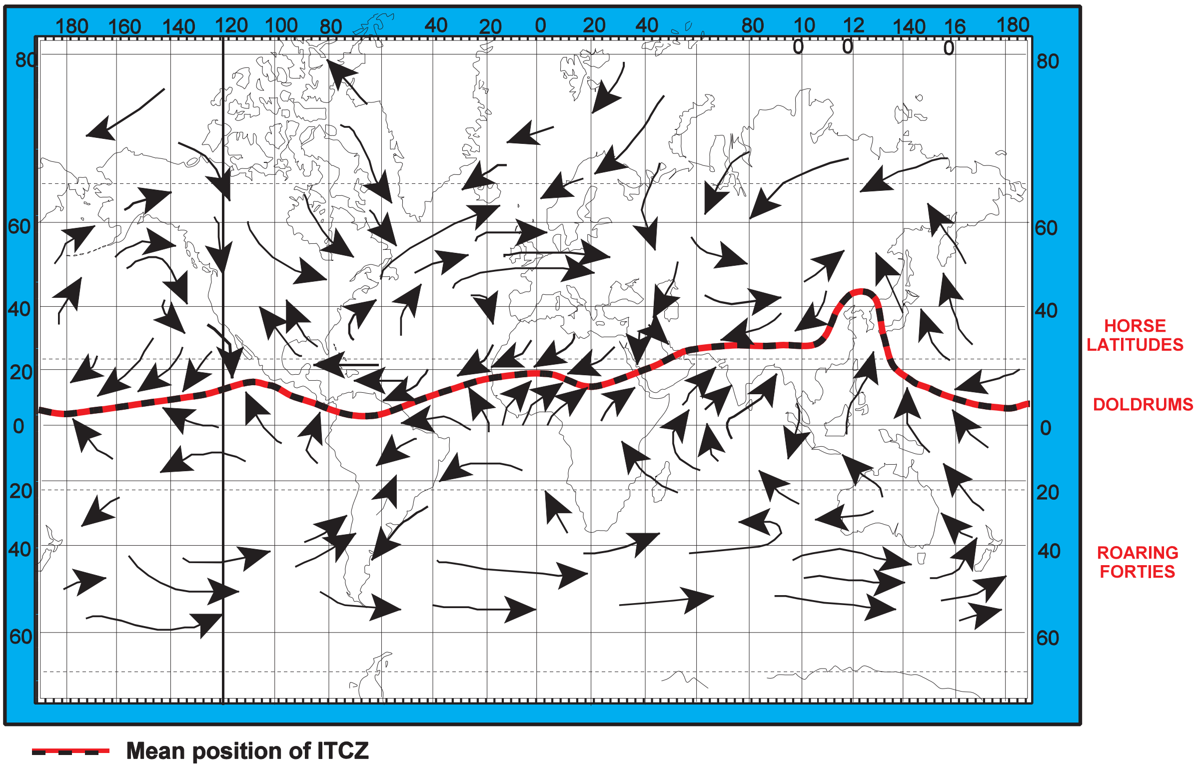


Figure 20.17 Prevailing surface winds in July

Monsoons. These are seasonal winds due to the winter high pressure, or summer low pressure, which develops over large continents. They are particularly marked in **South** and **Southeast Asia** and also occur in **West Africa.** They blow in concert with the trade winds.

Weather will depend very much on the track followed. NE monsoons over central India will be dry with little cloud, whilst the SW monsoon will be warm and moist with much convective cloud and heavy rain. NE monsoon over the Far East will be relatively dry whilst the SW monsoon, with its long sea track over the tropical oceans will produce very wet conditions.

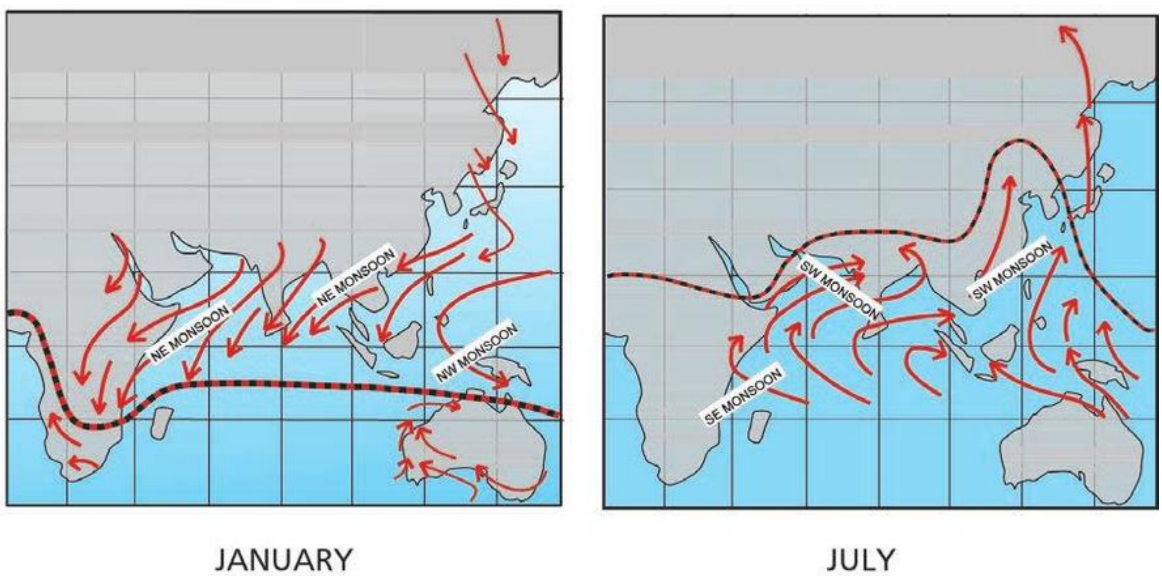


Figure 20.18 Monsoons

Other winds. Outside the main currents there are:

- Winds applicable to the local pressure system prevailing at the time. Example variations are shown at *Figure 20.19.*

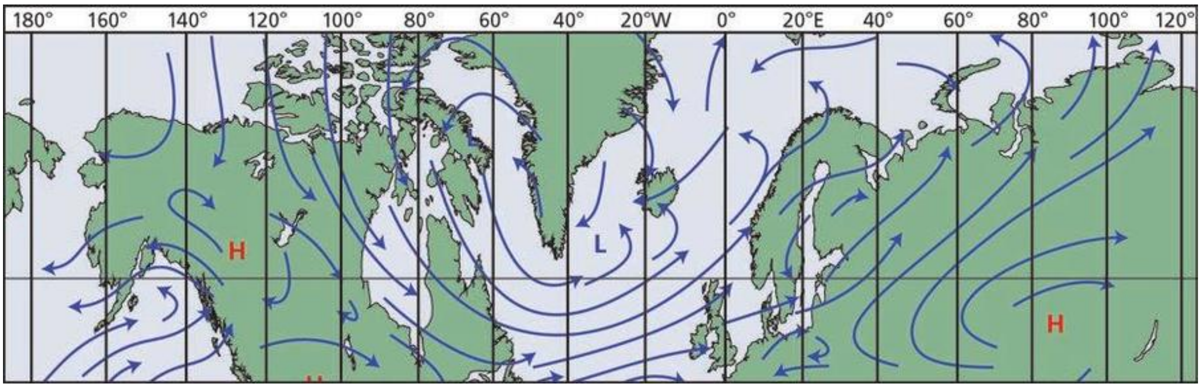


Figure 20.19 Cool temperate (winter)

- Strong **easterlies** near the **South Pole.** (Outflow from S Polar high turns **left**).

- Generally strong **easterlies** near the **North Pole** but in **summer westerlies** over **N Atlantic** & **N Pacific** seas.

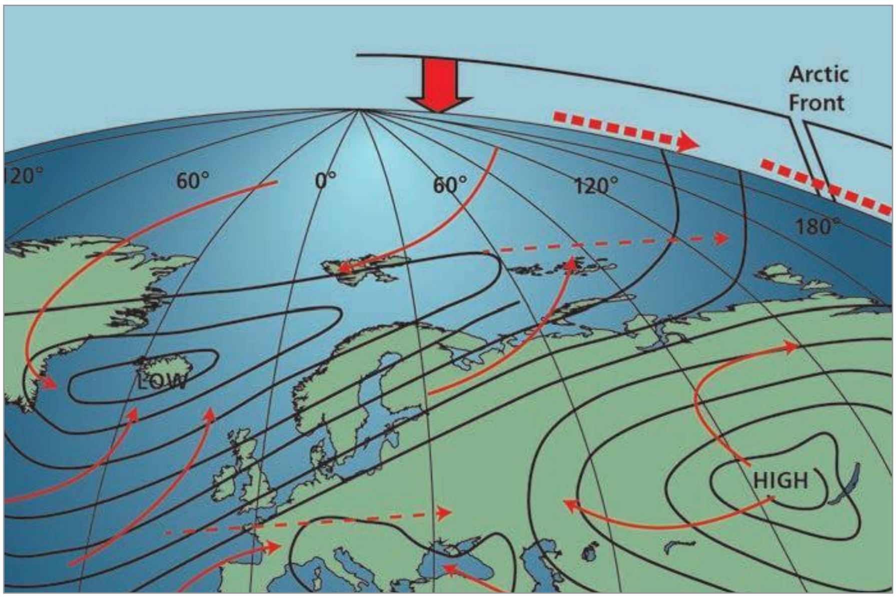


Figure 20.20 Polar Easterlies

- **Sea breezes**, which can be dominant in lower latitudes.

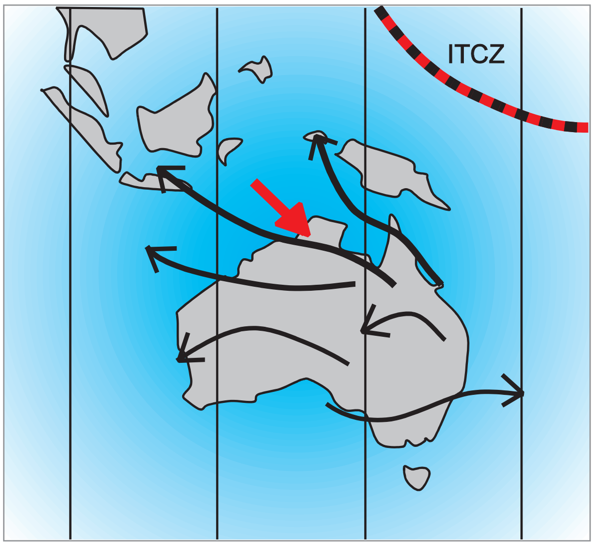


Figure 20.21 Sea breeze at Darwin in the winter (against the flow)

Weather

Temperate latitude depressions. Frontal depressions will breed along the polar front where this lies over wide ocean areas. In the **Northern Hemisphere** this will occur between 35°N and 65°N across the **Atlantic between N America and Europe**, and a similar pattern will exist across the **North Pacific** to affect the west coast of N America. In the **Southern Hemisphere** polar front depressions will centre around 50°S in all seasons with fronts affecting the west coast of South America also New Zealand and the South Coast of Australia.

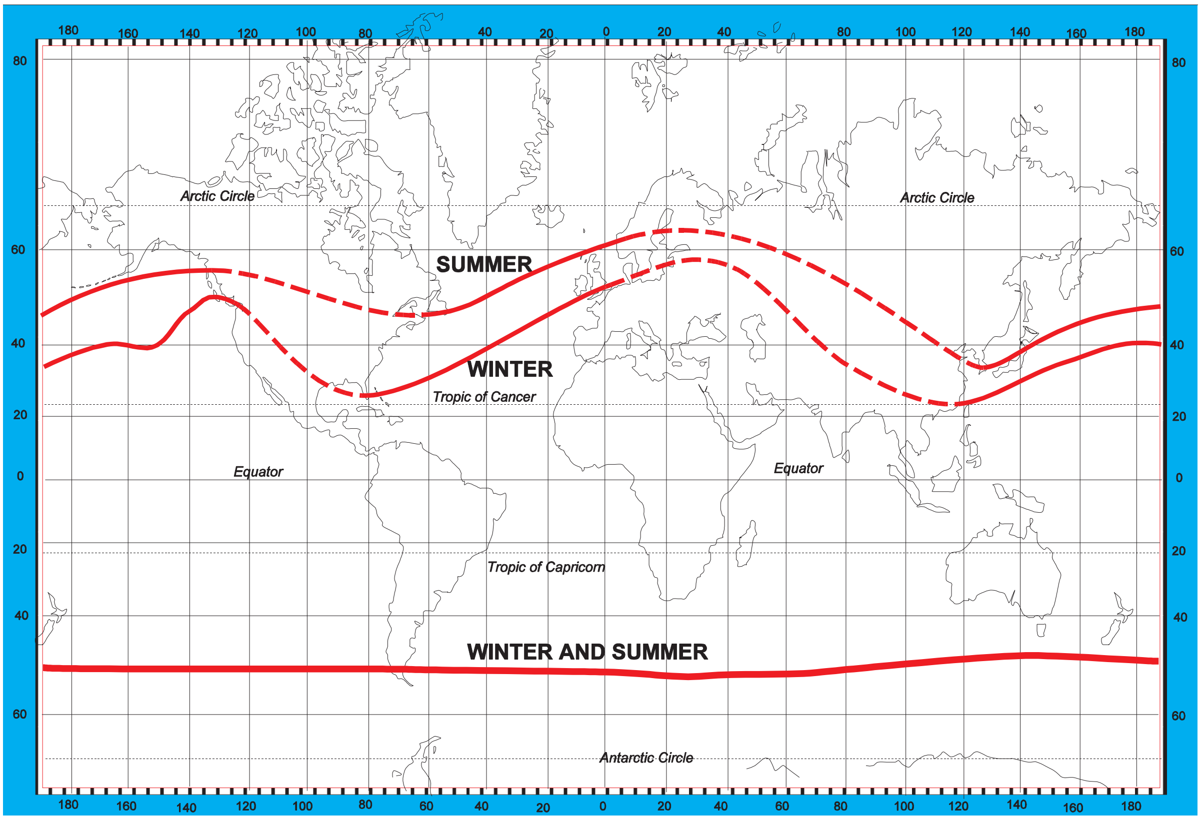


Figure 20.22 Alignment of polar front - winter and summer

Polar Air Outbreaks. Found generally in wintertime, these are depressions affecting Central and North China as well as Central and Southern United States. Behind the cold front fresh outbreaks of very cold continental polar air greatly reduce mean temperatures. These winter mean temperatures are considerably below those of equivalent latitudes.

The Equatorial Trough / ITCZ

- The trough is centred on the **thermal equator**. High temperatures cause low pressure, particularly over land, with widespread lifting of air from the Trade Winds which converge below at the surface. This area is known as the ITCZ.

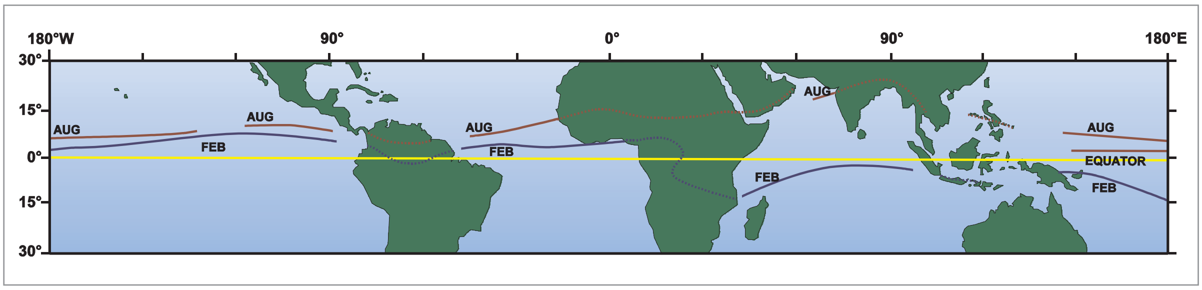


Figure 20.23 The approximate position of the equatorial trough

- The main feature of the **ITCZ** is **extensive Cu, Cb & thunderstorms.** When stable air exists, there will be extensive sheets of **As** & **Ns** cloud and more continuous type rain

- The **ITCZ** can vary from 25 NM to 300 NM in width and there is no well defined frontal surface. Cloud is **not** caused by air mass temperature differences as at the polar front, but by **convergence** of the NE and SE trade winds which are normally the same temperature. The cloud tops are sometimes as low as 20 000 ft but more frequently 50 000 ft or more.

- Turbulence is usually severe, as is icing, which can be from 16 000 ft upwards.

- Vigorous and quiet **ITCZ** cross sections are shown below.

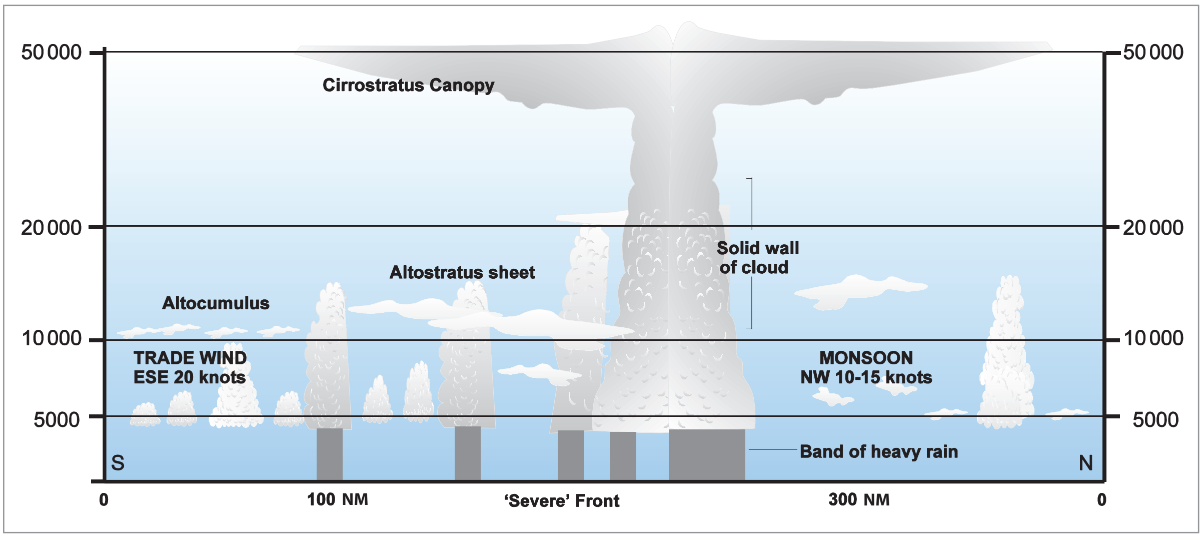


Figure 20.24 Cross-section of a vigorous ITCZ

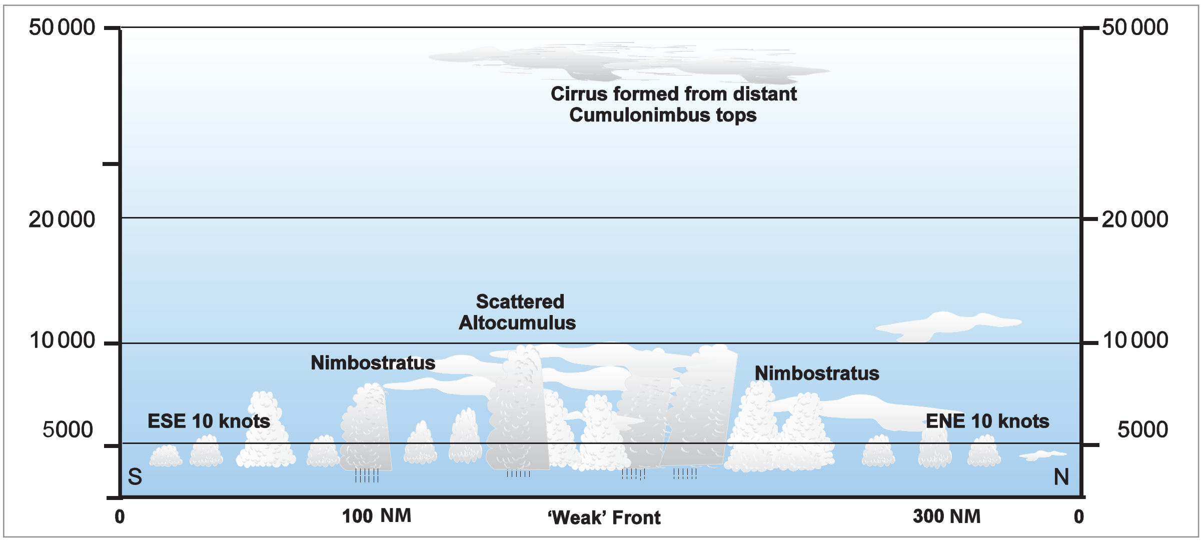


Figure 20.25 Cross-section of a quiet ITCZ

Monsoons

- When **trade winds** blow ***to*** continental low pressure or ***from*** continental high pressure the associated weather is known as a **monsoon.** There are three monsoon flows; the **NE, NW & SW.**

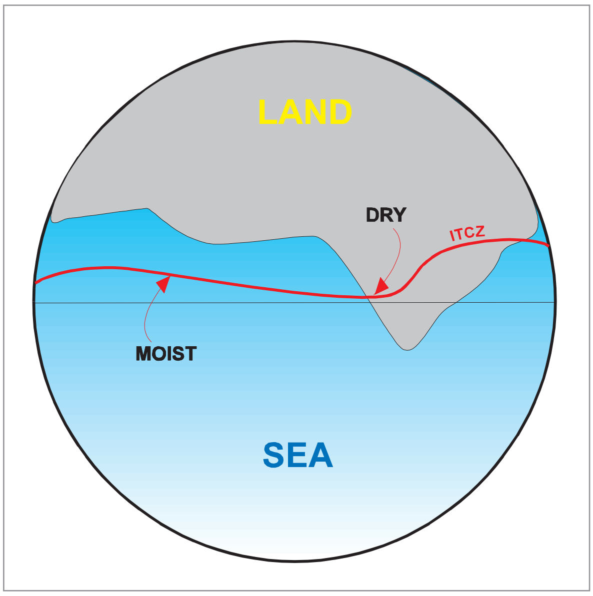


Figure 20.26 Monsoon on globe

- The **NE MONSOON** of **Asia** blows from the winter **siberian high** and is consequently **cool & comparatively dry** giving **clear** weather over **Bangladesh, Burma and Thailand. SE India, Sri Lanka & east coast of West Malaysia** are also affected by this monsoon, but here the over-sea track picks up **moisture** and produces **heap type clouds and thunderstorms and heavy precipitation** when crossing coastal mountain ranges.

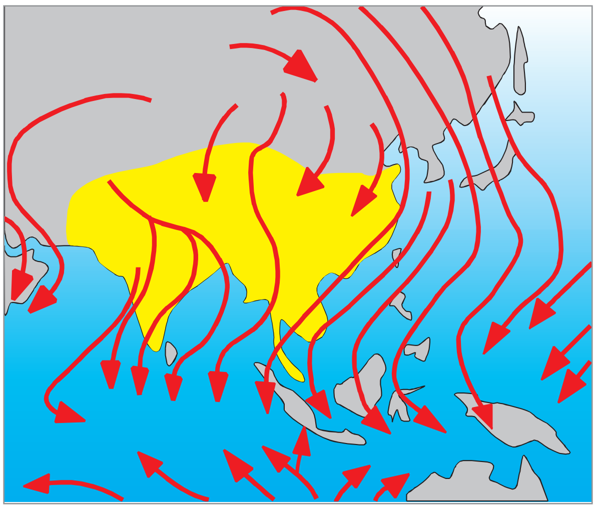


Figure 20.27 Northeast monsoon and northwest monsoon

- The **NW MONSOON** is really an extension of the NE Monsoon which backs on crossing the Equator southbound and brings Cu, Cb and **thunderstorms to North Australia & New Guinea**. See *Figure 20.27*.

- The **SW MONSOON** is produced by the SE trade wind crossing the Equator and veering to SW and thence to the summer Baluchistan Low. Having a long sea track, this monsoon is very moist and produces much **heavy Cu & Cb with large scale thunderstorms**. It affects **all of India, Sri Lanka, Burma** and exposed coasts of **West Malaysia**. It has a more serious effect on flying than the NE Monsoon, with **heavy thunderstorms, low cloud base & severe turbulence.** The SW Monsoon also affects the **West African coast**, notably **Guinea, Ghana & North Nigeria.**

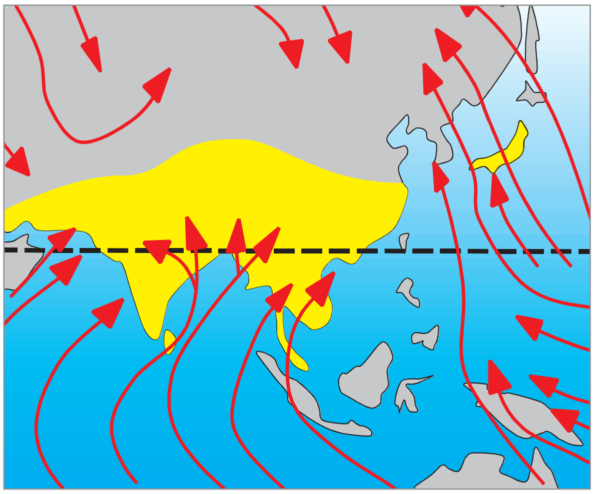


Figure 20.28 Southwest monsoon

- In **summary**. The world's rainfall is produced principally by the weather from the ITCZ and associated monsoons, also from the two cool temperate zones. The two subtropical high belts and two polar highs will usually be dry. Nevertheless these patterns may be altered significantly by local topographical features. The extremes of rainfall are indicated on the chart at *Figure 20.29.*

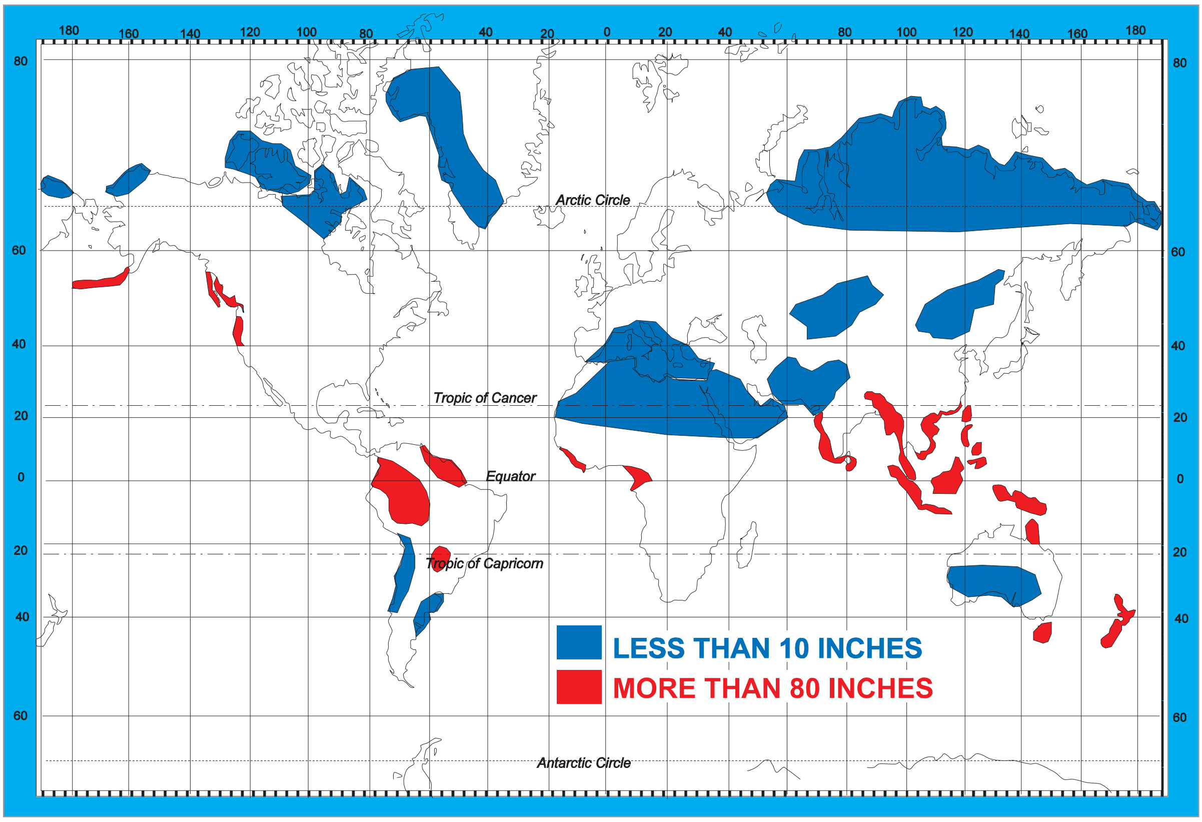


Figure 20.29 Mean annual precipitation showing extreme wet and dry areas

Upper Winds

- **Subtropical Jets.** These jets blow at the **200 hPa level** in each hemisphere between 25° and 40° latitude in winter and 40° and 45° in summer. The **cause** is the upper pressure gradient between the descending warm and cold air on either side of the subtropical high pressure belt. See *Figure 20.30* and *Figure 20.31*. Speeds can be in excess of 100 kt. (Up to 300 kt near Japan).

- **Polar Front Jets.** The polar front jets in the Northern Hemisphere are of a transient nature and move with the polar front as it moves south in winter and north in summer. Polar front Jets are caused by the upper pressure gradient between the Tm warm and Pm cold air masses on either side of the polar front.

- In the Southern Hemisphere they are more constant and blow around the 50th parallel. They are less strong than those in the Northern Hemisphere.

- **Tropical Easterly Jet (Equatorial Easterly Jet).** Strong easterlies that occur in the Northern Hemisphere's summer between 10° and 20° North, where the contrast between intensely heated central Asian plateaux and upper air further south is greatest. It runs from South China Sea westwards across southern India, Ethiopia and the sub Sahara. Typically heights circa 150 hPa (13-14 km; 45 000 ft). These easterlies can give way to westerlies especially in January as the ITCZ moves south.

- **Arctic Jet Stream.** Found between the boundary of Arctic air and polar air. Typically in winter at around 60° North but in the USA around 45° to 50° North. The core varies between 300 and 400 hPa. It is a transient feature found over large continents during Arctic air outbreaks.

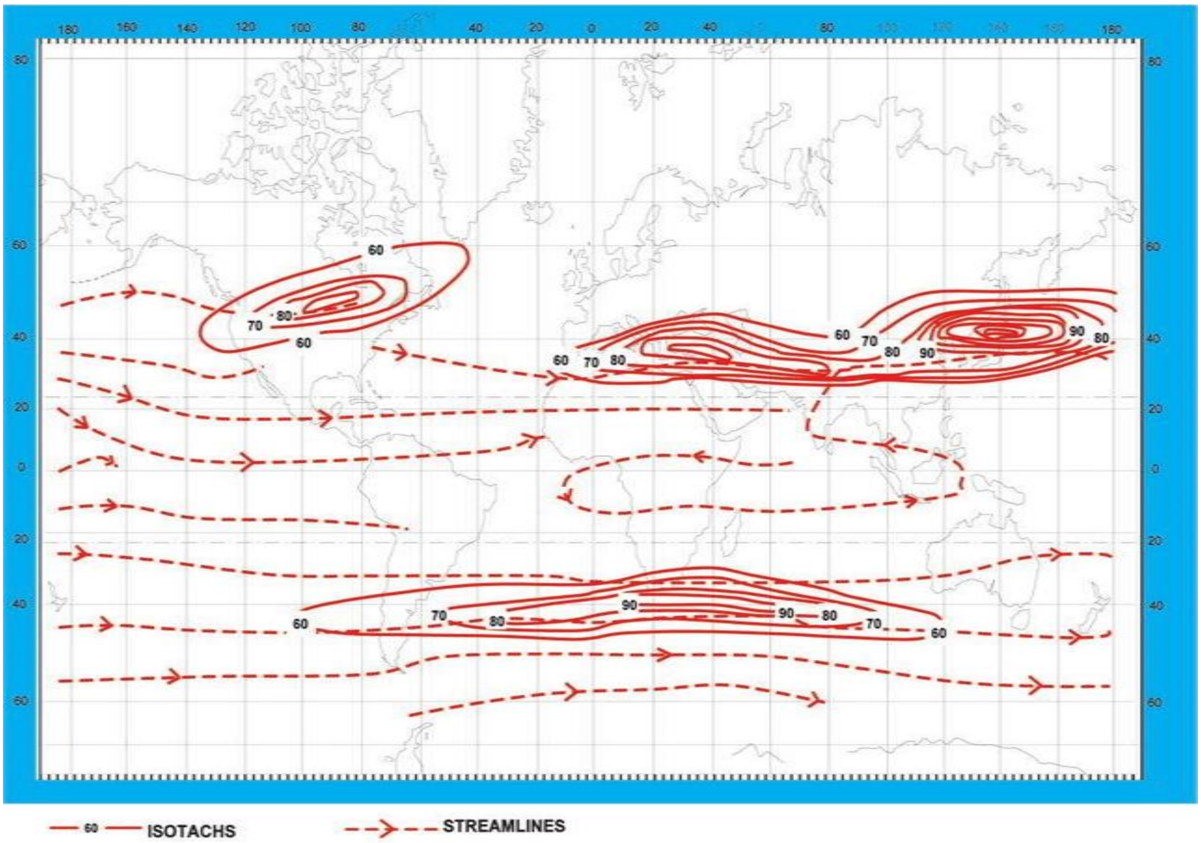


Figure 20.30 Subtropical jet streams - January

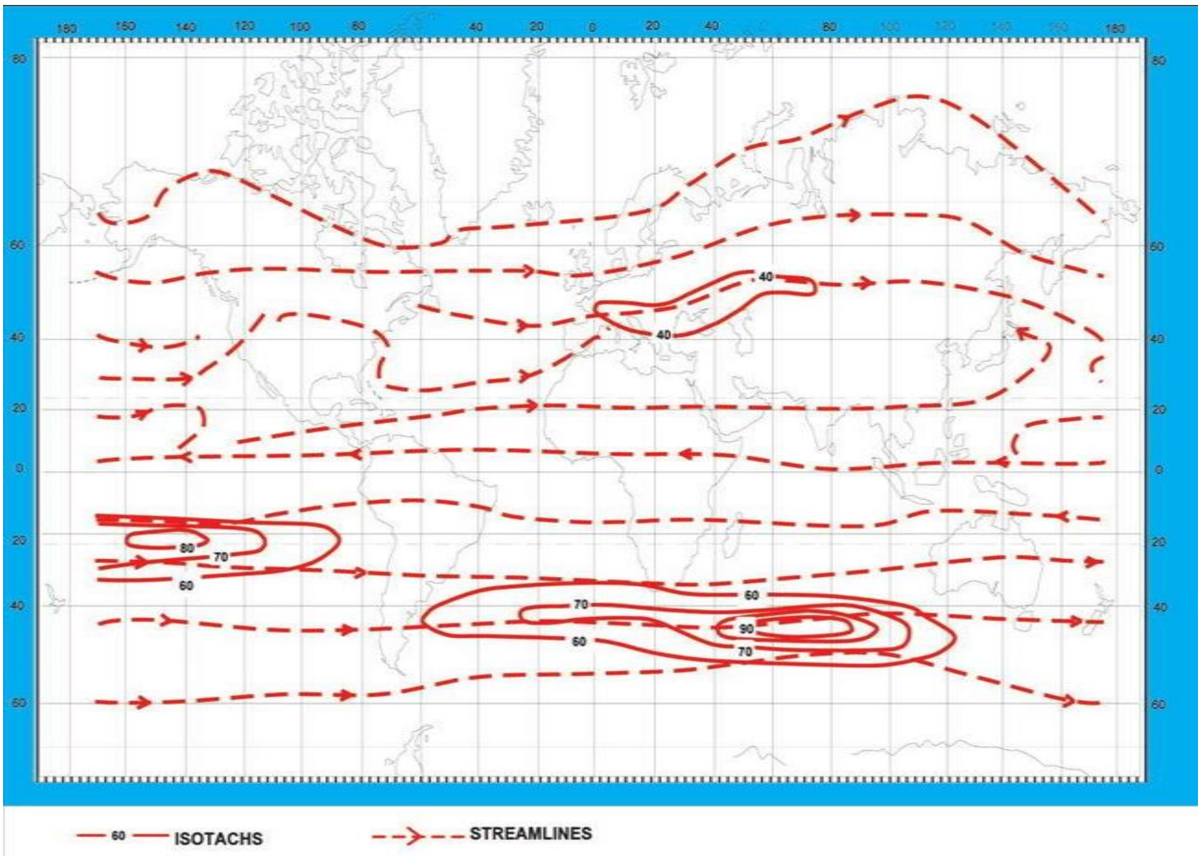


Figure 20.31 Subtropical jet streams - July

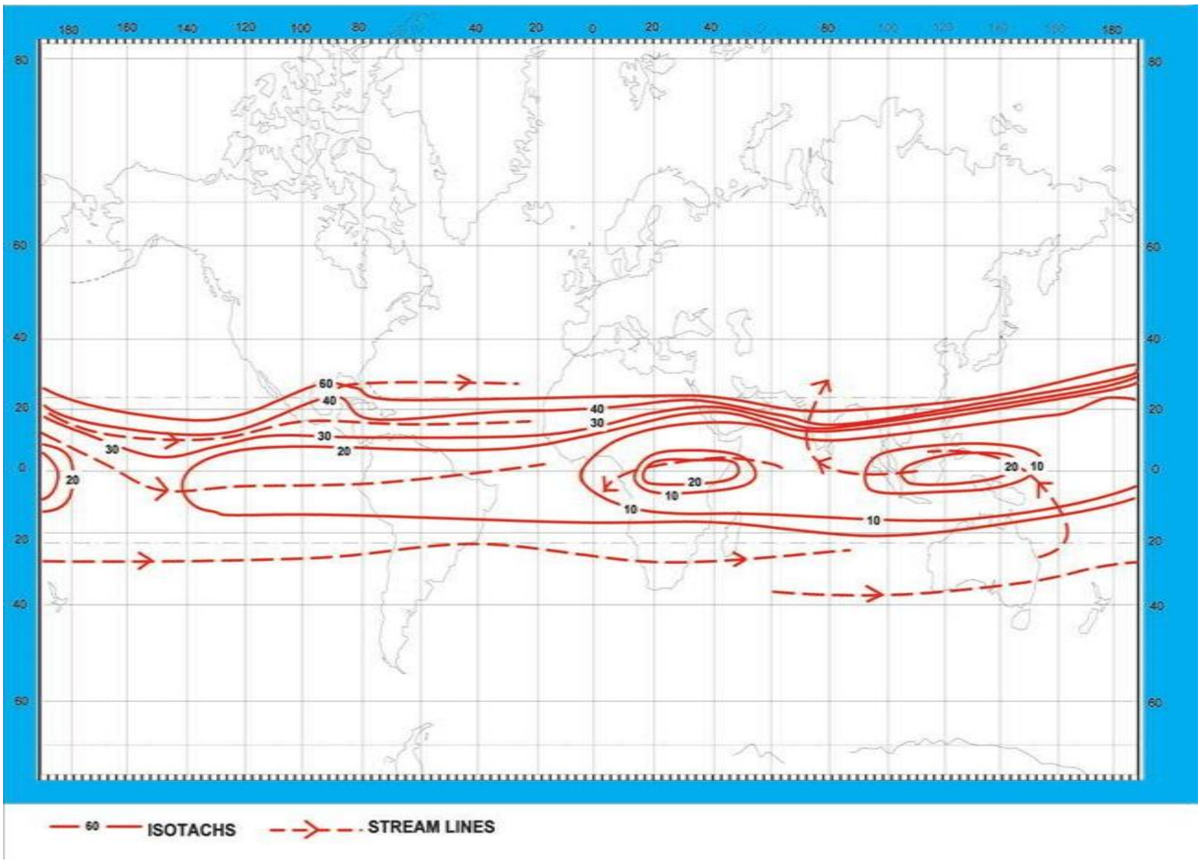


Figure 20.32 Equatorial upper winds - January

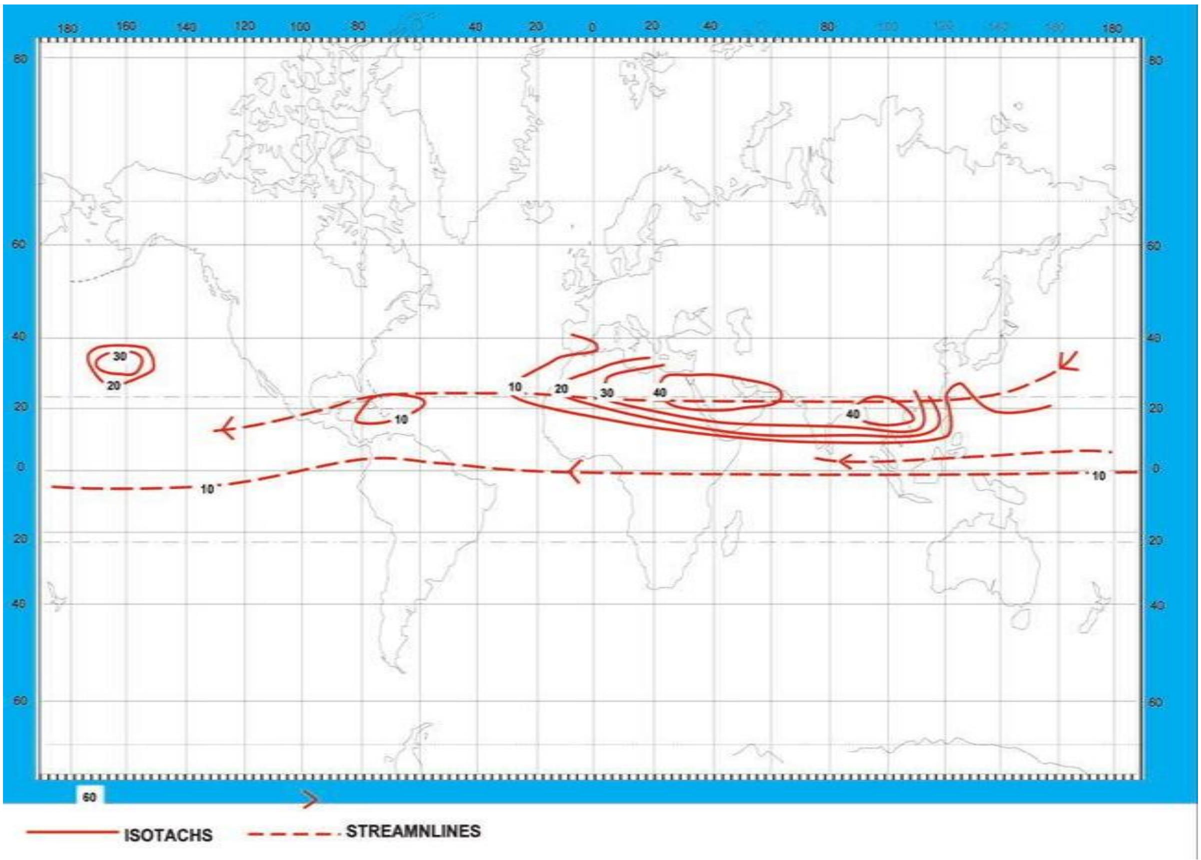


Figure 20.33 Equatorial upper winds - July

- **High Level Winds Over India.** With the onset of the SW Monsoon (May to June), large changes occur over India at the 200 hPa level. The axis of the westerly subtropical jet moves north of the Himalayas and the high level winds across India become easterly.

- **Eastern Mediterranean.** In the eastern Mediterranean in winter, subtropical jet stream winds occur particularly at the **200 hPa level.** They are normally in the Cyprus/Egyptian Coast area with westerlies in excess of 100 kt. 225 kt has been recorded. (See *Figure 20.32* & *Figure 20.33*)

- **Polar Winds.** Near the poles there are strong **westerlies** in **winter** because the polar tropopause temperature is lower than that at temperate latitude. Remember - back to the wind - Northern Hemisphere - (**low temperature on the left**).

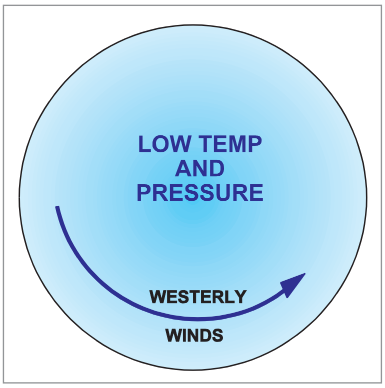


Figure 20.34 Polar Upper Winds - Winter

In **summer**, as the polar tropopause temperature rises and exceeds that at temperate latitudes, the westerlies reduce and become **easterlies.**

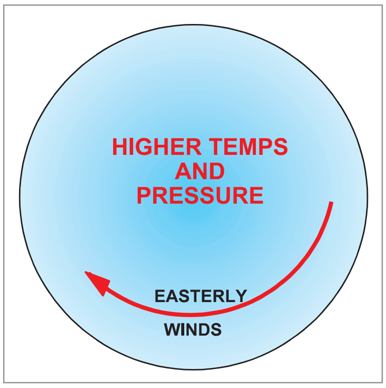


Figure 20.35 Polar Upper Winds - Summer

Waves

- **Easterly Waves.** An easterly wave is a wave or trough of low pressure, originating over West Africa between latitude 5° North and 20° North and moving towards the **Caribbean.** Some of the waves proceed beyond the Caribbean and into the Pacific. They occur during the summer and autumn, usually numbering about 50 each year. Weather produced will be like that associated with **tropical revolving storms,** though to a much lesser extent in severity. They may develop into tropical revolving storms themselves.

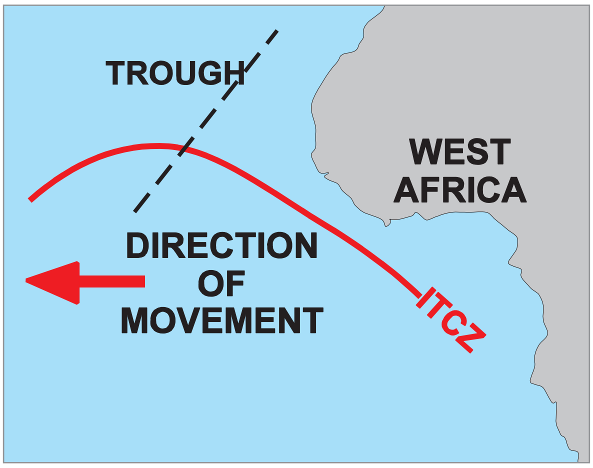


Figure 20.36 An Easterly Wave

- **Westerly Waves.** These are very similar to easterly waves but are simply interconnecting warm front and cold front bands of weather (associated with a polar frontal depression) that move from the west to the east creating a pattern that is very similar to that of a wave. *Figure 20.37* shows a typical westerly wave.

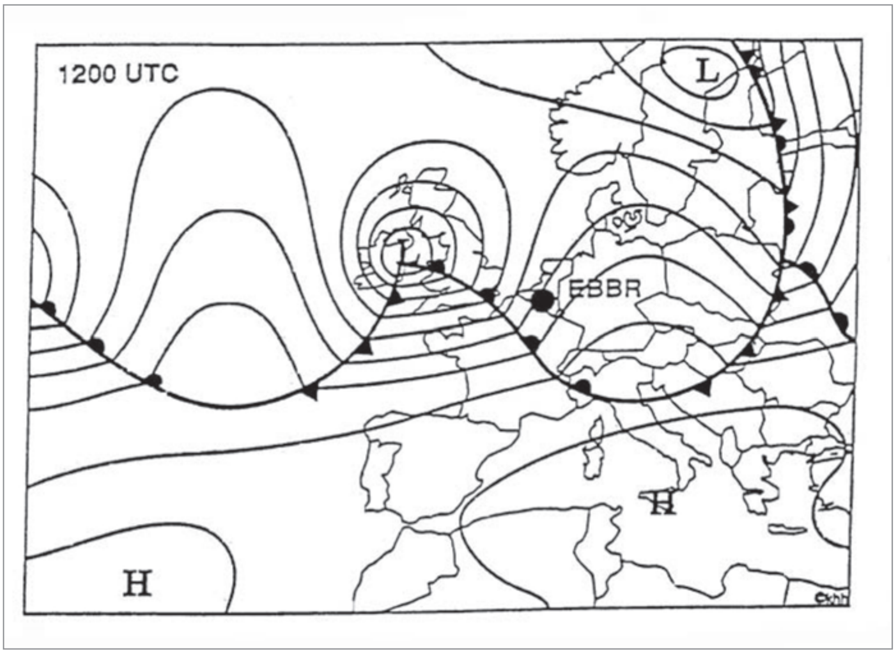


Figure 20.37 A westerly wave

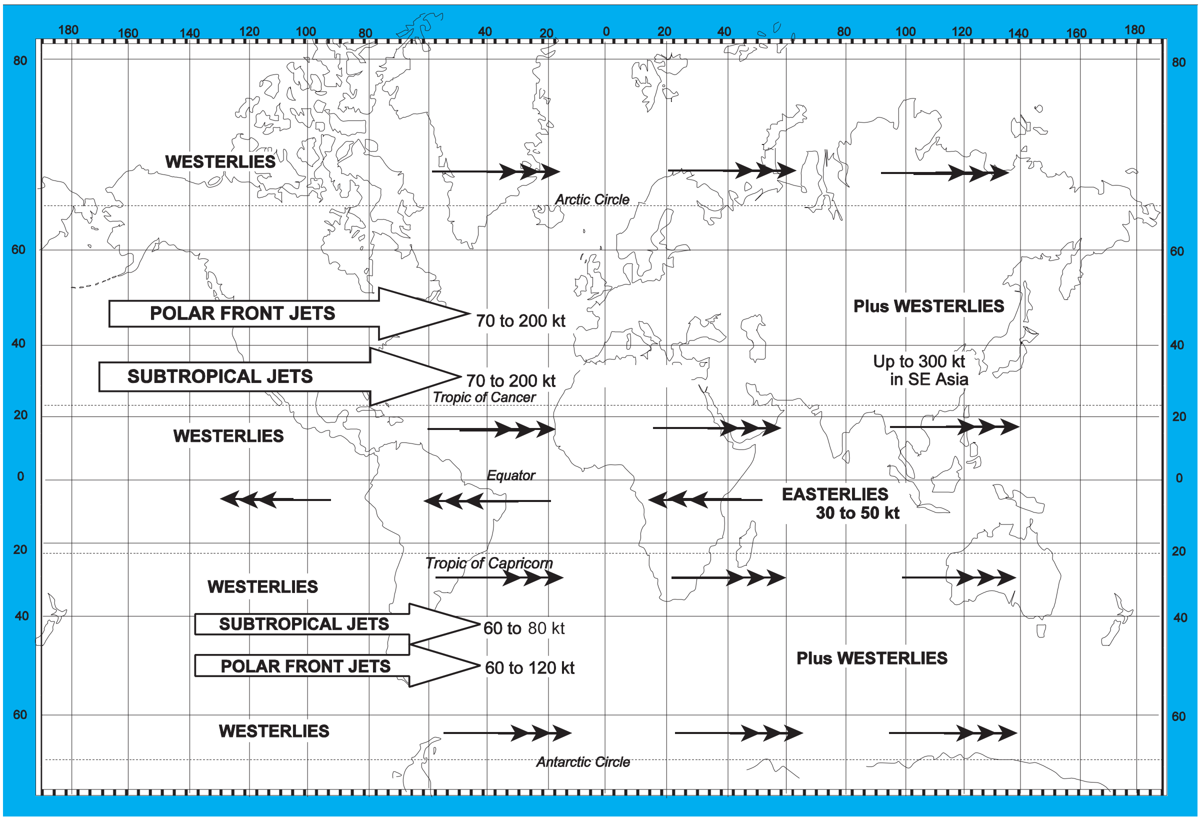


Figure 20.38 A simplified upper wind diagram for - January

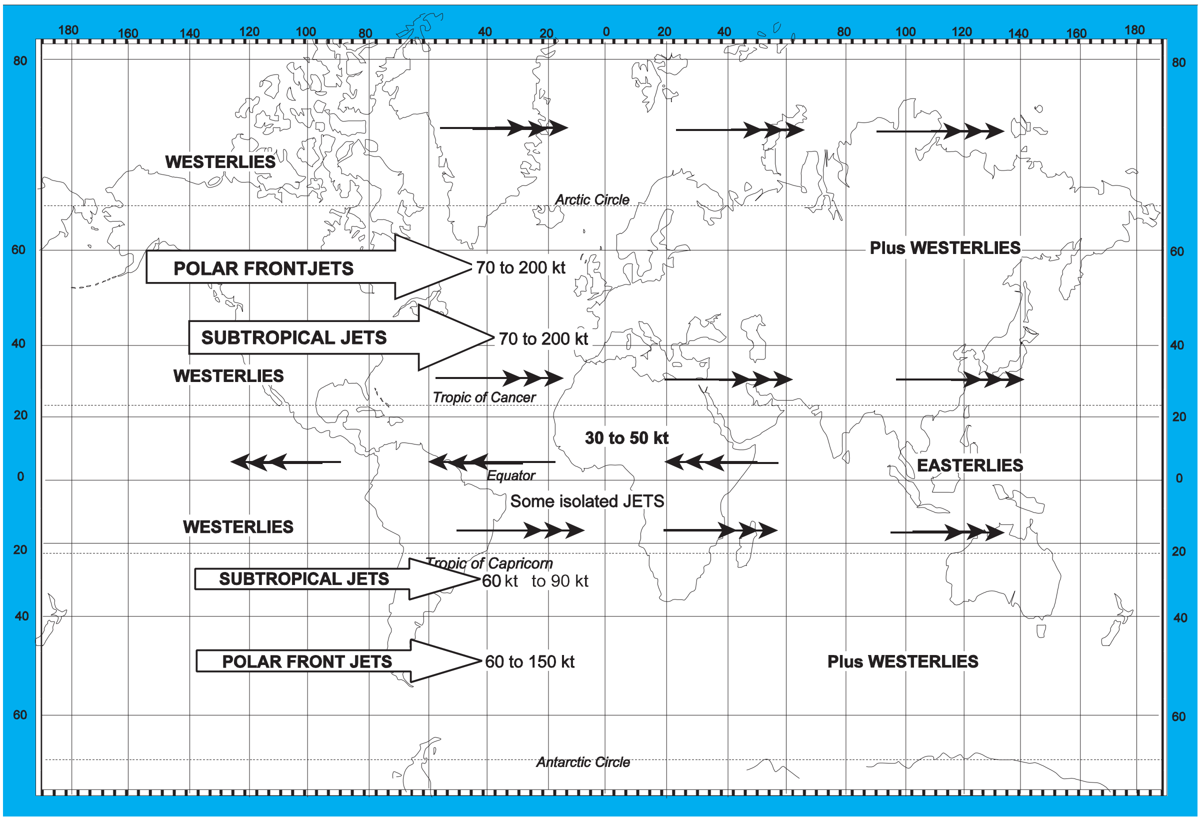


Figure 20.39 A simplified upper wind diagram for July

Questions

1. **The tropical transitional climatic zone is:**

   a. approximately 20° - 30° of latitude and provides very dry desert conditions throughout the year
   b. approximately 10°- 20° of latitude and provides dry trade wind conditions in winter and a wet summer season
   c. approximately 10° - 20° of latitude and provides a wet winter season and a dry hot summer
   d. approximately 10° - 30° of latitude and has a period of long rains in spring and autumn, but is never dry

2. **The temperate transitional climatic zone is:**

   a. approximately 20° - 35° of latitude and covers the high pressure desert regions of the world
   b. approximately 35° - 40° of latitude and is under the influence of polar front depressions throughout the year
   c. approximately 35° - 40° of latitude and provides a warm dry summer with a cool wet winter
   d. approximately 35° - 40° of latitude and provides a wet summer season and a dry cold winter

3. **Northern Hemisphere summers tend to be:**

   a. warmer than the Southern Hemisphere and winters are warmer too
   b. colder than the Southern Hemisphere due to the smaller amount of solar radiation
   c. colder than the Southern Hemisphere because of the large land masses
   d. warmer than the Southern Hemisphere and the winters are colder

4. **The effect of mountain barriers on temperature is exemplified by the following:**

   a. European temperatures are low in winter because there is no barrier to prevent cold Atlantic air crossing the area
   b. the Rocky mountains of North America prevent cold Pacific air reaching inland, so summer temperatures to the east of the mountains are high
   c. the Himalayas prevent warm dry air from Russia reaching India and Pakistan
   d. the Ural mountains of West Russia prevent most of the cold Siberian air reaching Europe in summer

5. **The tropopause is:**

   a. more or less constant for any latitude
   b. is a boundary layer between the troposphere and the stratosphere
   c. normally the upper limit of weather
   d. the upper limit for jet streams and mountain waves

6. **Statistical pressure values tend to be:**

   a. on average parallel to the lines of latitude
   b. on average parallel to the lines of latitude in the Southern Hemisphere and much more variable in the Northern Hemisphere
   c. much lower in winter in the Northern Hemisphere than in the Southern Hemisphere
   d. higher over the oceans in winter

7. **The heat equator is:**

a. another name for the geographic equator
b. coincident with the equatorial trough and ITCZ
c. a line over the land joining places where the summer temperatures are highest
d. a line over the land joining places where the winter temperatures are highest

8. **The average temperature around the equatorial regions:**

a. is always above +40°C
b. is higher over the sea areas
c. varies on average from winter to summer by only some 5°C
d. has a very high range of temperatures throughout the year

9. **Trade winds:**

a. blow towards the subtropical anticyclones
b. are caused by lifting over the heat equator and the subsequent air movements from the subtropical anticyclones
c. only blow in the winter months
d. blow from the equatorial low pressure systems throughout the year

10. **Trade winds in the Southern Hemisphere are:**

a. southeasterly
b. southeast at first becoming southwest
c. in opposition to the monsoons
d. usually from the northeast

11. **The Hadley cell is the name given to:**

a. the CU cells which continue to form a CB
b. an initial bubble of air which is lifted by convection
c. the centre portion of a jet stream
d. a cell formed by lifted air over the heat equator descending to the subtropical highs

12. **The large change in the direction of trade winds is caused by:**

a. local pressure differences
b. an excess of air at height in association with the Hadley cells
c. the change in geostrophic force when crossing the geographic equator
d. the cyclostrophic force in the equatorial regions

13. **Monsoons are seasonal winds which:**

a. develop due to the high pressure over continents in winter and the subsequent low pressure which develops over the same areas in summer
b. are never in combination with trade winds
c. blow only in the southeast Asia region
d. are from the southeasterly direction over the Indian sub continent in summer

14. The outflow from the Siberian High:

a. is northwesterly over Japan, northerly and northeasterly over China and northerly over the whole of India
b. is the source of Polar Maritime air
c. is northwesterly over Japan, northeasterly over southeast Asia and easterly over Europe
d. is evident throughout the year

15. The upper winds tend to be westerly outside the tropics because:

a. the rotation of the earth is west to east
b. the thermal winds are westerly on average
c. surface winds are nearly always westerly
d. jet streams are usually westerly

16. Jet stream main locations are:

a. in the warm air some 400 NM ahead of a warm or cold front and near the subtropical highs
b. in the warm air some 400 NM ahead of a warm front and some 200 NM behind a cold front and near the subtropical highs
c. only in association with the polar front
d. in association with the polar front and with mountain waves

17. Jet streams:

a. only occur in the troposphere
b. have a speed in excess of 80 kt
c. are located above the tropopause
d. are caused by a large difference in mean temperature in the horizontal

18. Near the Equator upper winds tend to be:

a. easterly
b. westerly
c. at speeds greater than 60 kt
d. calm

19. The polar front is:

a. the boundary surface between polar continental and tropical continental air
b. near the poles
c. only apparent over the Atlantic ocean
d. the region where warm sector depressions develop

20. The ITCZ is:

a. the region between the two trade wind systems centred on the heat equator
b. the boundary region between the two monsoons
c. the boundary between polar air and equatorial air
d. a region of calm winds and layer type clouds with much haze

21. **Tropical revolving storms:**

a. are a summer weather feature
b. are easily predictable
c. can be very active well inland
d. can travel at speeds of 100 kt

22. **The areas of greatest rainfall are:**

a. those where there is much polar front depression activity
b. in the equatorial regions
c. in the polar regions
d. in central North America in summer due to the large convective cloud formations

23. **Thunderstorms most frequently occur:**

a. in association with the ITCZ over central Africa
b. over the east Indies area (Java) due to the intense surface heating
c. in regions affected by cold fronts
d. in association with tropical revolving storms

24. **Dust storms and haze are most common:**

a. in association with the subtropical anticyclones over land
b. with the Haboobs in winter
c. in unstable air with low pressure
d. in temperate latitudes

25. **The most notorious advection fogs occur:**

a. over southwest UK
b. over the sea in the region of Newfoundland and the Kamchatka peninsula
c. over Europe with high pressure to the north
d. over central North America in autumn and winter

26. **The cloud to be expected along the front at A3 in Appendix A is:**

a. CU CB
b. ST SC
c. ST NS
d. AS NS

27. **The cloud to be expected at B2 between the fronts in Appendix A is:**

a. AS
b. ST SC
c. NS
d. NIL

28. **The cloud to be expected at C2 along the front in Appendix A is:**

a. CU CB
b. AS NS
c. ST SC
d. AC

29. **The cloud to be expected along the front at A2 in Appendix A is:**

a. CI
b. AS NS
c. ST
d. CU

30. **The average surface level winds at A3, B3 and C3 in Appendix A are respectively:**

a. easterly, westerly, southwesterly
b. westerly, westerly, southwesterly
c. southwesterly, westerly, northwesterly
d. southwesterly, westerly, northerly

31. **The average upper winds at A1, B1 and C1 in Appendix A are respectively:**

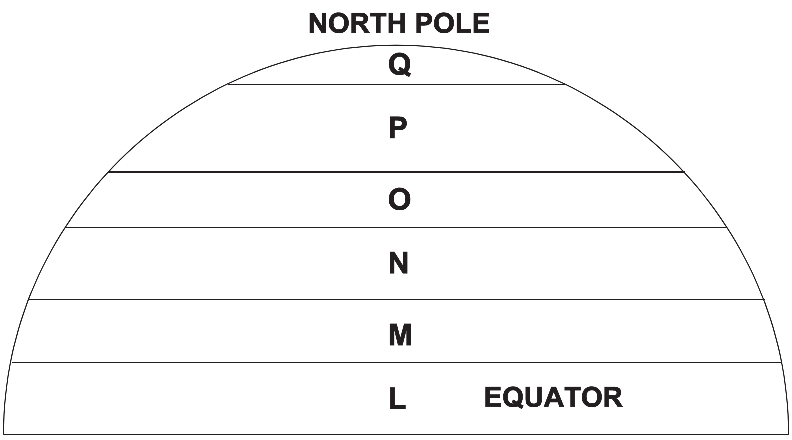
a. easterly, westerly, northwesterly
b. northwesterly, westerly, southwesterly
c. southwesterly, westerly, northwesterly
d. southwesterly, westerly, northerly

32. **The names of the air masses indicated A, B, C and D at Appendix B are respectively:**

a. Polar Maritime, Polar Continental, Tropical Maritime, Tropical Continental
b. Returning Polar Maritime, Arctic, Tropical Continental, Tropical Maritime
c. Polar Maritime, Arctic, Tropical Continental, Tropical Maritime
d. Polar Maritime, Arctic, Polar Continental, Tropical Maritime

33. **The names of the air masses indicated E, F, G and H at Appendix B are respectively:**

a. Tropical Maritime, Polar Continental, Tropical Continental, Arctic
b. Polar Continental, Tropical Maritime, Tropical Continental, Arctic
c. Polar Continental, Tropical Continental, Tropical Maritime, Arctic
d. Tropical Maritime, Polar Maritime, Tropical Continental, Polar Maritime



REFER TO THE ABOVE DIAGRAM FOR QUESTIONS 34 - 39.

34. In area L the main wet seasons will be:

a. at the equinoxes
b. in January/February
c. in July/August
d. in November/December

35. In area M in winter there will be:

a. equatorial rains
b. extensive low cloud
c. the Doldrums
d. dry trade wind conditions

36. In area N there will be:

a. extensive winter rains
b. anticyclonic desert areas
c. dry summers and wet winters
d. polar front weather

37. In area O the climate will include:

a. the trade winds
b. dry warm summers and a wet winter season
c. steppe type with grassy plains
d. a wet summer and dry cold winters

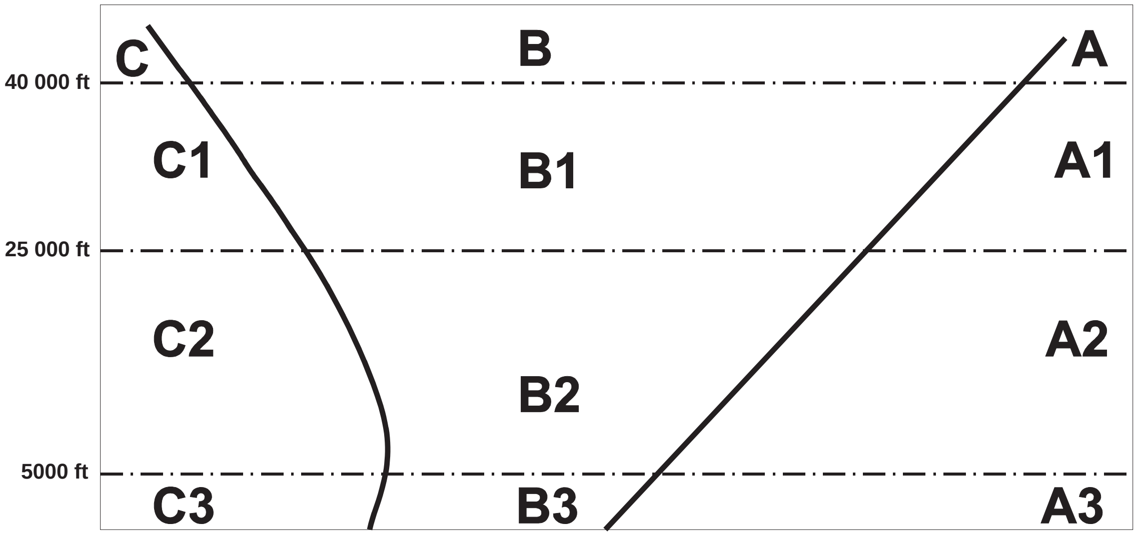
38. In area P the main weather factor will be:

a. polar front depressions
b. depressions in winter, anticyclones in summer
c. extensive low cloud throughout the year
d. monsoon weather

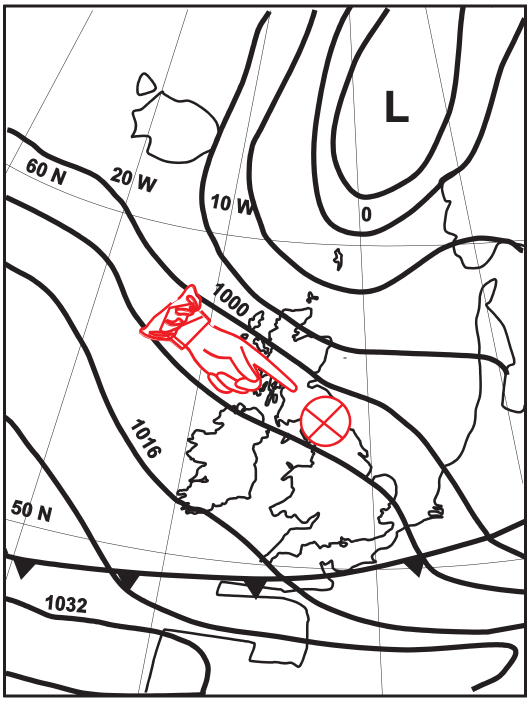
39. In area Q the climate will include:

a. polar front depressions
b. cold anticyclonic weather
c. temperatures above zero for 3 months of the year
d. good visibility throughout the year

Appendix A

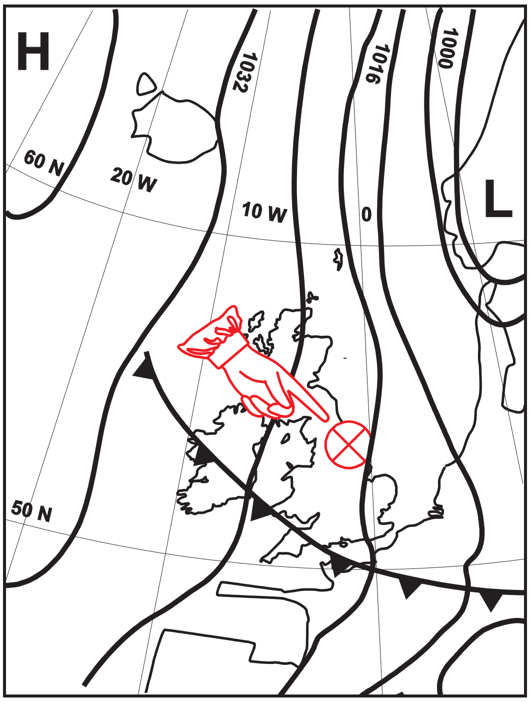


Appendix B



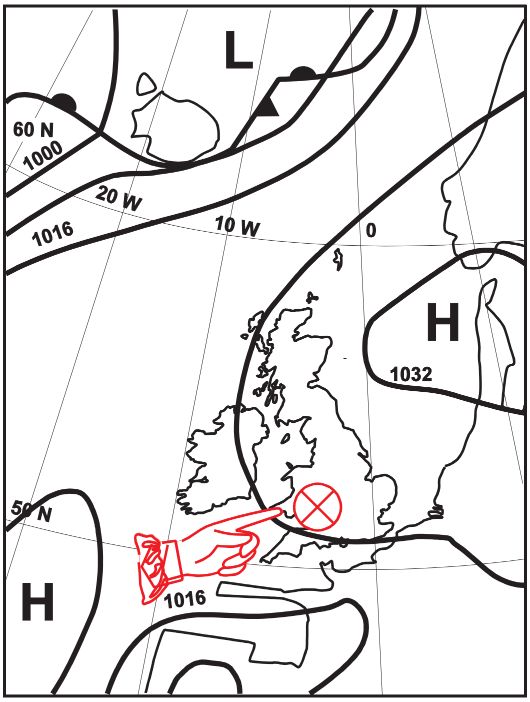
February

A



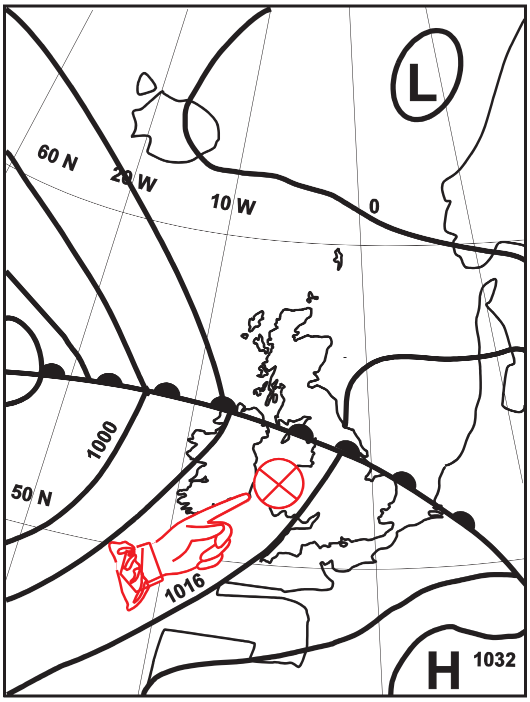
May

B



August

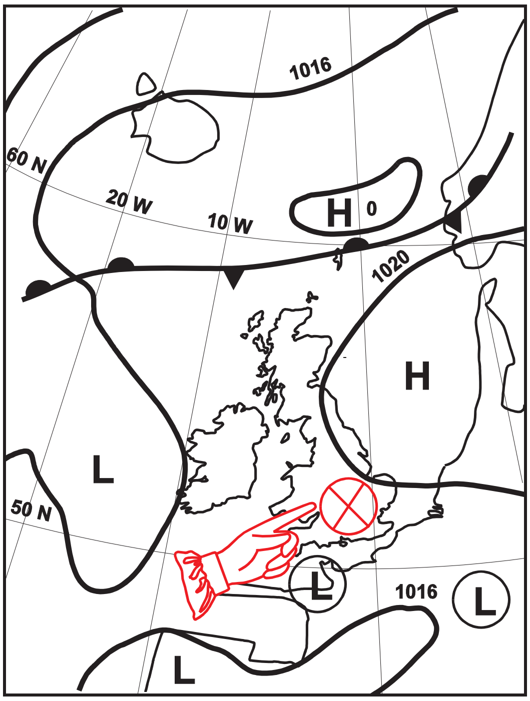
C



November

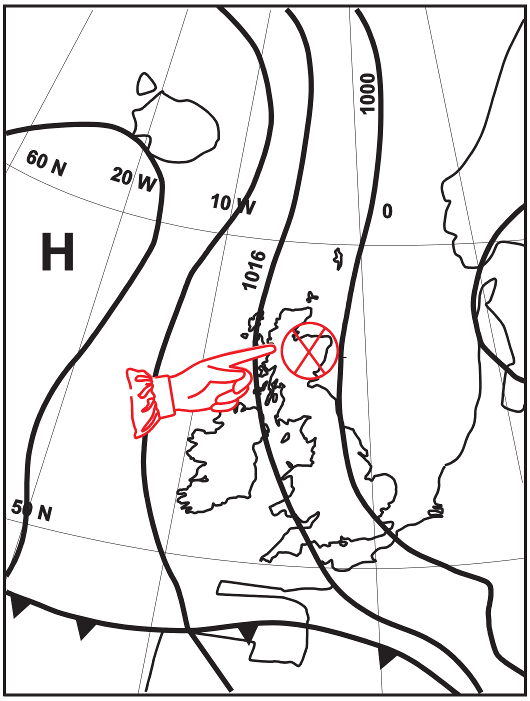
D

Appendix B Continued



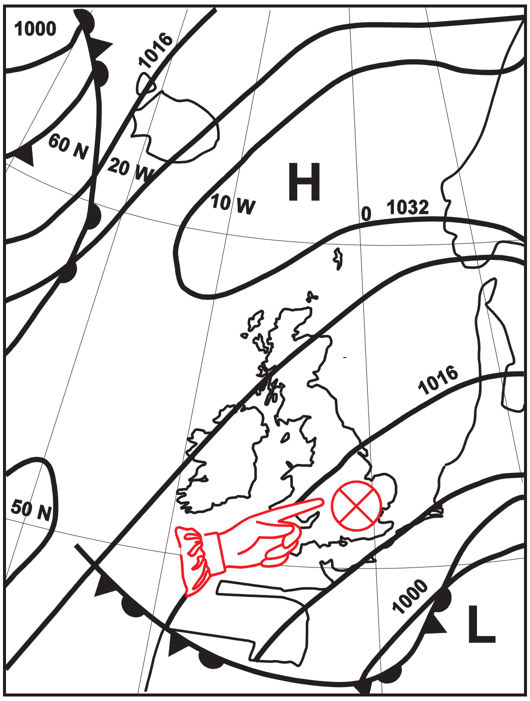
July

G



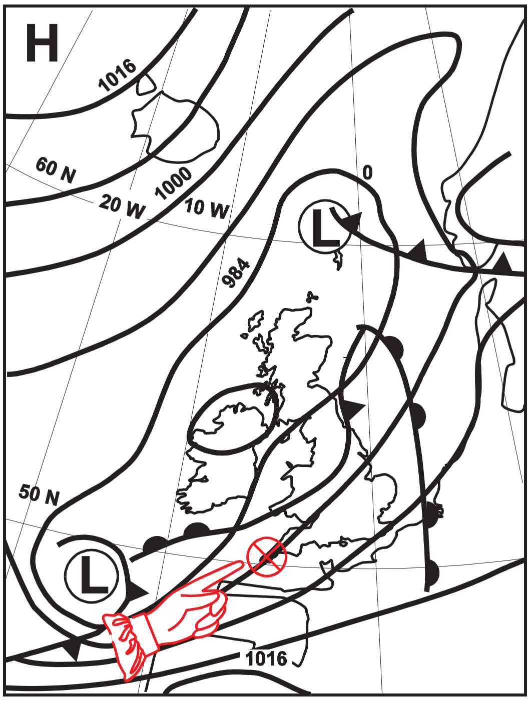
November

H



February

E



March

F

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	c	d	b	c	b	b	c	b	a	d	c

13	14	15	16	17	18	19	20	21	22	23	24
a	c	b	b	d	a	d	a	a	b	b	a

25	26	27	28	29	30	31	32	33	34	35	36
b	c	d	a	b	c	b	c	b	a	d	b

37	38	39
b	a	b

Chapter

21

Local Winds and Weather

Introduction

The last chapter dealt with the general theory of climatology: this chapter deals with a number of winds around the world and the weather patterns associated with them. The winds are in five sections, **Föhn** type, **Valley**, some **Mediterranean**, **Storm squalls** and a **West African** wind.

Föhn Winds

Föhn Winds were dealt with in Chapter 10 and the diagram explaining the resultant increase in temperature on the lee side of the mountain range is shown here.

Although Föhn winds blow in the Alps, the name is used generically to describe winds which blow with similar effect in other parts of the world.

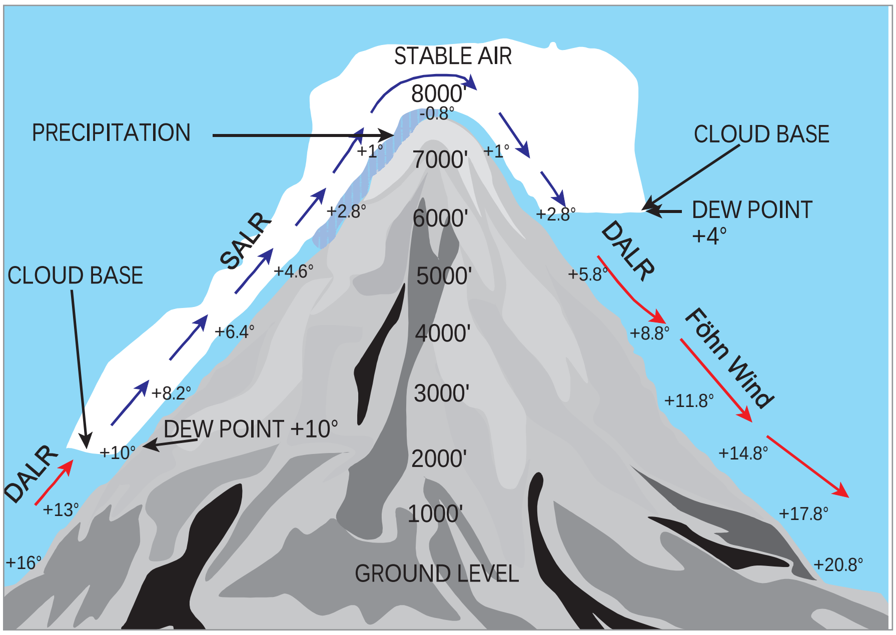


Figure 21.1 The Föhn effect

One such wind is the **Chinook** which blows on the eastern side of the Rocky mountains of North America. *Figure 21.2* shows the location of the Chinook.

The Chinook usually blows during the winter months and produces a rapid and considerable rise in temperature. A rise of 20° in 15 minutes is not unusual. The wind may blow for several days and snow on the eastern side of the Rockies may clear completely. The area covered runs from **southern Colorado** up to the **Mackenzie Basin.**

Figure 21.2 Chinook wind

Valley Winds

Mistral

Valley winds are caused by air funnelling through a mountain gap or down a valley. The Mistral, which is a good example of such a wind, blows down the **Rhône Valley** between the Massif Central and the Alps to the French Mediterranean coast and beyond. It is usually a winter wind with **high pressure** over **Central France** and **low pressure** over the **Gulf of Genoa.** Temperatures are **low** with winter Mistral temperatures well below zero, flying conditions are **turbulent** and the winds are **strong,** 40 to 75 kt.

The Bora

This wind is part valley and part katabatic. As *Figure 21.4* shows, it blows down the north **Adriatic** with high pressure over **Central Europe** and the **Balkans** and a **low** over the **Adriatic.** The wind speed is around **70 kt** with great gusts **exceeding 100 kt** in places. The Bora is strongest and most frequent in winter. *Note: EASA examine this as a katabatic wind*.

Mediterranean Winds

The Sirocco

All three of the major Mediterranean winds we are dealing with are similar in that they blow ahead of frontal depressions tracking along the North African coastline. The Sirocco, which blows over Algeria is a **hot** and **dusty** southerly wind blowing out of the desert. This wind is usually a **springtime** wind and may last a day or so. **Visibility** may be reduced to **below fog limits** (1000 m). The Sirocco may travel as far as the **French coast** and in the process it may pick up moisture and produce low **stratus, drizzle** and **fog.**

The Ghibli

This is a similar wind which blows over Libya.

The Khamsin

Blows ahead of depressions tracking along the Mediterranean coast of **Egypt**. Conditions are similar to the Sirocco and the Ghibli. The name is also given to south or southwest gales blowing in the **Red Sea**.

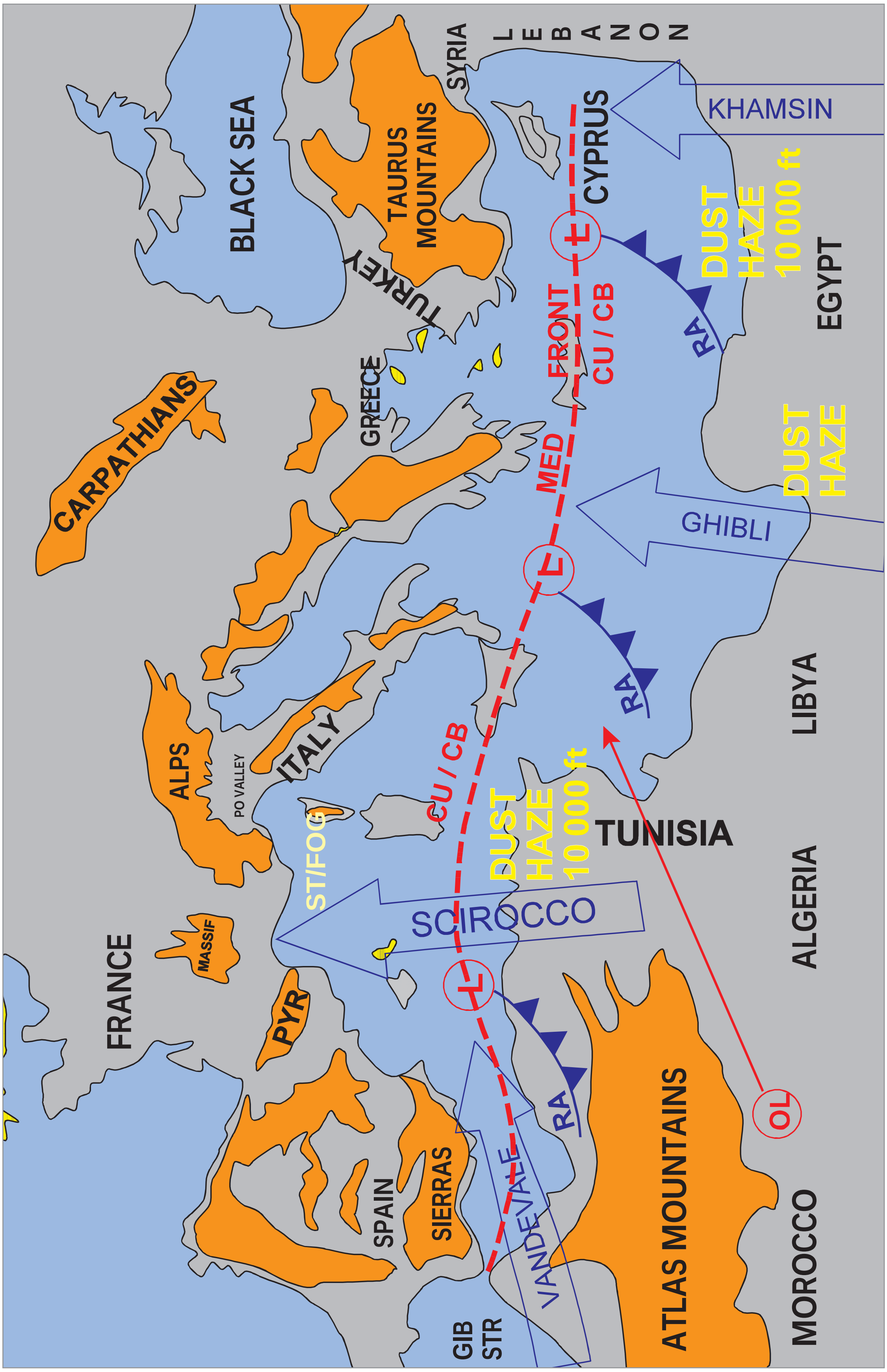


Figure 21.3 Winter pressure systems and surface winds in southern parts

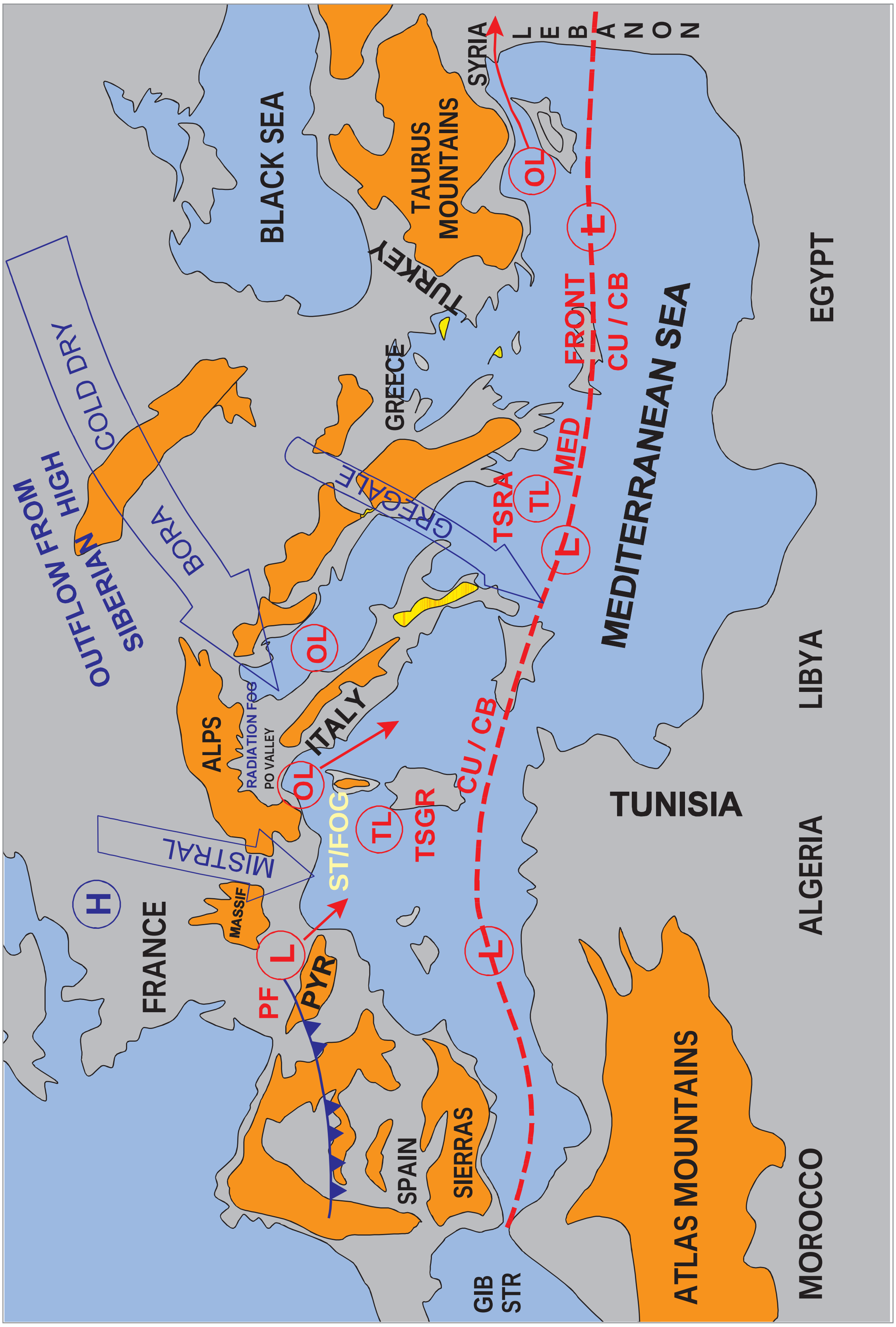


Figure 21.4 Winter pressure systems and surface winds in northern parts

Squalls

The Pampero

This is a **severe windstorm** blowing around the estuary of the **River Plate** (Uruguay and Argentina). It is a **cold dusty south** to **southwest** wind blowing behind a cold frontal depression. Stormy, gusty conditions prevail, with a considerable **temperature fall** after the storm passes. The squall is **short lived**, but the strong, steady wind may last for **some hours**. Pamperos usually blow in **spring** and **summer**

Figure 21.5 The Pampero

Sumatras

These occur in the **Straits of Malacca** (see *Figure 21.6*) blowing between southwest and northwest, most frequently between **April** and **November** during the time of the southwest monsoon. During the day thunderstorms build up over the high ground of Sumatra, assisted by the **sea breeze**, but at night the subsiding cumulonimbus clouds drift eastward under the influence of the **land breeze** and the **katabatic** effect. The storms are rejuvenated over the warm sea and **violent storms** result late at night and in the early morning. There is a sudden **temperature drop** as the squall passes through. Sumatras take on a pronounced **arched shape** as the Cb anvils spread out at the tops of the clouds.

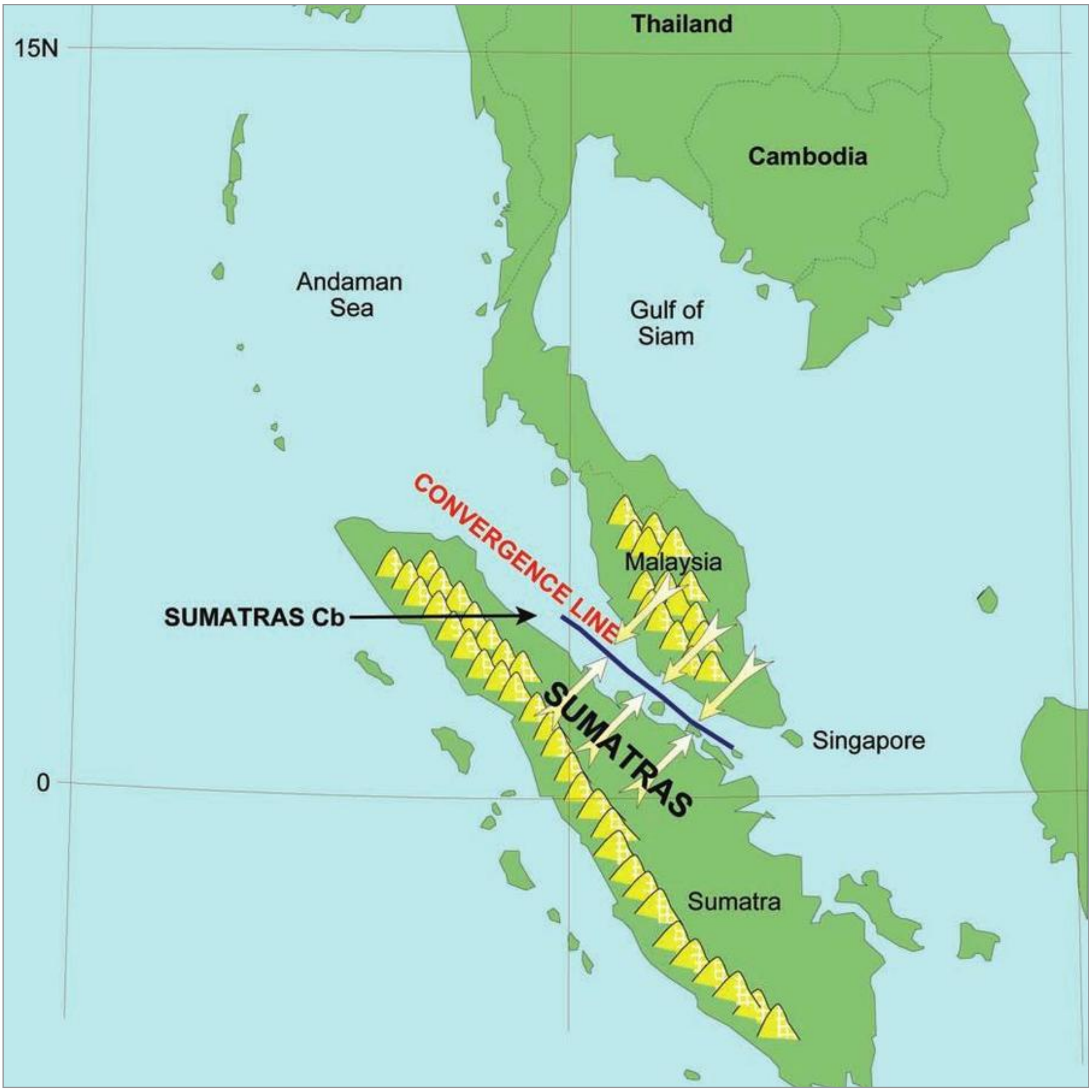


Figure 21.6 Sumatras

The Harmattan

The last of the major local winds is the **Harmattan**. This blows mostly during the winter from the **high pressure** desert areas of North Africa as a **northeasterly** wind towards the ITCZ. (Northeast trade winds). The Harmattan is a cool dusty wind that may reduce visibility to below 1000 m, especially in areas bordering desert regions, such as Kano, Nigeria. The dust layer may extend to 7000 or 10 000 ft or more, and visibility improves towards the coast. The Harmattan blows from **November** through to **April**, though by this time the winds will be light, especially in the south.

Chapter

22

Area Climatology

Northwest Africa

Introduction

The region includes the area between the Mediterranean in the north, and the Nigeria - Ghana - Senegal coast in the south, that is between 35°N and 5°N and west of 10°E. It also includes parts of Ivory Coast, Guinea, Liberia, Mauritania, Morocco, Mali and Algeria.

Geographical Considerations

The area is bounded to the east by the Sahara desert, centred near 23°N, which is a source of Tropical Continental air and brings much dust to the region. The cold Canaries sea current running south close to the Atlantic Coast helps advection fog to form.

Pressure Systems

The **ITCZ** (equatorial trough) traverses the **southern half** of the region bringing **rain and a change of surface W/V as it passes**. It is south of the coastal regions of Ghana and Nigeria in January, then pushes north to 18° - 20°N in July, thereafter moving south again, to clear the south coast by the next January. North of the ITCZ lies the **Subtropical High**. In winter it extends from the west across the Sahara desert and the surface outflow brings **dry dusty conditions** to all parts especially the south and west. Towards summer, the subtropical high and associated dry dusty conditions will be increasingly restricted northwards as the ITCZ advances from the south.

Weather and Surface Winds

It is convenient to divide the region into two areas split at the mid latitude of 20°N. The southern region includes **Dakar** on the west coast at 15°N.

South of 20°N - Winter Season

The ITCZ is south of the area. High pressure is dominant over the Sahara and there is no cloud or precipitation. The NE tradewind outflow from the Sahara to the ITCZ is extremely dusty and is known as the Harmattan. The duration of the Harmattan period decreases southwards because the ITCZ recedes southwards in Autumn then advances north in the Spring. Visibility in the dust is frequently down to 4000 metres and occasionally down to the fog limits. Outflow over the cold Canaries sea current favours advection sea fog, which can then drift inland when there is a sea breeze.

North of 20°N - Winter Season

High pressure over the **Sahara** and to the **west** can be modified by encroaching polar front lows and their associated cold fronts, which in turn bring onshore westerlies or Northwesterlies to the coasts of Mauritania and Morocco. Passing over the cold Canaries current this wind can bring cold fronts with low cloud and precipitation - **the wet season.** Cold fronts from the Mediterranean can also affect northern Algeria but are prevented from moving further south by the Atlas mountains. Elsewhere the prevailing NE **Harmattan** wind will traverse the area bringing **dry dusty conditions.**

At times outflow to the north will produce the dusty but dry **Scirocco** wind to the Mediterranean

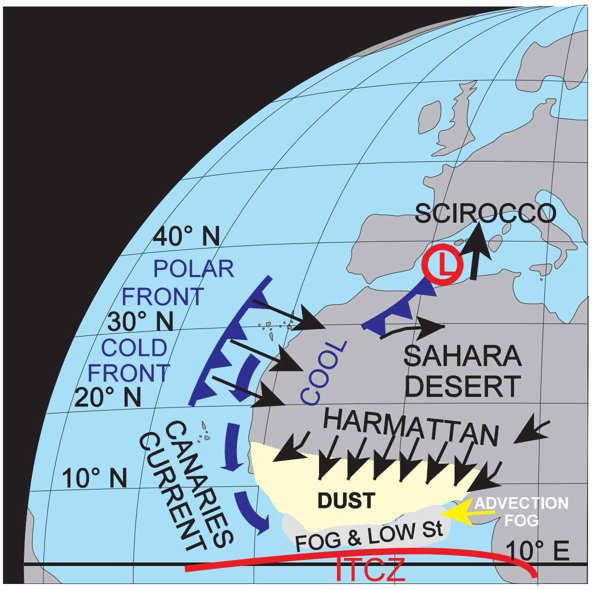


Figure 22.1 Northwest Africa in January, weather details at the surface

South of 20°N - Summer Season

The ITCZ will advance northwards across the region during the Spring and **with its passage** the **NE Harmattan** will **veer through east** to become the **SW Monsoon wind.** The SW direction results from the SE trades which have crossed the equator and have therefore veered. The **SW Monsoon** brings the wet season with much CU, CB, heavy rain showers and thunderstorms. In the Autumn the ITCZ will recede southwards and **with its passage** the SW monsoon will **back through east** to become the dry dusty NE Harmattan once more. Note the **surface W/V** is **easterly** at each **ITCZ passage**.

North of 20°N - Summer Season

The winter Sahara High has moved north to the Mediterranean. The outflow gives **NE dusty winds** flowing to the ITCZ to the south, and to beyond the west coast where **advection sea fog** can form over the cold Canaries current. This fog can then be drawn **inland** by sea breezes.

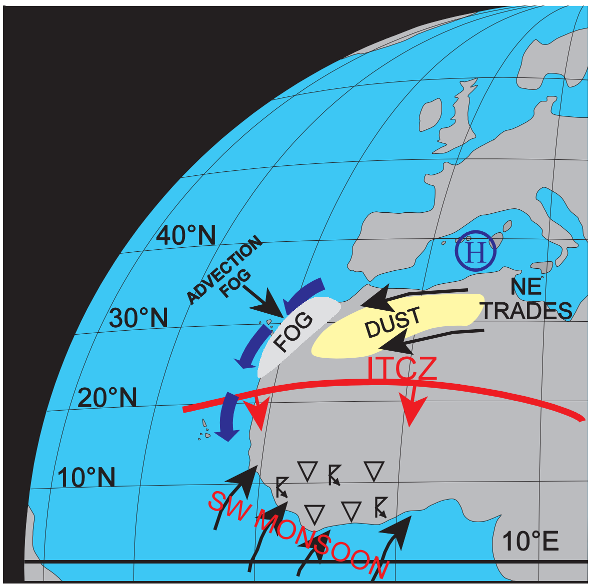


Figure 22.2 Northwest Africa in July, weather details at the surface

Area Climatology 22

West African Tornadoes

Tornadoes occur in the **SE** of the area over the **Southern Nigerian valleys**, where the air is moist and the surface heating strong. They are **thunderstorms** which form in a **north/south line** above the valleys **as the ITCZ passes** northbound in March/April, and southbound in September/October. The **wind** is **temporarily from the east** at these times and the storms are therefore carried westwards to affect other coastal countries before passing out to the Atlantic.

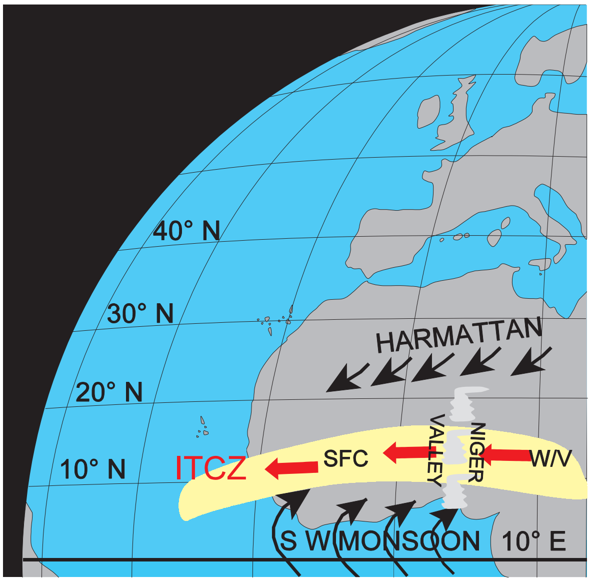


Figure 22.3 Northwest Africa in spring and autumn, the formation and movement of West African tornadoes

Upper Winds

Winter

The ITCZ with light easterlies aloft lies well south. Overland **light westerlies** will occur in the **south** increasing to the **westerly subtropical jet** of **100 knots or more** over **Morocco.**

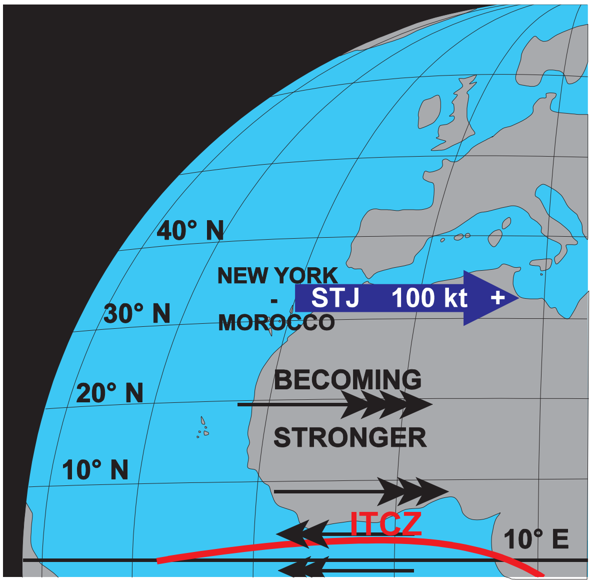


Figure 22.4 Northwest Africa, upper winds in January

Summer

The ITCZ with **light easterlies** aloft affects the **south** of the region. In the **north** the wind will become light westerly only. Note that the subtropical jet has moved out of the area to Bordeaux.

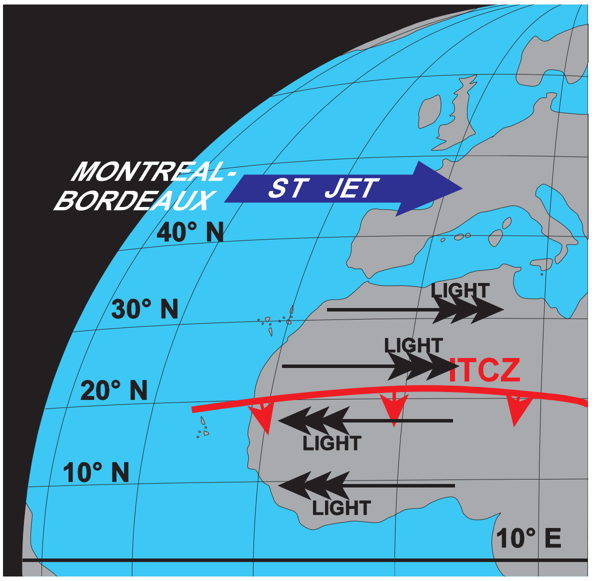


Figure 22.5 Northwest Africa, upper winds in July

Tropopause and Freezing Level

The tropopause averages 54 000' and the Freezing level 15 000' throughout the year.

North Atlantic Region

Geographical Area

The area considered reaches from **10°N** to **70°N** latitude and from the **Caribbean** and **New York** in the west to **London** and the **Norwegian Sea** in the Northeast. The area lies across the **Disturbed Temperate** and **Subtropical High** climatic belts. *Figure 22.6* and *Figure 22.7* refer.

Winter

Pressure Systems	North American High	1020 hPa
	Icelandic "Statistical" Low	1000 hPa
	Azores High 30°N	1020 hPa
	Polar Air Depressions	65°N - 55°N

Polar front activity is dominant across the disturbed temperate region. In the west, diverging air from the North American High moves SE over the sea to meet warm Tm air overlying the warm gulfstream waters flowing northbound off the N.American East Coast. This convergence causes much instability and the formation of depressions where the two air masses meet. This well-defined but erratic frontal line forms the western end of the **polar front** which in **winter** lies near **SW Florida** and stretches across the Atlantic. These depressions will be driven east/northeastwards by the thermal mid latitude winds and will track along the polar front towards the UK and Norwegian Sea. Some of the lows will become slow moving and/or occluded between S Greenland and Norway, giving rise to the **"Statistical" Low** near **Iceland** as the depressions pass by.

In the eastern Atlantic the northeastward outflow from the subtropical **Azores High** will ensure that the travelling frontal depressions track to the Northeast, a typical **winter** landfall being **SW England**. See *Figure 22.6*.

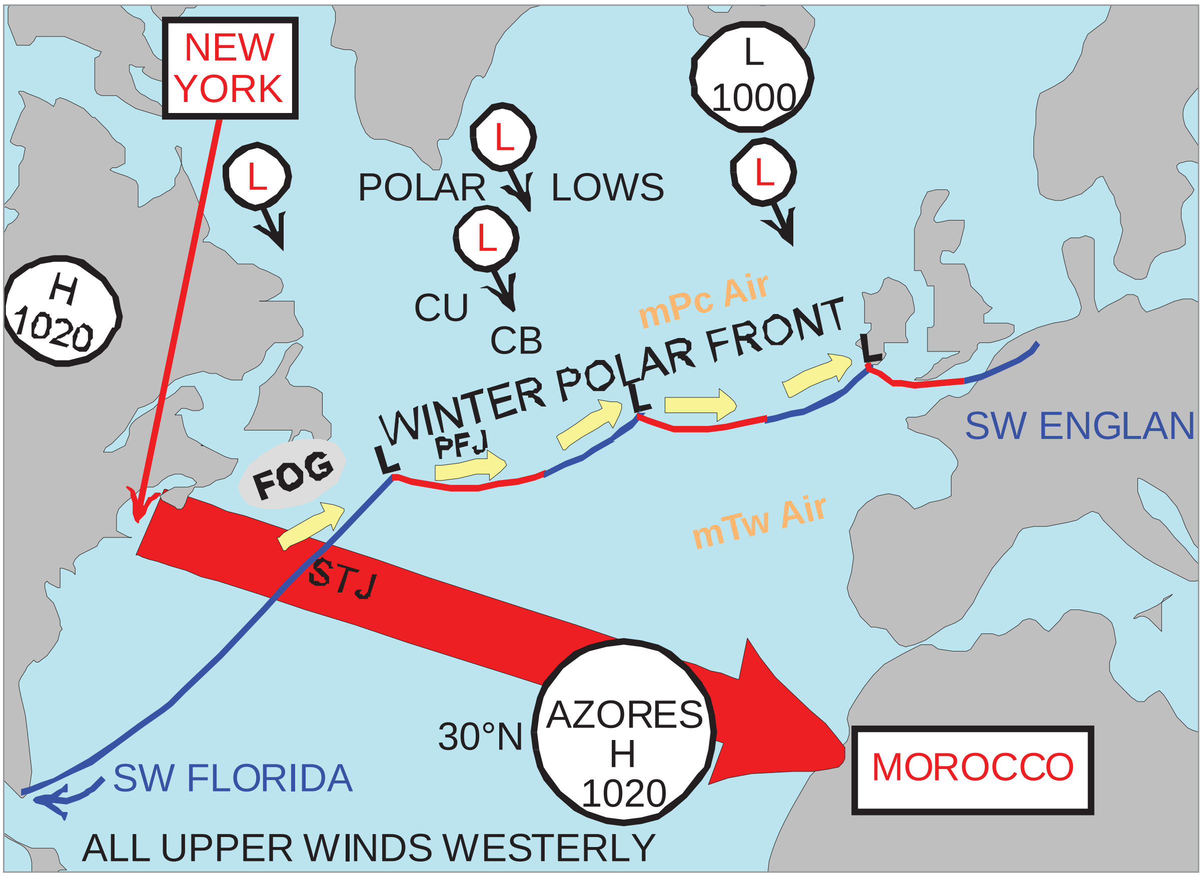


Figure 22.6 North American weather details January

Over the Atlantic, the **polar front** will remain the **boundary** between **mPc air to the north and mTw air to the south**. As the travelling depressions develop, a portion of the **mTw air** will be increasingly **trapped between** areas of **mPc air** either side, forming warm and cold fronts. See also *Figure 22.8*.

North of the polar front, **polar air depressions** are formed by **Arctic air moving south** 65°N - 55°N over relatively warmer seas causing **instability** weather.

Weather

The contrast between London and New York. Although New York is 40°N and London 52°N the winter weather is worse in New York. Why?

Cold continental outflow from the North American High becomes unstable over the adjacent but warmer sea forming low pressure. The resultant instability can then swing inland bringing snow to the New York area.

London in winter can also be affected by cold continental outflow - from the Siberian High. The difference is that such air will have a long land track and therefore will remain dry. Secondly, if the wind in London is from the prevailing west, it will be flowing off the Atlantic and therefore will be relatively warm, possibly giving rain but not snow.

Cloud

In the north of the region, cloud averages 6 oktas, mostly associated with travelling depressions and a cross-section is shown below. Cirrus and stratoform cloud below the tropopause will thicken down to near the surface preceding a warm front. Extensive stratus/stratocumulus will occur as mTw air moves north over colder seas to the polar front and especially while trapped in the warm sector of polar front depressions. Cumulus and cumulonimbus will occur on cold fronts with cumulus forming in the following unstable northwesterly air. In the Caribbean the moist NE trade winds will produce orographic cloud and rainfall on windward slopes.

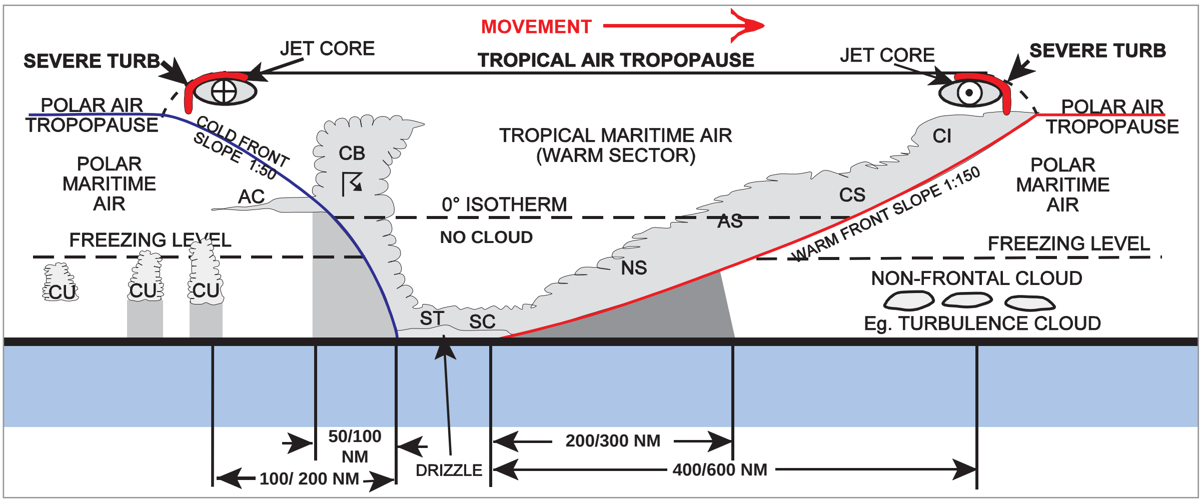


Figure 22.7 Typical Cross-section through a polar front depression

Flying west through a polar front depression the pilot should find:

CI	**400 - 600 NM ahead** of the warm front surface position
CS	**300 - 500 NM ahead** of the warm front surface position
AS	**200 - 400 NM ahead** of the warm front surface position
ST/NS	**200 - 300 NM ahead** of the warm front surface position.
ST/SC	**Above warm sector** at low level.
CU/CB	**At cold front** surface position and 100 - 200 NM beyond.
	Behind cold front region, the same but smaller amounts.

Icing

Icing occurs widely and through great depth in convective and frontal cloud and is frequently moderate to severe. Rain ice/freezing rain, in cold air below warm frontal air, can cause severe clear ice affecting airfields near Washington and New York.

Visibility

Radiation fog can occur inland especially in **autumn** and **winter** when **pressure is high.**

Advection fog can occur when moist mTw air overruns previously cold-soaked inland areas especially in **late winter/early spring.**

Surface Winds

North of the subtropical Bermuda-Azores High, winds are generally westerly but locally easterly on the north side of depressions. There are frequent gales. In the south, NE trade winds prevail all year.

Upper Winds

These are generally westerly because their direction is governed by the thermal wind which blows with **low temperature on the left.** The average winter wind component from **London** to **New York** is **minus 50 knots** - locally winds can be stronger and if greater than 60 knots are known as jetstreams. Over the Atlantic there are two distinct jet stream patterns – the **polar front Jet** and the **subtropical jet.** Each may reach **200 knots.**

Polar Front Jet

This will normally blow from between NW and SW and occasionally outside this range, depending on the **surface orientation of the polar front.** With low temperature on the left, the **warm front jet** will normally be **from the NW** and **ahead of a warm front** and due to the slope of the front, some **400 NM ahead** of its surface position. Similarly the cold front jet will normally blow from the **south-west** and some 200 NM behind the surface position of the front. *Figure 22.7* and *Figure 22.8* refer. The level is around 300 hPa (30 000') and its average location is **SW Florida to SW England** is shown at *Figure 22.6.*

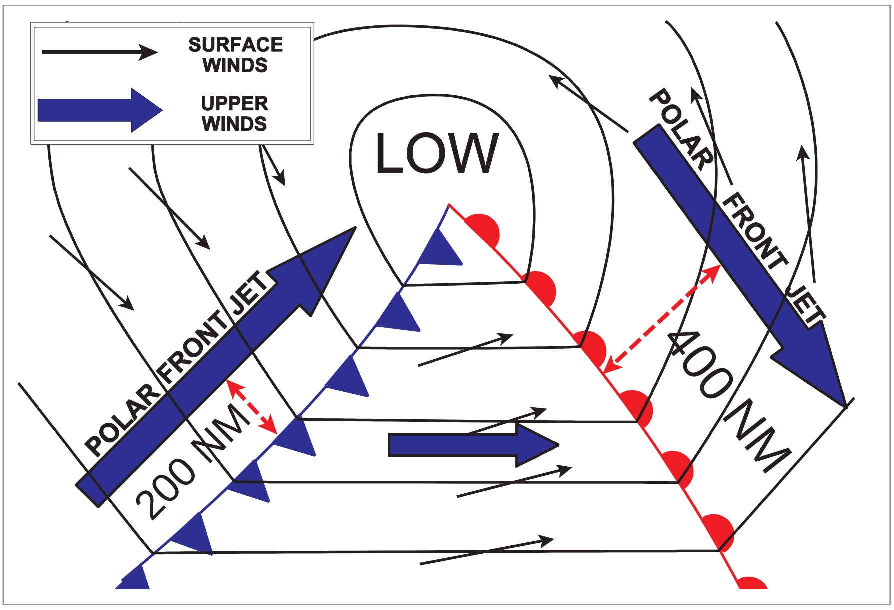


Figure 22.8 The upper winds over a north Atlantic polar front depression.

A pilot flying at **high level** from **East to West across a polar frontal depression** would experience **wind and drift** as follows and as shown in *Figure 22.9*.

- Initially winds will be northwesterly giving strong **port drift.**
- Some 500 NM ahead of the warm front, jet axis speeds of 100-200 knots give **increased port drift**. This will last for 200 NM.
- Winds remain strong NW until crossing **the surface position of warm front** when winds will **back** sharply to west or south-west giving **near-zero drift.**
- Above **surface position of cold front** winds will **back again** sharply to Southwest giving **starboard drift.**
- After 100 NM enter the jet axis, speeds 100-200 knots, giving **increased starboard drift**. This will last for 200 NM.
- Passing out of the jet stream SW winds, **starboard drift decreases.**

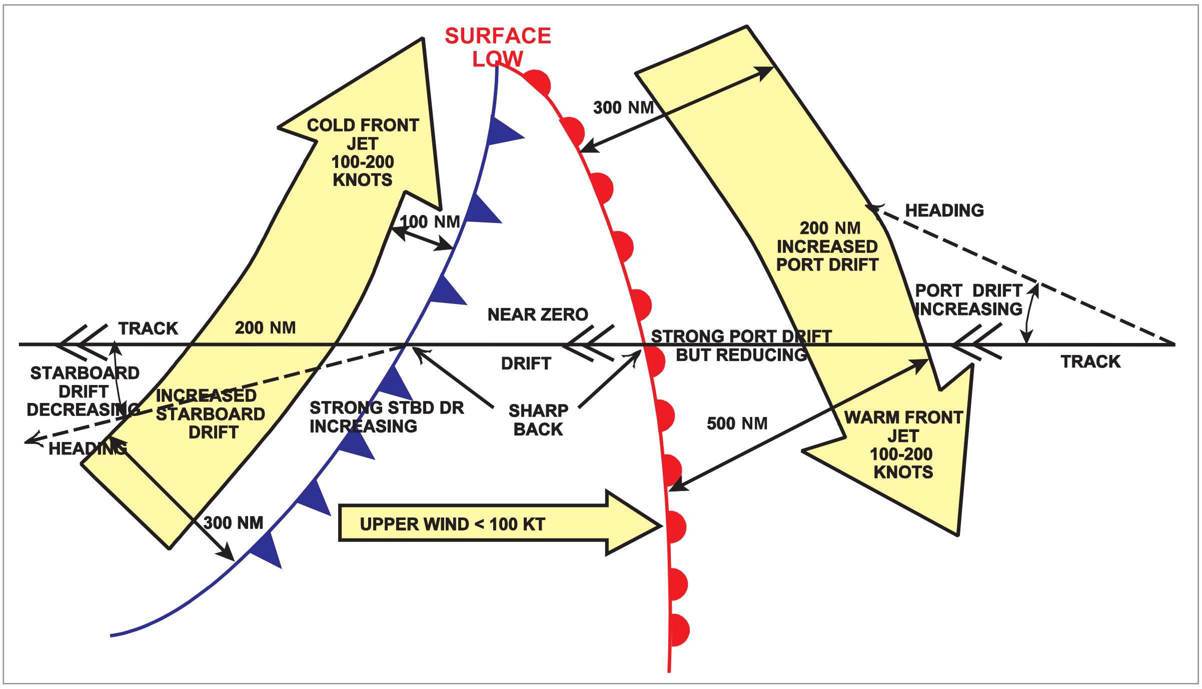


Figure 22.9 Upper wind changes crossing polar front depression east to west

Sub Tropical Jet

This will be located close to the surface position of the Subtropical High (in the North Atlantic, the Azores High) and is caused by the temperature difference between the adjacent columns of descending air from the warmer Hadley cell to the South and the cooler Ferrel cell to the North. The wind will be westerly, blow at 200 hPa (39 000') and in Winter be located between 25°N-40°N. Over the **N.Atlantic in Winter** it blows from **New York to Morocco** as shown at *Figure 22.6*.

Summer

Pressure Systems

North American Low replaces Winter High. Icelandic "Statistical" Low 1010 hPa. Less deep and split. Azores High 1025 hPa intensified. Further North at 35°N. Hurricanes in Caribbean and Florida area. The **polar front** is still present but **less active**. The North American Winter High has disappeared and with it the east coast temperature contrast between land and sea. This part of the polar front therefore disappears in Summer and the western end starts at Labrador, Newfoundland, E. Canada where the advanced warm Gulf Stream sea current now meets the receded cold Labrador Sea current.

In the East, the Azores High is intensified and further North, thus pushing the Polar Front northwards to Scotland.

In **Summer** the **Polar Front** average position thus lies from **Labrador/Newfoundland** to **North of Scotland** to **Norway**. See *Figure 22.10*.

Temperature differences across the front are less, so frontal activity is less intense and less frequent. The weakened Icelandic "statistical" low is now split with average 1010 hPa centred West of Greenland, over Iceland and in the Baltic.

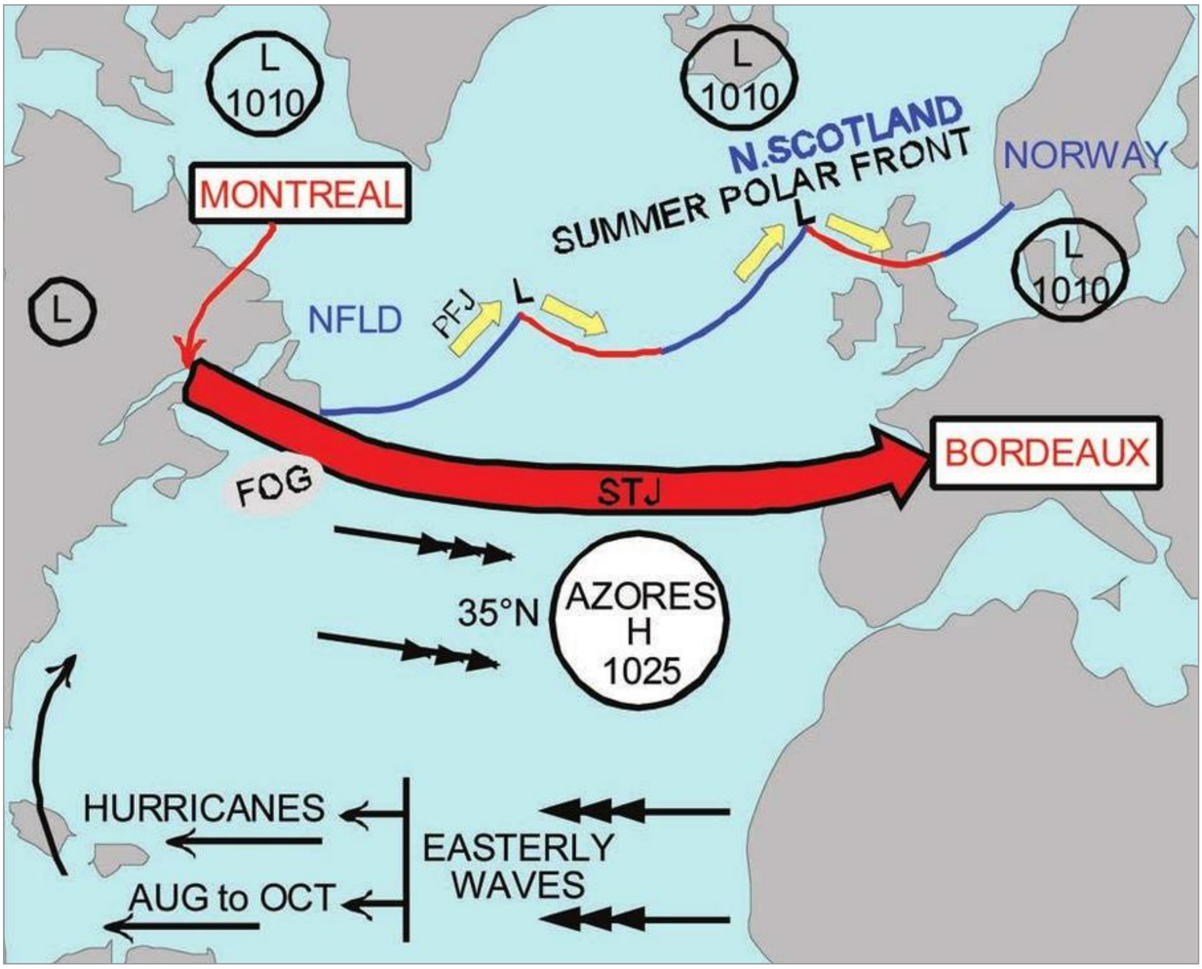


Figure 22.10 North Atlantic Weather details in July

Weather and Cloud

The New York Winter snows are gone. London temperatures remain moderated by air flow from the Atlantic. Polar air is less cold and the reduced temperature contrasts mean less convection cloud over the sea. From the **Azores High** warm moist **mTw outflow northwards** over cooler seas causes **advection fog/stratus/stratocumulus** and this can widely affect SW English coasts in late Spring/early Summer.

In the **Caribbean** the NE trade winds will continue to cause **orographic cloud and rain** on windward slopes. Additionally in Summer, rainfall will be increased by **convection.**

Visibility

Inland radiation fog is less likely in spring and summer and if formed, early morning insolation will cause quick clearance**. Advection Fog** can form over the **cooler seas** and near **SW facing coasts of UK and France** in **late spring/early summer** by **mTw air** from the Azores moving northeast. Near **Newfoundland** widespread advection fog can form over the Grand Banks (approx 45°N 50°W) in **May/June** by advancing warm moist air from the Mexican Gulf overrunning the very cold Labrador sea current.

Winds

In mid latitude, surface winds are still generally westerly but less strong than in winter, as are upper winds because the temperature differences are less. In the Caribbean, NE trade winds prevail at the surface.

Jet Streams

The polar front jet streams will still be around the 300 hPa level and be positioned in relation to the polar warm and cold fronts as in winter but will be less frequent, less strong, and displaced further north with the summer alignment of the polar front. The Subtropical Jet at 200 hPa will also be further north and in the latitude band 40°N-45°N.

Specifically across the Atlantic in summer, it will blow from Montreal to Bordeaux, as shown at *Figure 22.5*.

Easterly Waves

Easterly waves are similar to shallow troughs extending north from the equatorial low pressure belt. They move slowly east to west under the influence of the anticyclonic wind around the subtropical high pressure. In the North Atlantic autumn, West African tornadoes, which form over Nigeria, drift westwards with these waves and can become seedlings of Caribbean hurricanes.

Hurricanes

Hurricane is the name given to tropical revolving storms in the Caribbean/Gulf of Mexico area. Frequency of developed hurricanes is, on average, 3 per year. They occur from **August to October**, tracking **westwards** across the Atlantic near 10°N-15°N latitude and at **10 - 15 knots**. Internal **wind speeds** can exceed **100 knots.** They then cross the Bay of Mexico or turn right around the subtropical high to track NW, N, NE up the USA East Coast. They are energized by the latent heat of condensation and are therefore **more active over the sea.** Each season they are **named alphabetically** in order of occurrence using alternate male/female first names.

Tropopause Heights	70°N	30 000′	
	20°N	50 000′	
Freezing Level Height		January	July
	70°N	Surface	5000′
	20°N	12 000′	16 000′

Continental Northwest Europe

Geographical Considerations

The **mountains of Norway** lie to the **north** while to the **south** there are many mountain ranges dominated by the **Alps. Between** the two regions lies the **North European Plain** with no mountain barrier against the Atlantic winds from the west nor to the cold winter winds from the east.

Winter

Polar Front Depressions

These move **from the Atlantic towards Russia** and principally between the mountain barriers to north and south although tracks are variable. Areas to the **south of each low** will experience **frontal weather.**

The **Alps** often block and delay cold fronts, causing **frontal and orographical cloud** to persist on the northern side. An active **secondary depression** may develop on such a front, tending to run **east-north-east** along the front until the cyclonic circulation around it eventually drives the front into the Mediterranean.

Thermal Depressions
Thermal lows can form in **Winter** to the east of the Alps over the low lying **Danube** area which is **moist and comparatively warm**. Associated cyclonic circulation on the east side will bring warm air north from the Mediterranean forming active warm fronts. These can bring extensive **low stratus** to Germany and **snowfall** as far north as SE England.

Polar Air Depressions
These can sometimes affect the extreme NW sea areas of the region in winter. (PL in *Figure 22.11*)

Siberian High Extension
Pc air gives cold dry weather. Steaming fog or low stratus may be produced locally over water near German and Dutch coasts as the cold air reacts with the warmer water.

Temporary Highs
Ridges or transient anticyclones may exist in the N/NW in between travelling polar front lows.

Cloud and Precipitation
Cloud amount exceeds **six octas** on average. Cloud is frontal from the many polar front depressions also from warm fronts moving north from the Mediterranean although cloud amounts decrease from west to east.

There is much precipitation, in the East mainly of snow.

Visibility
Radiation fog can form **inland** with a slack pressure gradient, principally in autumn and winter. With a SW warm moist wind from the Atlantic, **advection fog** can form over previously **cold soaked inland** areas. **Smoke haze** may reduce visibility to the **lee of industrial areas. Frontal fog** can occur on the **warm fronts** of deep active **polar front depressions.**

Winds
Surface winds are generally **westerly** although easterly on the north side of depressions.

E or NE winds can occur as an outflow from the **Siberian High.**

Upper winds become increasingly westerly with ascent, due to the increasing westerly thermal component. **Polar front jets**, located in relation to the moving **warm** and **cold front** surface positions, and centred around **300 hPa/30 000'** are common and often exceed **100 knots**. The subtropical jet is to the south near Morocco and therefore does not affect the region.

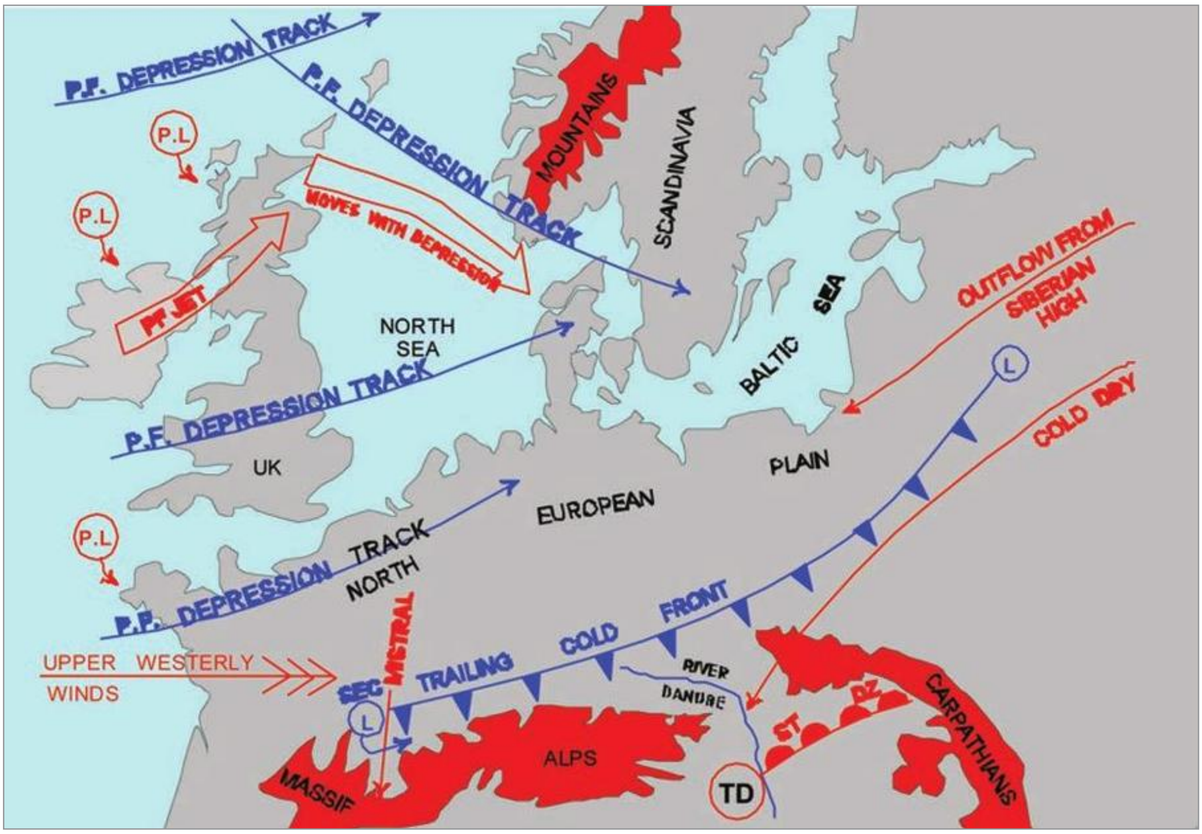


Figure 22.11 January weather

Icing
As over the North Atlantic, **icing** occurs widely and through great depth in frontal cloud and is frequently **moderate** to **severe**. **Freezing Rain (Rain Ice)** can cause severe **clear ice** in cold air under a warm front or warm occlusion. A rare occurrence in UK, it is more common over **Central Europe** where the ground is generally much colder, indeed the freezing level may frequently be on the surface especially in the east.

Summer

Pressure Systems

Polar Front Depressions
These will track eastwards as in winter but **further north** (seasonal movement is with the sun). They will also be **less intense** because of the smaller Polar/Tropical temperature difference that forms them.

Thermal Depressions
Strong insolation can cause active thermal depressions over France and Southern Germany. Thunderstorms are common when moist unstable conditions exist. **Azores High.** This is well established west of Africa at 35°N. An associated ridge across Europe often gives a limited period of fine dry weather.

Temporary Highs
Temporary ridges or transient anticyclones to the NW are more dominant in summer, in between weaker polar front lows.

Scandinavian Highs
These can persist for a few days drawing air across the North Sea from western Russia.

Cloud and Precipitation
Frontal cloud amounts and rain will be much less than in winter because the associated polar front depressions are fewer, less intense, and further north, and by summer the Mediterranean warm fronts are gone. Cloud is mainly **convective** in **thunderstorms** produced by **thermal lows**. **Rainfall** is therefore mainly in the form of **heavy showers** but the effect may be increased by orographic lifting in the southern mountains.

Visibility
Radiation fog is much **less likely.** It can occur in early spring but morning insolation will normally ensure quick clearance. In late spring/early summer an easterly wind round a Scandinavian High blowing over the North Sea can often result in extensive **advection sea fog** along the **UK East Coast.** In Scotland this is known as **haar.** It can travel inland some distance.

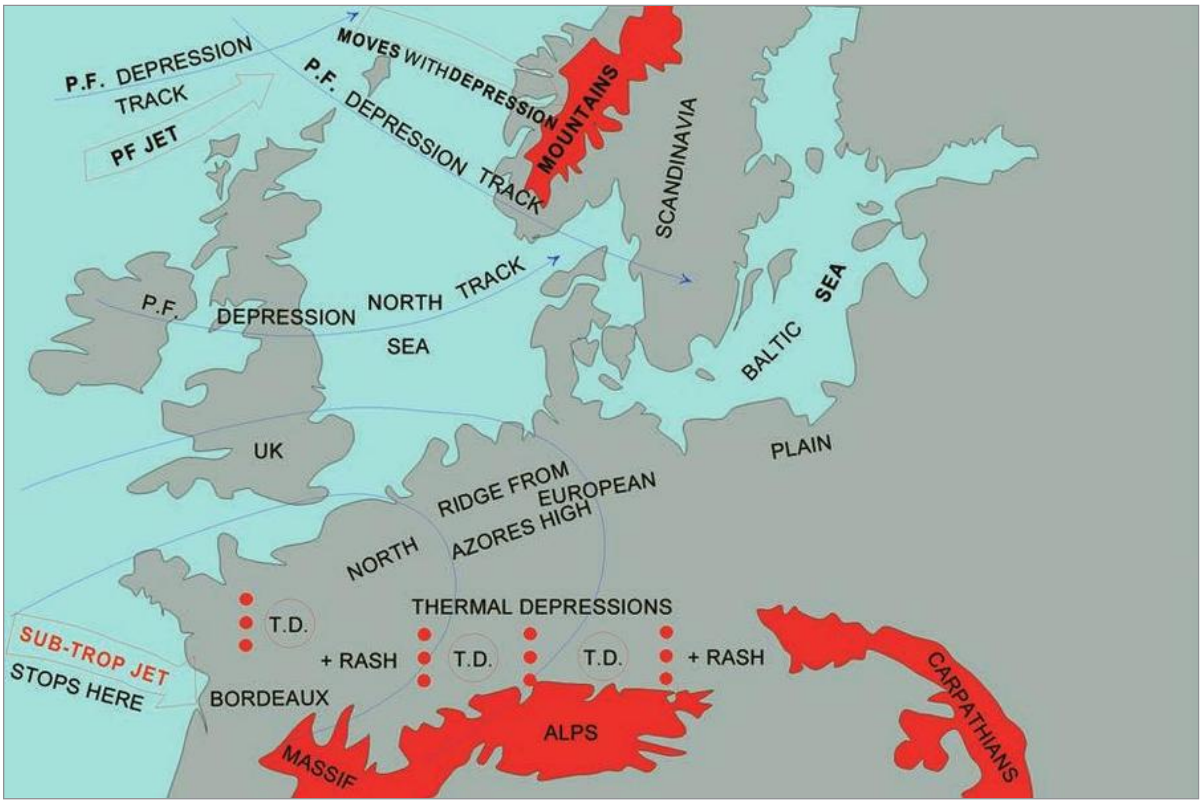


Figure 22.12 July weather

Winds
Surface winds are generally **westerly** but **lighter** than in winter. Winds may be modified by **sea breezes** along coasts.

Upper winds become increasingly westerly with ascent but the thermal wind component is less than in winter and upper winds will therefore be less strong. **Reduced Speed Polar Front Jets** will occur but **further north** with the summer movement of the polar fronts. The Atlantic **subtropical jet** will reach the coast near Bordeaux but due to mountain interference will not extend overland at jet speeds. It therefore **does not affect the region.**

Icing
The freezing level will be higher in summer and frontal activity is less, but icing in thunderstorms and orographical cloud may still be severe.

Average Tropopause and Freezing Level Heights over Central France

	January	July
Tropopause	35 000′	39 000′
Freezing Level	4000′	12 000′

Mediterranean Sea and Adjacent Lands

Geographical Considerations

The Mediterranean sea is almost entirely surrounded by land. **Compared with the land**, the sea will be **relatively warmer in winter** (giving unstable conditions above) and **relatively cooler in summer** (giving stable conditions above). Therefore during the **winter** surface air will tend to **flow in** from surrounding land areas and during **summer** it will tend to **flow out**.

There are significant **mountain areas** to the **north** and to the **west.** In winter, the **mountains** to the **north** will **hold back** much of the **cold air** from Europe/Asia. The **high ground** to the **west** will **resist** the **advance** of **polar front depressions except** via the mountain gaps in **SW France** and at the **Straits of Gibraltar** between Spain and Morocco.

To the **south** there is **no mountain barrier** to prevent **dry dusty air** from the **Sahara** desert spreading north, except the Atlas mountains in the extreme SW.

Winter

Pressure Systems

Mediterranean Front Depressions
The Mediterranean front lies **east/west** along the **centre** of the **Mediterranean**, and is formed by inflowing cold **cPc air** from the north and inflowing less cold **cTw air** from the south. Air will be forced to rise along the convergence line forming **frontal depressions** in the west which **move eastwards** along the frontal divide driven by the westerly upper airflow. Because of the dryness of the desert cTw air, warm front and warm sector cloud does not form, thus there is **cold front weather only.**

Orographic or Lee Depressions
These can form **south of the Alps** over the **Northern Adriatic** and over the **Gulf of Genoa.** The Genoa Low can move south along the Italian coast giving **unstable weather**. Lee lows can form **south of the Atlas mountains** in Morocco with a cold W/NW airstream and then move NE to enter the Mediterranean east of Tunisia. They can also form **south of the Turkish Taurus mountains** to form the **Cyprus Low** between Cyprus and Turkey. The **Cyprus Low** gives not only instability but is accompanied by **NE gales**. Weak depressions moving into the area can become **deepened** and reactivated. These lows can then move **eastwards into Lebanon and Arabia.**

Siberian High
The Siberian High is well **north of the region** but its **cold outflow** can reach the warm Mediterranean and cause **instability.**

Thermal Depressions
When **cold** air from the **Siberian High** flows **over** a relatively **warm landlocked sea area** such as the **Mediterranean**, instability or **thermal lows** are created. Over the Mediterranean, these form particularly in central and eastern areas and move eastwards to Arabia, the Arabian Gulf, Iran and Afghanistan.

Polar Front Depressions
Polar front lows and sometimes secondary lows can enter the region via **SW France** or **Gibraltar**, after which they tend to **become absorbed** by other depressions.

Cloud and Precipitation
Cold fronts associated with Mediterranean front depressions, also orographic and thermal depressions, produce **CU and CB** with attendant **heavy rain** or **hail showers** and **thunderstorms.** There is some layer type cloud and more continuous rain in association with the few polar front depressions in the west.

Visibility
Radiation Fog is **less common** than in NW Europe **but** can be persistent in the **Po Valley** in North Italy. Otherwise visibility is excellent between showers except when air blows from the south bringing dust laden air from the Sahara desert. These **southerly winds**, called the **Sirocco in Algeria**, the Chili in Tunisia, the Ghibli in Libya and the **Khamsin in Egypt** blow **ahead of depressions** travelling east over the sea.

Surface Winds
Surface winds will blow in accord with the location of depressions but there are some **named winds** blowing **into** the **Mediterranean** from surrounding land areas that should be noted:

Mistral
This is a strong **northerly** wind up to **70 kt** blowing down the **Rhône valley** in SE France, especially when high pressure is to the north. It is a **valley** wind, normally **stronger at night and in winter**, which brings **cold air** from the north. It helps form the Genoa orographic low.

Bora
This is a stronger dry gusty **NE** wind up to **100 kt** which is **part valley/part katabatic**. The wind blows through the mountain passes into the **Northern Adriatic** and can be reinforced by high pressure to the NE. It can bring snow and is **strongest at night**.

It can set in suddenly and is therefore dangerous. It can help form the Adriatic orographic low.

Gregale
This is similar to the **Bora** but **less strong**, **further south** and more **moist**. It blows from the **NE** near southern Italy and Malta and is due to continental relatively high pressure to the north, and low pressure over the Mediterranean Sea. It occurs in 1-2 day spells in association with Mediterranean depressions to the south which are moving eastwards.

Sirocco (or Scirocco)
Blows out of **Algeria** and the Sahara Desert into the **western Mediterranean** ahead of travelling Mediterranean lows, and can carry dust up to 10 000′. The Sirocco can **sometimes continue northwards to France**; while in transit it will be cooled and humidified by the sea and can thus cause **advection fog and/or low stratus** along the **South French Coast**.

Khamsin

Similar to the Sirocco, but **further east**, the Khamsin originates in Northern **Sudan,** blows **from the south** through **Egypt** and can affect Jordan, Syria and Cyprus. Dust can be carried to 10 000'.

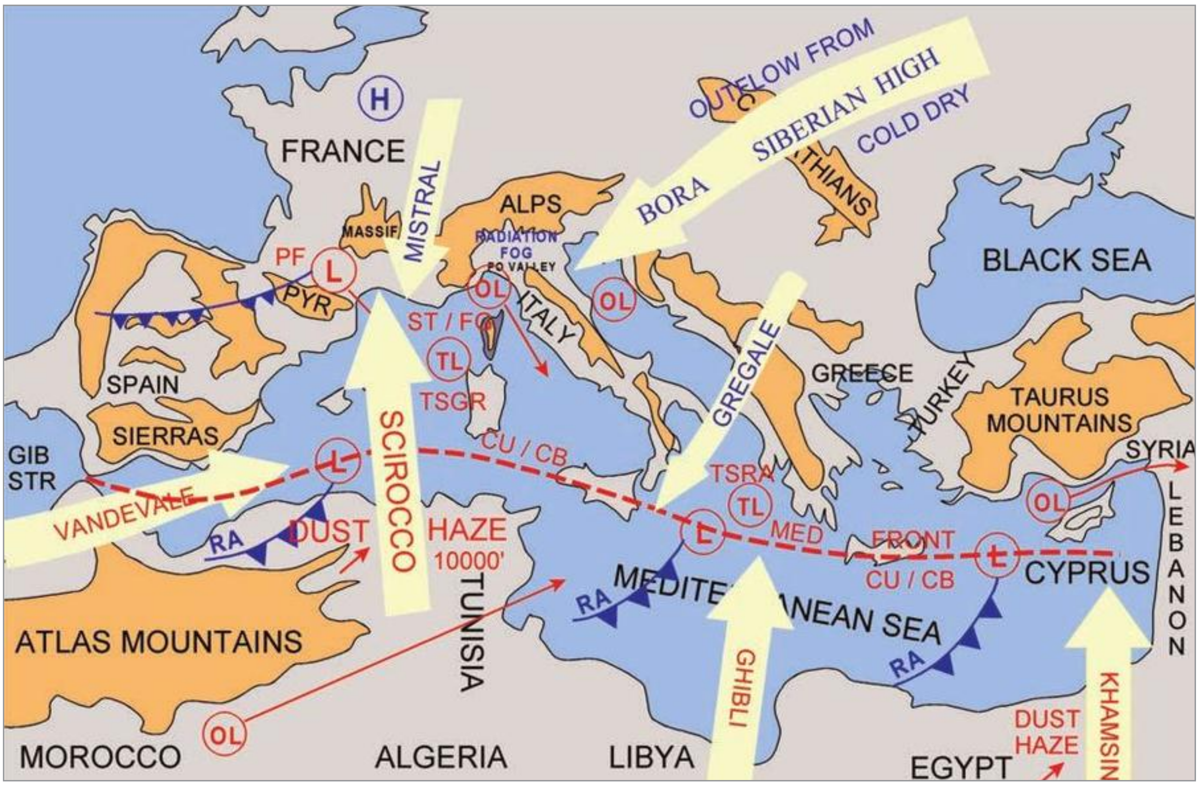


Figure 22.13 Winter pressure systems and surface winds

Vandevale

Strong **SW** to **W** wind in the **Straits of Gibraltar.** Blows ahead of a polar front cold front approaching from the Atlantic. It is very squally with much low cloud.

Upper Winds

In the **extreme west** a **few polar front jet streams** occur in association with PF lows. The **Subtropical jet** over **Morocco** does not affect the west of the sea area but can affect the eastern Mediterranean in the Cyprus and Egypt region. It is centred at the 200 hPa level with maximum westerly winds at over 100 kt.

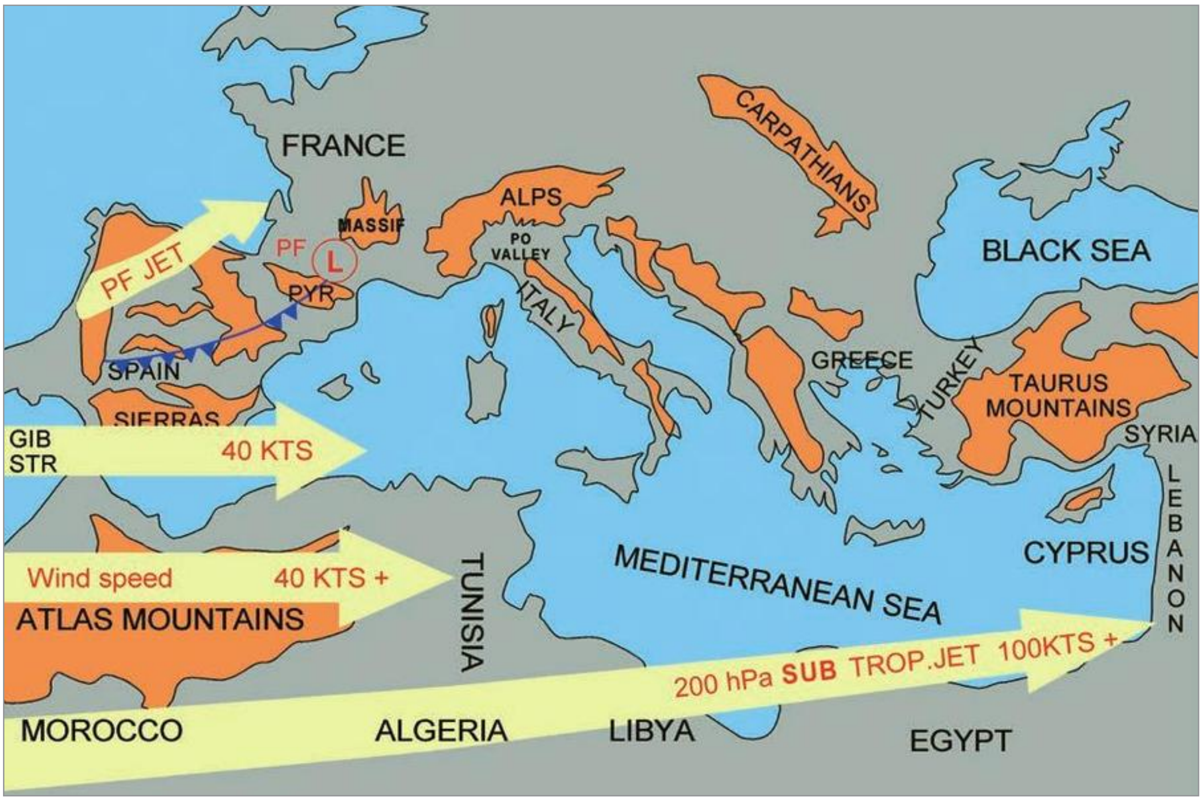


Figure 22.14 Winter upper winds

Icing

Clear ice can occur in convective cloud and thunderstorms. Freezing rain/rain ice can occur over N Italy where the freezing level may occasionally be on the surface.

Summer

Pressure Systems

Azores High

The Azores subtropical high at 35°N extends eastwards across the Mediterranean.

Thermal Lows

Pressure over Egypt, Lebanon, and lands to the East is relatively low due to intense insolation.

Cloud and Precipitation

There is little cloud aside from **fair weather CU**. **Local CU/CB** can occur over the high ground of Greece, Italy and Turkey due to **convective** and **orographic uplift**, possibly resulting in local thunderstorms.

Visibility

Trapped near the surface by generally descending air, **dust** can reduce visibility **across the region**. In the straits of **Gibraltar**, warm moist air **flowing out** over the cooler Atlantic can produce **advection fog** or **low ST/SC**.

Surface Winds

Levanter
Summer **outflow** from the Mediterranean occurs at Gibraltar and is called the Levanter. It blows from the east (the Levant) during **July-October** and **March** and can reach gale force. The axis of the Rock of Gibraltar is north/south and orographic uplift on the east side through some 1100′ can produce a **banner of ST/SC** which then **streams westward** from the top of the Rock. In stable air **standing waves** can occur over the Rock. Considerable **turbulence** up to 5000′ can exist above the adjacent airfield.

Etesian
This **moderate persistent** wind blows **from the north** across the Greek Islands of the **Aegean Sea** towards the island of Rhodes then southwards. It is caused by the pressure gradient between the Azores ridge, extending across the western and central Mediterranean, and heat induced low pressure overland to the east. The wind is dry and brings **clear skies** and **good visibility**. Strong Etesians can bring gales and affect the area from W Greece to W Turkey and as far south as the N African coast when CU may develop after the long sea track.

Sea Breezes
These can be strong at this time of the year and will **locally modify** surface wind direction.

Upper Winds
Light westerly in the **west. Westerly** average **40-50 knots** in the **east.** Both **jet streams** are **out of the region** to the north.

Icing
The freezing level is high and icing is not normally a problem in summer.

Average Tropopause
South Region 53 000′   North Region 40 000′

Average Freezing Levels
Winter 6000′   Summer 14 000′

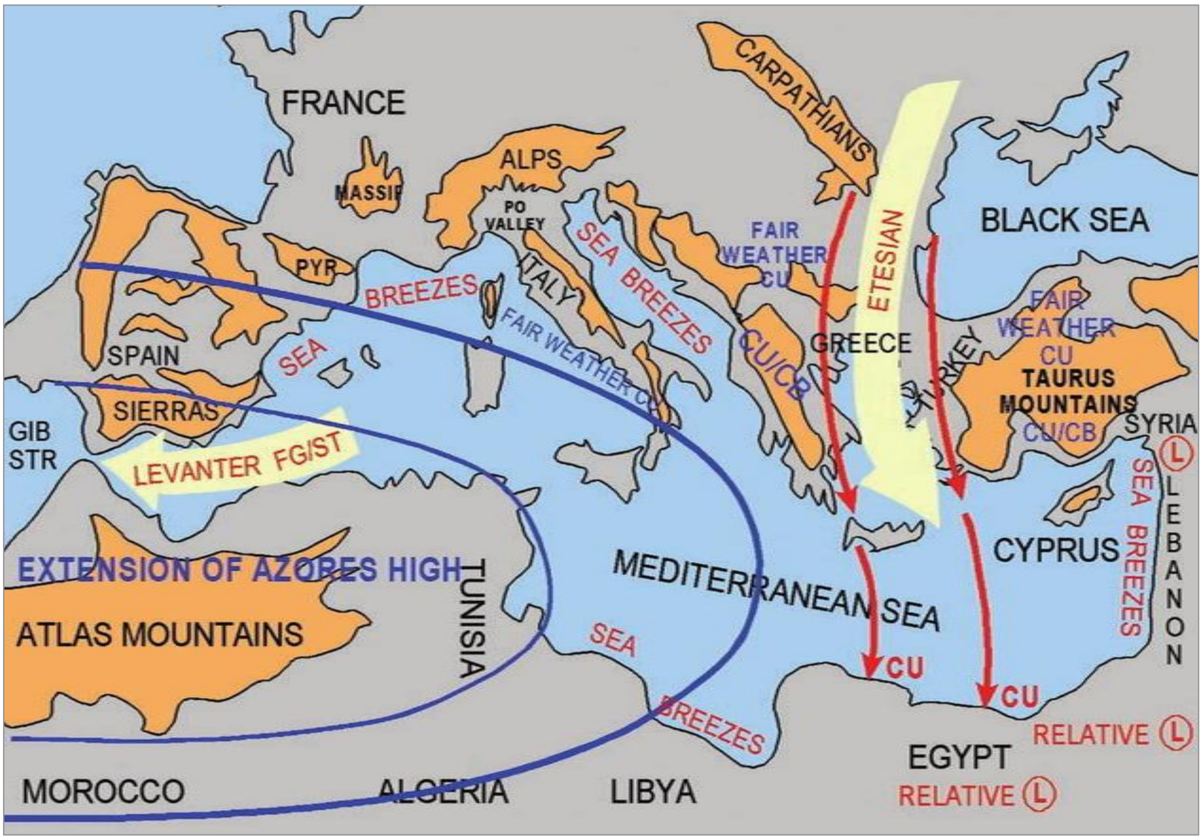


Figure 22.15 Summer pressure, surface wind velocity and cloud

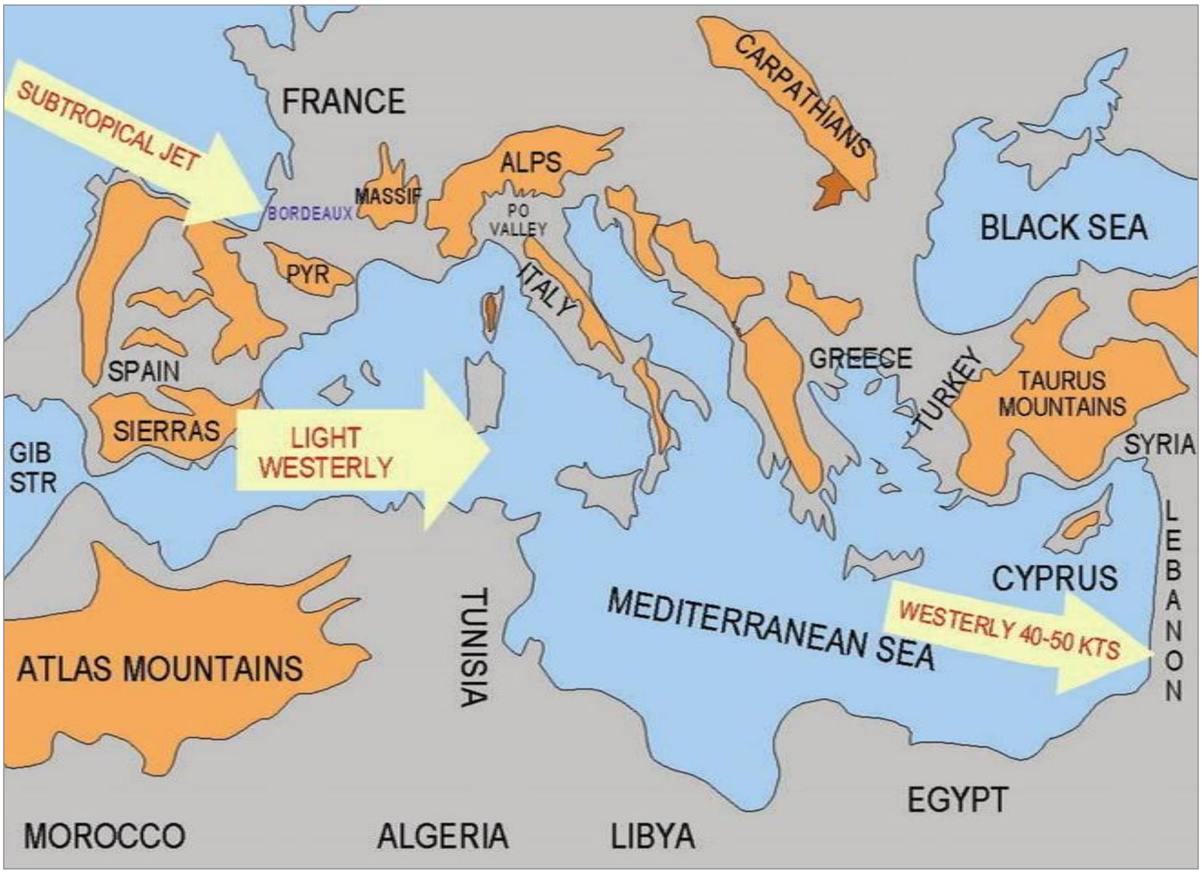


Figure 22.16 Summer upper winds

Arabia, the Gulf Area, Arabian Sea and Borders Enclosed within 15°N-35°N And 35°E-75°E

Geographical Considerations

Inland areas of Iraq, Saudi Arabia and Oman are largely desert. The Tropic of Cancer at 23½° N almost bisects the region so that in summer the noon sun is virtually overhead. The daytime interior is extremely dry and hot. The warm Gulf waters cause oppressive humidity along coasts. Surface wind direction is generally governed in the west by the NW/SE axis of the Zagros mountains in W. Iran and in the east by the Himalayas.

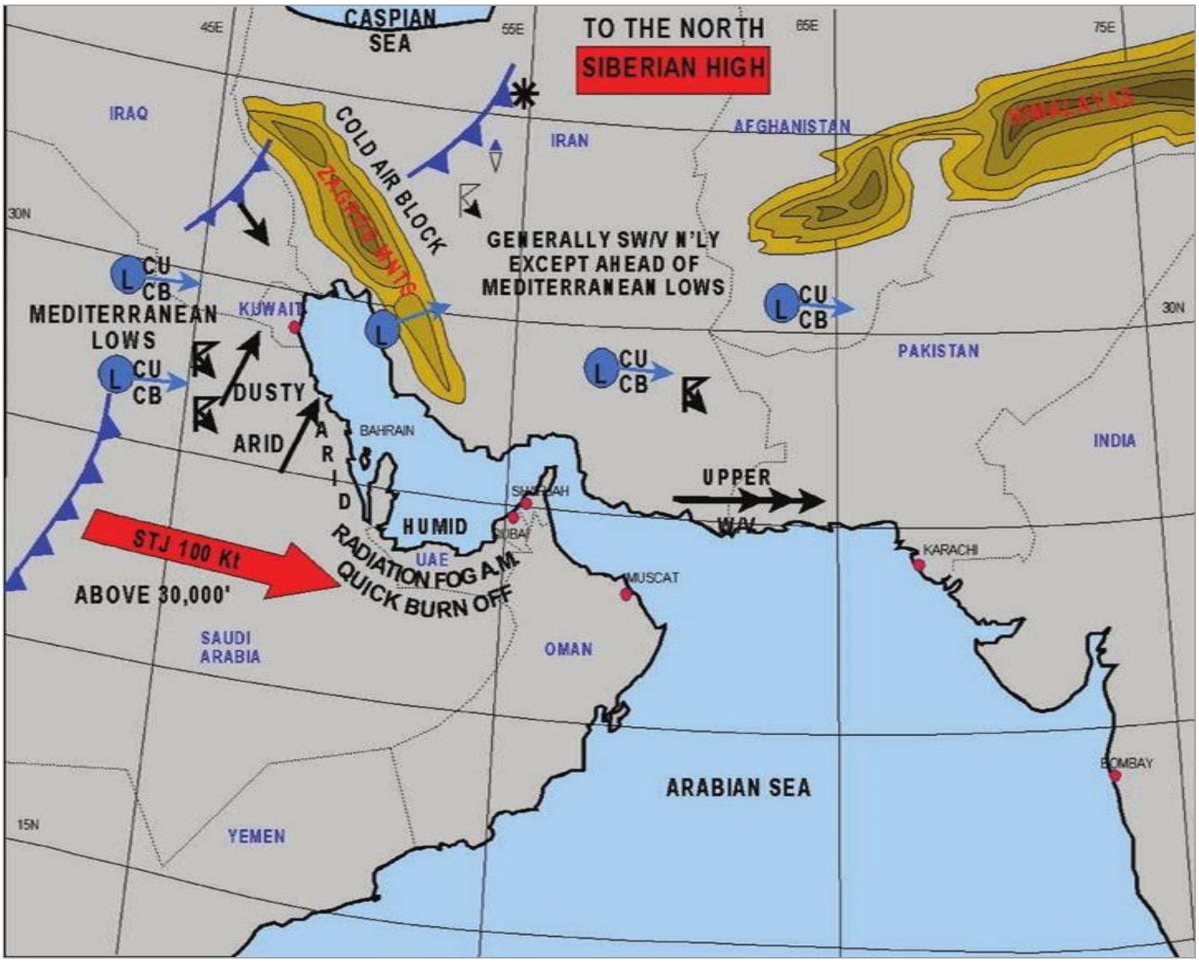


Figure 22.17 Arabian weather - winter

Winter

Pressure Systems

The Siberian High is established over Asia to the NE but its surface outflow affects the region. **Thermal Lows**, often with associated cold fronts, travel eastward from the Mediterranean across Arabia into Iran and Afghanistan.

Siberian dry cold frontal air passing over the relatively warm Caspian Sea to the north can initiate considerable thermal instability.

Cloud and Precipitation .
Restricted to the north and west only. **Travelling lows** from the **Mediterranean** will produce **CU/CB, heavy showers and thunderstorms,** and their associated cold fronts may bring some weather and **duststorms** to the more southern interior of Arabia. **Thermal instability** over the **Caspian Sea** can bring **thunderstorms, hail** and possibly **snow** to high ground to the north.

Surface Winds.
In the west the **Zagros mountain range** and parallel ridges are **oriented NW/SE**. These **block** and **deflect** the cold Siberian outflow so that the **surface winds** become **north** or **northwesterly.** In the east, the Siberian outflow escaping round the western end of the Himalayan air block will again be **northerly.** The exception is the **temporary southerly** wind which occurs **ahead** of the travelling depressions from the Mediterranean.

Visibility.
Winter visibility is generally much better than in the summer convection currents, but in the NW of the region rising **dust** can occur with any wind direction and especially in the **southerly** winds **ahead of** the travelling ex Mediterranean **Lows.** Violent but short lived **duststorms** may accompany the **passage** of associated **cold fronts.** Overland near coasts where humidity is high, **radiation fog** may form, but **dispersal** is quick after sunrise.

Upper Winds
Are westerly. The **200 hPa subtropical jet** covers the west of the region and may extend as low as 300 hPa (30 000’). Core speeds frequently exceed 100 knots.

Icing is not a problem except when climbing or descending through large CU/CB.

Summer

Pressure Systems.
The Baluchistan Low is the lowest pressure point of general warm weather low pressure over the Asian continent. It centres on the area of Baluchistan, lying across the Iran/Pakistan border, due to the mainly south-facing rocky nature of the surface, and intense solar heating from the high noonday sun.

The ITCZ just reaches Oman in the west. In the east it traverses the N. Arabian Sea northwards in June/July and southwards during September.

Thermal Low Pressure. Over Eastern Pakistan and NW India, March to June is dry. With advancing spring, the land mass begins to warm, thus pressure begins to fall, drawing in warm moist air from the Arabian Sea in response to the pressure gradient; first at lower latitudes then progressively further north. The ITCZ follows.

Cyclones occur over the **Arabian Sea** during the advance and retreat of the ITCZ between **June** and **September.**

Surface Winds
In the west there will be anticlockwise rotation around the Baluchistan Low, as modified by the Zagros mountains with a NW/SE orientation, gives a northerly or northwesterly winds. In particular the shamal wind originates as dry and dusty convection currents from Iraq. It is northwesterly and blows the length of the Gulf picking up moisture and bringing a dusty humid wind to facing coasts around Bahrain and Dubai.

Cloud and Precipitation

Most of the region is almost rainless and temperatures can exceed 50°C. Inland areas are very dry but Gulf coastal regions facing the N/NW onshore winds can be oppressively humid. An exception is the **SE of Oman.** The **ITCZ** reaches the **coast** where the desert terrain temporarily "bursts into bloom". Further east towards the Indian coast, the ITCZ northward movement is followed by the onset of the SW monsoon. The monsoon is very moist and convectively unstable. Orographic and convection cloud and heavy rain are widespread.

Visibility.

The **north/northwesterly winds** can cause much **dust** in the desert regions. The **shamal** will bring **dusty moist air** to coastal areas. Visibility will also be reduced in regions affected by the ITCZ.

Upper Winds.

Above 20 000′ winds are light easterly.

Icing.

Icing should not be a problem in summer.

Average Tropopause and Freezing Level Heights

	Tropopause	Freezing Level
January	38 000′	11 000′
July	56 000′	16 000′

Chapter

23

Route Climatology

Calcutta to Singapore

Geographical Considerations

The route is located between latitudes 23°N and 01°N. It overflies the eastern Bay of Bengal and is just off the west coast of Bangladesh, Burma, Thailand and W. Malaysia. The Himalayas lie to the north of low lying Bangladesh. The Cameron Highlands form a spine the length of West Malaysia, and Sumatra Island to the SW also has a mountain backbone.

Winter (January)

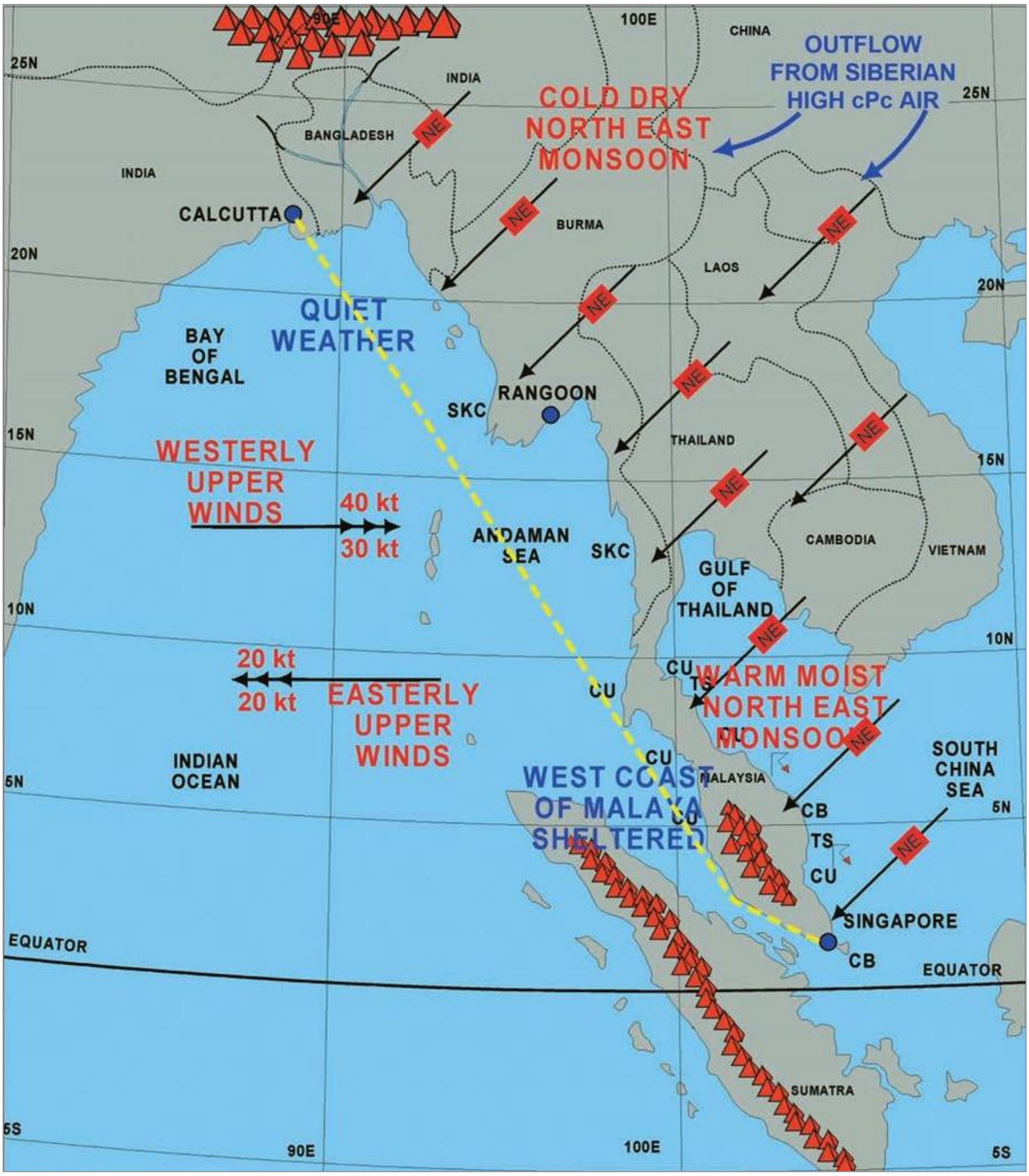


Figure 23.1 Weather and Winds in January.

Pressure Systems

Continental outflow from the **Siberian High** establishes the **NE Monsoon** over the whole route as shown in *Figure 23.1*. The **ITCZ** is **south** of the route.

Weather

In winter the route weather is generally very good. Calcutta and Bangladesh are protected from the north by the Himalayas. Abeam Burma, the NE monsoon will have had a long land track and, although isolated convective cumulus are possible, the dry cold air will in general ensure clear skies.

Further south the monsoon will cross the Gulf of Thailand picking up warmth and moisture encouraging some CU and CB to form over the isthmus of southern Thailand.

On the last section of the route the NE monsoon arrives warm and moist from the expanse of the South China Sea giving large scale orographic cumulus and thunderstorms over the east coasts and central highlands of West Malaysia and Sumatra.

The West Coasts are more sheltered and generally less wet although all equatorial land areas including Singapore have considerable convective heating resulting in almost daily thunderstorms.

Visibility

Early morning mist can occur in the moist river delta regions of Bangladesh and Burma. Otherwise visibility is very good outside showers and thunderstorms.

Winds

Low level winds are northeasterly over the whole route under the influence of the NE monsoon. Above 20 000′ upper winds overrun the monsoon. The 200 hPa subtropical jet lies just south of the Himalayas and is therefore north of the route; decreasing westerlies of around 40 knots over Calcutta reduce to zero near 10°N thereafter becoming the normal light equatorial easterlies.

Icing

Icing can occur above 16 000′ but is a lesser problem in January than July as skies are generally clear on the route.

Summer (July)

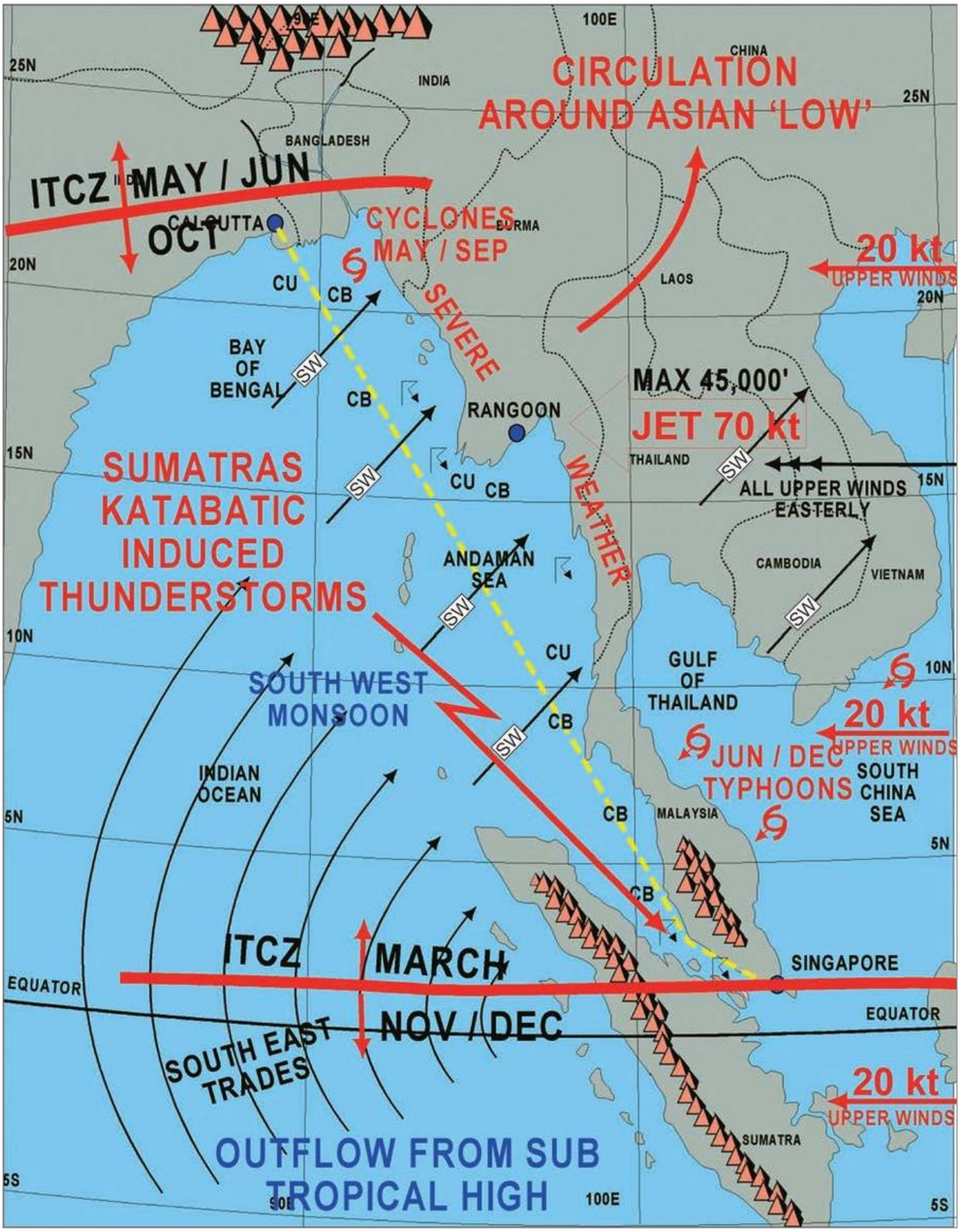


Figure 23.2 Weather and winds in July

Pressure Systems

The Siberian High of winter has been replaced by the **Asian Low** centred over **Baluchistan.** The **ITCZ** rapidly traverses the route northbound in spring to be by Singapore in March and Calcutta in May, then again southbound in the autumn to be by Calcutta in October and Singapore again in November/December. In **July** it is therefore located well to the **north**. The inflow to the ITCZ cyclonically round the Asian Low establishes the **SW monsoon** as shown at *Figure 23.2*. The monsoon is supplied from the Southern Hemisphere SE trade winds which veer to SW on crossing the Equator.

The lengthy equatorial sea track of these winds ensures high temperatures and high humidity so that wherever they landfall, the orographic uplift will trigger intense instability with thunderstorms and severe weather.

Weather

In summer, flying conditions are poor. The whole route lies on the windward side of the Bangladeshi, Burmese, Thai and West Malaysian coasts. Thunderstorms and severe weather will occur throughout except over the extreme south of the route, where in the Straits of Malacca there will be some protection by the mountains of Sumatra from the SW monsoon. Nevertheless the high mountains on either side of the straits can cause a new hazard.

At **night**, the **katabatic winds from each side**, aided by the land breeze effect, will meet in the middle of the straits causing a convergence line with consequent uplift. Along the straits this double sided uplift can cause a line of **night time thunderstorms arched** in the middle, known as **Sumatras**. (Jingle: **S**umatras occur in **S**ummer).

Cyclones

Tropical revolving storms are known as **cyclones** in the Bay of Bengal. To form they need a summer **warm sea** (evidence suggests in excess of + 27°C) and the close **instability** of the **ITCZ**. In July the ITCZ is north, over the land, so that in this area they form only in early and late summer when the ITCZ is over the sea, that is in **June** or **October**. Tropical revolving storms also occur in the Gulf of Thailand and occasionally move west to affect the route.

Visibility

Visibility is generally impaired by much cloud and frequent rainfall. Reduction in tropical rainstorms can be considerable.

Winds

Surface winds are **SW** over the whole route. Aloft, the 200 hPa subtropical jet is now located north of the Himalayas thus above 20 000' the equatorial mostly light **upper easterlies** apply over the **whole route.** Also in this region, summer high temperatures in the land mass of Asia cause a reversal of the south-north temperature gradient. Aloft, with warm air to the north, the upper pressure gradient movement is southward, which Coriolis/GF will turn to the right, giving a pronounced **easterly jet** over **Rangoon** of **70 knots** centred near the 150 hPa level (45 000').

Icing

Icing can be a problem on this route during the summer, when descending through cumulo-form clouds.

Tropopause Heights average 56 000' all year.

Freezing Level Heights average 16 000' all year.

Singapore to Tokyo via Hong Kong

Geographical Considerations

The route traverses the “Western Pacific Rim” from latitude 01°N to 35°N. It passes close to the east coasts of W. Malaysia, Vietnam and China. The en route weather is dominated by the **changing seasonal pressure over Asia** and the temperature differences between continent and ocean and between sea currents. East of Japan, the cold Oyasiwo sea current sweeps down from the Russian Kamchatka peninsula, and is countered by the warm Kurosiwo sea current flowing northeastward from the Northern Philippines. Much of the area, including Japan, has a mountainous interior.

Winter (January)

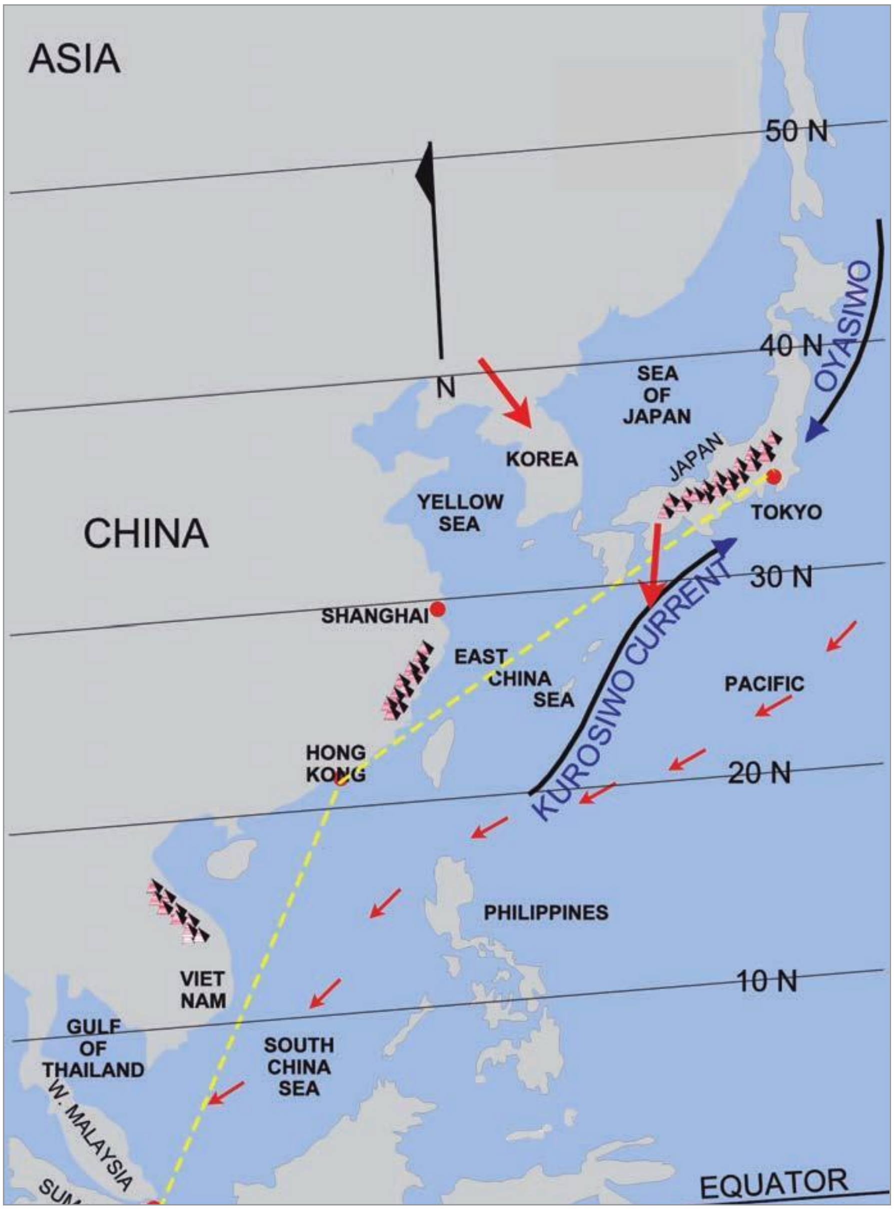


Figure 23.3 Surface conditions in January

Pressure Systems

The **ITCZ** lies well south of the route.

The **Siberian High** is well established to the west over Asia.

Some **polar front lows** traverse the extreme north of the region.

Surface Winds

Clockwise outflow from the **Siberian High** establishes the wind flow over the route as shown in *Figure 23.3*. From **Singapore to Vietnam** the **NE monsoon** blows. From **Vietnam to China** the wind remains **north or northeast**. Near **Japan** the wind is **north or northwest.**

Weather

In the south of the route, the NE monsoon sweeps down from the warm expanse of the South China Sea producing intense convective instability. This will produce CU, CB, heavy showers and thunderstorms along any windward coast in its path, for example the east/NE coasts of W. Malaysia and Vietnam. Inland areas, sheltered by mountains, will remain drier aside from convective weather.

Towards Hong Kong, after the ITCZ has passed southbound in September, some shelter will be afforded from north/NE winds by the Chinese mountainous landmass; from October to December the weather in Hong Kong is fine and dry. A change occurs in January as the wind veers and the source area is over the warm Kurosiwo sea current. These new warm moist winds form, over seasonally cooled coastal **Hong Kong** waters, **advection fog, low stratus drizzle and gloomy conditions.** This coastal condition is known as the **Crachin** and lasts in Hong Kong from **January to April** after which the northward movement of the ITCZ will dispel it.

In the north of the route very cold dry SE ward outflow from Siberia crosses the comparatively warm Sea of Japan. Moderate instability generated is orographically enhanced over the **Japanese NW coast** and **central mountains** causing CU and **heavy snow showers**. Eastern lee areas, such as Tokyo, will be drier and less cold due to the Föhn effect and warming from the Kurosiwo sea current.

Visibility

In the south of the route, visibility is good between showers. At Hong Kong visibility is **excellent October-December**, but **abysmal** from **January-April** in the **Crachin** conditions discussed above. Near Tokyo and other big Japanese cities visibility can be reduced to near fog limits by industrial smoke.

Upper Winds

Equatorial 10 - 30 kt easterlies blow from Singapore to 10°N. Further north, winds become westerly increasing in speed towards 25°N-40°N where the 200 hPa subtropical jet blows, frequently up to 150 knots, and occasionally to 300 knots near Japan. This exceptional speed is due to a combination of the strong low level geostrophic southeastward Siberian outflow and the extreme thermal wind component generated by the marked Siberia/Pacific temperature difference. Further north, there are some occasional westerly jets in association with polar front lows.

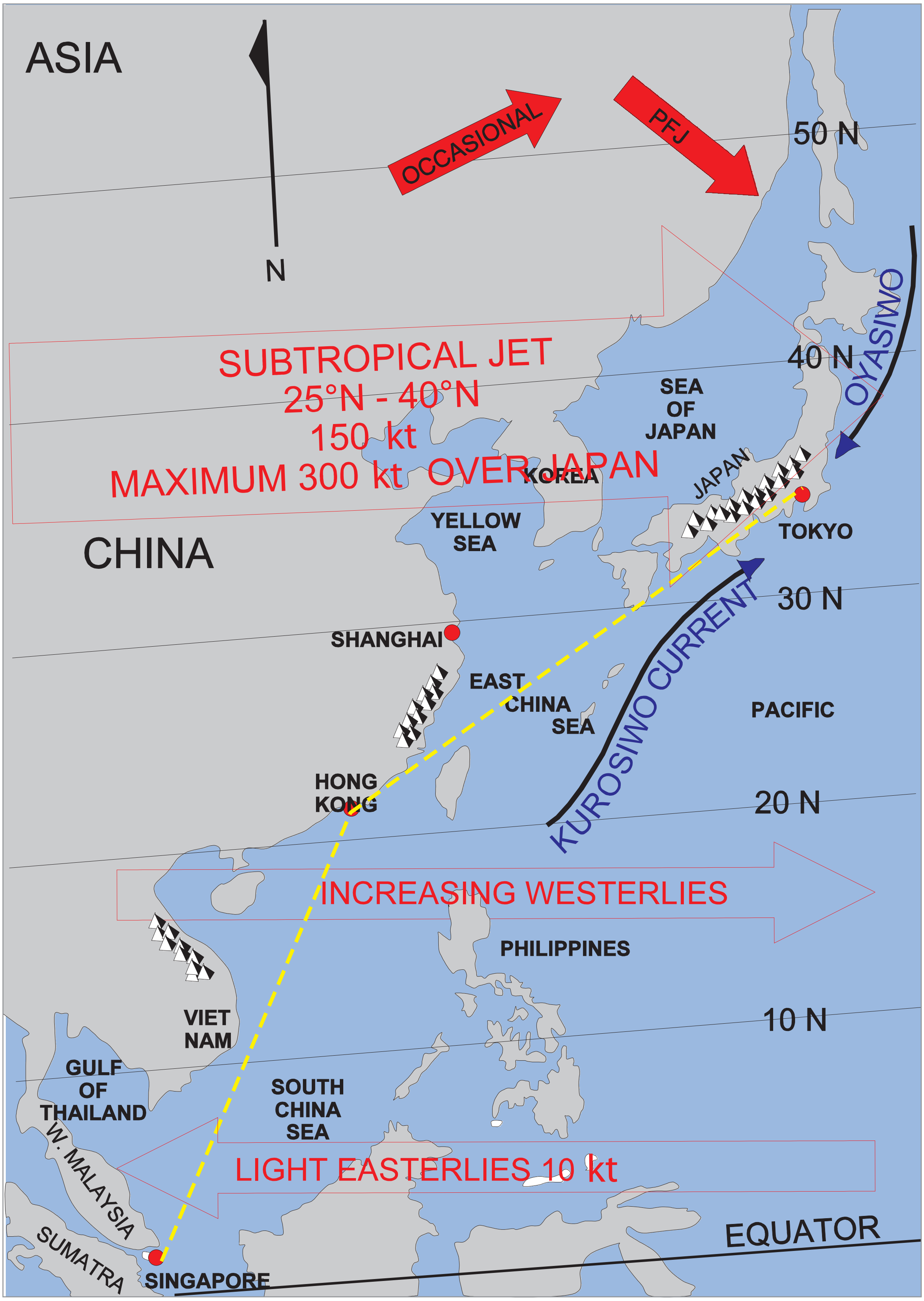


Figure 23.4 Upper winds in January.

Summer (July)

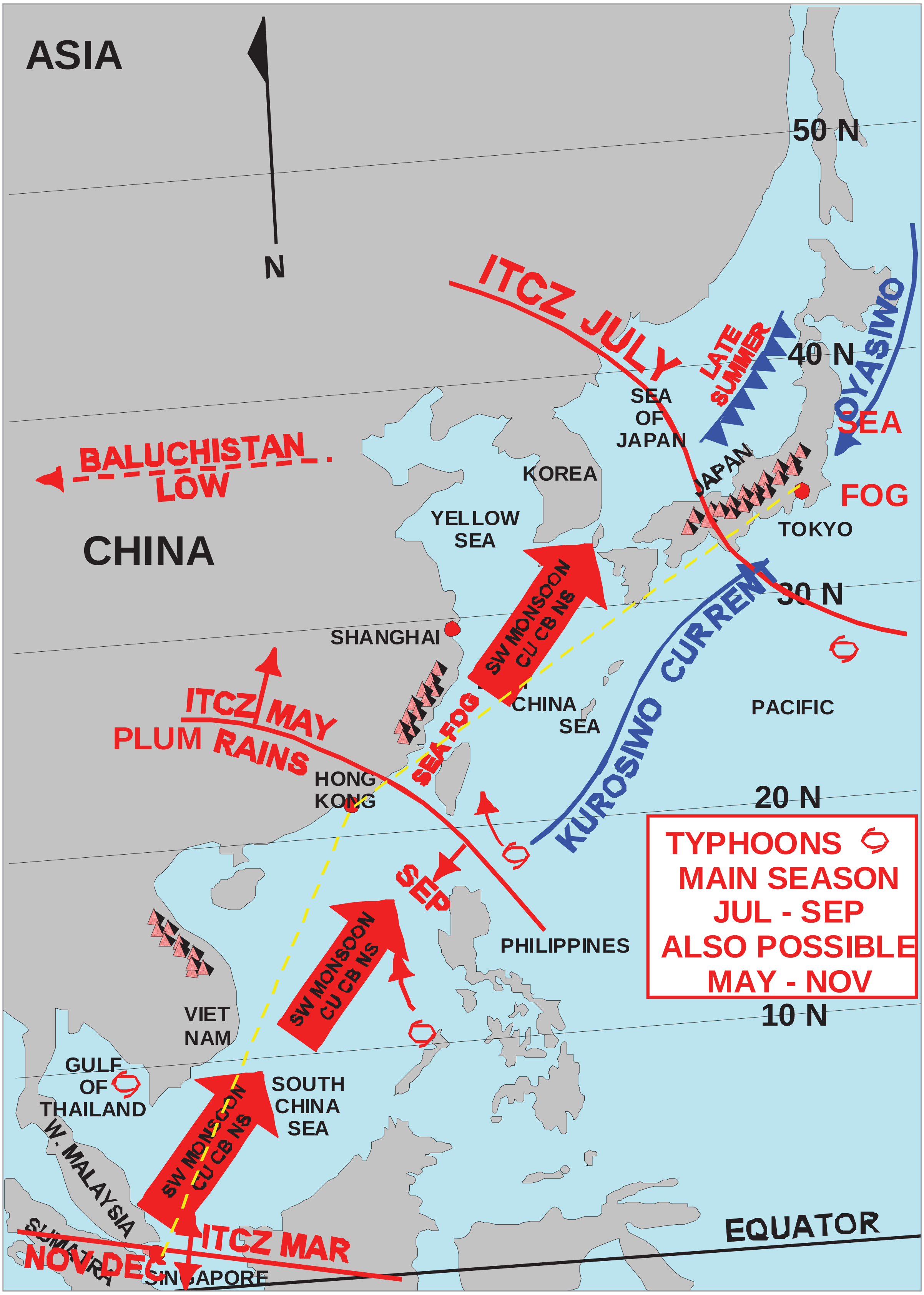


Figure 23.5 Surface conditions in July.

Pressure Systems

Baluchistan Low

The Winter Siberian High is replaced by the Summer Asian Low centred over Baluchistan. Its **anticlockwise inflow** produces the **SW monsoon** over the route as far north as Central Japan - the northern limit of the ITCZ.

ITCZ/Equatorial Trough

The SW monsoon will follow northwards the ITCZ which will be over Singapore in March, China in May and Japan in July. The northern extent of the SW monsoon will then recede southwards again driven before the ITCZ, which passes Hong Kong in September and Singapore again in November/December.

Typhoons

In the North Pacific, tropical revolving storms are known as typhoons. Evidence suggests that to form, requirements include a sea temperature greater than +27°C, a proximity to ITCZ instability, plus a displacement away from the Equator where Coriolis is zero, and location south of the jet stream belts which would destroy their vertical continuity. They form in the central Pacific, at around 10°-15°N then drift westward at 10-15 knots with the clockwise wind direction around the N. Pacific subtropical high. Nearing the Philippines they will generally track near the seasonal ITCZ but can curl northwards extending the season in some locations. Up to 12 per year can affect southern Japan, principally in July - September and in Hong Kong occurrence is commonly in September. The overall season may extend from May to November depending on latitude. The southern limit is the Gulf of Thailand.

Surface Winds

In July the southwest monsoon extends over the whole route as far north as Central Japan where the ITCZ then lies. By late summer, the cold northwesterlies will re-establish behind the retreating ITCZ as the Siberian High begins to rebuild. Where typhoons occur, winds of varying direction may exceed 100 knots. Sea breezes will affect coastal wind direction in sunny conditions especially in the south.

Weather

To the west of Singapore in the Malacca Straits, the Katabatic thunderstorm Sumatras will form overnight. The SW monsoon will bring orographic CU CB to SW facing coasts, while east coasts will be more sheltered.

Nevertheless in these equatorial regions including Singapore purely convective cloud will be heavy, often giving daily thunderstorms.

Most route weather arises on the ITCZ as it travels from **Singapore** in **March** to **Tokyo** in **July** and back to **Singapore** in **November/December**. The **northbound ITCZ** will pass **China** in **May** where associated precipitation is known as the **Plum Rains**.

High typhoon internal wind speeds, coupled with intense rain and thunderstorms, can locally bring much structural damage and flooding.

Over Japan in late summer some frontal rain occurs as cPc air spreading south from Siberia meets retreating tropical air.

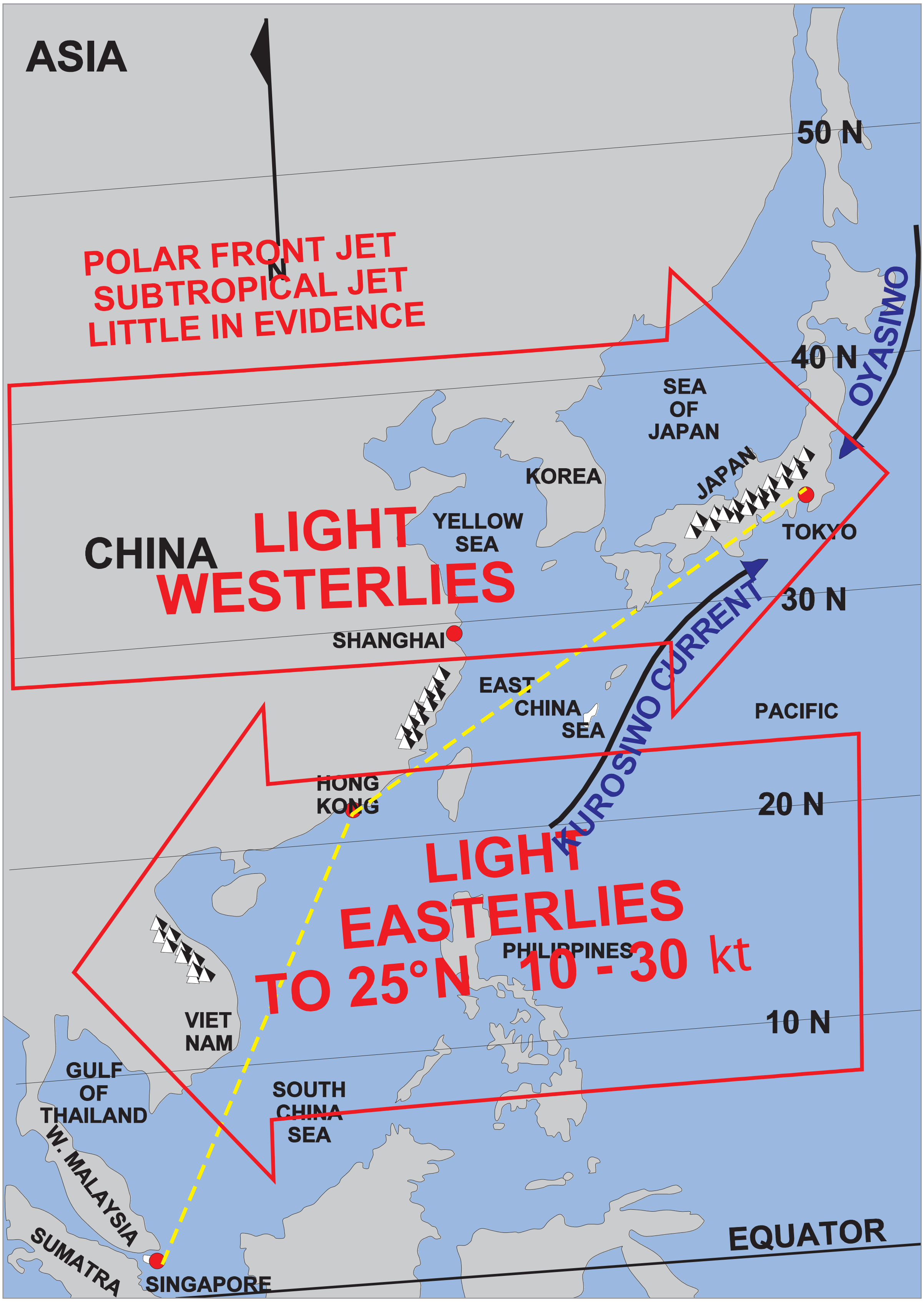


Figure 23.6 Upper winds in July

Visibility

In early summer, warm moist SW monsoon winds, advancing north, can bring sea fog to cooler Chinese coastal waters and extensive blanket advection sea fog over the cold Oyasiwo sea current between eastern Japan and the mainland Kamchatka peninsula further to the northeast. Some industrial smoke can occur near cities in Japan.

Upper Winds

Equatorial **light easterlies** of 10-30 knots extend to 25°N, beyond which winds become **light westerly**. Subtropical and polar front jets are little in evidence over the summer North Pacific.

Tropopause Heights

Singapore	Japan
56 000’	38 000’

Freezing Levels

Singapore	Japan
16 000’	3000’ -15 000’

Singapore to Auckland via Darwin and Sydney 01°N - 37°S 105° - 175°E

Geographical Considerations

The route crosses the Equator just south of Singapore then overflies the Java sea and many of the Indonesian islands. Next is the Timor Sea followed by the Central North Australian coast at Darwin, at latitude 12°S. From Darwin the route crosses the dusty largely flat Australian interior to the mountainous SE coast at Sydney, latitude 34°S. The last leg then heads across the Tasman Sea to New Zealand's low lying Auckland airport at 37°S.

Winter (July)

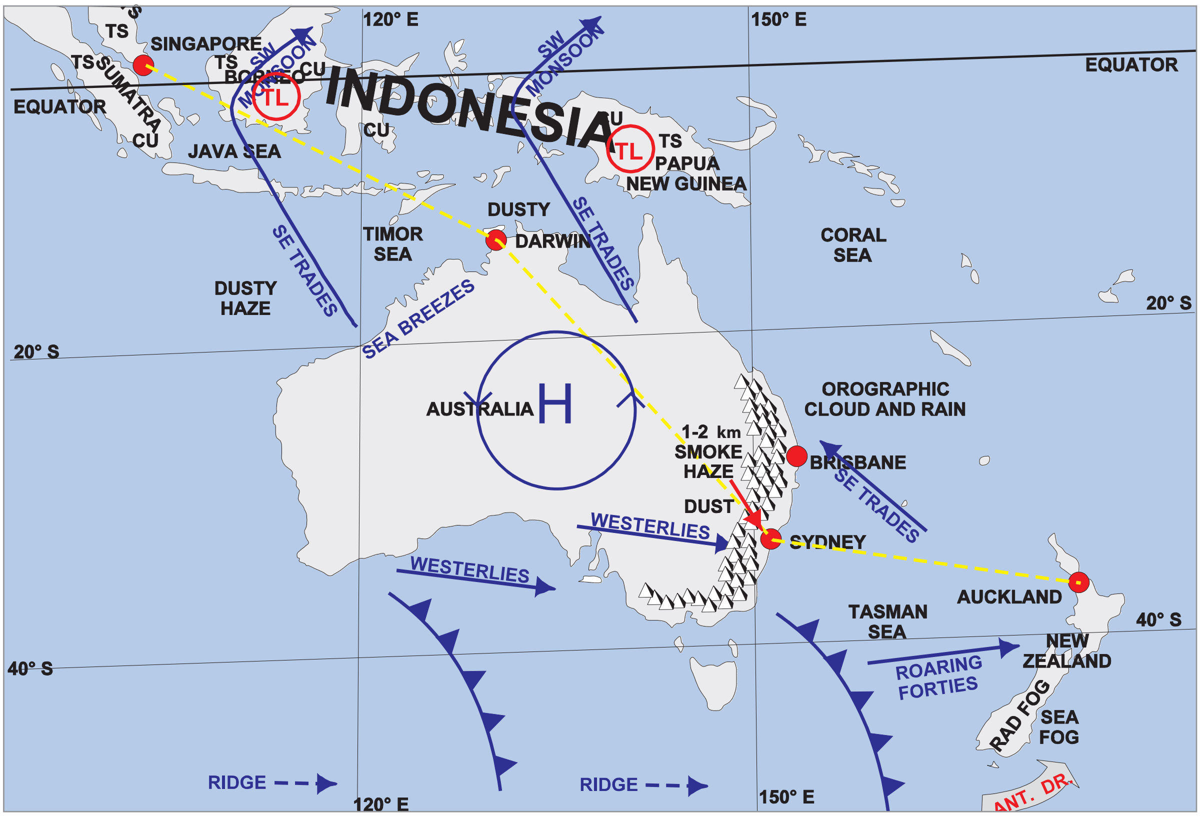


Figure 23.7 Surface pressure and weather - July (Winter)

Pressure Systems

ITCZ

The ITCZ is in the Northern Hemisphere **well clear** of the route.

Thermal Lows

Convective thermal lows will occur over the Indonesian islands. These are formed by a combination of island insolation and high humidity from the surrounding sea.

Subtropical High

The Australian interior in winter lies in the Southern Hemisphere Subtropical high belt. Relatively **cool** seasonal temperature overland will **reinforce high pressure** within the continent.

Polar Front Depressions

Travelling polar front lows in the Southern Hemisphere's disturbed temperate zone will themselves be located **well south** of the route; but associated troughs, and secondary lows, can bring **frontal weather** as far north as the **Australian South Coast** and to **New Zealand**. As in the Northern Hemisphere, these eastward-travelling fronts will alternate with temporary ridges and anticyclones. Cold frontal activity can be quite severe from Sydney to Auckland.

Surface Winds

The **SW Monsoon Wind** at **Singapore** will soon back to **SE** (Coriolis change), as the route crosses the Equator. These SE "trade" winds will remain as far as Darwin and beyond although at Darwin itself **strong local sea breezes** may blow from the north. On the **Darwin to Sydney** sector the **SE** trade winds gradually veer to **southwesterly** to conform with the anticlockwise rotation round the Central Australian winter high.

Towards **Sydney,** and beyond **to Auckland**, the wind direction will locally be governed by the location of the travelling polar front depressions to the south but be generally **westerly.** South of the Australian land mass, these westerlies will encircle the globe largely unimpeded by land and will therefore strengthen. Here they are known as the **'Roaring Forties'** from the principal latitude band in which they blow.

Sea breezes can affect **Sydney** even in winter.

Visibility

Between frequent equatorial showers over Singapore and the Indonesian islands, visibility will be **good until near 05°S** beyond which there will be **haze** caused by the dry dust laden SE trade wind blowing from Australia.

Beyond Darwin, the dusty outflow from the interior will maintain haze. Near large cities visibility may be reduced to 1-2 km by **industrial smoke haze**.

Over the two islands of New Zealand, the clear air gives good visibility in between cold frontal precipitation. **Radiation fog** can occur inland, especially over the colder South Island. **Advection/sea fog** can occur off the South Island east coast over the cold Antarctic Drift sea current.

Cloud and Precipitation

Daily convective CU with showers over Singapore and the Indonesian Islands will give way to quieter weather towards Darwin. The anticyclonic Australian interior will be dry but, rising over the mountainous east coast, the onshore SE trade winds can give orographic cloud and rain. The Sydney area and Tasman Sea route are affected by the disturbed temperate region lows to the south. They are thus crossed by fronts which bring moderate to heavy precipitation interspersed with highs giving several days of cool fine weather.

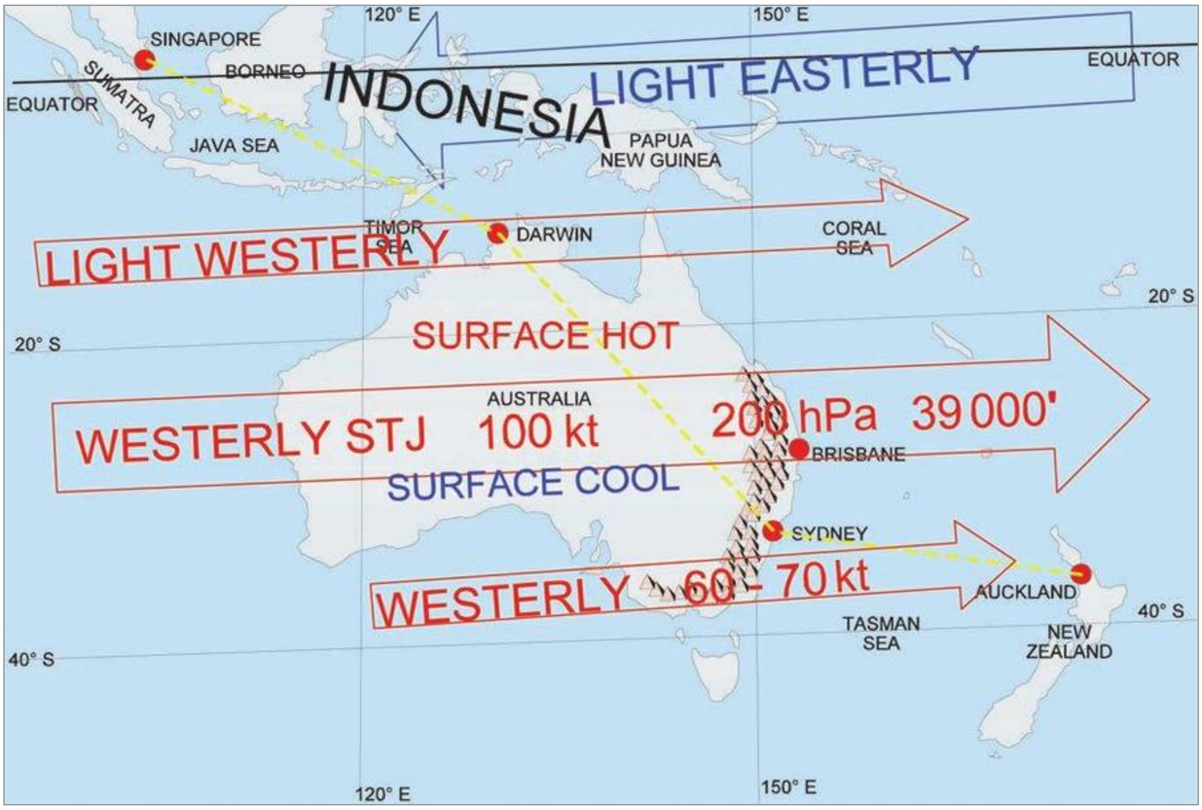


Figure 23.8 Upper winds - July (Winter)

Upper Winds

Above Singapore the **upper equatorial easterlies** will blow until 10°S after which the winds will increase from the west. In the southern winter, tropical North Australia remains hot whereas the south is comparatively cool. The temperature difference over the intervening subtropical and continental high will produce the westerly **subtropical jet stream** at the **200 mb** level across the **centre of the continent** around 25°S. Speeds may reach 100 knots. From Sydney to Auckland, the westerly wind will moderate to 60-70 knots.

Icing

Icing is not a special problem on this route.

Summer (January)

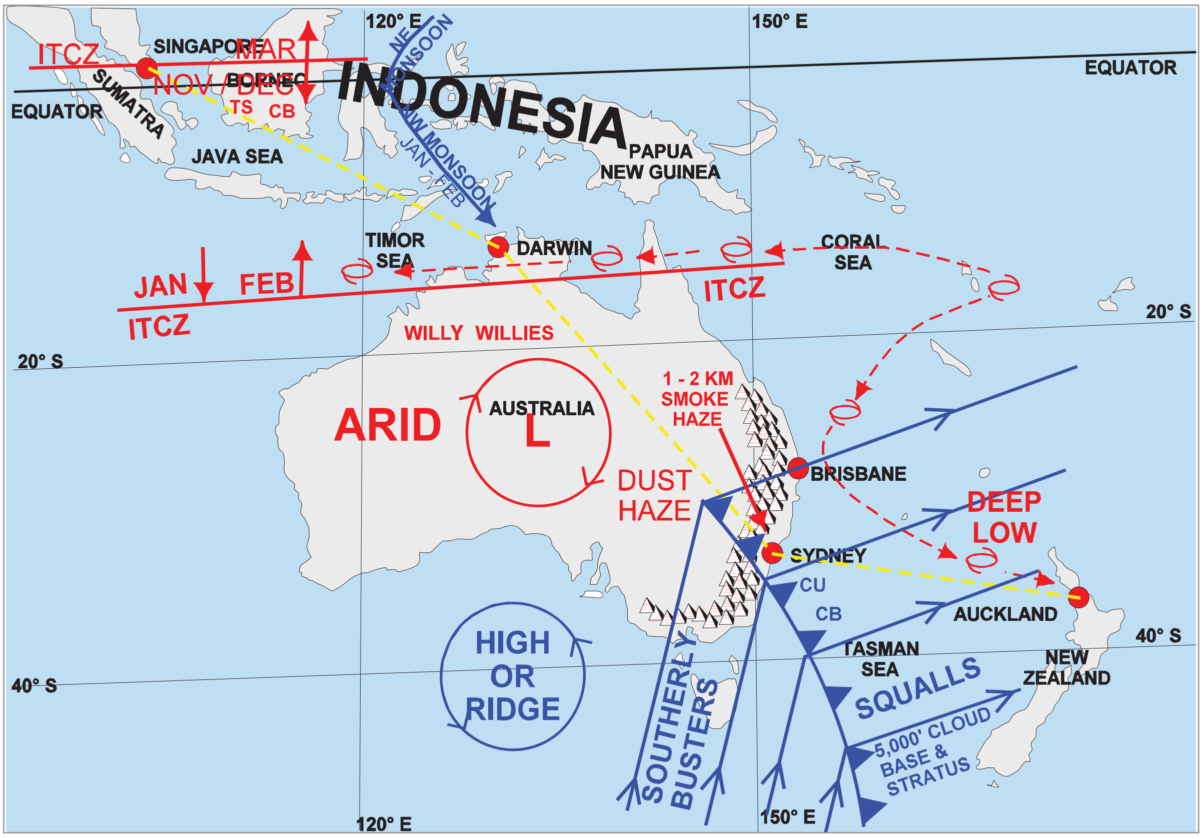


Figure 23.9 Surface pressure and weather - January (Summer)

Pressure Systems

ITCZ

Over Singapore the ITCZ is southbound in November/December and northbound in March. Its southerly extreme is just **south of Darwin** at the end of **January.** Thus it affects the **Singapore - Darwin** section of the route from **November to March.**

Continental Low

The Australian subtropical high belt of winter has moved south with the sun. Over **Australia** itself intense insolation brings **low pressure** to the interior.

Cyclones

Tropical cyclones and associated weather form adjacent to the ITCZ over the **Coral** and **Timor Seas.** They move at 10-15 knots in one of two general directions:

- Westwards, close to the North Australian coast, or
- Curve to the left from the Coral Sea around the South Pacific High to affect the Australian east coast at Brisbane.

Occasionally they travel further southeastwards degrading to a deep depression as they cross the Tasman Sea to New Zealand's North Island.

Surface Winds

The northeast monsoon wind blowing from the South China Sea to Singapore will continue across the Equator to become now the **northwest monsoon** (Coriolis change) as far as the ITCZ; which in late January is just south of Darwin. Beyond the ITCZ there will be **southeast trade winds** although overland they will be modified around thermal low pressure centres.

At Sydney the SE trades can give way to a strong **E/NE sea breeze**, or **southerly** winds after the passage of a polar front cold front. The latter are known locally as **Southerly Busters** (see 'cloud and precipitation' below).

Cyclones from the Coral Sea via Brisbane occasionally continue southeastwards over the Tasman Sea to produce very deep lows with **strong variable winds** but otherwise winds between Sydney and Auckland are generally **westerly**.

Visibility

Visibility over Darwin and to the north is good except in precipitation from CB/TS. Between Darwin and Sydney, clockwise rotation around continental low pressure carries dust to the centre and south of the route and occasional dust storms will occur sometimes known in the NW as "Willy-Willies". **Industrial haze** near cities may reduce visibility to **1 - 2 km**. Visibility over the Tasman Sea is good except in precipitation.

Cloud and Precipitation

The Singapore and Indonesia region is one of the most **active daily thunderstorm** areas in the world. This is due to high ambient temperature, strong overland insolation coupled possibly with orographic uplift, and high humidity from the abundant supply of sea water. At no time of the year is this region free from daily convective cloud, but the presence of the **ITCZ enhances instability** even further. Therefore in the southern summer, thunderstorms may be present all the way from Singapore to Darwin, and are reinforced by the ITCZ near Singapore in November/December and March, and near Darwin in January/February.

South of the ITCZ , the Australian **interior** is mainly **arid**. Towards Sydney, the weather is mainly subtropical excepting cyclones, but occasional cold troughs or fronts give squally wet weather.

The passage of these **fronts** causes a marked drop in temperature, CU CB, and squalls and a **sharp back** in the wind to south known in Sydney as **"Southerly Busters"**. Indeed the Sydney weather can be worst in summer.

From Sydney to Auckland, eastward travelling high cells, in the subtropical high belt, are interspersed with troughs and associated cold fronts.

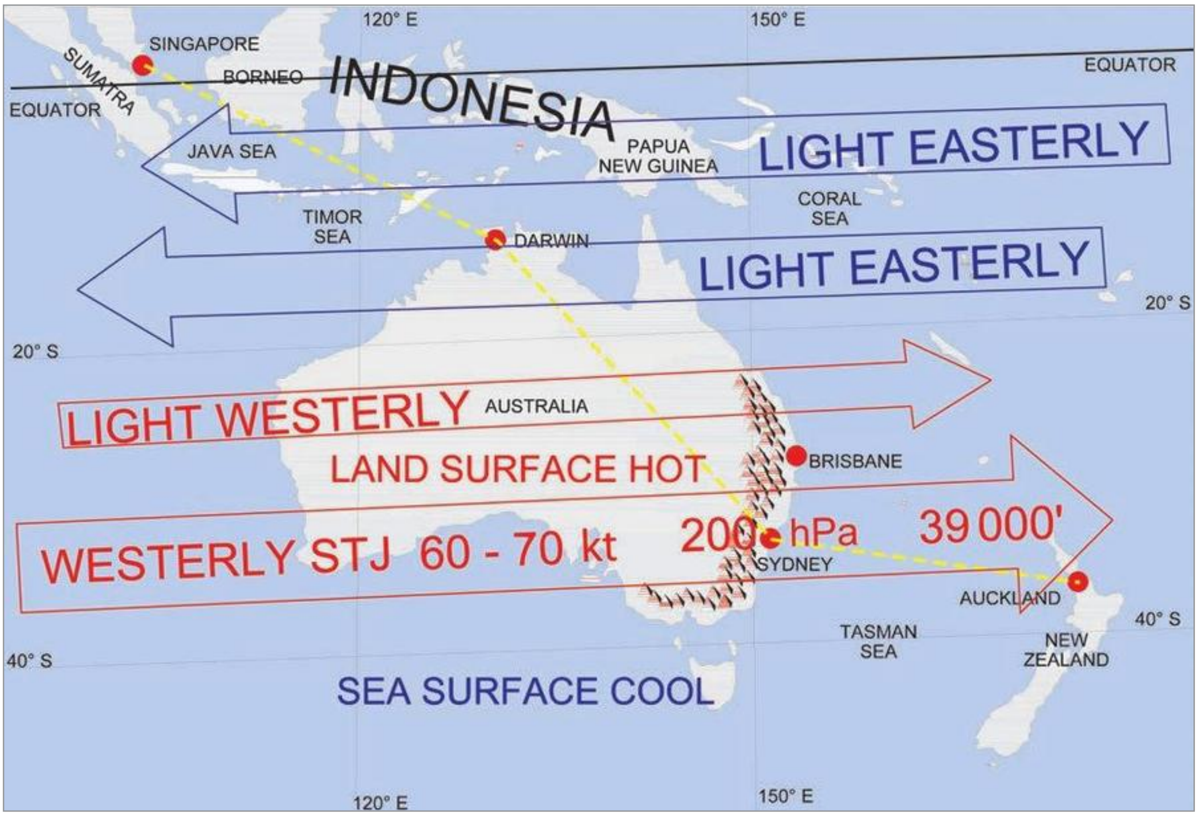


Figure 23.10 Upper winds - January (Summer)

Upper Winds

Light upper equatorial easterlies blow from Singapore to approximately 20°S after which winds will increase from the West. In summer the whole continent of Australia is hot with cooler sea to the south. Thus the **200 hPa subtropical westerly jet** is now along the south coast at around **70 knots** reducing to 40 knots towards Auckland.

Icing

Icing can be severe above 16 000’ in CBs.

Tropopause and Freezing Levels

	North	South
Tropopause	56 000’	51 000’ (tropical air) - 36 000’ (polar air)
Freezing Level	16 000’	10 000’ (summer) - 5000’ (winter)

Cairo to Johannesburg via Nairobi 30°N - 27°S   28° - 37°E

Geographical Considerations

The route over Egypt and Sudan is almost all over low lying Sahara desert. At the Kenya border latitude 06°N, the land rises, at the beginning of the equatorial vegetation belt, to over 5000' by 02°S at Nairobi. The route then traverses the eastern edge of the Kalahari plateau to the high veld of Johannesburg.

January (Northern Winter/Southern Summer)

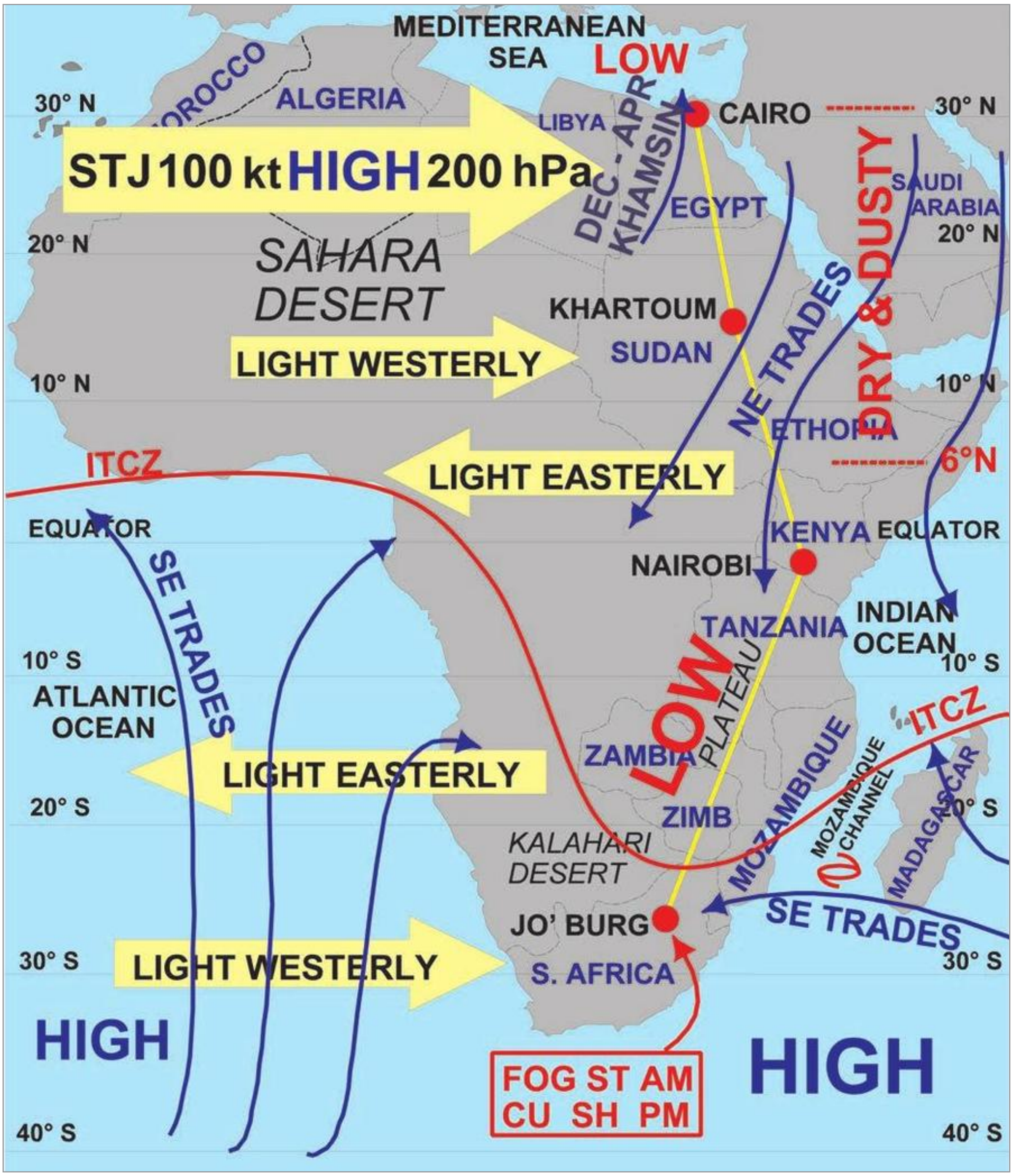


Figure 23.11 January surface weather and wind velocity, upper wind velocity in yellow

Pressure Systems

In the northern winter, **pressure** will be **high** over the comparatively cool **Sahara desert**.

The **ITCZ** will be at its southern extreme over Zimbabwe. This will lead to overland **low pressure** extending south from **Nairobi to Johannesburg.**

Weather

The northern section from **Cairo to 06°N** will be **dry and dusty.**

Convective CU/CB and some **NS** will form near Nairobi, and further south instability will be further enhanced by the ITCZ.

At Johannesburg, orographic **low cloud and fog** can occur early morning, but this clears quickly to give way to **convective CU** and showers in the afternoon. It is the wet season.

Cyclones originating in the Mozambique Channel can sometimes move west to affect Zimbabwe and northern South Africa.

Surface Winds

The southerly **Khamsin** wind to the Mediterranean blows from Egypt between **December and April.**

Further south over Sudan and Kenya, clockwise outflow from the Sahara High will become first northerly then northeasterly to become the trade winds blowing from dry Saudi Arabia.

South of the Equator they will back again northerly (Coriolis change) to blow **clockwise** around **southern Africa's summer low** pressure of some 1005 hPa; and for this reason, become easterly again near Johannesburg.

Visibility

Visibility is poor over the dusty Sahara but good towards Nairobi except in showery precipitation. At Johannesburg early morning fog can be caused by the easterly surface winds from the Indian Ocean orographically rising to the Kalahari plateau.

Icing

Icing can be severe above 16 000' in CB near the ITCZ.

July (Northern Summer/Southern Winter)

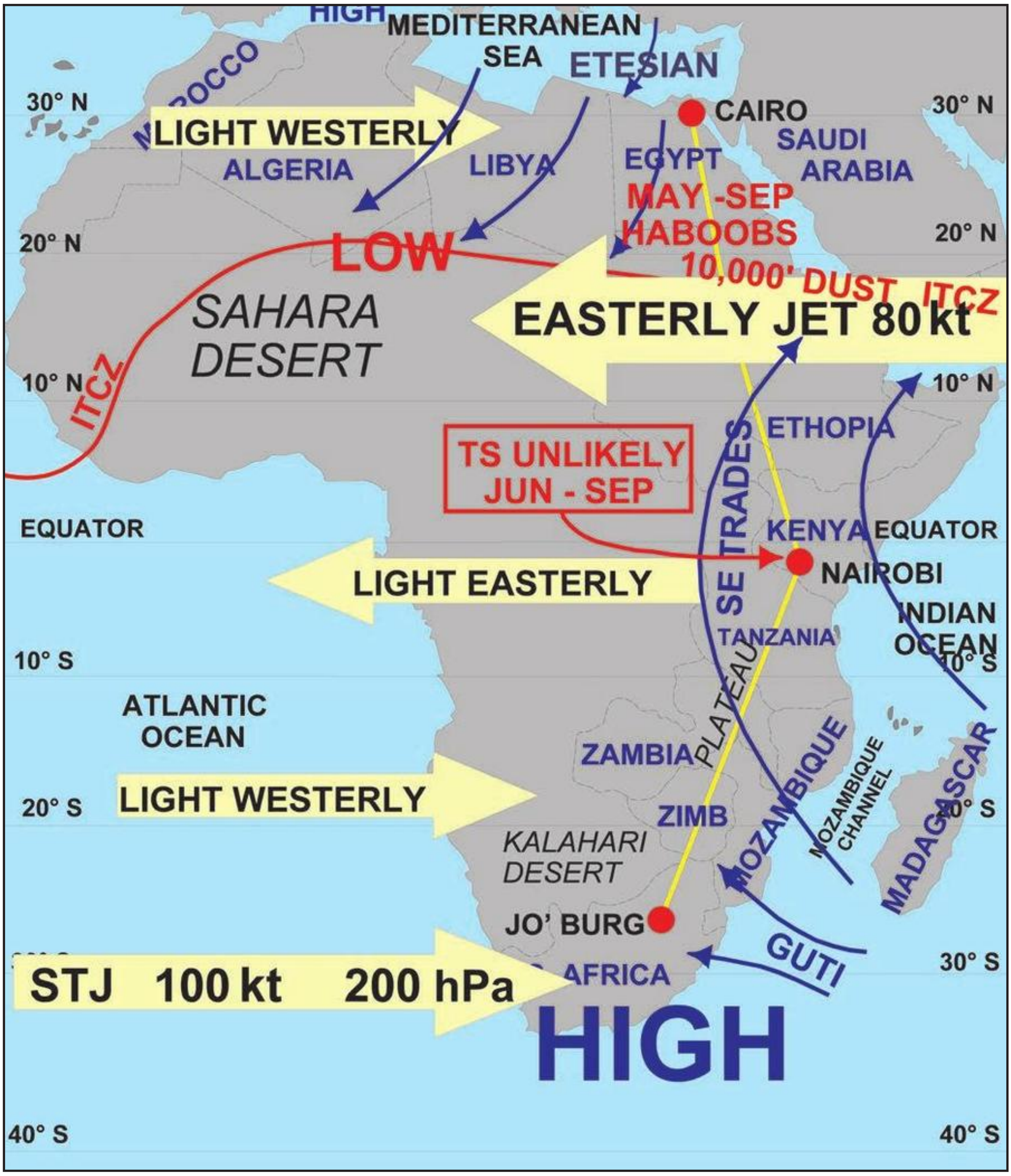


Figure 23.12 July surface weather and wind velocity, upper wind velocities in yellow

The ITCZ equatorial trough has moved north with the sun to approximately 18°N, thus pushing the winter Sahara anticyclone northwards to the Mediterranean.

Behind and south of the ITCZ, cooler winter temperatures over the **southern African landmass** will build pressure.

Weather

The ITCZ northern extreme is just north of Khartoum in July. This is therefore normally that city's only wet month of the year. The ITCZ brings a tropical rain belt, line squalls and dust storms known as **Haboobs** which often appear as walls of dust lifted to 10 000'. Haboobs can appear in Northern Sudan from May to September as the ITCZ sweeps north then south. They form during the day when convection is strong.

It is winter in Johannesburg. Continental high pressure prevails and it is the **dry season** although ST and SC turbulence cloud may form in air rising orographically from the Indian Ocean to the Johannesburg high veld.

Surface Winds

High pressure over the Mediterranean, and low pressure over Arabia will give northerly surface winds (an extension of the Mediterranean Etesian) over the route from Cairo to the ITCZ which in July is near 18°N.

South of the ITCZ and north of the Equator, winds will be from the SW (Coriolis effect), reverting to the SE trade winds south of the Equator. Over southeastern Africa these SE trades are known as the **Guti.** The southeasterly Guti blows anticlockwise around the overland winter high, often being in place for five days or so at a time. It can bring the orographically formed ST & SC to Johannesburg.

Visibility

Visibility over the Sahara will be appalling in Haboobs, and poor elsewhere in Sahara dust. Near Nairobi it will be good except in showers. At Johannesburg visibility may be reduced below low ST/SC formed by the Guti SE wind.

Icing.

As in winter, icing can be severe above 16 000' in CB.

Nairobi Region

This region is of special interest because the **two ITCZ transits** in the **year** each give their own instability rainfall pattern.

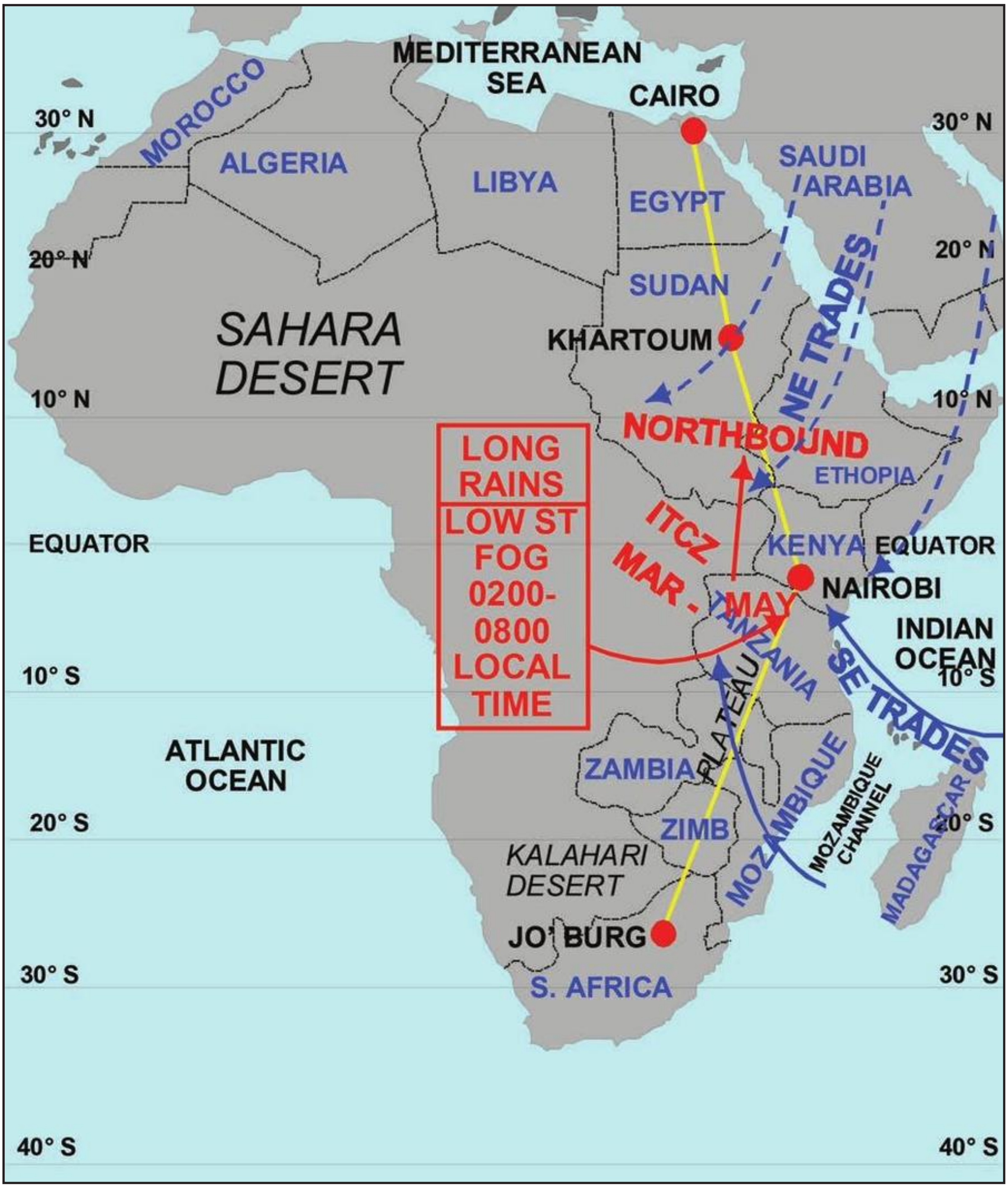


Figure 23.13 Nairobi weather March - May

Northern Hemisphere Spring

ITCZ passage will be **northbound** (March/May) and will be followed by the **moist** SE trade winds from the Indian Ocean. Rainfall will be extensive and is known as the **Long Rains.**

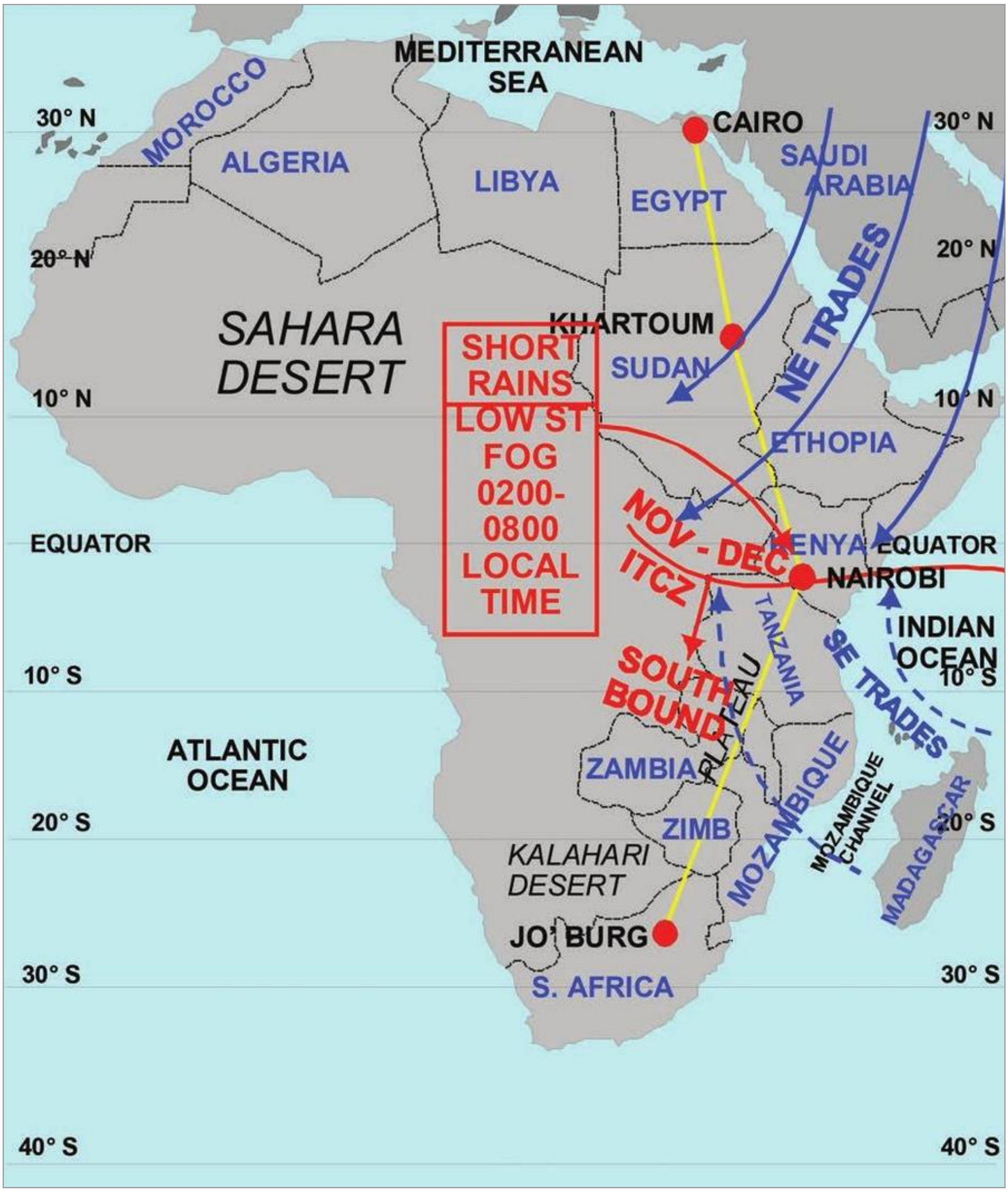


Figure 23.14 Nairobi weather November - December

Northern Hemisphere Autumn

ITCZ passage will be **southbound** (November/December) and will be followed by the dry NE trade winds from Saudi Arabia. Rainfall will still occur but will be less and is known as the **Short Rains.**

Orographic Uplift

At each ITCZ passage the surface W/V will be alternating between NE and SE. Nairobi has an elevation of over 5000’ and is only 200 NM from the east coast. **Especially during the long and short rains** at ITCZ passage, and between **0200 and 0800 local time**, orographic uplift in the generally easterly winds can frequently produce low stratus, often lowering to the undulating surface as **fog**.

Thunderstorms

Convective thunderstorms can occur at any time but are very infrequent from June to September when the ITCZ is well north.

Tropopause and Freezing Levels

Tropopause heights average 56 000’ all year.

Freezing level heights are 16 000’ in equatorial regions and average 14 000’ in the higher latitudes in winter.

Chapter

24

Satellite Observations

Introduction

Meteorology has benefited considerably by the use of satellites in recent years. Apart from the obvious advantages of satellite communications over the old land-based systems, providing prompt and trouble free communication of meteorological data, satellite photography has provided weather images that were impossible to produce in the past and were often merely ‘artist’s impressions’ of the weather.

There are two types of satellite; the polar orbiting and the geostationary and two methods of producing the weather picture; visual photography and infrared.

Polar Orbiting Satellites

The so-called polar orbiting satellites have been put up principally by Russia (Meteor) and USA (NOAA). The NOAA orbit is inclined at an angle of 99° to the Equator, takes 1 h 42 min to orbit the earth, is between 820 and 870 km above the surface and covers a band 1500 NM wide. Each successive orbit is a little further west and there will be an overlap, greatest at the poles and small near the Equator. Any spot on the globe will experience a southbound pass of the satellite in the morning and a northbound pass in the afternoon or evening. Although picture definition is good, polar orbiting satellites do not give a continuous view of the weather.

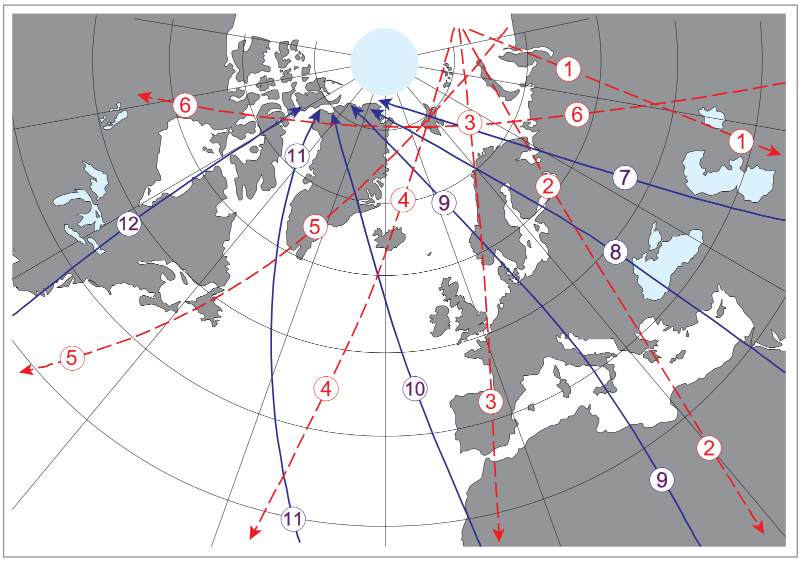


Figure 24.1 Successive tracks of a polar orbiting satellite

Geostationary Satellites

Geostationary satellites are put into orbit over the Equator and since they take 24 hours to complete the orbit, they will appear to be stationary over a selected longitude. In 1987 there were 5 geostationary satellites in orbit; meteosat 2 over the Greenwich meridian, GOES E over longitude 75W, GOES W over longitude 135W, GMS 2 over longitude 140E and INSAT over longitude 70E.

These satellites are considerably higher than the polar orbiting satellites (36 000 km) and picture definition may not be as good, but the advantage of a continuous picture outweighs this disadvantage. Because of the Equatorial orbit the picture becomes somewhat distorted towards the poles, but this may be corrected by computer processing. Meteosat covers about

1/3 of the earth's surface from 70° West to 70° East. The satellite transmits a picture every 4 minutes and a useful feature is the time lapse sequence showing movement of weather over a period of time.

Visual Images

Although visual photography may be easy to interpret, it suffers the disadvantage of not being available continuously, due to lack of sunlight at night. Clouds will appear white, the land grey and the sea black.

Infrared (IR)

Infrared images have the advantage of being available for 24 hours a day and the shading of the picture will be more or less the same by day and by night. Cold (high) cloud will give a white image, lower cloud a somewhat darker one, whilst warm land will give a dark image. There are 9 IR temperature bands, black normally denoting cloud free areas. IR may not be able to distinguish between a sea surface and fog, which may have a similar temperature. In this case, a visual picture would be able to show the position of fog more precisely. (See *Figure 24.2* & *Figure 24.3*).

Figure 24.2 Visual picture of north sea fog

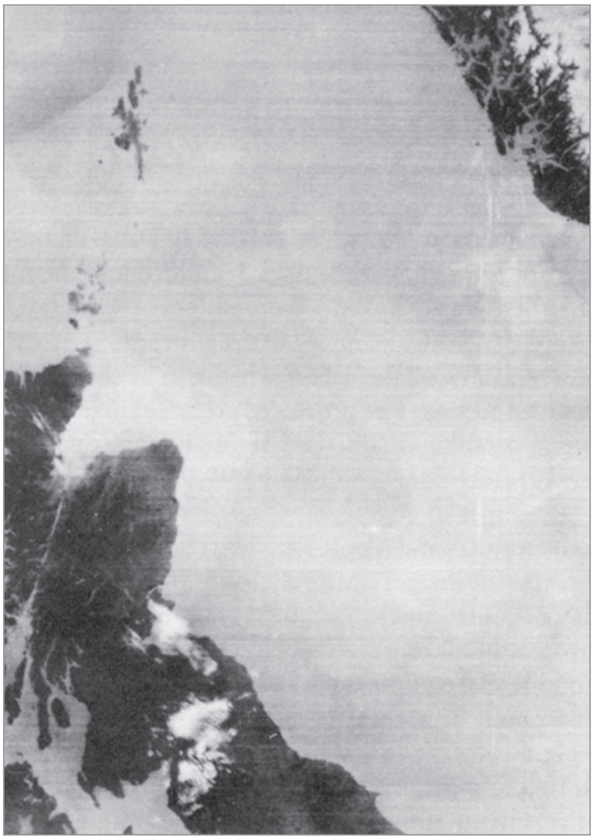


Figure 24.3 Infrared picture of north sea fog

False Colour Pictures

To help differentiate between the various shades of grey produced by both visual and IR photography, the shades may be converted by computer into various colours. This is used particularly with IR systems.

Location of the Image

It is often difficult to pick out geographical features, especially when there is thick cloud and of course, areas of oceans are completely featureless. Satellite images are therefore presented with a computer produced graticule of numbered parallels and meridians superimposed. Coastlines may be enhanced as well.

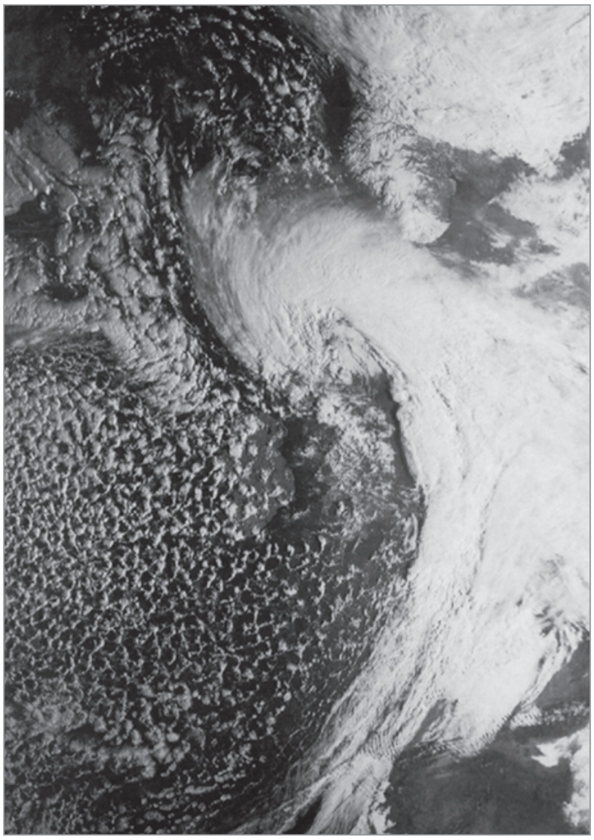


Figure 24.4 Satellite Visible Image, 0909 GMT

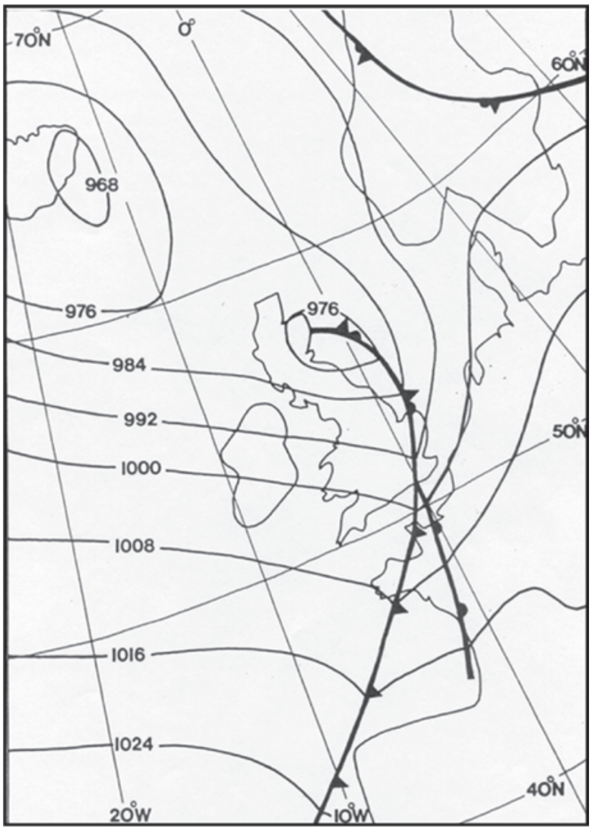


Figure 24.5 Surface Weather Map for the same time

Interpretation of Satellite Photography

Whilst violent weather such as tropical revolving storms may produce an easily identifiable picture, normal weather pictures are best used in conjunction with synoptic charts. The time-lapse sequences can be used to confirm existing and forecast weather before setting off on a flight. *Figure 24.4* & *Figure 24.5* show a surface analysis and a satellite picture for the same time.

Figure 24.6 shows the visual image with the surface analysis superimposed.

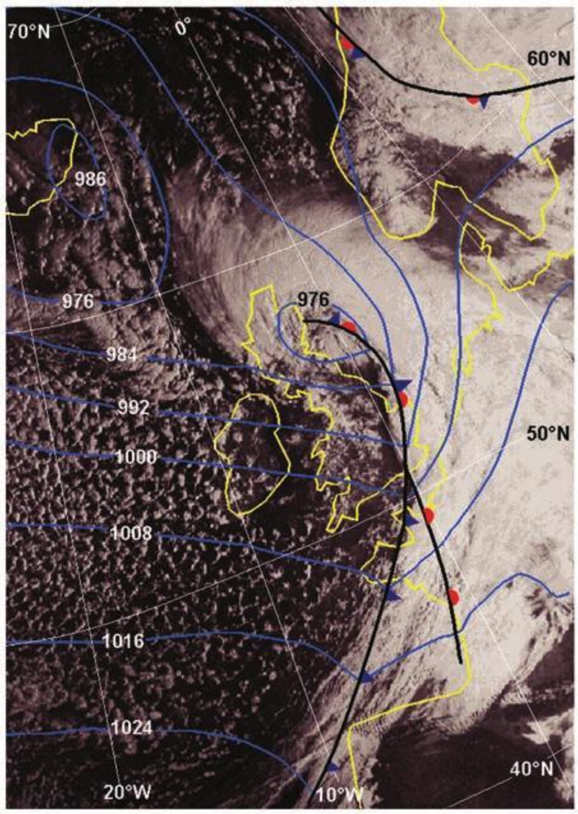


Figure 24.6 Weather map and visual image

Chapter

25

Meteorological Aerodrome Reports (METARs)

Introduction

The letters **METAR** stand for **MET**eorological **A**erodrome **R**eport. METARs contain coded messages pertaining to the **actual weather conditions** at a **given aerodrome**, at a **stated time**. Typical METARs for United Kingdom aerodromes, extracted from the United Kingdom Met Office website, are shown below.

```
ZCZC ZKA498 031428
GG EGTKZGZX
031428 EGGYYBYA
SAUK34 EGYY 031420
METAR EGDG NIL=
METAR EGHD 031420Z 00000KT 9999 SCT025 13/08 Q1032=
METAR EGHE NIL=
METAR EGHK 031420Z 34005KT 9999 SCT020 BKN040 15/08 Q1031 NOSIG=
METAR EGJA 031420Z 05008KT 020V100 9999 FEW030 SCT050 15/09 Q1031=
METAR EGJB 031420Z 04008KT 9999 FEW028 BKN250 15/08 Q1031
METAR EGJJ 031420Z 04010KT 010V100 9999 FEW030 16/08 Q1030 NOSIG=
METAR EGTE 031420Z 02005KT 040V050 9999 FEW024 BKN045 15/07 Q1031=
METAR EGTG 031420Z 00000KT 9999 BKN036 14/06 Q1032=
```

METARs are usually issued every **half hour** during aerodrome operating hours. The aim of this chapter is to explain the METAR coding, group by group.

Decoding the METAR

This example reproduces the first eight code-groups normally found in a **METAR**.

METAR EGTK 231020Z 26012G25KT 220V300

For clarity the METAR has been split into its significant parts - (a) to (h):

METAR	**EGTK**	**231020Z**	**260**	**12**	**G**	**25KT**	**220**	**V**	**300**
(a)	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**		**(h)**	

Report Type

The first code, **(a)**, is the identification of the type of report; in this case a METAR.

Aerodrome

The four-letter **ICAO designator** of the **issuing aerodrome** is shown next, **(b)**; this example is for Oxford/Kidlington, EGTK.

Date-Time Group

The third group, **(c)**, is the **date/time group**, which simply gives the date of the actual weather observation. The first **two digits represent the day of the month**, followed by the **time in hours and minutes**. Time is always given as Coordinated Universal Time (UTC), which is, for all practical purposes, the same as Greenwich Mean Time (GMT): the local time at Greenwich, London. In the METAR, itself, UTC is indicated by the code **Z**, pronounced "Zulu".

Wind Information

The next items in the METAR (**d, e, f** and **g**) are the **observed wind information**. Firstly, the **direction** of the wind given in **degrees true**, rounded up or down to the **nearest 10 degrees, (d)**, and then the **wind speed in knots, (e),** which is a **mean speed** taken over a **10 minute** period. However, if a gust is observed which is at least 10 knots more than the mean wind speed, then a **gust figure, (g)**, comes after the mean wind; this gust figure is preceded by the letter **G, (f).**

The next code-group, **(h)**, may or may not appear depending on the directional **variability** of the wind. Variability of direction is included when the wind direction, over the preceding 10 minutes, has changed by 60° or more. The letter **V** will appear between these two extremes. If there is no wind, the coding, **00000KT**, will be used. If the wind direction cannot be defined then VRB (for variable) replaces the direction.

Visibility

Visibility in the METAR is represented by the next group, depicted in **red** in the example. In the METAR, the reported visibility is the prevailing visibility and, may, under certain conditions, include the minimum visibility. Here, the prevailing visibility is reported as 0800 metres.

Prevailing visibility is the visibility value which is either reached, or exceeded, around at least half the horizon circle, or within at least half of the surface of the aerodrome. If the **visibility** in one direction, which is not the prevailing visibility, is less than 1500 m, or less than 50% of the prevailing visibility, the lowest visibility observed, and its general direction, should also be reported.

Up to 10 km, the visibility is measured in metres. For example, 6000 means that the prevailing visibility is 6000 metres. Once the visibility reaches 10 km or more, the code figure used is 9999.

Visibility of **less than 50 metres** is indicated by the code **0000**. In this example the prevailing visibility is 800 metres.

METAR EGTK 231020Z 26012G25KT 220V300 0800

In some instances, **runway visibility** information is given in a METAR; this is known as **Runway Visual Range (RVR.)** RVR is given only when either the horizontal visibility or the RVR, itself, is less than 1500 metres. The RVR group starts with the letter **R**, and then goes on to give the **runway in use**, followed by the **threshold visibility in metres**.

In the following example, for Oxford Kidlington, we have a prevailing visibility of 800 metres, with an RVR, at the threshold of Runway 30, of 1100 metres.

METAR EGTK 211020Z 26012G25KT 0800 R30/1100

If the RVR is more than the **maximum reportable value of 1500 metres**, the code **P** is used in front of the visibility value, R30/P1500. If the visibility is less than 50 m then the prefix M will be used e.g. R30/M0050

A letter can sometimes come after the RVR to indicate any trends that the RVR has shown. A **U** means that the visibility has increased by **100 m** or more in the last **10 minutes**, e.g. R30/1100U. A **D** shows that visibility has **decreased** by 100 m or more in that same time period, R30/1100D. An **N** added to the visibility group shows that there is no distinct trend observed, R30/1100N.

The Weather Group

The next section of the METAR is the weather group. The **weather group** gives information on the **present weather** at, or near, the aerodrome at the time of the observation. The weather group **+SHRA** added to our example METAR means **"heavy showers of rain"**.

METAR EGTK 211020Z 26012G25KT 0800 R30/1100 +SHRA

The following table lists the various codes which may be used in the METAR weather group to describe different weather phenomena.

Significant Present and Forecast Weather Codes				
Qualifier		Weather Phenomena		
Intensity or Proximity	**Descriptor**	**Precipitation**	**Obscuration**	**Other**
- Light Moderate (no Qualifier) +Heavy (well developed in the case of FC and PO) VC - In the vicinity	MI - Shallow BC - Patches BL - Blowing SH - Shower(s) TS - Thunderstorms FZ - Freezing (Supercooled) PR - Partial (covering part of aerodrome)	DZ - Drizzle RA - Rain SN - Snow IC - Ice Crystals (Diamond Dust) PL - Ice Pellets GR - Hail GS - Small hail - (<5 mm in diameter and/or snow pellets) UP - Unknown Precipitation PY - Spray	BR - Mist FG - Fog FU - Smoke VA - Volcanic Ash DU - Widespread Dust SA - Sand HZ - Haze	PO - Dust/Sand Whirls (Dust Devils) SQ - Squall FC - Funnel Cloud(s) (tornado or water spout) SS - Sandstorm/ Duststorm

The first column represents the **intensity** or **proximity** of a weather phenomenon. These have the following meaning:

- - meaning light
- + meaning heavy
- VC meaning in the vicinity of, but not at, the observation point
- If there is no qualifier (+ or -) in front of precipitation then the precipitation is moderate

The second column in the table, bearing the title **Descriptor**, contains letters which add **detail** to each weather phenomenon; for example, **BC** means **patches**, and is frequently used to describe **fog**, **SH** means **showers**, and **TS** means **thunderstorm**.

The last three columns in the table contain codes which describe the weather phenomena themselves.

The column headed **Precipitation** contains codes for **drizzle, rain, snow, hail** etc. The next column covers those weather phenomena which are classified as **Obscurations**; these include **mist**, **fog**, **smoke**, and **ash**.

The last column in the table contains those weather phenomena which have not already been mentioned in the table. This group mainly consists of the more unusual weather events that are rarely reported in the United Kingdom.

Referring to the weather group of the partially complete METAR which indicated heavy showers of rain, **+SHRA**, we see that + means **heavy, SH** indicates **showers** and **RA** stands for **rain.**

Thunderstorms

A **Thunderstorm** report will appear in a METAR if **thunder has been heard within the last 10 minutes.**

A thunderstorm is represented by the letters **TS**. If there is **no precipitation**, the letters TS will appear on their own. However, if there is **precipitation**, a further two letters, which signify the type of precipitation, are inserted after the TS. For example, if there is **rain** observed from the thunderstorm, **TSRA** will appear in the METAR. If **hail** were to be observed, the code would read **TSGR**, or **TSGS**, with **GS** meaning **small hail.**

Cloud Coverage

The next code-group to appear in the METAR gives detail of **cloud coverage**, as highlighted in red below. In this case the highlighted code means: overcast sky, base 2000 ft, with cumulonimbus.

METAR EGTK 211020Z 26012G25KT 0800 R30/1100 +SHRA OVC020CB

There are several prefixes which are used to describe **cloud amount**, at any given level. Cloud coverage is reported in the METAR using the following three-letter codes:

- **FEW (FEW)** meaning **one to two eighths** of cloud coverage.
- **SCATTERED (SCT)** meaning **three to four eighths** of cloud coverage.
- **BROKEN (BKN)** meaning **five to seven eighths** of cloud coverage.
- **OVERCAST (OVC)** meaning **complete cloud coverage**, or **eight eighths.**

Figure 25.1

Cloud base is given as a **three-digit figure** showing **hundreds of feet.** Cloud base in a METAR is always measured as **height above aerodrome level**, using the current aerodrome **QFE**.

For example, 6 eighths of cloud (6 oktas) at 1900 ft above aerodrome level would appear in the METAR as BKN019. 8 oktas at five hundred feet would be abbreviated to OVC005.

The only **cloud types** that are specified in the METAR are the **significant convective clouds**. These are **cumulonimbus (CB)** and **towering cumulus (TCU)**.

Looking back to the cloud group we see the code **OVC020CB**. This refers to an overcast sky covered by convective cumulonimbus cloud whose base is 2000 ft above aerodrome level. The previous weather group, +SHRA, indicates that the cloud detailed in the cloud group is producing a heavy shower of rain. If there is no cloud of operational significance (CB or TCU) or no cloud at or below the greater of 5000 ft or the highest minimum sector altitude then the term NSC (no significant cloud) will be used unless CAVOK (see below) is appropriate.

Obscuration

If the sky at an aerodrome is **obscured** for reasons other than cloud cover, and cloud coverage cannot easily be determined, the code **VV** is used in place of the cloud information. VV is followed by the **vertical visibility** in hundreds of feet.

METAR EGTK 231020Z 26005KT 0300 FG VV002
(a) (b)

The highlighted codes in this METAR indicate that:

Visibility is 300 m in fog (a), the sky is obscured and the vertical visibility is 200 ft.

This METAR decodes as follows:

METAR for Oxford/Kidlington, observed at 1020 UTC on 23rd of the month; the surface wind is 260° True, at 5 kt; the visibility is 300 m in fog (a); the sky is obscured with a vertical visibility of 200 ft (b).

If the vertical visibility cannot be assessed, **three forward slashes** will replace the cloud height figures, e.g. **VV///**.

The code **CAVOK** is frequently used in the METAR code, being the abbreviation for **"cloud, ceiling** and **visibility** are **OK**." If CAVOK is used, it will replace the visibility, RVR, weather and cloud groups. There are four criteria which must be met in order for CAVOK to appear in the METAR. These are:

- the visibility must be **10 kilometres** or more.
- the **height of the lowest cloud** must be **no less than 5000 ft**, or the level of highest minimum sector altitude, whichever is the greater.
- there must be **no cumulonimbus** or **'towering cumulus' (TCU)** present.
- there must be **no significant weather** at or in the vicinity of the aerodrome.

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK

Temperature and Dew Point

The **temperature** and **dew point** constitute the next group in the METAR code. The temperature and dew point code is simply a **two-digit number** giving the **air temperature**, with a **forward slash**, followed by another **two-digit number** which indicates the **dew point**. Both temperatures are measured in **degrees Celsius**. For example, the code 10/02 indicates that the air temperature is plus 10°C, and the dew point is plus 2°C. If either figure is **negative**, the prefix **M** will be used, as in 10/M02. The dew point in the example just given is minus 2°C.

Note: *the normal mathematical convention of rounding 0.5 to the next highest digit is used. So +1.5 would be reported as '02', and -1.5 would be reported as 'M01'. -0.5 would be reported as M00.*

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK 10/M02

This METAR decodes as follows:

METAR for Oxford/Kidlington, observed at 1020 UTC on 23rd of the month; the surface wind is 260° (True) at 12 knots, gusting to 25 knots and varying in direction from 220° (T) to 300° (T); the visibility is 10 km or more, with no cloud below 5000 ft; there are **no CB or TCU** and there is no significant weather at, or in the vicinity of, the aerodrome; the air temperature is +10°C and the dew point is -2°C.

QNH

The next METAR code is the **QNH**. The QNH will be represented by the letter **Q**, followed by a **four digit number** representing the **actual pressure value.** If the QNH is less than **1000 hectopascals**, the value will be preceded by a zero. For example, a **QNH** of **991 hectopascals** would appear as Q0991.

METAR EGTK 231020Z 26012G25KT 220V300 9999 -RA FEW060 SCT120 10/M02 Q0991

It is important to note that the only pressure value given in a METAR is the QNH. The QNH is always rounded **down** for safety reasons, if there are digits after the decimal point; for instance, if the QNH were 991.7 hectopascals, the QNH would be reported as Q0991.

In N. America QNH is reported in inches of mercury. The letter 'A' is used to indicate this, e.g. A2989 means a QNH of 29.89 inches of mercury.

The above **METAR** decodes as follows:

METAR for Oxford/Kidlington observed at **1020 UTC** on **23rd** of the month; the **surface wind** is **260° (T) at 12 kt, gusting to 25 kt**, and **variable in direction from 220° (T) to 300° (T);** the **prevailing visibility is 10 km** or more with **light rain**; there are **1 to 2 oktas of cloud at 6000 ft** and **3 to 4 oktas at** 12 000 ft; the air temperature is **+10° C** and the dew point is **-2° C**; the **QNH is 991 hectopascals.**

Recent Weather

If there has been **recent significant weather**, either in the past hour, or since the last METAR was issued, and if the significant weather has ceased, or reduced in intensity, a METAR code group beginning with **RE** will appear. **RE** stands for **recent.** If there has been a thunderstorm during the hour, but which has now abated, giving only light rain, the present weather is reported as light rain, –RA; the fact that there have been thunderstorms in the past hour is reported by the code RETS:

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS

Windshear

Although not currently issued at **United Kingdom** airfields, **windshear** information may be reported in the **METAR.** This will simply be denoted by the letters **WS**, followed by the necessary details, such as **WS ALL RWY**, meaning **windshear on all runways**, or **WS 30**, meaning **windshear present on Runway 30**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY

TREND, BECMG, TEMPO

A **TREND** forecast is valid for **2 hours** after the time of the observation of the METAR, and constitutes the final section of the METAR. The change in weather conditions indicated by the code, TREND, can be further qualified by the codes, **BECMG**, meaning **becoming**, or **TEMPO** meaning **temporarily.**

BECMG indicates that the change in the present weather will be long-lasting. **TEMPO**, on the other hand, means that the change is **temporary**, and that the different conditions will prevail for periods of **less than one hour**, only, and **no more than half the time period**, in aggregate. The codes may be followed by a time period in hours and minutes. The time periods given may be preceded by **FM** meaning **from**, **TL** meaning **until**, or **AT** meaning **at**.

For example, TEMPO FM1020 TL1220 1000 +SHRA translates as: temporarily, from 1020Z to 1220Z, the visibility will reduce to 1000 metres, in heavy showers of rain.

If there is no expected change in the meteorological conditions being forecast by the METAR, the code **NOSIG** is used to indicate that **no significant change** is expected in the next two hours.
METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG

Runway State Group

A runway state group will be added to a METAR or SPECI (see below) when there is significant contamination on the runway. The format is RXX/XXXXXX the runway designator followed by an oblique then 6 digits describing the contamination state.

Runway Designator
R27 = Runway 27 or R27L = runway 27 left
R88 = All runways
R99 = A repetition of the last message received because no new information received

Runway Deposits - 1st digit
0 = Clear and dry
1 = Damp
2 = Wet or water patches
3 = Rime or frost covered (depth normally less than 1 mm)
4 = Dry snow
5 = Wet snow
6 = Slush
7 = Ice
8 = Compacted or rolled snow
9 = Frozen ruts or ridges
/ = Type of deposit not reported (e.g. due to runway clearance in progress)

Extent of Runway Contamination - 2nd digit
1 = 10% or less
2 = 11% to 25%
5 = 26% to 50%
9 = 51% to 100%
/ = Not reported (e.g. due to runway clearance in progress)

Depth of Deposit - 3rd & 4th digits
The quoted depth is the mean number of readings or, if operationally significant, the greatest depth measured.
00 = less than 1 mm
01 = 1 mm etc. through to ...
90 = 90 mm
91 = not used
92 = 10 cm
93 = 15 cm
94 = 20 cm
95 = 25 cm
96 = 30 cm
97 = 35 cm
98 = 40 cm or more
99 = Runway(s) non-operational due to snow, slush, ice, large drifts or runway clearance, but depth not reported
// = Depth of deposit operationally not significant or not measurable

Friction Coefficient or Braking Action - 5th & 6th digits
The mean value is transmitted or, if operationally significant, the lowest value.
For example:
28 = Friction coefficient 0.28
35 = Friction coefficient 0.35
or
91 = Braking action: Poor
92 = Braking action: Medium/Poor
93 = Braking action: Medium
94 = Braking action: Medium/Good
95 = Braking action: Good
99 = Figures unreliable (e.g. if equipment has been used which does not measure satisfactorily in slush or loose snow)
// = Braking action not reported

Note 1:
CLRD. If contamination conditions on all runways cease to exist, a group consisting of the code R88/, the abbreviation CLRD, and the Braking Action, is sent.

Note 2:
Within the UK friction coefficient measurements are only made on runways contaminated by ice (gritted or ungritted) and dry or compacted snow. Where contamination is caused by water, slush or wet snow then the friction coefficient or braking action should be reported as //.

Note 3:
It should be noted that runways can only be inspected as frequently as conditions permit, so that a re-issue of a previous half hourly report does not necessarily mean that the runway has been inspected again during this period, but might mean that no significant change is apparent.

Note 4:
It is emphasized that this reporting system is completely independent of the normal NOTAM system and these reports are not used by AIS for amending SNOWTAM received from originators.

If the aerodrome is closed due to contamination of runways, the abbreviation **SNOCLO** is used in place of a runway state group.

Special Reports

A variation on the METAR is the **Special Report**. A Special Report, which is denoted by the abbreviation, **SPECI**, has the same format as a METAR except that the code SPECI will replace METAR at the beginning of the report. A SPECI will be issued when the **weather conditions significantly change** in the period between routine observations. A SPECI can be issued to indicate either an **improvement** or a **deterioration** in the weather.

SPECI EGTK 231025Z 26012G25KT 220V300 2000 +RA OVC010 5/M02 Q0991 RETS WS ALL RWY NOSIG

Auto

Many aerodromes which are not used on a regular basis, or have limited staff available, have automatic meteorological stations which generate the METARs. This is an example of such a METAR:

EGDL 070650Z AUTO 03013KT //// // FEW110/// 09/06 Q1023 =

Note that where a field cannot be determined it is not omitted but replaced by '/'. So at Lyneham the visibility, weather and type of cloud cannot be determined and these groups have been replaced by a '/' for each element of the group.

End of Message

An equals sign (=) appears at the end of the METAR to denote that the **message is complete**.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG =

Summary

Although METARs may appear confusing to the uninitiated, with practice, it is quite a simple task to decode a METAR accurately and speedily. Pilots should consult METARs for **departure and destination aerodromes** and also for other **aerodromes along the planned route**, and, in particular, for aerodromes **upwind** of a destination aerodrome, in order to get a picture of the weather which is approaching the destination.

If the aerodrome of destination does not issue a METAR, consult a METAR from an aerodrome in the vicinity of your destination.

Questions

1. **When a TREND is included at the end of a METAR, the trend is a forecast valid for:**

   a. 1 hour after the time of observation
   b. 2 hours after the time of observation
   c. 2 hours after it was issued
   d. 1 hour after it was issued

2. **A METAR may be defined as being:**

   a. a routine weather report for a large area
   b. an aerodrome forecast containing a TREND for the next 2 hours
   c. a routine weather report concerning a specific aerodrome
   d. a forecast weather report concerning a specific aerodrome

3. **In the METAR shown below, the cloud base has been omitted. At what height might you expect the cloud base to be?**

   28005KT 9999 ?????? 12/11 Q1020 NOSIG

   a. SCT042
   b. OVC090
   c. SCT280
   d. OVC005

4. **Which of the following correctly decodes the METAR shown below?**

   METAR EGKL 130350Z 32005KT 0400N DZ BCFG VV002

   a. Observed on the 13th day of the month at 0350Z, surface wind 320° True, 05 kt, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft

   b. Reported on the 13th day of the month at 0350Z, surface wind 320° magnetic, 05 kt, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft

   c. Valid on the 13th day of the month between 0300 and 1500Z, surface wind 320°T/05 kt, minimum visibility 400 metres, drizzle, with fog patches and a vertical visibility of 200 ft

   d. Valid between 1300 and 1350Z, surface wind 320°T/05 kt, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft

5. **A temperature group of 28/24 in a METAR means that:**

   a. the temperature is 28°C at the time of reporting, but it is expected to become 24°C by the end of the TREND report
   b. the dry bulb is 28°C and the wet bulb temperature is 24°C
   c. the dew point is 28°C and the temperature is 24°C
   d. the temperature is 28°C and the dew point is 24°C

6. **Providing the minimum sector altitude is not a factor, CAVOK in a TAF or METAR:**

   a. means visibility 10 km or more, and no cloud below 5000 ft
   b. means visibility 10 km or more, and few cloud below 5000 ft
   c. means visibility 10 nm or more, and no cloud below 5000 ft
   d. means visibility 10 nm or more, and no scattered cloud below 5000 ft

7. **The visibility group R20/0050 in a METAR means:**

   a. as measured by runway measuring equipment for runway 20, a current visibility of 50 metres
   b. for runway 20, a current visibility of 500 metres measured by runway visual range equipment
   c. the runway visibility reported is 50 metres as measured by runway visual range equipment in the last 20 minutes
   d. on runway 20 the current viability is less than 5000 metres

8. **The code "BECMG FM 1100 –RASH" in a METAR means:**

   a. from 1100UTC, the cessation of rain showers
   b. becoming from 1100UTC slight rain showers
   c. becoming from 1100UTC rain showers
   d. becoming from 1100UTC till 0000UTC slight rain showers

Answers

1	2	3	4	5	6	7	8
b	c	d	a	d	a	a	b

Chapter

26

Terminal Aerodrome Forecasts (TAFs)

Introduction

Terminal Aerodrome Forecasts (TAFs) are **forecasts** of meteorological conditions at an aerodrome, as opposed to the report of actual, present conditions as given in a METAR. The format of the TAF is similar, however, to that of a METAR, with many of the coding groups identical in both the METAR and TAF. TAFs usually cover a period of between **9** and **30 hours**. **9-hour TAFs** are issued every **3 hours**, and **12 to 24-hour TAFs** every **6 hours**.

```
9 Hour TAFs
KIRKWALL      TAF EGPA 160602Z 1607/1616 15010 9999
              SCT012 BKN030 PROB320 TEMPO 1607/1613 7000 -RADZ
              SCT008 BKN012=
 ABERDEEN     TAF EGPD 160656Z 1607/1616 13008KT 4000HZ
              TEMPO 1609/1612 5000 HZ BKN007=
INVERNESS     TAF EGPE 160656Z 1607/1616 VRB03KT 9999
              FEW035=
SANTIAGO      TAF LEST 160800Z 1610/1619 24007KT 9999
              SCT040=
VALENCIA      TAF LEVC 160800Z 1610/1619 12008KT CAVOK
              TEMPO 1614/1619 05006KT=
```

Decoding TAFs

The first code which appears in the TAF is the identifier, **TAF**. The next code is the **ICAO location indicator** of the aerodrome for which the report is issued. The example given below is for EGTK, Oxford, Kidlington, airport.

TAF EGTK 130600Z 1307/1316 31015KT 8000 -SHRA SCT010 BKN018=

The Date-Time Information

As we have established, the TAF gives a **forecast for a period of time**. Consequently, the date-time information in TAFs is slightly different from that given in a METAR. In the TAF, there are two items of **date-time information.**

The first date-time group, highlighted in red below, indicates the date and time at which the TAF was issued.

TAF EGTK 130600Z 1307/1316 31015KT 8000 -SHRA SCT010 BKN018=

The digits 13 identify the day of the month; this information is followed by the time in **hours and minutes UTC**. The above TAF, then, was issued on 13th of the month, at 0600 hours, UTC. In the TAF, Coordinated Universal Time, **UTC**, is indicated by the letter, **Z.**

The next code-group identifies the **period of validity** of the TAF. The information here uses an eight-digit format. The first four digits show the start date and time, so 1307 indicates that the TAF's validity period starts on the 13th at 0700Z. The next four digits are the end date and time of the validity period. So, in the example given below, the date and time of the origin of the report is 0600 UTC on 13th of the month, and the **validity period**, highlighted in red, is from the 13th at 0700 UTC to **1600 UTC** on the same day. This example, then, is a **nine hour TAF**.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Wind

The **wind codes** in the TAF are the same as in the METAR. Our example TAF shows a **mean wind direction** of 310° (True), at a **wind speed** of 15 knots.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Weather

The **weather coding** in the TAF is also the same as in the METAR. In our example, the visibility is 8000 m with light showers of rain.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Cloud

Cloud coding in the TAF can be slightly different from the METAR.

If there is no cloud below the greater of 5000 ft or minimum sector altitude and if there is no CB or TCU and CAVOK is not appropriate, the code **NSC** is used, which stands for **no significant cloud**.

As with METARs, only CB or TCU clouds will be included in TAFs.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Our example TAF, above, is forecasting 3-4 oktas of cloud at 1000 ft, with 5-7 oktas of cloud at 1800 ft.

The main TAF information ends with the cloud group. TAFs do not contain information on temperature and dew point, QNH, recent weather, windshear or runway state information. However, some countries do forecast maximum and minimum temperatures for the forecast period (see below).

Only significant changes of weather follow the cloud group. These significant changes are introduced by codes classified as **forecast change indicators.**

Forecast Change Indicators

There are distinctive TAF codes which indicate that a change is expected in some or all of the forecast meteorological conditions. The nature of the change can vary: it may, for instance, be a rapid, gradual or temporary change. These codes are **FM** (meaning **FROM**), **BECMG** (meaning **BECOMING**), **TEMPO** (meaning **TEMPORARILY**), and **PROB** (meaning **PROBABILITY**).

The From (FM) Group

The **FROM** group in a TAF is introduced by the code **FM** and marks the fact that a **rapid change in the forecast conditions is expected**, which will lead to the appearance of a new set of prevailing conditions becoming established at the aerodrome.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 131220 27017KT 4000 BKN010=

The change indicator FM is followed by a **six-digit date and time group.** The first two digits are the day of the month followed by the hours and minutes to indicate the time at which the change is expected to begin. In our example FM 131220 means that certain weather changes will occur from the 13th at 1220 UTC. This weather forecast following the code **FM supersedes** the TAF forecast, prior to 1220 UTC.

The FM indicator, therefore, introduces what is effectively a new forecast, associated with a new weather situation, and which supersedes the previous forecast. The FM group contains all the elements of a complete TAF forecast: **wind**, **visibility**, **weather** and **cloud**.

In the example below, highlighted in red, we read that from the 13th at 1220Z until the end of the TAF period, the wind will change to be 270° (T) at 17 kt, with a prevailing visibility of 4000 metres, and broken cloud at 1000 ft.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 131220 27017KT 4000 BKN010=

The forecast following the FM indicator continues either to the end of the current TAF, or until another change indicator occurs in the TAF.

The Becoming (BECMG) Group

The change group **BECMG,** meaning **becoming,** is followed by an **eight-figure date and time group** which indicates the period during which there will be a **permanent change in the forecast conditions.**

The forecast change, introduced by BECMG, will occur at an **unspecified time** within the time period stated.

The following example TAF indicates that, at some time on the 13th between 0900 UTC and 1100 UTC, but definitely by 1100 UTC, the prevailing conditions will give 5000 metres visibility, in light rain. There is no new wind information after BECMG, so the inference is that the wind will be as previously forecast: 310° (T) at 15 kt.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 BECMG 1309/1311 5000 –RA=

The Temporary (TEMPO) Group

TEMPO, meaning **temporarily,** indicates that a change in meteorological conditions will occur **at any time within the specified time period**, but is expected to last **less than one hour** each time, and, in aggregate, will last no longer than half the time period of the complete forecast. The TEMPO indicator is followed by an **8-digit date and time group** indicating the hours between which the **temporary conditions** are expected to begin and end.

The example TAF, which follows, tells us that sometime on the 13th between 1200 UTC and 1400 UTC, the visibility will fall to 4000 metres, with the weather being thunderstorms and moderate rain. There will be 5 - 7 oktas of cumulonimbus cloud at 1000 ft. However, after 1400 UTC, the weather will return to the conditions specified in the first part of the message.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 TEMPO 1312/1314 4000 TSRA BKN010CB=

The Probability (PROB) Indicator

The code **PROB** (meaning probability) in a TAF indicates the **probability** of the occurrence of specified weather phenomena.

The probability indication is a **percentage probability** of the occurrence of **significant weather events** such as thunderstorms and associated precipitation. A **30% probability is considered low**, while a **40% probability** indicates that it is **highly likely** that the weather being forecast will actually occur. The code PROB can be followed by a **time group of its own**, and/or by an indicator, such as BECMG or TEMPO.

The example TAF below tells us that there is a high probability that, between 1000 UTC and 1400 UTC, there will be thunderstorms with heavy rain and hail, and from 3 to 4 oktas of cumulonimbus clouds at 500 ft.

The storms will not last longer than one hour at a time and less than two hours in total, which is one half of the period to which the TEMPO applies.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1310/1314 +TSRAGR SCT005CB=

Temperature

Some meteorological authorities include forecast **maximum** and **minimum temperatures likely to be experienced** in the forecast period of the TAF. The format is:

TX15/2016Z, meaning maximum temperature is expected to be 15°C at 201600Z.

TN09/2105Z, meaning minimum temperature is expected to be 9°C at 210500Z.

Amendment

When a TAF requires an **amendment**, the amended forecast may be indicated by the code **AMD**, highlighted in red, after the TAF identifier, as shown below:

TAF AMD EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1310/1314 +TSRAGR SCT005CB=

Used correctly, TAFs will enable a pilot to make accurate and informed decisions about a planned flight, including the expected conditions en-route, and at destination and alternate aerodromes.

End of Message

An equals sign **(=)** appears at the end of the TAF to denote that the message is complete.

Questions

1. **The weather group RERA in a TAF means:**

   a. rain in retreat
   b. recent rain
   c. returning rain
   d. retreating rain

2. **TEMPO in a TAF means:**

   a. a temporary variation to the main forecast that will last for less than one hour, or if recurring, for less than half the period indicated
   b. a temporary variation to the main forecast lasting less than an hour
   c. the development of unpredictable conditions that may be a hazard to aviation
   d. a variation to the base line conditions laid down in the main forecast that will continue to prevail until the end of the main forecast

3. **The weather group SHSNRA in a TAF means:**

   a. slight showers of snow and rain
   b. moderate showers of snow and rain
   c. heavy showers of snow and rain
   d. showers of snow and rain

4. **A TAF time group 0202/0220 means that the TAF:**

   a. is a short range forecast only, at 0220 UTC
   b. was observed at 0220 UTC
   c. was issued at 0220 UTC
   d. is a long range forecast for the 18 hour period from the 2nd at 0200 UTC to the 2nd at 2000 UTC

5. **BECMG 1618/1620 BKN030 in a TAF means:**

   a. becoming between 1800 UTC and 2000 UTC 3-4 oktas of cloud at 300 ft AGL
   b. becoming from 1820 UTC 5-7 oktas of cloud at 3000 ft AGL
   c. becoming from 1820 UTC 3-4 oktas of cloud at 3000 ft AGL
   d. becoming between 1800 UTC and 2000 UTC 5-7 oktas of cloud at 3000 ft AGL

6. **Which of the following correctly decodes a TAF that reads:**

   EGLL 1306/1315 VRB08KT 9999 SCT025=

   a. Valid from 0600 UTC to 1500 UTC; surface wind variable at 8 kt; visibility 10 NM or more; with a cloud base of 2500 ft above mean sea level
   b. Observed at 0615 UTC; the surface wind was variable in direction and speed; averaging 8 kt; with a visibility of 10 km or more, and a cloud base of 2500 ft above aerodrome level
   c. Valid from the 13th at 0600 UTC to the 13th at 1500 UTC; surface wind will be variable at 8 kt, with a visibility 10 km or more; 3-4 oktas of cloud with a base of 2500 ft above aerodrome level
   d. Observed at 0600 UTC; the surface wind was variable in direction and speed; with a visibility of 10 km and a cloud base of 2500 ft above ground level

7. **The correct decode for a TAF 1206/1215 14025G40KT 1200 BR would be:**

a. the forecast is for a nine hour period from 0615 UTC with a surface wind of 140° M at 25 kt gusting 40 kt, visibility 1200 metres in mist
b. the forecast is for a nine hour period from 0615 UTC with a surface wind of 140° T at 25, visibility 1200 metres in fog
c. the forecast is for a nine hour period from 0600 to 1500 UTC with a surface wind of 140° M at 25 kt gusting 40 kt, visibility 1200 metres in broken patches
d. the forecast is for a nine hour period from the 12th at 0600 to 1500 UTC on the same day with a surface wind of 140° T at 25 kt gusting 40 kt, visibility 1200 metres in mist

Answers

1	2	3	5	6	7
b	a	b	d	c	d

Chapter

27

Significant Weather and Wind Charts

Introduction

The **World Area Forecast System (WAFS)** was established by ICAO in conjunction with the World Meteorological Organization (WMO). The system has 2 world area forecast centres (WAFC):

- London (actually the UK Meteorological Office at Exeter)
- Washington (actually the National Oceanic and Atmospheric Administration - NOAA at Kansas City).

The centres are required to provide essential real time meteorological broadcasts for aviation to meet the requirements of ICAO Annex 3. These are medium level (FL100 to FL250) and high level (FL250 to FL630) significant weather (SIGWX) charts and spot wind and temperature charts for FL100, FL180, FL240, FL300, FL340, FL390, FL450, FL530 and FL610.

This data is broadcast by the UK Met Office on the Satellite Distribution System (SADIS) and by NOAA on the International Satellite Communication System (ISCS). The information is also available on line. The UK Met Office's area of responsibility extends from the West Atlantic Ocean through Europe and Africa to the west coast of the Pacific Ocean. NOAA covers the Pacific Ocean and the Americas. The two centres work in duplicate so each is capable of meeting the global requirement in the event of failure at one of the centres.

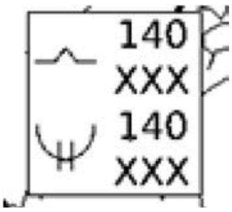
All the charts are fixed time charts valid only at the time stated on the chart. These charts are issued at 6 hour intervals usually 18 - 24 hours in advance. Flight in between the validity times will require the pilot to interpolate between consecutive charts.

Figure 27.1 is an example of a SIGWX chart. This chart is for Europe and surrounding areas. Top left on the chart are the details showing the WAFC reference (PGDE14) and date and time of issue - 280000 (Z). Below is the originating agency and issuing agency (both WAFC London). Then a reminder that these are fixed time charts valid only for the time stated (0000 UTC 29 APR 2013). Note that this chart, unlike other SIGWX charts, covers levels FL100 to FL450.

The thick black lines on the chart are jet streams. The jet stream to the west of the UK has a speed of 100 kt SW of Iceland rising to 120 kt to the NW of Ireland then dropping to 100 kt. The core of the jet stream is at FL310 with speeds exceeding 80 kt (40 mps) extending from FL250 to FL370. The start and end of the jet stream lines occur where the wind speed exceeds 80 kt. By convention the wind speed triangles and feathers point towards the low temperature.

The jet streams to the south and southwest of the UK have an enclosed area surrounded by a dashed line with the number 3 in a square box. This is an area of clear air turbulence (CAT) and is amplified in the legend on the left which advised of moderate CAT extending from FL240 to FL360.

Extending from SE England to the Northern Baltic is an area designated by a wavy line. This is an area of significant weather. Over the Southern Baltic is a box with an arrow attaching it to this area. The box shows:



moderate turbulence extending from below FL100 (the lowest level of the chart) to FL140 and moderate icing extending over the same altitude band.

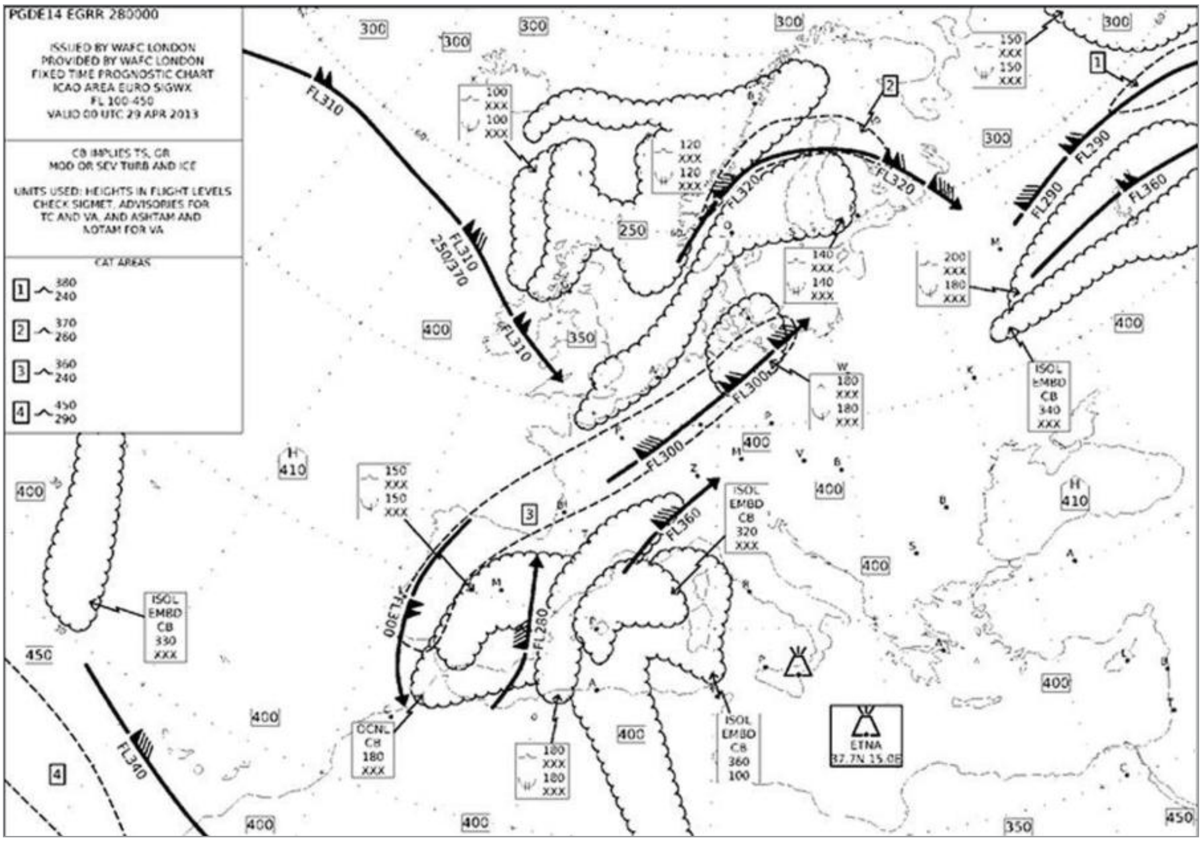
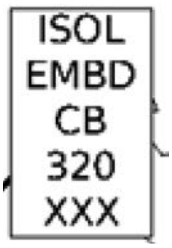


Figure 27.1 Europe significant weather chart

Between Sardinia, Spain and France is another area of significant weather attached to the following box:



Within the area we have individual cumulonimbus embedded in other cloud with base below FL100 and tops up to FL320. No further information is given here but the middle box of the legend advises what you should expect from CB. I hope no further amplification is necessary!

Here are some of the abbreviations associated with CB (and TS) with their meaning:

ISOL, (Isolated): individual
OCNL, (Occasional): well separated
FRQ, (Frequent): little or no separation between CB
SQL, (Squall): a line of CB with little or no separation

Over the UK is a rectangular box with the number 350, this shows that the height of the tropopause is FL350 in that location. West of northern Spain is a similar box with an upward pointing arrow indicating a tropopause high.
Finally you will recognize the letters as being the location of major cities or aviation locations.

Full symbology for significant weather charts is in *Figure 27.2* and *Figure 27.3*.

Symbols for Significant Weather, Tropopause, Freezing Level Etc

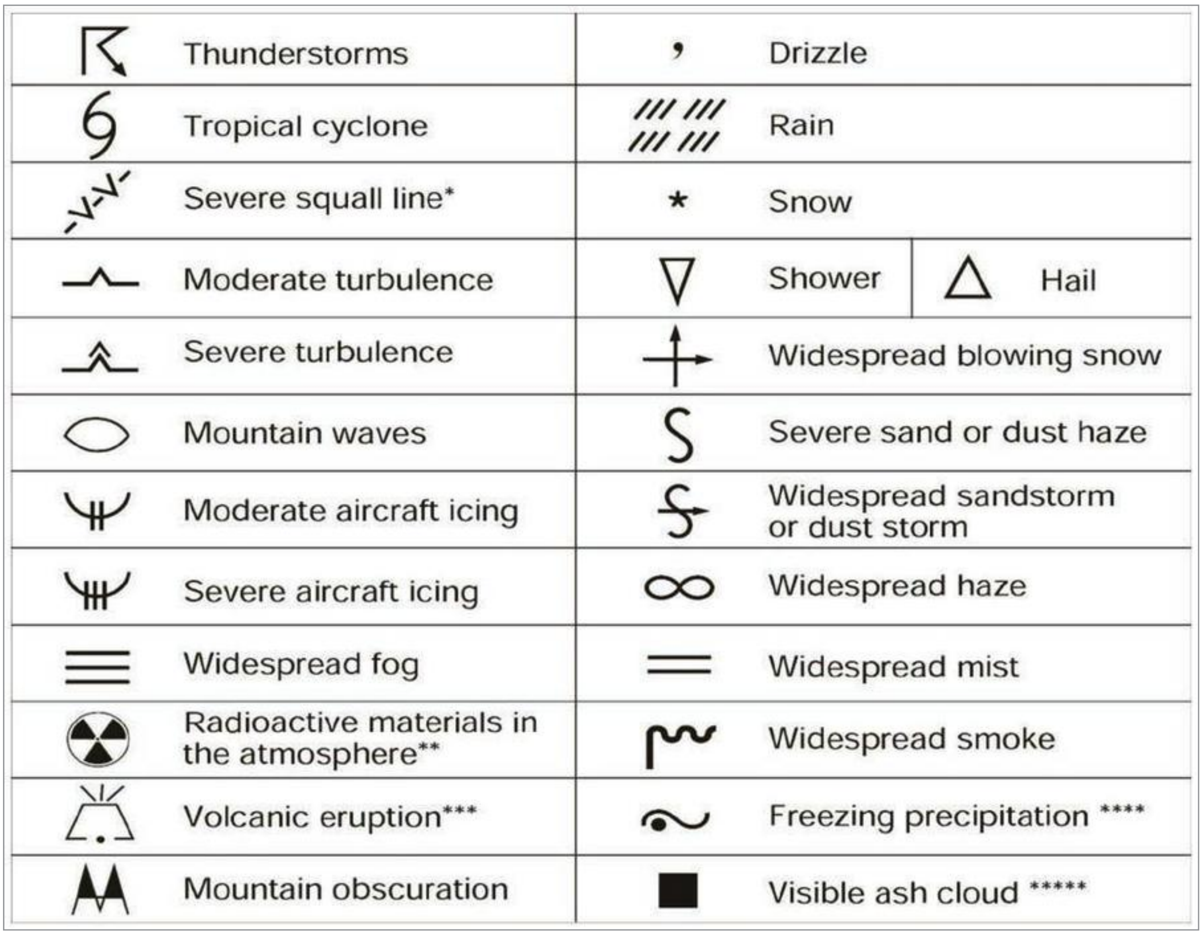


Figure 27.2 Significant weather symbology

* In flight documentation for flights operating up to FL100. This symbol refers to "squall line".

** The following information should be included at the side of the chart: radioactive materials symbol; latitude/longitude of accident site; date and time of accident; check NOTAM for further information

*** The following information should be included at the side of the chart: volcanic eruption symbol; name and international number of volcano (if known); latitude/longitude; date and time of the first eruption. Check SIGMETs and NOTAM or ASHTAM for volcanic ash.

**** This symbol does not refer to icing due to precipitation coming into contact with an aircraft which is at a very low temperature.

***** Visible ash cloud symbol applies only to model VAG not to SIGWX charts.

NOTE: Height indications between which phenomena are expected, top above base per chart legend.

Fronts and Convergence Zones and Other Symbols Used

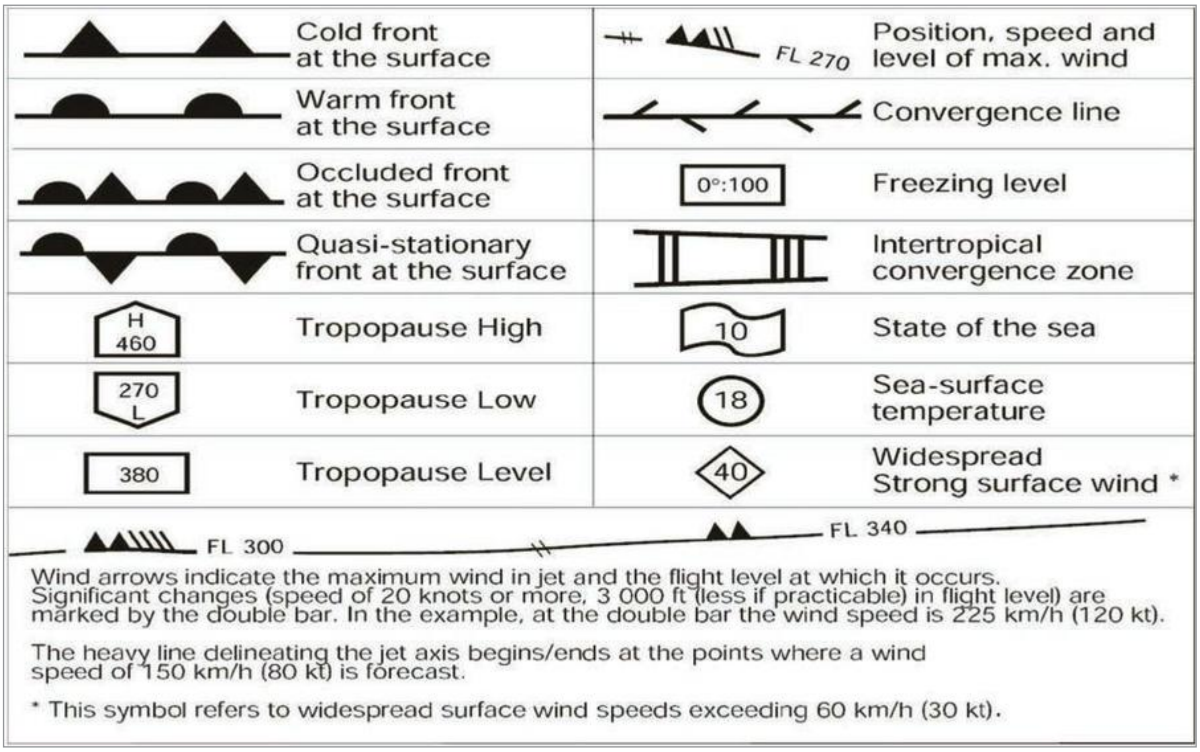


Figure 27.3 Significant weather symbology

- **Winds.** Corresponding to the charts listed above are charts of similar coverage, each chart showing wind and temperature for a particular flight level. The flight levels are listed in column 3 of page 3-5-10 of the GEN section of the Air Pilot (Appendix A to Chapter 18). On these charts winds are given every 5° of latitude and longitude using the symbology shown in *Figure 27.2* and *Figure 27.3*, an example of a wind chart is *Figure 27.4*.

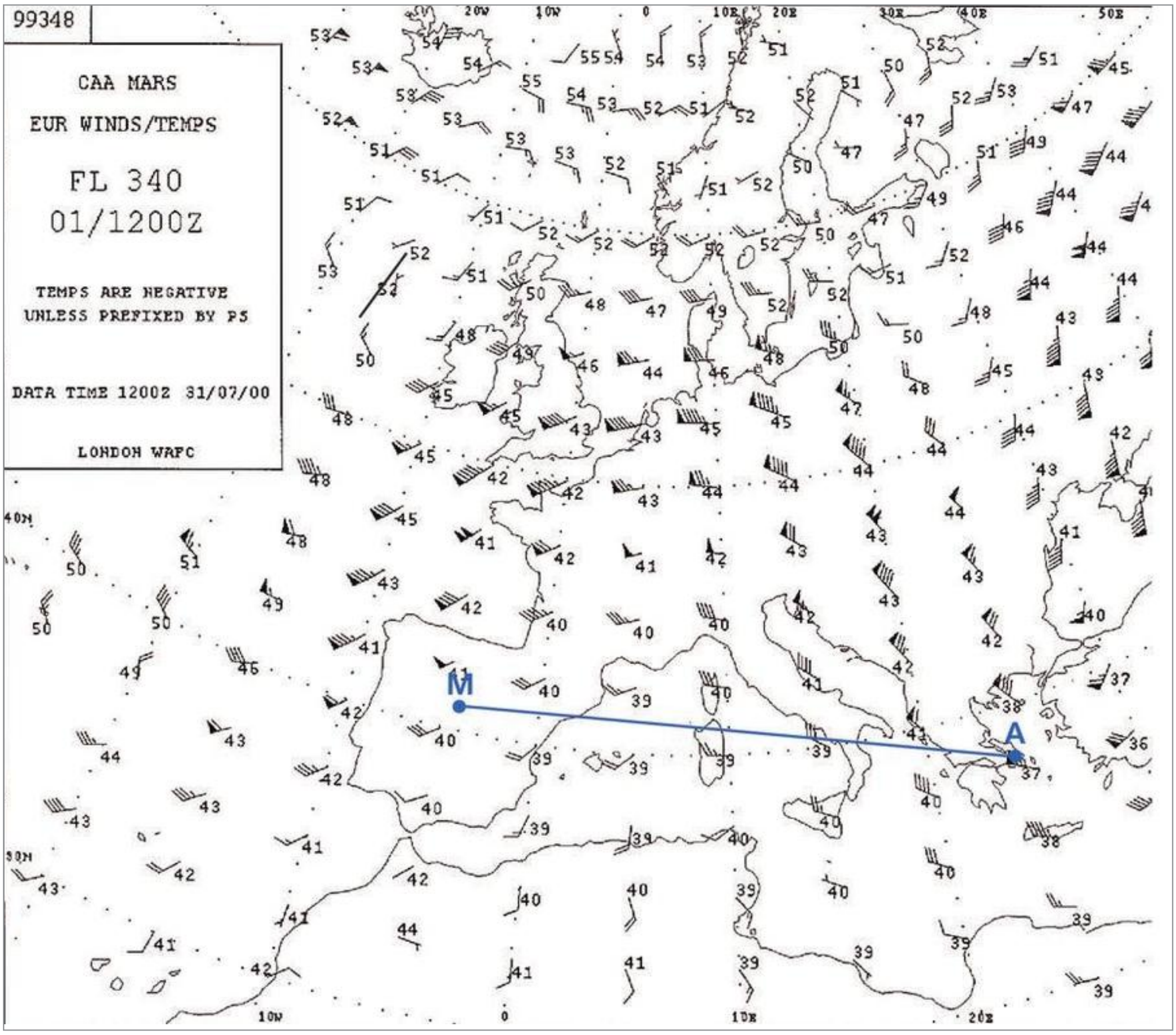


Figure 27.4 Wind temperature chart for FL340

To find the wind and temperature at a position other than that at a lat/long intersection, some careful interpolation is required. To find an **average** wind for a **whole** route you must split the route into a number of sections, say 10° of latitude or longitude (depending on the direction) find the wind & temperature for each section and find a mathematical average. If the winds found vary through 360°, you will have to take care e.g. the average of the two winds 310/20 and 010/30 is 340/25 and **not** 160/25!

NOTE: this chart is a portion of a polar stereographic projection which has the pole at the centre and the meridians radiate as the spokes of a bicycle wheel. Take care to check the local direction of north when estimating wind direction.

To find the wind **component**, the average W/V will have to be applied to the **mean track** for the route using a representative TAS and the navigation computer. (For normal subsonic jet transport aircraft flying between 30 000 and 40 000 ft, 480 kt is a reasonable figure). For example; determine the average wind and temperature for the route from Madrid to Athens:

As noted above, we must take wind/temperature along the route at suitable intervals, interpolating where necessary:

(We do not need to be precise in wind direction because the averaging will cancel minor error in measurement).

At 000°E by interpolation we get:	220°/25 kt	-40°C
At 005°E by interpolation we get:	250°/25 kt	-39°C
At 010°E by interpolation we get:	270°/25 kt	-39°C
At 015°E we have:	290°/30 kt	-39°C
At 020°E by interpolation we get:	310°/50 kt	-41°C

To determine the average add up the wind directions and divide by the total number of items collected: 1340/5=268°, repeating for wind speeds gives 31 kt and temperature gives -40°C. So the answer to nearest 5° for wind direction, 5 kt for speed and 1° for temperature is:

270°/30 kt, -40°C

The questions at the end of this chapter cover the use of both the significant weather and temperature charts.

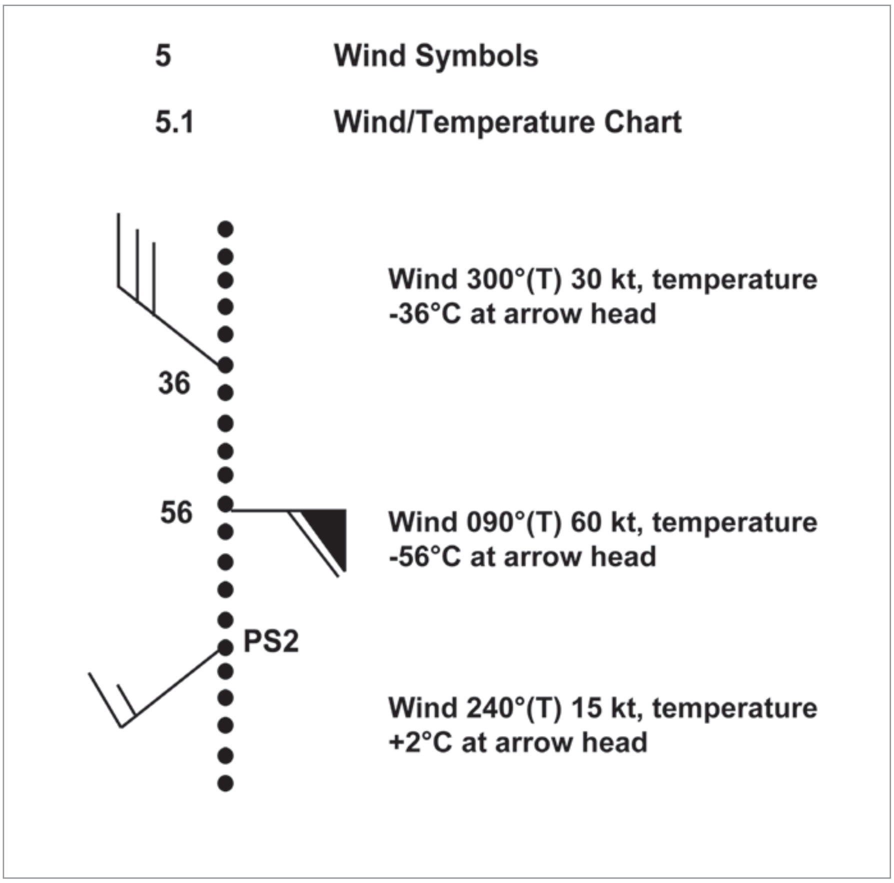


Figure 27.5

Low Level Forecast Information

To meet the low level requirement, the UKMO produces forecast weather charts giving conditions at 6 hourly intervals, 0000Z, 0600Z, 1200Z, and 1800Z. The charts are valid for a 9 hour period starting 4 hours before the forecast time and extending to 5 hours after, (i.e. a 9 hour period of validity. These charts are produced for the UK (form 215) and for NW Europe (form 415). Spot wind and temperature charts are also produced valid for 6 hour periods centred on the above times. Form 214 is produced for the UK and form 414 for NW Europe.

Forms 215/415

The presentation on these charts is somewhat different to the WAFS sig wx charts but the same symbology is used along with an extended set of abbreviations.

The chart is divided into lettered areas, delineated with wavy lines, with the surface visibility, weather, cloud and the altitude of the 0°C isotherm tabulated on the right for each of the areas. Areas may be subdivided as area B is on this chart when there are minor changes which do not justify the provision of an extra area.

The conditions in area A:

AREA	SURFACE VIS AND WX	CLOUD	0 C
A	15 KM NIL/-RA OCNL 7 KM RA/-RADZ ISOL 3000 M RADZ/BR ISOL 800 M FG/DZ OCNL HILL FG	BKN/OVC AC AS Ψ Λ 080 / XXX SCT/BKN (LCA OVC FRONT) CU SC ... ... Λ 015-030 / 040-080 OCNL SCT/BKN ST 004-010 / 015 ... ... (BASE 000 FG)	080-XXX

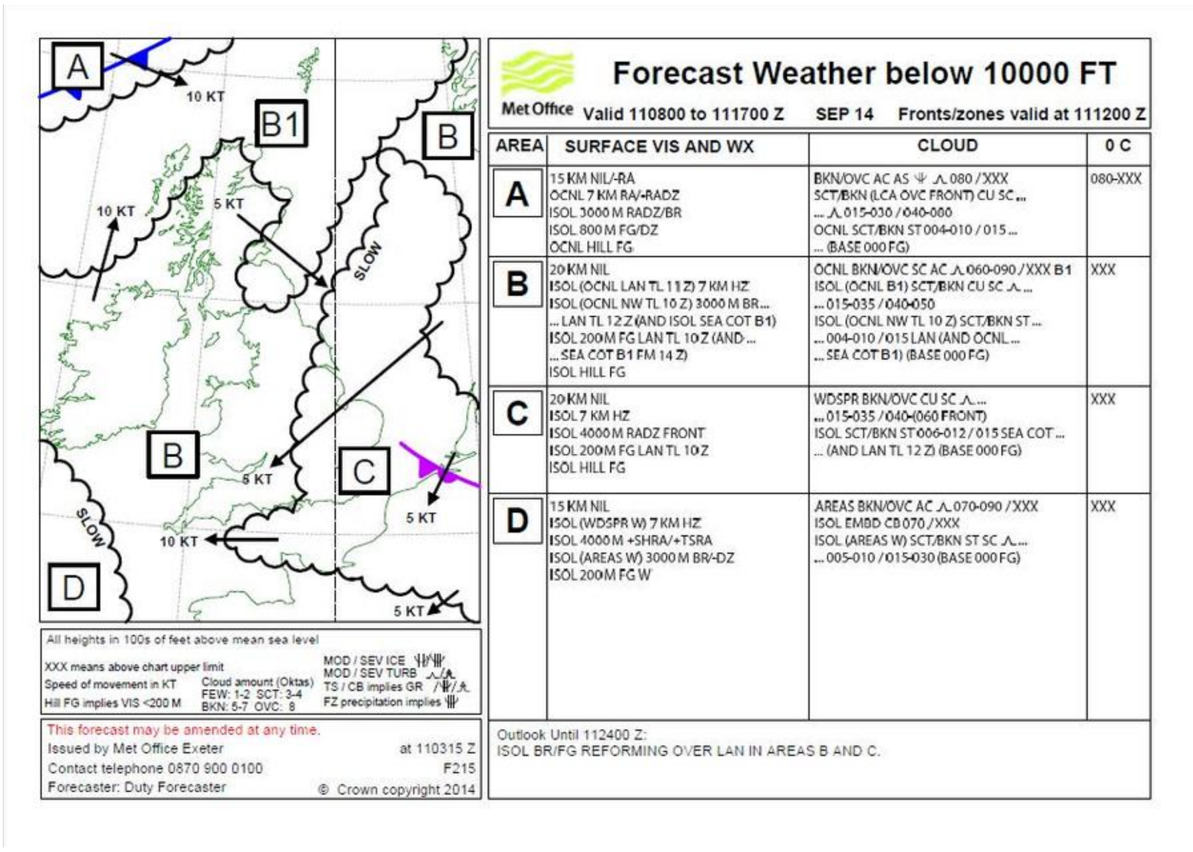
Generally, visibility will be 15 km with nil weather or light rain. In less than 50% of the area visibility will be 7 km in moderate rain or light rain and drizzle. Less than 25% of the area will have visibility 3000 m in moderate rain and drizzle and mist. Less than 25% of the area will have 800 m visibility in fog or drizzle and hill fog on some hills and less than 50% of the area will experience hill fog. See below for the interpretation of ISOL et al.

Cloud: 5 - 8 oktas of AC and AS with moderate icing and turbulence extending from base 8000 ft to tops which are above 10 000 ft (xxx). 3 - 7 oktas CU and SC (locally 8 oktas at the front) with moderate turbulence from base 1500 ft to 3000 ft and 4000 ft to 10 000 ft. In less than 50% of the area 3 to 7 oktas of ST base 400 ft, but on the surface in fog, tops 1000 to 1500 ft.

The freezing level varies from 8000 ft to above 10 000 ft.

Note: *All vertical positions are above mean sea level.*

The arrows indicate the direction and speed of movement of the fronts and weather areas. Slow means speed is less than 5 kt. When planning a flight account must be made of the movement of the weather systems.



The definitions used in the F215/415 relating to the extent of weather are adopted in the UK by the Aviation Met. Authority in the CAA, and used by the Met Office. These are:

Widespread (WDSPR)

Implies conditions affecting many places, which will be difficult to avoid (greater than 50% of area affected) (used for non-convective and convective types).

Frequent (FRQ)

Used if within a particular area there is little separation between phenomena, and the spatial coverage is greater than 50% of the area forecast to be affected by that phenomenon (used for convective types only). These features will be difficult to avoid.

Occasional (OCNL)

Used if an area consists of well separated features which are forecast to affect an area with a maximum spatial coverage of between 25% and 50% of the area concerned. These features can be avoided by users.

Isolated (ISOL)

Used if an area consists of individual features which are forecast to affect an area with a maximum spatial coverage of between less than 25% of the area concerned. These features can be easily avoided.

Other abbreviations which may be encountered

BLW	Below
BTN	Between
CIT	Near or over large towns
CLD	Cloud
COR	Correction
COT	At the coast
LAN	Inland (or over land)
LCA	Locally
LSQ	Line squall
LV	Light & variable (relating to wind)
SEV	Severe
SFC	Surface
VAL	In valleys
VRB	Variable
VSP	Vertical speed
WRNG	Warning
WS	Windshear
WSPD	Wind speed

Forms 214/414

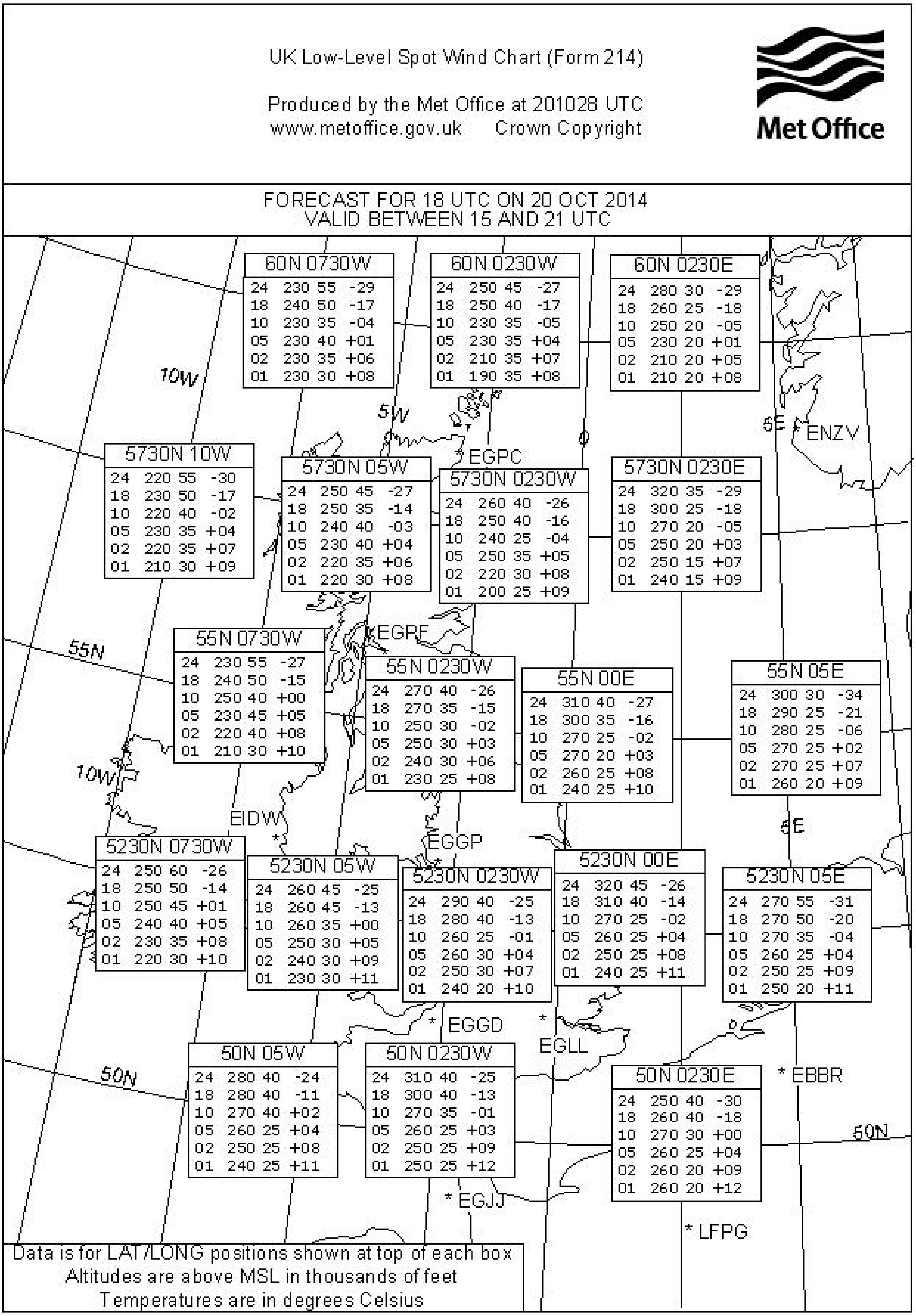
These forms give spot wind and temperature information at selected locations.

As stated on the form the heights are in thousands of feet above mean sea level. To extract winds and temperatures for a route will require interpolation between the heights and the appropriate data boxes.

For example flying a route at FL070 over Bristol (EGGD).

> Unless there is exceptionally high or exceptionally low pressure the will be no need to adjust the height for the difference between QNH and SPS.
>
> Now interpolating between the data from the boxes for 5230N 0230W and 5230N 0500W for FL140: gives temperature -7°C (to the nearest integer) and wind velocity – 260°T/35 kt (nearest 5° and 5 kt). Another question that may arise is to determine the stability between 2 levels. E.g. At 50N 0230W, what is the stability state between FL020 and FL050? Here the temperature reduction is 6° over 3000 ft giving a lapse rate of 2°C/1000 ft. So at that location between those levels the atmosphere is conditionally unstable.

In a situation where pressure patterns are changing rapidly, for example when a fast moving polar front depression is crossing the region, it would be prudent to interpolate between consecutive forms 214/414 particularly towards the limits of the forecast periods. As we have seen above the speed of movement of systems is found on the forms 215/415.


UK Low-Level Spot Wind Chart (Form 214)
Produced by the Met Office at 201028 UTC
www.metoffice.gov.uk Crown Copyright
Met Office
FORECAST FOR 18 UTC ON 20 OCT 2014
VALID BETWEEN 15 AND 21 UTC
60N 0730W
24 230 55 -29
18 240 50 -17
10 230 35 -04
05 230 40 +01
02 230 35 +06
01 230 30 +08
60N 0230W
24 250 45 -27
18 250 40 -17
10 230 35 -05
05 230 35 +04
02 210 35 +07
01 190 35 +08
60N 0230E
24 280 30 -29
18 260 25 -18
10 250 20 -05
05 230 20 +01
02 210 20 +05
01 210 20 +08
10W
5W
5E
ENZV
EGPC
5730N 10W
24 220 55 -30
18 230 50 -17
10 220 40 -02
05 230 35 +04
02 220 35 +07
01 210 30 +09
5730N 05W
24 250 45 -27
18 250 35 -14
10 240 40 -03
05 230 40 +04
02 220 35 +06
01 220 30 +08
5730N 0230W
24 260 40 -26
18 250 40 -16
10 240 25 -04
05 250 35 +05
02 220 30 +08
01 200 25 +09
5730N 0230E
24 320 35 -29
18 300 25 -18
10 270 20 -05
05 250 20 +03
02 250 15 +07
01 240 15 +09
55N
EGPF
55N 0730W
24 230 55 -27
18 240 50 -15
10 250 40 +00
05 230 45 +05
02 220 40 +08
01 210 30 +10
55N 0230W
24 270 40 -26
18 270 35 -15
10 250 30 -02
05 250 30 +03
02 240 30 +06
01 230 25 +08
55N 00E
24 310 40 -27
18 300 35 -16
10 270 25 -02
05 270 20 +03
02 260 25 +08
01 240 25 +10
55N 05E
24 300 30 -34
18 290 25 -21
10 280 25 -06
05 270 25 +02
02 270 25 +07
01 260 20 +09
10W
EIDW
EGGP
5E
5230N 0730W
24 250 60 -26
18 250 50 -14
10 250 45 +01
05 240 40 +05
02 230 35 +08
01 220 30 +10
5230N 05W
24 260 45 -25
18 260 45 -13
10 260 35 +00
05 250 30 +05
02 240 30 +09
01 230 30 +11
5230N 0230W
24 290 40 -25
18 280 40 -13
10 260 25 -01
05 260 30 +04
02 250 30 +07
01 240 20 +10
5230N 00E
24 320 45 -26
18 310 40 -14
10 270 25 -02
05 260 25 +04
02 250 25 +08
01 240 25 +11
5230N 05E
24 270 55 -31
18 270 50 -20
10 270 35 -04
05 260 25 +04
02 250 25 +09
01 250 20 +11
EGGD
EGLL
50N
50N 05W
24 280 40 -24
18 280 40 -11
10 270 40 +02
05 260 25 +04
02 250 25 +08
01 240 25 +11
50N 0230W
24 310 40 -25
18 300 40 -13
10 270 35 -01
05 260 25 +03
02 250 25 +09
01 250 25 +12
50N 0230E
24 250 40 -30
18 260 40 -18
10 270 30 +00
05 260 25 +04
02 260 20 +09
01 260 20 +12
EBBR
50N
EGJJ
LFPG
Data is for LAT/LONG positions shown at top of each box
Altitudes are above MSL in thousands of feet
Temperatures are in degrees Celsius

Questions

Using the attached significant weather chart (*Appendix A*) answer question 1 to 4 on the route from Madrid to Larnaca following the marked route.

1. **The highest tropopause height en route would be at:**

    a. overhead 20°E
    b. overhead Madrid
    c. Larnaca
    d. 10°E

2. **The CAT expected at 5°E en route would be:**

    a. moderate between FL230 and FL460
    b. moderate from below FL100 to FL160
    c. moderate from FL260 to FL370
    d. moderate between FL290 to FL440

3. **If this route was flown at FL290 moderate to severe turbulence and icing could be expected at:**

    a. 5°E
    b. 10°E
    c. overhead Larnaca
    d. 25°E

Using the attached upper wind and temperature chart (*Appendix B*) for flying the route from Madrid to Larnaca at FL300 answer Questions 4 to 6.

4. **The mean wind velocity and temperature between Madrid and 30°E would be:**

    a. 295/70 - 40
    b. 290/80 - 45
    c. 270/75 42
    d. 260/70 38

5. **The ISA deviation overhead Madrid is:**

    a. ISA -4
    b. ISA +4
    c. ISA +5
    d. ISA +3

6. **The highest ground speed would be achieved at:**

    a. 25°E
    b. 15°E
    c. 30°E
    d. 20°E

From the TAFs for MKPP and KBOS given below answer 7 to 11.

```
MKPP    270606 10017KT 3000 HZ SCT024 PROB30 TEMPO 0812 2000
        +SHRA BKN010CB BECMG 1215 VRB05KT CAVOK BECMG 0103
        10010KT 5000 SCT015

KBOS    271212 VRB05 CAVOK BECMG 1819 06012KT BECMG 0204
        05025G35KT 5000 OVC030 PROB40 1012 2800 SN
```

7. The visibility at MKPP at 1600 Z is expected to be:

a. 2000 m
b. 3000 m
c. 5000 m
d. 10 km or more

8. The lowest cloud base forecast for MKPP at 1100 is:

a. 2400 ft AMSL
b. above 5000 ft AMSL
c. 2400 ft AGL
d. 1000 ft AGL

9. The highest surface wind speed at MKPP is expected between:

a. 0600 Z and 0600 Z
b. 0600 Z and 1200 Z
c. 1200 Z and 1500 Z
d. 0800 Z and 1200 Z

10. At KBOS at 1100 Z which of the following weather conditions are expected?

a. Visibility of 28 km
b. 8/8 cloud at 2800 ft
c. 40% chance or moderate snow
d. Surface wind of 05025KT

11. At KBOS at 0600 Z the visibility is expected to be:

a. 5000 m
b. more than 10 km
c. 2800 m
d. 1012 m

12. Refer to appendix C to answer this question. What is the average temperature between 5730N 0500W and 5730N 0230W at FL075?

a. -01°C
b. -04°C
c. +03°C
d. +01°C

13. Refer to appendix C to answer this question. What is the average wind velocity between 60N 0730W and 60N 0230E at FL140?

a. 215°T/50 kt
b. 225°T/55 kt
c. 220°T/50 kt
d. 220°T/35 kt

14. Refer to appendix C to answer this question. What is the stability between FL050 and FL100 at 5230N 05W?

a. Absolute instability
b. Absolute stability
c. Conditional stability
d. Conditional stability

15. Refer to appendix D to answer this question. What is the worst visibility likely to be experienced in SW England?

a. 20 km
b. <1000 m
c. 5000 m
d. 3000 m

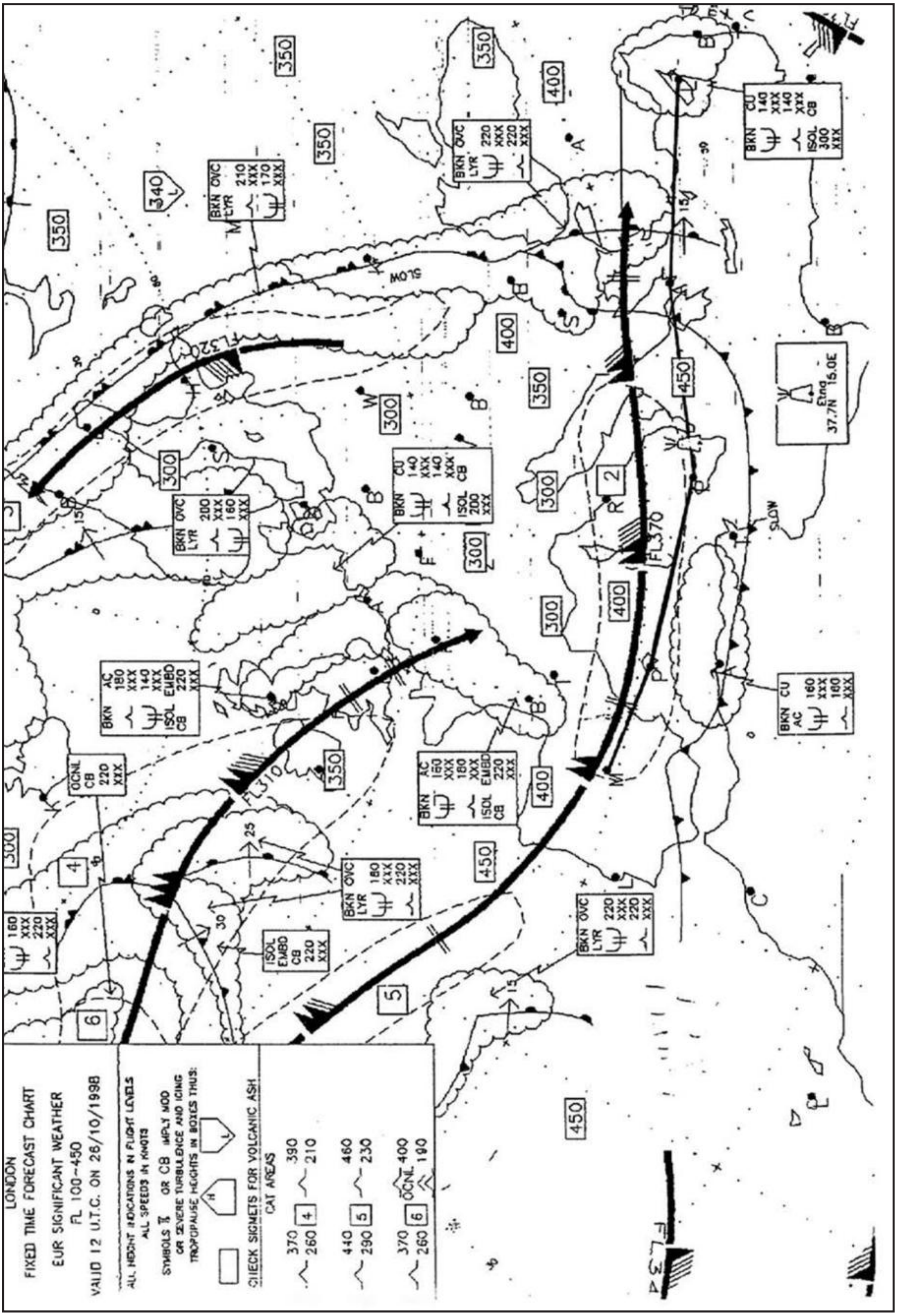
16. Refer to appendix D to answer this question. What is the altitude of the lowest cloud likely to be experienced over Scotland?

a. 500 ft
b. 1500 ft
c. 800 ft
d. 2000 ft

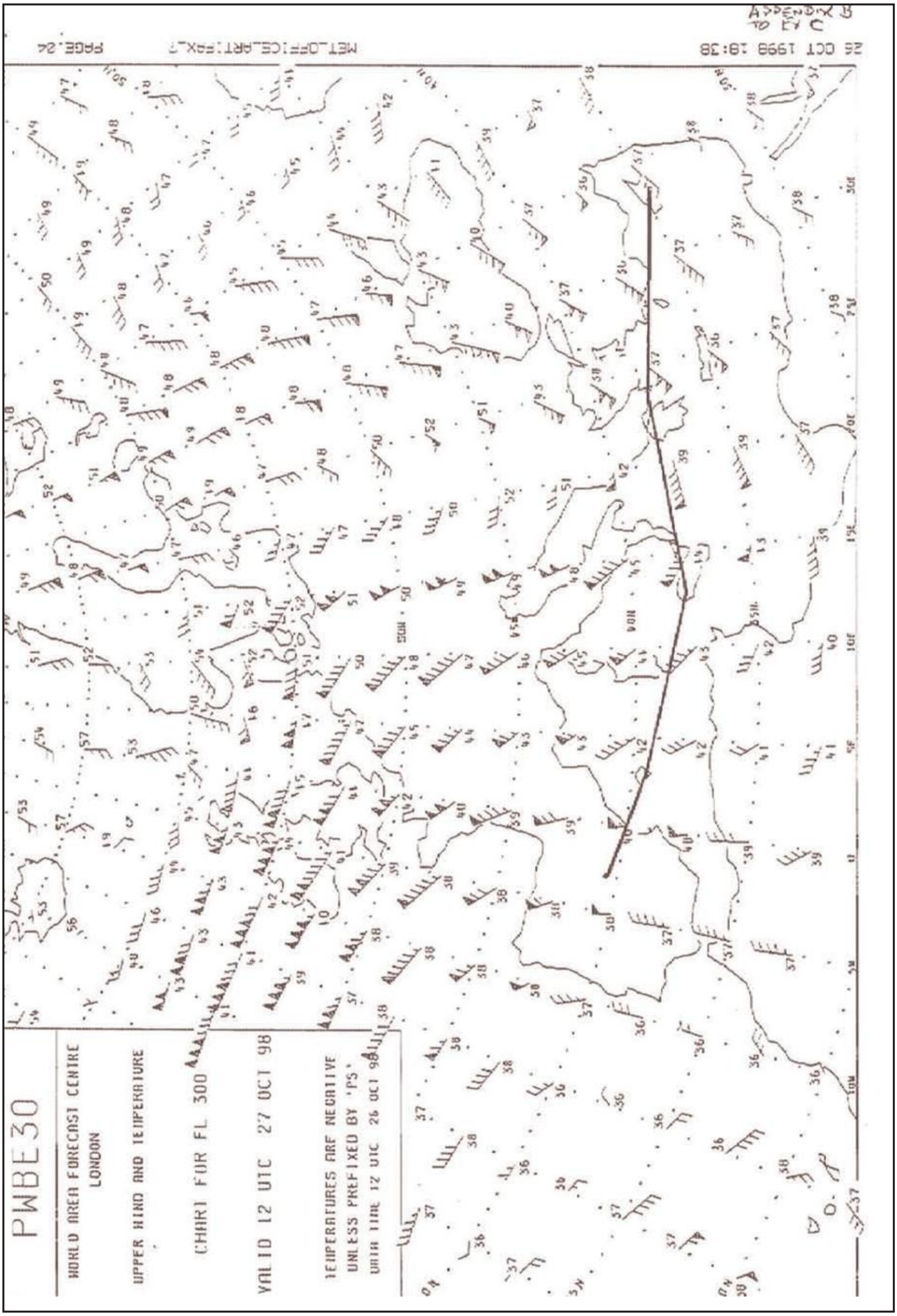
17. Refer to appendix D to answer this question. In which area is the most severe weather likely to be experienced?

a. D
b. B
c. A
d. C

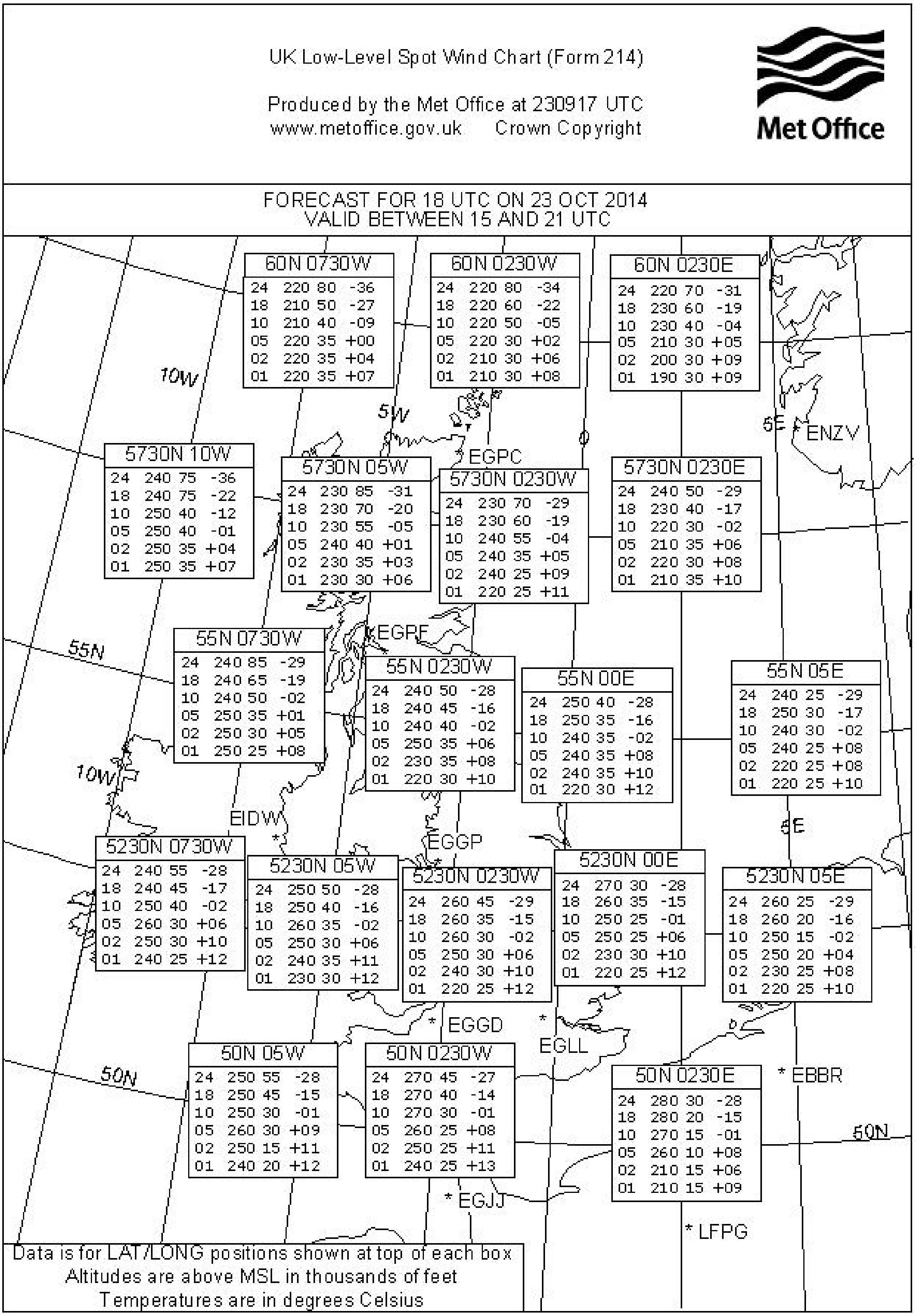
Appendix A


LONDON
FIXED TIME FORECAST CHART
EUR SIGNIFICANT WEATHER
FL 100-450
VALID 12 U.T.C. ON 26/10/1998
ALL HEIGHT INDICATIONS IN FLIGHT LEVELS
ALL SPEEDS IN KNOTS
TROPOPAUSE HEIGHTS IN BOXES THUS:
CHECK SIGMETS FOR VOLCANIC ASH
CAT AREAS
FL320
FL310
FL370
SLOW
Etna
37.7N 15.0E

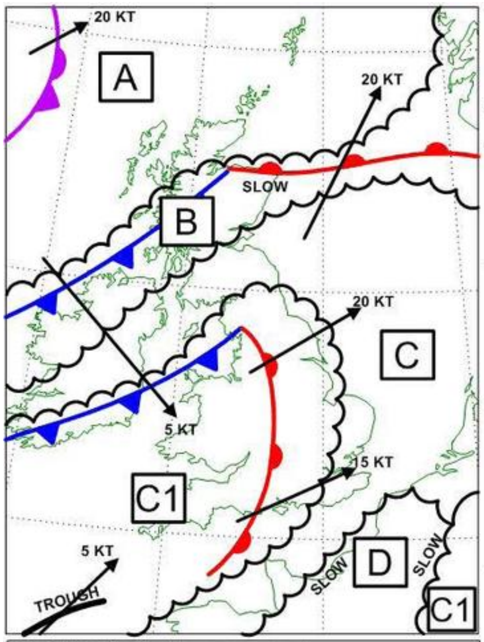
Appendix B


PWBE30
WORLD AREA FORECAST CENTRE
LONDON
UPPER WIND AND TEMPERATURE
CHART FOR FL 300
VALID 12 UTC 27 OCT 98
TEMPERATURES ARE NEGATIVE
UNLESS PREFIXED BY 'PS'
DATA TIME 12 UTC 26 OCT 98

Appendix C


UK Low-Level Spot Wind Chart (Form 214)
Produced by the Met Office at 230917 UTC
www.metoffice.gov.uk Crown Copyright
Met Office
FORECAST FOR 18 UTC ON 23 OCT 2014
VALID BETWEEN 15 AND 21 UTC
60N 0730W
24 220 80 -36
18 210 50 -27
10 210 40 -09
05 220 35 +00
02 220 35 +04
01 220 35 +07
60N 0230W
24 220 80 -34
18 220 60 -22
10 220 50 -05
05 220 30 +02
02 210 30 +06
01 210 30 +08
60N 0230E
24 220 70 -31
18 230 60 -19
10 230 40 -04
05 210 30 +05
02 200 30 +09
01 190 30 +09
10W
5W
5E
ENZV
EGPC
5730N 10W
24 240 75 -36
18 240 75 -22
10 250 40 -12
05 250 40 -01
02 250 35 +04
01 250 35 +07
5730N 05W
24 230 85 -31
18 230 70 -20
10 230 55 -05
05 240 40 +01
02 230 35 +03
01 230 30 +06
5730N 0230W
24 230 70 -29
18 230 60 -19
10 240 55 -04
05 240 35 +05
02 240 25 +09
01 220 25 +11
5730N 0230E
24 240 50 -29
18 230 40 -17
10 220 30 -02
05 210 35 +06
02 220 30 +08
01 210 35 +10
55N
55N 0730W
24 240 85 -29
18 240 65 -19
10 240 50 -02
05 250 35 +01
02 250 30 +05
01 250 25 +08
EGPF
55N 0230W
24 240 50 -28
18 240 45 -16
10 240 40 -02
05 250 35 +06
02 230 35 +08
01 220 30 +10
55N 00E
24 250 40 -28
18 250 35 -16
10 240 35 -02
05 240 35 +08
02 240 35 +10
01 220 30 +12
55N 05E
24 240 25 -29
18 250 30 -17
10 240 30 -02
05 240 25 +08
02 220 25 +08
01 220 25 +10
10W
EIDW
EGGP
5E
5230N 0730W
24 240 55 -28
18 240 45 -17
10 250 40 -02
05 260 30 +06
02 250 30 +10
01 240 25 +12
5230N 05W
24 250 50 -28
18 250 40 -16
10 260 35 -02
05 250 30 +06
02 240 35 +11
01 230 30 +12
5230N 0230W
24 260 45 -29
18 260 35 -15
10 260 30 -02
05 250 30 +06
02 240 30 +10
01 220 25 +12
5230N 00E
24 270 30 -28
18 260 35 -15
10 250 25 -01
05 250 25 +06
02 230 30 +10
01 220 25 +12
5230N 05E
24 260 25 -29
18 260 20 -16
10 250 15 -02
05 250 20 +04
02 230 25 +08
01 220 25 +10
EGGD
EGLL
50N
50N 05W
24 250 55 -28
18 250 45 -15
10 250 30 -01
05 260 30 +09
02 250 15 +11
01 240 20 +12
50N 0230W
24 270 45 -27
18 270 40 -14
10 270 30 -01
05 260 25 +08
02 250 25 +11
01 240 25 +13
50N 0230E
24 280 30 -28
18 280 20 -15
10 270 15 -01
05 260 10 +08
02 210 15 +06
01 210 15 +09
EBBR
50N
EGJJ
LFPG
Data is for LAT/LONG positions shown at top of each box
Altitudes are above MSL in thousands of feet
Temperatures are in degrees Celsius

Appendix D



All heights in 100s of feet above mean sea level

XXX means above chart upper limit
Speed of movement in KT
Hill FG implies VIS <200 M

Cloud amount (Oktas)
FEW: 1-2 SCT: 3-4
BKN: 5-7 OVC: 8

MOD / SEV ICE Ψ/Ψ
MOD / SEV TURB Λ/Λ
TS / CB implies GR /Ψ/Λ
FZ precipitation implies Ψ

This forecast may be amended at any time.
Issued by Met Office Exeter at 230315 Z
Contact telephone 0870 900 0100 F215
Forecaster: Duty Forecaster

Met Office **Forecast Weather below 10000 FT**

Valid 230800 to 231700 Z OCT 14 Fronts/zones valid at 231200 Z

AREA	SURFACE VIS AND WX	CLOUD	0 C
A	25 KM NIL OCNL 7 KM SHRA ISOL 3000 M +SHRA/+TSRA ... ... W OF FRONT ISOL Λ ISOL HILL FG	SCT/BKN AC Ψ Λ 080 / XXX FRONT ISOL CB 020-040 / XXX W OF FRONT SCT/BKN CU SC Ψ Λ 015-030 / 060-XXX ISOL SCT/BKN ST 008-012 / 015	040-060
B	15 KM NIL/-RA OCNL (ISOL LEE MON) 7 KM RA/-RADZ ISOL 3000 M +RA FRONTS ISOL 2000 M RADZ SEA WINDWARD ... ... COT AND UPSLOPES ISOL Λ OCNL HILL FG	BKN/OVC AC AS Ψ Λ 080 / XXX BKN/OVC (LCA SCT LEE MON) CU SC ... ... Ψ Λ 015-030 / 080 OCNL (ISOL LEE MON) SCT/BKN ... ... ST 005-010 / 015	070-090
C	20 KM NIL ISOL (OCNL SEA COT AND ... ... UPSLOPES **C1**) 7 KM -RADZ/HZ ISOL 5000 M TSRA TROUGH ISOL 3000 M RADZ/BR SEA COT ... ... AND UPSLOPES **C1** ISOL Λ FAR N ISOL (OCNL **C1**) HILL FG	OCNL SCT/BKN AC AS Ψ Λ 080 / XXX ISOL CB 060-080 / XXX TROUGH BKN/OVC (LCA SCT LEE MON) CU SC ... ... Λ 015-030 / 050-080 ISOL (OCNL **C1**) SCT/BKN ST 006-012 / 015 ... ... (LCA BASE 003 SEA COT **C1**)	080-XXX
D	25 KM NIL ISOL 7 KM HZ ISOL HILL FG	AREAS SCT/BKN CU SC Λ ... ... 020-030 / 040-050 ISOL SCT/BKN ST 003-008 / 015 LAN ... ... TL 11 Z	XXX

Outlook Until 232400 Z:
SIMILAR.

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	d	c	a	c	d	d	d	b	c	a	a

13	14	15	16	17
c	b	b	a	d

Chapter 28

Warning Messages

Introduction

There are several different messages used to alert pilots to en route and terminal meteorological hazards to aviation. These are:

- Aerodrome Warnings
- Windshear Warnings
- SIGMET
- Volcanic Ash Advisory Messages
- Tropical Cyclone Warning Messages

Aerodrome Warnings

Aerodrome warnings will be issued by the competent meteorological authority for the following hazards:

a) gales

b) strong wind warnings when mean speed exceeding 20 kt (gust 28 kt) or 25 kt (gust 37 kt) dependent on aerodrome requirements

c) thunderstorms, hail or squalls

d) snow

e) frost warnings including hoar frost and glaze or rime ice

f) fog (when the visibility is expected to fall below 600 m)

g) freezing precipitation

Additionally a warning of a marked temperature inversion will be issued at selected aerodromes if a temperature increase of 10°C or more exists between the surface and 1000 ft above the surface.

Windshear Warnings

Windshear warnings for aerodromes may be appended to METARs (not UK) or passed by ATC. The format is variable and could be given as loss/gain in airspeed, crosswind variations or up/downdraughts dependent on what has been experienced or is likely to occur. They will be issued for conditions on approach or departure paths up to 1600 ft above aerodrome level unless a greater height is deemed prudent. Windshear warnings will be issued by the Met Office when conditions indicate that windshear is probable and/or when reported by pilots.

SIGMET

SIGMETs are warnings of the occurrence of the significant weather hazards noted below to aircraft within a flight information region (FIR), they are not issued for hazards at aerodromes. The competent meteorological watch office will issue a SIGMET when hazardous conditions are forecast and/or reported by aircraft.

ICAO requires that they are valid for 4 hours, but SIGMET for tropical cyclones (WC) or volcanic ash (WV) are valid for 6 hours. Practically they will be valid for the period stated in the message.

SIGMET will be issued for:

- thunderstorm;
- heavy hail;
- tropical cyclone;
- freezing rain;
- severe turbulence (not associated with convective cloud);
- severe icing (not associated with convective cloud);
- severe mountain waves;
- heavy sand/dust storm;
- volcanic ash cloud.

The SIGMET message uses abbreviated text format which is relatively easy to interpret. In the following table are some of the common terms used (the list is not exhaustive):

Abbreviation	Meaning	Interpretation
BTN	Between	
CNL	Cancelled	
EMBD	Embedded	CB or TS contained in stratiform cloud
FRQ	Frequent	Little or no separation between adjacent TS
INTSF	Intensifying	
ISOL	Isolated	Individual CB/TS
MTW	Mountain waves	
NC	No change	
OBS	Obscured	CB/TS hidden by haze, smoke or darkness
OCNL	Occasional	Well separated CB/TS
OTLK	Outlook	
SQL	Squall line	Line of TS with little or no separation between individual clouds
STNR	Stationary	
TC	Tropical cyclone	
VA	Volcanic ash	
WKN	Weakening	

Example:

```
EGPX  SIGMET 02 VALID 091115/091715 EGRR-
EGPX SCOTTISH FIR SEV TURB FCST AND OBS BLW FL060 NW OF A LINE
N5425 W00810 TO N5900 E00200 MOV SE AT 20KT AND SE OF LINE N5800
W01000 TO N6100 W00800 MOV SE AT 25KT NC=
```

Second SIGMET issued for the Scottish flight information region (EGPX) by the meteorological watch office at Exeter (EGRR), valid from 1115Z to 1715Z on the 9th of the month. Severe turbulence forecast and observed below FL060 northwest of a line from 5425N 00810W to 5900N 00200E moving southeast at 20 kt and southeast of a line from 5800N 01000W to 6100N 00800W moving southeast at 25 kt. No change in intensity expected.

Volcanic Ash

ICAO in conjunction with WMO has established 9 volcanic ash advisory centres (VAAC), see map.

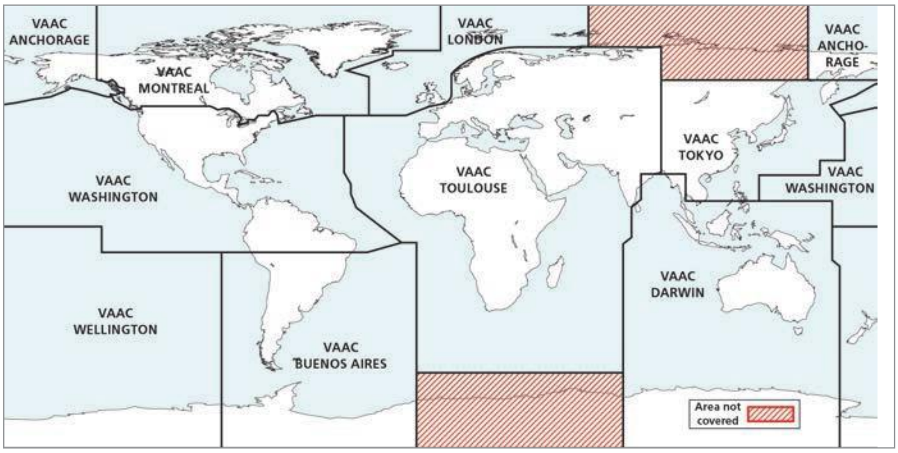


Figure 28.1 Map of VAACs

These centres are operated by the national meteorological services of the countries and are responsible for detecting volcanic ash clouds and tracking and forecasting future movement of the clouds both horizontally and vertically.

The following is an example of a message issued by a VAAC (note: these messages may be reissued as SIGMET (WV) by the meteorological watch office):

FVFE01 RJTD 010045 (message identifier)
VA ADVISORY (type of message)
DTG: 20120801/0045Z (year, month, day/UTC)
VAAC: TOKYO (issuing VAAC)
VOLCANO: SAKURAJIMA 0802-08 (Volcano and international identity)
PSN: N3135E13040 (location)
AREA: JAPAN
SUMMIT ELEV: 1060M
ADVISORY NR: 2012/656 (sequence number of message)
INFO SOURCE: JMA
AVIATION COLOUR CODE: NIL (see below)

ERUPTION DETAILS: EXPLODED AT 20120801/0035Z FL070 EXTD SW
OBS VA DTG: 01/0015Z
OBS VA CLD: VA NOT IDENTIFIABLE FM SATELLITE DATA WIND FL070 070/55KT
FCST VA CLD +6 HR: NO VA EXP
FCST VA CLD +12 HR: NO VA EXP
FCST VA CLD +18 HR: NO VA EXP
RMK: WE WILL ISSUE FURTHER ADVISORY IF VA IS DETECTED IN SATELLITE IMAGERY.
NXT ADVISORY: NO FURTHER ADVISORIES=

The aviation colour coding is:

AVIATION COLOUR CODES RECOMMENDED BY THE INTERNATIONAL CIVIL AVIATION ORGANIZATION.	
GREEN	Volcano is in normal, non-eruptive state. or, after a change from a higher level: Volcanic activity considered to have ceased, and volcano reverted to its normal, non-eruptive state.
YELLOW	Volcano is experiencing signs of elevated unrest above known background levels. or, after a change from higher level: Volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase
ORANGE	Volcano is exhibiting heightened unrest with increased likelihood of eruption. or, Volcanic eruption is underway with no or minor ash emission. [specify ash-plume height if possible]
RED	Eruption is forecast to be imminent with significant emission of ash into the atmosphere likely. or, Eruption is underway with significant emission of ash into the atmosphere. [specify ash-plume height if possible]

Volcanic ash is a form of silica which has a relatively low melting point. The hazards it presents to aviation are:

- Engine flame out
- Reduced visibility
- Scoring of windscreens
- Pitot blockage
- 'Sandblast' effect on the airframe and antennae

It should also be noted that volcanic ash is a very fine powder which, if inhaled, can cause severe respiratory problems.

Tropical Cyclone Advisory Centres (TCAC)

Six regional specialized meteorological centres (RSMCs) have been established to monitor, track and advise on tropical cyclones within their areas of responsibility. Additionally around the Australia area 6 tropical cyclone warning centres (TCWCs) exist to provide the same function (see map). These centres will issue warning messages which the meteorological watch offices may reissue as SIGMET (WC).

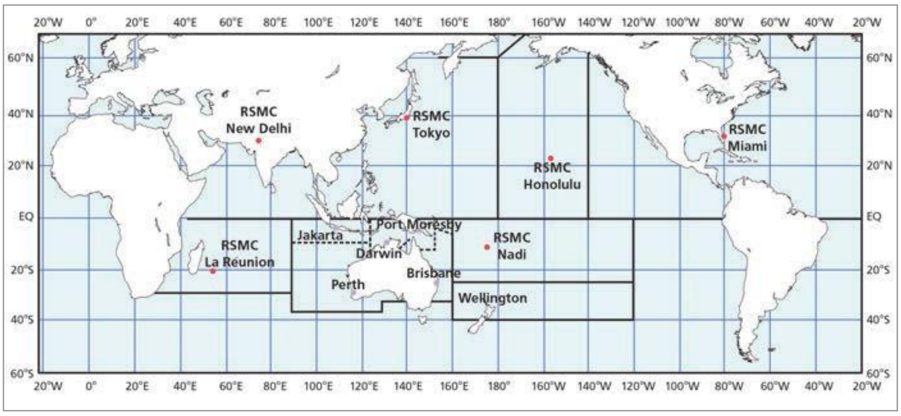


Figure 28.2 RSMC map

An example of such a message follows: (note: this message was originated by the National Hurricane Centre in Miami and does have minor differences to the WMO/ICAO recommended format)

ZCZC MIATCMAT3 ALL
TTAA00 KNHC DDHHMM
HURRICANE MICHAEL FORECAST/ADVISORY NUMBER 18
NWS NATIONAL HURRICANE CENTER MIAMI FL AL132012
1500 UTC FRI SEP 07 2012
THERE ARE NO COASTAL WATCHES OR WARNINGS IN EFFECT.
HURRICANE CENTER LOCATED NEAR 31.2N 41.1W AT 07/1500Z
POSITION ACCURATE WITHIN 15 NM
PRESENT MOVEMENT TOWARD THE NORTHWEST OR 320 DEGREES AT 3 KT
ESTIMATED MINIMUM CENTRAL PRESSURE 970 MB
EYE DIAMETER 15 NM
MAX SUSTAINED WINDS 90 KT WITH GUSTS TO 110 KT.
64 KT....... 20NE 20SE 20SW 20NW.
50 KT....... 30NE 30SE 30SW 30NW.
34 KT....... 60NE 60SE 50SW 50NW.
12 FT SEAS..180NE 180SE 120SW 150NW.
WINDS AND SEAS VARY GREATLY IN EACH QUADRANT. RADII IN NAUTICAL MILES ARE THE LARGEST RADII EXPECTED ANYWHERE IN THAT QUADRANT.
REPEAT...CENTER LOCATED NEAR 31.2N 41.1W AT 07/1500Z
AT 07/1200Z CENTER WAS LOCATED NEAR 31.1N 41.0W
FORECAST VALID 08/0000Z 31.5N 41.4W
MAX WIND 90 KT...GUSTS 110 KT.
64 KT... 25NE 20SE 20SW 20NW.
50 KT... 40NE 40SE 30SW 30NW.
34 KT... 70NE 70SE 60SW 60NW.
FORECAST VALID 08/1200Z 32.0N 41.9W

MAX WIND 85 KT...GUSTS 105 KT.
64 KT... 25NE 20SE 20SW 20NW.
50 KT... 40NE 40SE 30SW 30NW.
34 KT... 70NE 70SE 60SW 60NW.
FORECAST VALID 09/0000Z 32.7N 42.4W
MAX WIND 80 KT...GUSTS 100 KT.
64 KT... 25NE 20SE 20SW 20NW.
50 KT... 50NE 40SE 40SW 40NW.
34 KT... 80NE 80SE 60SW 70NW.
FORECAST VALID 09/1200Z 33.3N 43.0W
MAX WIND 75 KT...GUSTS 90 KT.
50 KT... 50NE 40SE 40SW 40NW.
34 KT... 80NE 80SE 60SW 70NW.
FORECAST VALID 10/1200Z 34.7N 44.8W
MAX WIND 70 KT...GUSTS 85 KT.
50 KT... 50NE 40SE 40SW 40NW.
34 KT... 90NE 90SE 70SW 80NW.
EXTENDED OUTLOOK. NOTE...ERRORS FOR TRACK HAVE AVERAGED NEAR 175 NM ON DAY 4 AND 225 NM ON DAY 5...AND FOR INTENSITY NEAR 20 KT EACH DAY
OUTLOOK VALID 11/1200Z 39.5N 47.0W
MAX WIND 60 KT...GUSTS 75 KT.
OUTLOOK VALID 12/1200Z 48.5N 46.0W...POST-TROPICAL
MAX WIND 50 KT...GUSTS 60 KT.
REQUEST FOR 3 HOURLY SHIP REPORTS WITHIN 300 MILES OF 31.2N 41.1W
NEXT ADVISORY AT 07/2100Z

The graphical forecast below, which covers the same information as the advisory above, shows the predicted track for the next 3 days in white with a further 2 days in outline. The size of the cone reflects the increasing uncertainty as the period of the forecast increases.

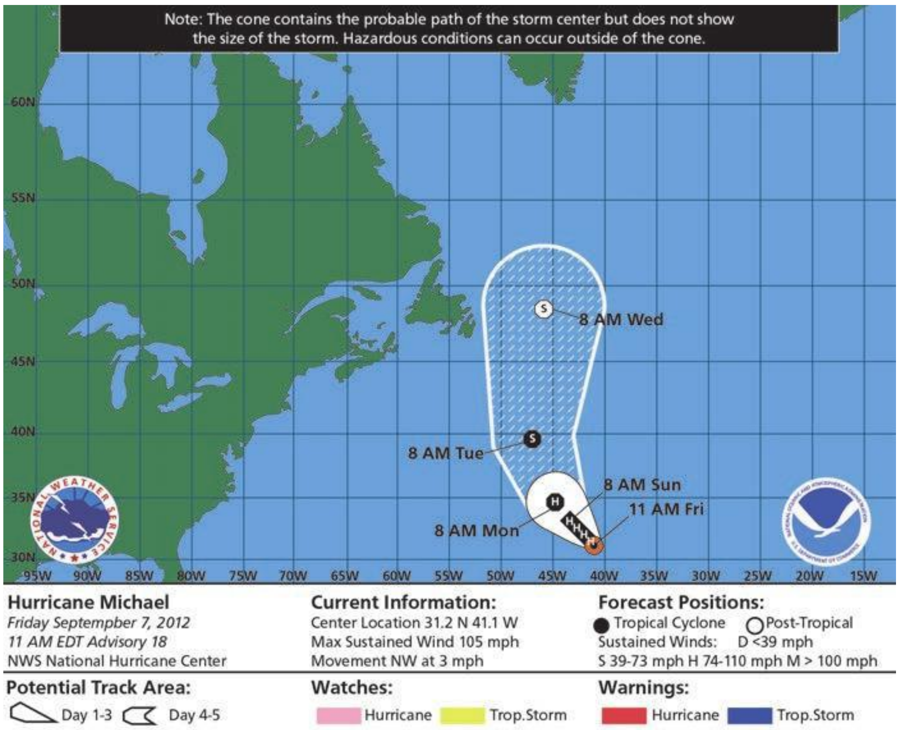


Figure 28.3

Questions

METARs, TAFs and SIGMETs

1. **Given the following METAR: EDDM 250850Z 33005KT 2000 R26R/P1500N R26L/1500N BR SCT002 OVC003 05/05 Q1025 NOSIG**

    a. runway 26R and runway 26L have the same RVR
    b. RVR on runway 26R is increasing
    c. visibility is reduced by water droplets
    d. there is a distinct change in RVR observed

2. **What does the abbreviation "NOSIG" mean?**

    a. Not signed by the meteorologist
    b. No significant changes
    c. No report received
    d. No weather related problems

3. **Refer to TAF below.**
   EGBB 2618/2712 28015G25KT 9999 SCT025 TEMPO 2618/2622 29018G35KT 5000 SHRASN BKN010CB PROB30 TEMPO 2618/2621 1500 TSGR BKN008CB BECMG 2621/2624 26010KT
   From the TAF above you can assume that visibility at 2055Z in Birmingham (EGBB) will be:

    a. more than 10 km
    b. not less than 1.5 km but could be in excess of 10 km
    c. a maximum 5 km
    d. a minimum of 1.5 km and a maximum of 5 km

4. **Refer to the following TAF for Zurich.**
   LSZH 2610/2619 20018G30KT 9999 -RA SCT050 BKN080 TEMPO 2610/2615 23012KT 6000 -DZ BKN015 BKN030 BECMG 2615/2618 23020G35KT 4000 RA OVC010=
   The lowest visibility forecast at ETA Zurich 1430 UTC is:

    a. 6 km
    b. 6 NM
    c. 4 km
    d. 10 km

5. **Which of the following statements is an interpretation of the SIGMET?**

   SIGMET VALID 121420/121820 embd ts obs and fcst in w part of athinai fir / mov e / intst nc =

    a. Athens Airport is closed due to thunderstorms. The thunderstorm zone should be east of Athens by 1820 UTC
    b. The thunderstorms in the Athens FIR are increasing in intensity, but are stationary above the western part of the Athens FIR
    c. Thunderstorms must be expected in the western part of the Athens FIR. The thunderstorm zone is moving east. Intensity is constant
    d. Thunderstorms have formed in the eastern part of the Athens FIR and are slowly moving west

6. **In the weather briefing room during the preflight phase of a passenger flight from Zurich to Rome, you examine the following weather reports of pressing importance at the time:**

EINN SHANNON 2808 sigmet 2 valid 0800/1100 loc sev turb fcst einn fir blw fl 050 south of 53n wkn =

LIMM MILANO 2809 sigmet 2 valid 0900/1500 mod sev cat btn fl 250 and fl 430 fcst limm fir stnr nc =

EGLL LONDON 2808 sigmet nr01 valid 0800/1200 for london fir isol cb embd in lyr cloud fcst tops fl 300 btn 52n and 54n east of 002e sev ice sev turb ts also fcst mov e wkn =

Which decision is correct?

a. Because of the expected turbulence you select a flight level below FL250
b. You show no further interest in these reports, since they do not concern the route to be flown
c. Owing to these reports and taking into account the presence of heavy thunderstorms at planned FL310 you select a higher flight level (FL370)
d. You cancel the flight since the expected dangerous weather conditions along the route would demand too much of the passengers

7. **Refer to the TAF for Bordeaux airport.**

FCFR31 281400
LFBD 2815/2824 26015KT 9999 SHRA BKN020 TEMPO 2816/2820 26020G30KT 8000 +SHRA BKN015CB PROB30 2816/2820 TSRA =

Flight Lisbon to Bordeaux, ETA 1800 UTC. What type of precipitation is forecast on the approach to Bordeaux ?

a. Continuous moderate rain
b. Light drizzle and fog
c. Moderate snow showers
d. Heavy rain showers

8. **What does the term TREND signify?**

a. It is a flight forecast, issued by the meteorological station several times daily
b. It is a brief landing forecast added to the actual weather report
c. It is the actual weather report at an aerodrome and is generally issued at half-hourly intervals
d. It is a warning of dangerous meteorological conditions

9. **Compare the following TAF and VOLMET reports for Nice:**
TAF 2407/2416 VRB02KT CAVOK =
0920Z 13012KT 8000 SCT040CB BKN100 20/18 Q1015 TEMPO TS =
What can be concluded from the differences between the two reports?

a. That the weather at Nice is clearly more volatile than the TAF could have predicted earlier in the morning
b. That the weather conditions at 0920 were actually predicted in the TAF
c. That the weather in Nice after 0920 is also likely to be as predicted in the TAF
d. That the VOLMET speaker has got his locations mixed up, because there is no way the latest VOLMET report could be so different from the TAF

10. Which statement is true?

a. QNH can be 1013.25 only for a station at MSL
b. QNH can be only lower than 1013.25 hPa
c. QNH can not be 1013.25 hPa
d. QNH is lower than 1013.25 hPa at any time

11. Which of the following statements is an interpretation of the SIGMET?

LSAW SWITZERLAND 0307 SIGMET 2 VALID 030700/031100 LSSW mod to sev cat fcst north of alps btn fl 260 and fl 380 / stnr / intsf =

a. Severe turbulence observed below FL260 north of the Alps. Pilots advised to cross this area above FL380
b. Moderate to strong clear air turbulence of constant intensity to be expected north of the Alps
c. Moderate to severe clear air turbulence to be expected north of the Alps. Intensity increasing. Danger zone between FL260 and FL380
d. Zone of moderate to severe turbulence moving towards the area north of the Alps. Intensity increasing. Pilots advised to cross this area above FL260

12. Refer to the TAF for Amsterdam airport:

FCNL31 281500
EHAM 2816/2901 14010KT 6000 -RA SCT025 BECMG 2816/2818 12015G25KT SCT008 BKN013 TEMPO 2818/2823 3000 RA BKN005 OVC010 BECMG 2823/2901 25020KT 8000 NSW BKN020 =
Flight from Bordeaux to Amsterdam, ETA 2100 UTC.

What is the minimum visibility forecast for ETA Amsterdam ?

a. 5 NM
b. 6 km
c. 3 km
d. 5 km

13. At a weather station, at 0600 UTC, the air temperature and dew point are respectively:
T = - 0.5°C, DP = -1.5°C.

In the METAR message transmitted by this station, the "temperature group" will be:

a. M00/M01
b. M01/M02
c. 00/M01
d. M01/M01

14. **Refer to the TAF for Zurich Airport**
TAF LSZH 2507/2516 00000KT 0100 FG VV001 BECMG 2508/2510 0800 VV002 BECMG 2510/2512 23005KT 2500 BKN005 TEMPO 2513/2516 6000 SCT007 =

Which of these statements best describes the weather that can be expected at 1200 UTC?

a. Meteorological visibility 6 kilometres, cloud base 500 ft, wind speed 5 kt
b. Meteorological visibility 2,5 kilometres, cloud base 500 ft, wind speed 5 kt
c. Meteorological visibility 800 metres, wind from 230°, cloud base 500 ft
d. Meteorological visibility 800 metres, vertical visibility 200 ft, calm

15. **In which of the following METAR reports, is the probability of fog formation in the coming night the highest?**

a. 1850Z 21003KT 8000 SCT250 12/m08 Q1028 NOSIG =
b. 1850Z 06018G30KT 5000 OVC010 04/01 Q1024 NOSIG =
c. 1850Z 25010KT 4000 RA BKN012 OVC030 12/10 Q1006 TEMPO 1500 =
d. 1850Z 15003KT 6000 SCT120 05/04 Q1032 BECMG 1600 =

16. **In which of the following circumstances is a SIGMET issued?**

a. Marked mountain waves
b. Fog or a thunderstorm at an aerodrome
c. Clear ice on the runways of an aerodrome
d. A sudden change in the weather conditions contained in the METAR

17. **What is the wind speed given in a METAR report based on?**

a. The average speed of the previous 30 minutes
b. The strongest gust in the previous hour
c. The actual speed at the time of recording
d. The average speed of the previous 10 minutes

18. **Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?**
(MSA above ground : LSZB 10000 FT, LSZH 8000 FT, LSGG 12000 FT, LFSB 6000 FT)

a. LFSB 24008KT 9999 SCT050 18/11 Q1017 RERA NOSIG =
b. LSZH VRB02KT 9000 BKN080 21/14 Q1022 NOSIG =
c. LSGG 22006KT 9999 BKN090 17/15 Q1008 RERA NOSIG =
d. LSZB 28012KT 9999 OVC100 16/12 Q1012 BECMG 5000 =

19. **What does the term METAR signify?**

a. A METAR is a flight forecast, issued by the meteorological station several times daily
b. A METAR is a landing forecast added to the actual weather report as a brief prognostic report
c. A METAR signifies the actual weather report at an aerodrome and is generally issued in half-hourly intervals
d. A METAR is a warning of dangerous meteorological conditions within a FIR

20. Does the following report make sense?
LSZH VRB02KT 5000 MIFG 02/02 Q1015 NOSIG

a. The report would never be seen, because shallow fog is not reported when the meteorological visibility is more than 2 km
b. The report is nonsense, because it is impossible to observe a meteorological visibility of 5 km if shallow fog is reported
c. The report is not possible, because, with a temperature of 2°C and a dew point of 2°C there must be uniform fog
d. The report is possible, because shallow fog is defined as a thin layer of fog below eye level

21. Runway Visual Range (RVR) is:

a. measured with ceilometers alongside the runway
b. usually better than meteorological visibility
c. reported when meteorological visibility is less than 2000 m
d. reported in TAFs and METARs

22. When will the surface wind in a METAR record a gust factor?

a. With gusts of at least 25 kt
b. With gusts of at least 35 kt
c. When gusts are at least 10 kt above the mean wind speed
d. When gusts are at least 15 kt above the mean wind speed

23. What does the term SIGMET signify?

a. A SIGMET is a brief landing forecast added to the actual weather report
b. A SIGMET is an actual weather report at an aerodrome and is generally issued at half-hourly intervals
c. A SIGMET is a warning of dangerous meteorological conditions
d. A SIGMET is a flight forecast, issued by the meteorological station several times daily

24. In which weather report would you expect to find information about icing conditions on the runway?

a. GAFOR
b. TAF
c. METAR
d. SIGMET

25. A SPECI is:

a. an aviation routine weather report
b. a warning for special weather phenomena
c. a forecast for special weather phenomena
d. an aviation selected special weather report

26. **Refer to the following TAF for Zurich.**
LSZH 0610/0619 20018G30KT 9999 -RA SCT050 BKN080 TEMPO 0610/0615 23012KT 6000 -DZ BKN015 BKN030 BECMG 0615/0618 23020G35KT 4000 RA OVC010=

The lowest cloud base forecast at ETA Zurich (1200 UTC) is:

a. 1000 ft
b. 1500 m
c. 5000 ft
d. 1500 ft

27. **Refer to the TAF for Bordeaux airport.**
FCFR31 281400
LFBD 2815/2824 26015KT 9999 SHRA BKN020 TEMPO 2816/2820 26020G30KT 8000 +SHRA BKN015CB PROB30 2816/2820 TSRA =

Flight Lisbon to Bordeaux, ETA 1800 UTC. At ETA Bordeaux what is the lowest quoted visibility forecast?

a. 10 or more km
b. 8 km
c. 8 NM
d. 10 NM

28. **Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?**

a. 26012KT 8000 SHRA BKN025 16/12 Q1018 NOSIG =
b. 27019G37KT 9999 BKN050 18/14 Q1016 NOSIG =
c. 34004KT 7000 MIFG SCT260 09/08 Q1029 BECMG 1600 =
d. 00000KT 0100 FG VV001 11/11 Q1025 BECMG 0500 =

29. **Which of the following weather reports is a warning of conditions that could be potentially hazardous to aircraft in flight ?**

a. SIGMET
b. ATIS
c. SPECI
d. TAF

30. **Refer to the TAF for Amsterdam airport.**
FCNL31 281500
EHAM 2816/2901 14010KT 6000 -RA SCT025 BECMG 2816/2818 12015G25KT SCT008 BKN013 TEMPO 2818/2823 3000 RA BKN005 OVC010 BECMG 2803/2901 25020KT 8000 NSW BKN020 =

Flight from Bordeaux to Amsterdam, ETA 2100 UTC. At ETA Amsterdam what surface wind is forecast ?

a. 120° / 15 kt gusts 25 kt
b. 140° / 10 kt
c. 300° / 15 kt maximum wind 25 kt
d. 250° / 20 kt

31. **Within a short interval, several flight crews report that they have experienced strong clear air turbulence in certain airspace. What is the consequence of these reports?**

a. The airspace in question, will be temporarily closed
b. The competent aviation weather office will issue a SPECI
c. The competent aviation weather office will issue a storm warning
d. The competent aviation weather office will issue a SIGMET

32. **In Zurich during a summer day the following weather observations were taken:**

160450Z 23015KT 3000 +RA SCT008 SCT020 OVC030 13/12 Q1010 NOSIG =
160650Z 25008KT 6000 SCT040 BKN090 18/14 Q1010 RERA NOSIG =
160850Z 25006KT 8000 SCT040 SCT100 19/15 Q1009 NOSIG =
161050Z 24008KT 9999 SCT040 SCT100 21/15 Q1008 NOSIG =
161250Z 23012KT CAVOK 23/16 Q1005 NOSIG =
161450Z 23016KT 9999 SCT040 BKN090 24/17 Q1003 BECMG 25020G40KT TS =
161650Z 24018G35KT 3000 +TSRA SCT006 BKN015CB 18/16 Q1002 NOSIG =
161850Z 28012KT 9999 SCT030 SCT100 13/11 Q1005 NOSIG =

What do you conclude based on these observations?

a. A cold front passed the station early in the morning and a warm front during late afternoon
b. A trough line passed the station early in the morning and a warm front during late afternoon
c. Storm clouds due to warm air came close to and grazed the station
d. A warm front passed the station early in the morning and a cold front during late afternoon

33. **Refer to the following TAF extract:**

BECMG 0918/0921 2000 BKN004 PROB30 BECMG 0921/0924 0500 FG VV001
What does the abbreviation "PROB30" mean?

a. Change expected in less than 30 minutes
b. Probability of 30%
c. Conditions will last for at least 30 minutes
d. The cloud ceiling should lift to 3000 ft

34. **Refer to the following TAF extract:**
BECMG 2218/2221 2000 BKN004 PROB30 BECMG 2221/2224 0500 FG VV001
What visibility is forecast for 2400 UTC?

a. 500 m
b. 2000 m
c. Between 500 m and 2000 m
d. Between 0 m and 1000 m

35. **What is a TREND forecast?**

a. An aerodrome forecast valid for 9 hours
b. A route forecast valid for 24 hours
c. A routine report
d. A landing forecast appended to METAR/SPECI, valid for 2 hours

36. SIGMET information is issued as a warning for significant weather to:

a. VFR operations only
b. heavy aircraft only
c. all aircraft
d. light aircraft only

37. Which of the following phenomena can produce a risk of aquaplaning?

a. SA
b. +RA
c. FG
d. BCFG

38. In which of the following 1850 UTC METAR reports, is the probability of fog formation, in the coming night, the highest?

a. 00000KT 9999 SCT300 21/01 Q1032 NOSIG =
b. VRB01KT 8000 SCT250 11/10 Q1028 BECMG 3000 =
c. 22004KT 6000 -RA SCT012 OVC030 17/14 Q1009 NOSIG =
d. VRB02KT 2500 SCT120 14/M08 Q1035 NOSIG =

39. How long from the time of observation is a TREND in a METAR valid?

a. 1 hour
b. 30 minutes
c. 2 hours
d. 9 hours

40. Refer to the following TAF extract:
BECMG 1918/1921 2000 BKN004 PROB30 BECMG 1921/1924 0500 FG VV001

What does the abbreviation "BKN004" mean?

a. 4 - 8 oktas, ceiling 400 m
b. 1 - 4 oktas, ceiling 400 m
c. 5 - 7 oktas, ceiling 400 ft
d. 1 - 4 oktas, ceiling 400 ft

41. What is a SPECI?

a. A warning of meteorological dangers at an aerodrome, issued only when required
b. An aerodrome forecast issued every 9 hours
c. A selected special aerodrome weather report, issued when a significant change of the weather conditions have been observed
d. A routine aerodrome weather report issued every 3 hours

42. Which of these four METAR reports suggests that rain is most likely in the next few hours?

a. 05016G33KT 8000 OVC015 08/06 Q1028 NOSIG =
b. 23015KT 8000 BKN030 OVC070 17/14 Q1009 BECMG 4000 =
c. 34004KT 9999 SCT040 SCT100 m05/m08 Q1014 NOSIG =
d. 16002KT 0100 FG SCT300 06/06 Q1022 BECMG 1000 =

43. **Refer to the following TAF extract:**
BECMG 1318/1321 2000 BKN004 PROB30 BECMG 1321/1324 0500 FG VV001

What does the abbreviation "VV001" mean?

a. Vertical visibility 100 m
b. Vertical visibility 100 ft
c. RVR less than 100 m
d. RVR greater than 100 m

44. **If CAVOK is reported then:**

a. low level windshear has not been reported
b. any CBs have a base above 5000 ft
c. no low drifting snow is present
d. no clouds are present

45. **The following weather message**
EDDM 2413/2422 VRB03KT 1500 HZ OVC004 BECMG 2415/2417 00000KT 0500 FG VV002 TEMPO 2420/2422 0400 FG VV001
is a:

a. 24 hour TAF
b. SPECI
c. METAR
d. 9 hour TAF

46. **Which of the following statements is an interpretation of the METAR?**
25020G38KT 1200 +TSGR BKN006 BKN015CB 23/18 Q1016 BECMG NSW =

a. Mean wind speed 20-38 kt, meteorological visibility 1200 metres, temperature 23°C
b. Broken, cloud base 600 ft and 1500 ft, temperature 18°C
c. Wind 250°, thunderstorm with moderate hail, QNH 1016 hPa
d. Gusts of 38 kt, thunderstorm with heavy hail, dew point 18°C

47. **Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?**
(MSA above ground: LSZB 10000 FT, LSZH 8000 FT, LSGG 12000 FT, LFSB 6000 FT)

a. LSZH 26024G52KT 9999 BKN060 17/14 Q1012 RETS TEMPO 5000 TSRA =
b. LSZB 30004KT 9999 SCT090 10/09 Q1006 NOSIG =
c. LFSB 00000KT 9000 SCT080 22/15 Q1022 NOSIG =
d. LSGG 22003KT 9999 SCT120 BKN280 09/08 Q1026 BECMG 5000 =

48. **On the European continent METARs of main airports are compiled and distributed with intervals of:**

a. 0.5 hour
b. 1 hour
c. 2 hours
d. 3 hours

49. **The RVR, as reported in a METAR, is always the:**

a. highest value of the A-, B- and C-position
b. lowest value of the A-, B- and C-position
c. value representative of the touchdown zone
d. average value of the A-, B- and C-position

50. **In the TAF for Delhi (India), during the summer, for the time of your landing you note: TEMPO TS. What is the maximum time this deterioration in weather can last in any one instance ?**

a. 60 minutes
b. 120 minutes
c. 10 minutes
d. 20 minutes

51. **Refer to the following TAF extract:**
BECMG 3018/3021 2000 BKN004 PROB30 BECMG 3021/3024 0500 FG VV001
What does the "BECMG" data indicate for the 18 to 21 hour time frame?

a. A quick change to new conditions between 1800 UTC and 1900 UTC
b. Many short term changes in the original weather
c. Many long term changes in the original weather
d. The new conditions are achieved between 1800 and 2100 UTC

52. **The cloud base, reported in the METAR, is the height above:**

a. airfield level
b. mean sea level
c. the pressure altitude of the observation station at the time of observation
d. the highest terrain within a radius of 8 km from the observation station

53. **Appended to a METAR you get the following runway report: 01650428**
What must you consider when making performance calculations?

a. The braking action will be medium to good
b. The runway will be wet
c. Aquaplaning conditions
d. The friction coefficient is 0.28

54. **Which of these four METAR reports suggests that a thunderstorm is likely in the next few hours?**

a. 1350Z 16004KT 8000 SCT110 OVC220 02/m02 Q1008 NOSIG =
b. 1350Z 34003KT 0800 SN VV002 m02/m04 Q1014 NOSIG =
c. 1350Z 04012KT 3000 OVC012 04/03 Q1022 BECMG 5000 =
d. 1350Z 21005KT 9999 SCT040CB SCT100 26/18 Q1016 TEMPO 24018G30 TS =

55. **The wind direction in a METAR is measured relative to:**

a. magnetic north
b. the 0-meridian
c. grid north
d. true north

56. **Which of the following weather reports could be, in accordance with the regulations, abbreviated to "CAVOK"?**

a. 04012G26KT 9999 BKN030 11/07 Q1024 NOSIG =
b. 15003KT 9999 BKN100 17/11 Q1024 NOSIG =
c. 24009KT 6000 RA SCT010 OVC030 12/11 Q1007 TEMPO 4000 =
d. 29010KT 9999 SCT045TCU 16/12 Q1015 RESHRA NOSIG =

57. **Marseille Information gives you the following meteorological information for Ajaccio and Calvi for 1600 UTC:**
Ajaccio: wind 360°/2 kt, visibility 2000 m, rain, BKN stratocumulus at 1000 FT, OVC altostratus at 8000 FT, QNH 1023 hPa.
Calvi: wind 040°/2 kt, visibility 3000 m, mist, FEW stratus at 500 FT, SCT stratocumulus at 2000 FT, OVC altostratus at 9000 FT, QNH 1023 hPa.

The ceilings (more than 4 oktas) are therefore:

a. 1000 FT at Ajaccio and 9000 FT at Calvi
b. 1000 FT at Ajaccio and 500 FT at Calvi
c. 8000 FT at Ajaccio and 9000 FT at Calvi
d. 1000 FT at Ajaccio and 2000 FT at Calvi

58. **Which of the four answers is a correct interpretation of data from the following METAR?**
16003KT 0400 R14/P1500 R16/1000N FZFG VV003 M02/M02 Q1026 BECMG 2000 =

a. Meteorological visibility 400 m, RVR for runway 16 1000 m, dew point -2°C, freezing fog
b. RVR for runway 16 1000 m, meteorological visibility increasing in the next 2 hours to 2000 m, vertical visibility 300 m, temperature -2°C
c. RVR for runway 14 1500 m, meteorological visibility 400 m, QNH 1026 hPa, wind 160° at 3 kt
d. Meteorological visibility 1000 m, RVR 400 m, freezing level at 300 m, variable winds, temperature 2°C

59. **You receive the following METAR:**
LSGG 0750Z 00000KT 0300 R05/0700N FG VV001 M02/M02 Q1014 NOSIG =
What will be the RVR at 0900 UTC?

a. 900 m
b. The RVR is unknown, because the "NOSIG" does not refer to RVR
c. 300 m
d. 700 m

60. **Which of the following statements is an interpretation of the METAR?**
00000KT 0200 R14/0800U R16/P1500U FZFG VV001 m03/m03 Q1022 BECMG 0800 =

a. Meteorological visibility 200 metres, RVR for runway 16 1500 metres, temperature -3°C, vertical visibility 100 metres
b. Meteorological visibility 200 ft, RVR for runway 16 more than 1500 metres, vertical visibility 100 ft, fog with hoar frost
c. Meteorological visibility for runway 14 800 metres, fog with hoar frost, RVR for runway 16 more than 1500 metres
d. RVR for runway 14 800 metres, vertical visibility 100 ft, calm, meteorological visibility improving to 800 metres in the next 2 hours

61. **Look at this TAF for Zurich Airport**
TAF LSZH 2113/2122 22018G35KT 9999 SCT012 BKN030 BECMG 2113/2115 25025G45KT TEMPO 2117/2120 4000 +SHRA BKN025TCU BECMG 2120/2122 25015KT T1815Z T1618Z =

Which of these statements best describes the weather most likely to be experienced at 1500 UTC?

a. Meteorological visibility 10 kilometres or more, main cloud base 3000 ft, wind 250°, temperature 18°C
b. Meteorological visibility 4000 metres, gusts up to 25 kt, temperature 18°C
c. Meteorological visibility 10 kilometres or more, main cloud base 1200 ft, gusts up to 45 kt
d. Severe rain showers, meteorological visibility 4000 metres, temperature 15°C, gusts up to 35 kt

62. **The validity of a TAF is:**

a. 2 hours
b. between 6 and 9 hours
c. 9 hours from the time of issue
d. stated in the TAF

63. **Runway visual range can be reported in:**

a. a METAR
b. a TAF
c. a SIGMET
d. both a TAF and a METAR

64. **Refer to the TAF for Amsterdam airport.**
FCNL31 281500
EHAM 2816/2901 14010KT 6000 -RA SCT025 BECMG 2816/2818 12015G25KT SCT008 BKN013 TEMPO 2818/2823 3000 RA BKN005 OVC010 BECMG 2823/2901 25020KT 8000 NSW BKN020 =

Flight from Bordeaux to Amsterdam, ETA 2100 UTC.
What lowest cloud base is forecast for arrival at Amsterdam?

a. 250 ft
b. 500 m
c. 800 ft
d. 500 ft

65. **ATIS information contains:**

a. only operational information
b. meteorological and operational information
c. only meteorological information
d. operational information and if necessary meteorological information

66. **In METAR messages, the pressure group represents the:**

a. QFE rounded to the nearest hPa
b. QNH rounded down to the nearest hPa
c. QFE rounded down to the nearest hPa
d. QNH rounded up to the nearest hPa

67. **What do the first four letters of the SIGMET message identify?**

a. The issue number
b. The ICAO identifier for the relevant airport
c. The name of the air traffic services controlling unit
d. The validity time

68. **What is the expected change in the weather intensity indicated by this SIGMET?**

EGTT SIGMET 1 VALID 310730/311130 EGRR LONDON FIR ISOL CB FCST TOPS FL370 ROUTES W OF W00400 NC=

a. Weakening
b. Strengthening
c. Dissipating
d. No change

69. **How would a severe mountain wave be coded in a SIGMET message?**

a. + MTW
b. SEV MTW
c. SEV MNTW
d. SEVERE MNTW

70. **In the following SIGMET message, what is the hazard forecast?**

LFFF SIGMET 1 VALID 310600/311100 LFPW- UIR FRANCE MOD TURB FCST BLW FL420 W of 04W MOVE E 30KT NC=

a. Moderate turbulence at 42 000 ft west of 4 degrees west and moving eastwards
b. Moderate turbulence below 42 000 ft west of 4 degrees west and moving from the east
c. Turbulence at 42 000 ft west of 4 degrees west and moving at 30 kt
d. Moderate turbulence below 42 000 ft west of 4 degrees west and moving eastwards

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	b	b	a	c	a	d	b	a	c	c	c

13	14	15	16	17	18	19	20	21	22	23	24
a	b	d	a	d	d	c	d	b	c	c	c

25	26	27	28	29	30	31	32	33	34	35	36
d	d	b	b	a	a	d	d	b	a	d	c

37	38	39	40	41	42	43	44	45	46	47	48
b	b	c	c	c	b	b	c	d	d	d	a

49	50	51	52	53	54	55	56	57	58	59	60
c	a	d	a	d	d	d	b	a	a	b	d

61	62	63	64	65	66	67	68	69	70
a	d	a	d	b	b	c	d	b	d

Chapter

29

Meteorological Information for Aircraft in Flight

Introduction

The weather-briefing material and services that you have read about in this book, so far, enable a pilot to obtain information on **forecast or actual weather conditions, prior to getting airborne**, during **flight planning**. However, pilots are also able to obtain **weather information** when they are in the air, by tuning into appropriate **frequencies** on the aircraft's **radio**.

One of these **in-flight weather briefing services** is the **VOLMET**. The first element of the code **VOLMET**, **vol**, is the French word for **flight**. **VOLMET**, therefore, is a term signifying **meteorological information for aircraft in flight**.

VOLMET broadcasts are **ground-to-air radio transmissions** of **meteorological reports** and **forecasts** made on the **High Frequency (HF)** and **Very High Frequency (VHF)** bands. These transmissions are broadcast in plain language, and give the latest weather **reports** and **forecasts**, in the form of spoken **METARs, TAFs** and **SIGMETs. VOLMET** broadcasts transmit weather information **for a number of different aerodromes**, sequentially. As a result, the pilot may have to wait for the forecast for the aerodrome pertinent to his flight to come around.

VOLMET Operation

The following table is an extract from the **United Kingdom Aeronautical Information Publication** (**GEN** Section), containing a list of **VHF VOLMET** services and their associated **radio frequencies** for the **United Kingdom** and the **near continent**.

UK AIP **(11 Jul 02) GEN 3-5-21**

GEN 3.5.7 — VOLMET SERVICES

Table 3.5.7.1 — Meteorological Radio Broadcasts (VOLMET)

Call Sign/ID	EM	Frequency MHz	Operating Hours	Stations	Contents	Remarks
1	2	3	4	5	6	7
London Volmet (Main)	A3E	135.375	H24 continuous	Amsterdam Brussels Dublin Glasgow London Gatwick London Heathrow London Stansted Manchester Paris/Charles de Gaulle	(1) Half hourly reports (METAR) (2) The elements of each report broadcast in the following order: (a) Surface wind (b) Visibility (or CAVOK) (c) RVR if applicable (d) Weather (e) Cloud (or CAVOK) (f) Temperature (g) Dewpoint (h) QNH (i) Recent Weather if applicable (j) Windshear if applicable (k) TREND if applicable (l) Runway Contamination Warning if applicable	The spoken word 'SNOCLO' will be added to the end of the aerodrome report when that aerodrome is unusable for take-offs and landings due to heavy snow on runways or runway snow clearance.
London Volmet (South)	A3E	128.600	H24 continuous	Birmingham Bournemouth Bristol Cardiff Jersey London Luton Norwich Southampton Southend		
London Volmet (North) (**Note 1**)	A3E	126.600	H24 continuous	Blackpool East Midlands Isle of Man Leeds Bradford Liverpool London Gatwick Manchester Newcastle Teesside	(3) Non-essential words such as 'surface wind', 'visibility' etc are not spoken. (4) Except for 'SNOCLO' (see Column 7), the Runway State Group is not broadcast. (5) All broadcasts are in English.	
Scottish Volmet	A3E	125.725	H24 continuous	Aberdeen/Dyce Belfast Aldergrove Edinburgh Glasgow Inverness London/Heathrow Prestwick Stornoway Sumburgh		

Note 1: Broadcasting range extended to cover Southeast England and English Channel.

Note 2: An HF VOLMET broadcast for North Atlantic flights (Shannon VOLMET) is operated by the Republic of Ireland.

Figure 29.1

Individual VOLMET stations, in each region, broadcast weather reports and forecasts for a **group of major aerodromes** in their region of responsibility.

From *Figure 29.1* you can see that there are four **UK VOLMET** stations: **LONDON VOLMET MAIN, LONDON VOLMET NORTH, LONDON VOLMET SOUTH** and the **SCOTTISH VOLMET.** Next to each of these **stations**, is the **frequency** on which the **VOLMET** transmission is broadcast, the operating hours, and the list of aerodromes covered by the broadcast. The **LONDON VOLMET MAIN** broadcast, for example, is transmitted on the **VHF frequency** of **135.375 MHz, continuously, over a 24 hour period.**

The content of each **VOLMET broadcast** is a set of pre-recorded weather elements. **VOLMET broadcasts** are updated every **half hour.**

You will also see from *Figure 29.1* that the **LONDON VOLMET MAIN** broadcast contains weather information for aerodromes in **France** and the **Republic of Ireland**, as well as in the **United Kingdom.** The **LONDON VOLMET SOUTH** broadcast contains **weather information** for major airfields between **Birmingham**, in the **Midlands**, and the island of **Jersey**, in the **English Channel.**

Column 6 of *Figure 29.1* details the **specific weather elements** which are included in the **VOLMET broadcasts.** You will notice that the **broadcast content** has the same format as that of a **METAR**; however, in *Figure 29.3* which contains examples of actual **VOLMET broadcasts**, you will notice that **TAF**-terminology **(BECMG, TEMPO)** is also used, giving the broadcast a **forecast element**, too.

London VOLMET Main

The following table shows sample **LONDON VOLMET MAIN** broadcasts. Six of the **major aerodromes** from the broadcast are included, with associated weather information.

THIS IS LONDON VOLMET MAIN AMSTERDAM AT 1125 WIND 160 DEGREES 16 KNOTS VARIABLE BETWEEN 130 AND 190 DEGREES VISIBILITY 7 KILOMETRES LIGHT RAIN SHOWERS CLOUD FEW 2 THOUSAND FEET FEW CUMULONIMBUS 2 THOUSAND 5 HUNDRED FEET BROKEN 4 THOUSAND FEET TEMPERATURE 14 DEW POINT 9 QNH 1004 BECOMING VISIBILITY 10 KILOMETRES OR MORE NIL SIGNIFICANT WEATHER	BRUSSELS AT 1120 WIND 190 DEGREES 14 KNOTS MAXIMUM 24 KNOTS VISIBILITY 10 KILOMETRES OR MORE LIGHT RAIN SHOWERS CLOUD SCATTERED 2 THOUSAND 3 HUNDRED FEET SCATTERED 5 THOUSAND FEET BROKEN 10 THOUSAND FEET TEMPERATURE 13 DEW POINT 10 QNH 1006 NOSIG
GLASGOW AT 1120 WIND 070 DEGREES 5 KNOTS VARIABLE BETWEEN 030 AND 110 DEGREES VISIBILITY 10 KILOMETRES OR MORE CLOUD FEW 1 THOUSAND 8 HUNDRED FEET SCATTERED 4 THOUSAND 5 HUNDRED FEET TEMPERATURE 14 DEW POINT 8 QNH 997	DUBLIN AT 1130 WIND 260 DEGREES 6 KNOTS VARIABLE BETWEEN 240 AND 300 DEGREES VISIBILITY 10 KILOMETRES OR MORE CLOUD SCATTERED 2 THOUSAND 4 HUNDRED FEET SCATTERED 20 THOUSAND FEET TEMPERATURE 13 DEW POINT 6 QNH 997 NOSIG

LONDON/GATWICK AT 1120 WIND 190 DEGREES 10 KNOTS VARIABLE BETWEEN 150 AND 220 DEGREES VISIBILITY 10 KILOMETRES OR MORE SHOWERS IN VICINITY FEW CUMULONIMBUS 2 THOUSAND 4 HUNDRED FEET SCATTERED 4 THOUSAND FEET TEMPERATURE 11 DEW POINT 9 QNH 999	LONDON/HEATHROW AT 1120 WIND 220 DEGREES 12 KNOTS VARIABLE BETWEEN 190 AND 250 DEGREES VISIBILITY 10 KILOMETRES OR MORE LIGHT RAIN SHOWERS FEW CUMULONIMBUS 2 THOUSAND 5 HUNDRED FEET BROKEN 11 THOUSAND FEET TEMPERATURE 11 DEW POINT 8 QNH 997 TEMPO VISIBILITY 4 THOUSAND 5 HUNDRED FEET RAIN SHOWERS

Figure 29.2

VOLMET Broadcasts in the High Frequency Band

The **VOLMET** broadcasts that we have spoken of, so far, are transmitted in the **VHF band**. However, **VOLMETS** are also broadcast, all over the world, in the **High Frequency (HF) band**, typically between **3** to **20 MHz**.

ATIS	Automatic Terminal Information Service
VOLMET	Routine Broadcast of Meteorological Information for Aircraft In Flight (INTL)
VOLMET	Routine Broadcast of Meteorological Information for Aircraft In Flight (NATL)
WX	Weather Broadcast
	Inactive or Planned Service

EUR-MET Europe

Freq (Mhz)	Type	BCH +	Call Sign	State	Station Name	Latitude (N)	Longitude (E/W)	Remarks
2.998	VOLMET							unassigned
3.413	VOLMET	00,30	EIP	IRL	Shannon	52 34 N	09 12 W	1800-0530Z
4.540	WX	15,45	MLD	GBR	Architect (Kinloss)	57 39 N	03 34 W	
4.645	ATIS	Cont	ES..	EST	Tallinn	59 25 N	24 50 E	ex-RPH 6
4.742	WX	00,30	MLP	GBR	Architect (Brize Norton)	51 45 N	01 35W	
	VOLMET	.., 35	GFG	GIB	Gibraltar	36 09 N	05 21 W	
	VOLMET	15, ..	GFW	CYP	Cyprus (Akrotiri)	34 35 N	32 58 E	Mo-Fr 0215-1815Z
5.450	VOLMET	00, 30	MPL 2	GBR	West Drayton (London)			"RAF"
5.505	VOLMET	00, 30	EIP	IRL	Shannon	52 34 N	09 12 W	
5.714	WX	00, 30	MLP	GBR	Architect (Brize Norton)	51 45 N	01 35 W	
6.580	VOLMET							**unassigned**

Figure 29.3

The **Shannon VOLMET** is a vital source of weather information for **North Atlantic flight routes**.

The types of **VOLMETs** shown contain the same information as the **VOLMETs** for mainland **United Kingdom**, although they are more likely also to contain additional weather forecast details, such as **SIGMETS** for en route weather.

VOLMET transmissions are designed to be simple and easily understood, so that fast, efficient weather briefing can be obtained by pilots, in flight.

During **preflight planning**, note down the **VOLMET frequencies** for the areas that you will be flying in, so that, en route, you can listen to broadcasts for aerodromes in the vicinity of your **destination**, as well as for **alternate aerodromes**.

Access to **VOLMET** broadcasts enables the pilot to confirm that **weather conditions** at his **destination airfield** are favourable. If a **diversion** becomes necessary, the current suitability of the planned **diversion airfield** can also be rapidly determined.

ATIS Introduction

The **Automatic Terminal Information Service (ATIS)** *is a continuous broadcast of* **current aerodrome weather** *and* **other aerodrome information**.

The purpose of the **ATIS** is to **improve controller effectiveness** and to **reduce congestion** on busy **ground, tower** and **approach frequencies** by automatically transmitting on a discrete VHF **radio frequency**.

Pilots **departing from** or **arriving at** aerodromes which offer **ATIS** are encouraged to listen to the **ATIS broadcast** and to **notify air traffic control**, on **initial contact**, that they have received the **ATIS broadcast**, by passing the **phonetic alphabet code letter** by which all **ATIS broadcasts** are identified.

At some aerodromes there will be a separate **ATIS broadcast** for **departure** and **arrival**.

In order to free up **air traffic VHF communication frequencies**, some aerodromes transmit the **ATIS** information on the voice channel of a **VOR** beacon located at the aerodrome.

EGCC AD 2.18 – ATS COMMUNICATION FACILITIES					
Service Designation	Callsign	Frequency MHz	Hours of Operation Winter	Summer	Remarks
1	2	3	4		5
APP	Manchester Radar	119.525 †	H24	H24	ATZ hours coincident with Approach hours. † Serves Manchester and Manchester Woodford.
	Manchester Radar	118.575	As directed by ATC	As directed by ATC	
	Manchester Director	121.350			
TWR	Manchester Tower	118.625 121.500 ‡ 119.400	H24	H24	
	Manchester Ground	121.850 121.700 § 125.375	0630-2200 2200-0630 As directed by ATC	0530-2100 2100-0530 As directed by ATC	‡ Emergency Ch O/R.
	Manchester Delivery	121.700 §	0630-2200	0530-2100	§ Departing aircraft are to make initial call on 121.700 MHz to 'Manchester Delivery' or 'Manchester Ground' as appropriate. ØAlso available by telephone: 0161-499 2324
Arrival ATISØ	Manchester Information	128.175	H24	H24	
Departure ATISØ	Manchester Departure Information	121.975	0520-2220	0420-2120	
FIRE	Manchester Fire	121.600	Available when Fire vehicle attending aircraft on the ground in an emergency.		Non-ATS frequency.

AMDT AIRAC 5/03 Civil Aviation Authority

Figure 29.4

Shown in *Figure 29.4* is an extract from the **Aerodrome** section of the **United Kingdom Aeronautical Information Publication (UK AIP)** illustrating that both an **arrival** and **departure ATIS** is available, on different frequencies, at **Manchester Airport.**

The following extract shows that, at **Southampton Airport**, the **ATIS broadcast** is made on the **Southampton VOR frequency.**

UK AIP SOUTHAMPTON (14 Apr 05) AD 2-EGHI-1-7

EGHI AD 2.18 – ATS COMMUNICATION FACILITIES					
Service Designation	Callsign	Frequency MHz	Hours of Operation Winter	Summer	Remarks
1	2	3	4		5
APP	Southampton Approach	128.850	As directed by ATC	As directed by ATC	ATZ hours coincident with Tower hours (but not by arrangement).
TWR	Southampton Tower	118.200	† Mon-Fri 0625-2100 Sat 0625-2000 Sun 0735-2100 and by arrangement	† Mon-Thu 0545-2030 Fri 0545-2115 Sat 0630-1915 Sun 0800-2000 and by arrangement	† Hours subject to change, consult latest NOTAM.
	Southampton Ground	121.775	As directed by ATC	As directed by ATC	
RAD	Southampton Radar	128.850	As directed by ATC	As directed by ATC	
ATIS	Southampton Information	113.350	HO	HO	Broadcast on Southampton VOR.
FIRE	Southampton Fire	121.600	Available when Fire vehicle attending aircraft on the ground in an emergency.		Non-ATS frequency.

Figure 29.5

ATIS Operation

If the **current aerodrome weather conditions** change, or if there is any change in other **pertinent aerodrome information,** the **ATIS broadcast** is immediately updated to reflect these changes. The updated **ATIS broadcast** is then given a new, sequential **alphabetical code**. For example, **ATIS broadcast BRAVO** will have replaced the previous **ATIS broadcast ALPHA**.

On initial contact with **Air Traffic Control (ATC)**, a pilot is required to state the **identifying letter code** of the **ATIS information last received**, in order that **ATC** may know that the pilot has the most recent information.

ATIS will be broadcast in plain language and will contain some or all of the following information, if applicable.

- Aerodrome name.
- ATIS sequence designator or information code.
- Time of observation.
- Runway in use and status.
- Surface wind in knots and referenced to magnetic north.
- Visibility and RVR.
- Present weather.
- Significant cloud.
- Temperature and dew point.
- Altimeter setting.
- Transition level.
- Type of approach expected.
- And finally any warnings pertinent to flight operations.

Use of ATIS

On **departure** from an aerodrome, **ATIS information** should be obtained by the pilot **before initial contact with Air Traffic Control**. When initial contact is made with **Air Traffic Control**, the pilot must mention the **identifying letter** of the ATIS broadcast obtained, in order to confirm to the controller that the latest airfield information has been received.

A pilot **arriving** at an aerodrome should also listen to the **ATIS broadcast before transmitting on the aerodrome's initial contact frequency**. On hearing that a pilot has the latest **ATIS information,** an approach controller may omit, in his reply to the pilot, certain details contained in the **ATIS broadcast**. Normally, however, the **aerodrome QNH** will always be confirmed by the controller.

If a pilot does not acknowledge receipt of the latest **ATIS broadcast** on initial contact with an aerodrome controller, the controller will pass the **essential aerodrome information** to the pilot.

Obtaining the latest **ATIS information** helps ensure that radio transmissions between **Air Traffic Control** and the pilot are kept to a minimum. This is especially important in **busy airspace** where radio transmissions must be kept short to allow for effective communication between controllers and all the aircraft to which they are giving a service.

Questions

1. An aerodrome VOLMET report for 0450 UTC, during the autumn in the United Kingdom is:

Surface wind	**150/05 kt**
Visibility	**2000 m**
Weather	**Nil**
Temperature	**9°C**
Dew point	**8°C**
QNH	**1029 hPa**
Trend	**NOSIG**

From the information above, what type of pressure system, do you deduce, is dominating the region?

a. An anti-cyclone
b. A cyclone
c. A low pressure
d. A trough

2. A VOLMET is defined as:

a. a radio broadcast of selected aerodrome forecasts
b. a continuous telephone message of selected aerodrome METARs
c. a continuous radio broadcast of selected aerodrome actual weather observations and forecasts
d. a teleprinter message of selected aerodrome TAFs and METARs

3. VOLMETs are updated:

a. every hour
b. 4 times a day
c. 2 times a day
d. every half hour

4. VOLMETs are:

a. air to ground radio transmissions on HF and VHF
b. air to ground radio transmissions on HF and SVHF
c. ground to air radio transmissions on LF and VHF
d. ground to air radio transmissions on HF and VHF

5. **An aerodrome VOLMET report for 0450 UTC, during the autumn in the United Kingdom is:**

Surface wind	**150/05 kt**
Visibility	**2000 m**
Weather	**Nil**
Temperature	**9°C**
Dew point	**8°C**
QNH	**1029 hPa**
Trend	**NOSIG**

Given that sunrise is at 0600 UTC, what might you expect during the 2 hours following this report?

a. CAVOK
b. Radiation Fog
c. Low Stratus
d. Advection Fog

6. **When are ATIS broadcasts updated?**

a. Any time the aerodrome or weather information changes
b. Only when the aerodrome information changes
c. Every 30 minutes
d. Every hour

7. **To minimize VHF frequency use, the ATIS can be broadcast on the voice frequency of which navigation aid?**

a. ILS
b. NDB
c. VOR
d. GPS

8. **In an ATIS broadcast, what is used to identify the current report?**

a. An alphabetical code
b. A number
c. A validity number
d. An issue time

9. **What is the ATIS?**

a. A chart of current aerodrome and weather information
b. A continuous broadcast of current aerodrome and weather information
c. A continuous broadcast of weather information
d. A printed text report of current aerodrome and weather information

10. **In what frequency band is the ATIS normally broadcast?**

a. LF
b. HF
c. ADF
d. VHF

Answers

1	2	3	4	5	6	7	8	9	10
a	c	d	d	b	a	c	a	b	d

Chapter 30

Questions

Questions

1. MSA given as 12 000 ft, flying over mountains in temperatures +9°C, QNH set as 1023 (obtained from a nearby airfield). What will the true altitude be when 12 000 ft is reached?

a. 11 940
b. 11 148
c. 12 210
d. 12 864

2. Why do TRS not occur in the SE Pacific and South Atlantic?

a. Low water temperatures
b. No Coriolis effect
c. SE trade crosses Equator
d. SE trade winds blow there

3. In the Northern Hemisphere a man observes a low pressure system passing him to the south, from west to east. What wind will he experience?

a. Backs then Veers
b. Constantly Backs
c. Veers then Backs
d. Backs then steady

4. When would a rotor cloud be ahead of a Cb?

a. Mature stage
b. Cumulus stage
c. Dissipating stage
d. Initial stage

5. What are the conditions under which advection fog will be formed?

a. Warm moist air over cold surface
b. Cold dry air over warm surface
c. Warm dry air over cold surface
d. Cold moist air over warm surface

6. What cloud does hail fall from?

a. Cb
b. Ns
c. Cu
d. Ci

7. What is a cold pool, in the Northern Hemisphere?

a. Cold air found on the lee side of the Alps in winter in a cold northwesterly air stream
b. Cold air brought down from the north behind frontal systems
c. Air from tropical continental origin
d. Air from Polar maritime origin only

8. **What is relative humidity dependent upon?**

a. Moisture content and temperature of the air
b. Temperature of the air
c. Temperature and pressure
d. Moisture content of the air

9. **If the ELR is 0.65°C/100 m:**

a. atmosphere is conditionally stable
b. atmosphere is stable
c. atmosphere is unstable
d. atmosphere is stable when dry

10. **Where are you most likely to find moderate to severe icing?**

a. In upper levels of cumulonimbus capillatus
b. Nimbostratus
c. Stratus
d. Cirrus

11. **Height of the tropopause at 50°N:**

a. 11 km
b. 16 km
c. 5 km
d. 20 km

12. **What are the indications of a TRS from a great distance?**

a. Thick Ci
b. Thick Cbs
c. Ns
d. Sc

13. **Flying form London to Bombay in January, what average wind might you expect?**

a. Light easterly
b. Light westerly
c. Westerly polar front jet stream
d. Tropical easterly jet

14. **What pressure systems affect the North Atlantic in summer?**

a. Azores low, Scandinavian high
b. Azores low, North Canadian low
c. North Canadian low, Azores High
d. Azores high, Scandinavian High

15. **A characteristic of a stable air mass:**

a. lapse rate of 1°C/100 m
b. rising air slows down and dissipates
c. lapse rate of 0.3°C/100 m
d. good visibility and showers

16. How do you recognize high level jet streams and associated CAT?

a. High pressure centre at high level
b. Streaks of cirrus
c. High level dust
d. Lenticularis

17. Which conditions lead to mountain waves?

a. Unstable moist air, speeds <5 kt across the ridge
b. Stable air, speed, >20 kt across the ridge
c. Unstable air, speed >20 kt across the ridge
d. Stable air, speed >30 kt, parallel to the ridge

18. Where is the coldest air in a cold occlusion?

a. Behind the cold front
b. At the junction of the occlusion
c. In front of the occlusion
d. Behind the warm front

19. What causes low level cloud in front of the warm front?

a. Rain falling into the cold air
b. Rain falling into warm air
c. Warm air passing over cold surface
d. Cold air passing over warm surface

20. Where is the largest chance of squalls occurring?

a. In front of an active cold front
b. Above the occlusion along the cold front
c. Behind the cold front
d. Above the occlusion along the warm front

21. ELR is 1°C/100 m:

a. Neutral when dry
b. Absolute stability
c. Absolute instability
d. Conditional stability

22. Typical tornado diameter:

a. Less than 100 m
b. 100 - 150 m
c. 2 - 6 km
d. More than 10 km

23. In the areas of the ITCZ why are the heights of the tropopause not reported?

a. Because it is too cold
b. Because it cannot be measured
c. Because it is likely to be above your FL
d. Because it is in the stratosphere

24. **Flying conditions in Ci cloud and horizontal visibility:**

a. less than 500 m vis, light/mod clear icing
b. greater than 1000 m vis, light/mod rime ice
c. less then 500 m vis, no icing
d. greater than 1000 m vis, no icing

25. **Description of radiation fog:**

a. marked increase in ground wind speed
b. marked increase in wind speed close to the ground
c. ground cooling due to radiation
d. warm air over warm surface

26. **Flying over an airfield, at the surface the temp. is -5°C, freezing level is at 3000 ft, rain is falling from clouds with a base of 4000 ft caused by warm air rising above cold air. Where would you experience icing?**

a. Never
b. No icing because you are not in cloud
c. Between 3000 - 4000 ft
d. Below 3000 ft

27. **Climbing out of Dhahran, Saudi Arabia on a clear night you suddenly lose your rate of climb. Why?**

a. Engine full of sand
b. Downdraft
c. Marked temperature inversion
d. VSI blocked

28. **What is the composition of Ci cloud?**

a. Supercooled water droplets
b. Ice crystals
c. Water droplets
d. Smoke particles

29. **What cloud types are classified as medium cloud?**

a. Ns + Sc
b. Ac + As
c. Cb + St
d. Ci + Cs

30. **What is the approximate height of the tropopause at 50°N?**

a. 14 km
b. 13 km
c. 11 km
d. 16 km

31. Isolated TS occur mostly due to:

a. warm frontal uplift
b. cold front uplift
c. insolation
d. convection

32. What type of cloud is associated with drizzle?

a. St
b. Cb
c. Ci
d. Ac

33. Fair weather cumulus gives an indication of:

a. poor visibility
b. thunderstorms
c. turbulence
d. smooth flying below

34. What cloud type are you least likely to get icing from?

a. Ci
b. Cu
c. St
d. Ns

35. When flying from south to north in the Southern Hemisphere crossing over and above a polar frontal jet at FL400, what might happen to the OAT?

a. Initially fall then rise
b. Initially rise then fall
c. Rise
d. Fall

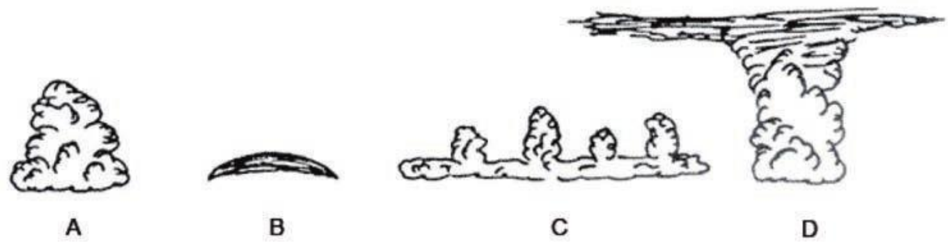
36. What type of jet stream blows constantly through the Northern Hemisphere?

a. Arctic jet
b. Equatorial jet
c. Polar night jet
d. Subtropical jet

37. Why is clear ice such a problem?

a. Translucent and forms along leading edges
b. Not translucent and forms along leading edges
c. Very heavy and can affect aircraft controls and surfaces
d. Forms in clear air

38. **What best shows altocumulus lenticularis?**

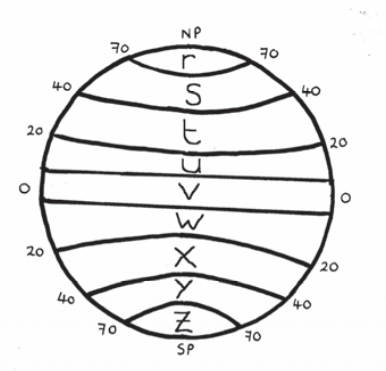


39. **A steep pressure gradient is characterized by:**

a. isobars close together, strengthened wind
b. isobars far apart, decreased wind
c. isobars close together, temperature increasing
d. isobars far apart, temperature decreasing

40. **Assuming a generalized zonal distribution of winds, which zones on the diagram contain the temperate lows?**

a. t
b. t + x
c. s + y
d. u + w



41. **If you fly with left drift in the Northern Hemisphere, what is happening to your true altitude?**

a. Increases
b. Decreases
c. Stays the same
d. Cannot tell

42. **What type of icing requires immediate diversion?**

a. Light
b. Moderate
c. Severe
d. Extreme

43. **What is the weather inside the warm sector in a frontal depression in central Europe?**

a. Fair weather Cu
b. Low stratus and drizzle
c. Cb and thunderstorms
d. As with light rain

44. **Flying from Dakar to Rio de Janeiro, where is the ITCZ in winter?**

a. > 8°S
b. 0 - 7°N
c. 8 - 12°N
d. 12 - 16°N

45. **At a stationary front:**

a. winds blow parallel to the isobars and front
b. winds blow perpendicular to the isobars
c. winds are always very strong
d. winds are usually gusty and variable

46. **In central Europe, where are the greatest wind speeds?**

a. Tropopause level
b. 5500 m
c. Where the air converges
d. Above the Alps

47. **Sublimation is:**

a. solid to vapour
b. vapour to liquid
c. liquid to vapour
d. liquid to solid

48. **Standing in the Northern Hemisphere, north of a polar frontal depression travelling west to east, the wind will:**

a. continually veer
b. continually back
c. back then veer
d. veer then back

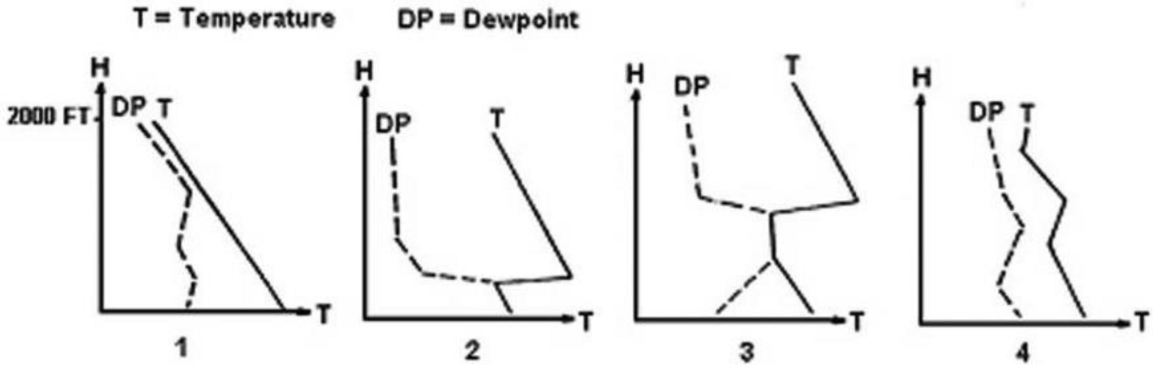
49. **What is the coldest time of the day?**

a. 1 hour before sunrise
b. 30 min before sunrise
c. At exact moment of sunrise
d. 30 min after sunrise

50. **Which of the following would lead to the formation of advection fog?**

a. Warm moist air over cold surface, clear night and light winds
b. Cold dry air over warm surface, clear night and light winds
c. Cold moist air over warm surface, cloud night with strong winds
d. Warm dry air over cold surface, cloudy night with moderate winds

51. **Using the radiosonde diagrams, which would most likely show ground fog?**



a. 1
b. 2
c. 3
d. 4

52. **Which of the following would lead to the formation of steaming fog?**

a. Cold air over warm sea
b. Warm air over cold sea
c. Cold sea near coast
d. Warm air over land

53. **When is diurnal variation a maximum?**

a. Clear sky, still wind
b. Clear sky, strong wind
c. OVC, still
d. OVC, windy

54. **QNH at Timbuktu (200 m AMSL) is 1015 hPa. What is the QFE? (Assume 1 hPa = 8 m)**

a. 1000
b. 990
c. 1020
d. 995

55. **The Arctic jet core is at:**

a. 20 000 ft
b. 30 000 ft
c. 40 000 ft
d. 50 000 ft

56. **If flying cross country at FL50 you first see NS, AS, CC then CI, you can expect:**

a. increasing temperature
b. decreasing temperature
c. a veer in the wind
d. increase in pressure

57. **Which is likely to cause aquaplaning?**

a. +RA
b. SA
c. FG
d. DS

58. **Prevailing winds in Northwest Africa will be:**

a. SW monsoon in summer, NE trade winds in winter
b. SE monsoon in summer, NW trade winds in winter
c. SE trade wind in summer, NE monsoon in winter
d. SE trade wind in winter, NE monsoon in summer

59. **ATC will only report wind as gusting if:**

a. gust speeds exceeds mean by >15 kt
b. gusts to over 25 kt
c. gusts exceed mean by 10 kt
d. gusts to over 25 kt

60. **Hill fog will be most likely when:**

a. clear sky, little wind, dry air
b. humid, stable, blowing onto a range of hills
c. precipitation is lifted by air blowing over the hills
d. high RH, unstable

61. **In temperate latitudes in summer what conditions would you expect in the centre of a high pressure system?**

a. TS, CB
b. calm winds, haze
c. TS, SH
d. NS

62. **Above a stable layer in the lower troposphere in an old high pressure system is called:**

a. radiation inversion
b. subsidence inversion
c. frontal inversion
d. terrestrial inversion

63. **If the pressure level surface bulges upwards, the pressure system is a:**

a. cold low
b. warm low
c. cold high
d. warm high

64. **What is a land breeze?**

a. From land over water at night
b. From land over sea by day
c. From sea over land by night
d. From sea over land by day

65. **When travelling from Stockholm (55N 18E) to Rio de Janeiro (22S 80W), you encounter:**

a. polar front jet stream then subtropical jet then polar jet
b. polar front jet then 1 or 2 subtropical jets
c. one subtropical jet stream
d. one subtropical jet stream then one polar front jet

66. **Why does air cool as it rises?**

a. It expands
b. It contracts
c. The air is colder at higher latitudes
d. The air is colder at higher altitudes

67. **When flying at FL180 in the Southern Hemisphere you experience a left crosswind. What is happening to your true altitude if indicated altitude is constant?**

a. Remains the same
b. Increasing
c. Decreasing
d. Impossible to tell

68. **In a polar front jet stream in the Northern Hemisphere, where is there likely to be the greatest probability of turbulence?**

a. Above the jet core in the boundary between warm and cold air
b. Looking downstream, to the right
c. In the core
d. Looking downstream, to the left

69. **Dew point is defined as:**

a. the lowest temperature at which evaporation will occur for a given pressure
b. the lowest temperature to which air must be cooled in order to reduce the relative humidity
c. the temperature below which the change of state for a given volume of air will result in absorption of latent heat
d. the temperature to which moist air must be cooled to reach saturation

70. **Flying from Marseilles (QNH 1012) to Palma (QNH 1015) at FL100. You do not reset the altimeter, why would true altitude be the same throughout the flight?**

a. Not possible to tell
b. Air at Palma is warmer than air at Marseilles
c. Air at Marseilles is warmer than air at Palma
d. Blocked static vent

71. **FL180, Northern Hemisphere with a wind from the left, what can you say about temperature with a heading of 360°?**

a. Not possible to tell without a pressure
b. Increases from south to north
c. Increases from north to south
d. Nothing

72. **From which of the following can the stability of the atmosphere be determined?**

a. Surface pressure
b. Surface temperature
c. DALR
d. ELR

73. **How do you define convection?**

a. Horizontal movement of air
b. Vertical movement of air
c. Same as advection
d. Same as conduction

74. **In a class A aircraft if you encounter freezing rain, you should:**

a. climb to the cooler air above
b. climb to the warmer air above
c. accelerate
d. descend

75. **When heading south in the Southern Hemisphere you experience starboard drift:**

a. you are flying towards a lower temperature
b. you are flying away from a lower temperature
c. you are flying towards a low pressure
d. you are flying out of a high

76. **When is the latest time radiation fog is most likely?**

a. Just after dawn
b. Late afternoon
c. Midday
d. Midnight

77. **When are thunderstorms most likely in Europe?**

a. Just after dawn
b. Late afternoon
c. Midday
d. Midnight

78. **How does the level of the tropopause vary with latitude in the Northern Hemisphere?**

a. Decreases north - south
b. Decreases south - north
c. Constant
d. It varies with longitude not latitude

79. **What is the tropopause?**

a. The layer between the troposphere and stratosphere
b. The boundary between the troposphere and stratosphere
c. Where temperature increases with height
d. Upper boundary to CAT

80. **Where do you find the majority of the air within the atmosphere?**

a. Troposphere
b. Stratosphere
c. Tropopause
d. Mesosphere

81. **What are lenticularis clouds a possible indication of?**

a. Mountain waves
b. Instability
c. Developing Cu and Cb
d. Horizontal windshear in the upper atmosphere

82. **What are the factors affecting the geostrophic wind?**

a. PGF, θ, Ω, ρ
b. θ, Ω, ρ
c. Ω, ρ
d. ρ

83. **What is the Bora?**

a. Cold katabatic wind over the Adriatic
b. Northerly wind blowing from the Mediterranean
c. Warm anabatic wind blowing to the Mediterranean
d. An anabatic wind in the Rockies

84. **Where is the 300 hPa level approx. in ISA?**

a. 30 000 ft
b. 39 000 ft
c. 18 000 ft
d. 10 000 ft

85. **What is the usual procedure when encountering CAT en route?**

a. Request climb to get out of it
b. Turn around immediately
c. Descend immediately to clear it
d. Accelerate through it and stay level

86. **When are cyclones most likely?**

a. Mid winter
b. Late autumn
c. Late summer
d. Late spring

87. **At a certain position the temperature on the 300 hPa chart is -48°C. According to the chart the tropopause is at FL330. The most likely temperature at FL350 is:**

a. -54°C
b. -50°C
c. -56.5°C
d. 58°C

88. **When are the rains most likely in Equatorial Africa?**

a. March to May, August to October
b. March to May, October to November
c. June to July
d. December to January

89. **What is the likely hazard association with the Harmattan?**

a. Poor visibility from dust and sand
b. Sand up to FL150
c. Thunderstorms
d. Dense fog

90. **General surface winds in West Africa with ITCZ to the north:**

a. NE trade wind to the north, SW monsoon to the south
b. east - west
c. SE trade winds to the north, NE trade winds to the south
d. west - east

91. **In what cloud is icing and turbulence most severe?**

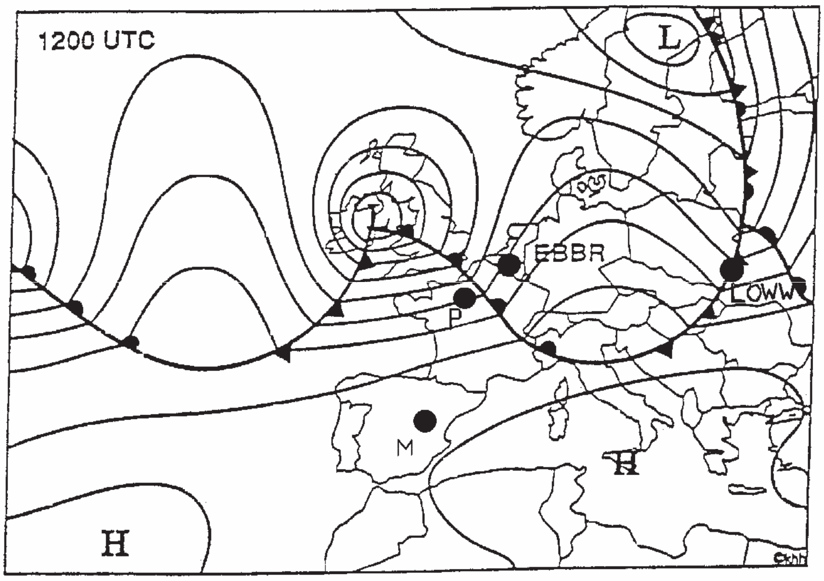
a. Cb
b. Ns
c. Sc
d. Ci

92. **What will snow most likely fall from?**

a. Ns
b. Ci
c. Cs
d. Ac

93. **Referring to the diagram below the TAF applies best to which aerodrome**

`19010KT 8000 RA BKN014 TEMPO 1518 4000 RADZ BKN010`



a. EBBR
b. Madrid
c. Paris
d. LOWW

94. **Rime ice is caused by:**

a. large supercooled water droplets
b. small supercooled water droplets
c. slow freezing of water droplets onto the wing
d. rapid re-freezing of large water droplets

95. **What is the most severe form of icing?**

a. Dry ice
b. Hoar frost
c. Clear ice
d. Rime ice

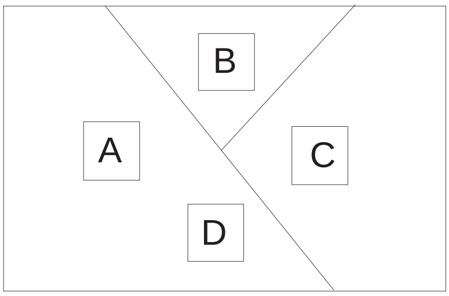
96. **Cold occlusion is:**

a. cold air undercutting warm air
b. warm air overriding cold air
c. air ahead of the warm front undercutting the air behind the cold front
d. air behind the cold front undercutting the air in front of the warm front

97. **Warm occlusion is:**

a. warm air undercutting cold air
b. warm air overriding cold air
c. air ahead of the warm front over riding the air behind the cold front
d. air behind the cold front over riding the air in front of the warm front

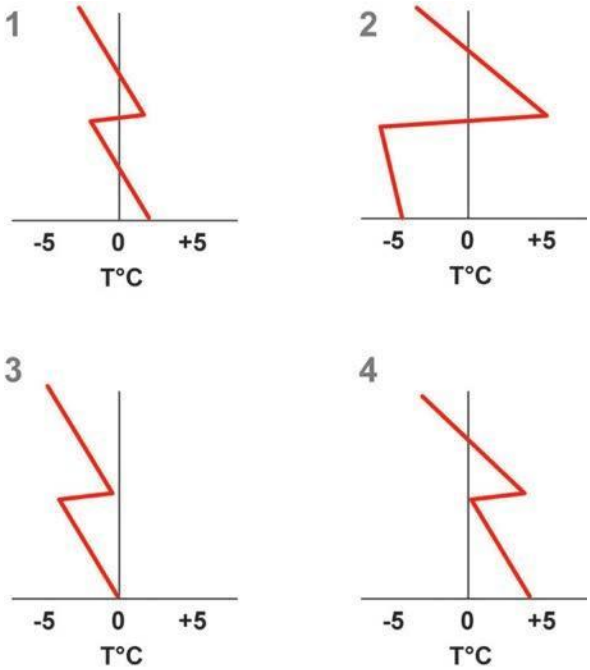
98. **Where is the warmest air?**



99. **What happens to the polar front jet stream in NH winter compared to summer?**

a. Moves south, speed increases
b. Moves north, speed increases
c. Moves south, speed decreases
d. Moves north, speed decreases

100. **Which is likely to give freezing rain?**



a. 1
b. 2
c. 3
d. 4

101. **What is the duration and size of a microburst:**

a. 5 min, 5 km
b. 20 min, 5 km
c. 15 min, 25 km
d. 45 min, 25 km

102. **Where is the surface wind usually westerly in a Northern Hemisphere polar front depression?**

a. In front of the warm front
b. In front of the cold front
c. Behind the cold front
d. To the north of centre of the depression

103. **Flying from an area of low pressure in the Southern Hemisphere at low altitudes, where is the wind coming from?**

a. Right and slightly on the nose
b. Left and slightly on the tail
c. Left and slightly on the nose
d. Right and slightly on the tail

104. **What causes the geostrophic wind to be stronger than the gradient wind around a low?**

a. Centrifugal force adds to the gradient force
b. Centrifugal force opposes the gradient force
c. Coriolis force adds to the gradient force
d. Coriolis force opposes the centrifugal force

105. **The subtropical high pressure belt is at which latitude?**

a. 25° - 35°
b. 10° - 15°
c. 55° - 75°
d. 40° - 55°

106. **A METAR for Paris gave the surface wind as 260/20. Wind at 2000 ft is most likely to be:**

a. 260/15
b. 210/30
c. 290/40
d. 175/15

107. **When the upper part of a layer of warm air is advected:**

a. stability increases within the layer
b. stability decreases within the layer
c. wind speed will always decrease with increase in height in the Northern Hemisphere
d. wind will back with increase in height in the Northern Hemisphere

108. **The QNH at an airfield 200 m AMSL is 1009 hPa; air temperature is 10°C lower than standard. What is the QFF?**

a. Not possible to give a definite answer
b. Less than 1009
c. 1009
d. More than 1009

109. A plain in Western Europe at 500 m (1600 ft) AMSL is covered with a uniform alto-cumulus cloud during summer months. At what height AGL is the base of the cloud expected?

a. 100 - 1500 ft
b. 15 000 - 25 000 ft
c. 7000 - 15 000 ft
d. 1500 - 7 000 ft

110. With the passage of a polar frontal depression what would be most likely?

a. Showers for 2 hours, Drizzle for 12 hours, then snow and rain
b. Continuous snow and rain, then it stops to be followed by showers of rain and snow
c. Continual backing of the wind
d. Heavy showers of rains and possible hail, followed by drizzle and light rain

111. A pilot experiences severe turbulence and icing. A competent met. man would issue a:

a. SPECI
b. METAR
c. TEMPO
d. SIGMET

112. Which of these would cause your true altitude to decrease with a constant indicated altitude?

a. Cold/Low
b. Hot/Low
c. Cold/High
d. Hot/High

113. Flying from Bangkok to Bombay, why does the wind at 30 000 ft change from 15 kt headwind in winter to 20 kt tailwind in summer?

a. Freak weather conditions experienced on route
b. The equatorial easterly jet changes direction through 180 degrees
c. This is due to local changes in the upper winds due to the movement of the ITCZ
d. The subtropical jet changes direction through 180 degrees

114. ITCZ weather is:

a. thundery strong convergence
b. clear Wx
c. showers
d. light winds

115. Where is the ITCZ during the year?

a. Does not move
b. Always north of the Equator
c. Always south of the Equator
d. Moves in accordance with the heat Equator

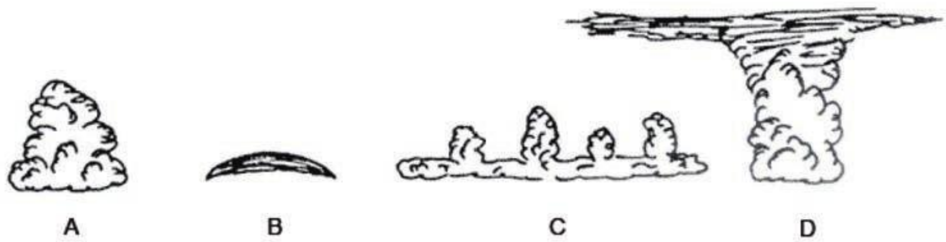
116. Flying from Marseilles to Dakar in summer where is the ITCZ?

a. Canaries
b. Algeria
c. Gibraltar
d. Near Dakar

117. Where is the ozone layer?

a. Ionosphere
b. Stratosphere
c. Tropopause
d. Troposphere

118. Which of the following diagrams depicts cumulus capillatus:



119. What wind would you expect between the Equator and 20° South?

a. NE monsoon
b. Trade wind
c. Strong westerlies
d. Roaring forties

120. Where are TRS not likely to form?

a. South China sea
b. South Pacific
c. South Atlantic
d. South Indian Ocean

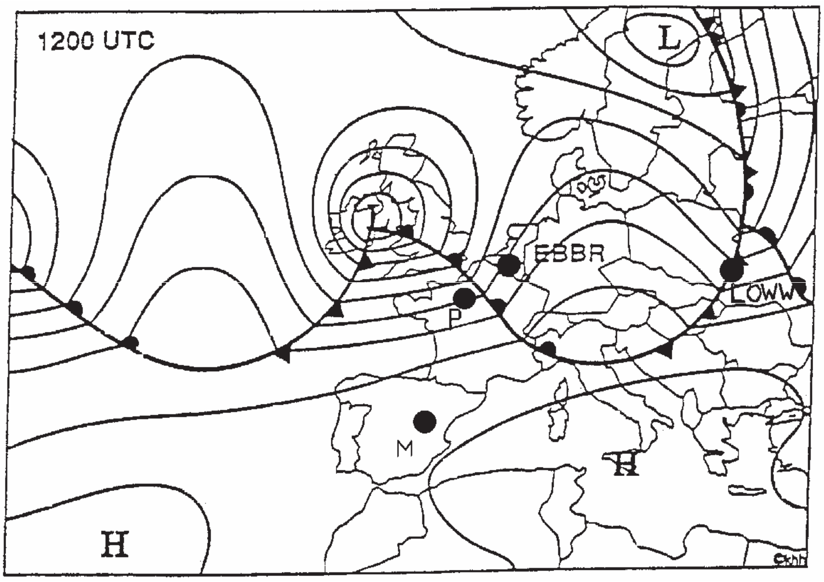
121. Where is the most severe weather in a TRS?

a. In the centre of the eye
b. In the wall of cloud surrounding the eye
c. Within the eye
d. 300 km from the eye

122. Satellite images are used to:

a. locate fronts in areas with few ground stations
b. achieve 14 day forecasts
c. locate precipitation zones
d. locate wind currents on the ground

123. What best describes the diagram below?



a. Cutting winds
b. Westerly wave
c. Easterly wave
d. Uniform pressure gradient

124. A large pressure gradient is shown by:

a. closely spaced isobars - low temperature
b. distant spaced isobars - high temperature
c. close spaced isobars - strong winds
d. close spaced isobars - light winds

125. The degree of CAT experienced by an aircraft is proportional to:

a. intensity of vertical and horizontal windshear
b. intensity of solar radiation
c. stability of the air
d. height of the aircraft

126. Squall lines are encountered:

a. in an air mass with cold air properties
b. ahead of a cold front
c. behind a stationary front
d. at an occluded front

127. Microbursts:

a. only affect tropical areas
b. average lifespan 30 min
c. typical horizontal dimensions 1 - 3 km
d. always associated with CB clouds

128. Which of the following are described as precipitation?

a. TS
b. SQ
c. SA
d. DZ

129. An aircraft flying in the Alps on a very cold day, QNH 1013 set in the altimeter, flies level with the summit of the mountains. Altitude from aneroid altimeter reads:

a. same as mountain elevation
b. lower than mountain elevation
c. higher than mountain elevation
d. impossible to determine

130. Clouds classified as low level are considered to have a base height of:

a. 500 - 1000 ft
b. 1000 - 2000 ft
c. the surface - 6500 ft
d. 100 - 200 ft

131. With a polar front jet stream (PFJ), the area with the highest probability of turbulence in the Southern Hemisphere is:

a. in the jet core
b. above the jet core in the boundary of the warm and cold air
c. looking downstream, on your left hand side
d. looking downstream, on your right hand side

132. After such a fine day yesterday, the ring around the moon indicated bad weather today. Sure enough, it is pouring down rain, with a very low cloud base of uniform grey. It is a little warmer though.

This describes:

a. a warm front
b. a cold front
c. the weather behind a cold front
d. poetic licence

133. On a flight from London to New York in summer, where would you cross the ITCZ?

a. Newfoundland, Grand Banks
b. New York
c. Azores
d. You wouldn't

134. What type of low is usually associated with frontal activity?

a. Polar front low
b. Mountain lee low
c. Warm low
d. Cold low

135. When would you encounter hoar frost?

a. Climbing through an inversion
b. Ns
c. Cb
d. Ac

136. What is the temperature decrease with height below 11 km?

a. 1°C - 100 m
b. 0.5°C - 100 m
c. 0.65°C - 100 m
d. 0.6°C - 100 m

137. Contours on a weather chart indicate:

a. heights of pressure levels
b. distance between pressure levels
c. thickness between pressure levels
d. height of ground

138. When do you get TRS at Darwin?

a. July - October
b. Never
c. November - April
d. In the winter

139. Subtropical highs are found:

a. 5 - 15°
b. 25 - 35°.
c. 40 - 60°.
d. between the Polar and Ferrell cells

140. Equatorial easterly jets occur in the:

a. Northern Hemisphere in summer
b. Northern Hemisphere all year
c. Southern Hemisphere all year
d. Southern Hemisphere

141. What causes 'echoes' on airborne weather radar screens?

a. Water vapour
b. All cloud
c. Fog
d. Hail

142. **In a tropical downpour the visibility is sometimes reduced to:**

a. 1000 m
b. 500 m
c. 200 m
d. less than 100 m

143. **Aircraft with thick wing (T) and thin wing (S) fly at the same TAS and altitude through cloud containing small super cooled water droplets. What extent of icing will be experienced?**

a. S and T same icing
b. Nothing as its super cooled water droplets
c. S more, T less
d. T more, S less

144. **What surface weather is associated with a stationary high pressure region, over land, in the winter?**

a. Ns and continuous rain
b. A tendency for fog and low stratus
c. The possibility of snow showers
d. Thunderstorms

145. **QNH is defined as:**

a. the pressure at MSL obtained using the standard atmosphere
b. the pressure at MSL obtained using the actual conditions
c. QFE reduced to MSL using the actual conditions
d. QFE reduced to MSL using the standard atmosphere

146. **Where would you expect to find the strongest wind on the ground in temperate latitudes?**

a. In an area of low pressure
b. In an area of high pressure
c. In the warm air between two fronts
d. In a weak anticyclone

147. **Landing at an airfield with QNH set the pressure altimeter reads:**

a. zero feet on landing only if ISA conditions prevail
b. zero
c. the elevation of the airfield if ISA conditions prevail
d. the elevation of the airfield

148. **The fastest moving thunderstorms are:**

a. orographic
b. thermal
c. frontal
d. lifting

149. **Where are the fastest winds in a Tropical Revolving Storm?**

a. Near the eye
b. In the wall of cloud surrounding the eye
c. To the right of the track
d. To the right of the track in hurricanes and cyclones

150. **What type of cloud is usually found at high level?**

a. St
b. Ac
c. Cc
d. Ns

151. **You are flying in an atmosphere which is warmer than ISA, what might you expect?**

a. True altitude to be the same as Indicated altitude
b. True altitude to be lower than Indicated altitude
c. True altitude to be the decreasing
d. True altitude to be higher than Indicated altitude

152. **The environmental lapse rate in the real atmosphere:**

a. has a fixed value of 2°C / 1000 ft
b. has a fixed value of 0.65°C / 100 m
c. varies with time
d. has a fixed value of 1°C / 100 m

153. **Airfield is 69 metres below sea level, QFF is 1030 hPa, temperature is ISA -10°C. What is the QNH?**

a. Impossible to tell
b. Less than 1030 hPa
c. 1030 hPa
d. More than 1030 hPa

154. **The QNH is 1030 hPa and at the Transition Level you set the SPS. What happens to your indicated altitude?**

a. Drops by 510 ft
b. Rises by 510 ft
c. Rises
d. Drops

155. **What is the movement of air relating to a trough?**

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Converging and ascending

156. What is the movement of air relating to a ridge?

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Ascending and converging

157. What would the code 01650428 tell you about the condition of the runway?

a. It is raining
b. It is snowing
c. Braking coefficient of 0.28
d. It is broken

158. What time of year is the tornado season in North America?

a. Spring to summer
b. Summer and autumn
c. Spring
d. Summer

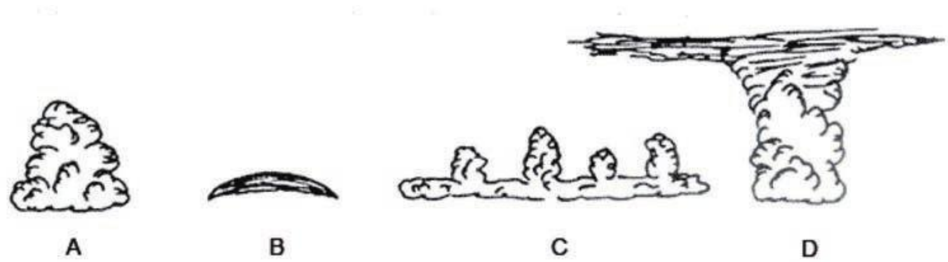
159. What is the min. temperature according to ISA?

a. -56.5°C
b. -273°C
c. -100°C
d. 215.6 K

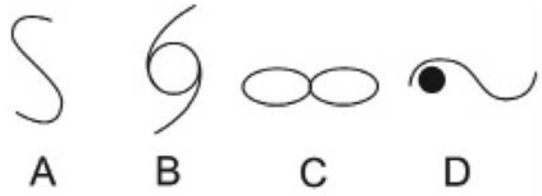
160. At a coastal airfield, with the runway parallel to the coastline. You are downwind over the sea with the runway to your right. On a warm summer afternoon, what would you expect the wind to be on finals?

a. Crosswind from the right
b. Headwind
c. Tailwind
d. Crosswind from the left

161. What diagram best shows Acc?



For questions 162 to 164, use the diagram below.



162. What symbol is used to describe widespread haze?

163. What symbol is used to describe a TRS?

164. What symbol is used to describe freezing rain?

165. The temperature at the surface is 15°C, the temperature at 1000 m is 13°C. The atmosphere is:

a. unstable
b. conditionally unstable
c. stable
d. cannot tell

166. Altostratus is:

a. a low level cloud
b. a medium level cloud
c. a high level cloud
d. a heap type cloud

167. Which of the following would give you the worst airframe icing?

a. GR
b. SN
c. FZFG
d. +FZRA

168. Small supercooled water droplets hit the aerofoil, will it:

a. freeze on impact giving clear ice
b. partially freezing and running back giving clear ice
c. freeze on impact giving rime ice
d. partially freezing and running back giving a cloudy rime ice

169. In a METAR you see the coding R16/P1300. What does this imply?

a. RVR assessed to be more than 1300 metres
b. RVR equipment is problematic
c. RVR is improving
d. RVR is varying

170. If at 0600 the temperature and dew point were recorded as T= - 0.5 and DP = - 1.5, how would a METAR record this?

a. M01, M02
b. M01, M01
c. M00, M01
d. 00, M01

171. What causes wind?

a. Difference in pressure
b. Rotation of the earth
c. Frontal systems
d. Difference in temperature

172. What is the approximate height of the 250 hPa level?

a. 30 000 ft
b. 32 000 ft
c. 39 000 ft
d. 34 000 ft

173. Several aircraft report clear air turbulence in a certain area en route:

a. ATC should issue a storm warning
b. ATC should close the specified area
c. a competent ATC should issue a SPECI
d. a competent ATC should issue a SIGMET

174. What is the flight hazard associated with the Harmattan?

a. Sand up to FL150
b. Windshear
c. Dust and poor visibility
d. Dense fog

175. Where are icing conditions on a runway specified?

a. TAF
b. METAR
c. SIGMET
d. GAFFO

176. Where are icing conditions en route specified?

a. TAF and METAR
b. METAR and SIGMET
c. SWC (**s**ig. **w**eather **c**hart) and SIGMET
d. SPECI and TREND

177. **If flying in the Alps with a Föhn effect from the south:**

a. clouds will be covering the southern passes of the Alps
b. CAT on the northern side
c. wind veering and gusting on the northern side
d. convective weather on the southern passes of the Alps

178. **If flying en route and you encounter moderate turbulence with convective clouds and you decide to continue, you should:**

a. decrease power and climb above the clouds if flight parameters allow
b. decrease power and fly below the clouds
c. increase power and climb above the clouds if flight parameters allow
d. increase power and fly below the clouds

179. **You are flying from Madrid (QNH 1012) to Paris (QNH 1015) at FL80. If your true altitude and indicated altitude remain the same then:**

a. the air at Madrid is warmer than Paris
b. the air at Paris is warmer than Madrid
c. the altimeters are incorrect
d. your indicated altitude must be changing

180. **If you are flying on a QNH 1009 on very cold day and you circle the top of a peak in the Alps, your altimeter will read:**

a. the same as the elevation of the peak
b. lower than the elevation of the peak
c. higher than the elevation of the peak
d. not enough information to tell

181. **ICAO statement no diversion necessary, de-icing is not required or is effective; the icing in this case is:**

a. light
b. moderate
c. severe
d. extreme

182. **Aircraft A has a sharp leading edge and a thin aerofoil. Aircraft B has a thick cambered wing aerofoil. If they are flying at the same TAS into clouds with small supercooled water droplets then:**

a. depends upon the differential kinetic heating
b. B gets more icing than A
c. both get the same
d. A gets more icing than B

183. What is subsidence?

a. Horizontal motion of air
b. Vertical down draught of air
c. Vertical up draught of air
d. Adiabatic cooling

184. If an isohypse on a surface pressure chart of 500 hPa shows a figure of 522, this indicates:

a. topography of 522 m above MSL
b. topography of 522 decametres above MSL
c. pressure is 522 hPa
d. a low surface pressure

185. Moderate turbulence can be expected in:

a. altocumulus lenticularis
b. cirrocumulus
c. nimbostratus
d. stratus

186. The polar front jet stream in summer compared to winter in the Northern Hemisphere moves:

a. north and decreases in strength
b. north and increases in strength
c. south and decreases in strength
d. south and increases in strength

187. The Bora is a:

a. cold katabatic wind with a air mass of maritime origin
b. cold katabatic wind with a air mass of Arctic origin
c. cold katabatic wind that may produce violent gusts
d. warm squally katabatic wind

188. RVR is:

a. measured using ceilometers along the runway
b. displayed in TAFs and METARs
c. usually greater than met visibility
d. given when the met visibility is below 2000 m

189. Comparing the surface wind to the 3000 ft wind:

a. surface wind veers and is less then the 3000 ft wind
b. surface wind blows along the isobars and is less than the 3000 ft wind
c. surface wind blows across the isobars and is less than the 3000 ft wind
d. both are the same

190. In which air mass can extreme cold temperatures be found?

a. Polar continental
b. Arctic maritime
c. Polar maritime
d. Tropical maritime

191. Up and down going draughts in a thunderstorm occur in which stage?

a. Cumulus stage
b. Mature stage
c. Dissipating stage
d. Precipitation stage

192. Relative humidity increases in:

a. warmer air compared to colder air
b. warm air at a constant vapour pressure
c. cold air at a constant vapour pressure
d. colder air compared to warmer air

193. Supercooled water droplets are found in:

a. clouds only
b. clouds, fog and precipitation
c. precipitation and clouds
d. precipitation

194. Which of the following, with no orographic intensification, will give rise to light to moderate icing conditions?

a. Ns and Cs
b. As and Ac
c. Cb and Ns
d. Ns and Cc

195. If an active cold front is approaching what will the altimeter read on a parked aircraft shortly before the front arrives?

a. Decrease
b. Increase
c. Fluctuates -50 ft to +50 ft
d. Stays the same

196. Which of the following METARs at 1850UTC will most likely give fog formation over the coming night?

a. 240/04 6000 -RA SCT012 OVC 3000 17/14 Q1002 NOSIG=
b. VRB002 9999 SCT150 17/M08 Q1012 NOSIG=
c. VRB001 8000 SCT280 11/10 Q1028 BECMG 3000
d. VRB002 8000 FEW100 12/09 Q1025 BECMG 0800

197. The lowest temperature in the international standard atmosphere (ISA) is?

a. -50.6°C
b. -56.5°F
c. 216.5 K
d. 56.5°C

198. What would be reflected to radar?

a. Fog
b. Hail
c. Cloud
d. Mist

199. A jet stream with a wind speed of 350 kt is:

a. impossible
b. possible but very rare
c. possible in polar areas
d. common

200. Turbulence is worst in a jet stream:

a. in the core
b. along the axis of the core to the right
c. along the axis of the core to the left
d. between the boundaries of the cold and warm air

201. If you fly at right angles to a jet stream in Europe with a decreasing outside air temperature, you will experience:

a. increasing headwind
b. increasing tailwind
c. wind from the left
d. wind from the right

202. Low level windshear is likely to be greatest:

a. at the condensation level when there is a strong surface friction
b. at the condensation level when there is no night radiation
c. at the top of the friction layer during strong solar radiation
d. at the top of a surface based inversion during strong night radiation

203. The North African rains occur:

a. March to May and August to October
b. March to May and October to November
c. December to April
d. June to August

204. TEMPO TS indicates:

a. TS that will last for the entire period indicated
b. TS that will last for a max of 1 hour in each instance
c. TS that will last for at least 30 min
d. TS that will last for less than 30 min

205. What happens in a warm occlusion?

a. Warm air behind the cold front overrides the cold air in front of the warm front
b. Cold air under rides the warm air
c. Cold air behind the cold front undercuts the warm air ahead of the warm front
d. Warm air undercuts the cold air

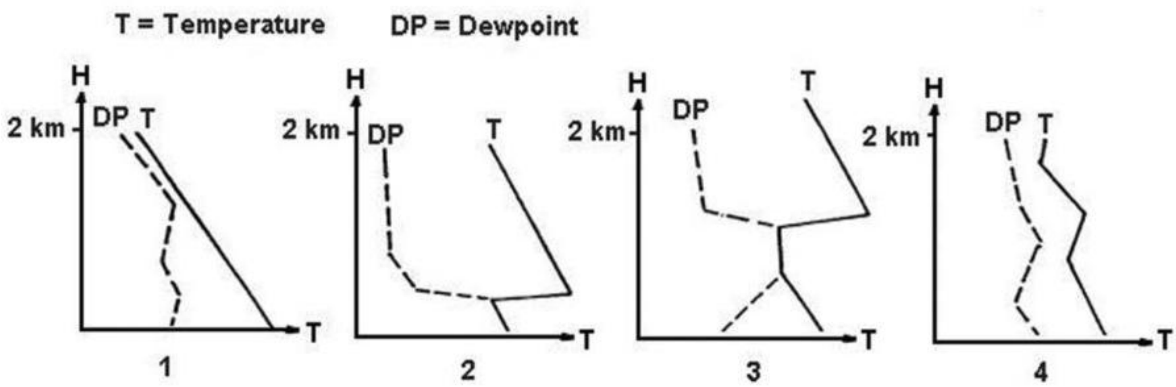
206. Which of the following gives conditionally unstable conditions?

a. 1°C/100 m
b. 0.65°C/100 m
c. 0.49°C/100 m
d. None of the above

207. A mass of unsaturated air is forced to rise till just under the condensation level. It then settles back to its original position:

a. temp. is greater than before
b. temp. stays the same
c. temp. is less than before
d. it depends on QFE

208. Which of the radiosonde diagrams below will show low stratus?



a. 4
b. 2
c. 3
d. 1

209. What is a microburst?

a. Air descending at high speed, the air is colder than the surrounding air
b. Air is descending at high speed; the air is warmer than the surrounding air
c. A small tropical revolving storm
d. A small depression with high wind speeds

210. The high bringing tropical continental air masses to Europe in summer is positioned over:

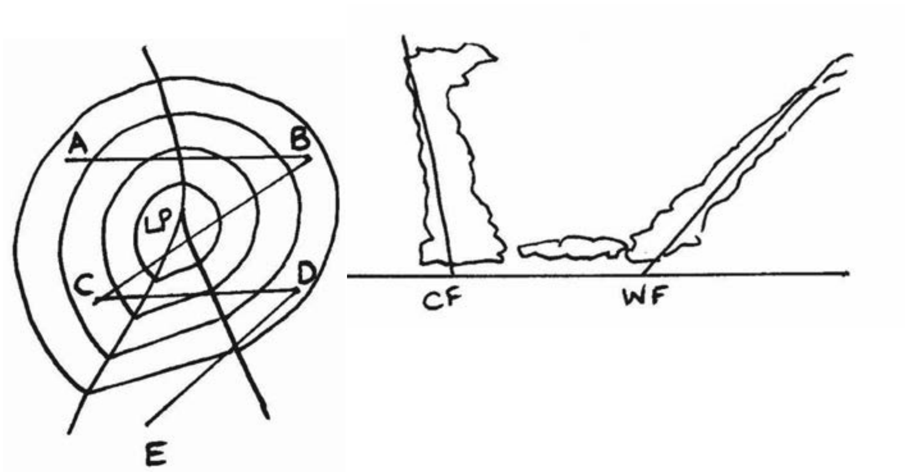
a. southern Italy
b. southern France
c. the Balkans
d. the Azores

211. What most likely gives freezing rain over Central Europe?

a. Warm occlusion
b. Cold occlusion
c. Warm front
d. Cold front

212. Which of the cuts in the plan view of the polar front depression best represents the profile view?

a. A, B
b. B, C
c. C, D
d. D, E



213. On a polar front depression, the point of occlusion moves mainly in which direction in the Northern Hemisphere?

a. Along the front to the west
b. Across the front to the north
c. Across the front to the south
d. Along the front to the east

214. In the Northern Hemisphere between lat. 35°N - 65°N in the North Atlantic during winter, the principle land based depression affecting the region is located at:

a. USA high
b. Siberia high
c. Greenland/Icelandic low
d. Azores high

215. The ITCZ is best described as:

a. where the trade winds of the Northern and Southern Hemispheres meet
b. where the west winds meet the subtropical high pressure belt
c. where cold fronts are formed in the tropics
d. where the Harmattan meets the NE trades in Africa

216. When would you most likely find cold occlusions across central Europe?

a. Winter and spring
b. Summer
c. Winter and autumn
d. Winter

217. Clear ice is most likely to form:

a. -10°C to -17°C
b. -30°C to -40°C
c. -20°C to -30°C
d. -40°C to -60°C

218. How do you calculate the lowest flight level?

a. Lowest QNH and lowest negative temperature below ISA
b. Lowest QNH and highest negative temperature below ISA
c. Highest QNH and highest temperature above ISA
d. Highest QNH and lowest temperature

219. TRS off Somalia are called:

a. hurricanes
b. typhoons
c. cyclones
d. tornadoes

220. In which cloud would you encounter the most intensive rain?

a. Ci
b. Ns
c. St
d. Sc

221. What height is the tropopause and at what temperature?

a. At the poles 8 km and -16°C
b. At the pole 18 km and -75°C
c. At the Equator 8 km and -40°C
d. At the Equator 18 km and -76°C

222. Where do you get freezing rain?

a. Rain hitting the ground and freezing on impact
b. Rain falling into warmer air
c. Rain falling from an inversion into an area below 0°C
d. Rain falling into colder air and freezing into pellets

223. Flying from Dakar to Rio de Janeiro in winter where would you cross the ITCZ?

a. 0 to 7°N
b. 7°N to 12°N
c. 7°S to 12°S
d. 12°S to 18°S

224. Where are polar front depressions located?

a. 10 to 15°N
b. 25 to 35°N
c. 35 to 55°N
d. 55 to 75°N

225. Which of the following is worst for icing?

a. -2°C to -15°C
b. -15°C to -20°C
c. -25°C to -30°C
d. Near freezing level

226. Which of the following is worst for icing?

a. Speed and shape of aerofoil
b. Relative humidity and temperature
c. Size of droplet and temperature
d. Freezing levels

227. With low pressures dominating the Med, which of the following would likely be found in central Europe?

a. Thunderstorms and snow
b. Thermal depressions
c. Northerly Föhn wind over the Alps
d. Warm clear sunny spells

228. Which of the following will give the greatest difference between temperature and dew point?

a. Dry air
b. Moist air
c. Cold air
d. Warm air

229. CB cloud in summer contains:

a. water droplets
b. ice crystals
c. water droplets, ice crystals and supercooled water droplets
d. water droplets and ice crystals

230. Using the diagram below you are on a flight from A to B at 1500 ft. Which statement is true?

a. True altitude at A is greater than B
b. True altitude at B is greater than A
c. True altitude is the same
d. Cannot tell

231. Solar radiation heats the atmosphere by:

a. heating the air directly
b. heating the surface, this then heats the air in the atmosphere
c. heating the water vapour in the atmosphere directly
d. heating the water vapour directly unless there are clouds present

232. How are CBs that are not close to other CBs described on a SIGMET?

a. Isolated
b. Embedded
c. Frequent
d. Occasional

233. When do you mainly get cold occlusions?

a. Summer
b. Autumn and winter
c. Winter
d. Winter and spring

234. A coded SIGMET message for Athens reads "TS W Athenia MOV E"

a. there will be TS coming from the east
b. there will be TS coming from the west
c. there will be TS coming from the west, moving east
d. there will be TS coming from the east, moving west

235. In a very deep depression in Iceland, the likely weather is:

a. convection causing snow
b. high wind, clear vis
c. high wind, rain, snow
d. high windshear

236. What affects how much water vapour the air can hold?

a. RH
b. Temperature
c. Dew point
d. Pressure

237. In a METAR/TAF what is VV?

a. RVR in metres
b. Vertical visibility
c. Horizontal visibility in metres
d. Vertical visibility in feet

238. In a METAR the cloud height is above:

a. MSL
b. aerodrome level
c. the measuring station
d. the highest point within 5 km

239. Aerodrome at MSL, QNH is 1022. QFF is:

a. greater than 1022
b. less than 1022
c. same as QNH
d. cannot tell without temperature information

240. Air at the upper levels of the atmosphere is diverging. What would you expect at the surface?

a. Rise in pressure with clouds dissipating
b. Rise in pressure with clouds forming
c. Fall in pressure with cloud dissipating
d. Fall in pressure with cloud forming

241. What happens to the stability of the atmosphere in an inversion? (Temp increasing with height)

a. Absolutely stable
b. Unstable
c. Conditionally stable
d. Conditionally unstable

242. What happens to stability of the atmosphere in an isothermal layer? (Temp constant with height)

a. Absolutely stable
b. Unstable
c. Conditionally stable
d. Conditionally unstable

243. Air temperature in the afternoon is +12°C with a dew point of +5°C. What temperature change must happen for saturation to occur?

a. Cool to +5°C
b. Cool by 5°C
c. Cool to +6°C
d. Cool to +7°C

244. What is the gradient of a warm front?

a. 1:50
b. 1:150
c. 1:300
d. 1:500

245. Subsidence would be described as:

a. vertical ascension of air
b. horizontal movement of air
c. the same as convection
d. vertical down flow of air

246. What is the technical term for an increase in temperature with altitude?

a. Inversion
b. Advection
c. Adiabatic
d. Subsidence

247. What units are used to measure vertical windshear?

a. m/sec
b. kt
c. kt/100 ft
d. km/100 ft

248. The Pampero is:

a. marked movement of cold polar air in North America
b. marked movement of cold air in South America
c. Föhn type wind in North America
d. polar air over the Spanish Pyrenees

249. If you fly from Bombay to Karachi in summer you might experience a 70 kt tailwind and the same flight in winter experiences a headwind. This is due to:

a. the normal local changes in the winds at that time of the year
b. the route happens to be in a region of the STJs
c. in winter you had unusually unfavourable conditions
d. in summer you had unusually good weather conditions

250. Why is the "Icelandic low" more intense in winter?

a. The temperature contrast between Arctic/polar air and Equatorial areas are much greater in winter
b. The developments of lows over the North Atlantic Sea, east of Canada are stronger in winter
c. The winds over the North Atlantic are more favourable for lows during winter
d. In winter, strong winds favour the developments of lows

251. What causes the formation of aircraft contrails at certain altitudes?

a. Water vapour that condenses behind the engines
b. Soot particles from the engine exhaust
c. Water vapour that condenses in the wing tips due to pressure changes in the relative warm air
d. Unburnt fuel

252. QNH is 1003. At FL100 true altitude is 10 000 ft. It is:

a. warmer than ISA
b. colder than ISA
c. same as ISA
d. cannot tell

253. Winds in western India:

a. SW monsoon in summer, NE monsoon in winter
b. NE monsoon in summer and SW monsoon in winter
c. SE monsoon in summer and SW monsoon in winter
d. SE monsoon in summer and NE monsoon in winter

254. Ice pellets on the ground are evidence that:

a. a warm front has past
b. a cold front has passed
c. there are thunderstorms in the area
d. there may be freezing rain at a higher level

255. You have to fly through a warm front. The freezing level in the warm air is at 10 000 ft and the freezing layer in the cold air is at 2000 ft. Where are you least likely to encounter freezing rain?

a. 12 000 ft
b. 9000 ft
c. 5000 ft
d. 3000 ft

256. You are flying at FL170. The pressure level which is closest to you is the:

a. 300 hPa
a. 700 hPa
c. 500 hPa
d. 850 hPa

257. **When you have icing conditions forecast en route, on what chart would you find this information?**

a. 500 hPa
b. 300 hPa
c. Surface charts
d. Significant weather charts

258. **The average duration of a microburst is:**

a. 1-5 min
b. 10 min
c. 15 min
d. less than 2 min

259. **How is QFE determined from QNH?**

a. Using the temperature of the airfield and the elevation of the airfield
b. Using the temperature
c. Using the elevation
d. Using the temperature at MSL and the elevation of the airfield

260. **Which cloud would produce showers?**

a. NS
b. AS
c. CS
d. CB

261. **What clears radiation fog?**

a. Temperature drop
b. Wind speed decreases
c. Wind speed increases
d. Mixing

262. **QFE is 1000 hPa with an airfield elevation of 200 m AMSL. What is QNH?**

a. 976 hPa
b. 1024 hPa
c. 1008 hPa
d. 992 hPa

263. **With the approach of a warm front:**

a. QNH/QFE decreases
b. QNH/QFE increases
c. QNH decreases and QFE increases
d. QNH increases and QFE decreases

264. **With the approach of a cold front, temperature will:**

a. decrease
b. remain the same
c. increase
d. decrease then increase

265. On a surface weather chart, isobars are lines of:

a. QNH
b. QFE
c. QFF
d. QNE

266. What is the effect of a strong low level inversion?

a. Good visibility
b. Calm conditions
c. Turbulence
d. Unstable conditions

267. A moist stable air mass is forced to rise against a mountain range. What might you expect?

a. Large Cu clouds and turbulence
b. Altocumulus lenticularis
c. Cap clouds and standing waves
d. Clear skies

268. Air temperature is 12°C, Dew point is 10°C and the sea temperature is 8°C. What might you expect if the air is blown over the sea?

a. Steaming fog
b. Radiation fog
c. Arctic smoke
d. Advection fog

269. A cold pool over land in summer would give rise to:

a. clear skies
b. low stratus with intermittent rain
c. a potentially very unstable atmosphere
d. extensive industrial haze

270. Near industrial areas with lots of smoke the worst situation for met vis is:

a. low level inversion
b. strong winds
c. fast moving cold fronts
d. Cbs in the area

271. Upper level winds are forecast in significant weather charts as:

a. true/knots
b. magnetic/knots
c. magnetic/km/h
d. true/km/h^2

272. Melbourne in July will experience:

a. the Equatorial low pressure belt
b. subtropical high
c. continuous waves of troughs and ridges
d. the Antarctic high

273. **How often are METARs issued at main European airfields?**

a. 1 h
b. 30 min
c. 3 h
d. 1 h 30 min

274. **METAR winds are meaned over the .... period immediately preceding the time of observation.**

a. 10 minute
b. 30 minute
c. 1 hour
d. 1 minute

275. **Main TAFs at large aerodromes are valid for approximately:**

a. 1 hour
b. 2 hours
c. 6 hours
d. 24 hours

276. **What are the TRS off the west coast of Africa called?**

a. Typhoons
b. Cyclones
c. Easterly waves
d. Hurricanes

277. **The most severe in-flight icing occurs in:**

a. Cb
b. Cu
c. Ns
d. FZRA

278. **Which of the following constituents in the atmosphere has the greatest effect on the weather?**

a. Nitrogen
b. Oxygen
c. Hydrogen
d. Water vapour

279. **When would you mostly likely get fair weather Cu?**

a. 15:00
b. 12:00
c. 17:00
d. 07:00

280. RVR is defined as being:

a. the maximum distance an observer on the runway can see marker boards by day and runway lights by night
b. the maximum distance a pilot in the threshold area at 15 ft above the runway can see marker boards by day or runway lights by night, when looking in the direction of take-off or landing
c. the maximum distance in metres a pilot 15 ft above the touchdown zone can see marker boards by day and runway lights by night in the direction of take-off
d. the distance it would be possible to see an observer 15 ft above the runway when standing in the direction of take-off or landing

281. What type of cloud extends into another level?

a. As
b. Acc
c. Ns
d. Ci

282. Ceilometers measure:

a. RVR
b. Cloud height
c. Met vis
d. Turbulence

283. In a METAR, the pressure group represents:

a. QFE rounded up to the nearest hectopascal
b. QFE rounded down to the nearest hectopascal
c. QNH rounded up to the nearest hectopascal
d. QNH rounded down to the nearest hectopascal

284. On a station circle decode, the cloud cover is divided into:

a. 8 parts
b. 6 parts
c. 4 parts
d. 10 parts

285. Which of the following is true?
QNH is:

a. Always more than 1013.25 hPa
b. Always less than 1013.25 hPa
c. Never 1013.25 hPa
d. Can never be above or below 1013 hPa

286. When does Darwin (Australia) experience TRS?

a. June and July
b. December to March
c. Early summer
d. Not at all

287. Radiation fog extends from the surface to:

a. 5000 ft
b. 2000 ft
c. 10 000 ft
d. 800 ft

288. Flying from Marseilles to Palma you discover your true altitude is increasing, but oddly the QNH is identical at both places. What could be the reason?

a. Re-check the QNH
b. Re-check the radio altimeter
c. The air at Palma is warmer
d. Palma is lower than Marseilles

289. Hurricanes in the Caribbean generally move:

a. west, then NE
b. east, then SE
c. west, then SE
d. east, the NE

290. Low level inversions give:

a. good vis at night
b. good vis in the morning
c. poor vis due to the lack of vertical moving air
d. poor vis because of the lack of horizontal movement of air

291. What are the TRS off the coast of Madagascar called and when would you expect to find them?

a. Cyclones, in December and January
b. Hurricanes, in July and August
c. Typhoons, in May to November
d. Cyclones, in June and July

292. A forecast trend is:

a. for an aerodrome and valid for 9 hours
b. for a route and valid for 24 hours
c. a SPECI and valid for 2 hours
d. for a landing and valid for 2 hour

293. On rare occasions TS can be found along the warm front. What conditions could lead to this?

a. The warm sector being stable
b. The warm sector being unstable
c. The cold air being stable
d. The cold air being unstable

294. **QNH is 1030. Aerodrome is 200 m AMSL. What is QFF?**

a. Higher than 1030
b. Lower than 1030
c. Same
d. Not enough info

295. **Where are downdraughts predominant in a thunderstorm?**

a. Mature
b. Dissipating
c. Initial
d. Cumulus

296. **If an aerodrome is 1500 ft AMSL on QNH 1038, what will the actual height AGL to get to FL75?**

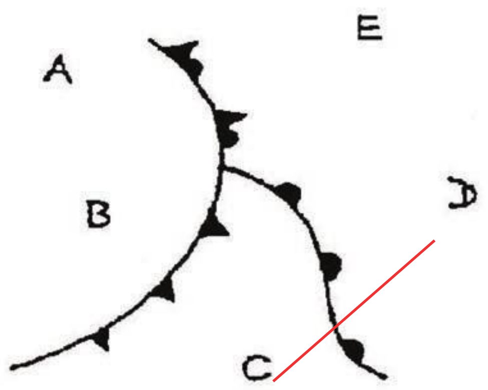
a. 6670 ft
b. 8170 ft
c. 8330 ft
d. 2330 ft

297. **What is FG VV100?**

a. RVR less than 100 m
b. RVR less than 100 ft
c. Vertical visibility is 100 m
d. Vertical visibility is 100 ft

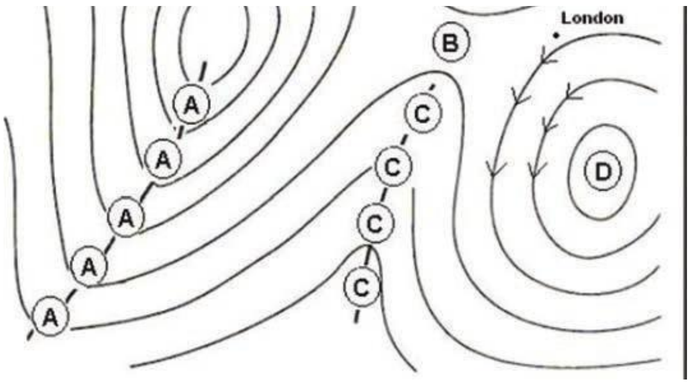
298. **The line connecting C to D crosses which type of front?**

a. Cold front
b. Warm front
c. Warm occlusion
d. Cold occlusion



299. What is B?

a. A trough of high pressure
b. Col
c. A ridge of low pressure
d. A low



300. On a particular day the PFJ runs north to south in the Northern Hemisphere:

a. the temperature gradient runs north to south below the jet core
b. the temperature gradient runs north to south above the jet core
c. the polar air is east of the jet above the core
d. the polar air is below the jet to the east

301. A 350 kt jet stream is:

a. impossible
b. common near Equator
c. possible but rare
d. common in the Southern Hemisphere over the oceans

302. Why do TRS tend to form in the western side of tropical oceans?

a. Because the land temperature and sea temperature provide unstable gradient for formation
b. Because the coastal gulf provides a strong rotational force
c. Because the areas tend to have high ‘shear’ in the atmosphere
d. Because the air humidity is high, due to long passage of trade winds over ocean

303. Where would an anemometer be placed?

a. Close to station, 2 m above ground
b. On the roof of the station
c. 10 m above aerodrome elevation on a mast
d. Next to the runway, 1 m above ground

304. Altimeter set to 1023 at aerodrome. On climb to altitude the SPS is set at transition altitude. What will indication on altimeter do on resetting to QNH?

a. Dependent on temperature
b. Decrease
c. Increase
d. Same

305. 90 km/h wind in kt is:

a. 70
b. 60
c. 50
d. 30

306. The ITCZ is best described as:

a. the area where trade winds from the Northern Hemisphere meets those from the Southern Hemisphere
b. where west winds meet subtropical high pressure zone
c. where Harmattan meets the N.E. trade winds
d. where cold fronts form in the tropics

307. When landing at Dakar in July, the weather to be expected is:

a. clear and dry
b. wet and stormy, due to proximity of the ITCZ
c. settled/warm/clear skies due to influence of the Azores High
d. low visibility/dust storms due to the Harmattan

308. When is the hurricane season in the Caribbean?

a. July to November
b. October to January
c. January to April
d. April to July

309. An aircraft is stationary on the ground. With the passage of an active cold front its altimeter will:

a. show an increase then a decrease
b. fluctuate ± 50 ft
c. show a decrease then an increase
d. remain constant

310. What is the average vertical extent of radiation fog?

a. 2000 ft
b. 500 ft
c. 5000 ft
d. 10 000 ft

311. Where is clear ice most likely in a Cb?

a. Near the freezing level
b. -2°C to -15°C
c. -20°C to -40°C
d. Below -40°C

312. You have to make an emergency ditch at sea. The QNH of a nearby island airfield is 1025 hPa, airfield elevation 4000 ft. The temp is -20°C. With 1025 set on your sub-scale, on ditching the altimeter will read:

a. 0 ft
b. less than 0 ft
c. > 0 ft but less than 4000 ft
d. 4000 ft

313. Which of the following will indicate medium level instability, possibly leading to thunderstorms?

a. Halo
b. Altocumulus castellanus
c. Altocumulus capillatus
d. Red Cirrus

314. Radiation fog extends to:

a. 8000 ft
b. 4000 ft
c. 2000 ft
d. 500 ft

315. What is reported as precipitation?

a. FZFG
b. FG
c. TS
d. SN

316. At FL60 what pressure chart would you use?

a. 700 hPa
b. 850 hPa
c. 800 hPa
d. 900 hPa

317. On a descent through cloud cover at high level you notice a white, cloudy or opaque, rough powder like substance on the leading edge of the wing. This contamination is likely to be:

a. frost
b. clear ice
c. mixed ice
d. rime ice

318. In association with CB in temperate latitudes, at about what levels can hail be anticipated?

a. Ground to FL100
b. Ground to FL200
c. Cloud base to FL200
d. Ground to FL450

319. Moderate turbulence gives:

a. changes in altitude and/or attitude but the aircraft remains in positive control at all times
b. slight erratic changes in altitude and/or attitude
c. large, abrupt changes in altitude and/or attitude. Aircraft maybe momentarily out of control
d. slight, rapid and somewhat rhythmic bumpiness

320. ATIS reports:

a. aerodrome operational and meteorological information
b. met only
c. operational only
d. none of the above

321. +TSRA come from what sort of cloud?

a. Cb
b. Ns
c. Cc
d. Cu

322. Flying 2500 ft below core of jet, with temperature increasing in the Southern Hemisphere, where does the wind come from?

a. Head
b. Tail
c. Left
d. Right

323. Secondary depressions move:

a. around the primary in a cyclonic fashion
b. around the primary in an anticyclonic fashion
c. eastwards
d. westwards

324. What temperature and pressure conditions would be safest to ensure that your flight level clears all the obstacles by the greatest margin?

a. Cold temp/low pressure
b. Warm temp/high pressure
c. Temp less than or equal to ISA and a QNH less than 1013
d. Temp more than or equal to ISA and a QNH greater than 1013

325. In which part of the world are TRS most frequent?

a. Caribbean
b. Madagascar, Eastern Indian Ocean
c. NW Pacific i.e. Japan, Korea
d. Northern Indian Oceans around India, Sri Lanka

326. As an active cold front passes, the altimeter of an a/c parked on the apron:

a. increases then decreases
b. fluctuates by ± 50 ft
c. decreases then increases
d. remains unchanged

327. Where does a TRS gain its energy from?

a. Energy gained directly from the sun
b. Latent heat from water in oceans
c. The very fast winds
d. The very low pressures inside the storm

328. What is the height and temperature of the tropopause?

a. 8 km and -40°C at Equator
b. 16 km and -75°C at Equator
c. 16 km and -40°C at Pole
d. 8 km and -75°C at Pole

329. What is the easterly wave?

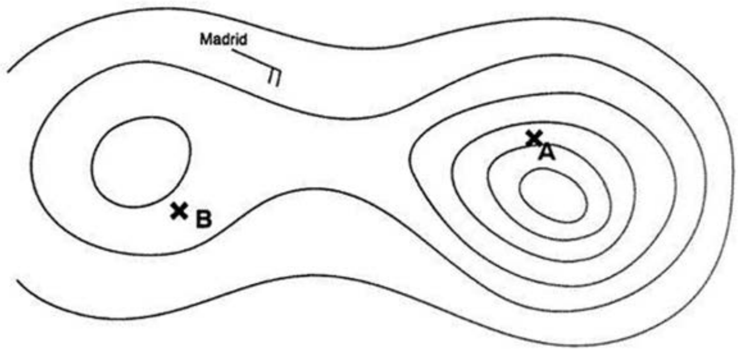
a. A wave of weather travelling east-west
b. A wave of weather travelling west-east
c. A wave of weather travelling north-south
d. A wave of weather travelling south-north

330. Where is icing worst?

a. Near condensation level
b. Near freezing level
c. -2°C to -15 °C
d. -16°C to -30°C etc.

331. What is in position A?

a. Col
b. Ridge of high pressure
c. A low
d. A high



332. The geostrophic wind blows at your flight level in Northern Hemisphere, true altitude and indicated altitude remain constant, is the crosswind:

a. from the left
b. from the right
c. no crosswind
d. impossible to determine

333. What is the base of altocumulus in summer?

a. 0 - 1500 ft
b. 1500 - 7000 ft
c. 7000 ft - 15 000 ft
d. 7000 ft - 16 500 ft

334. What is the general height of radiation fog?

a. 500 ft
b. 2000 ft
c. 3000 ft
d. 1500 ft

335. When a CC layer lies over a West European plain in summer, with a mean terrain height of 500 m above sea level, the average cloud base could be expected:

a. 0- 100 ft above ground level
b. 5000 - 15 000 ft above ground level
c. 15 000 - 25 000 ft above ground level
d. 15 000 - 35 000 ft above ground level

336. Which of the following cloud types can stretch across all three cloud levels (low, medium and high level)?

a. CI
b. ST
c. AC
d. CB

337. Which of the following cloud types can stretch across at least two cloud levels?

a. ST
b. NS
c. CI
d. SC

338. Shortly after the passage of an active cold front you observe the aneroid altimeter of a parked aircraft. The indication of the instrument will:

a. decrease
b. not be influenced by the air pressure
c. increase
d. show no appreciable change due to such minor pressure fluctuation

339. In a shallow pressure distribution (widely spaced isobars or low pressure gradients) you observe the aneroid altimeter of a parked aircraft for 10 minutes (no thunderstorms observed). The reading of the instrument will:

a. not be influenced by the air pressure
b. increase greatly
c. show no appreciable change due to such a minor pressure fluctuation
d. experience great changes

340. You are flying from Marseilles (QNH 1012 hPa) to Palma de Mallorca (QNH 1012 hPa) at FL100. You notice that the effective height above MSL (radio altitude) increases constantly. Hence:

a. one of the QNH values must be wrong
b. you have the altimeters checked, as their indications are obviously wrong
c. the air mass above Palma is warmer than that above Marseilles
d. you have to adjust for a crosswind from the right

341. Which air mass has the coldest temperature?

a. mAc
b. mPc
c. cPc
d. mTw

342. You are flying from Marseilles (QNH 1026 hPa) to Palma de Mallorca (QNH 1026 hPa) at FL100. You notice that the effective height above MSL (radio altitude) decreases constantly. Hence:

a. one of the QNH values must be wrong
b. the air mass above Marseilles is warmer than that above Palma
c. you have the altimeters checked, as their indications are obviously wrong
d. you have to adjust for a crosswind from the right

343. Flying at FL135 above the sea, the radio altimeter indicates a true altitude of 13 500 ft. The local QNH is 1019 hPa. Hence the crossed air mass is, on average:

a. at ISA standard temperature
b. colder than ISA
c. warmer than ISA
d. there is insufficient information to determine the average temperature deviation

344. What happens to an aircraft altimeter on the ground once a cold front has passed?

a. Increases
b. Decreases
c. Increases then decreases
d. Remains the same

345. What happens to an aircraft's altimeter on the ground at the approach of a cold front?

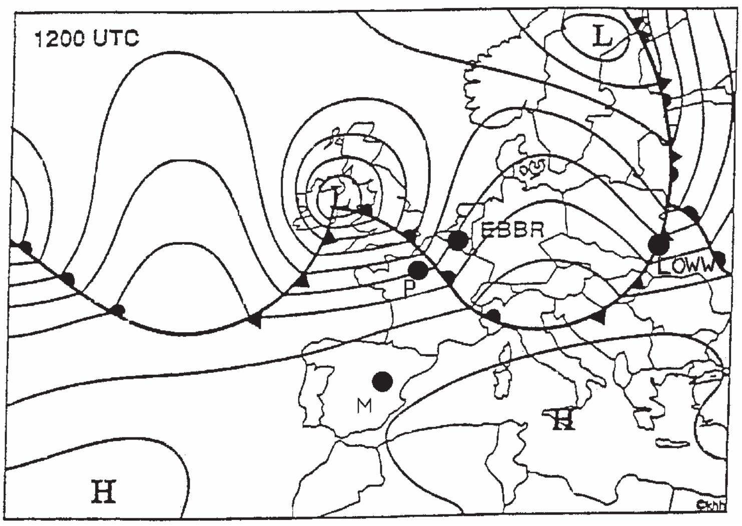
a. Increases then decreases
b. Decreases then increases
c. Remains the same
d. Increases

346. Even pressure system, no CB - what would you notice the altimeter in an aircraft on the ground do during a 10 min period?

a. Remains the same as any fluctuations are small
b. Increases
c. Rapidly fluctuates
d. Impossible to tell

347. What weather phenomenon is over northern Italy?

a. A high
b. Easterly wind
c. Cloud and rain
d. A col



348. You are flying in the Alps at the same level as the summits on a hot day. What does the altimeter read?

a. Same altitude as the summit
b. Higher altitude as the summit
c. Lower altitude as the summit
d. Impossible to tell

349. What cloud is between a warm and cold front?

a. St with drizzle
b. Cs
c. Ns
d. St with showers

350. From which cloud do you get hail?

a. Sc
b. Cb
c. Ns
d. Ts

351. When flying from south to north in the Southern Hemisphere, you cross over the polar front jet. What happens to the temperature?

a. It increases
b. It decreases
c. It remains the same
d. Impossible to determine

352. If you see alto castellanus what does it indicate?

a. The upper atmosphere is stable
b. Subsistence
c. Instability in the lower atmosphere
d. Middle level instability

353. To dissipate cloud requires:

a. subsidence
b. a decrease in temperature
c. an increase pressure
d. convection

354. When would a SIGMET be issued for subsonic flights?

a. Thunderstorms and fog
b. Severe mountain waves
c. Solar flare activity
d. Moderate turbulence

355. Which of these statements about icing is correct?

a. Ice will occur going through cirrus cloud
b. Large amounts of icing if temperature is way below -12°C
c. Icing increases if dry snow starts to fall from cloud
d. Icing will occur if supercooled water and ice are present

356. You will get least amount of icing in which cloud?

a. NS
b. SC
c. CS
d. AS

357. The core of a jet stream is located:

a. at the level where temperature change with altitude becomes little or nil and the pressure surface is at maximum slope
b. in the warm air where the pressure surface is horizontal
c. in the warm air and directly beneath at the surface
d. in cold air

358. Isolated TS in summer are because of:

a. convection
b. cold fronts
c. warm front occlusions
d. cold front occlusions

359. Trade winds are most prominent or strongest in the:

a. upper troposphere over sea
b. lower troposphere over ocean
c. lower troposphere over land
d. upper troposphere over land

360. A layer of air can be:

a. conditional; unstable when unsaturated and stable when saturated
b. conditional; unstable when saturated and stable when unsaturated
c. neutrally stable when saturated and unstable when unsaturated
d. all of the above

361. On a significant weather chart you notice a surface weather front with an arrow labelled with the no. 5 pointing outward perpendicular from the front. This would indicate:

a. front speed is 5 kt
b. front movement is 5 NM
c. front thickness is 5 km
d. front is 5000 ft AMSL

362. With all other things being equal with a high and a low having constantly spaced circular isobars, where is the wind the fastest?

a. Anticyclonic
b. Cyclonic
c. Where the isobars are closest together
d. Wherever the PGF is greatest

363. Blocking anticyclones prevent the polar front from arriving over the UK and originate from where?

a. Warm anticyclones over the Azores
b. Warm anticyclones over Siberia
c. Cold anticyclones over the Azores
d. Cold anticyclones over Siberia

364. Föhn winds are:

a. warm katabatic
b. cold katabatic
c. warm descending winds
d. warm anabatic

365. The gust front is:

a. characterized by frequent lightning
b. formed by the cold outflow from beneath TS
c. another name for a cold front
d. directly below a TS

366. Cu is an indication of:

a. vertical movement of air
b. stability
c. the approach of a warm front
d. the approach of a cold front

367. Which clouds are evidence of stable air?

a. St, As
b. Cb, Cc
c. Cu, Ns
d. Cu, Cb

368. Lack of cloud at low level in a stationary high is due to:

a. instability
b. rising air
c. sinking air
d. divergence at high level

369. What is the ratio of height to width in a typical jet stream?

a. 1:10
b. 1:100
c. 1:1000
d. 1:10000

370. When and where does an easterly jet stream occur?

a. All year through the Equator
b. In Summer from SE Asia through S. India to Central Africa
c. In Summer from the Middle East through N. Africa and the Mediterranean to S. Spain
d. In winter in Arctic Russia

371. What degree of turbulence, if any, is likely to be encountered while flying through a cold front in the summer over central Europe at FL100?

a. Light turbulence in ST cloud
b. Moderate turbulence in NS cloud
c. Light turbulence in Cb cloud
d. Severe turbulence in Cb cloud

372. An easterly wave is a:

a. wave in a trade wind belt, moving from east to west with severe convective activity in rear of its trough
b. small scale wave disturbance in the tropics, moving from east to west with severe convective activity ahead of its trough
c. wave-like disturbance in the monsoon regime of indices moving from east to west with severe convective activity ahead of its trough
d. disturbance in the higher levels associated with the Equatorial easterly jets, moving from east to west, with severe convective activity in rear of its trough

373. What is the most common freezing precipitation?

a. Freezing pellets
b. Freezing rain and freezing drizzle
c. Freezing graupel
d. Freezing hail and freezing snow

374. Which of the following is an example of a Föhn wind?

a. Bora
b. Harmattan
c. Chinook
d. Ghibli

375. From which of the following clouds are you least likely to get precipitation in summer?

a. CS/NS
b. CS/AS
c. CB/CU
d. CU/ST

376. What is a cold pool?

a. Found south of the Alps if there is NW airflow
b. Cool area of weather which disappears at night
c. Cold pool is most evident behind polar frontal weather in mid temperate areas with little or no sign on significant weather charts
d. Air trapped on the leeward side of mountain ranges

377. **Where do you find information on ICING and CAT?**

a. 300 hPa chart
b. 700 hPa chart
c. Sig. WX chart
d. Analysis chart

378. **Which of these statements is true about hurricanes?**

a. They are 400-500 m wide
b. They pick up in force when they hit land
c. The air inside is warmer than outside and can reach up to the tropopause
d. They are never found more than 25° latitude

379. **Relative humidity:**

a. is not affected by temperature
b. is not affected by air expanding and contracting
c. does not change when water is added
d. changes when water is added, even if the temperature is the same

380. **What happens to the temperature of a saturated air mass when forced to descend?**

a. It heats up more than dry because of expansion
b. It heats up less than dry because of evaporation
c. It heats up more than dry because of sublimation
d. It heats up less than dry because of latent heat released during condensation

381. **A warm front occlusion is approaching the east coast of the UK. What WX would you expect in the North Sea during summer?**

a. High level Ci
b. TS/showers/CB
c. Medium level cloud 3/8 oktas, isolated showers
d. Low level stratus

382. **What is the average height of the tropopause at the Equator?**

a. 16 km
b. 11 km
c. 5 km
d. 3 km

383. **The tropopause is lower:**

a. in summer in mid latitudes
b. at the North Pole than at the Equator
c. in summer at the Equator
d. at the Equator than at the South Pole

384. **An airfield has an elevation of 540 ft with a QNH of 993 hPa. An aircraft descends and lands at the airfield with 1013 hPa set. What will its altimeter read on landing?**

a. 380 ft
b. 1080 ft
c. 0 ft
d. 540 ft

385. In a METAR a gust is reported when:

a. it is 10 kt greater than the mean wind speed
b. it is 15 kt greater than the mean wind speed
c. it is 20 kt greater than the mean wind speed
d. it is 5 kt greater than the mean wind speed

386. When is pressure altitude equal to true altitude?

a. In standard conditions
b. When surface pressure is 1013.25 hPa
c. When the temperature is standard
d. When the indicated altitude is equal to the pressure altitude

387. What is the relationship between QFE and QNH at an airport 50 ft below MSL?

a. QFE = QNH
b. QFE < QNH
c. QFE > QNH
d. There is no clear relationship

388. Where would a pilot find information about the presence of a jet stream?

a. On an Upper Air chart
b. On a Significant Weather chart
c. On a Surface Analysis chart
d. On a Wind/Temperature chart

389. Up to FL180 ISA Deviation is ISA +10°C. What is the actual depth of the layer between FL60 and FL120?

a. 6000 ft
b. 6240 ft
c. 5760 ft
d. 5700 ft

390. Thunderstorms will occur on a warm front:

a. when air is cold moist and cools quicker than SALR
b. when air is warm moist and cools quicker than SALR
c. when air is cold moist and cools slower than SALR
d. when air is warm moist and cools slower than DALR

391. What is the effect of a mountain valley wind?

a. It blows down a mountain to a valley at night
b. It blows down a mountain to a valley during the day
c. It blows from a valley up a mountain by day
d. It blows from a valley up a mountain at night

392. What is the name of the dry, dusty wind blowing in Northwest Africa from the northeast?

a. Pampero
b. Khamsin
c. Harmattan
d. Ghibli

393. **What is the difference between gradient and geostrophic winds?**

a. Difference in temperatures
b. A lot of friction
c. Curved isobars and straight isobars
d. Different latitudes and densities

394. **In still air a lapse rate of 1.2°C/100 m refers to:**

a. DALR
b. SALR
c. ELR
d. ALR

395. **What happens to the temperature of a saturated air mass when descending?**

a. Heats up more than dry because of expansion
b. Heats up less than dry because of evaporation
c. Heats up more than dry because of compression
d. Heats up less than dry because of latent heat released during condensation

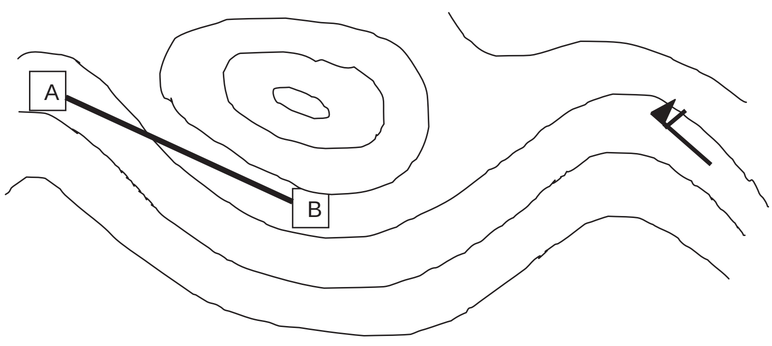
396. **What prevents air from flowing directly from a high to a low pressure?**

a. Centripetal force
b. Centrifugal force
c. Pressure force
d. Coriolis force

397. **You are flying at FL160 with an OAT of -27°C. QNH is 1003 hPa. What is your true altitude?**

a. 15 540 ft
b. 15 090 ft
c. 16 330 ft
d. 15 730 ft

398. **Flying from A to B at a constant indicated altitude in the Northern Hemisphere:**



a. true altitude increases
b. wind is northerly
c. true altitude decreases
d. wind is southerly

399. What is the relationship between the 5000 ft wind and the surface wind in the Southern Hemisphere?

a. Surface winds are veered from the 5000 ft and have the same speed
b. Surface winds are backed from the 5000 ft and have a slower speed
c. Surface winds are veered from the 5000 ft and have a slower speed
d. Surface winds are backed from the 5000 ft and have a faster speed

400. What is the relationship between the 2000 ft wind and the surface wind in the Northern Hemisphere?

a. Surface winds blow across isobars towards a high
b. Surface winds blow parallel to isobars
c. Surface winds blow across isobars towards a low
d. Surface winds have laminar flow

401. The DALR is:

a. variable with time
b. fixed
c. variable with latitude
d. variable with temperature

402. Which frontal or occlusion system is the fastest moving?

a. Warm front
b. Cold front
c. Cold occlusion
d. Warm occlusion

403. From the preflight briefing you know a jet stream is at 31 000 ft whilst you are at FL270. You experience moderate CAT, what would be the best course of action?

a. Stay level
b. Descend
c. Climb
d. Reduce speed

404. On a significant weather chart you notice a symbol with the letter "H" and the number "400" inside. What does this imply?

a. The height of the significant weather chart
b. Tropopause "low"
c. Tropopause "high"
d. Tropopause "middle"

405. You are at 12 000 ft (FL120) with an outside air temperature of -2°C. Where would you find the freezing level?

a. FL110
b. FL100
c. FL090
d. FL140

406. **How does a polar front depression normally move?**

a. Same direction as the isobars behind the cold front
b. Same direction as the isobars in the warm sector
c. Same direction as isobars in front of the warm front
d. Same direction as the isobars north of the centre of the low

407. **Flying away from a low pressure at low levels in the Southern Hemisphere, where is the wind coming from?**

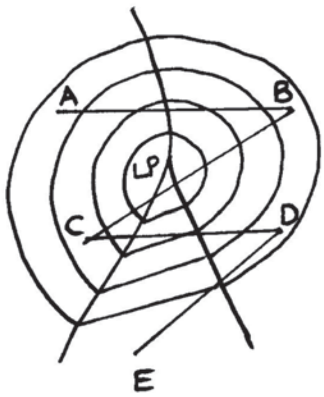
a. From the left and slightly on the nose
b. From the right and slightly on the nose
c. From the rear and slightly on the left
d. From the rear and slightly on the right

408. **The ITCZ in July is:**

a. over West Africa at 25°N and stretches up to the north of the Arabian Sea
b. 20°N over West Africa
c. over the Canaries
d. passing through Freetown

409. **Using the diagram shown, what cross-section is through an occluded front?**

a. DE
b. CD
c. CB
d. AB



410. **What is true about the dew point temperature?**

a. Can be higher or lower than the air mass temperature
b. Can be higher than the temperature of the air mass only
c. Can be only lower than the temperature of the air mass
d. Can be equal to or lower than the temperature of the air mass

411. **What kind of weather system might you typically find between 45° - 70°N?**

a. Subtropical highs
b. Polar highs
c. Polar front depressions
d. Arctic front depressions

412. **What is true regarding supercooled water droplets?**

a. Always below -60°C
b. All large
c. All small
d. All below 0°C

413. What is most different about the equatorial easterly jet stream?

a. Its height
b. Its length
c. Its direction
d. Its speed

414. Flying towards a warm front, at what distances might you expect the following cloud types from the surface position of the front?

a. CS 600 km; AS 400 km: NS 200 km
b. CS 200 km: AS 400 km: NS 600 km
c. CS 800 km: AS 200 km: NS 400 km
d. CS 400 km: AS 600 km: NS 800 km

415. Wind is caused by:

a. mixing of fronts
b. horizontal pressure difference
c. earth rotation
d. surface friction

416. What weather might you expect behind a fast moving cold front?

a. 8 oktas of layered cloud
b. Scattered ST
c. Isolated CBs and showers
d. Continuous rain

417. How would an unstable atmosphere likely reduce the visibility?

a. By mist
b. By haze
c. By rain and or snow
d. Low stratus

418. Which is true regarding a polar front jet stream?

a. It is found in the warm air and so does its plan projection show this
b. It is located where there is little vertical temperature gradient but the horizontal pressure gradient is at its steepest
c. It is located where there is significant horizontal temperature difference but the pressure gradient is flat
d. It is always in the colder of the air masses

419. Which of the following indicates upper level instability and possibly the formation of TS?

a. Halo
b. Red cirrus
c. Altocumulus lenticularis
d. Altocumulus castallanus

420. When are the North Atlantic lows at their most southerly position?

a. Spring
b. Summer
c. Autumn
d. Winter

421. A layer of air cooling at the SALR compared to the DALR would give what kind of cloud?

a. Stratus if saturated
b. Cumulus if saturated
c. No cloud if saturated
d. Convective cloud

422. For the same pressure gradient at 50N, 60N and 40N, the geostrophic wind speed is:

a. greatest at 60N
b. least at 50N
c. greatest at 40N
d. the same at all latitudes

423. What is a SPECI?

a. A forecast valid for 3 hours
b. A report produced when significant changes have occurred
c. A forecast and valid for 6 hours
d. A landing forecast

424. A parcel of air cooling by more than 1°C/100 m is said to be:

a. conditionally stable
b. conditionally unstable
c. unstable
d. stable

425. The wind in the Northern Hemisphere at the surface and above the friction layer at 2000 ft would be:

a. veered at the surface, veered above the friction layer
b. backed at the surface, veered above the friction layer
c. veered at the surface, backed above the friction layer
d. backed at the surface, backed above the friction layer

426. Where are easterly and westerly jets found?

a. Northern Hemisphere only
b. Southern Hemisphere only
c. Northern and Southern Hemisphere
d. There are no easterly jets

427. Which weather phenomena are typical for the north side of the alps with stormy winds from the south (Föhn)?

a. Drop in temperature, moderate to severe icing
b. Icing, huge mass of cloud
c. Good visibility, turbulence
d. Continuous precipitation and moderate turbulence

428. At 15 000 ft in nimbostratus cloud with an outside air temperature of -12°C, what icing might you expect?

a. Moderate rain ice
b. Moderate to severe mixed ice
c. Moderate to severe ice if orographically intensified
d. Light rime ice

429. Comparing rain to drizzle, visibility will generally:

a. rain has a visibility of 1 km, drizzle has 2 km
b. remains the same
c. deteriorate
d. improve

430. What statement is true regarding the tropopause?

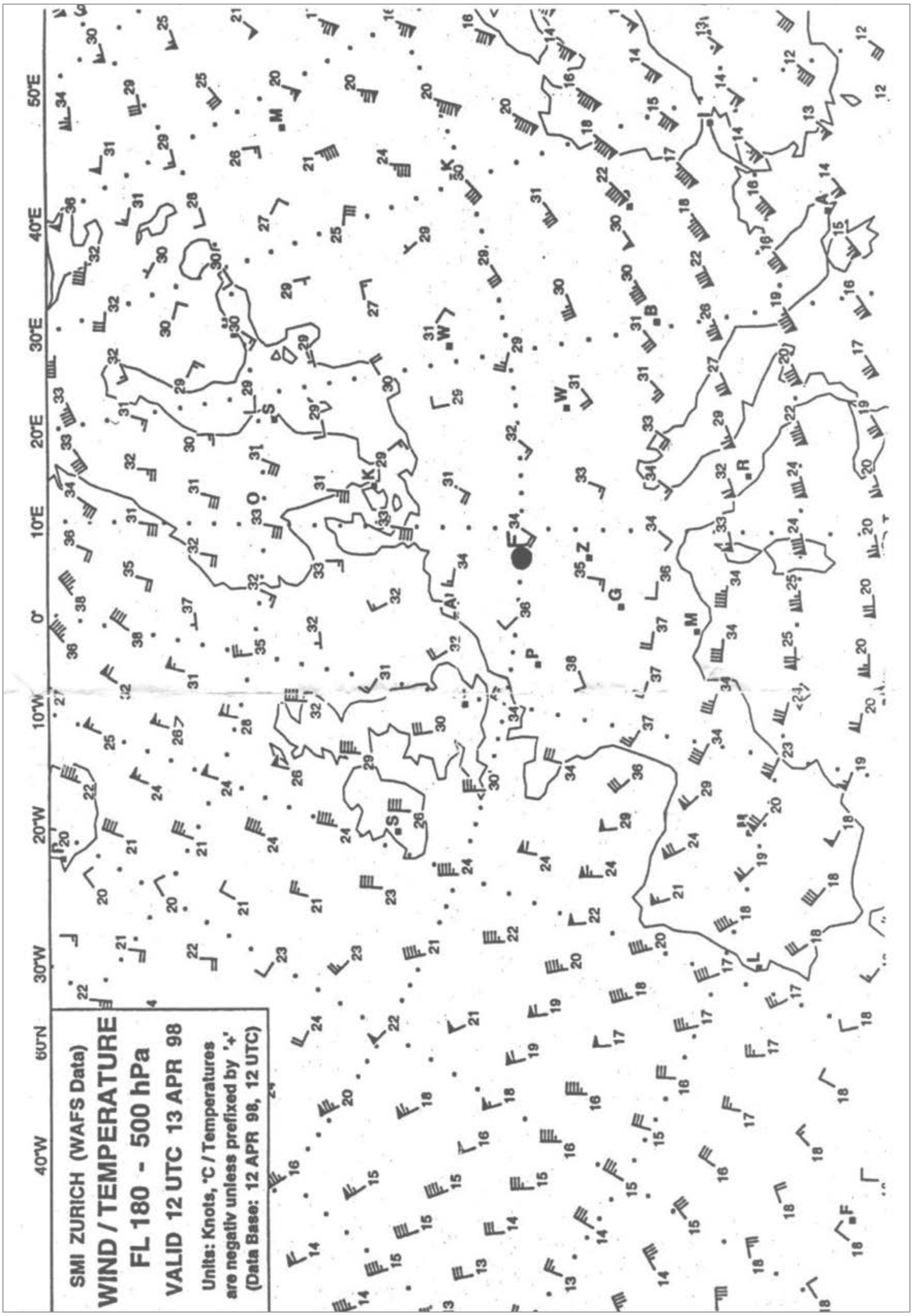
a. It is higher over the Equator with a higher temperature
b. It is lower over the Equator with a lower temperature
c. It is higher over the poles with a lower temperature
d. It is lower over the poles with a higher temperature

431. See Figure opposite.
What is the temperature deviation, in degrees Celsius, from the International Standard Atmosphere overhead Frankfurt (50N 08E) at FL180?

a. ISA +2°C
b. ISA -13°C
c. ISA +13°C
d. ISA -2°C

432. Polar front depression normally move:

a. in the direction of the isobars behind the cold front
b. in the direction of the isobars in front of the warm front
c. in the direction on the isobars ahead of the depression
d. in the direction of the isobars inside the warm sector


SMI ZURICH (WAFS Data)
WIND / TEMPERATURE
FL 180 - 500 hPa
VALID 12 UTC 13 APR 98
Units: Knots, °C / Temperatures are negativ unless prefixed by '+'
(Data Base: 12 APR 98, 12 UTC)

433. QNH in a METAR is:

a. rounded up to the nearest whole hectopascal
b. rounded down to the nearest even hectopascal
c. rounded up to the nearest even hectopascal
d. rounded down to the nearest whole hectopascal

434. Thermal lows usually develop:

a. over the sea in summer
b. over the sea in winter
c. over the land in summer
d. over the land in winter

435. TAFs are usually valid:

a. for the period indicated in the TAF itself
b. for 18 hours
c. for 24 hours
d. for 8 hours

436. Tornadoes are usually associated with which cloud type?

a. Ns
b. Cu
c. Cb
d. Ts

437. Wind at altitude is usually given as .... in ....

a. true, m/s
b. magnetic, m/s
c. true, kt
d. magnetic, kt

438. The surface wind circulation found between the subtropical highs and the Equatorial lows are called:

a. the doldrums
b. the trade winds
c. the easterlies
d. the westerlies

439. If an occlusion is mimicking a cold front, where would the coldest air be found?

a. Behind the original cold front
b. Behind the original warm front
c. In front of the occlusion
d. In front of the original warm front

440. In high pressure systems:

a. the winds tend to be stronger in the morning
b. the angle between the isobars and the wind direction is greatest in the afternoon
c. the winds tend to be stronger at night
d. the winds tend to be stronger in early afternoon

441. Over flat dry land what would cause cloud?

a. Orographic uplift
b. Convective uplift during the day
c. Release of latent heat
d. Advection

442. Where does freezing rain come from?

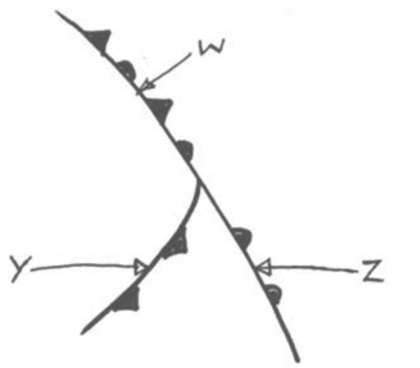
a. Cold hail falling into a warm layer
b. Cold rain falling into a warmer layer
c. Warmer rain falling into a colder layer
d. Cold rain falling into cold layer

443. Without the ability to de-ice or land immediately, what should you do if you encounter rain ice at about 2000 ft?

a. Turn around immediately before loss of controllability
b. Descend immediately to stop the rain ice
c. Climb into the warm air found above
d. Fly faster

444. What is the feature W?

a. Warm occlusion
b. Cold occlusion
c. Quasi-stationary front
d. Warm front



445. Using the picture shown above, what will be expected to happen to the surface pressure after the feature Y has passed?

a. Increase
b. Decrease
c. Remain the same
d. Increase, then decrease

446. A man is flying east to west in the Northern Hemisphere. What is happening to his altitude?

a. Flying into a headwind will decrease altitude
b. If the wind is from the south, he will gain altitude
c. If the wind is from the north, he will gain altitude
d. Tailwind will increase altitude

447. Up to FL180 ISA Deviation is ISA -10°C. What is the actual depth of the layer between FL60 and FL120?

a. 6000 ft
b. 6240 ft
c. 5760 ft
d. 5700 ft

448. In central Europe in summer, under the influence of a polar depression in a wide warm sector, you would expect the following wx:

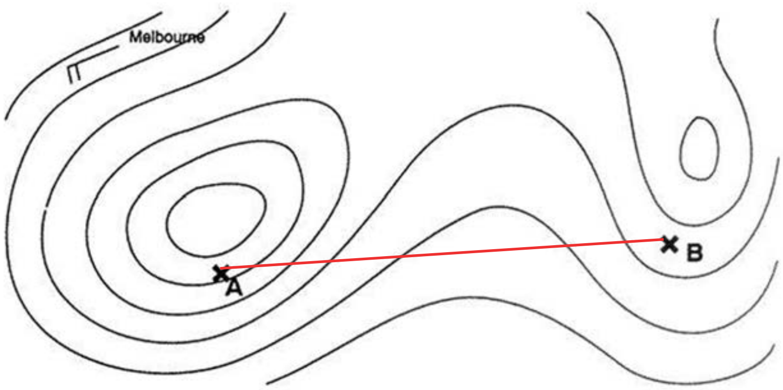
a. thunderstorms and rain showers
b. low stratus and drizzle
c. fair weather Cu
d. clear skies

449. An easterly wave will produce:

a. frontal weather
b. thunderstorms and rain
c. low stratus
d. clear skies

450. The line connecting A to B crosses what pressure system?

a. A trough
b. A ridge
c. A front
d. An occlusion



451. Which coast of the USA is affected by the most frequent hurricanes?

a. NE
b. NW
c. SE
d. SW

452. Flying over France at dawn, with 8/8 St at 200 ft, QNH 1026, wind Var3, what will be the most likely conditions at mid-day in winter and summer?

a.	OVC 2000 ft St	OVC 200 ft St
b.	OVC 500 ft AGL St	SCT 3000 ft St
c.	OVC 2000 ft AGL St	OVC 200 ft St
d.	clear skies	CBs

453. What do the following one hour interval METARS indicate the passage of?

```
22010KT 9999 SCT200 14/08 Q1012=
22010KT 9999 OVC200 13/08 Q1011=
23012KT 9KM  SCT 060 OVC120 13/08 Q1010=
24012KT 8KM -RA BKN040 OVC090 12/08 Q1009=
25015KT 2000 +RA SCT002 OVC008 12/08 Q1008=
27015KT 0800 DZ BKN002 OVC010 17/16 Q1008=
27015KT 0800 DZ BKN002 OVC010 17/16 Q1008=
27015G30KT 1000 +SHRA TS OVC010 17/16 Q1008=
29020KT 9000 SHRA BKN020 14/07 Q1010=
31020KT 9999 SCTO30 13/07 Q1012=
```

a. Cold occlusion
b. Polar front
c. Ridge
d. Warm front

454. Paris reports OVC 8/8 St at +3°C during the day. What will happen on the night of 3/4 Jan?

a. Slightly above +3°
b. Slightly below +3°
c. Stays at +3°
d. Well below 0°

455. With a cold front over the North Sea, what weather would you expect 300 km behind the front?

a. Stratus with drizzle
b. Thunderstorms and heavy showers
c. Scattered Cu and showers
d. Clear skies

456. Surface wind is 320/12 what is the wind at 2000 ft in the Northern Hemisphere?

a. 330/25
b. 220/20
c. 270/20
d. 210/12

457. Lucarno airfield elv 1735 ft altimeter indicates 1310 ft with 1013 hPa set what is the QNH?

a. 990 hPa
b. 980 hPa
c. 1028 hPa
d. 998 hPa

458. Where is the ITCZ in July?

a. 25N over the Atlantic
b. 10 - 20N over East Africa and the Arabian sea
c. 10 - 30N over West Africa
d. 20 - 30N over East Africa

459. The letters NC used at the end of a SIGMET, mean:

a. no cloud
b. no change
c. no cumulus
d. not clear

460. On the route London to Bombay, which feature would you most likely encounter between 30E and 50E?

a. Polar front jet in excess of 90 kt
b. Sub tropical jet in excess of 90 kt
c. Variable winds less than 30 kt
d. Easterly winds

461. When would the strongest convection occur?

a. Land in summer
b. Land in winter
c. Sea in summer
d. Sea in winter

462. Which way does a depression move?

a. Direction of the isobars in the warm sector
b. 90 degrees to the plane of the warm front
c. Towards the east
d. Direction of the isobars behind the cold front

463. Freezing rain is most likely from a:

a. warm front in summer
b. cold front in summer
c. warm front in winter
d. cold front in winter

464. With regard to RVR and met vis:

a. met vis is usually less than RVR
b. met vis is usually greater than RVR
c. RVR is usually less than met vis
d. met vis and RVR are usually the same

465. When are thermal lows most likely?

a. Land in summer
b. Land in winter
c. Sea in summer
d. Sea in winter

466. What is the validity of a significant weather chart?

a. 3 h
b. 6 h
c. 9 h
d. 12 h

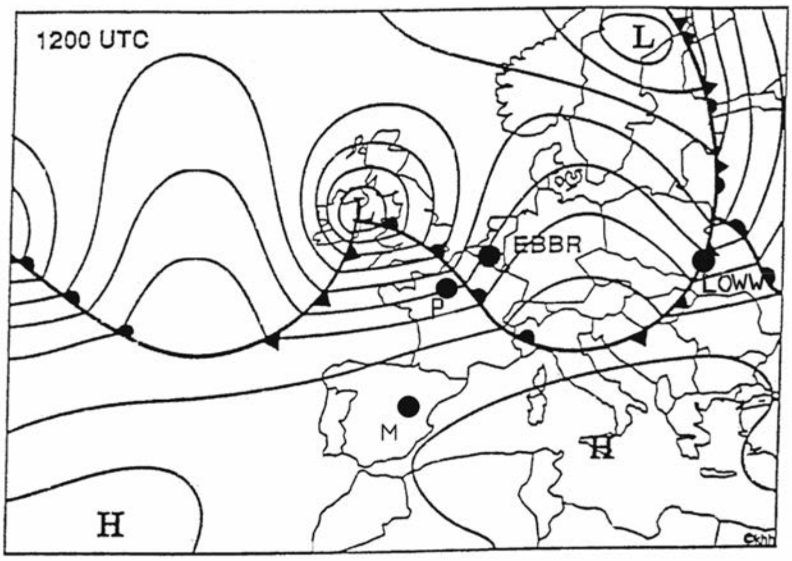
467. What is the main feature of the initial stage of a thunderstorm?

a. Downdrafts
b. Up currents
c. Rain
d. Rotor cloud

468. What is haze?

a. Poor visibility due to drizzle
b. Poor visibility due to rain
c. Poor visibility due to dust or sand
d. All of the above

469. On the chart below, where is rain least likely?



a. EBBR
b. Madrid
c. Paris
d. LOWW

470. On a flight from Zurich to Rome, which of the following METARs would be applicable?

a. London
b. Shannon
c. Madrid
d. Milan

471. Which of the following is true about freezing precipitation?

a. It only falls from a warm front
b. It is either rain or drizzle
c. It only falls from a cold front
d. It only falls from an occlusion

472. What do the letters NO SIG mean at the end of a METAR?

a. No significant change
b. No significant weather
c. No significant cloud
d. No signature on report

473. What is a TREND forecast?

a. An aerodrome forecast valid for 9 hours
b. A routine report
c. A landing forecast appended to a METAR/SPECI valid for 2 hours
d. A route forecast, valid for 24 hours

474. How does clear ice form?

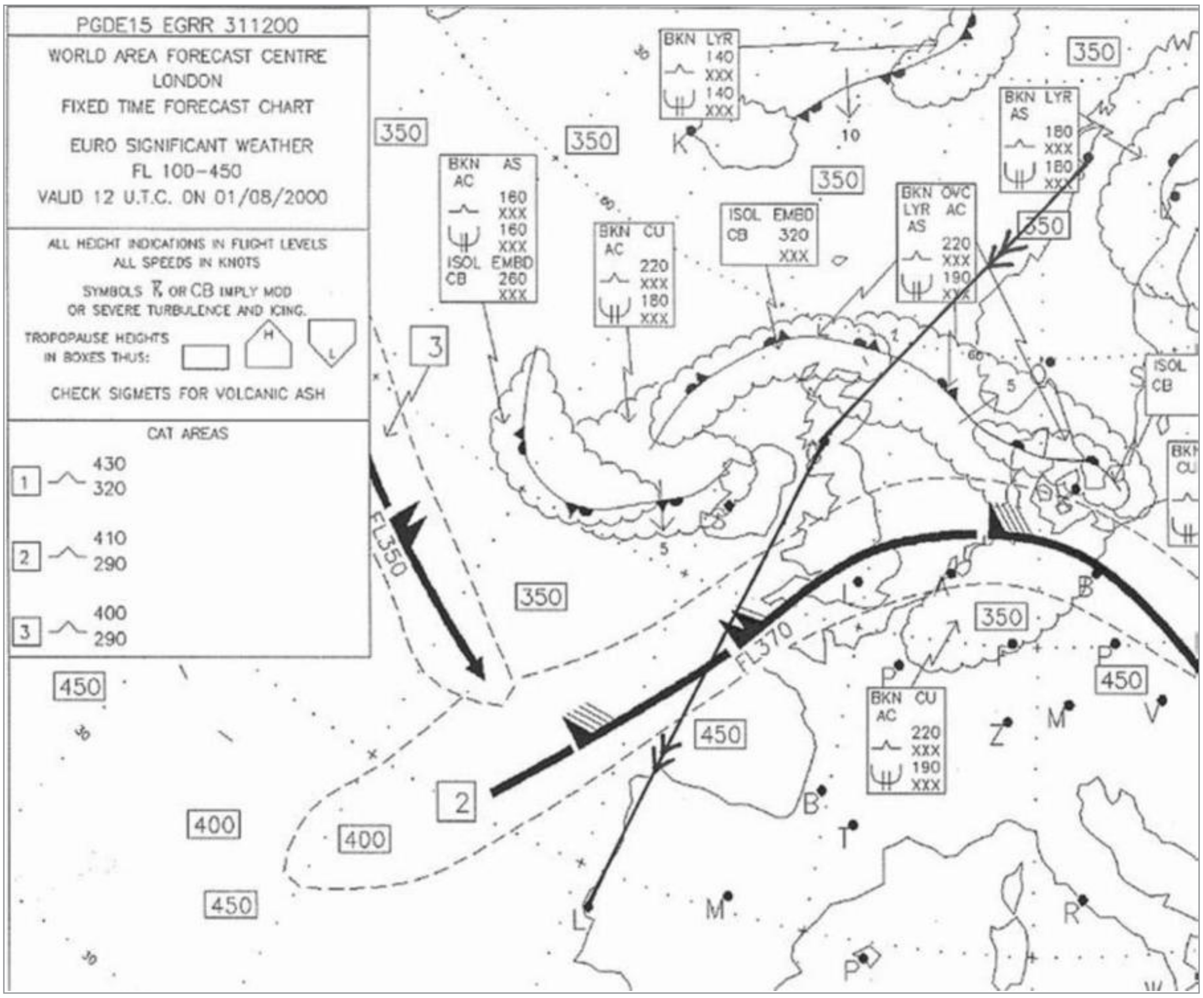
a. SWDs spreading on impact
b. Ice pellets shattering on impact
c. Frost on the wing
d. Water vapour freezing on the aircraft surface

475. Where is windshear the greatest?

a. Near a strong low level inversion and in the region of a thunderstorm
b. Near a valley with wind speeds greater than 35 kt
c. On the windward side of a mountain
d. When the wind is greater than 35 kt

477. On the chart below, for the route Edinburgh to Zurich, state the optimum flight level.

a. FL220
b. FL240
c. FL370
d. FL390



476. Where do you find squall lines?

a. Where there are thunderstorms
b. Ahead of a fast moving cold front
c. Foggy areas
d. Regions of snow

478. A Föhn wind occurs:

a. on the windward side caused by surface heating
b. on the leeward side, because the condensation level is higher
c. on the windward side, caused by surface cooling and wind flow reversal
d. on the leeward side, caused by precipitation

479. The Harmattan is:

a. a SE monsoon wind
b. a NE wind over NW Africa between Nov - April reducing visibility with dust
c. a local depression wind
d. SE wind over NW Africa between Nov - April reducing visibility with dust

480. Icing is most likely:

a. -20 to –35 C
b. +10 to 0 C
c. 0 to -10C
d. below - 35 C

481. At what height is half the mass of the atmosphere?

a. 5 km
b. 11 km
c. 8 km
d. 3 km

482. How can you determine QNH from QFE?

a. Temperature and elevation
b. Elevation
c. Pressure and temperature
d. Temperature

483. What is true about moderate to severe airframe icing?

a. It will occur in clear sky conditions
b. Always occurs in AS cloud
c. May occur in the uppermost levels of CB capillatus formation
d. Most likely in NS

484. A winter day in N Europe with a thick layer of SC and surface temperature zero degrees C. You can expect:

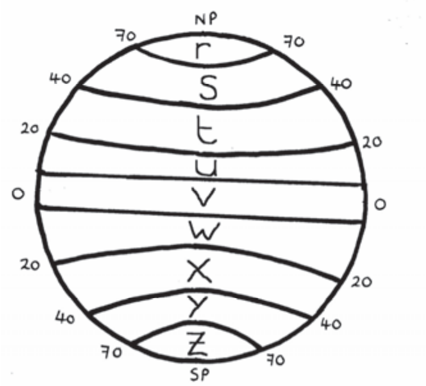
a. decreasing visibility due to snow below the cloud base and light icing in cloud
b. high probability of icing in clouds, severe icing in the upper levels due to large droplets
c. turbulence due to a strong inversion, but no icing due to clouds being formed from ice crystals
d. reduced visibility and light icing in cloud

485. If an aircraft flies into an area of supercooled rain with a temperature below zero, what kind of icing is most likely?

a. Clear
b. Rime
c. Hoar frost
d. Granular frost

486. **With regard to the idealized globe below, where are travelling lows located?**

a. V
b. S + Y
c. T + W
d. U + W



487. **If Paris has a surface wind of 160/40, what is the wind at 2000 ft?**

a. 180/60
b. 120/40
c. 160/60
d. 160/40

488. **What causes convection in a low pressure system?**

a. Height
b. Latitude
c. Centripetal force
d. Friction

489. **What is the cause of the formation of the polar front jet?**

a. Pressure
b. Azores High
c. Temperature
d. Tropopause height

490. **You are flying at FL120 with a true altitude of 12 000 ft, why would this be?**

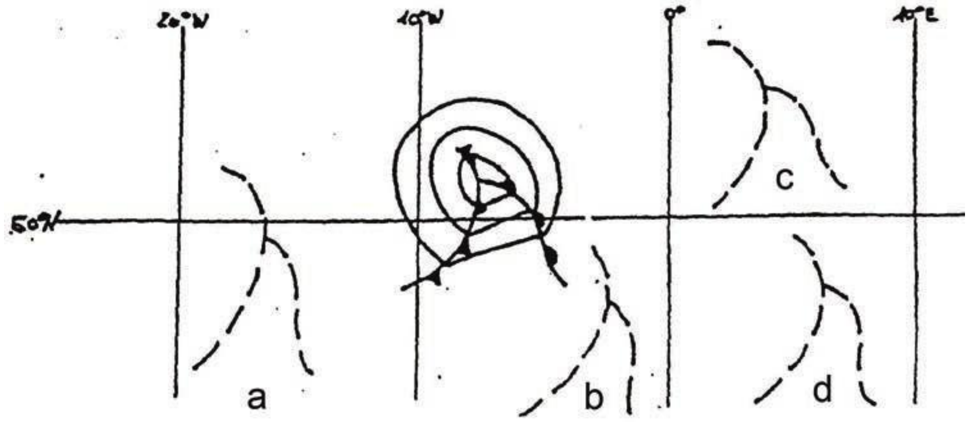
a. ISA conditions prevail
b. Temperature higher than ISA
c. Temperature lower than ISA
d. An altimeter fault

491. **TAF 130600Z 130716 VRB02 CAVOK =**

Volmet 0920 28020G40KT BKN050CB OVC090 TEMPO TS =

a. TAF is correct Volmet is wrong
b. TAF & Volmet match
c. Volmet speaker surely must have mixed up airports because there is no way that TAF & Volmet can differ by that much
d. Conditions just turned out to be much more volatile than originally forecast

492. **What will be the position of the polar front in 24 hours time, assuming the usual path of movement of the PF?**



493. **Considering the North Atlantic area at 60°N in winter, the mean height of the tropopause is approximately:**

a. 56 000 ft
b. 37 000 ft
c. 29 000 ft
d. 70 000 ft

494. **An unsaturated parcel of air is forced to rise through an isothermal layer. As long as it stays unsaturated the temperature of the parcel will:**

a. remain the same
b. become equal to the temperature of the isothermal layer
c. decrease at 1.0 deg C per 100 m
d. decrease at 0.65 deg C per 100 m

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	a	b	a	a	a	b	a	d	b	a	a

13	14	15	16	17	18	19	20	21	22	23	24
b	c	c	b	b	a	a	a	a	b	c	d

25	26	27	28	29	30	31	32	33	34	35	36
c	d	c	b	b	c	d	a	c	a	c	d

37	38	39	40	41	42	43	44	45	46	47	48
c	b	a	c	a	c	b	b	a	a	a	b

49	50	51	52	53	54	55	56	57	58	59	60
d	a	b	a	a	b	a	b	a	a	c	b

61	62	63	64	65	66	67	68	69	70	71	72
b	b	d	a	b	a	b	d	d	c	c	d

73	74	75	76	77	78	79	80	81	82	83	84
b	b	b	a	b	b	b	a	a	a	a	a

85	86	87	88	89	90	91	92	93	94	95	96
c	c	a	b	a	a	a	a	a	b	c	d

97	98	99	100	101	102	103	104	105	106	107	108
d	b	a	b	a	b	c	b	a	c	b	d

109	110	111	112	113	114	115	116	117	118	119	120
c	b	d	a	c	a	d	d	b	d	b	c

121	122	123	124	125	126	127	128	129	130	131	132
b	a	b	c	a	b	c	d	c	c	d	a

133	134	135	136	137	138	139	140	141	142	143	144
d	a	a	c	a	c	b	a	d	d	c	b

145	146	147	148	149	150	151	152	153	154	155	156
d	a	d	c	b	c	d	c	d	a	d	a

157	158	159	160	161	162	163	164	165	166	167	168
c	a	a	a	c	c	b	d	c	b	d	c

169	170	171	172	173	174	175	176	177	178	179	180
a	c	a	d	d	c	b	c	a	a	a	c

181	182	183	184	185	186	187	188	189	190	191	192
a	d	b	b	c	a	c	c	c	a	b	c

193	194	195	196	197	198	199	200	201	202	203	204
b	b	b	d	c	b	b	d	c	d	d	b

205	206	207	208	209	210	211	212	213	214	215	216
a	b	b	c	a	c	c	c	d	c	a	b
217	218	219	220	221	222	223	224	225	226	227	228
a	c	c	b	d	c	a	c	a	c	c	a
229	230	231	232	233	234	235	236	237	238	239	240
c	b	b	a	a	c	c	b	d	b	c	d
241	242	243	244	245	246	247	248	249	250	251	252
a	a	a	b	d	a	c	b	a	a	a	a
253	254	255	256	257	258	259	260	261	262	263	264
a	d	a	c	d	a	c	d	c	b	a	b
265	266	267	268	269	270	271	272	273	274	275	276
c	c	c	d	c	a	a	c	b	a	d	d
277	278	279	280	281	282	283	284	285	286	287	288
d	d	d	b	c	b	d	a	c	b	d	c
289	290	291	292	293	294	295	296	297	298	299	300
a	c	a	d	b	d	b	a	d	b	b	d
301	302	303	304	305	306	307	308	309	310	311	312
c	d	c	c	c	a	b	a	a	b	b	b
313	314	315	316	317	318	319	320	321	322	323	324
b	d	d	c	d	d	a	a	a	c	a	d
325	326	327	328	329	330	331	332	333	334	335	336
c	a	b	b	a	c	a	c	d	a	d	d
337	338	339	340	341	342	343	344	345	346	347	348
b	a	c	c	c	b	b	b	d	a	c	c
349	350	351	352	353	354	355	356	357	358	359	360
a	b	a	d	a	b	d	c	a	a	b	b
361	362	363	364	365	366	367	368	369	370	371	372
a	a	a	c	b	a	a	c	b	b	d	a
373	374	375	376	377	378	379	380	381	382	383	384
b	c	b	c	c	c	d	b	d	a	b	b
385	386	387	388	389	390	391	392	393	394	395	396
a	a	c	b	b	b	a	c	c	c	b	d
397	398	399	400	401	402	403	404	405	406	407	408
b	c	c	c	b	b	b	c	a	b	a	b
409	410	411	412	413	414	415	416	417	418	419	420
d	d	c	d	c	a	b	c	c	b	d	d

421	422	423	424	425	426	427	428	429	430	431	432
a	c	b	c	b	a	c	c	d	d	b	d
433	434	435	436	437	438	439	440	441	442	443	444
d	c	a	c	c	b	a	d	b	c	a	a
445	446	447	448	449	450	451	452	453	454	455	456
a	c	c	b	b	a	c	b	b	b	c	a
457	458	459	460	461	462	463	464	465	466	467	468
c	b	b	b	a	a	c	a	a	c	b	c
469	470	471	472	473	474	475	476	477	478	479	480
b	d	b	a	c	a	a	b	b	b	b	c
481	482	483	484	485	486	487	488	489	490	491	492
a	b	d	d	a	b	a	d	c	a	d	c
493	494										
c	c										

EASA Final Examination

1. **MSA given as 12,000 ft, flying over mountains in temperatures +9°C, QNH set as 1023 (obtained from a nearby airfield). What will the true altitude be when 12 000 ft is reached?**

   a. 11 940
   b. 11 148
   c. 12 210
   d. 12 864

2. **In the Northern Hemisphere a man observes a low pressure system passing him to the south, from west to east. What wind will he experience?**

   a. Backs then Veers
   b. Constantly Backs
   c. Veers then Backs
   d. Backs then steady

3. **What is Relative Humidity dependent upon?**

   a. Moisture content and temperature of the air
   b. Temperature of the air
   c. Temperature and pressure
   d. Moisture content of the air

4. **If the ELR is 0.65°C/100 m:**

   a. atmosphere is conditionally stable
   b. atmosphere is stable
   c. atmosphere is unstable
   d. atmosphere is stable when dry

5. **Height of the tropopause at 50°N:**

   a. 11 km
   b. 16 km
   c. 5 km
   d. 20 km

6. **ELR is 1°C/100 m:**

   a. neutral when dry
   b. absolute stability
   c. absolute instability
   d. conditional stability

7. **A steep pressure gradient is characterized by:**

   a. isobars close together, strengthened wind
   b. isobars far apart, decreased wind
   c. isobars close together, temperature increasing
   d. isobars far apart, temperature decreasing

8. If you fly with left drift in the Northern Hemisphere, what is happening to your true altitude?

a. Increases
b. Decreases
c. Stays the same
d. Cannot tell

9. Sublimation:

a. solid to vapour
b. vapour to liquid
c. liquid to vapour
d. liquid to solid

10. What is the coldest time of the day?

a. 1 h before sunrise
b. 1/2 h before sunrise
c. at exact moment of sunrise
d. 1/2 h after sunrise

11. When is diurnal variation a maximum?

a. Clear sky, still wind
b. Clear sky, strong wind
c. OVC, still
d. OVC, windy

12. QNH at Timbuktu (200 m AMSL) is 1015 hPa. What is the QFE? (Assume 1 hPa = 8 m)

a. 1000
b. 990
c. 1020
d. 995

13. Above a stable layer in the lower troposphere in an old high pressure system is called:

a. radiation inversion
b. subsidence inversion
c. frontal inversion
d. terrestrial inversion

14. Why does air cool as it rises?

a. It expands
b. It contracts
c. The air is colder at higher latitudes
d. The air is colder at higher altitudes

15. **When flying at FL180 in the Southern Hemisphere you experience a left crosswind. What is happening to your true altitude if indicated altitude is constant?**

a. Remains the same
b. Increasing
c. Decreasing
d. Impossible to tell

16. **Dew point is defined as:**

a. the lowest temperature at which evaporation will occur for a given pressure
b. the lowest temperature to which air must be cooled in order to reduce the relative humidity
c. the temperature below which the change of state for a given volume of air will result in absorption of latent heat
d. the temperature to which moist air must be cooled to reach saturation

17. **Flying from Marseilles (QNH 1012) to Palma (QNH 1015) at FL100. You do not reset the altimeter, why would true altitude be the same throughout the flight?**

a. Not possible to tell
b. Air at Palma is warmer than air at Marseilles
c. Air at Marseilles is warmer than air at Palma
d. Blocked static vent

18. **From which of the following can the stability of the atmosphere be determined?**

a. Surface pressure
b. Surface temperature
c. DALR
d. ELR

19. **If when heading south in the Southern Hemisphere you experience starboard drift:**

a. you are flying towards a lower temperature
b. you are flying away from a lower temperature
c. you are flying towards a low pressure
d. you are flying out of a high

20. **How does the level of the tropopause vary with latitude in the Northern Hemisphere?**

a. Decreases north - south
b. Decreases south - north
c. Constant
d. It varies with longitude not latitude

21. **What is the tropopause?**

a. The layer between the troposphere and stratosphere
b. The boundary between the troposphere and stratosphere
c. Where temperature increases with height
d. Upper boundary to CAT

22. **Where do you find the majority of the air within the atmosphere?**

a. Troposphere
b. Stratosphere
c. Tropopause
d. Mesosphere

23. **Flying from an area of low pressure in the Southern Hemisphere at low altitudes, where is the wind coming from?**

a. Right and slightly on the nose
b. Left and slightly on the tail
c. Left and slightly on the nose
d. Right and slightly on the tail

24. **The QNH at an airfield 200 m AMSL is 1009 hPa; air temperature is 10°C lower than standard. What is the QFF?**

a. Not possible to give a definite answer
b. Less than 1009
c. 1009
d. More than 1009

25. **Which of these would cause your true altitude to decrease with a constant indicated altitude?**

a. Cold/Low
b. Hot/Low
c. Cold/High
d. Hot/High

26. **Where is the ozone layer?**

a. Ionosphere
b. Stratosphere
c. Tropopause
d. Troposphere

27. **An aircraft flying in the Alps on a very cold day, QNH 1013 set on the altimeter, flies level with the summit of the mountains. Altitude from aneroid altimeter reads:**

a. same as mountain elevation
b. lower than mountain elevation
c. higher than mountain elevation
d. impossible to determine

28. **QNH is defined as:**

a. the pressure at MSL obtained using the standard atmosphere
b. the pressure at MSL obtained using the actual conditions
c. QFE reduced to MSL using the actual conditions
d. QFE reduced to MSL using the standard atmosphere

29. **Where would you expect to find the strongest wind on the ground in temperate latitudes?**

a. In an area of low pressure
b. In an area of high pressure
c. In the warm air between two fronts
d. In a weak anticyclone

30. **Landing at an airfield with QNH set the pressure altimeter reads:**

a. zero feet on landing only if ISA conditions prevail
b. zero
c. the elevation of the airfield if ISA conditions prevail
d. the elevation of the airfield

31. **You are flying in an atmosphere which is warmer than ISA, what might you expect?**

a. True altitude to be the same as indicated altitude
b. True altitude to be lower than indicated altitude
c. True altitude to be the decreasing
d. True altitude to be higher than indicated altitude

32. **The environmental lapse rate in the real atmosphere:**

a. has a fixed value of 2°C / 1000 ft
b. has a fixed value of 0.65°C / 100 m
c. varies with time
d. has a fixed value of 1°C /100 m

33. **Airfield is 69 metres below sea level, QFF is 1030 hPa, temperature is ISA -10°C. What is the QNH?**

a. Impossible to tell
b. Less than 1030 hPa
c. 1030 hPa
d. More than 1030 hPa

34. **The QNH is 1030 hpa and at the transition level you set the SPS. What happens to your indicated altitude?**

a. Drops by 510 ft
b. Rises by 510 ft
c. Rises
d. Drops

35. **What is the movement of air relating to a trough?**

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Converging and ascending

36. **What is the movement of air relating to a ridge?**

a. Descending and diverging
b. Ascending and diverging
c. Descending and converging
d. Ascending and converging

37. **What is the min. temperature according to ISA?**

a. -56.5°C
b. -273°C
c. -100°C
d. 215.6 K

38. **The temperature at the surface is 15°C, the temperature at 1000 m is 13°C. The atmosphere is:**

a. unstable
b. conditionally unstable
c. stable
d. cannot tell

39. **You are flying from Madrid (QNH 1012) to Paris (QNH 1015) at FL80. If your true altitude and indicated altitude remain the same then:**

a. the air at Madrid is warmer than Paris
b. the air at Paris is warmer than Madrid
c. the altimeters are incorrect
d. your indicated altitude must be changing

40. **If you are flying on a QNH 1009 on very cold day and you circle the top of a peak in the Alps, your altimeter will read:**

a. the same as the elevation of the peak
b. lower than the elevation of the peak
c. higher than the elevation of the peak
d. not enough information to tell

41. **What is subsidence?**

a. Horizontal motion of air
b. Vertical down draught of air
c. Vertical up draught of air
d. Adiabatic cooling

42. **Relative humidity increases in:**

a. warmer air compared to colder air
b. warm air at a constant vapour pressure
c. cold air at a constant vapour pressure
d. colder air compared to warmer air

43. **Which of the following gives conditionally unstable conditions?**

a. 1°C/100 m
b. 0.65°C/100 m
c. 0.49°C/100 m
d. None of the above

44. **A mass of unsaturated air is forced to rise till just under the condensation level. If it then settles back to its original position:**

a. temp. is greater than before
b. temp. stays the same
c. temp. is less than before
d. it depends on QFE

45. **What height is the tropopause and at what temperature?**

a. At the poles 8 km and -16°C
b. At the pole 18 km and -75°C
c. At the Equator 8 km and -40°C
d. At the Equator 18 km and -76°C

46. **Which of the following will give the greatest difference between temperature and dew point?**

a. Dry air
b. Moist air
c. Cold air
d. Warm air

47. **Solar radiation heats the atmosphere by:**

a. heating the air directly
b. heating the surface, this then heats the air in the atmosphere
c. heating the water vapour in the atmosphere directly
d. heating the water vapour directly unless there are clouds present

48. **What affects how much water vapour the air can hold?**

a. RH
b. Temperature
c. Dew point
d. Pressure

49. **Aerodrome at MSL, QNH is 1022. QFF is:**

a. greater than 1022
b. less than 1022
c. same as QNH
d. cannot tell without temperature information

50. **What is the technical term for an increase in temperature with altitude?**

a. Inversion
b. Advection
c. Adiabatic
d. Subsidence

51. **On a surface weather chart, isobars are lines of:**

a. QNH
b. QFE
c. QFF
d. QNE

52. **Which of the following constituents in the atmosphere has the greatest effect on the weather?**

a. Nitrogen
b. Oxygen
c. Hydrogen
d. Water Vapour

53. **Which of the following is true?**
QNH is:

a. always more than 1013.25 hPa
b. always less than 1013.25 hPa
c. never 1013.25 hPa
d. can never be above or below 1013 hPa

54. **If an aerodrome is 1500 ft AMSL on QNH 1038, what will be the actual height AGL to get to FL75? (27 ft = 1 hPa).**

a. 6675 ft
b. 8170 ft
c. 8330 ft
d. 2330 ft

55. **Altimeter set to 1023 at aerodrome. On climb to altitude the SPS is set at transition altitude. What will indication on altimeter do on resetting to QNH?**

a. Dependent on temperature
b. Decrease
c. Increase
d. Same

56. **Secondary depressions move:**

a. around the primary in a cyclonic fashion
b. round the primary in an anticyclonic fashion
c. eastwards
d. westwards

57. **What temperature and pressure conditions would be safest to ensure that your flight level clears all the obstacles by the greatest margin?**

a. Cold temp/low pressure
b. Warm temp/high pressure
c. Temp less than or equal to ISA and a QNH less than 1013
d. Temp more than or equal to ISA and a QNH greater than 1013

58. In a shallow pressure distribution (widely spaced isobars or low pressure gradients) you observe the aneroid altimeter of a parked aircraft for 10 minutes (no thunderstorms observed). The reading of the instrument will:

a. not be influenced by the air pressure
b. increase greatly
c. show no appreciable change due to such a minor pressure fluctuation
d. experience great changes

59. You are flying from Marseilles (QNH 1012 hPa) to Palma de Mallorca (QNH 1012 hPa) at FL100. You notice that the effective height above MSL (radio altitude) increases constantly. Hence:

a. one of the QNH values must be wrong
b. you have the altimeters checked, as their indications are obviously wrong
c. the air mass above Palma is warmer than that above Marseilles
d. you have to adjust for a crosswind from the right

60. You are flying from Marseilles (QNH 1026 hPa) to Palma de Mallorca (QNH 1026 hPa) at FL100. You notice that the effective height above MSL (radio altitude) decreases constantly. Hence:

a. one of the QNH values must be wrong
b. the air mass above Marseilles is warmer than that above Palma
c. you have the altimeters checked, as their indications are obviously wrong
d. you have to adjust for a crosswind from the right

61. Flying at FL135 above the sea, the radio altimeter indicates a true altitude of 13 500 ft. The local QNH is 1019 hPa. Hence the crossed air mass is, on average:

a. at ISA standard temperature
b. colder than ISA
c. warmer than ISA
d. there is insufficient information to determine the average temperature deviation

62. You are flying in the Alps at the same level as the summits on a hot day. What does the altimeter read?

a. Same altitude as the summit
b. Higher altitude as the summit
c. Lower altitude as the summit
d. Impossible to tell

63. To dissipate cloud requires:

a. subsidence
b. a decrease in temperature
c. an increase pressure
d. convection

64. A layer of air can be:

a. conditional; unstable when unsaturated and stable when saturated
b. conditional; unstable when saturated and stable when unsaturated
c. neutrally stable when saturated and unstable when unsaturated
d. all of the above

65. **Relative humidity:**

a. is not affected by temperature
b. is not affected by air expanding and contracting
c. does not change when water is added
d. changes when water is added, even if the temperature is the same

66. **What happens to the temperature of a saturated air mass when forced to descend?**

a. It heats up more than dry because of expansion
b. It heats up less than dry because of evaporation
c. It heats up more than dry because of sublimation
d. It heats up less than dry because of latent heat released during condensation

67. **An airfield has an elevation of 540 ft with a QNH of 993 hPa. An aircraft descends and lands at the airfield with 1013 hPa set. What will its altimeter read on landing?**

a. 380 ft
b. 1080 ft
c. 0 ft
d. 540 ft

68. **When is pressure altitude equal to true altitude?**

a. In standard conditions
b. When surface pressure is 1013.25 hPa
c. When the temperature is standard
d. When the indicated altitude is equal to the pressure altitude

69. **What happens to the temperature of a saturated air mass when descending?**

a. Heats up more than dry because of expansion
b. Heats up less than dry because of evaporation
c. Heats up more than dry because of compression
d. Heats up less than dry because of latent heat released during condensation

70. **The DALR is:**

a. variable with time
b. fixed
c. variable with latitude
d. variable with temperature

71. **Which of the following defines RH?**

a. HMR/ Satuaration mixing ratio × 100
b. Absolute humidity/ mixing ratio × 100
c. Saturation mixing ratio/ HMR × 100
d. Amount of water held/ amount of water air could hold × 100

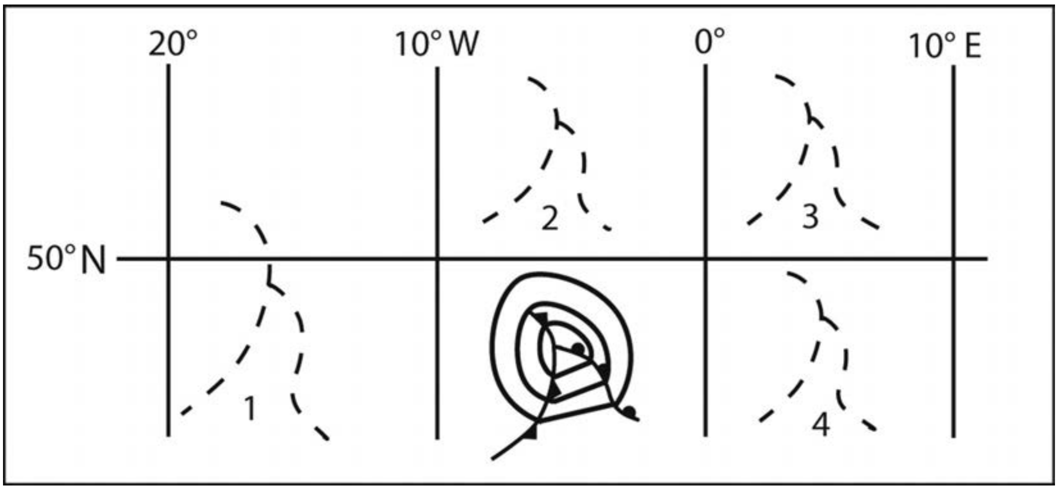
72. **A winter day in N Europe with a thick layer of SC and surface temperature zero degrees C. You can expect:**

a. decreasing visibility due to snow below the cloud base and light icing in cloud
b. high probability of icing in clouds, severe icing in the upper levels due to large droplets
c. turbulence due to a strong inversion, but no icing due to clouds being formed from ice crystals
d. reduced visibility and light icing in cloud

73. **TAF 130600Z 130716 VRB02 CAVOK =**
Volmet 0920 28020G40KT BKN050CB OVC090 TEMPO TS =

a. TAF is correct Volmet is wrong
b. TAF & Volmet match
c. Volmet speaker surely must have mixed up airports because there is no way that TAF & Volmet can differ by that much
d. Conditions just turned out to be much more volatile than originally forecast

74. **What will be the position of the polar front depression in 24 hours time, assuming the usual path of movement of the polar front depression?**



a. 1
b. 2
c. 3
d. 4

75. **The Harmattan is:**

a. a SE monsoon wind
b. a NE wind over NW Africa between Nov - April reducing visibility with dust
c. a local depression wind
d. a SE wind over NW Africa between Nov - April reducing visibility with dust

76. **Which of the following factors have the greatest effect on aircraft icing?**

a. Aircraft speed and curvature of the airfoil
b. RH inside the cloud
c. Cloud temperature and droplet size
d. Aircraft speed and size of cloud droplets

77. In which of the following regions does polar maritime air originate?

a. British Isles
b. Baltic sea
c. Black sea
d. East of Greenland

78. What is the validity of a significant weather chart:

a. 3 h
b. 6 h
c. 9 h
d. 12 h

79. On the route London to Bombay, which feature would you most likely encounter between 30E and 50E?

a. Polar front jet in excess of 90 kt
b. Subtropical jet in excess of 90 kt
c. Variable winds less than 30 kt
d. Easterly winds

80. Where is the ITCZ in July?

a. 25N over the Atlantic
b. 10 - 20N over East Africa and the Arabian sea
c. 10 - 30N over West Africa
d. 20 - 30N over East Africa

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	b	a	d	a	a	a	a	a	d	a	b

13	14	15	16	17	18	19	20	21	22	23	24
b	a	c	d	c	d	b	b	b	a	c	d

25	26	27	28	29	30	31	32	33	34	35	36
a	b	c	d	a	d	d	c	d	a	d	a

37	38	39	40	41	42	43	44	45	46	47	48
a	c	a	c	b	c	b	b	d	a	b	b

49	50	51	52	53	54	55	56	57	58	59	60
c	a	c	d	c	a	c	a	d	c	c	b

61	62	63	64	65	66	67	68	69	70	71	72
b	c	a	b	d	b	b	a	b	b	a	d

73	74	75	76	77	78	79	80
d	c	b	c	d	b	c	c

1. 12 000ft = 12 × 2 = 24 - 15 = -9 ISA
Ambient +9 ISA -9, deviation ISA +18
12(000) × 18 × 4 (constant) = 864
12 000 + 864 (ISA +) = 12 864 ft.

67. Aircraft is 540 ft above
the 993 hPa level, but
a further 540 ft above
the 1013 hPa level

Chapter

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