notes on Meteorology

Third Edition

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Kemp & Young

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Preface to first edition

Weather conditions are ever changing and, in order to make the best use of favourable conditions or to counter unfavourable ones successfully, the seafarer should have some theoretical as well as practical knowledge of meteorology.

Many of the theories of weather phenomena are revised from time to time and, so as to keep the text concise, we have described the more common of these theories as simply as possible.

A large number of diagrams have been included to supplement the text and to enable the student to make his own forecast of the likely weather in the various situations.

Although written primarily to cover the needs of those studying for their examinations, all interested in meteorology, particularly yachtsmen, will find the book of great value.

Our thanks are due to Mr P.N. Colepeper, FRMetS. Master Mariner and First Class Air Navigator, for his painstaking reading of the text and for his helpful suggestions.

We are indebted to the Controller of Her Majesty's Stationery Office for permission to reproduce certain drawings of instruments from the Admiralty Manual of Seamanship and the map of the weather forecast areas supplied by the Meteorological Office.

KENLEY, SURREY
May 1961

J.F. KEMP
PETER YOUNG

Preface to revised edition

The changeover to metrication with SI units has necessitated several alterations in the numerical quantities in this book but, wherever appropriate, both SI and Imperial values are given. It should be noted, however, that the imperial units are not necessarily an exact conversion from SI units.

The opportunity has also been taken to revise the text and introduce notes on further topics such as facsimile plotting and weather routeing so that the book may continue to fulfil its original purpose of providing a basic text on meteorology for examination candidates, yachtsmen and all interested in the subject of weather.

Our thanks are due to those who have read and criticised the revised text and to Negretti and Zambra (Aviation) Limited, who have supplied illustrations.

J.F. KEMP
PETER YOUNG

January 1971

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CHAPTER ONE

Instruments

In order to get as complete a picture as possible of the weather, careful observations should be made of the individual phenomena which go to make up the weather. Many of these observations are made visually: for example, the form of clouds, and direction of the wind. Others must be made by instruments; for instance one cannot 'feel' the pressure or the relative humidity although one may hazard a guess at the air temperature.

Various instruments have been designed to observe the different phenomena. The principal ones measure pressure, temperature and wind velocity, whilst others have been designed to measure sunshine hours and rainfall.

There is no necessity for a ship to carry every instrument, as a barometer and a hygrometer together with the broadcast weather information will enable one to make an accurate forecast for the next few hours. The Meteorological Office recognises this and usually supplies a precision aneroid or a mercurial barometer, a barograph, a sea thermometer and a hygrometer to observing ships.

Pressure and its measurement

Pressure is force per unit area. The unit of pressure in the SI system is the **bar** which is approximately equivalent to a load of 10 tonnes weight per square metre (10 tf/ m^2).

The average pressure at ground level is slightly in excess of 1 bar and to avoid the necessity of having large numbers of figures after the decimal point in order to express pressure accurately, the bar is divided into 1000 parts. Each of these parts is a **millibar,** and pressure is expressed in these units.

For many years pressure was also expressed in millibars under the Imperial system although it was also, and still may be, expressed as 'inches of mercury'. This is the length of a column of mercury which will balance a column of air. As the column of air exerts a pressure of approximately 14.7 lb per square inch the height of the column of mercury (relative density 13.6) necessary to exert this pressure is about 30 in.

Isobar A line joining places having equal pressure. On weather charts these are plotted at 4 millibar intervals, so that the isobars shown are divisible by 4.
Isallobar A line joining places having an equal change of pressure. A study of these can give an indication of the direction of movement of pressure systems.
Pressure gradient This is the difference in pressure in unit distance measured at right angles to the isobars.

There is a **diurnal range** of barometric pressure which results in the barometric pressure being higher than normal at 1000 and 2200 local time and lower than normal at 0400 and 1600 local time. The semi-diurnal pressure wave is due to the atmospheric tides which are caused by the sun and moon. It is possible that there are other causes, as this semi-diurnal change of pressure is still being investigated.

The diurnal range is most marked in the tropics where the barometer is frequently 1.5 millibars above or below normal at the times mentioned above. It is less noticeable in higher latitudes where frequent pressure changes occur due to the passage of depressions. However, when the pressure gradient is constant and small, this daily range may be seen clearly on a barograph trace although the variation is very much less than in low latitudes.

Mercurial barometer (Figure 1)

This is constructed by filling a tube, about 1 metre (39 in) long with mercury. The end of the tube is temporarily closed and is inverted and placed into a reservoir of mercury. When the closure is removed it will be seen that the level of mercury falls in the tube. The space above the mercury at the top of the tube is known as a Torricellian vacuum (after Torricelli). If an air bubble were to get into this space it would depress the mercury (as the vacuum would no longer be complete) and an incorrect reading would result. To prevent this, an air trap is incorporated in the tube. A further refinement in the **Kew pattern marine barometer** is the capillary tube between the air trap and the marine tube (Figure 1(b)).
The mercurial barometer is liable to error on account of the following:

1 **Capillarity.** The surface tension of the mercury forms a **meniscus** and readings should always be taken at the top of this.
2 **Capacity.** The height of the barometer should be taken from the top of the mercury in the cistern to the top of the mercury in the marine tube. If the pressure increases, the level of the mercury in the cistern falls, so that the measurements cannot be taken from a fixed point. This error is compensated by adjusting the distance between the graduations. On the inch barometer the barometer inch will be seen to be 24/25ths of a linear inch. (In the **Fortin** barometer used in laboratory work the level of mercury in the cistern is adjustable so that the readings can always be taken from the same level.)

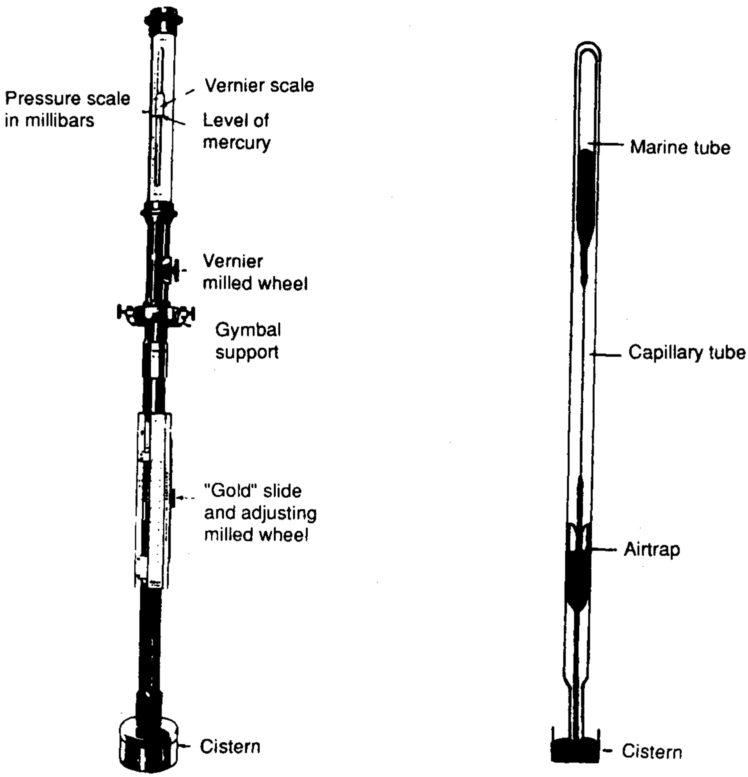


Figure 1 (a) Mercurial barometer (b) Kew pattern marine barometer

3 **Pumping.** Due to the constant change in height above mean sea level of a barometer on a vessel in a seaway, there will tend to be a continual change of reading. This movement of the mercury will make it difficult to get an accurate reading. Gusty winds can also cause pumping. The effect of pumping is considerably reduced by fitting the capillary tube above the air trap. (If pumping is present, try to get a mean of the highest and lowest readings.)

4 **Height.** All readings should be corrected to sea level. Increase of height means a decrease of pressure by approximately 1 millibar for every 10 m (30 ft). This correction can be made by tables or by the Gold Slide.

5 **Latitude.** Due to the earth being somewhat 'flattened' at the poles, mercury weighs more at the poles than at the equator. For equal atmospheric pressures the barometer would appear to read less at the poles and more at the equator. Readings should all be corrected for a mean latitude of 45°. The correction can be made by tables or by the Gold Slide (see below).

6 **Temperature.** The column of mercury will expand with an increase of temperature and contract with a decrease of temperature in exactly the same way as does a thermometer. All readings must be reduced to a standard temperature which is 285 K in the case of most millibar barometers and 28.6°F in the case of inch barometers. The correction can be made by tables or by the Gold Slide.

N.B. The attached thermometer should always be read before the barometer as otherwise heat from the observer's body may give a false reading.

The temperature at which a barometer reads correctly is known as the **Fiducial Temperature.** In lat. 45° at sea level this is the same as the standard temperature, but at sea level in lat. 57° the fiducial temperature would be 291 K, and in lat. 21° at sea level it would be 273 K. At 20 m (60 ft) above sea level in 45° it would be 297 K. (All the foregoing figures are to the nearest degree).

7 **Observational errors** (Figure 2)

(a) The barometer should always be upright; it is the vertical height of the column of mercury that balances the column of air. If the barometer is not upright, too high a reading is obtained.

(b) The back and front of the vernier must be on the same level as the observer's eye, otherwise the reading will be too high.

Gold slide (Figure 3)

This takes its name from its inventor, Lt Col Gold, and gives a rapid means of getting the latitude, height and temperature correction.

To use the slide, set the height of the barometer above sea level against the latitude and read off the correction opposite the top of the mercury in the thermometer.

Aneroid barometer

This is a very much more robust and compact instrument than the mercurial barometer.

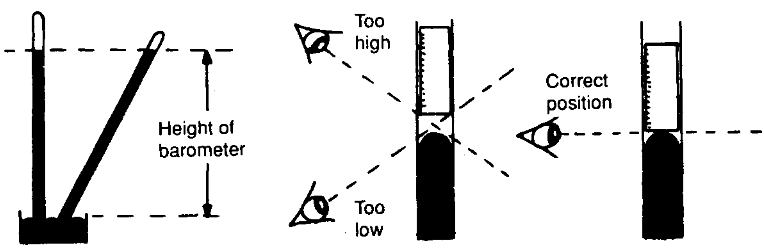


Figure 2 Observational errors

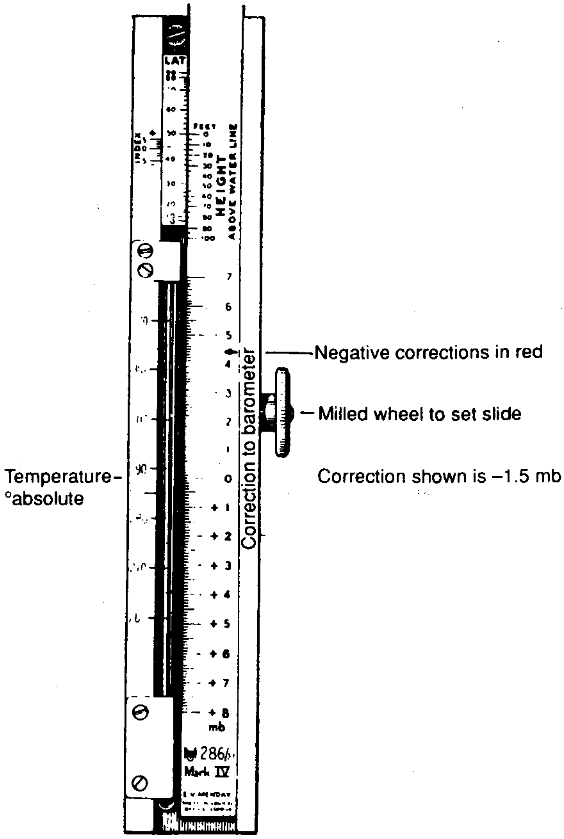


Figure 3 Gold slide

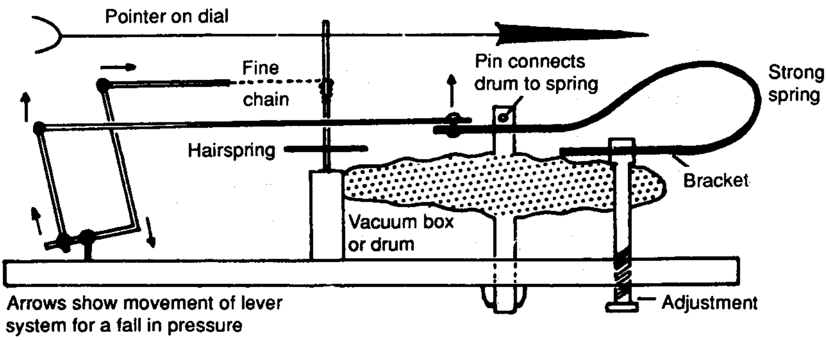


Figure 4 Aneroid barometer

As can be seen from Figure 4, the main component is a vacuum box which is partially exhausted of air. An increase of atmospheric pressure compresses this box, causing the pointer on the dial (via the lever system) to register a higher pressure. The converse occurs with a decrease of pressure.

As there is no mercury in this barometer there are no corrections for latitude or temperature, but a height correction must be applied. There are no errors due to capillarity, capacity or pumping. There is an adjustment screw on the back of the instrument to take out any index error.

The greater the area of the vacuum box, the greater the accuracy of the instrument. It is usual to give the barometer a light tap before reading; this helps to free the fine chain which may stick if pressure changes are only small.

Precision aneroid barometer

This instrument is now supplied to observing ships in place of the Kew Pattern mercurial barometer. It is simpler to transport and to read, whilst temperature correction is unnecessary. Height corrections can be 'built in' by resetting the datum on the instrument. A pressure choke can be attached if rapid height variations, leading to rapid pressure variations, are expected; this smoothes the variations to negligible amounts.

The precision aneroid works on the same principle as that of any aneroid, namely the movement of a 'pressure pile' here called a 'capsule', caused by variations in air pressure. The difference between the precision aneroid and an ordinary aneroid is in the means of transmitting the change in air pressure to a reading. Figure 5 shows how this is done.

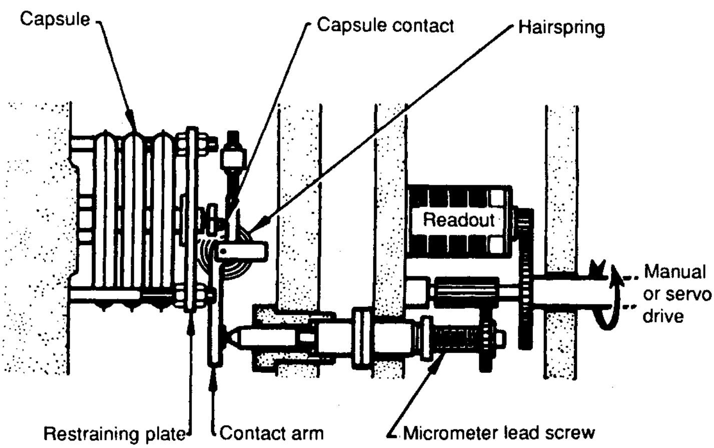


Figure 5 Precision aneroid barometer (courtesy Negretti & Zambra (Aviation) Ltd)

The movement of the 'capsule' causes the capsule contact to move towards or away from the contact arm. If the contact is broken, the 'magic eye' shows this and this is the instant at which to take the reading. The reading can range from 900 mb to 1050 mb and the accuracy to which it can be taken is 0.1 mb. At the instant of taking the reading the capsule is only under atmospheric pressure as there is no load or pressure on it from the contact arm.

The only maintenance necessary is the infrequent renewal (about 3–6 months) of the small battery powering the electronic circuit (not illustrated here) which operates the minute cathode ray tube or 'magic eye'.

Barograph

This is a recording aneroid barometer. As can be seen (Figure 6), the lever system connects the vacuum pile to a pen arm which makes a mark on the chart on the drum which is driven by clockwork. The drum is wound and the chart changed weekly.

The prime purpose of the barograph is to record the pressure tendency, which it would be impossible to observe with the mercurial or aneroid barometers unless an observer was detailed to record the pressure every five minutes or so.

Temperature and its measurement

The forecasting of weather depends as much on a knowledge of temperatures as of pressure.

The instruments for measuring temperature all depend on the expansion and contraction of liquids or metals when heated and cooled.

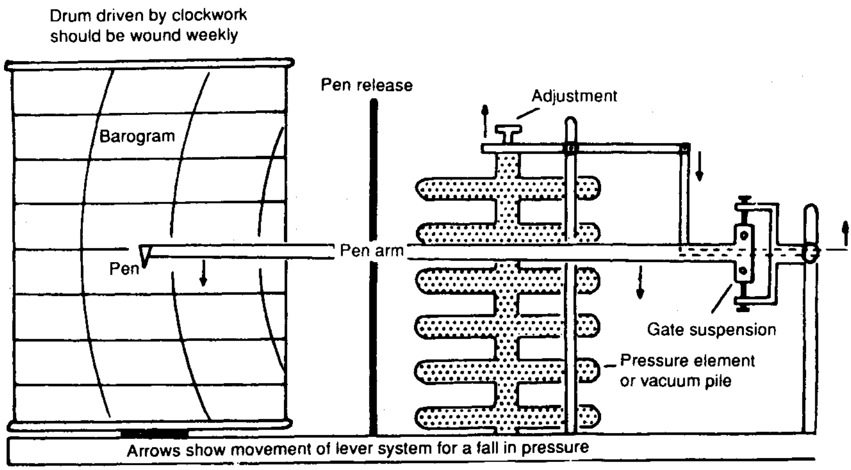


Figure 6 Barograph

The thermometer, in its simplest form, consists of a capillary tube on the end of which is a bulb filled with mercury. This thermometer is graduated (as are all others) by placing it in pure melting ice and marking the position of the mercury, then placing it in boiling distilled water and again marking the position of the mercury. The barometric pressure in each case should be 760 mm (30 in) of mercury. These two points are known as the fixed points of the thermometer. The part of the tube between these points is then divided into a number of equal divisions.

The number of divisions depends on the scale to be used. The various scales are shown below.

	Water freezing point temperature	Water boiling point temperature	Scale divisions
Celsius (°C)	0	100	100
Absolute or kelvin (K)	273	373	100
Fahrenheit (°F)	32	212	180
Réaumur (°R)	0	80	80

Conversions from one scale to another can be made quickly as:–

Celsius	=	(°F − 32°) × 5/9
Fahrenheit	=	(°C × 9/5) + 32°
Absolute	=	°C + 273°
Réaumur	=	°C × 4/5

It may be noted that at −40° the Celsius and Fahrenheit scale readings are the same.

The specific heat of a substance is the number of joules required to raise 1 kg of the substance 1°C, e.g. water is 4.182 whereas sand is 0.84, which means that a given quantity of sand will heat 5 times as much as the same quantity of water provided the same amount of heat is applied. It will also cool 5 times as quickly under similar conditions.

An isotherm is a line joining places having equal temperature.

In measuring **air temperature**, the thermometer should be placed out of the direct rays of the sun and away from local draughts or warm air currents. **Ground temperature** is taken at shore stations only, the thermometer being placed horizontally 50 mm (2 in) above the ground.

Sea temperature may be taken with a thermometer, specially guarded against breakage, set inside a canvas bucket and trailed in the sea. However, the more common method is to get a canvas bucket full of the surface water and push the thermometer into the bucket after it has been brought up on deck. In both cases the water must be from the surface and preferably well forward so as to be clear of all discharges.

Dew point temperature is the temperature to which the air has to be cooled for the water vapour to condense out into water droplets. It is also known as the **saturation temperature**, and is dependent on the absolute humidity.

Absolute humidity is the actual weight of water vapour in a parcel of air and is expressed in grams per cubic metre. The greater the air temperature, the more water vapour it can absorb before becoming saturated. **Relative humidity** is the ratio between the amount of water vapour in the air and the amount that it can contain at that temperature. It is usually expressed as a percentage.

Maximum thermometer (Figure 7)

This is usually used at shore stations in order to record the maximum daily temperature. There are two types, one having a constriction in the tube (as with a clinical thermometer) and the other with an index in the bore. With this latter type the mercury pushes the index up the tube when the temperature rises and when it falls the index is left in position. The maximum temperature is read at the end of the index nearest to the mercury. Mercury is used as it has a high boiling point.

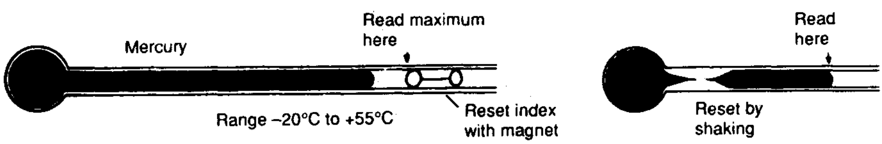


Figure 7 Maximum thermometer

Minimum thermometer

Like the maximum thermometer, this is generally used at shore stations to record the minimum daily temperature. The liquid is usually alcohol as this has a low freezing temperature. The index is immersed in the alcohol and, as the temperature falls and the alcohol contracts, the surface tension of the alcohol draws the index down the tube. As the temperature increases the alcohol is free to flow past the index. The minimum temperature is read at the end of the index nearest the open end of the alcohol.

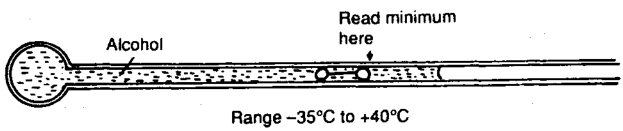


Figure 8 Minimum thermometer

Six's thermometer (Figure 9)

This is a useful little instrument which incorporates a maximum and minimum thermometer and is much used by gardeners. The expansion of the alcohol in the round bulb, as the temperature rises, forces the mercury round towards the pear-shaped bulb, and in turn forces the index up the tube. The converse occurs when the temperature falls. The maximum and minimum temperatures are read at the ends of the indices nearest the mercury.

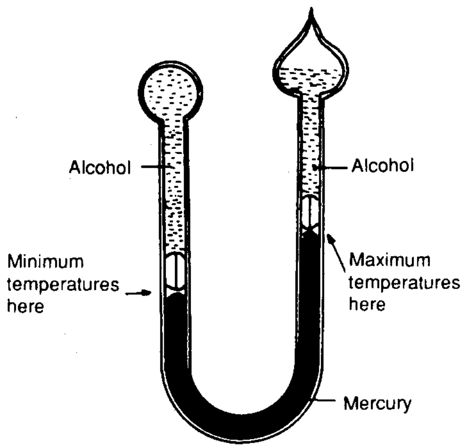


Figure 9 Six's thermometer

Thermograph

This recording thermometer is not often seen aboard ship. A pen, attached to a metallic coil which expands and contracts, records the temperatures on a drum moved by clockwork.

Psychrometer or hygrometer

Mason's hygrometer consists of two thermometers mounted side by side in a Stevenson's screen. One is a dry bulb thermometer, the other a wet bulb thermometer.

Cambric is wrapped round the bulb of the latter and it is kept moist by means of a piece of cotton wick leading to a container of distilled water. The evaporation of water requires heat and this is taken from round the wet bulb which, unless the air

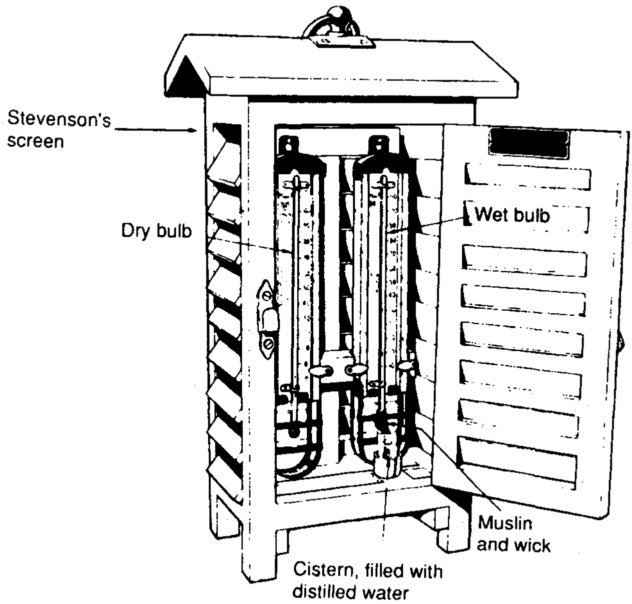


Figure 10 Psychrometer

is saturated, shows a lower reading than the dry bulb. The screen and thermometers should be hung up to windward away from local draughts or warm air currents.

More accurate readings can be obtained by using a whirling psychrometer. This looks rather like a football rattle. The whirling ensures a steady flow of air over the two bulbs.

By entering tables with the dry bulb temperature and the difference between the wet and dry bulbs as arguments the dew point and relative humidity can be found.

Wind-measuring instruments

These are rarely found aboard ship although every shore station has one.

The Robinson cup anemometer (Figure 11) consists of four hemispherical cups fixed to the ends of rods set 90° from each other in a horizontal plane. The spindle, to which the rods are attached, is connected to a tachometer and from the number of revolutions made in a given time the 'run' of the wind can be calculated.

The Dines are anemometer (Figure 12) works on the U-tube principle, whereby the wind blowing in one side forces liquid round the bend of the U. The actual

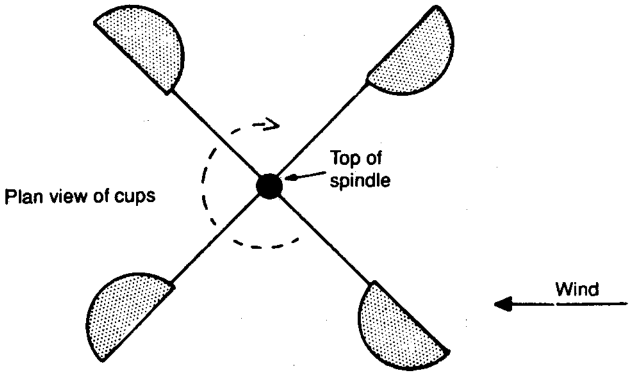


Figure 11 Robinson cup anemometer

instrument is very much more refined, and usually, there is a revolving drum fitted so that the recorder arm can make a continuous record; the anemometer then becomes an anemomograph.

Besides the two principal anemometers mentioned above, there are several smaller types, some of great accuracy, others not so accurate.

Rain gauge

This is infrequently found aboard ship but will be found at all shore stations.

It consists of a cylinder 130 mm (5 in) in diameter, having inside a small jug. The rain is collected in this jug by means of a funnel, which also prevents the rainfall evaporating.

To measure the rainfall, the water is poured from the jug into a measuring glass which is graduated in millimetres or hundredths of an inch.

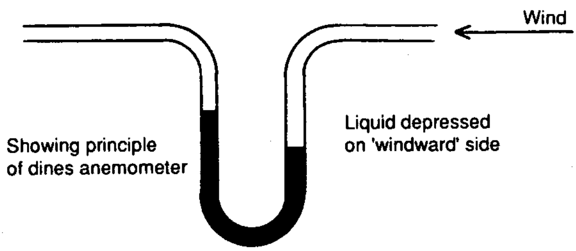


Figure 12 Dines anemometer

Snowfall is measured with a ruler and it is reckoned that 300 mm (12 in) of snow is the equivalent of 25 mm (1 in) of rain.

An **Isohyet** is a line joining places having equal rainfall.

Sunshine recorder

This is found at all shore stations and at most coastal resorts but not aboard ship.

In the Campbell–Stokes sunshine recorder, the sun's rays are focused by means of a glass sphere onto a piece of sensitized paper which discolours when the sun shines. The hours of sunshine can then be counted up.

An **isohel** is a line joining places having equal sunshine.

Hydrometer

Although hardly an instrument for foretelling weather in the usual sense, the hydrometer can none the less be valuable in helping to decide which currents may be influencing the vessel.

The hydrometer works on Archimedes' principle that a floating body displaces its own weight of the liquid in which it floats. It consists of a float chamber through which passes a stem, the lower end of which is weighted so that it floats upright. The

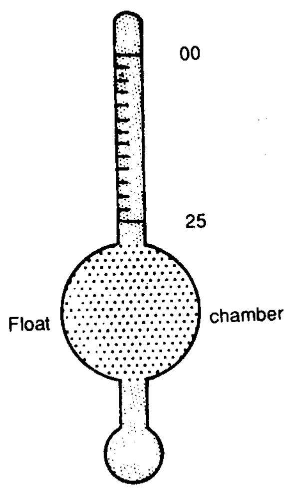


Figure 13 Hydrometer

upper end is graduated to read the density of water. The instrument is frequently made of glass, although polished steel hydrometers are more robust. Whichever type is used, the surface should always be kept clean.

Salinometer

This is a similar instrument to the hydrometer, differing only in the graduations, which are parts of salt per thousand (‰).

An **isohaline** is a line joining places having equal salinity.

The radio-sonde

This is a miniature radio station which is carried into the air by a large hydrogen-filled baloon. Attached to the transmitter are an aneroid barometer, a thermometer and a hygrometer, and readings of these are radioed back to the point of release (frequently an ocean weather ship). The upper wind velocity and direction may also be found when the radio-sonde is tracked by radar.

Nephoscope

This instrument is used to find the velocity/height ratio of cloud. If the height is known, the velocity is known, and vice-versa.

There are two main types; one, the Besson's comb nephoscope, looks rather like a garden rake and here the time of passage of a cloud between the spikes is noted.

In the Fineman reflecting nephoscope the time of passage of the cloud's reflection between rings on a horizontal mirror is noted.

An **isoneph** is a line joining places having equal cloud amounts.

CHAPTER TWO

The Atmosphere

Most of the weather changes take place in the lower layer of the atmosphere which is known as the **troposphere.** This layer extends about 11 miles high over the equatorial regions and about 5 miles high over the polar regions. The layer above the troposphere is known as the **stratosphere,** where there is little water vapour and the lower part appears to be isothermal. There is a rise in temperature towards its upper limit. The boundary between the troposphere and the stratosphere is known as the **tropopause.** About 20 miles above the Earth the stratosphere gives way to the **ozonosphere,** where there is a high concentration of ozone which absorbs ultra-violet radiation. The **ionosphere** starts about 50 miles above the Earth and this is the layer that contains the various radio wave reflecting areas known as the Kennelly–Heaviside (55 miles) and Appleton (150 miles) layers. See Figure 14.

The density of the atmosphere decreases with height and high-flying aircraft must be pressurized to avoid severe discomfort to passengers. Oxygen is also rarer at the higher levels and oxygen masks must be worn in non-pressurized craft. Approximate

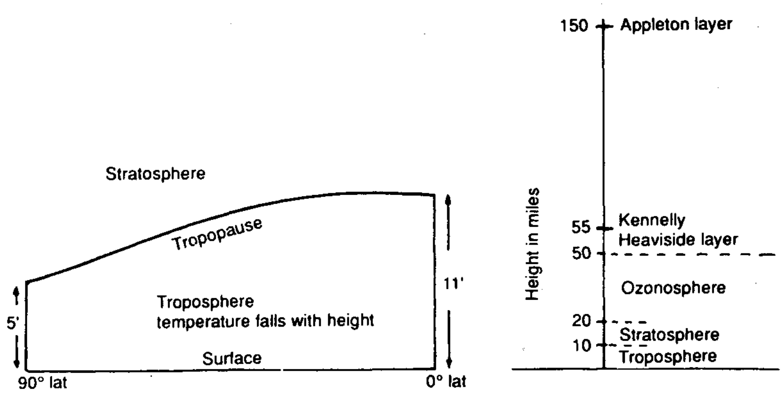


Figure 14 The layers of the Earth's atmosphere

percentage volumes of the various gases forming dry air in the troposphere may be of interest to the reader: They are nitrogen 78%, oxygen 21%, argon 0.9%, carbon dioxide 0.03%, with the balance being made up of traces of hydrogen, helium, neon, krypton, radon, xenon and ozone.

As most of the weather changes take place in the troposphere, it is in this region that the changes in temperature are most important.

The sun, at a distance of about 93, 000, 000 miles and at a temperature of about 6000°C, is the principal source of light and heat for the Earth. The heat from the sun travels to the Earth in the form of short wave radiation, which passes through the atmosphere without appreciably warming it. On striking the Earth, some of the heat will be absorbed to warm the Earth. The heat received at the Earth from the sun is known as **insolation.**

The amount of insolation per unit area varies with latitude. It can be seen in Figure 15 that a band of rays has to heat a very much larger area in a high latitude than it does in a low latitude.

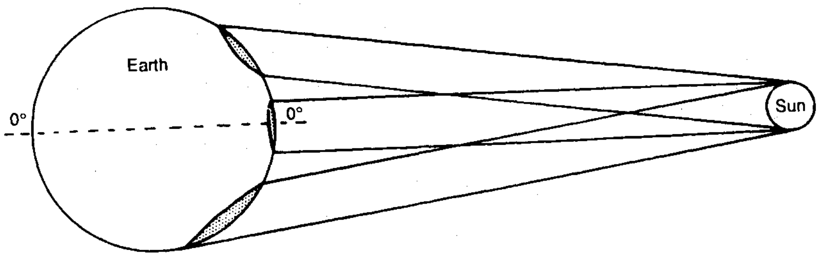


Figure 15 Insolation at different latitudes

The increase in the temperature of the Earth will depend, amongst other things which will be discussed later, on the amount of insolation and the specific heat of the Earth. Assuming that the insolation is constant, a surface with a high specific heat warms and cools less quickly than a surface with a low specific heat. For instance, the sea temperature in non-tidal waters hardly changes in the 24 hours. A contributing factor to this small change is its depth. It will be found that, in general, sea temperatures are less than the temperatures of adjacent land by day and greater by night. There is a similar difference in summer and winter. The amount of insolation will depend on the sun's altitude and the degree of cloud cover. It may be noted that the **solar constant,** which is the intensity of solar radiation at the outer boundary of the atmosphere, is 1.39 kW/m^2.

The height of the station under consideration above sea level will be a factor influencing the heating, as will the prevailing wind. Air which has flowed over warm surfaces will have a smaller cooling effect than air which has flowed over cold surfaces.

As the Earth is a warm body, it radiates heat. This radiation will cool the surface. If the Earth is radiating heat at a greater rate than it is receiving it, the net result will be a cooling of the surface. The converse is also true.

In Figure 16 the curves of insolation and radiation are shown to increase and decrease at a regular rate, for ease of illustration. Quite clearly the temperature falls until point A is reached, when it begins to rise. The rise continues to point B and then, once again, the temperature falls. It will be noted that the lowest temperature occurs shortly after sunrise, whereas the maximum temperature occurs about 1400 hours local time, i.e. not at the maximum and minimum of insolation. A similar lag takes place on an annual basis. In northern latitudes the lowest temperatures do not usually occur until February and the maximum temperatures occur in July and early August. The sea temperature lags even further behind the sun, the minimum occurring in March and the maximum in September.

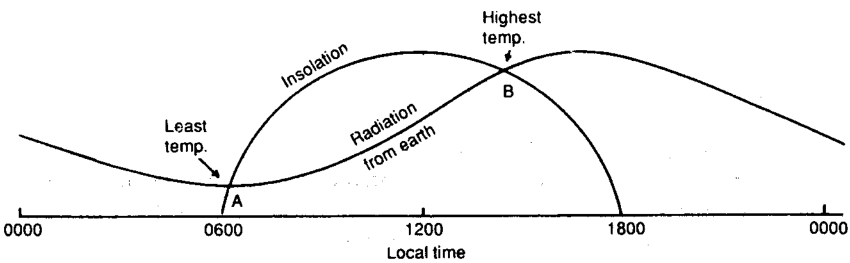


Figure 16 The effects of insolation and radiation on temperature

It must be understood that all the above general statements can be considerably modified by local weather conditions, particularly cloud amounts.

The foregoing has described the process by which the Earth is heated, but what about the air surrounding it? Heat is transferred to it by one or more of the following means:

Radiation
Conduction
Convection
Turbulence

Radiation

As previously mentioned, the heat rays from the sun are in short wave form which pass through the atmosphere causing very little heating. Some heating will occur as water vapour in the atmosphere absorbs heat.

The heat rays from the Earth are in long wave form, which tend to warm the lower layers of air. If the sky is cloudless, most of the Earth's radiated heat will go to outer space. However, if there is a cloud cover, most of the heat will be reflected back to Earth. The cloud acts as an insulator for the Earth.

The heat radiated from the Earth on cloudless nights is considerable and a great deal of surface cooling takes place.

Conduction

The heat is transferred from particle to particle. Thus, air which is in contact with a warm surface is warmed; this occurs by day when the sun is shining. Air which is in contact with a cold surface is cooled; this occurs on clear nights. Air masses (see Chapter 5) acquire their characteristics by the same process.

Convection

Air which is warmed expands and consequently its density decreases. This makes it lighter than the unwarmed air surrounding it and the warm air rises. Convectional processes take large amounts of warm air and water vapour from the surface to the upper levels. When the water vapour condenses into water drops and precipitation occurs, the latent heat remains. Most of the atmospheric heating takes place in this way.

Conversely, air which is colder than the surrounding air has a greater density, and as it is heavier, it sinks. An example of this is the Katabatic wind (see Chapter 4).

Turbulence

Air which flows over a rough surface tends to be deflected upwards. The rising air will be replaced by some air from levels up to 600 m (2000 ft), giving an interchange of air between the surface and 600 m (2000 ft). The rising air carries its warmth (acquired by conduction) with it, and the falling air brings its coolness.

Lapse rate

Increase of height above sea level generally means a decrease of temperature. The rate at which the temperature changes with height is known as the **lapse rate**, an average value being about 0.7°C/100 m (3°F/1000 ft).

Environment lapse rate

The lapse rate can vary and the **environment lapse rate** will be referred to when a particular air mass is under consideration. This rate will be dependent on many factors and will vary with the altitude, although it is usually between the SALR and DALR (see below). Plotting temperatures of the air at various heights will give environment curves.

Adiabatic temperature change

If a volume of air rises to a region of lower pressure, the volume will increase and, following the gas laws, the temperature of the volume will fall. The converse will occur if the air falls to an area of greater pressure. The change of temperature is solely due to expansion or contraction and no heat has been given to or received from adjacent air. This change of temperature is known as an **Adiabatic temperature change.**

Dry adiabatic lapse rate (DALR)

When dry air is forced to rise, it has been found that it decreases in temperature by 1°C/100 m (5.4°F/1000 ft) and this is known as the **dry adiabatic lapse rate.** With dry air which is forced down, an increase at a similar rate is found. Dry air is any air which is not saturated.

Saturated adiabatic lapse rate (SALR)

Latent heat is the heat necessary to change, for instance, 1 kilogram of water to 1 kilogram of vapour at saturation temperature. If a quantity of water changes to vapour, an amount of latent heat will have been required. This sort of thing will happen with air at a temperature above dewpoint (it should be noted that the higher the air temperature, the greater is the amount of water vapour that it can hold). Now the latent heat that has been required to change the water to vapour is not lost, as, when the air is cooled to its saturation or dew point temperature, the water vapour condenses into water droplets and the latent heat is released. This is the latent heat of condensation.

When the cooling of the air to its dewpoint temperature is caused by the air rising, the latent heat released will modify the overall cooling rate.

For rising air:

DALR	− 1.0°C/100 m	
Latent heat	+ 0.5°C/100 m	(average for near surface in middle latitudes)
SALR	− 0.5°C/100 m	(2.7°F/1000 ft)

The SALR is a variable quantity depending on the latent heat of the condensing water vapour. The SALR is low near the equator and high in polar regions. It will also increase with height.

Stable air

If air which has been forced to rise (or fall) from its initial level tends to return to that level, it is said to be stable. This condition occurs when the environment lapse rate is less than the SALR.

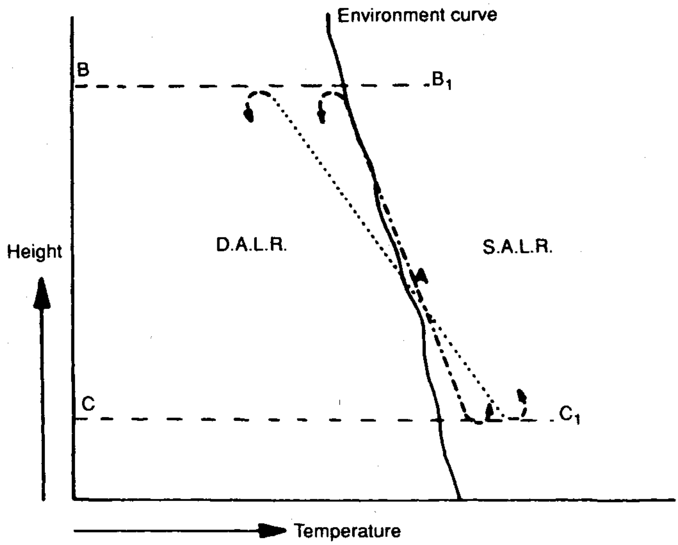


Figure 17

Figure 17 shows by an unbroken line the environment curve of some tropical air, whose lapse rate is about 0.3°C/100 m (2°F/1000 ft). Suppose some dry air at point A is forced upwards, it will cool at the DALR, and follow the dotted line. When the rising air reaches the level BB, it will be much colder than the environment or surrounding air. As it is colder it is denser, and will want to return to A, a tendency shown by the arrow. If instead of the air rising from A, it fell, then at the level CC_1 the falling air would have warmed adiabatically to a considerably higher temperature than the environment or surrounding air. It would then be less dense and the tendency would be for it to return to A as indicated.

If the air forced to rise or fall from A was saturated instead of dry, the path indicated by the dot/dash line would be followed. Again, for the same reasons as are given above, the tendency is for the air to return to A.

Unstable air

If air which has been forced to rise (or fall) from its initial level tends to continue its upward (or downward) movement, it is said to be unstable. This condition occurs when the environment lapse rate is greater than the DALR.

Figure 18 shows by an unbroken line the environment curve of some polar air whose lapse rate is about 1.2°C/100 m (6.0°F/1000 ft).

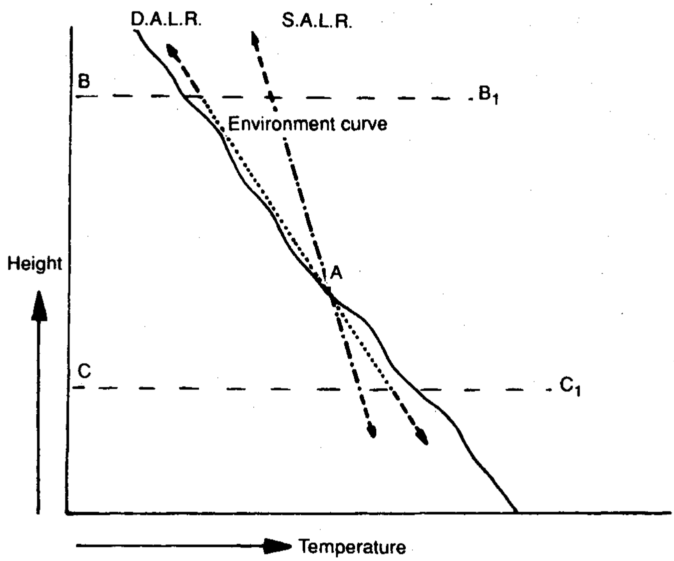


Figure 18

Suppose some saturated air at point A is forced upward, it will cool at the SALR and follow the dot/dash line. When this rising air reaches the level BB, it will be warmer than the environment or surrounding air. As it is warmer it will be less dense and the tendency is for it to continue upwards. If, instead of the air rising from A, it fell, then at the level CC_1 the falling air would be at a lower temperature than the environment or surrounding air. It would then be denser and it would continue to fall.

If the air forced to rise or fall from A was dry instead of saturated, the path indicated by the dotted line would be followed. Again, for the reasons given above, the rising or falling air continues to rise or fall.

Neutral air

This condition occurs when the environment lapse rate is the same as the DALR if dry air is under consideration, or the SALR in the case of saturated air. The air which has been forced to rise or fall will have no tendency to continue its upward or downward movement, nor will it have any tendency to return to its original position.

Conditional instability

This occurs when stable conditions exist for dry air and unstable conditions exist when the air is saturated. Figure 19 illustrates this. The environment curve has a lapse rate between the SALR and the DALR. The dotted line, representing dry air forced up or down, follows a similar pattern to Figure 17, whilst the dot/dash line representing saturated air forced up or down follows a similar pattern to Figure 18. This conditionally unstable condition is quite common, the air below the condensation level being stable and that above being unstable.

Temperature inversion

The usual tendency for the temperature to fail with height is sometimes reversed. When the temperature increases with height, an inversion is said to exist. An inversion also exists if a layer of air is isothermal.

Inversions may occur at any level at all. They frequently occur at ground level on clear nights. They also occur just above cloud layers.

As an inversion gives rise to very stable conditions, convection and turbulence are damped out and there will be no upward movement of air through the inversion.

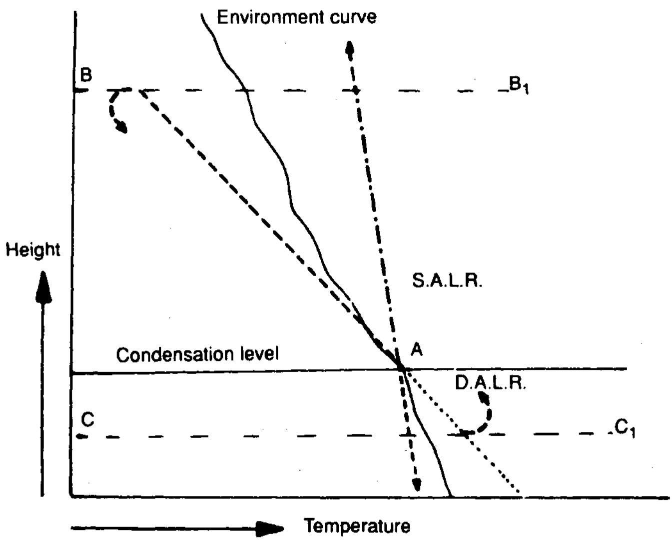


Figure 19

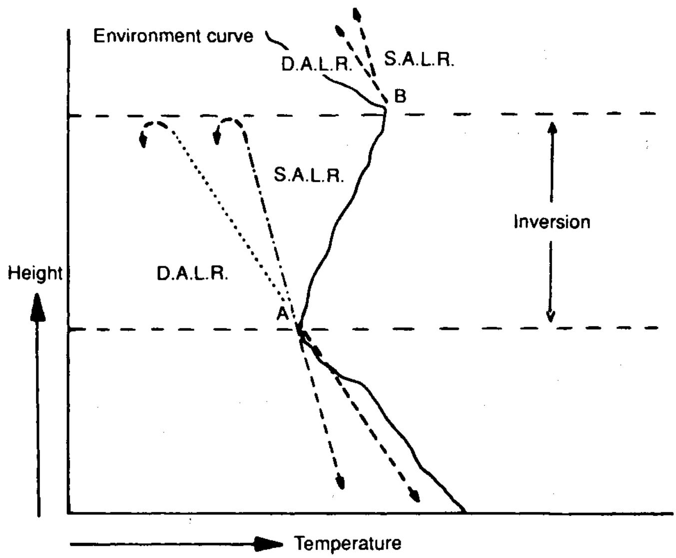


Figure 20

Inversions may be caused in anticyclonic conditions by subsiding air warming adiabatically to a temperature above that of the lower layers of air.

Figure 20 shows a curve for the environment where there is an inversion above the surface. Dry and saturated air forced up from A will clearly return showing stable conditions, whereas if forced up from B (or down from A) unstable conditions exist.

Tephigram

For accurate forecasting, a knowledge of upper air conditions is essential. If upper air temperatures are known (from radiosonde measurements) the other conditions can be deduced from a tephigram.

The tephigram is a graticule formed by plotting a series of straight lines representing temperature, water vapour content and dry adiabatics (also called lines of constant potential temperature) against curves (almost horizontal straight lines) which indicate height–pressure for a standard condition of the atmosphere (known as the ICAN atmosphere). Also included on the graticule are curves to show saturated adiabatics for the same standard atmosphere. Such curves are shown on Metform 2810 but they are unlikely to be found aboard ship.

CHAPTER THREE

Cloud and Precipitation

When air is cooled below its dewpoint the water vapour therein starts to condense out into water droplets. The water droplets form either fog or cloud, depending on the process by which the air is cooled. It is generally understood that the fog is formed when the cooling of the air takes place at the surface by conductive processes, whereas cloud generally forms above the surface due to the adiabatic cooling of the rising air. The cooling of the air occurs as the air is forced to rise as follows:

(a) at a warm front
(b) at a cold front
(c) by convectional processes
(d) by high ground
(e) by turbulence

Cloud

Contributory causes in cloud formation may be:

(i) radiation of heat by water vapour in the atmosphere
(ii) mixing of two masses of nearly saturated air at different temperatures.

Table 3.1 *Types of cloud (see Figure 21)*

Class	*Stratiform (Stable air conditions)*	*Free convective (Unstable air conditions)*	*Limited convective (Air conditions tending to be unstable)*
Low	Stratus (St) Nimbostratus (Ns)	Cumulus (Cu)	Stratocumulus (Sc)
Medium	Altostratus (As)	Cumulonimbus (Cb)	Altocumulus (Ac)
High	Cirrostratus (Cs)	Cirrus (Ci)	Cirrocumulus (Cc)

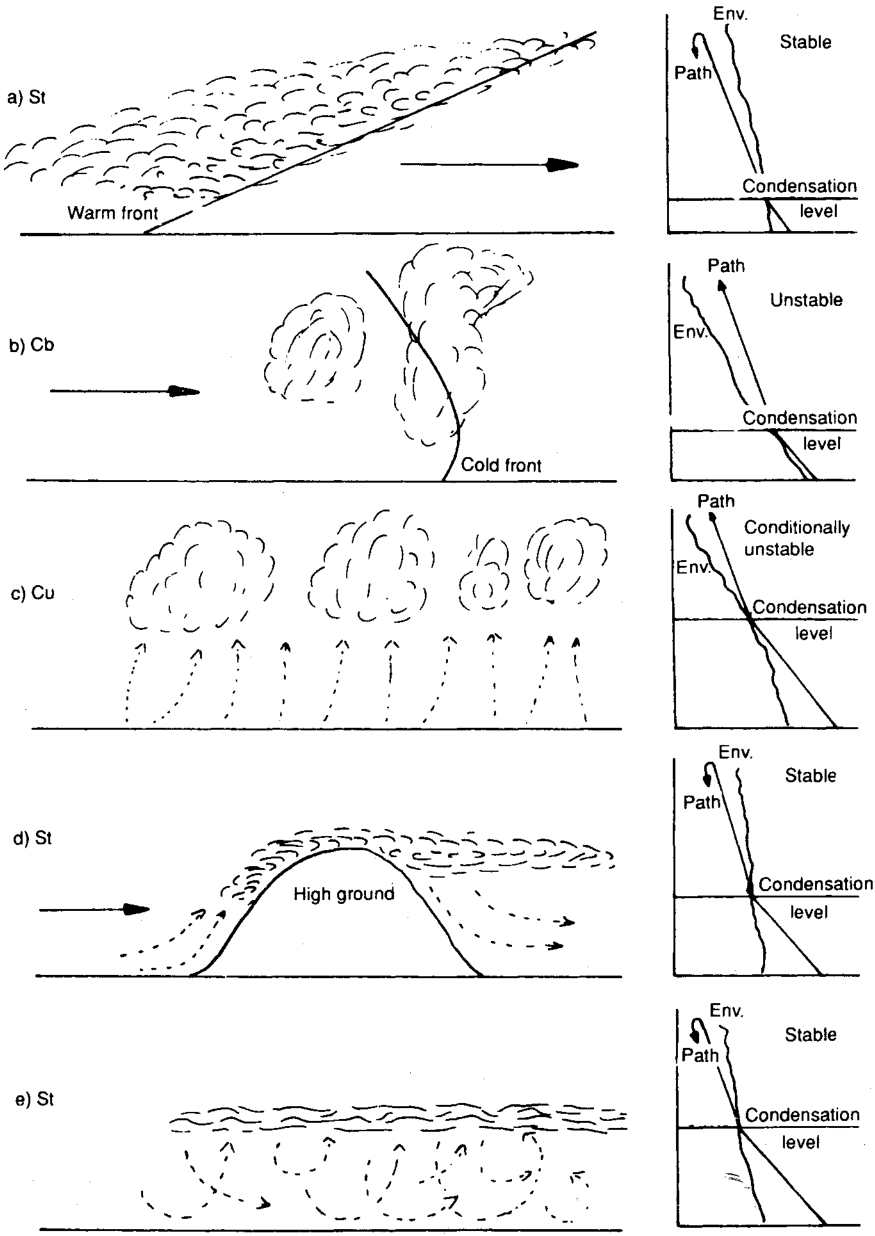


Figure 21 Cloud types

Clouds are classed as being either high, above 6000 metres (20 000 ft); medium, 2500–6000 metres (8000–20 000 feet); or low, below 2500 metres (8000 ft).

There are several types in each class, the main ones being shown in Table 3.1.

Other forms of cloud include:

Fractostratus or scud. Fracto means broken and may be applied to other types of clouds besides stratus.

Lenticularis. Indicates clouds of lens or airship shape.

Castellatus. Here the tops of the cloud may extend vertically to form 'castles'. This often occurs with altocumulus.

Mammatus. The lower side of the cloud projects to form festoons. Not very common, but may be found with unstable conditions, where there are strong down as well as up currents.

The water vapour mentioned earlier cannot condense into large-size water drops unless condensation nuclei are present. These nuclei, which may be salt or dust particles, are always present although the numbers will vary from about 1000 per cm^3 over the sea to about 150 000 per cm^3 over industrial areas.

Water drops of less than 0.1 mm diameter cannot reach the ground as they evaporate on the way. These drops are cloud drops and their average diameter is 0.01 mm.

Drops over 0.1 mm are drizzle drops and over 0.5 mm are raindrops. The maximum size to which a drop can grow is 5.5 mm. The process of growth of these water drops has brought forth many theories, one of which is that in the original stages of condensation, some drops form larger than the rest are formed. Their growth, due to the attraction of the smaller drops, is then assured.

Another theory is that for growth to take place, part of the cloud must be above the freezing level, in which case the ice crystal will grow at the expense of water drops (see Figure 22). When these get sufficiently large they will fall through the cloud, warming and melting as they fall, until they arrive at the lower level as rain. This is known as the **Bergeron process.** It should be noted that the freezing level over the British Isles is about 1000 m (3000 ft) in winter and about 2500m (8000 ft) in summer. This latter theory would account for the tendency to greater rainfall in winter than in summer.

Rain

Rain is usually described as being either frontal, convectional or orographic. This is in accordance with the process of cloud formation. Appreciable rainfall is unlikely with turbulent cloud. **Frontal rain** occurs at a warm front. The precipitation commences from altostratus cloud and increases in intensity as the lower nimbostratus cloud comes in.

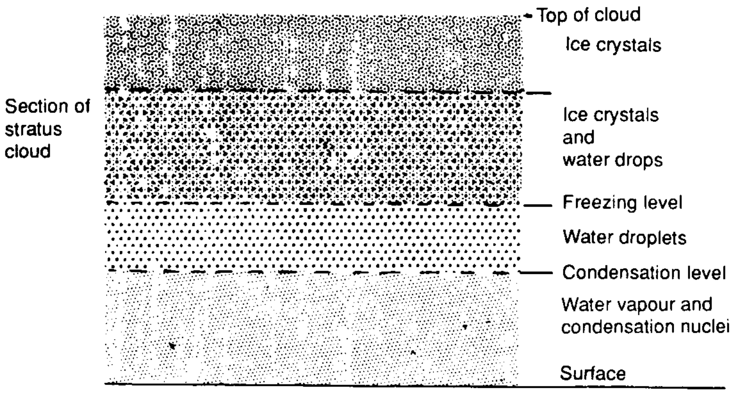


Figure 22 The Bergeron process

Where the front is not so marked, **occasional precipitation** may occur. This has the same characteristics as frontal rain and lasts less than 30 minutes.

Convectional rain falls when the strong up-currents, within the cumulus-type cloud, cease or are so reduced that they can no longer keep the raindrops within the cloud (see Figure 23). It may be noted that an up-current of 8 m/s (25 ft/ps) will keep the maximum-sized raindrops from falling. If this velocity is slightly reduced, only the largest-sized drops will fall and the smaller drops will remain in the cloud. A feature of convectional-type rain is that rainfall always starts heavily and often with little warning. Another name for convectional rain is showers. These last less than 30 minutes, although showers frequently merge to give a period of prolonged rainfall.

Orographic rain falls on the weather side of mountain ranges and gives some of the heaviest rain known.

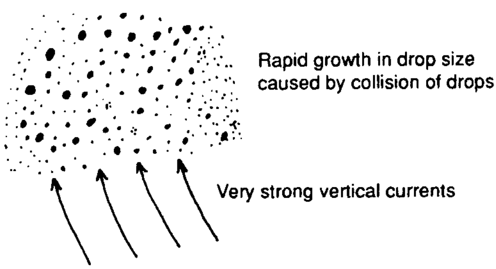


Figure 23 The formation of convectional rain

Snow

When water vapour condenses at a temperature below freezing point, ice crystals form. These join together to form snowflakes. If the air temperature is much above freezing point the flakes will melt. In general the temperature near the surface must not exceed 3°C (37°F) for snow to fall. It should be understood that at temperatures less than 3°C rain is still very likely and is not necessarily replaced by snow.

Sleet is partially melted snow.

Storm clouds

The cumulonimbus cloud

This is a cloud of great vertical development formed in unstable conditions and may extend up to 13 000 m (40 000 ft) from a base which may be as low as 500 m (1500 ft).

The Cb cloud may be formed (i) at a cold front, (ii) at a mountain range, (iii) when there is considerable heating of the ground, or (iv) when cold air flows over a warm surface. However, by whichever method it is formed it will still have its characteristic appearance. Air currents at high levels may, and often do, produce an 'anvil' (see Figure 24). Within the cloud will be water drops and ice crystals and in between the two there may be supercooled water drops: these are water drops in their liquid state at a temperature below freezing. As long as they do not contact anything they can remain liquid at temperatures down to −40°. If, however, they touch anything, they immediately freeze into a globule of clear ice.

Hail

Due to the turbulence within the Cb cloud, ice crystals frequently contact the supercooled water drops. When this occurs the supercooled drop freezes to give a layer of clear ice round the ice crystal. This is the start of the hailstone, which will then grow as convection currents carry it through the cloud.

During this process the stone acquires alternate coats, one of clear ice (from the supercooled drops) and one of opaque ice (from the ice crystals). If a hailstone is cut open the various layers can be seen, and the number of times it has been carried up and down can be estimated.

When the hailstone can no longer be supported within the cloud it will fall to the ground. The hailstone varies considerably in size, being anything from 5 mm to 50 mm in diameter.

Thunderstorm

When raindrops reach their maximum size of 5.5 mm they break up. This splitting gives the air a negative electrical charge whilst the raindrop retains a positive electrical charge.

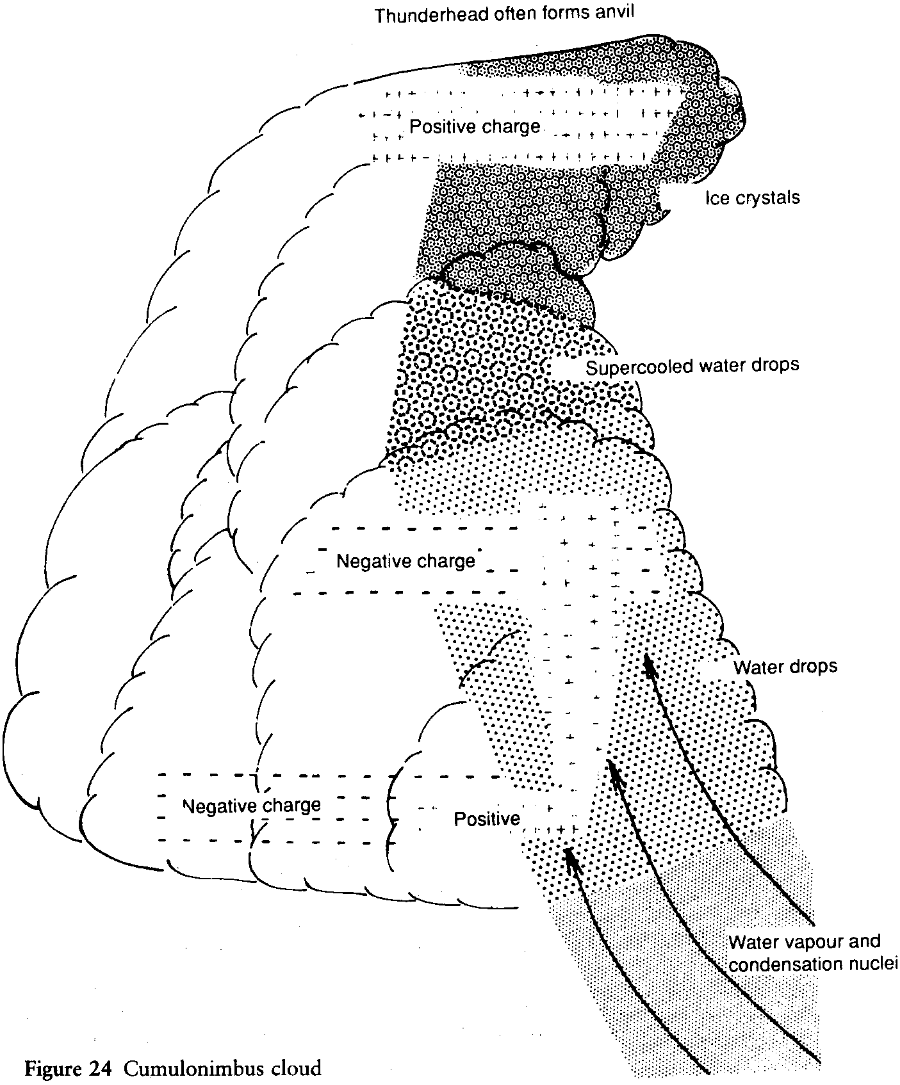


Figure 24 Cumulonimbus cloud

This action takes place within the Cb cloud and it is found that there is a large positive charge near the top of the cloud. At the bottom there is a large negative charge with a small positive charge due to the raindrops.

When there is sufficient difference of potential between the top and bottom of the cloud, or between two clouds, or between a cloud and the Earth, there is a visible electrical discharge which is called **lightning**.

When the PD is between the cloud and the Earth, the negative charge on the underside of the cloud induces a positive charge on the Earth. A leader stroke known as a stepped leader finds a path from the cloud to a point near the Earth when an upward stroke from the Earth comes up to meet it. This up-stroke continues along

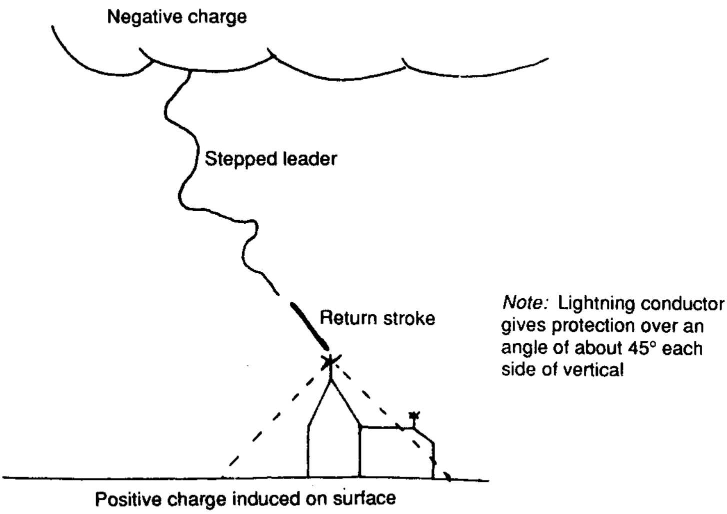


Figure 25 Lightning strike

the ionized path made by the stepped leader. There will probably be many up and down strokes in the space of a microsecond or so, each striking the same place. A lightning conductor concentrates the charge and ensures that the lightning will be discharged without damage to the building. In any place the upward stroke is likely to originate from the highest point in the vicinity of the downward leader. Ships will not suffer any damage when struck by lightning, as the charge will go directly to earth. If vessels have wooden topmasts, lightning conductors properly bonded to earth must be fitted to them.

The intense heat generated by the lightning spark causes the air to expand rapidly with the resultant noise called **thunder**. The noise lasts a considerable time compared with the duration of the lightning, mainly because of the difference in speed of light,

300×10^6 m/s (186 000 miles per second), and sound, 335 m/s (1100 ft/s). The sound may also echo from cloud or mountains. It may be noted that the sound of thunder is unlikely to travel more than about four miles, consequently much lightning may be seen without thunder being heard. This is particularly so at sea when lightning may be seen over 100 miles.

Storms occurring during the afternoon are nearly always due to heating of the surface. Storms occurring at other times are usually of the frontal type. Storms frequently occur off the east coast of N America and Siberia during the winter because of the cold continental air flowing over the relatively warm sea surface.

During thunderstorms a brushlike discharge may be seen emanating from masts, yards, aerials or stays. This discharge is due to electrical charges on these parts and is known as **st elmo's fire.**

Air cooled by conduction

So far the phenomena caused by air cooling through rising have been considered. If air is cooled below its dewpoint by conduction (i.e. contact with a cold surface) then the water vapour will condense into droplets on or near that surface. As noted in Chapter 2 the radiation from the Earth on cloudless nights will cause considerable surface cooling, with the possible deposit of water droplets if the air near the Earth is cooled until saturated.

Dew

Dew consists of the water droplets deposited on the surface by the above process. Clear skies and practically no wind are necessary conditions for its formation.

Hoar frost

Formation is the same as for dew except that the dewpoint temperature is below freezing. Hoar frost may also be formed by the freezing of water droplets which were deposited as dew.

Fog

Fog occurs when visibility is reduced to less than 1000 metres. There are different means by which fog is formed and these are detailed below.

Mist is similar to fog but here the visibility is 1000 m to 2000 m. It should be noted that **Haze**, giving the same visibility as mist, is formed of dust particles not water droplets.

Radiation fog occurs over land at night when radiation from the Earth has cooled its surface to below the dewpoint of the air adjacent to it. Conduction cools this air until condensation takes place. Slight turbulence (wind 3–7 knots) will carry this cold saturated air to higher levels and will bring to the surface drier air, which will in turn be cooled and saturated. As the process continues, the whole lower layer of air will become saturated. A temperature inversion is often associated with radiation fog, which, acting as a 'lid' keeps the fog low down and causes it to thicken. See Figure 26.

Stronger winds will disperse the fog, as will the heat from the sun, provided the fog layer is not too thick. In winter there is rarely sufficient heat to disperse fog and persistent fogs occur. If over industrial areas, **'smog'** frequently forms as the smoke from chimneys is trapped under the temperature inversion.

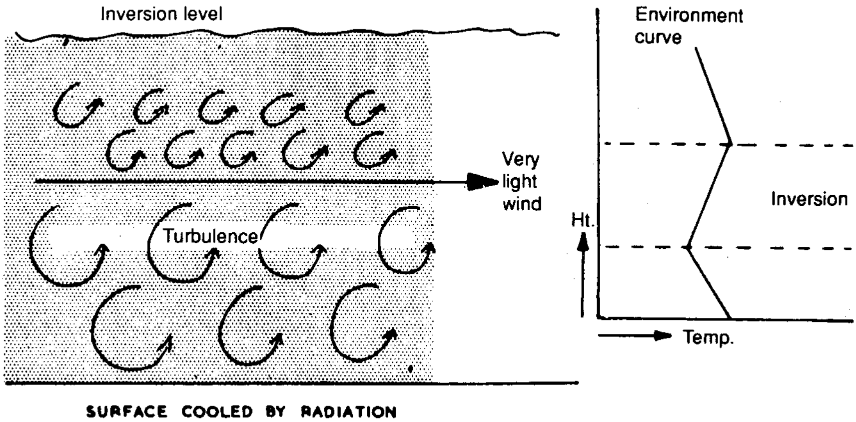


Figure 26 Radiation fog

This type of fog may occur overnight on the banks of rivers but usually disperses fairly quickly in the morning.

Advection fog occurs over the sea when warm tropical maritime air is cooled below its dewpoint by conduction from a cold sea surface. The likelihood of fog occurring may be judged if graphs of the air dewpoint temperatures and the sea temperatures are drawn and plotted against time. In the graph shown in Figure 27 fog is likely to occur about 2000 hours, if the present trends are maintained. A change of course to the southward would alter conditions considerably.

In general terms, fog is likely to occur if tropical maritime air crosses seven sea isotherms from its source.

Sea fog occurs mainly in the summer months in the following areas: British Isles, Banks of Newfoundland, west coast of North America, Japan, west coasts of South Africa and South America.

If reference is made to the current chart (Figure 79), it will be seen that the areas mentioned have cold sea currents flowing through them.

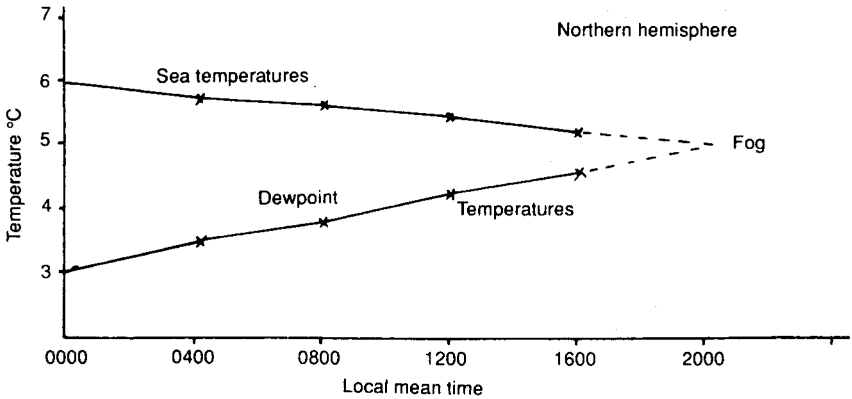


Figure 27 Advection fog formation

Sea smoke or arctic smoke

This occurs over the sea when the sea is warm compared with the air which flows over it. The air next to the water is warmed by conduction. This warmed air takes up water vapour before rising through the colder air above, where cooling condenses out the water vapour. The overall effect is that of visible steaming (Figure 28).

This frequently occurs in winter over rivers and also off the east coasts of continents.

Orographic fog

This is found on windward coasts. Its formation is the same as that of orographic cloud.

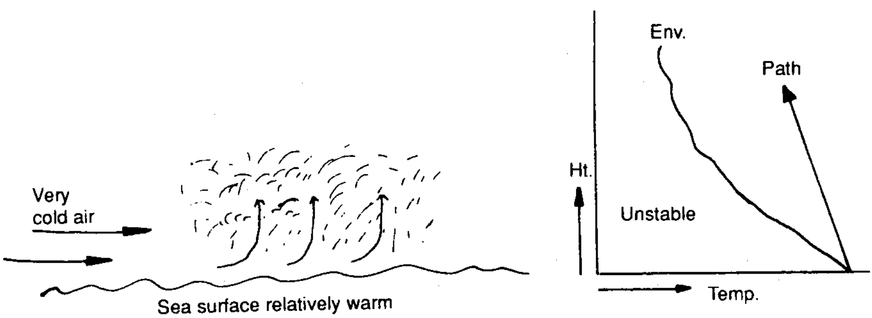


Figure 28 Sea smoke

Other phenomena associated with water drops

Rime

This occurs when supercooled water drops (often in fog) freeze into opaque ice on coming into contact with rigging on ships or trees or telegraph wires on land. The ice formed grows out to windward (Figure 29).

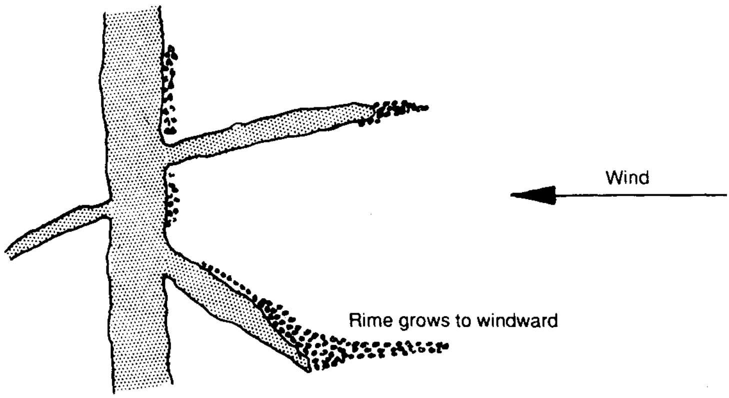


Figure 29 Rime formation

Glazed frost or black frost

This occurs when water drops fall onto a surface which is below freezing. A layer of clear ice is formed and this creates chaos on roads as the ice conditions cannot be seen. However, the effect at sea is much more serious as, if water falls onto decks, rigging and superstructures which are below freezing, the weight of the ice which forms can affect the stability so that the safety of the vessel is endangered. Although ice axes and steam hoses are partially effective in removing the unwanted ice, the only sure way of combating black frost is to steam into warmer conditions.

Optical phenomena

Various optical phenomena are associated with water vapour or ice crystals in the atmosphere, others being associated with dust particles. Some of the more common ones are described briefly below.

Aureole A brownish-red ring surrounding a bluish-white glow 2°–3° in diameter around the sun or moon. The light is diffracted by water drops. See Figure 30.

Bishop's ring A reddish-brown ring 10°–20° radius, occasionally seen round the sun with a clear sky. The light is diffracted by dust particles.

Corona A number of coloured rings round the sun or moon which appear outside the aureole. The radius is generally less than 10°, but this differs with the size of the water drops from which the light is diffracted. The smaller the drops, the larger is the radius of the corona. If colours are visible, violet will be nearest the sun and red away from it. Colour is rarely visible with lunar coronae.

Halo Occurs when light from the sun or moon is refracted through ice crystals. In its most common form it is a ring of 22° radius. When the colours can be distinguished, red is nearest to the sun and violet on the side of the halo furthest from the sun. A halo of 46° radius is sometimes seen. The difference in radii is due to the different angles which the faces of the ice crystal make with one another. See Figure 30.

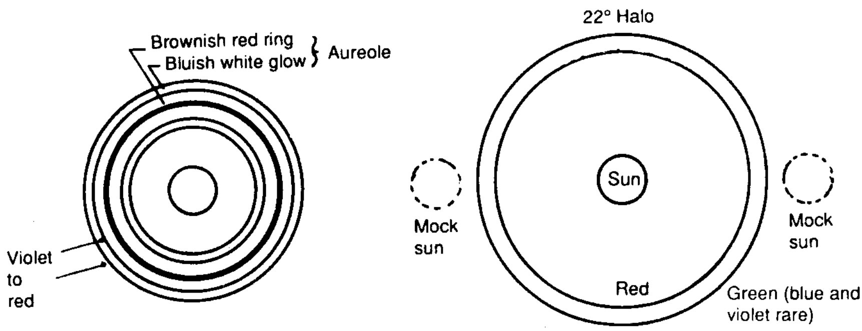


Figure 30 Corona (left) and halo (right)

Mock sun or parhelion This may form at the same altitude as the sun, about 22°–36° from the real sun. When coloured, red (as with the halo) is nearest the sun. Mock moons or paraselenae may also occur. The formation is by refraction of light through ice crystals.

Parhelic circle or mock sun ring This is another of the halo phenomena and is a white circle parallel to the horizon at the same altitude as the sun. Its width is about 1° and, under ideal conditions, it can be seen all round the horizon.

Rainbow This forms when light from the sun (or moon) enters a raindrop and is reflected from the far side. An observer looking towards raindrops with his back to the sun will see a rainbow radius about 42° provided that the sun's altitude does not exceed 42° (see Figure 31). The colours of a primary bow are red, orange, yellow, green, blue, indigo and violet, the red being on the outside. The secondary bow may form about 9° outside the primary. The colours of the secondary bow

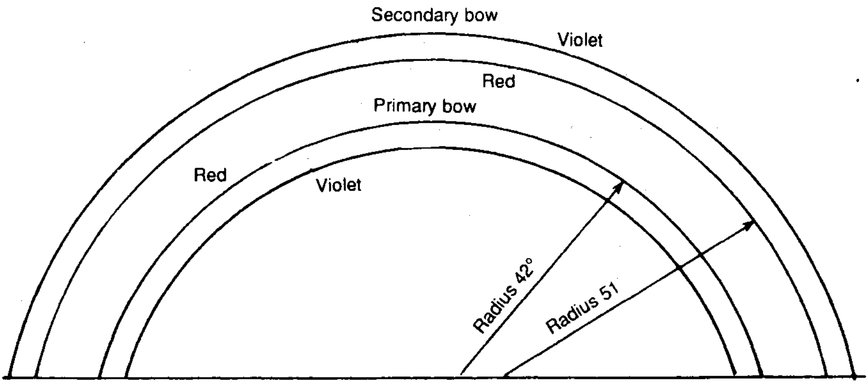


Figure 31 Rainbow

are in the opposite order to those of the primary. A secondary bow cannot form if the sun's altitude is more than 54°. The colours seen depend on the intensity of light and if the rainbow is formed by moonlight it will nearly always appear to be white.

Mirage

A well-known phenomenon which is unconnected with either waterdrops or dust particles is the **mirage**. This occurs when there is abnormal refraction. This may occur with a temperature inversion, particularly in the polar regions. With these conditions a distant ship may be seen in triplicate with one of the images inverted. Mirages formed when the air next to the ground is less dense than that above appear to cut off the bottom of objects so that land and ships appear to float in the air.

CHAPTER FOUR

Wind

Effect of pressure

Consider the two columns of air AB and CD in Figure 32. These are of equal cross-sectional area, height and temperature, so that the pressures at A and C are equal, as are those at B and D. Suppose the column AB is warmed: it will expand to AE, if the area remains constant, and although the pressure at A will remain unaltered, the pressure at B will have increased relative to that at D, and to equalize these air will flow from B to D. This transfer of air from column AB to CD will cause a drop in pressure at A and a rise at C, and air will now flow from C to A.

This illustrates the vertical circulation of air in that the outflowing or diverging air from C is replaced by subsiding air from above, whilst the inflowing or converging air at A escapes to the upper levels and there completes the circulation back to D.

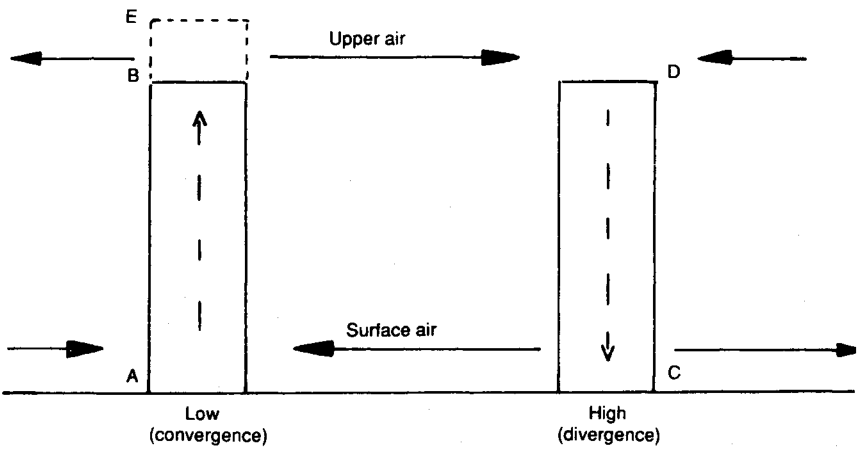


Figure 32 The vertical circulation of air

The rate of flow of air from C to A will depend on the pressure gradient (see Chapter 1) between C and A.

The movement of air straight from a high pressure to a low pressure only occurs either very close to the equator or in places where the high and low pressure areas are small and their centres are near to each other (see Land and sea breezes). Elsewhere, due to the rotation of the Earth, there is a deflective force which prevents the air flowing directly from high pressure to low. This force is known as the **geostrophic** or **coriolis** force.

Figure 33(i) is a view of the Earth from a point above the North Pole (Pn) whilst Figure 33(ii) is the Earth viewed from a point above the South Pole (Ps). In each case a parcel of air is sent from point A towards a point C in space. At the outset, point B on the Earth is in transit with A and C, but by the time the parcel of air reaches a point above B, B will have moved to B_1 due to the Earth's rotation. To an observer at B in the northern hemisphere the air appears to have been deflected to the right, whereas in the southern hemisphere it appears to have been deflected to the left.

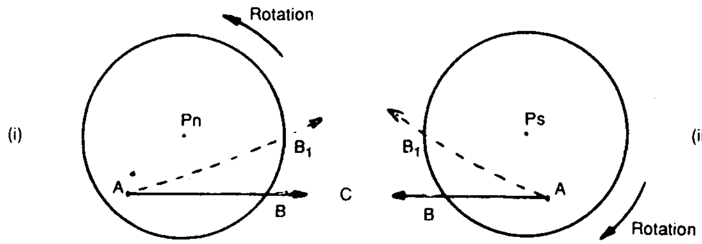


Figure 33 Effect of the Earth's rotation

The geostrophic force for any wind velocity is zero at the equator and maximum at the poles. Its force in any latitude increases with the wind velocity. It always acts at 90° to the direction in which the wind is blowing.

In Figure 34 a situation is shown where the isobars are running in parallel straight lines. The force P due to the pressure gradient starts the particle of air A moving towards the low pressure. The geostrophic force G acting at right angles to the existing direction of motion of the particle causes the particle to follow the curved path A, B, C. When the particle reaches C the forces G and P are equal and opposite and the wind is blowing parallel to the isobars. This is known as the **geostrophic wind.**

It can be seen from Figure 34 that if an observer faces the wind in the northern hemisphere, the low pressure lies to his right, whilst in the southern hemisphere the low pressure lies to his left. These facts were first propounded by Buys Ballot and are known as Buys Ballot's law.

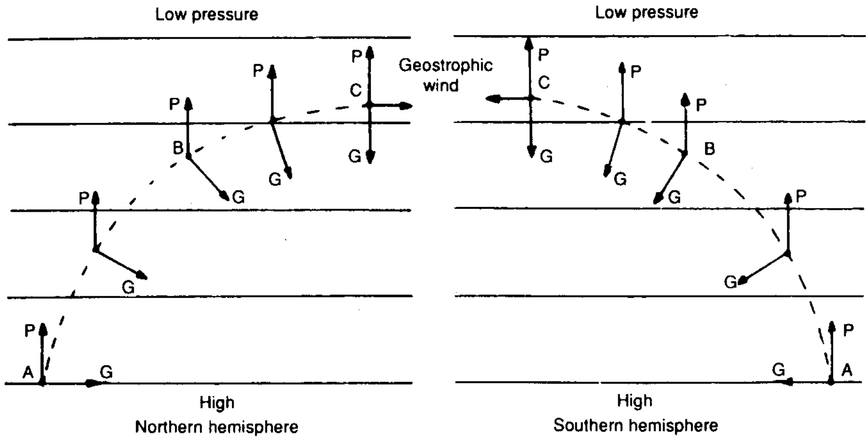


Figure 34 Geostrophic wind

If the pressure gradient is known, the geostrophic wind speed can be calculated from the formula

$$V_g = \frac{P}{2\rho\ \omega \sin\phi}$$

where V_g is the geostrophic wind speed
P is the pressure gradient
ρ is the density of air
$\omega\sin\phi$ is the rate of turntable motion in latitude 0.

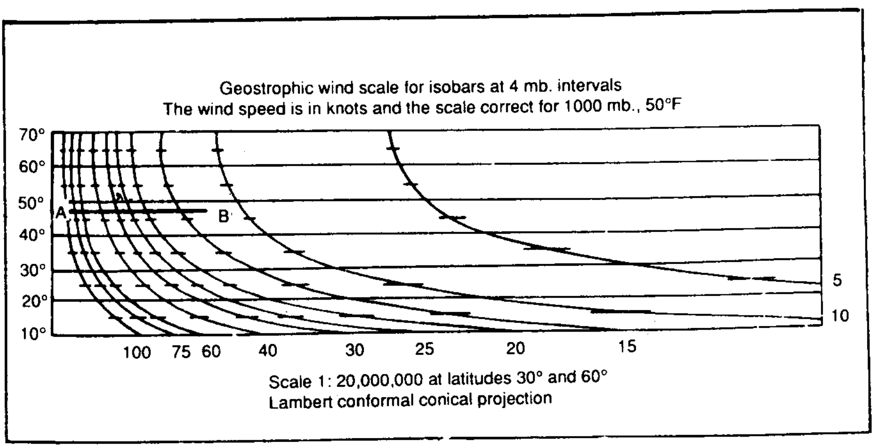


Figure 35 Geopstrophic wind scale

If a scale distance is to be used for isobar spacing, a diagram showing wind speeds for different pressure gradients can be drawn. Such a diagram is shown on Metform 1258 – the North Atlantic Plotting Chart – and is reproduced in Figure 35 with the permission of the controller of HM Stationery Office and the Director of the Meteorological Office.

To use the scale, take a pair of dividers and measure the perpendicular distance between isobars spaced at 4 millibar intervals at the required position on the plotting

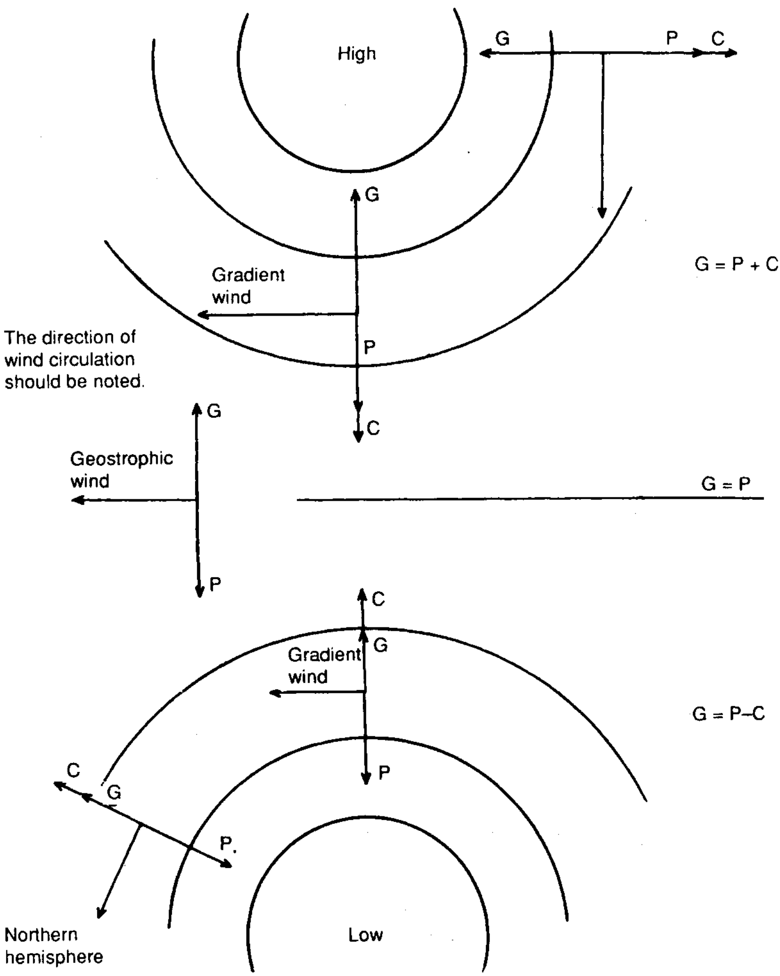


Figure 36 Cyclostrophic force

chart (i.e. after drawing the synoptic chart as detailed in Chapter 8). The distance is now transferred to the geostrophic wind scale so that one leg of the dividers is placed on the vertical scale on the latitude of the position, whilst the other will be at a point on or between the wind speed curves horizontally to the right of the vertical. Follow the curve down to the base line where the wind speed can be read off either directly or by interpolation.

For example, if the distance between isobars 4 mb apart in latitude 48°N is represented by AB, the geostrophic wind is 13 knots.

It must be emphasised that this is the geostrophic wind which blows at and above 600 m (2000 ft); the surface wind speed is about 2/3 that of the geostrophic.

It is useful to know that for equal pressure gradients the wind velocity in the tropics (lat. 15°) is three times as great as that in temperate latitudes (lat. 52°).

If the isobars are curved, as around a high or low pressure area, a further force will come into being. This force, an outward force from the centre of high or low pressure, is called the **cyclostrophic force.**

In the diagrams below it can be seen that the cyclostrophic force C acts in the same direction as P with the high pressure circulation, so that $G = P + C$, and in the opposite direction to P with the low pressure system such that $G = P - C$. The resulting wind is the **gradient wind.** It may be noted that the wind will be stronger around the high pressure system than around the low pressure system *always provided* that the pressure gradient is the same in each case.

Effect of friction

The winds so far referred to have been unaffected by friction; such winds will blow above 600 metres (2000 ft). The effect of friction is to reduce the wind velocity. The reduction gets progressively greater between 600 metres (2000 ft) and sea level. At sea level the wind velocity is only half to two thirds that at 600m (2000 ft),

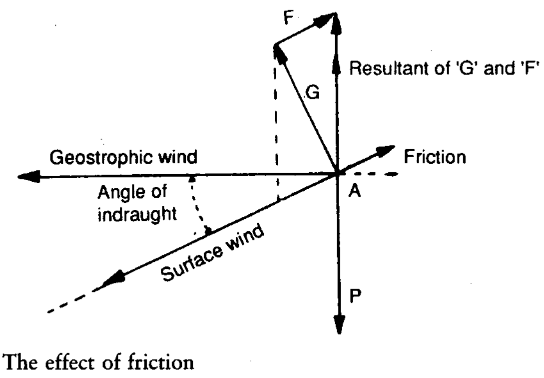


Figure 37 The effect of friction

Table 4.1 *Beaufort wind scale*

Beaufort scale number	*Description and limit of wind speed in knots*	*Sea criterion*
0	Calm Less than 1	Sea like a mirror
1	Light air 1–3	Ripples with the appearance of scales are formed but without foam crests
2	Light breeze 4–6	Small wavelets, still short but more pronounced, crests have a glassy appearance and do not break.
3	Gentle breeze 7–10	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.
4	Moderate breeze 11–16	Small waves, becoming longer; fairly frequent white horses.
5	Fresh breeze 17–21	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray.)
6	Strong breeze 22–27	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray).
7	Near gale 28–33	Sea heaps up and white foam form breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen.)
8	Gale 34–40	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind.
9	Strong gale 41–47	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Spray may affect visibility.
10	Storm 48–55	Very high waves with long overhanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility affected.
11	Violent storm 56–63	Exceptionally high waves. (Small and medium-size ships might be for a time lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.
12	Hurricane 64–71	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.

depending on the type of surface, the reduction being greater over the land than over the sea.

Figure 37 shows that, although the wind velocity is reduced by friction, the pressure gradient is unchanged. In order that the equilibrium of point A shall be maintained, the direction of the wind must be moved towards the force *P*. Thus the surface wind is inclined towards the low pressure and away from the high pressure. The angle which the wind makes with the isobars is known as the **angle of indraught.**

During the daytime, turbulence due to surface heating causes the higher velocity winds at 600 metres (2000 ft) to be brought to the surface and it will be noted that during this time the surface wind veers and increases in velocity. By night, turbulence is damped out and it will be noted that the surface wind backs and decreases in velocity. The effects mentioned above are hardly noticeable over the sea as turbulence due to surface heating is negligible.

Direction of true wind

The direction of the true wind should be noted in the logbook and in weather messages. It may be estimated by noting the direction of the waves. The approximate speed of the wind may be estimated from the appearance of the sea (see Beaufort scale, Table 4.1). The apparent wind direction and speed are the resultant of the ship's course and speed and the true wind direction and speed. If any two of the foregoing are known, the third can be found by plotting a triangle of velocities.

Example

An officer on a vessel steaming NNE at 11½ knots observes the apparent wind to be 6 points on the port bow at 15 knots. What would be the true wind direction and speed?

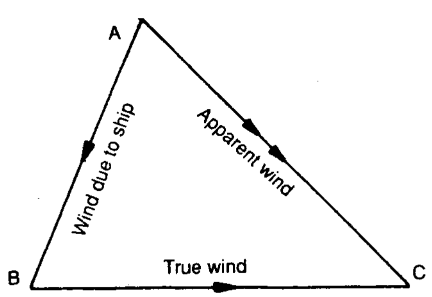


Figure 38

AB in Figure 38 represents the ship's course and speed. This is the wind caused by the ship; hence the direction of the arrowhead is opposite to the course. AC represents the apparent wind direction and speed. A double arrowhead denotes this as it is the resultant of the wind caused by the vessel and the true wind. Joining B to C completes the triangle of velocities. BC will be the direction and speed of the true wind.

True wind West 15 knots.

EXCEPTIONAL WIND

There is an extended scale for exceptional wind as follows:

Force	Knots
13	72–80
14	81–89
15	90–99
16	100–109
17	110–118

Storm warnings are hoisted at stations on the coasts of the British Isles when winds of force 8 or more are expected shortly within 50–100 miles of the station.

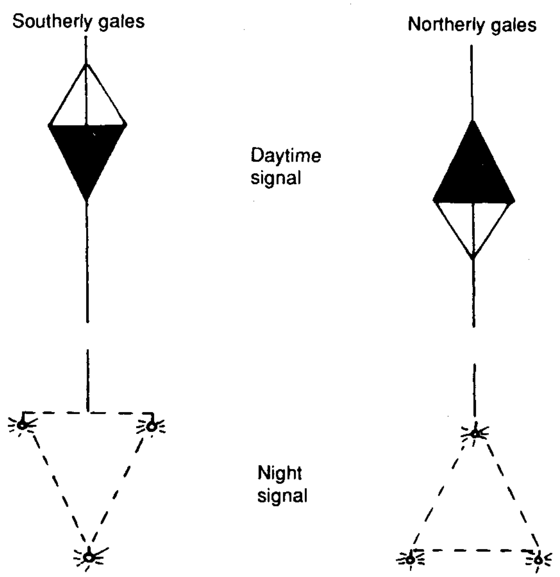


Figure 39 Storm warnings

The day signal consists of a cone 1 metre (3 ft) wide and 1 metre (3 ft) high. A nightime signal is hoisted at a few stations and consists of a triangle of lights 1.3 metres (4 ft) wide at the base. See Figure 39.

If the gale is expected to commence from a northerly point, the cone or triangle of lights is hoisted point upwards. If the gale is expected from a southerly point, the signal is shown with its point downwards. Gales starting from east or west and likely to change to a northerly direction will be indicated by a north cone whilst those likely to change to a southerly direction will be indicated by a south cone.

The warnings will be taken down only if a period of at least 12 hours is expected to be free of gales.

Prevailing winds

Wind roses are found on climatological charts and they depict the frequency and

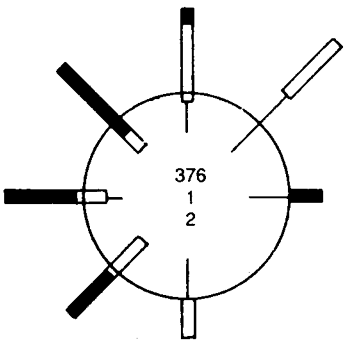


Figure 40 Baillie rose

strength of the winds blowing from the various directions. There are many forms of wind rose, each having its own features.

The Baillie rose shown in Figure 40 is comprehensive yet simple. From the circle to the inner end of the wind arrow represents a scale of 5%. A thin line represents wind force 1–3, a double line represents forces 4–7, and a broad line forces 8 upwards. The figures in the centre show the number of observations, the percentage frequency of variables and the percentage frequency of calms in that order.

Thus the figure shows north winds 4% light, 10% moderate and 2% gales; NE winds 10% light, 9% moderate; E winds 5% light, 4% gales; S winds 5% light, 5%

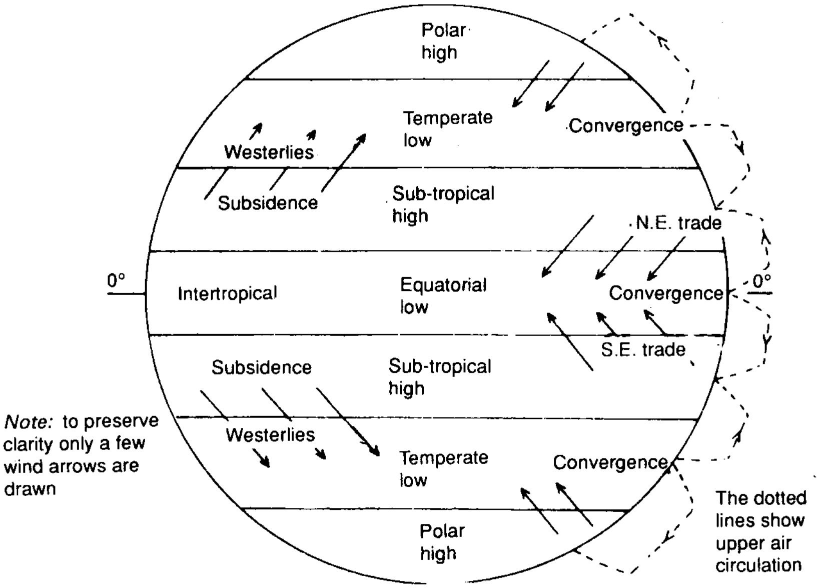


Figure 41 Wind circulation

moderate; SW winds 6% moderate, 7% gales; W winds 2% light, 4% moderate, 9% gales; NW winds 3% moderate, 12% gales. The total number of observations is 376, the frequency of variables is 1% and there is a 2% frequency of calms.

Figure 41 shows the planetary wind circulation for the 'ideal' Earth which would be one covered all over with water. The circulation will be modified wherever there are land masses. The general circulation on the Earth is shown in Figures 42 and 43 for February and August. As can be seen, the trades move slightly north and south with the sun; their approximate limits are as follows:

	February	August
Atlantic doldrums	0°–2°N	5°N–10°N
NE trade	2°N–25°N	10°N–30°N
E trade	0°–30°S	5°N–25°S
Pacific doldrums	4°N–8°N	8°N–12°N
NE trade	8°N–25°N	12°N–30°N
SE trade	4°N–30°S	8°N–25°S
Indian SE trade	15°S–30°S	0°–25°S

The **anti-trades** are winds which blow above about 2500 metres (8000 ft) in the opposite direction to the trades on the surface.

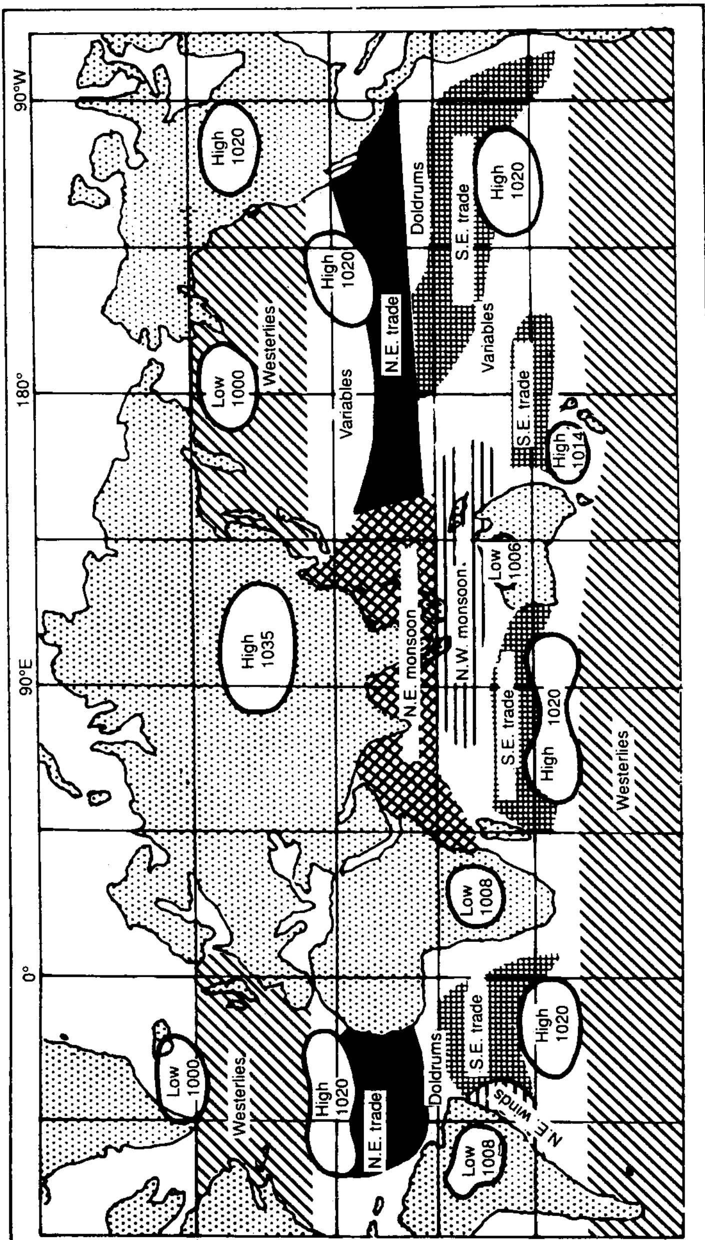


Figure 42 Prevailing winds and pressure centres, northern winter (December to April)

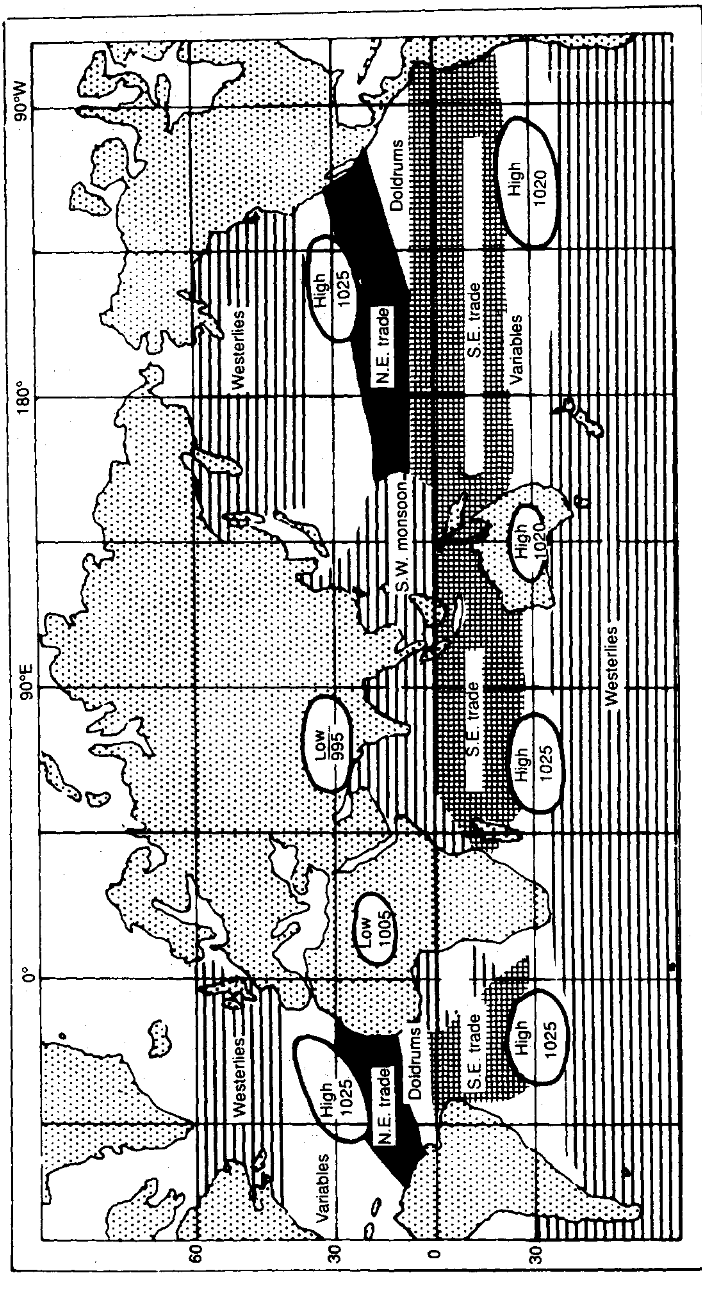


Figure 43 Prevailing winds and pressure centres, northern summer (June to October)

Land and sea breezes

As the land is heated during the daytime, the air over it will be heated by conduction. This heating causes a decrease in the density of the air and the pressure falls. The sea temperature remains more or less the same and the pressure over it is high compared with that over the land. The pressure gradient is sufficient for air to flow from over the sea to the land; this is the **sea breeze** (Figure 44).

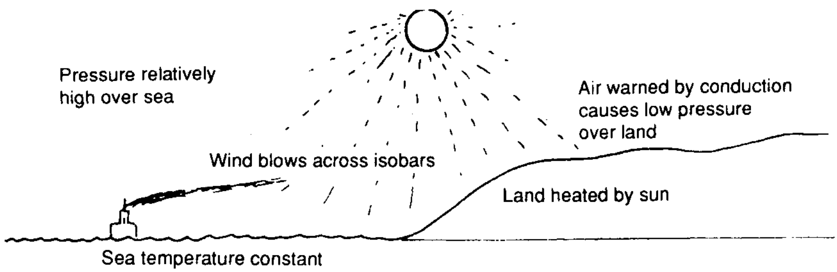


Figure 44 Sea breeze

The sea breeze sets in during the morning, reaches its maximum strength about 1400 hours and then dies away towards sunset.

After sunset the land cools rapidly and the air above it also cools and its density increases, giving rise to an increase in pressure. The pressure over the sea is now low compared with that over the land. The pressure gradient causes air to flow from the land to the sea; this is the **land breeze** (Figure 45).

The land breeze sets in shortly after sunset and continues until dawn.

The sea breeze is the more noticeable; it reaches force 3–4 and gives a pleasantly cool breeze on the coast during the heat of the day. The land breeze is generally lighter than the sea breeze.

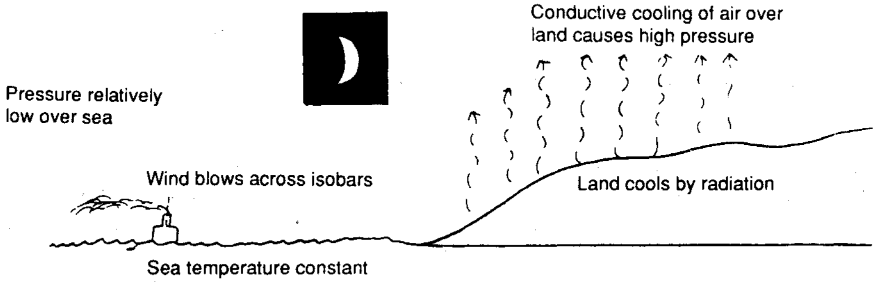


Figure 45 Land breeze

NE monsoon of the China Seas and Indian Ocean

During the northern winter the Asian continent is cooled and an intense high pressure area forms over Eastern Siberia (Figure 46). The winds circulating round this form the NE monsoon. In the northern part of the China Sea the pressure gradient is large and winds are likely to be north westerly force 6–7; further south

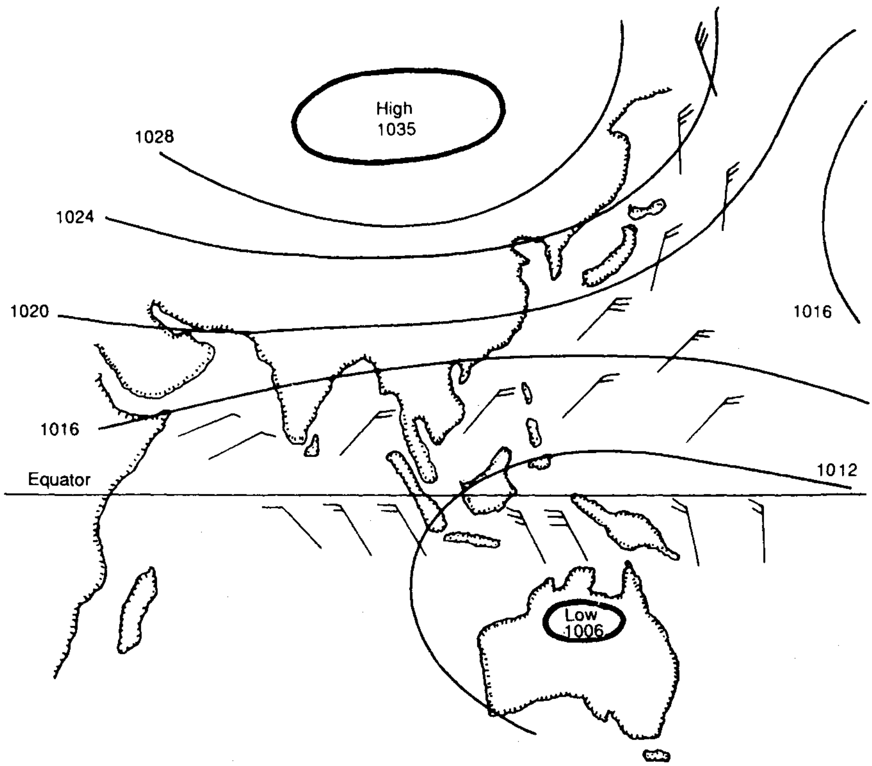


Figure 46 NE monsoon of the China Seas and NW monsoon of Australia

where the pressure gradient is smaller the winds will be northerly force 5–6. In the Bay of Bengal and Arabian Sea winds are north easterly, force 3–4. Rainfall of the showery type is likely on windward coasts especially in the China Sea. As the air is of polar origin the relative humidity will be low.

The NE monsoon becomes established in early December and continues until April.

NW monsoon of Australia

During the southern summer a low pressure forms over the deserts of Australia (Figure 46). The pressure gradient from the high over Siberia is continued to the aforementioned low. The NE monsoon winds blow down to and past the equator. On crossing the equator these winds are deflected to the left, giving NW winds on the coasts of Australia. Having blown over thousands of miles of ocean, the air has a high relative humidity and periods of rain may be expected. The wind force is unlikely to exceed force 6–7 and is frequently less. Intensification or otherwise of the Siberian high will affect this monsoon as well as the NE monsoon.

The duration of this monsoon is similar to that of the NE monsoon.

SW Monsoon of the Indian Ocean and China Sea

During the northern summer, the Asian continent is warmed; the high pressure over Siberia declines and is replaced by a low pressure over NW India (Figure 47).

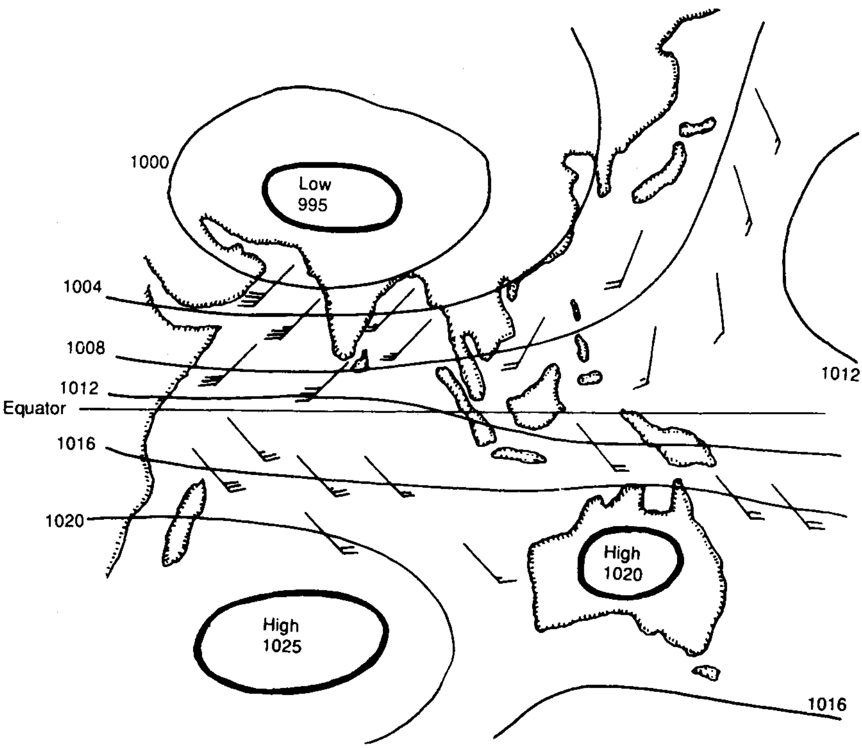


Figure 47 SW monsoon of the Indian Ocean

There is a pressure gradient between the high pressure over the South Indian Ocean and the lows over Africa and India. This causes the SE trade to blow up to the equator, and on crossing it, the wind near the African coast circulates round the low over Africa and brings rainfall to East Africa. Away from the coast the wind is deflected to the right and blows from a south westerly direction.

In the Arabian sea the wind is SW force 7–8, in the Bay of Bengal SW winds of force 6–7 can be expected, whilst in the southern part of the China Sea the wind is southerly force 4–5. The northern part of the China Sea has light south easterly winds.

The air forming the SW monsoon has travelled over thousands of miles of ocean and is saturated. This results in heavy rain, especially near the coasts, and poor visibility.

The SW monsoon sets in during June and lasts until October, the early months being the worst.

SW winds of West Africa

During the northern summer the low pressure over Africa moves north of the equator (Figure 48). The pressure gradient between the high over the South Atlantic and the low over Africa causes the SE trade to be deflected and it arrives on the West Coast of Africa as a SW wind often called a monsoon, although its intensity is nothing like that of the SW monsoon of India.

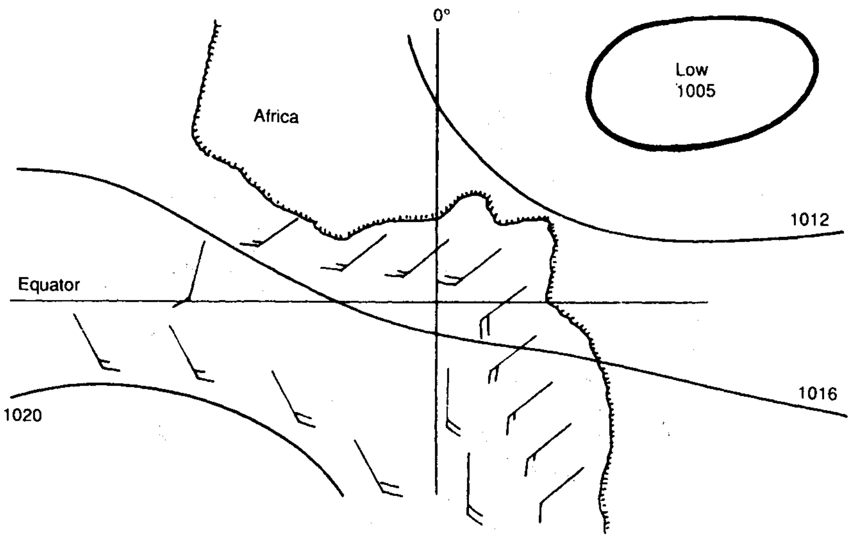


Figure 48 SW winds of West Africa

NE winds of Brazil

The South American continent is heated during the southern summer and a low pressure area forms over NE Brazil (Figure 49). The SE trade is deflected to circulate around this low giving east to NE winds on the coasts. Having travelled over thousands of miles of sea, the relative humidity of the air is high, giving heavy rainfall on the coast.

Katabatic and anabatic effects

When the Earth's surface cools by night, the air next to the surface is also cooled and thus its density is increased. If this cold air is on high ground there is a tendency for it to sink down to lower ground. If the high ground is a cliff top or a high coastal plateau, the downflowing cold air will move horizontally when it reaches sea level to form a **katabatic wind**, which may reach force 6–7.

The katabatic wind is common off the coasts of Greenland where cooling is helped by the snow-covered land surface. It is also experienced in the Adriatic and many other areas having high land adjacent to the coast.

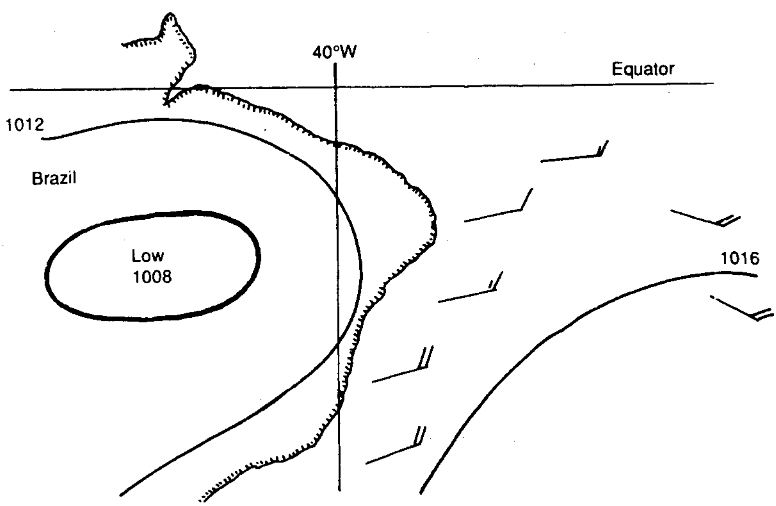


Figure 49 NE winds of Brazil

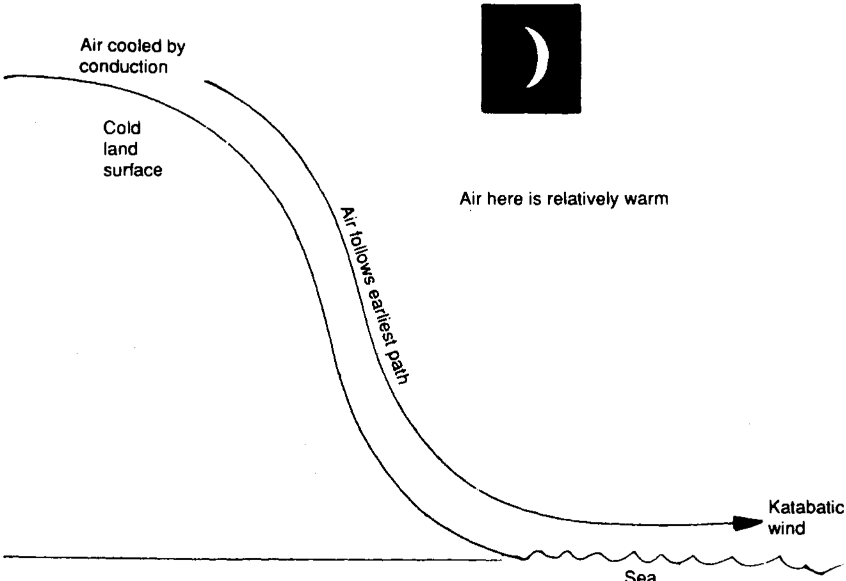


Figure 50 Katabatic wind

The **anabatic wind** is less noticeable as it blows up the sides of valleys with considerably less force than the katabatic wind. The air at the bottom of the valley is warmed by conduction from the heated land during the day, and this air, being less dense than the air above it, takes the easiest path to the top of the valley by following the warm sides (Figure 51).

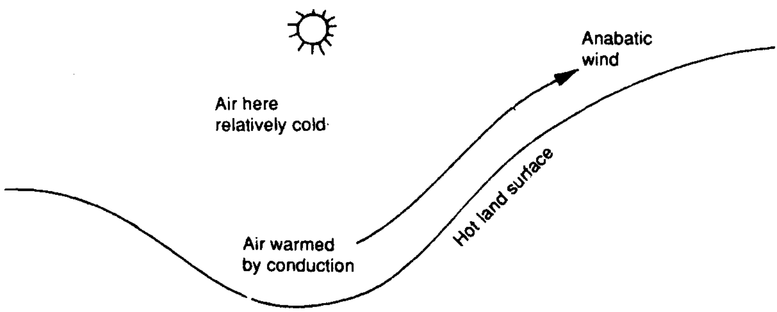


Figure 51 Anabatic wind

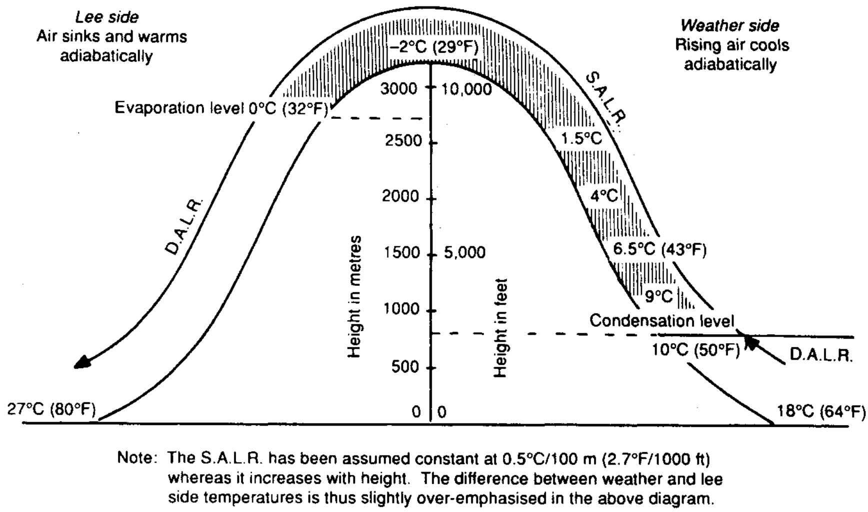


Figure 52 Föhn wind effect

Föhn wind effect

This is felt on the lee side of high ground and results in temperatures on the lee side being higher than those on the weather side if the air passing over the high ground has been cooled to below its dewpoint.

Figure 52 shows maritime tropical air rising over a mountain range. As it rises, the air is first cooled to its dewpoint and, as precipitation occurs, the absolute humidity decreases. Due to the decrease in absolute humidity the dewpoint temperature on the lee side will be considerably lower than that on the weather side, which means that the condensation level will be higher on the lee side.

Below the condensation level the air will change its temperature at the DALR, whilst above it, it will change its temperature at the SALR. As the condensation level on the lee side is higher than on the weather side it follows that the descending air will warm at a greater rate than the ascending air cools; this results in higher temperatures on the lee side.

The difference in temperatures can be considerable, depending on the height of the land and the humidity of the rising air.

Local winds

In many parts of the world seasonal and occasional winds are given local names; some of the better known of these are illustrated in Figures 53 and 54.

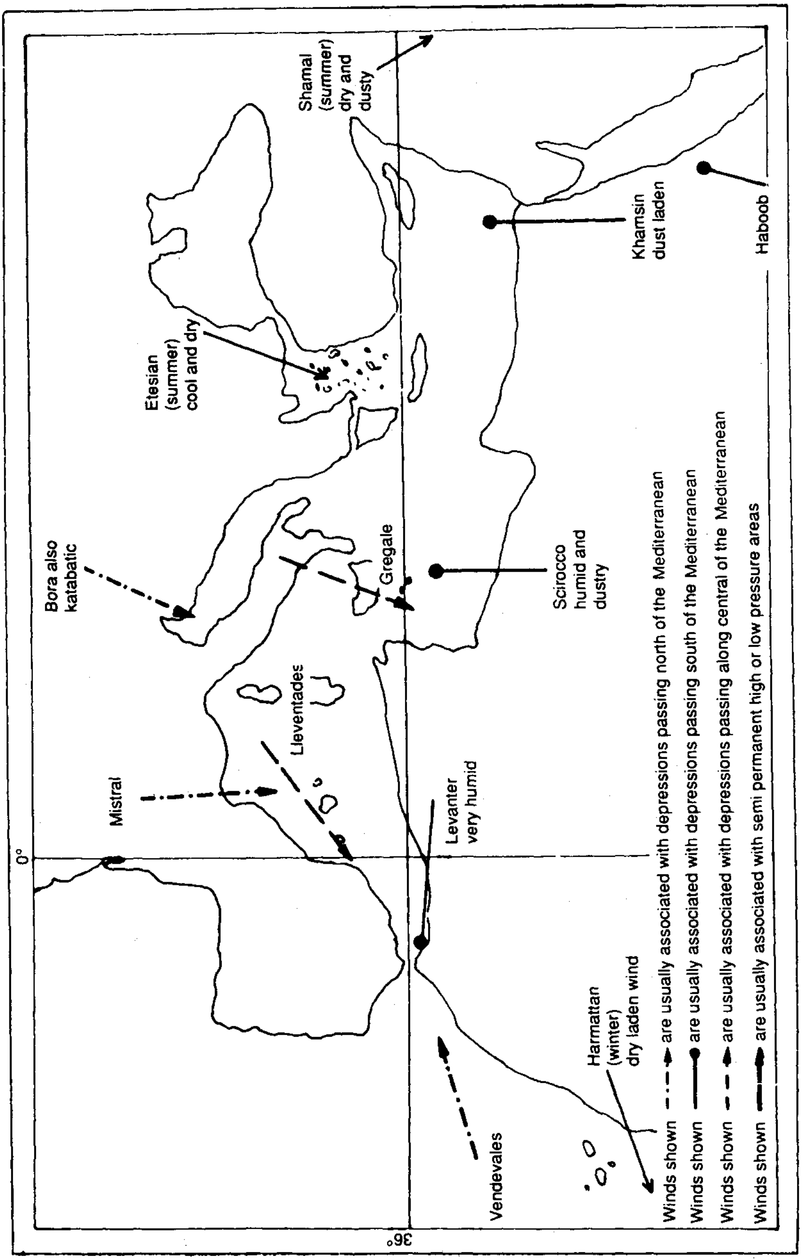


Figure 53 Mediterranean winds

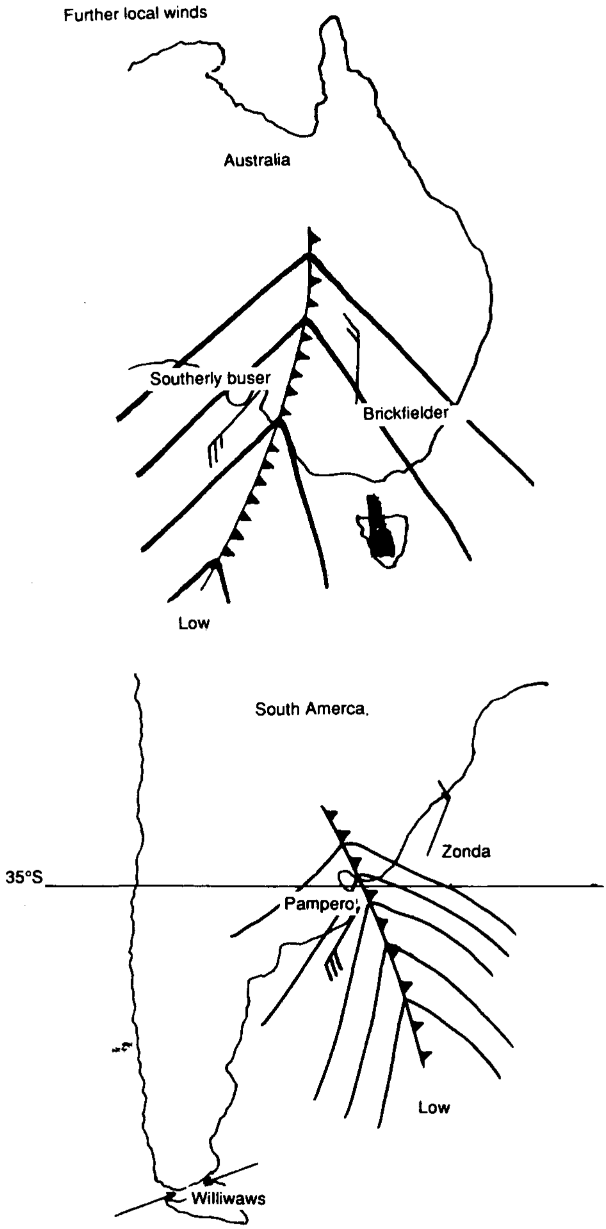


Figure 54 Local winds in Australia and South America

CHAPTER FIVE

Isobaric Systems

ANTICYCLONE

Anticyclone is the name given to a system of high pressure (Figure 55). The wind circulation around this system will be clockwise in the northern hemisphere and anti-clockwise in the southern hemisphere. Anticyclones are associated with small pressure gradients and consequently light winds. As they are areas of subsidence, rainfall is unlikely. They may be classed as either cold or warm and each of these may be either permanent (long lasting) or temporary.

When the high pressure is brought about by the air over an area being denser than that nearby, a cold anticyclone is formed, cold air having a greater density than warm air. On the other hand, a high pressure can be formed by larger than normal amounts of warm air over an area, in which case a warm anticyclone is formed.

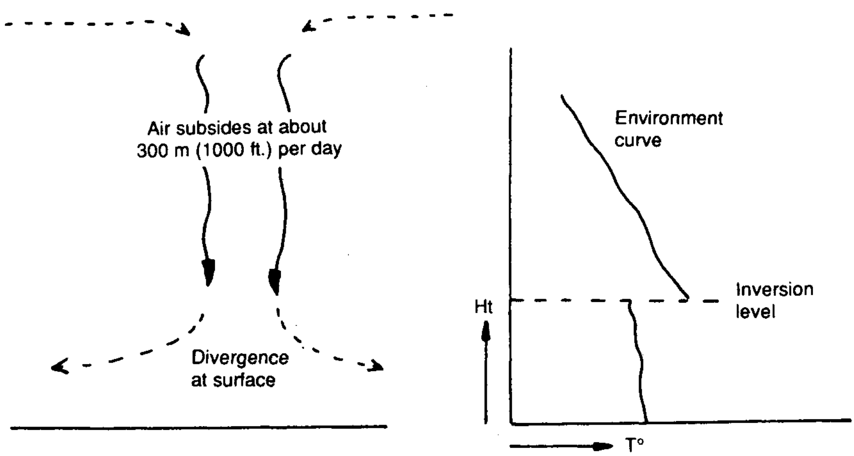


Figure 55 Anticyclone

The cold anticyclone gives brilliant frosty weather in the centre but near the outer regions dull foggy weather is frequently experienced, as there is usually a temperature inversion close to the surface. The inversion is formed by the subsiding air warming adiabatically. The best known of the cold anticyclones is that over Siberia in winter, which is a permanent one. Cold anticyclones are unlikely over oceans or over the land in summer; if they do form they rapidly become warm ones or disperse.

Temporary cold anticyclones occur between the middle latitude depressions and bring a welcome though brief spell of very bright weather. Occasionally the ridge with which the temporary anticyclone is associated will intensify to build up an anticyclone composed entirely of cold air. If this occurs over the land in winter it may merge with the continental high and be kept as a cold anticyclone by continuous cooling of the land. If it occurs over the land in summer or over the sea at any time it is hardly likely to persist as a cold anticyclone; it may collapse or become a warm anticyclone.

Warm anticyclones occur when the air in the troposphere is warmer than the surrounding air, and the high pressure is caused by an excessive depth of this warm air.

Permanent warm anticyclones are those which are found over the oceans and are generally referred to as the sub-tropical highs. They are composed of warm dry air and the visibility is excellent.

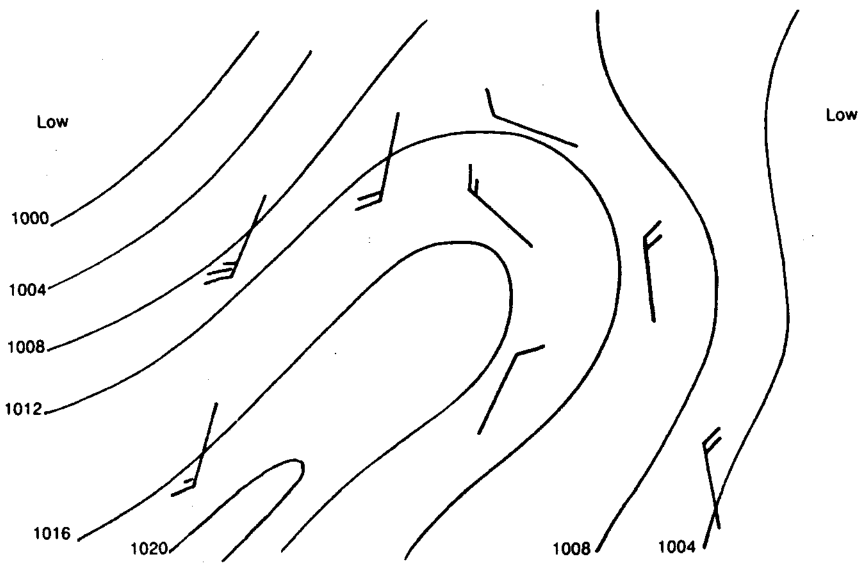


Figure 56 Ridge of high pressure

Temporary warm anticyclones may occur when there is an extension from the sub-tropical high or when a temporary cold anticyclone warms adiabatically. Over the land the air is very dry and by day fine hot weather will be experienced during the summer. By night there may be sufficient radiation cooling to give fog, this being particularly likely during the autumn.

Over the sea, advection fog may occur at any time but this is most probable during spring and early summer.

The pressure tendencies of the anticyclone are frequently helpful in forecasting the movement of depressions, the general rules for these being given on page 59.

A **ridge of high pressure** (Figure 56) is an extension of an anticyclone and may be in any direction from its parent. During the winter, ridges from the sub-tropical high and from a high over Greenland frequently join to give a continuous period of Northerly winds over the British Isles (see page 67). The ridge may also be referred to as a wedge.

Air masses

Air masses are large areas of air which have the same characteristic throughout. For such conditions to occur, the air must remain over an area for several days. The ideal conditions will be found where there is a permanent anticyclone and these are the principal **source regions** for the air masses.

Table 5.1 *Air masses that affect the British Isles*

Air mass and abbreviation	*Source*	*Temperature*	Relative humidity	*Sky*	*Air condition*
Maritime tropical mT	Azores	High	High	Covered with stratus	Stable
Continental tropical cT	Sahara	Very high	Low	Clear	Stable
Maritime polar mP	Greenland	Low-high depending on time over sea	Medium	Cumulus cloud	Unstable
Continental polar cP	Siberia	Very low	Low	Possible stratus through turbulence	Stable
Arctic A	Arctic Ocean	Very low	Low-medium	Cumulus	Unstable

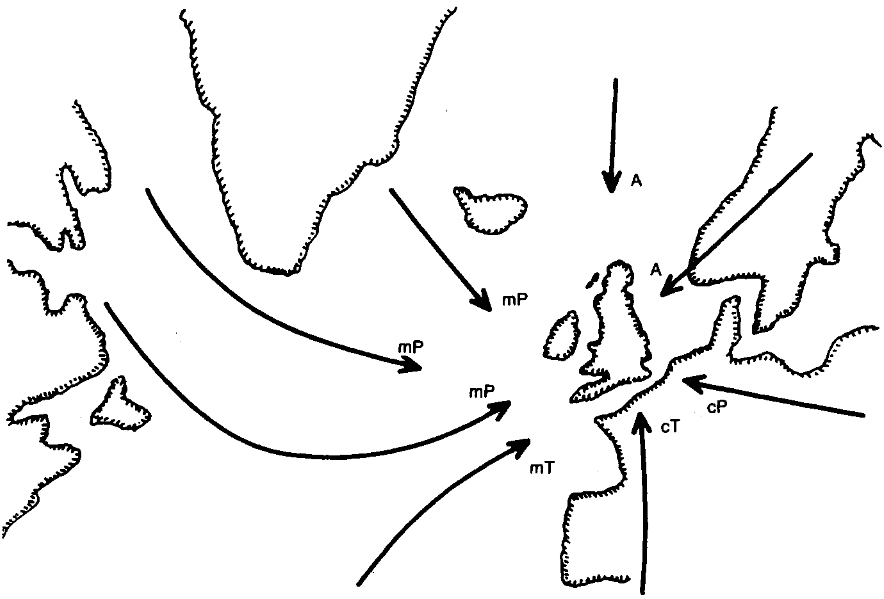


Figure 57 Air masses that affect the British Isles

Air masses may be either warm or cold, depending on whether their source is tropical or polar. They are further described as being either maritime or continental.

Table 5.1 and Figure 57 describe and show the approximate tracks of air masses which affect the British Isles. It can be seen that each air mass has a different characteristic to the other air masses and consequently they will not mix with one another. The boundary of each air mass is generally well defined and on the ground it is known as a **front.** The boundary above the ground is known as a **frontal surface.** Most fronts are in motion, but if a front is stationary or behaving as if it were stationary, it is referred to as being **quasi-stationary.**

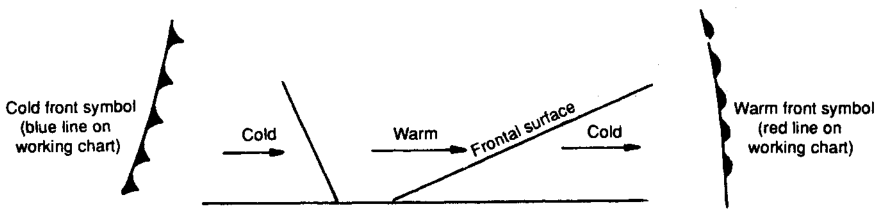


Figure 58 Cold and warm fronts

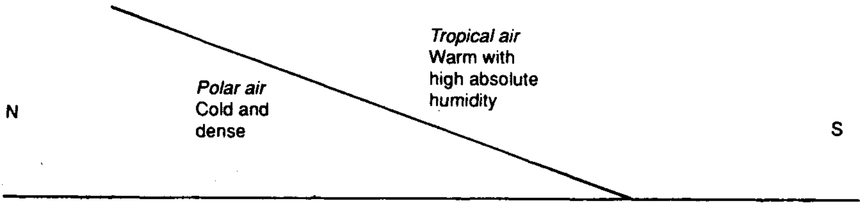


Figure 59 Polar front

When the approaching air is colder than the present air the boundary will be a **cold front**, whereas if the approaching air is warmer than that at present the boundary will be a **warm front** (Figure 58).

The general line of demarcation between polar and tropical air masses is known as the **polar front** (Figure 59). The density of the polar air is greater than that of the tropical and the frontal surface cannot be vertical, but is inclined polarwards so that the tropical air overrides the polar air. The slope of the frontal surface is about 1 in 150.

Frontal depression

The warm air is moving relatively faster than the cold air and every now and again it forces its way into the cold air, making a bulge in the polar front. This is the commencement of a **frontal depression**, for as the warm, less dense air pushes into the cold, denser air the pressure falls. Figure 60 shows the successive stages in the formation and degeneration of the depression.

It will be seen that when the depression is fully developed the air behind the cold front is moving faster than the air in the warm sector. This causes the warm sector to be undercut and lifted off the ground, the front is then said to be **occluded** (Figure 61).

The air ahead of and behind the occlusion was originally of the same temperature but circumstances (the warm sector intervening and the passage of time) cause a change in their temperatures. If the air behind the occluded front is colder than that in front the occlusion is said to be a cold one, but if the air behind the occlusion is warmer than that ahead of it, the occlusion is a warm one.

The depression tends to move in a north easterly direction in the Northern Hemisphere and south easterly in the Southern Hemisphere. However, if tracks of depressions are studied, they will be seen to be in every direction, although the above directions predominate. Temperate latitude depressions moving westwards are rare and even if they do move in this direction, they will not do so for any length of time.

If the way in which the depression is formed is considered carefully, the changes of weather which occur as the depression passes any point will be apparent. The

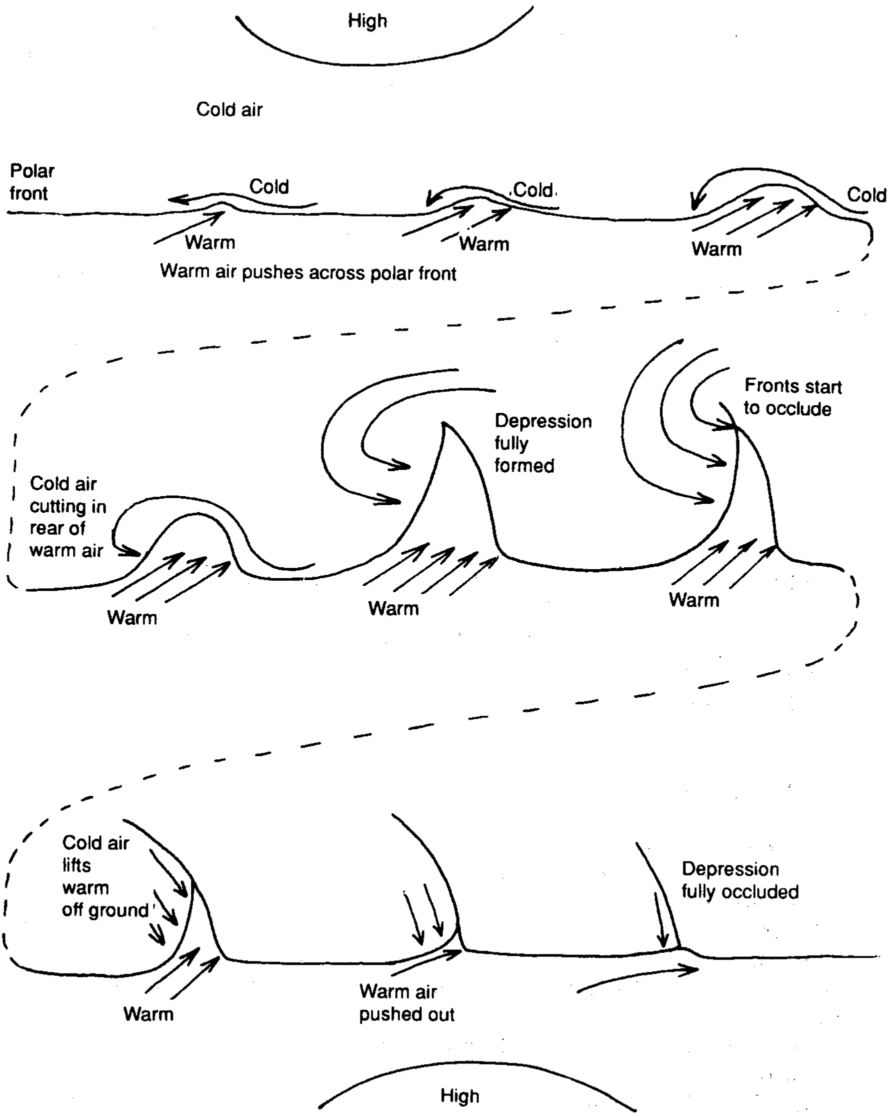


Figure 60 The life of a frontal depression

reader should check his deductions for the weather changes as the depression moves along the line AB, Figure 62, with those shown in Table 5.2.

A southern hemisphere frontal depression is formed in exactly the same way as one in the northern hemisphere – namely by a warm maritime air mass encroaching on a cold polar air mass. The reader should attempt the drawing of a formation of such a depression and then compare his fully developed depression with the plan view shown in Figure 63.

The section along AB is exactly the same as that shown in Figure 61 and the

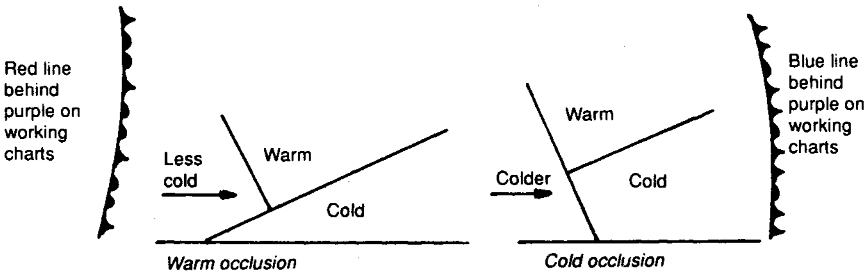


Figure 61 Occluded front

weather changes in Table 5.2 are also applicable, except that for the wind. The wind will back from north westerly to south westerly as the depression approaches and passes. It should be noted that the feathers on the wind arrows in the southern hemisphere should always be placed on the left hand side of the wind arrow when facing the wind.

Secondary depression

Frontolysis is the term applied to 'spreading' of the isotherms at a front, which means that the front is less active and the depression will be filling. This occurs when the isobars are cyclonic.

Frontogenesis is the term applied to the 'closing' of the isotherms at a front. This means that the activity at the front is increasing, with a deepening of the depression or, more likely, the formation of a secondary depression. It occurs when the isobars are anticyclonic.

The ideal conditions for the formation of a **secondary depression** are usually found on the cold front between the point where the warm and cold fronts are occluded and the point where the front runs parallel to the isobars. The secondary, which may only show as a bulge in the isobars, moves around the primary (the original depression) in an anticlockwise direction and tends to deepen as the primary

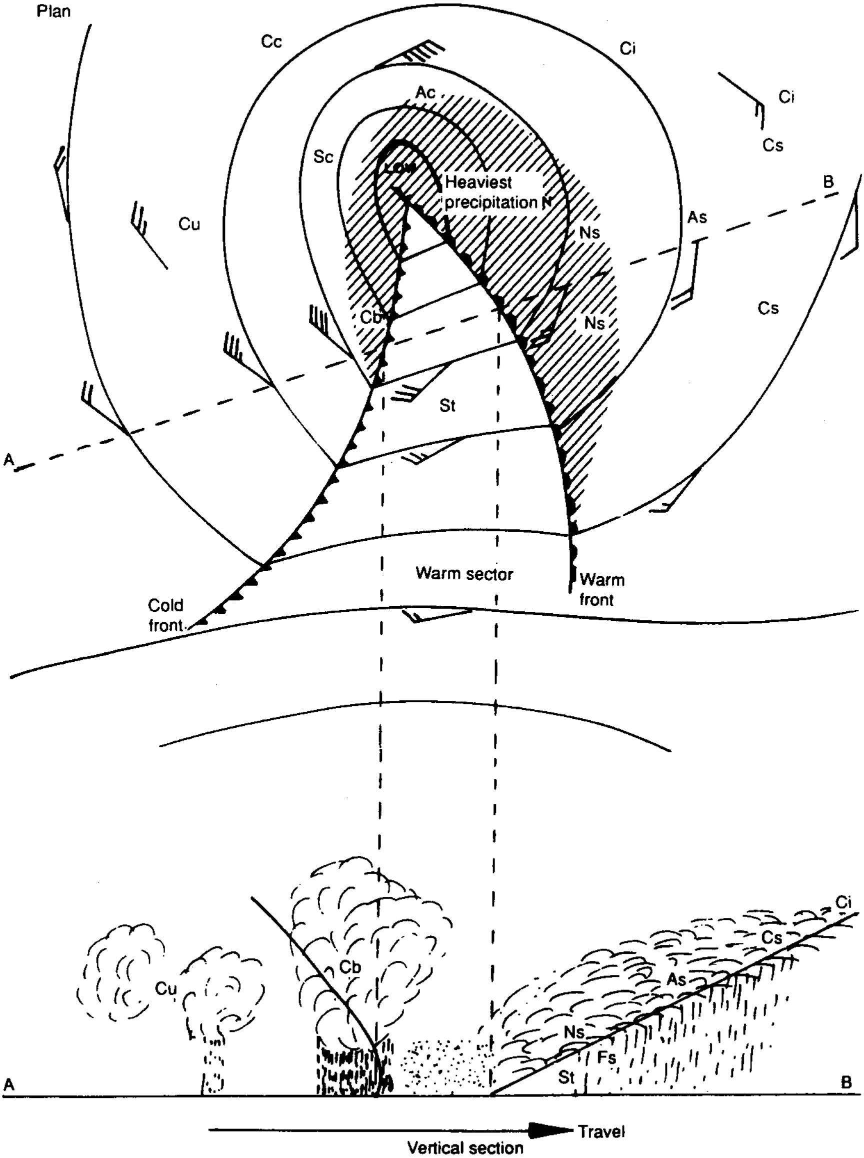


Figure 62 Weather associated with a frontal depression

Table 5.2 *Frontal depression (weather changes)*

	Warm front		*Warm sector*	*Cold front*	
	Approaching	*Passing*		*Passing*	*At the rear*
Pressure	Steady fall	Stops falling	Little change	Sudden rise	Rising steadily
Wind	Veers from S to SW and increases	Veers with possible increase in velocity	Steady, possibly backing as cold front approaches	Sudden veer from S to SW or NW with squalls	Velocity tends to decrease, steady in direction
Temperature	Rising slowly	Slight rise	Little change with relatively high temperatures	Sudden drop	Little change but tendency to fall.
Sky	Becoming overcast Ci, Cs, As, Ns	Ns and Fs	Overcast with St turning to Sc	Cb	Cb, Ac and Cu with blue sky
Precipitation	Continuous from drizzle to heavy rain or snow	Rain stops but may be slight drizzle	Intermittent slight rain or drizzle possibly fog	Heavy rain thunder and possibly hail	There may be a narrow belt of continuous heavy rain, turning to heavy showers later
Visibility	Deteriorating	Poor	Poor	Great improvement	Excellent except in showers
Humidity	Increasing	Rapid rise	Very high	Rapid fall	Fairly low but variable in rain
Upper air	Stable	Very stable	Stable	Very unstable	Unstable

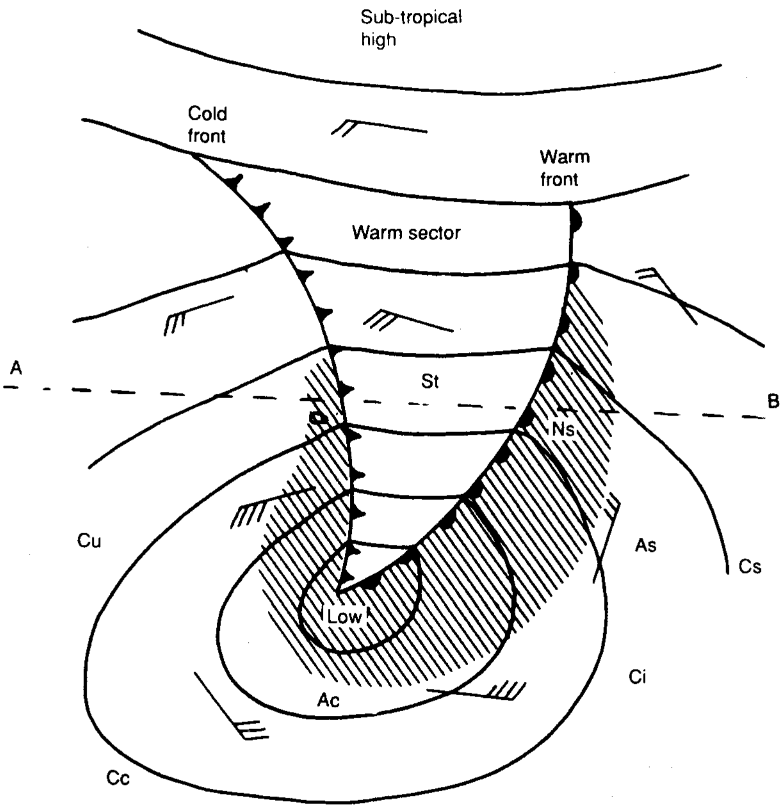


Figure 63 Plan of a southern hemisphere frontal depression

fills (Figure 64). The phenomena associated with a secondary are often more violent than those around the primary.

Secondary depressions may form where there is a kink or wave on the cold front; they may then be referred to as **wave depressions.**

As the cold front of a frontal depression 'trails' to join up with the polar front, it is quite likely that, when the next depression is already forming on the polar front, the trailing cold front will join the warm front of the new depression. This may be repeated with several depressions, and is known as a **family of depressions** which may be six or seven strong (Figure 65).

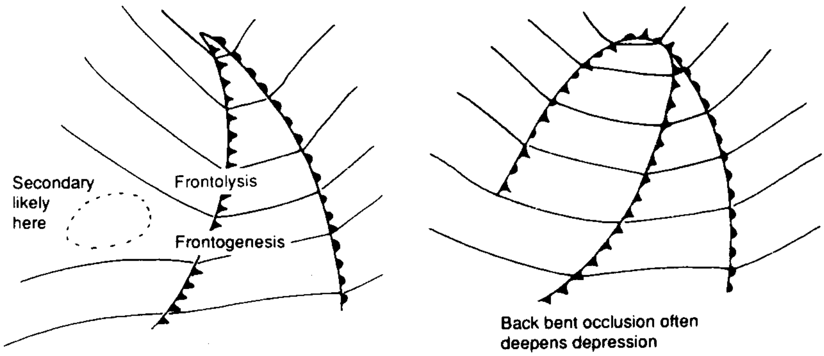


Figure 64 Secondary depression

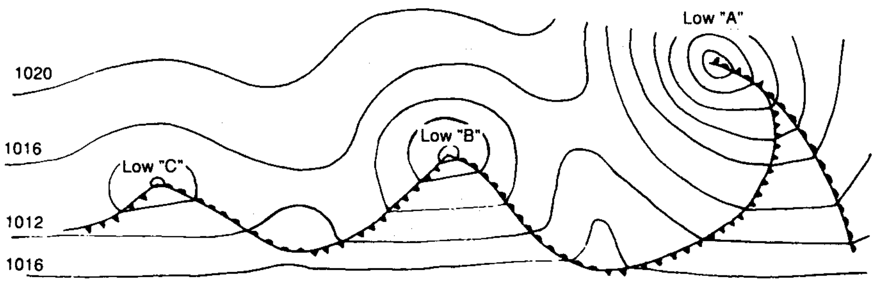


Figure 65 Family of depressions

Most of the diagrams show the frontal depression in the Northern Hemisphere. The manner in which it is formed in the Southern Hemisphere is similar, as shown in Figure 63. The reader should have no difficulty in drawing the other sketches for the Southern Hemisphere.

Non-frontal depressions

Depressions may also be of non-frontal origin, these being formed when there is a large amount of surface heating, in the lee of mountain ranges, or where there is great vertical instability.

The last type occur particularly in polar air streams; the depression thus formed may remain small or it may grow to quite a large size.

A knowledge of the movement of depressions is essential if any attempt is to be made to forecast the weather. Although each depression must be treated on the merits of the general synoptic situation, the following general rules can usually be applied.

1 A frontal depression tends to move in a direction parallel to the isobars in the warm sector. It moves at a speed approximately equal to that of the geostrophic wind in the warm sector. The warm front will move somewhat slower than this, whereas the cold front will move somewhat faster. The greater the angle which the front makes with the warm sector isobars, the faster it moves.

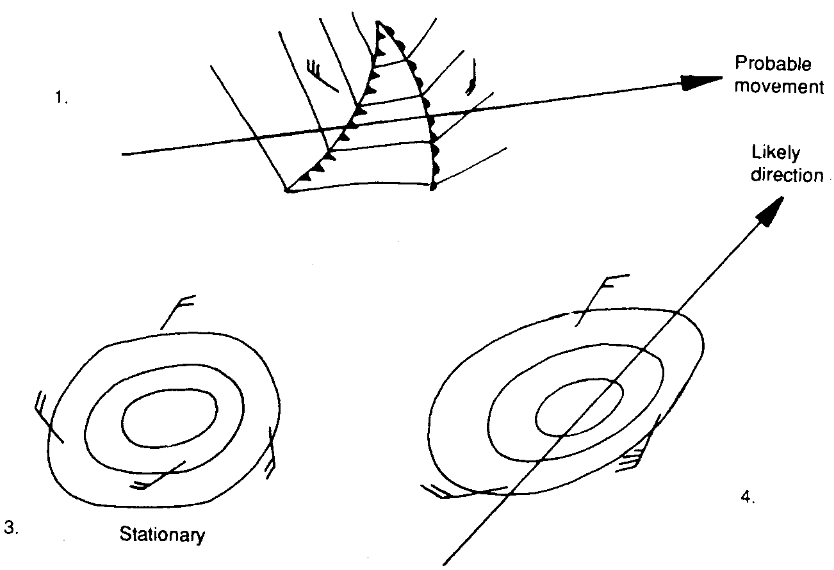


Figure 66 Characteristics of depressions

2 An occluded depression moves slowly or is often stationary.
3 A depression which has the same pressure gradient on all sides is stationary.
4 A depression tends to move in the direction of the strongest winds circulating round it.
5 A depression tends to move towards the isallobaric low, i.e. where the pressure is falling fastest.
6 Small depressions tend to move quickly in the general direction of the air stream in which they form.
7 Secondary depressions move cyclonically around their primary and if two depressions are more or less the same size, forming a dumb-bell shape, these tend

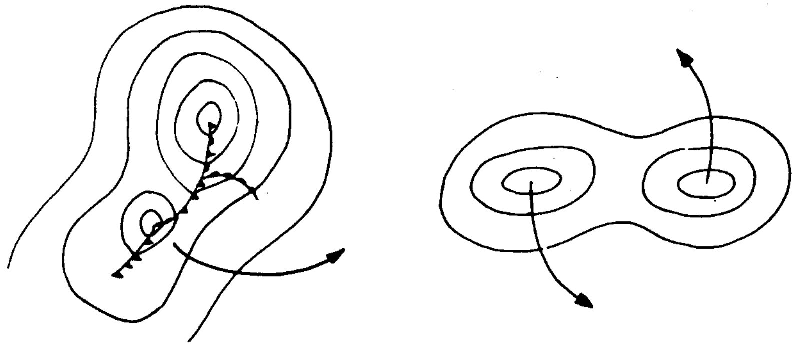


Figure 67 Movement of secondary depressions

to revolve cyclonically about a common centre somewhere between the two (Figure 67).

8 Elongated or elliptical-shaped depressions tend to move in a direction between the direction of the major axis and the direction of the isallobaric low.

9 Depressions having wind less than normal tend to deepen and those with winds greater than normal tend to fill.

Trough of low pressure

Sometimes called a V-shaped depression, this is an extension of a depression into a high pressure area. It nearly always points towards the equator. The trough may be frontal, in which case there is a marked change in the direction of the isobars on the trough line, or non-frontal, where the isobars are well rounded (Figure 68).

Frontal troughs may be associated with warm, cold, secondary cold or occluded fronts and the weather changes will be similar to those associated with these fronts.

Weather associated with cold fronts

A **line squall** occurs when the cold front is well marked. In other words, there is a large temperature difference between the warm and cold air. The line squall is common off the east coast of South America during the spring, where it is known as a **pampero.** In South Eastern Australia a similar squall is known as a **southerly buster.** See Figure 69.

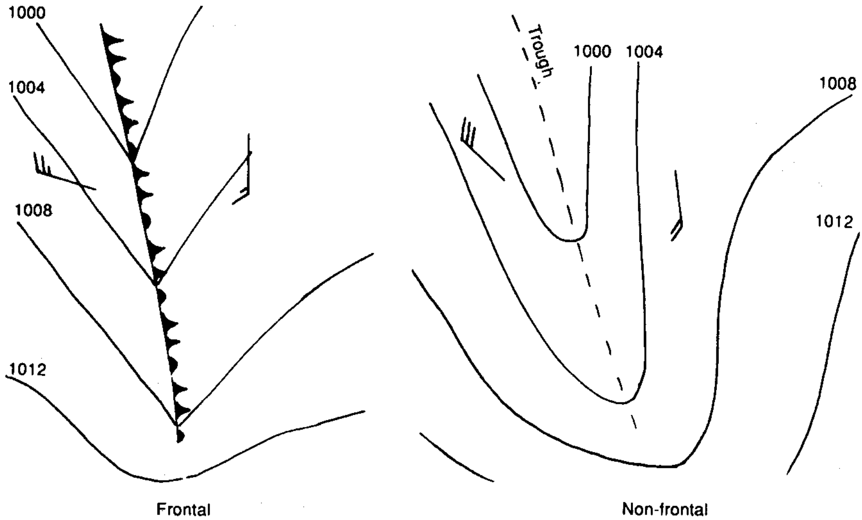


Figure 68 Troughs of low pressure

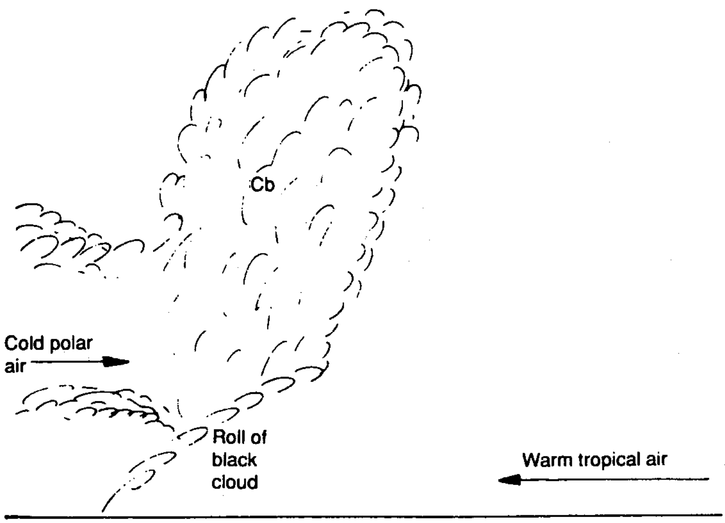


Figure 69 Line squall

The following changes in the weather may be expected at the passage of a line squall.

1 Sudden rise in barometric pressure.
2 Sudden drop in temperature
3 Change in wind direction and increase in velocity.
4 Heavy black cloud often appearing to roll along just above the surface.
5 Heavy rain.
6 Thunder and lightning.

The tornado of North America also forms on a cold front where there is strong convergence. The winds of hurricane force circulate cyclonically round the centre where there is a very low pressure and which is small in diameter, seldom more than a couple of hundred metres (yards). The path rarely exceeds 20 miles, but everything on the track is likely to have suffered great damage: roofs ripped off, trees uprooted and windows blown out. Similar tornadoes occur infrequently in England.

A similar but smaller phenomenon over the sea forms a **waterspout**. The low pressure and the convergence cause the sea to be sucked up towards the lower portion of the cumulonimbus cloud, from which a funnel-shaped cloud goes down towards the sea.

The tornadoes of West Africa are very different from those of North America, in that they are violent squalls of wind, without any cyclonic circulation, blowing outward from an approaching thunderstorm. They occur mainly during the rainy season.

Col

When two anticyclonic systems and two cyclonic systems are diametrically opposed there is an area in the centre of the four systems which cannot be considered as a high pressure or a low pressure area (Figure 70). This area is known as a **col** and the pressure is lower than that round the high pressures and higher than that round the low pressures.

In a col the pressure gradients are small, giving light variable winds. In general the relative humidity is high and there may be fog, or there may be thunderstorms.

Straight isobars

When the distance from a centre of high or low pressure is large, the isobars may run in parallel straight lines over a large area, a situation which is known as **straight isobars**.

The weather associated with straight isobars is usually of the changeable type, although in certain situations a spell of fine weather can be expected.

Figure 71 shows pictorially the following principal isobaric forms:

Cyclonic
Secondary
Trough
Anticyclonic
Ridge
Col
Straight isobars.

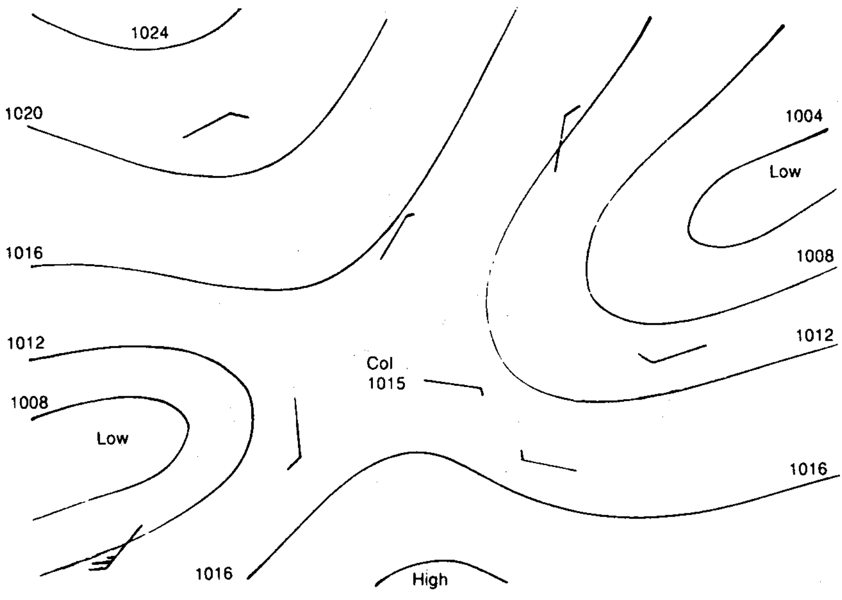


Figure 70 Col

Types of weather around the British Isles

The disposition of anticyclones around the British Isles gives rise to Northerly, Easterly, Southerly, and Westerly types of weather. It is emphasised that a northerly wind does not of itself indicate a Northerly type of weather; there must also be the right disposition of high and low pressure areas.

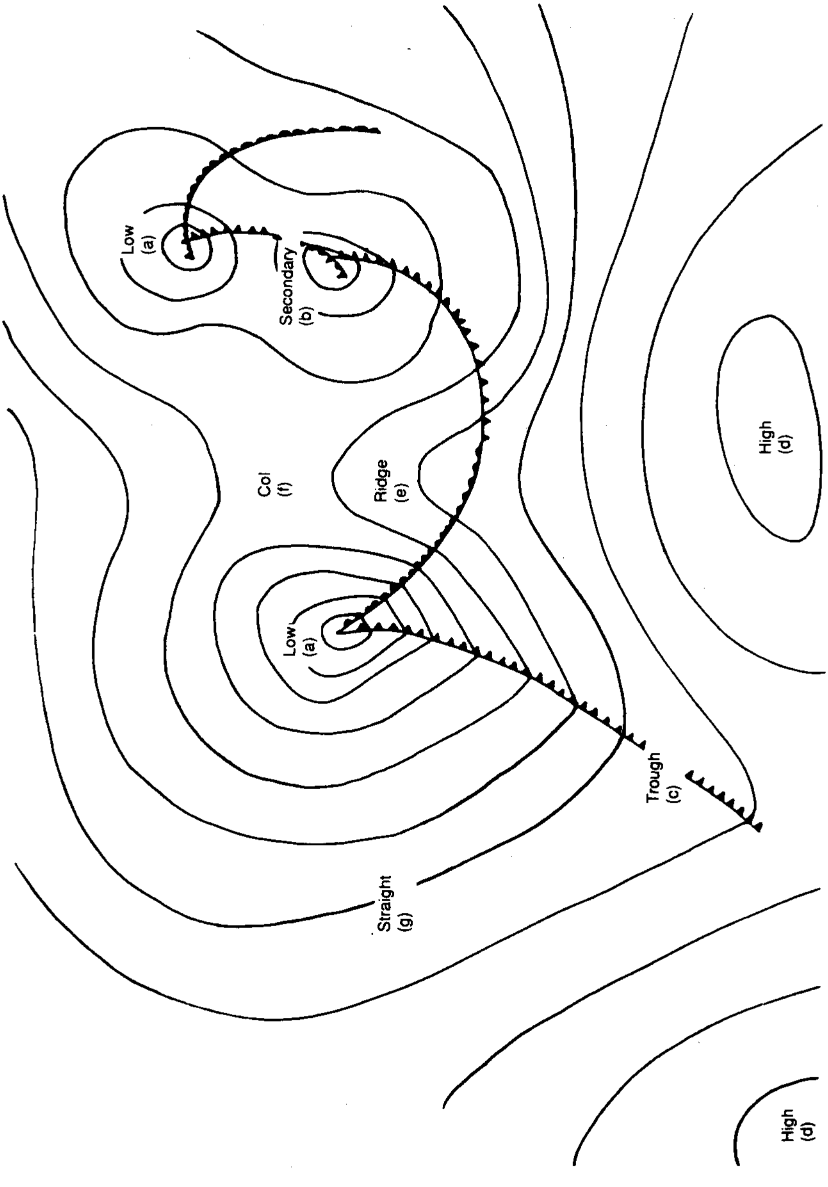


Figure 71 Forms of isobar

Northerly type (Figure 72) occurs when a high pressure over the Greenland–Iceland area has extensions towards the Azores high, with relatively low pressure over Scandinavia. Most likely in spring and early summer, the weather is cold and bright with showers of rain, sleet or snow on high ground and exposed eastern coasts.

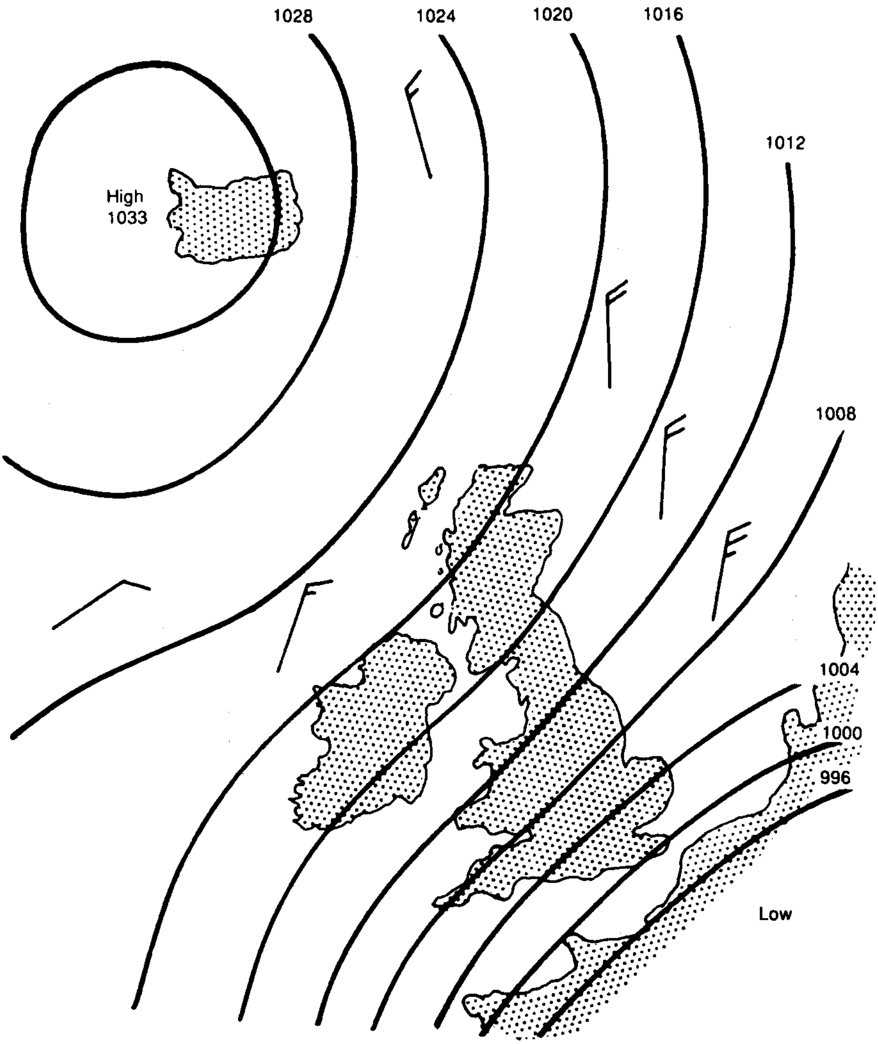


Figure 72 Northerly-type weather

Easterly type occurs when there is a high pressure over Scandinavia which extends towards Iceland (Figure 73). It is most likely in winter and spring when very cold easterly winds flow over the continent and to the British Isles. There is heavy frost by day and night. By night, skies are usually clear; by day, a layer of turbulent cloud (low stratus) frequently covers the sky.

Due to the Atlantic depressions being prevented from following their usual track up to the Norwegian Sea, they frequently move south to pass over France where the

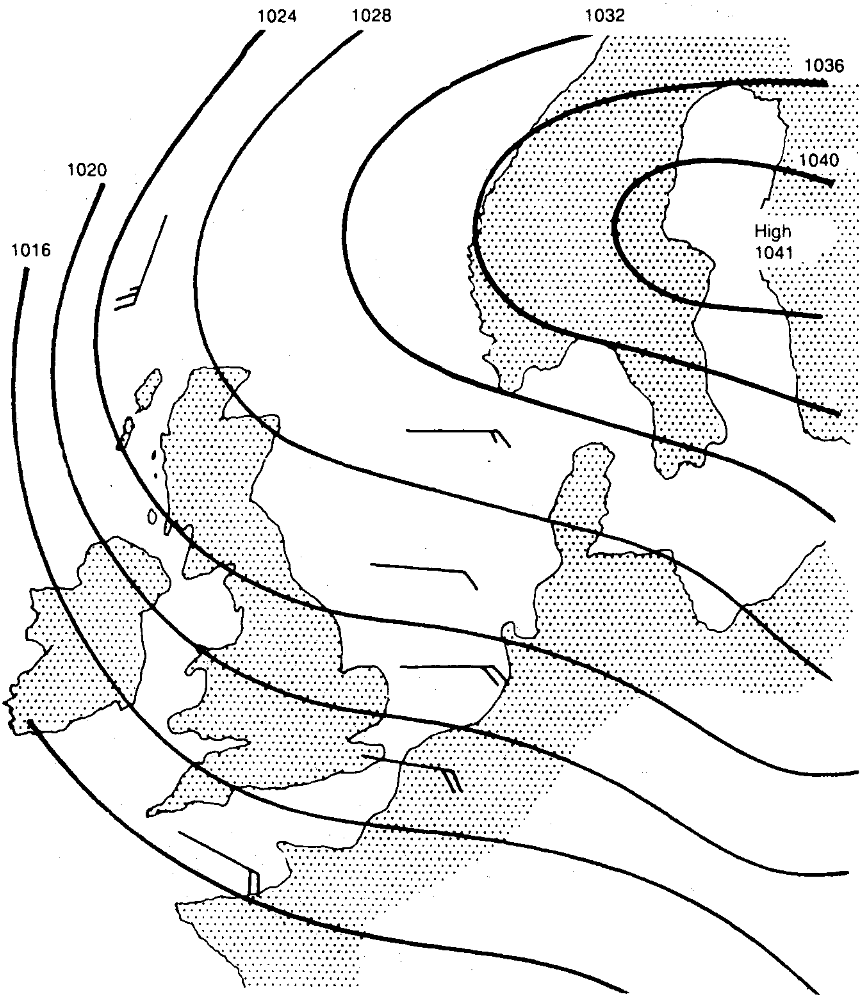


Figure 73 Easterly-type weather

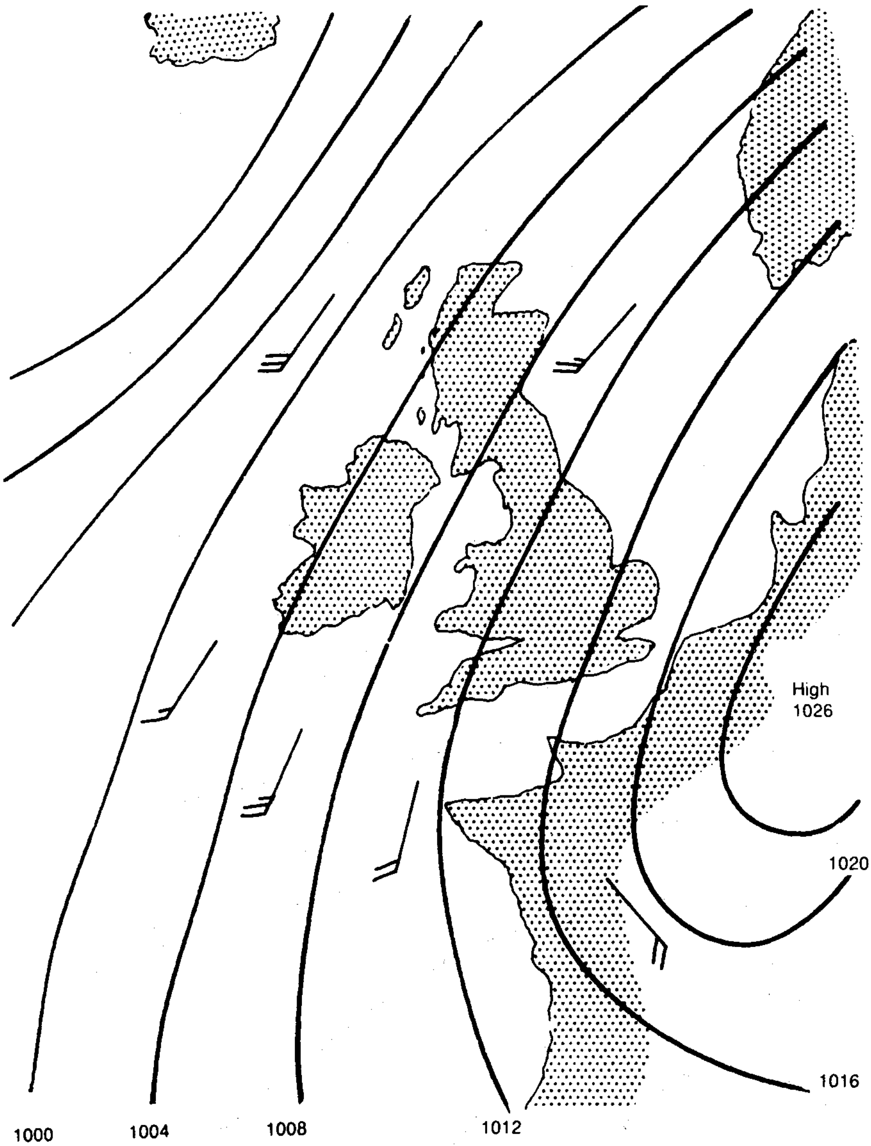


Figure 74 Southerly-type weather

pressure is somewhat lower. As these depressions pass to the south of the British Isles, easterly gales may be experienced together with prolonged snowfall over Southern England. If the Scandinavian high is joined to the Siberian high, the Easterly type weather will be very persistent.

When this type occurs in summer, very warm weather will be experienced, but is unlikely to last long.

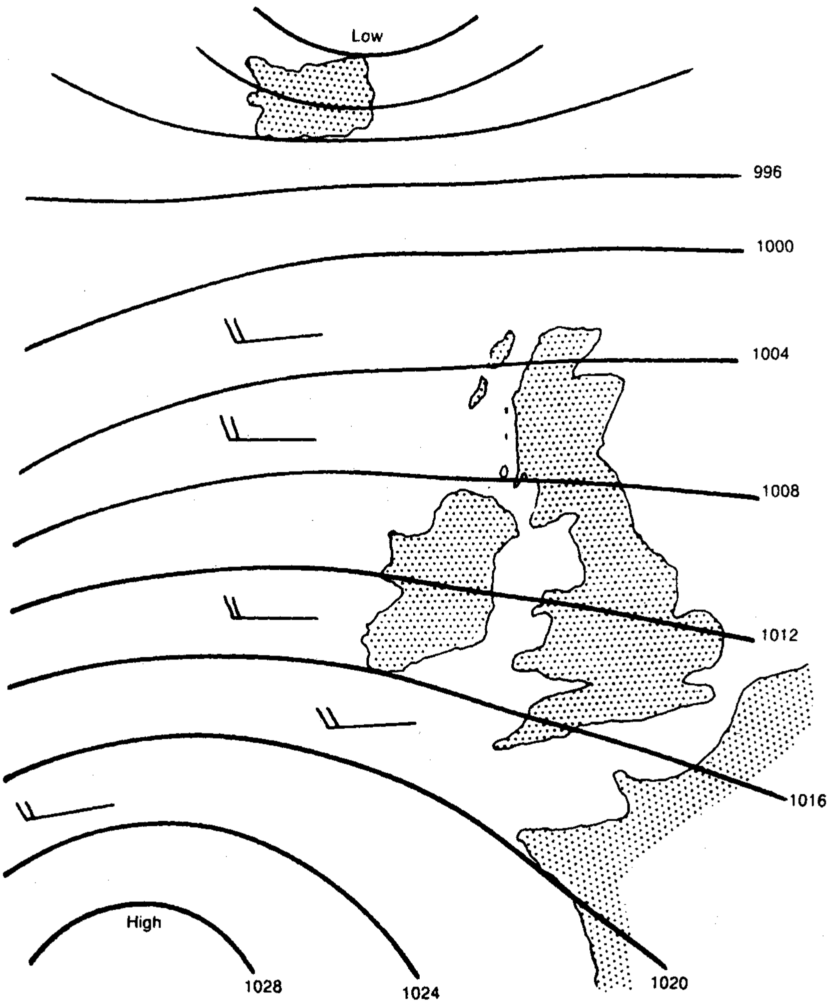


Figure 75 Westerly-type weather

Southerly type occurs mainly during the autumn and early winter when there is a high pressure over the continent. The British Isles experiences a warm, humid southerly to south westerly airstream, which is associated with the warm sectors of depressions on north north easterly tracks (Figure 74).

Westerly type may occur at any time (Figure 75). In winter, changeable weather may be expected as the high pressure is situated well to the south over the Azores, and the weather is influenced by passing depressions.

In summer, when the subtropical high pressure area is often situated well north of the Azores, fine sunny weather with light westerly winds can be expected.

CHAPTER SIX

Tropical Storms

It will be remembered that the air circulations of the northern and southern hemispheres are in opposite directions, so that disturbances which form in one hemisphere cannot cross into the other hemisphere.

The area near the equator is one of convergence as the northern hemisphere NE trade wind blows towards it, as does the SE trade of the southern hemisphere. The general name for this area is the **intertropical convergence zone** (ITCZ), also known as the doldrums.

When the ITCZ is well to the north or south of the equator, the change in direction of the trades after crossing the equator will cause very strong convergence currents and it is possible that a cyclonic disturbance will form in this area. The possibility is increased when the ITCZ is in the vicinity of islands, when local surface heating of air of high humidity gives rise to very unstable conditions.

Low pressure areas frequently occur in the ITCZ but cyclonic circulations can only result if the geostrophic force is sufficiently large (there is no geostrophic force on the equator) and this is unlikely in latitudes less than 5°.

The cyclonic disturbance, once formed, is known as a **tropical revolving storm** (TRS) whose diameter varies between 50 and 800 miles, 500 miles being an average. Wind speeds of over 130 knots may be experienced in the storm field, which should be avoided if at all possible. After formation between 5° and 10° of latitude, the storm moves westwards at 10–12 knots until reaching the tropic, where it slows down before recurving eastwards and proceeding at 15–20 knots to the higher latitudes.

Tropical revolving storms do not usually cross the land, but when they do, the supply of warm moist air necessary to their existence is cut off and they tend to fill. If they return to the sea they usually deepen again.

Wind velocities vary greatly, depending on the pressure gradient. The strongest winds are usually found just abaft the trough line in the dangerous semi-circle. The velocity is greatest here because the storm tends to force itself into the sub-tropical high pressure and therefore the isobars are packed more closely together, giving a greater pressure gradient and wind than in the navigable semi-circle where the isobars are not so packed. A similar packing of the isobars takes place on the equatorial side of many temperate latitude depressions.

In the central part of the storm (the eye or vortex) the winds are quite light, the sky is usually fairly clear as well, although conditions are far from pleasant as there is usually a high confused swell.

It must be emphasised that not all storms follow such an ideal path as that outlined above and shown in Figure 76. Reference to charts showing storm tracks shows what varied paths a TRS can take, but if the rules for avoiding storms are followed the storm centre can almost always be avoided.

Table 6.1 *Tropical revolving storms*

Area	*Name*	*Season*
North Atlantic Ocean Western side	Hurricane	June to November
North Pacific Ocean Eastern side	Hurricane or Cordonazo	June to November
Western side	Typhoon or Baguios	All the year, but greatest frequency and intensity June to November
South Pacific Ocean Western side	Hurricane	December to April
South Indian Ocean Eastern side	Willy-willy	December to April
Western side	Cyclone	December to April
Bay of Bengal and Arabian Sea	Cyclone	June and November, but may occur during the SW monsoon season

Table 6.1 shows the areas in which tropical storms are likely to be encountered, together with the most likely season and the local name. It will be noted that the TRS is not found in the South Atlantic or the eastern side of the South Pacific. Reference to Figures 42 and 43 will show that the ITCZ is at no time south of 5°S in these areas.

The following terms are in common usage when reference is made to a TRS; some are shown in Figures 76 and 77:

PATH The direction in which the storm is moving.
TRACK The area which the storm centre has traversed.
STORM FIELD The horizontal area covered by the cyclonic conditions of the storm.
SOURCE REGION The region where the storm first forms.

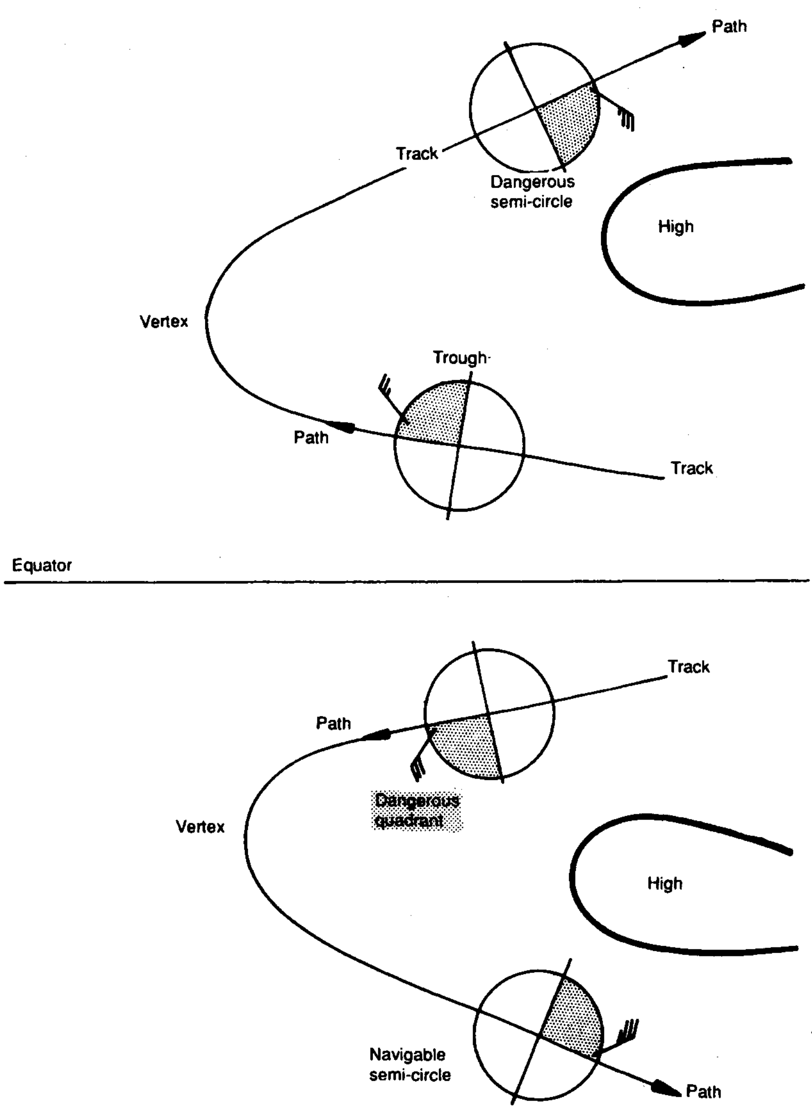


Figure 76 Tropical revolving storm

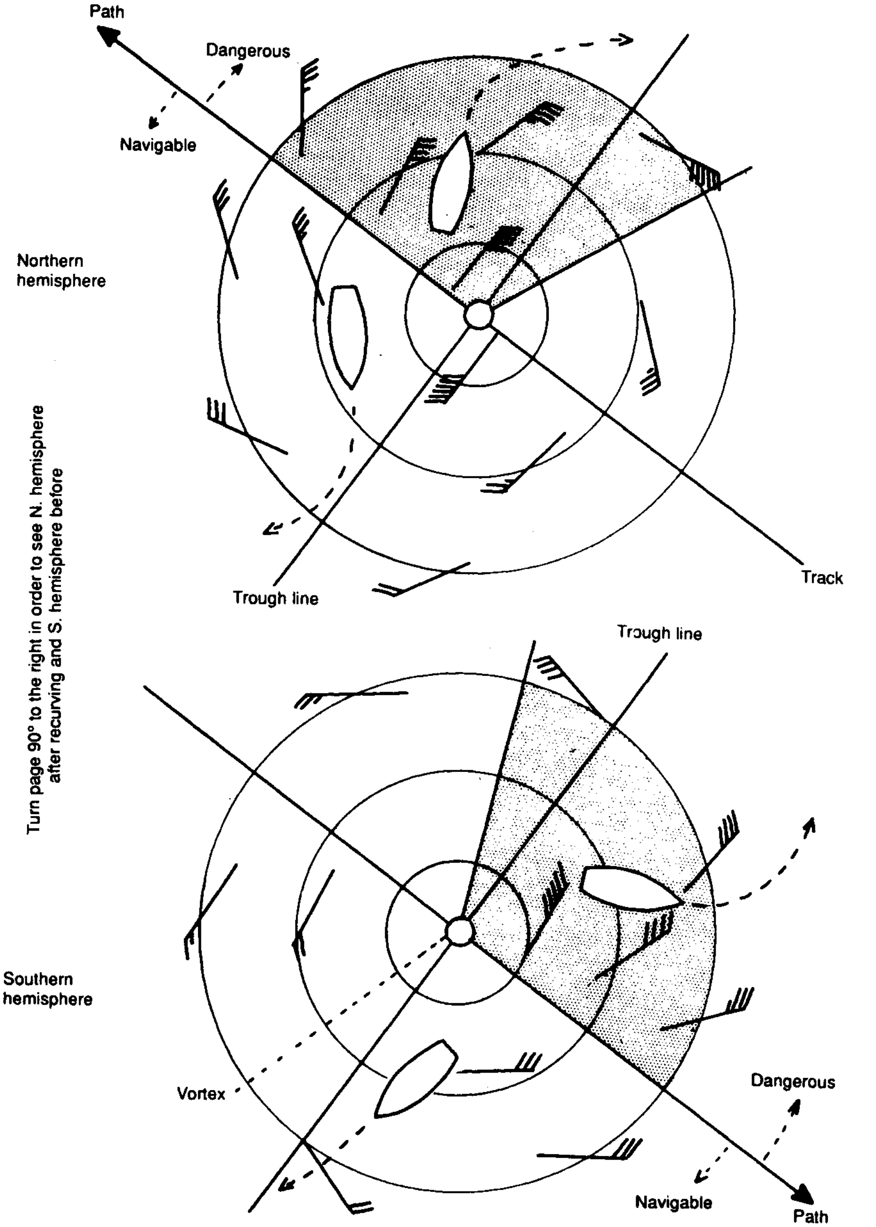


Figure 77 The navigable and dangerous semi-circles

VERTEX OR COD The furthest westerly point reached by the storm centre.
EYE OF THE STORM The storm centre.
BAR OF THE STORM The advancing edge of the storm field.
ANGLE OF INDRAUGHT The angle which the wind makes with the isobars.
VORTEX The central calm of the storm.
DANGEROUS SEMI-CIRCLE The half of the storm which lies to the right of the path in the Northern Hemisphere and to the left of the path in the Southern Hemisphere.
DANGEROUS QUADRANT The leading portion of the dangerous semi-circle where the winds blow towards the path.
NAVIGABLE SEMI-CIRCLE The half of the storm which lies to the left of the path in the Northern Hemisphere and to the right of the path in the Southern Hemisphere.
TROUGH LINE A line through the centre of the storm at right angles to the path. The dividing line between falling and rising pressure.

Some or all of the following signs will be evident as a TRS approaches.

1 A swell for no apparent reason. This may be felt up to 1000 miles from the storm centre.
2 Irregularity in the diurnal range of the barometer. In the tropics a barometer reading appreciably (3 mb) different from the corrected reading for that time, as shown on the weather chart, should be regarded with suspicion. Frequently, a slow fall occurs between 500 and 120 miles from the centre; the diurnal range is still noticeable on the barograph trace. Between 120 and 60 miles from the centre, the diurnal range is masked and the fall is distinct. From 60 miles to the centre the fall is very rapid, and after the centre has passed the rise will be just as rapid (Figure 78).

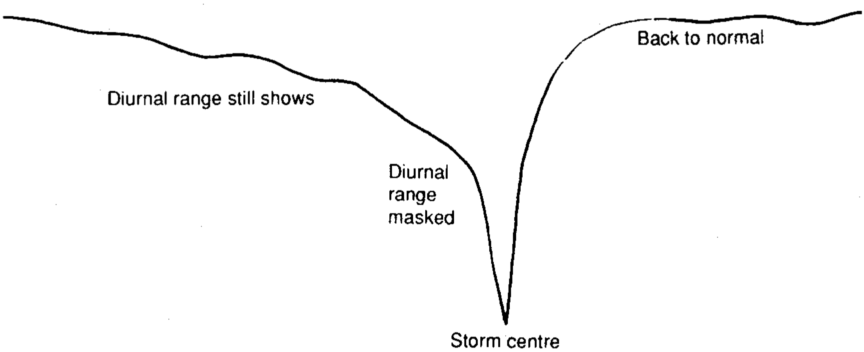


Figure 78 Barograph trace in the vicinity of a TRS

3 A change in the appearance of the sky. Cirriform cloud first appears with cirrus in bands converging towards the centre. This is followed by cirrostratus, cirrocumulus and then altocumulus with banks of black clouds on the horizon. The black cloud (nimbostratus) is called the bar of the storm. Up to this time precipitation has been sporadic but it now becomes continuous and is torrential.
4 An increase in velocity or change in direction of the trade wind, particularly with an unsteady barometer, usually indicates that a TRS is not very far away.
5 An oppressive feeling in the air.

Avoiding the storm centre

If a vessel gets within the storm field she should find her position relative to the centre as soon as possible.

This can be done in the following manner: after observing the wind direction, the storm centre can be estimated as being 12 points to the right of this direction in the Northern Hemisphere when the barometer starts to fall. If the barometer has fallen 10 mb the storm centre is approximately 10 points to the right of the wind and, when the barometer has fallen a further 10 mb, the centre is about 8 points to the right of the wind. If the vessel is in the Southern Hemisphere, left should be substituted for right in the foregoing explanation.

The storms on the western side of the South Indian Ocean have a very large angle of indraught, and in some parts the wind blows straight across the isobars towards the storm centre. In these cases the method of finding the approximate bearing of the centre fails. A freshening SE trade with a falling barometer indicates that the vessel is on the path of or in the dangerous semi-circle of a TRS.

The vessel's position in relation to the path of the storm may be found by noting the wind direction and then, after an interval of time, noting it once more. If the wind shifts to the right (veers), the vessel is in the right hand semi-circle, and if it shifts to the left (backs), the vessel is in the left hand semi-circle. This applies to both hemispheres. If there is no shift of wind, the vessel is on the direct path if the barometer is falling, or is proceeding at the same speed and in the same direction as the storm if the barometer is unchanged. If there is doubt as to the relative movement of the ship and storm, the ship should be stopped until this movement is found.

A continual check on the storm's movement must be made either by radio weather reports or, if these are not available, by estimation as outlined above.

When radio warnings of a storm's position and track are received, an allowance for error in the forecast position and track may be made as follows. Plot the given position of the storm centre. With this as centre, draw a circle with the storm's radius (half the forecast diameter – see Figure 79). Draw the storm's forecast path. Draw lines ahead of the storm tangential to the outside diameter of the storm and making an angle of about 40° with the path. With the storm's centre as centre, and

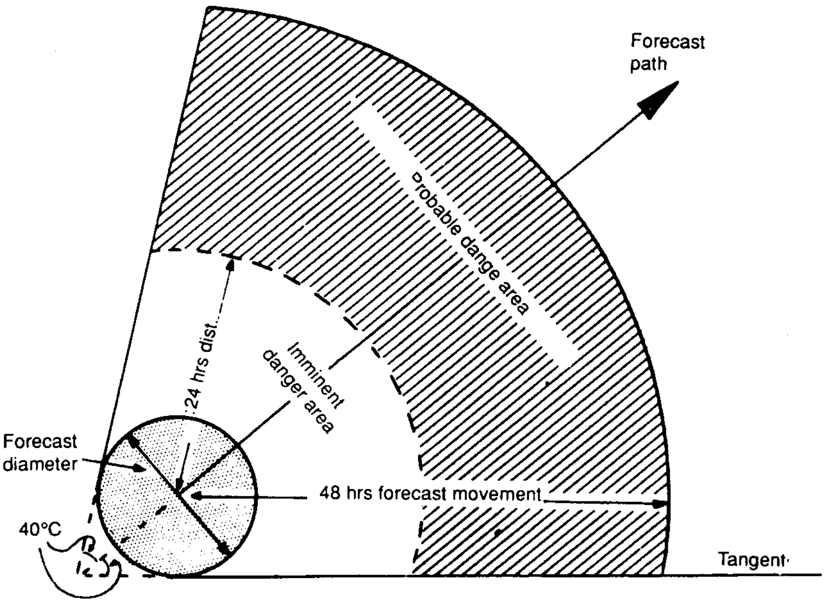


Figure 79 Identifying the danger area

a forecast day's movement as radius, draw an arc between the two 40° lines. Do likewise with a radius equal to two days' forecast movement. The area enclosed by the two-day arc and the 40° lines is a danger area and the ship's course and speed should be adjusted to try to avoid this area.

The danger area should be replotted each time a new radio report is received.

Rules for vessels navigating in the vicinity of a Northern Hemisphere TRS

If the vessel is in the dangerous semi-circle she should make as much speed as possible, keeping the wind on the starboard bow. If it is impossible to make headway because of bad weather or the proximity of land, the vessel should heave to with the wind and sea in as comfortable a position as possible. To have the sea on one bow and the wind on the other bow is often a good plan, as there is quite an angle between the wind and swell.

If the vessel is in the navigable semi-circle she should run with the wind on the starboard quarter, or if there is no room to run then she should heave to as above.

If the vessel is in the direct path she should run with the wind just abaft the starboard beam into the navigable semi-circle.

If the vessel is in the Southern Hemisphere the manoeuvres outlined above should be carried out reading Port for Starboard.

If the vessel is in a hurricane or typhoon anchorage she should have both anchors down with a good scope of cable; she should also have the engines in readiness to ease the strain on the cables.

If the vessel is in an open roadstead, she will probably have a better chance of weathering the storm if out at sea, but the decision to put to sea must be taken early, otherwise the vessel may well be caught on a lee shore.

If the vessel is alongside a wharf, all hatches should be securely battened down and derricks lowered and secured. Extra moorings should be put out fore and aft. Adequate fenders should be placed between the ship and the quay. It may be advisable to lay out the anchors. The engines should be ready for instant use. In many ports it is usual for the vessel to leave the wharf and proceed to a typhoon anchorage.

In all cases a vessel should be made as stable as possible, ballast tanks filled and free surface in tanks reduced as much as possible, as during a TRS the force of wind pressing on a ship's side will cause a considerable heeling moment which could have disastrous consequences. Cargo and other movable objects should be well secured or tommed off.

CHAPTER SEVEN

Currents and Ice

Most places have a daily or twice daily rise and fall of water level known as a tide. The change in level at a port is caused by water flowing into or out of that port. This water flow is a **tidal stream** which is caused by the gravitational effect of the sun and moon.

Ocean currents are not dependent upon gravitational effect but are caused by either a difference in level or a difference in density, in which case they are called **stream currents**, or by the wind blowing continuously over the surface in the same direction, in which case they are called **drift currents**.

Stream currents may attain a rate of 3 to 4 knots. The best known examples of these are the Gulf Stream, Kuro Siwo and the surface current through the Strait of Gibraltar into the Mediterranean (whose level has been lowered by evaporation).

Drift currents are usually of the order of 1 to 2 knots, the principal ones being the Southern Ocean or Great West Wind Drift and the Trade Drifts.

It will be realized that the measurement of current sets and drifts is difficult, as accurate DR and observed positions must be worked out by many ships on a worldwide basis before being collected and finally plotted. Drift bottles or plastic envelopes are extensively used, but even when these are recovered, one cannot tell whether or not the bottle or envelope has travelled direct from the position where it was thrown overboard, or how long it has taken on its journey, as it may have lain on the beach for days or weeks before being found.

Since the advent of gyro compasses and wireless time signals, many of the stronger currents and certain local currents have disappeared! Many local currents still remain but these are mainly counter currents which, because of land or sea bed configurations, flow in the opposite direction to the main current.

Figure 80 shows the principal currents. The terms 'warm' and 'cold' are relative, as the north flowing portion of the North Atlantic Drift is shown as being warm whereas the southern branch is shown as being cold.

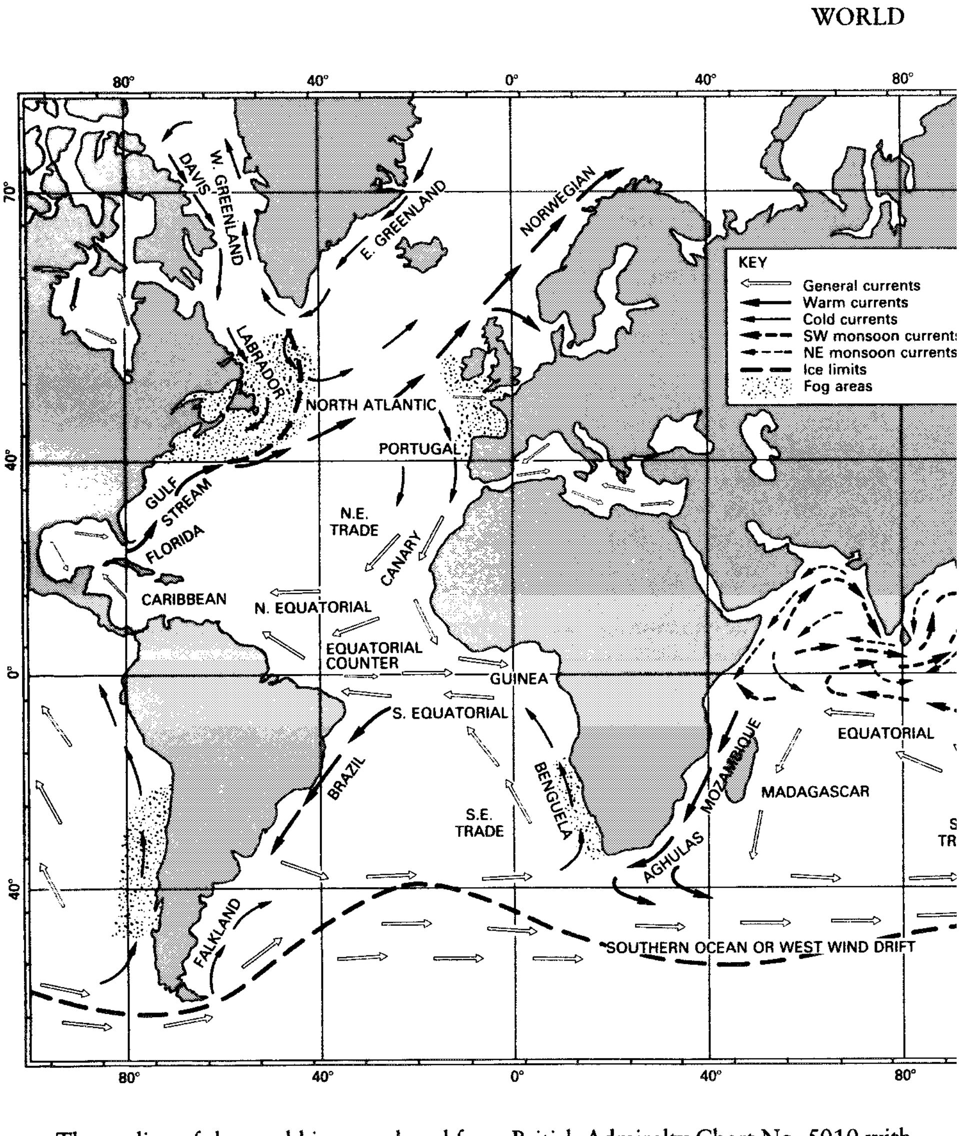
The temperature of the sea will vary from almost 32°C (90°F) in the equatorial regions to −2°C (28½°F) at the edge of the ice in the polar regions.

If the temperature of the water is −2°C for a considerable depth, ice will start to form at the surface. Navigation will not be impaired by thin ice, but unless specially strengthened for navigation in ice, no attempt should be made to force a ship through the thicker ice. However, in many areas where this occurs, icebreaker assistance is available. Due attention should be paid to broadcast warnings of ice conditions in the area the vessel is to transit. Broadcast messages frequently refer to the following ice terms, which are given in the order in which they generally form.

Sludge or slush The initial stages in the freezing of sea water, when its consistency is gluey or soapy.
Brash Small fragments and rounded nodules; the wreckage of other forms of ice.
Pancake ice Small pieces of new ice, approximately circular and with raised rims.
Young ice Newly formed ice.
Bay ice The young ice which first forms on the sea in autumn, and is of sufficient thickness to impede or prevent navigation.
Pack ice Term used in a wide sense to include any area of sea ice, other than fast ice, no matter what form it takes or how disposed.
Floe An area of ice, other than fast ice, whose limits are within sight.
Field ice Area of pack ice of such extent that its limits cannot be seen from the masthead.
Level ice All unhummocked ice, no matter of what age or thickness.
Hummock A ridge or elevation on a floe due to pressure.
Pressure ridge Hummocked ice where floes have been pressed together and broken against each other.
Bergy-bits Medium-sized pieces of glacier ice, or of hummocky pack, washed clear of snow. Typical bergy-bits have been described as about the size of a cottage.
Growlers Smaller pieces of ice than bergy-bits, appearing greenish in colour, because barely showing above water.
Rotten ice Floes which have become much honeycombed in the process of melting.
Fast ice Sea ice which remains fast in the position of growth throughout the winter, and sometimes even during the ensuing summer.
Land ice Ice attached to the shore, within which there is no channel.

Icebergs

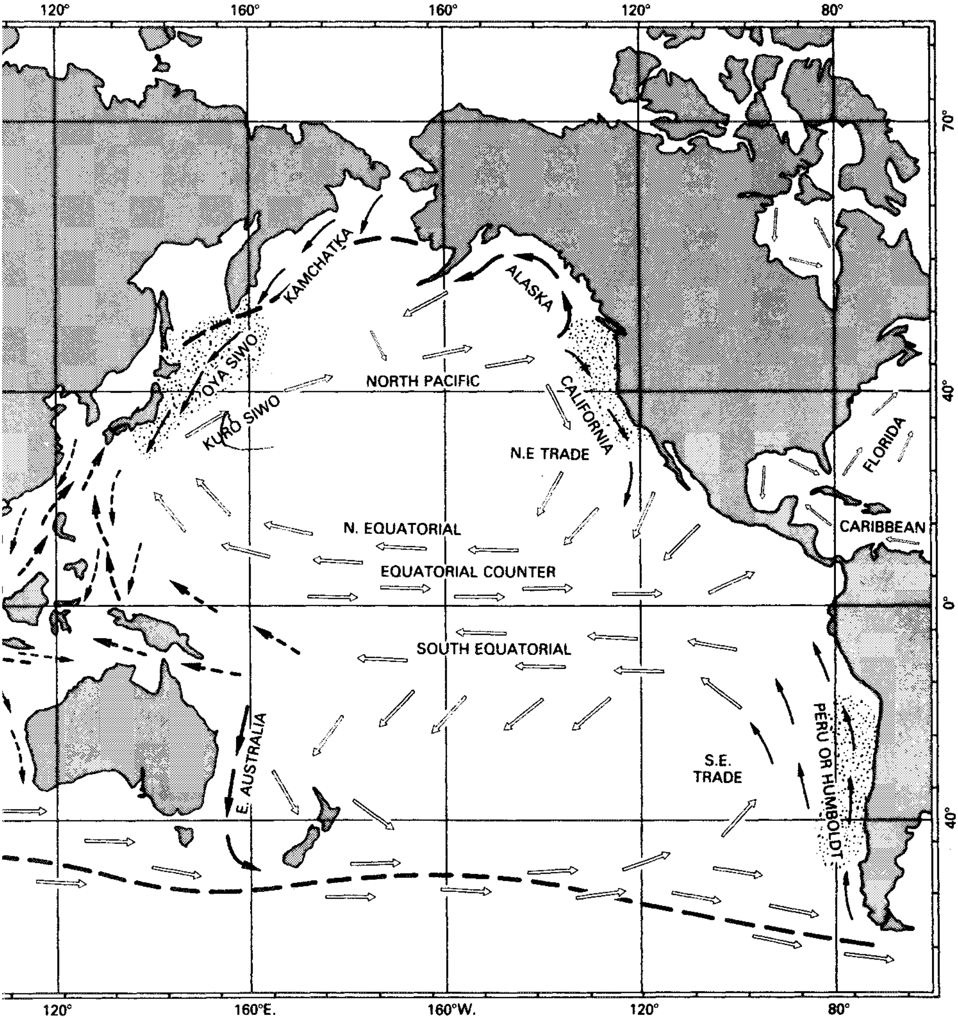
Large masses of land ice which become detached are known as **icebergs**. In the Northern Hemisphere these bergs are 'calved' from the glaciers on the east and west coasts of Greenland (Figure 81). Many of these bergs get stuck fast in the pack ice on the east Greenland coasts, but those that do not are taken south by the East Greenland current to Cape Farewell, whence they are carried into the Davis Strait



The outline of the world is reproduced from British Admiralty Chart No. 5010 with the permission of H.M. Stationery Office and of the Hydrographer of the Navy.

Figure 80 World currents

CURRENTS


120°
160°
160°
120°
80°
70°
40°
0°
40°
KAMCHATKA
ALASKA
OYA SIWO
KURO SIWO
NORTH PACIFIC
CALIFORNIA
N.E TRADE
FLORIDA
N. EQUATORIAL
CARIBBEAN
EQUATORIAL COUNTER
SOUTH EQUATORIAL
E. AUSTRALIA
PERU OR HUMBOLDT
S.E.
TRADE
120°
160°E.
160°W.
120°
80°

where they melt. Other large bergs calved up on the west Greenland coast are carried northward to Baffin Bay before returning south in the Labrador current to reach the shipping lanes off the Banks of Newfoundland. Due to the short summer, the bergs usually reach the shipping lanes the year after they have calved, having been frozen in the pack ice for their first winter. The maximum size of a northern berg is unlikely to exceed 1/4 mile in length. Its height may be up to 90m (270 ft). It should be noted that about 89% of the iceberg is submerged and the underwater portion may extend laterally quite a way from the portion above water. The eastern limit of the area in which icebergs may be found is about 40°W and the southern limit about 40°N.

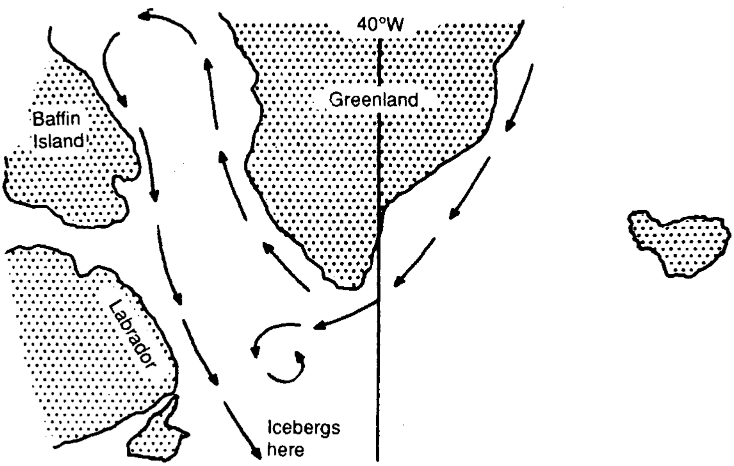


Figure 81 Icebergs in the northern hemisphere

In the Southern Hemisphere the bergs are calved from the ice foot and tend to be flat topped or tabular up to 60 m (180 ft) high. Their length is considerably greater than the Northern Hemisphere bergs. Bergs up to 70 miles long and 10 miles wide have been reported. The bergs are rarely encountered to the northward of 40°S and, as there is not much traffic in the higher southern latitudes, less importance is attached to southern bergs than to their northern counterparts.

Indications of ice

1 Ice blink by day and night. A yellowish white light reflected from the ice onto the sky near the horizon.
2 There is often a wall of thick fog at the ice edge.
3 A rapid fall in the sea temperature to below freezing.
4 Herds of seals or flocks of birds far from land.

5 Absence of sea or swell in a fresh breeze is an indication of ice or land to windward.
6 Noise of the ice cracking or falling into the sea may be heard.
7 Radar. The echoes will depend on the configuration of the ice: also, in the case of a berg, on the amount of moraine (glacial material) in it. It should be noted that radar is not infallible in picking up ice.
8 On calm days echoes may be heard from higher ice.

Navigating in ice

Vessels navigating in areas where icebergs may be encountered should go at a moderate speed keeping a good lookout. If in fog, as frequently occurs on the Banks of Newfoundland, extra special care must be taken.

If navigating through pack ice, the lanes and leads should be followed. The leads may be seen showing up as dark lines or patches on the ice blink. The greatest care must be exercised to prevent the vessel becoming 'nipped' in the ice. This may occur if the ice is hummocking, and no attempt should be made to enter or cross ice which is forming these pressure ridges.

If collision with a berg cannot be avoided then every endeavour should be made to collide with it head on.

International ice patrol service

This service is financed by the countries whose shipping uses the Northern Atlantic, but is maintained by United States Coast Guard vessels whose call sign whilst on ice patrol is NIDK. The object of this patrol is to locate by air and surface scouting, and radio information from all sources, the icebergs and field ice nearest to and menacing the North Atlantic Lane Routes. The southerly limits of the ice will be determined, and contact maintained with the ice as it moves south, by a continuous surface patrol.

The patrol continues throughout the ice season from approximately 1 March to 1 July, or later or earlier if conditions warrant it.

Ships sighting ice should report its position to the ice patrol vessel, or to the headquarters of the service at Argentia Newfoundland, call sign NIK.

North Atlantic lane routes

Vessels trading across the North Atlantic are expected to keep to the track specified for the time of year. There are seven of these tracks, each track having westbound and eastbound routes.

The Transatlantic Track Association comprises the principal North Atlantic Shipowners and decisions made by them are communicated by means of Notices to Mariners and the shipping press.

CHAPTER EIGHT

Weather Charts and Routeing

Synoptic charts

In addition to the Ocean Weather Ships, which are stationed permanently at selected positions in the North Atlantic, there are merchant ships observing and radioing weather information every six hours. From this information and from information supplied by land stations all over the Northern Hemisphere, the Meteorological Office prepares weather charts.

Selected and Supplementary Ships radio their position, the wind direction and speed, the pressure and temperature, the amount of cloud and cloud types, the visibility, and the past and present weather. Selected ships also radio information about the sea temperature, the dewpoint temperature, waves and the ship's course and speed. The information to be radioed is coded in the form given in the 'Decode for Use of Shipping' (Met.O.509) to which reference should be made for full details of weather messages.

Weather forecasts for shipping are broadcast by the BBC on the 1500 metre wavelength programme. The forecast areas lie to the east of 40°W and between 35°N and 60°N, the areas around the coasts of the British Isles being smaller than those in the Atlantic.

An Atlantic Weather Bulletin for Shipping from 'Bracknell Weather' to 'All Ships' is broadcast from Portishead radio. This broadcast is in six parts, parts I, II, and III consisting of storm warnings, a synopsis of weather conditions and weather forecasts for areas from 35°N to 65°N between 15°W and 40°W. These are all given in plain language and are broadcast at 0930 and 2130 GMT.

Parts V and VI are also broadcast at 0930 and 2130 GMT, and consist of a selection of ship and shore reports. These are broadcast in code and besides the ships' positions and station identification numbers the following information is included: the wind direction and speed in knots, the barometric pressure, the air temperature, cloud amount, visibility, and past and present weather. This information can be plotted in the form of a station model, as shown in Figure 82, at

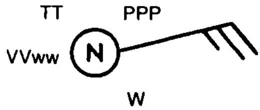


Figure 82

the approximate position on a chart. The ideal chart for plotting weather observations is Metform 1258.

PPP is the pressure; the initial 9 or 10 is usually omitted.
TT is the air temperature.
VV is the code figure for the visibility.
N is the Beaufort symbol for the cloud amount.
ww is the Beaufort symbol for the present weather.
W is the Beaufort symbol for the past weather.

The line with the feathers represents the wind direction and speed. The arrow flies with the wind and a speed of 5 knots is represented by a short feather, 10 knots by a long feather, 15 knots by a short and a long feather, and so forth. The feathers always point towards the low, so that in the northern hemisphere the feathers are always on the observer's right hand when he faces the wind. In Figure 82, a wind of 075°T 25 knots has been plotted.

Part IV of the bulletin is broadcast at 1130 GMT and consists of a weather analysis. Contained herein is sufficient information to construct a weather chart. Metform 1258 should be used for the plotting of the following given data:

The positions of high, low or other pressure systems.
The type of front and its positions.
The positions of selected isobars.

When the information given in parts IV, V and VI of the Atlantic Weather Bulletin has been plotted on Metform 1258, the chart should be completed by drawing in isobars at 4 millibar intervals between those given in Part IV.
Bearing in mind the rules for the movement of depressions given in Chapter 5 and the pressure characteristic (broadcast in Part IV), a weather forecast may be made for a selected position for the next few hours.

If examination candidates have to construct a weather chart from coded information similar to that broadcast in the Atlantic Weather Bulletin, the Decode Book Met. 0.509 will be supplied but, nevertheless, practice is required in plotting the data and drawing in the isobars if the chart is to be completed within the time available. It is suggested that this practice could be done most profitably at sea, using actual broadcast information.

It is also suggested that candidates who are pressed for time should only put in the wind, temperature and pressure on the station model.

It may be found occasionally that some information in Part IV, V or VI does not correspond with the general synoptic situation. This should be disregarded, as there may have been an error in receiving or decoding the message.

Facsimile weather charts

Vessels fitted with facsimile plotters can receive signals by radio which will produce, on a moving roll of paper, a weather chart in the same form as those drawn by the Meteorological Office. This removes any possibility of mistakes in reading, decoding or plotting weather information sent out by code as in the Atlantic Bulletin.

Impressions of black or white signals are made on a roll of paper as it passes an electronic marker pen. Different types of transmissions require different drum speeds and in order that the chart reproduction is perfect the receiver must be kept correctly tuned and the drum speed also correct throughout the transmission. Any spots which are too dark or insufficiently dark cannot be overprinted by the machine as the transmission takes several minutes and the chart cannot be fed back into the machine. If a bad chart is produced a further chart will have to be produced at the next transmission.

Full details of the scale and type of the map projection, the drum speed, the type of chart (surface analysis, surface prognosis i.e. forecast, wave analysis, wave prognosis, sea ice observations etc.), the transmitting stations with wavelengths and times are given in Volume III of the List of Radio Signals.

Weather routeing

This is carried out by private companies in the USA and by the British Meteorological Office in the UK. A small charge is made for the service.

During the comparatively short period that it has been in operation, many hundreds of crossings of the North Atlantic have been made by vessels using this service. Whilst it is impossible to give the time saved or reduction in heavy weather damage for individual passages, the average time taken by weather-routed vessels is less than that of similar vessels not so routed and the damage caused by heavy weather during a routed period is significantly less than that during a similar period when not routed. The following description of weather routeing is taken from the Meteorological Office leaflet on weather routeing with the permission of the Controller of HM Stationery Office and the Director of the Meteorological Office.

To enable ships to make the best of the weather the British Meteorological Office offers a weather routeing service for vessels trading on the North Atlantic. Voyages in both east–west and west–east directions are covered and ships of any nation may participate.

Each ship is given individual advice on the best course to steer in order to avoid heavy weather as far as possible. The Master still remains responsible for deciding his course, but experience has shown that the use of weather-routeing advice can offer the following advantages:

Higher speeds
Quicker crossings
Better punctuality
Greater comfort for passengers and crew
Less damage to ships
Less damage to cargoes
More opportunities for maintenance at sea.

Just before sailing, the Master contacts the Meteorological Office at Bracknell where the Central Forecast Office gives advice covering at least the next 48 hours. This can be very important. For example, should a ship leaving Liverpool go north around Ireland, or will it pay to go the longer way via Fastnet? The shortest route is not always the quickest.

This initial advice is followed by further advisory messages transmitted to the ship by Portishead Radio. These are normally sent every 48 hours, but messages can be sent more frequently – every 12 hours if necessary. These messages advise the course to follow and, if required, a special weather forecast for 48 hours and forecasts of wind and sea can also be provided.

The Central Forecast Office at Bracknell receives a constant flow of meteorological data from the North Atlantic and adjacent areas. These data are fed into a high-speed electronic computer which produces regular forecasts for the North Atlantic for 2–3 days ahead. The computer converts the predicted wind field into wave heights and makes allowance for swell. Comprehensive information about currents and ice movements is also available. In order to know as much as possible about the performance of an individual ship in varying wave and weather conditions, the Office asks in advance for all the necessary details about each ship and each voyage, including, for example, the size, draught and loading of the vessel and any special characteristics which might affect her performance on a particular crossing.

Armed with all this information, expert weather forecasters, aided by nautical officers with long ocean-going experience, calculate the best course for the ship to follow during the next 48 hours to enable it to reach its destination in the shortest time and with the minimum of bad weather. Sometimes, of course, bad weather is too widespread to avoid completely, but practical experience has proved that over a few voyages weather routeing soon pays for itself in terms of time saved and damage avoided.

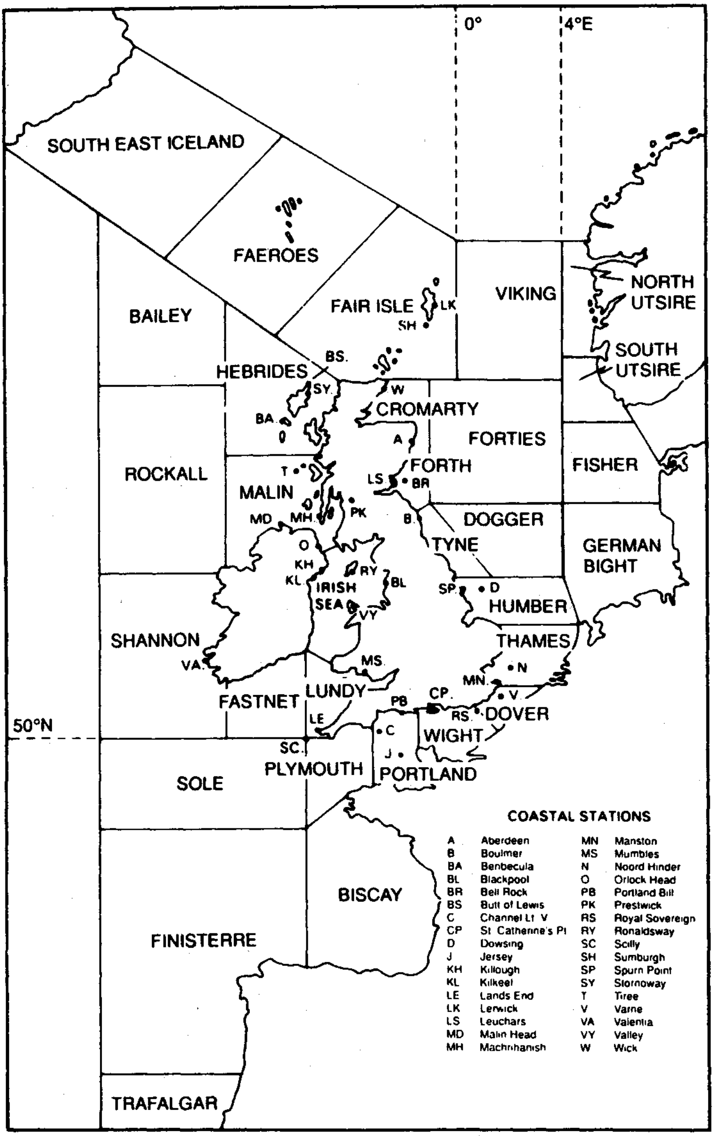


Figure 83 Sea areas and coastal stations used in marine forecasts prepared by the Meteorological Office at Bracknell and broadcast by the BBC and Coast Radio Stations, incorporating changes to areas made in 1984. Weather within an estuary, and particularly visibility, may often be expected to differ from that forecast for the coastal sea areas within which the estuary lies, though this will not necessarily be mentioned in the forecast.

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