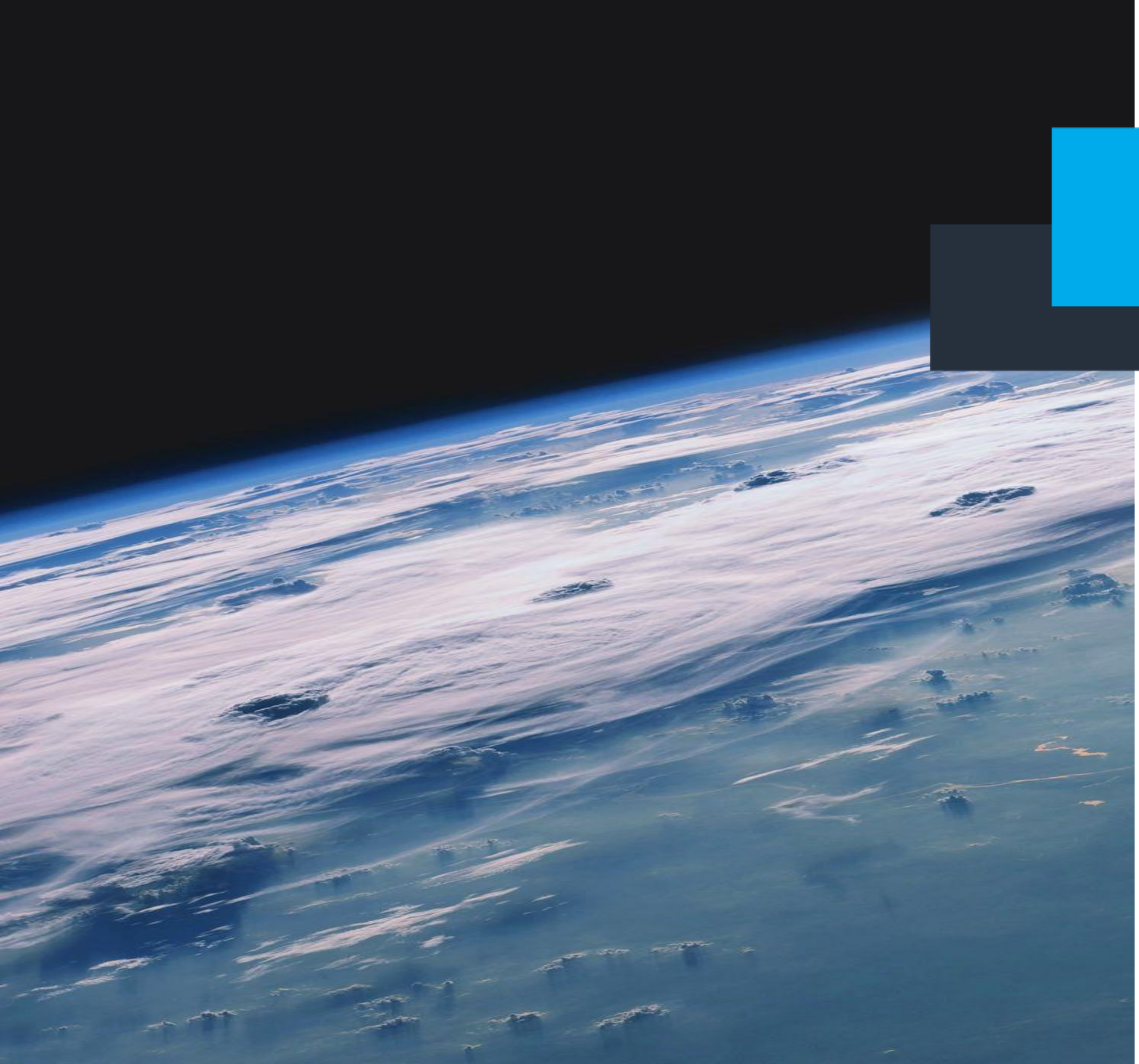
Meteorology



Chapter 1

The Atmosphere

Reasons for Studying Meteorology

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

The Constituents of the Atmosphere

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

Plus traces of other gases

- The proportions of the constituents remain constant up to a height of at least 60 km .

- the trace of ozone in the atmosphere is important as a shield against ultraviolet radiation, if the whole of the layer of ozone were brought down to sea level it would only be 3 mm thick.

Properties of the Earth's Atmosphere

The earth's atmosphere varies vertically and horizontally in:

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

The Structure of the Atmosphere

The Troposphere :

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

The Stratosphere :

is the layer above the troposphere where temperature initially remains constant to an average height of 20 km then increases to reach a temperature of -2.5°C at a height of 47 km, then above 51 km temperature starts to decrease again.

The Tropopause :

• This marks the boundary between the troposphere and the stratosphere and is where temperature ceases to fall with an increase in height.
Practically taken as the height where the temperature fall is less than 0.65°C per 100 m (2°C per 1000 ft.)
• The height of the tropopause is controlled by the temperature of the air near the surface. The warmer the air, the higher the tropopause. The colder the air, the lower the tropopause.
• The temperature of the tropopause is controlled by its height. The higher it is, the colder the temperature at the tropopause. The lower it is, the warmer the temperature at the tropopause.
The temperature at the tropopause can be as high as -40°C over the poles and as low as -80°C over the Equator.

The Significance of Tropopause Height

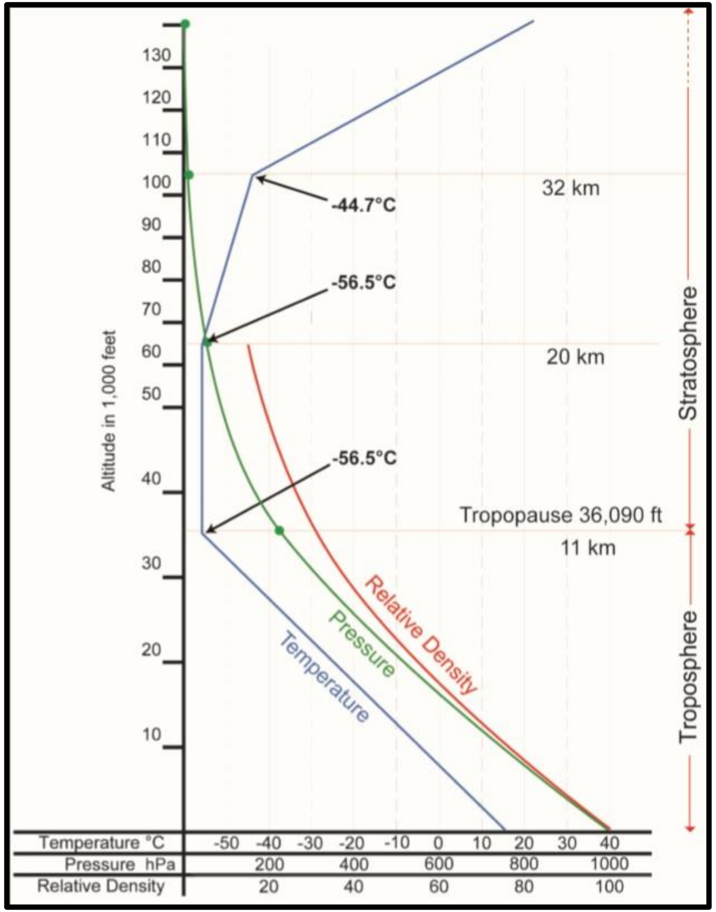
- the maximum height of significant cloud.
- the presence of jet streams.
- the presence of Clear Air Turbulence (CAT). It is now referred to as TURB.
- the maximum wind speed.
- the upper limit of most of the weather

Temperatures

- Temperature in the troposphere increases from the poles to the Equator.
- Temperature in the lower stratosphere increases from the Equator to the poles in summer.

The International Standard Atmosphere (ISA)

- a MSL temperature of +15° Celsius,
- a MSL pressure of 1013.25 hectopascals (hPa),29.92 inch,760 mm
- a MSL density of 1225 grams / cubic metre,
- a lapse rate of 0.65°C/100 m (1.98°C/1000 ft) up to 11 km (36 090 ft),
- a constant temperature of -56.5°C up to 20 km (65 617 ft),
- an increase of temperature 0.1°C/100 m (0.3° C/1000 ft), up to 32 km (104 987 ft).


130
120
110
100
90
80
70
60
50
40
30
20
10
Altitude in 1,000 feet
-44.7°C
-56.5°C
-56.5°C
32 km
20 km
Tropopause 36,090 ft
11 km
Stratosphere
Troposphere
Relative Density
Pressure
Temperature
Temperature °C -50 -40 -30 -20 -10 0 10 20 30 40
Pressure hPa 200 400 600 800 1000
Relative Density 20 40 60 80 100

ISA Deviation

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

ISA Deviation = actual temperature - ISA temperature

Height change in hpa in feet (pressure lapse rate)

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

0-5000	27
5-10	31
10-18	36
18-30	48
30-36	73
36-45	103

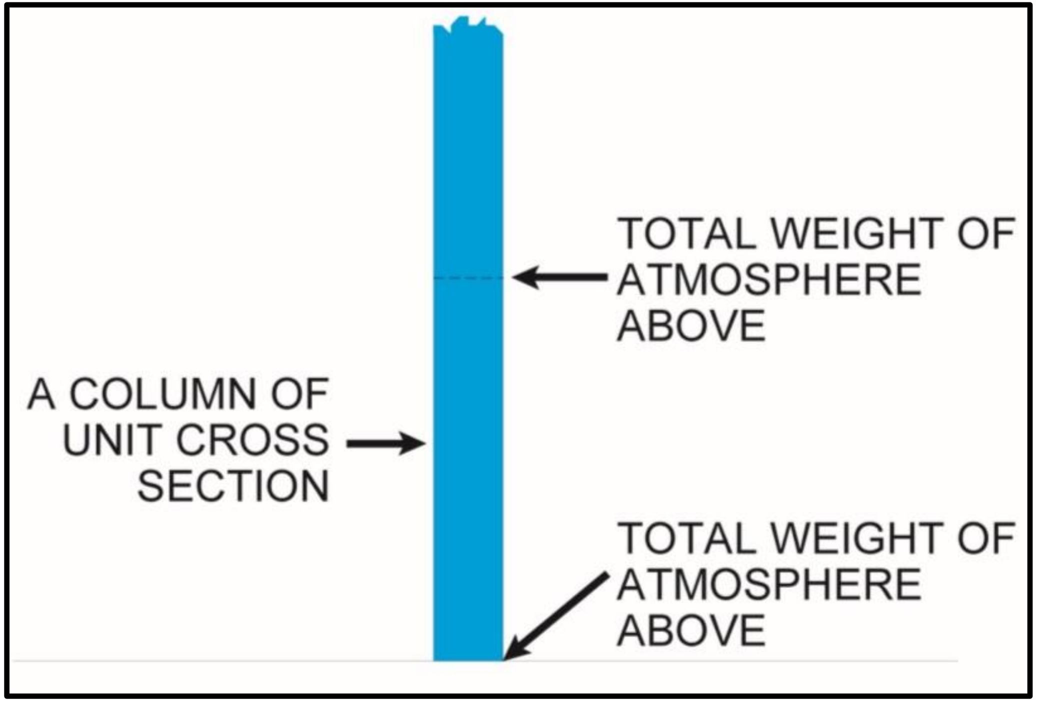
H = height change per hPa in feet
T = Actual Absolute Temperature at that level in kelvin (K)
P = Actual Pressure in hPa

Chapter 2

Pressure

Atmospheric Pressure

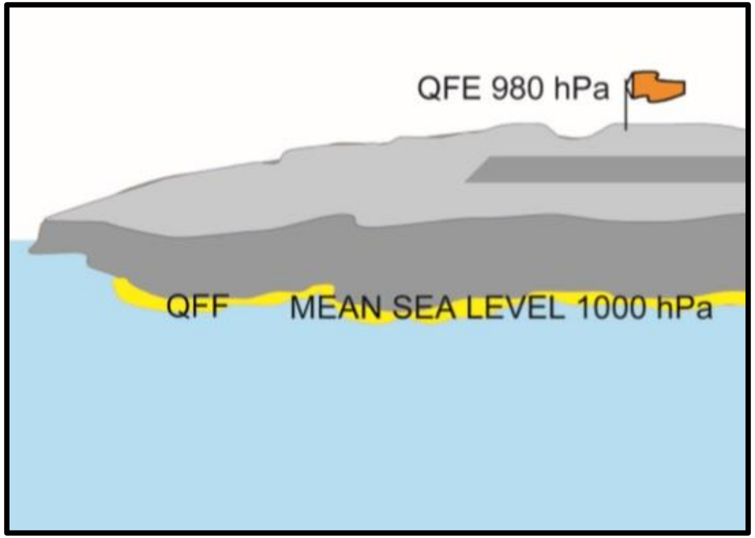
Atmospheric pressure is the force per unit area exerted by the atmosphere on any surface in contact with it.
Thus atmospheric pressure will decrease with an increase in height.



Types of Pressure

- **QFE**

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



- **QNH**

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

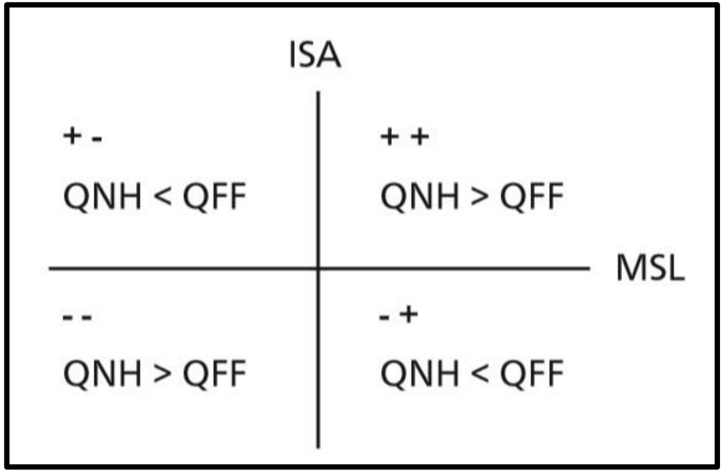
- **QFF**

QFE converted to mean sea level using the actual temperature.

ISOBAR

A line joining places of the same atmospheric pressure (usually MSL pressure QFF).

relationship between QFF and QNH



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

Stations at MSL Regardless of temperature QNH = QFF = QFE

Chapter 3

Density

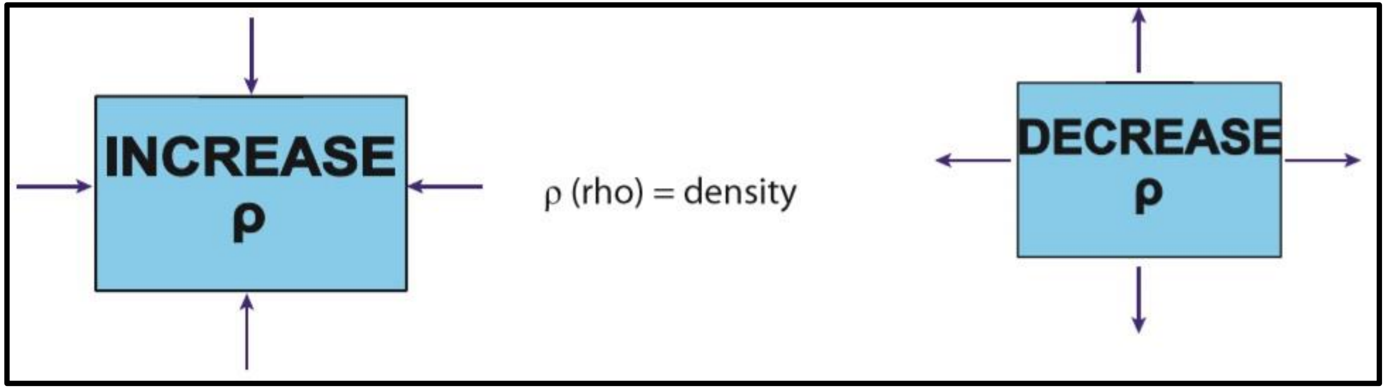
Introduction

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

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

Effect of Changes of Pressure on Density

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



DENSITY IS DIRECTLY PROPORTIONAL TO PRESSURE

Effect of Change of Temperature on Density

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

DENSITY IS INVERSELY PROPORTIONAL TO TEMPERATURE.

Effect of Changes in Humidity on Density

DENSITY IS INVERSELY PROPORTIONAL TO WATER VAPOUR CONTENT

Effect of Change of Altitude on Density

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

Effect of Change of Latitude on Density

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

• at the surface density increases as latitude increases

• at about 26 000 ft density remains constant with an increase in latitude.

• above 26 000 ft density decreases with an increase in latitude. (Maximum deviation from standard occurs at about 50 000 ft.)

Chapter 4

Pressure Systems

Introduction

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

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

Buys Ballot's Law

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

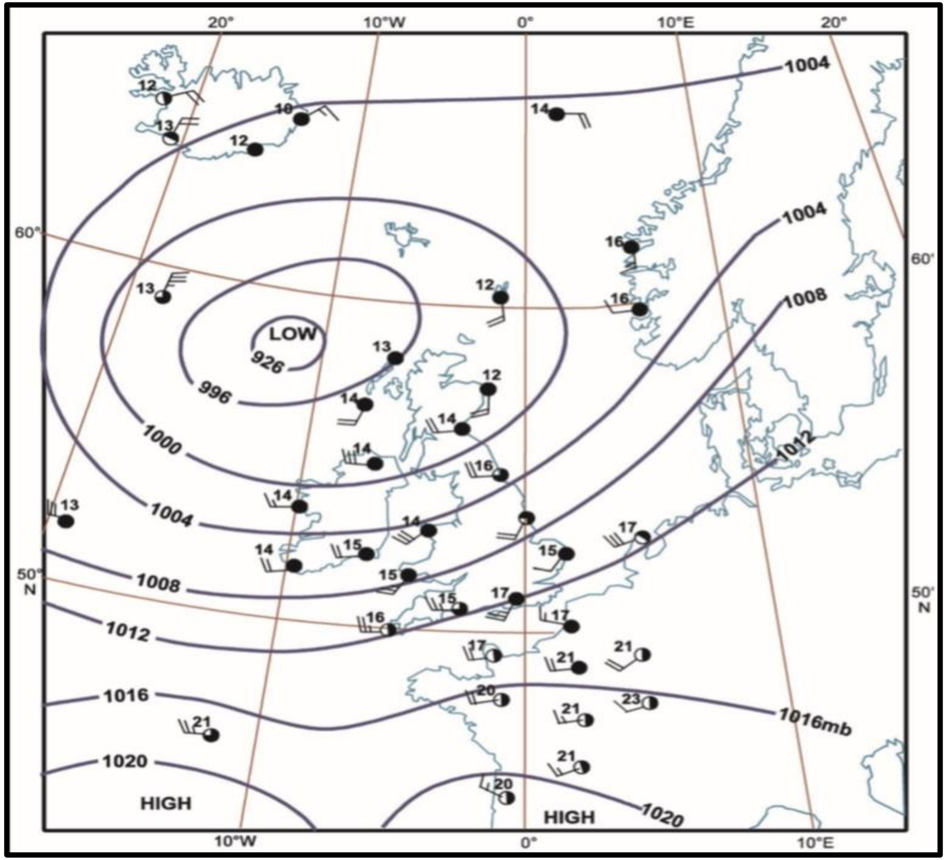
Advection

Advection is a meteorological term for horizontal movement of air.

Depressions

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

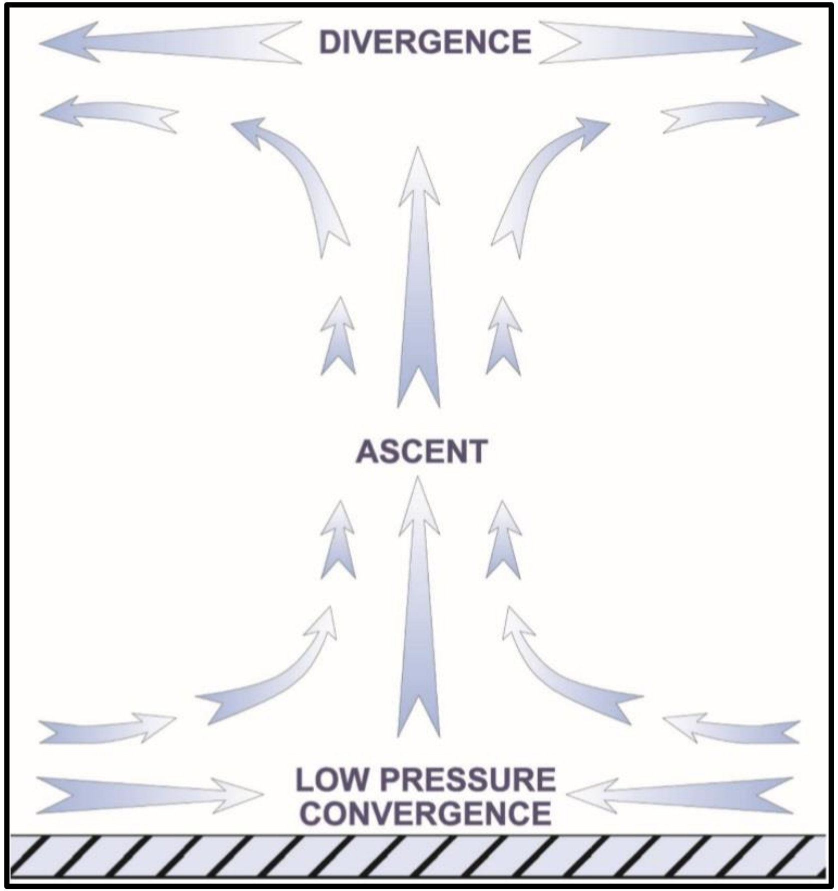
There are two types of depression, frontal (large scale) found in our temperate latitudes and non-frontal (small scale) depressions which can occur virtually anywhere.



In a depression

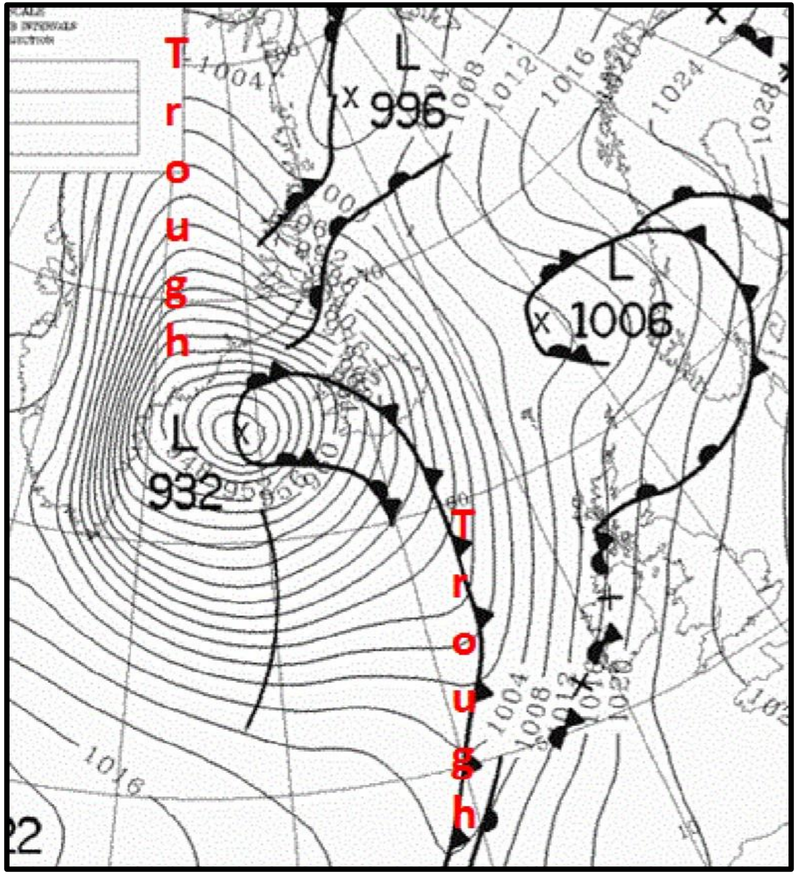
- air is converging at the surface
- rising from the surface to medium to high altitude (convection)
- diverging at medium to high altitude

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



Troughs

A trough is an extension of a low pressure system. The weather associated with a trough will be similar to that of a depression.



Depression Weather

- **Cloud**

extensive and may extend from low altitude to the tropopause.

- **Precipitation**

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

- **Visibility**

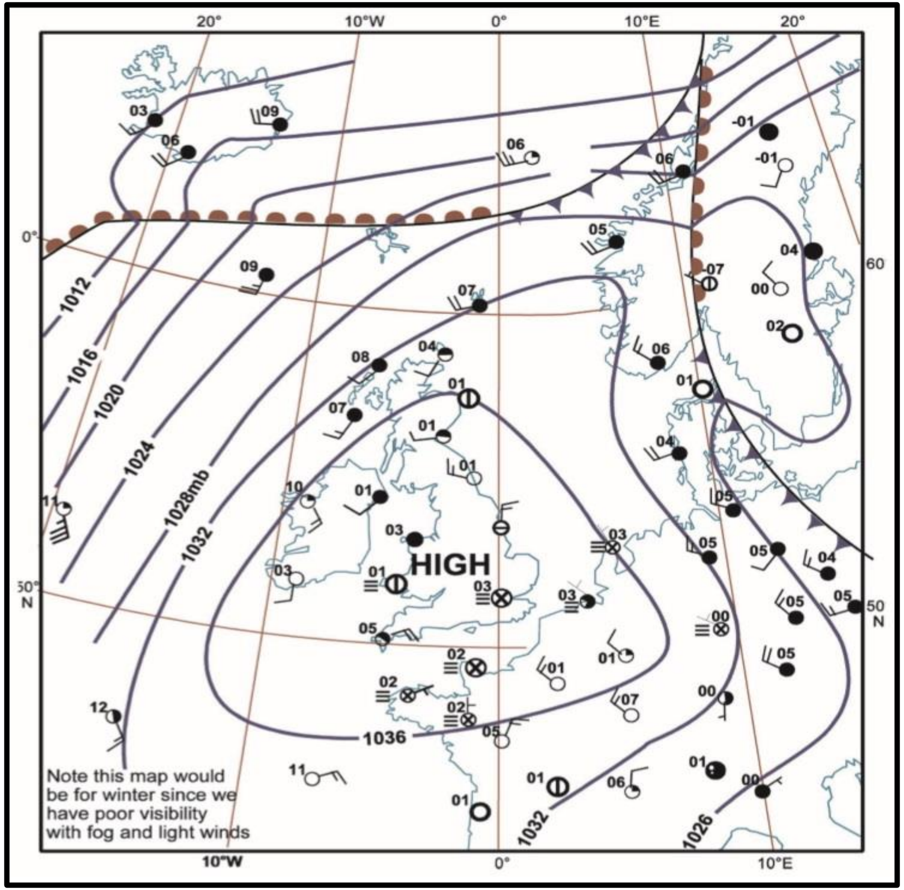
Poor in precipitation, otherwise good due to ascending air.

- **Winds**

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

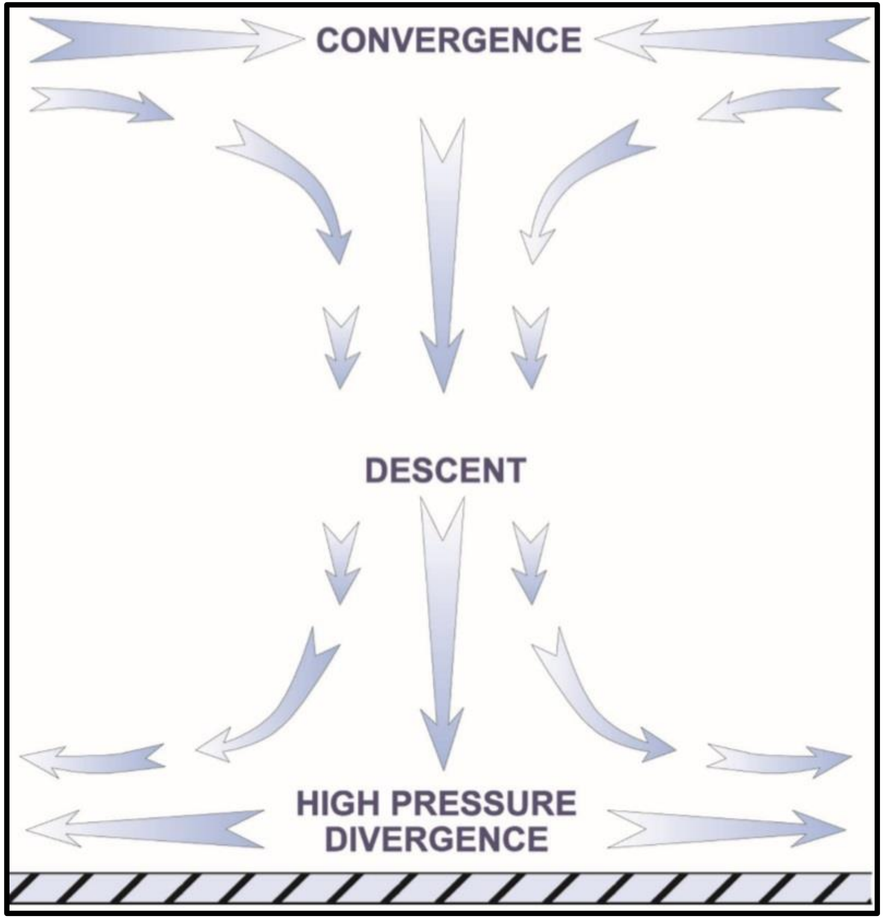
Anticyclones

An anticyclone or high is a region of relatively high pressure shown by more or less circular isobars similar to a depression but with higher pressure at the centre. Isobars are more widely spaced than with depressions. There are five types of anticyclone, warm, cold, temporary cold, ridges (or wedges) and blocking.



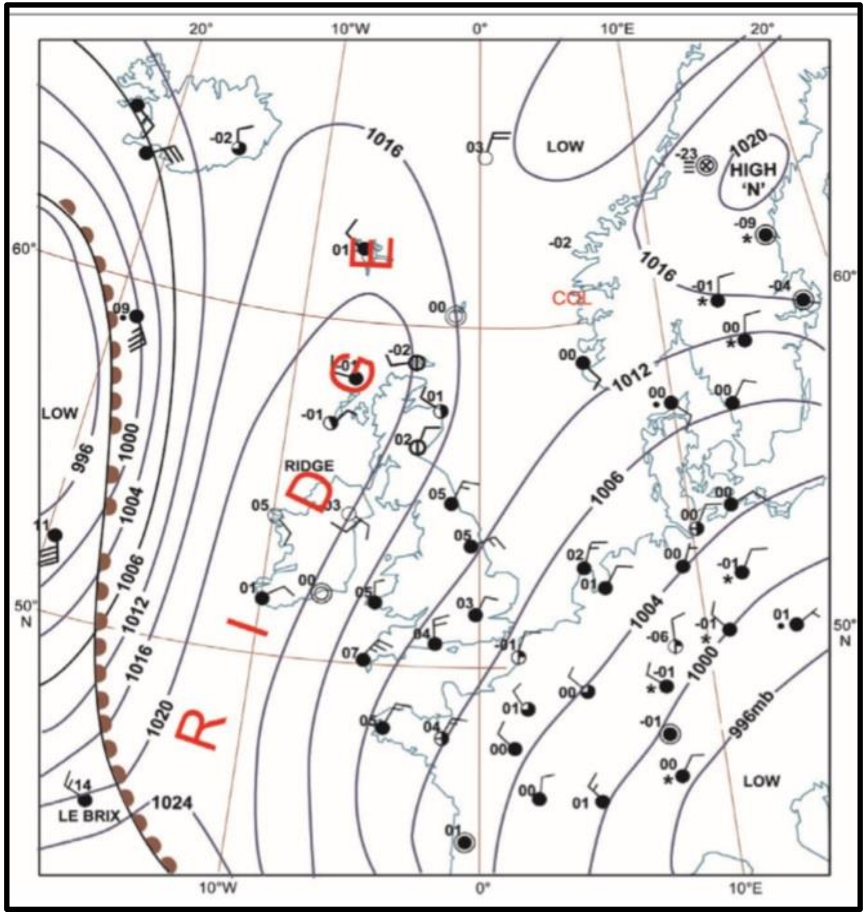
In an Anticyclones

- at high altitude air is converging
- descent of air within the anticyclone (subsidence)
- divergence at the surface


CONVERGENCE
DESCENT
HIGH PRESSURE
DIVERGENCE

Ridges

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



Anticyclonic Weather

SUMMER (and cold anticyclones in winter):

- **Cloud**

None except on the edge of the anticyclone.

- **Precipitation**

None

- **Visibility**

Generally moderate with haze

- **Winds**

Light

WINTER (warm anticyclones):

- **Cloud**

Extensive stratus with a low base and limited vertical extent.

- **Precipitation**

Possibly drizzle

- **Visibility**

Generally moderate to poor with mist and fog likely

- **Winds**

Light

- **Temperature**

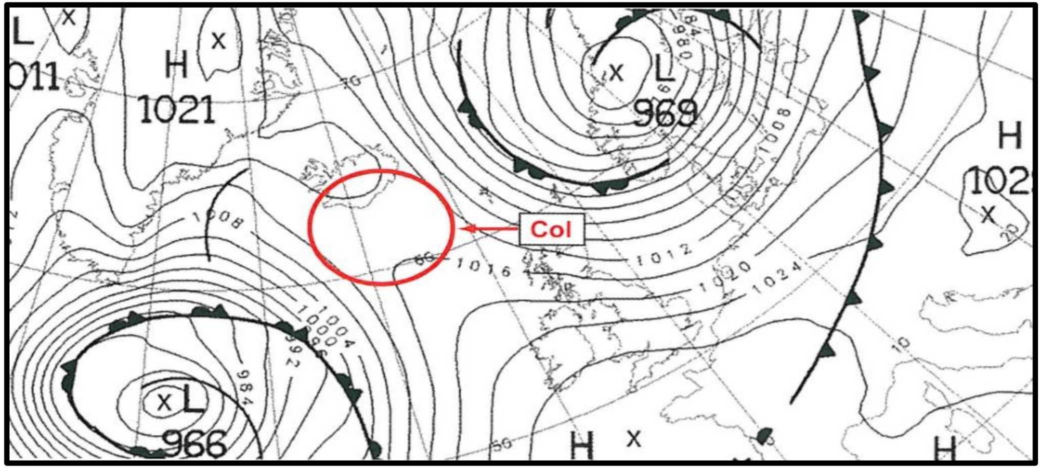
Relatively warm

Cols

Cols are regions of almost level pressure between two highs and two lows. It is an area of stagnation.

Col Weather

Col weather is normally settled, but is dependent on changing pressure.
In autumn and winter cols produce poor visibility and fog, whilst in summer thunderstorms are common.



Pressure Systems Movement

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

Terminology

- Depressions will fill up or decay as pressure rises.
- Depressions will deepen as pressure falls.
- Frontal depressions move rapidly, their average lifetime is 10 to 14 days.
- Anticyclones will build up as pressure rises.
- Anticyclones will weaken or collapse as pressure falls.
- Anticyclones are generally slow moving and may persist for long periods.
- Cols may last up to a few days before being replaced by other pressure systems.

Chapter 5

Temperature

Introduction

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

Measurement

$$°C = \frac{5}{9} \times (°F - 32)$$

$$°F = \frac{9}{5} \times °C + 32$$

$$K = °C + 273$$

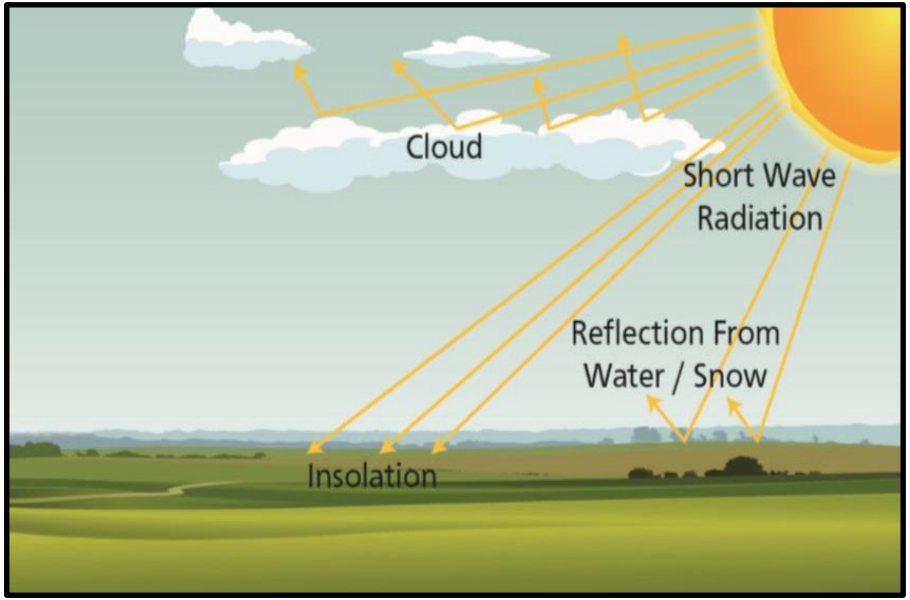
Heating of the Troposphere

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

Solar Radiation

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

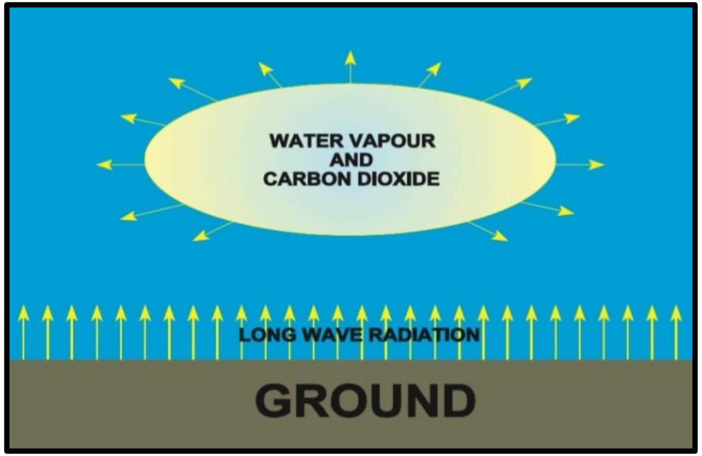
Some solar radiation is reflected back to the upper air from cloud tops and from water surfaces on the earth. The rest of this radiation heats the earth's surface. The process whereby the surface is heated by solar radiation is called insolation.



There are four processes which heat the troposphere:

- **Terrestrial Radiation**

The earth radiates heat at all times. This radiation is absorbed by the so-called greenhouse gases giving rise to the lapse rate in the troposphere, principally water vapour, carbon dioxide and methane. The increase in the amount of carbon dioxide in the troposphere is one of the factors contributing to global warming.

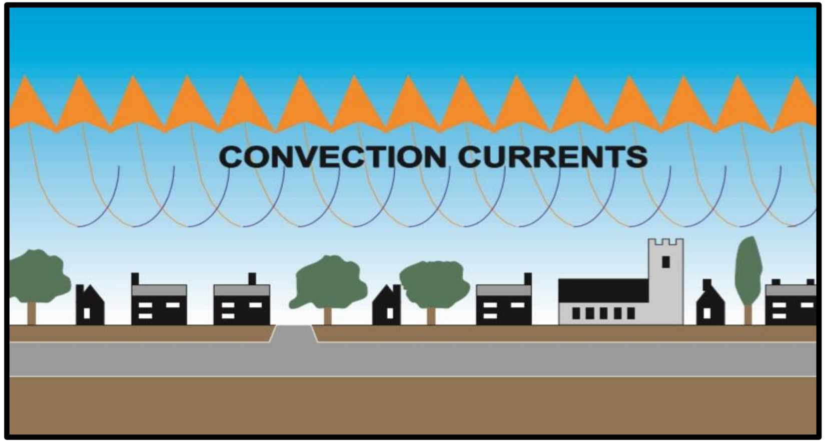


- **Conduction**

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

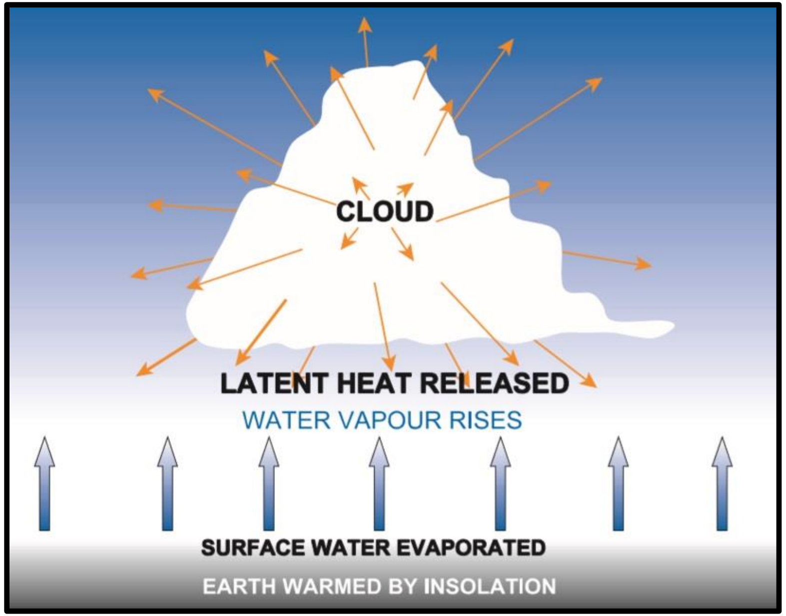
- **Convection**

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



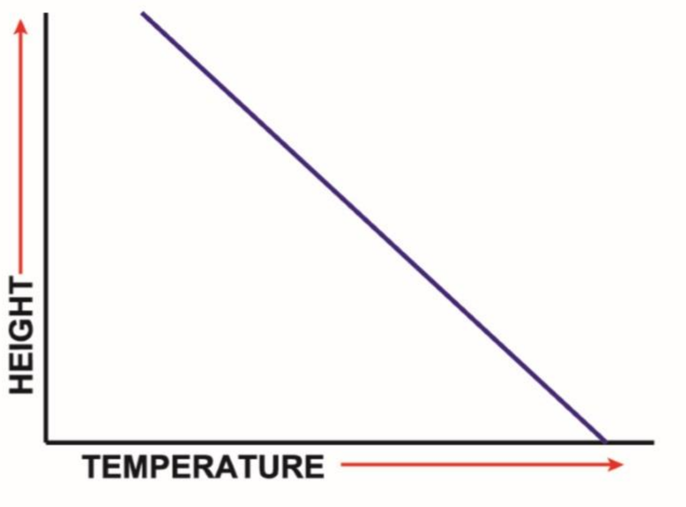
- **Condensation**

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



Temperature Variation with Height and lapse rate

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



Isotherm

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

Inversions

• Where the temperature increases with an increase in height, then we have what is called an inversion.

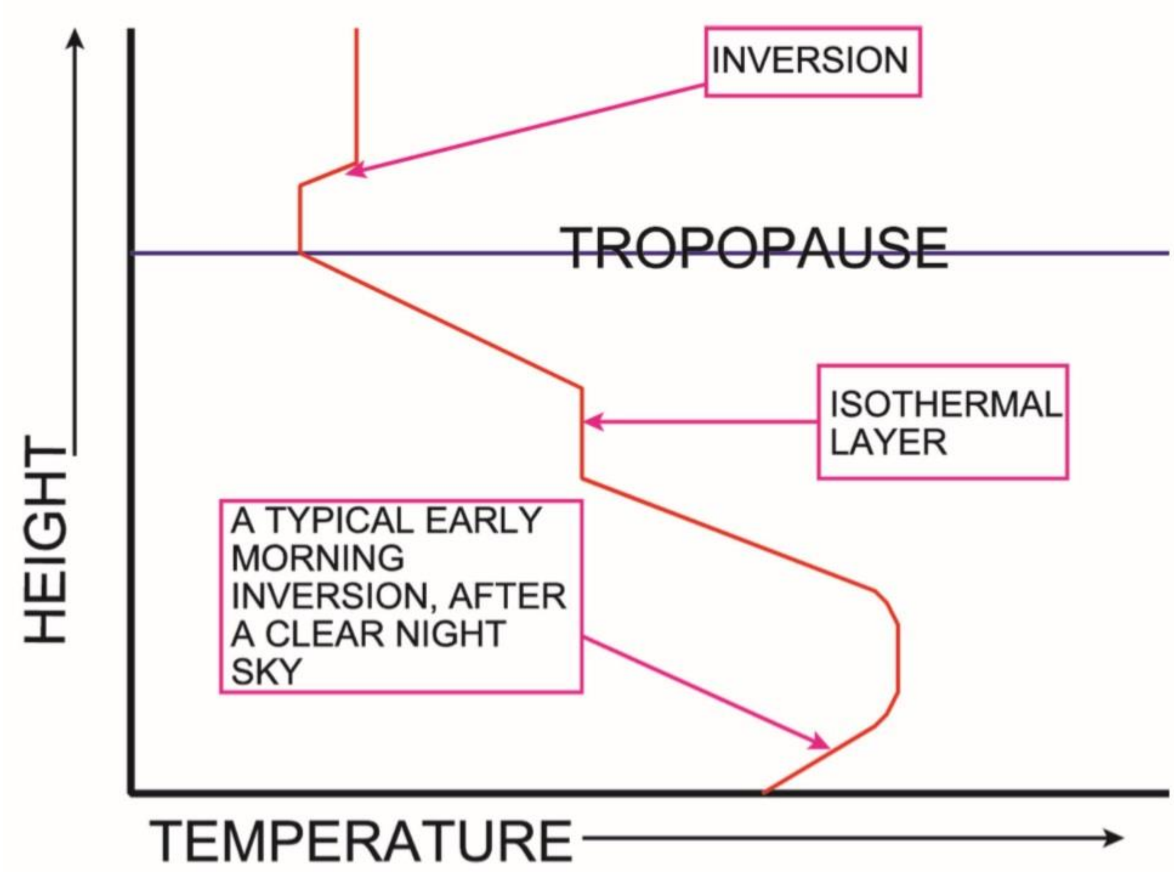
• We have already seen that at night we can expect an inversion above the surface, but this can occur in many different ways.

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

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

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

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

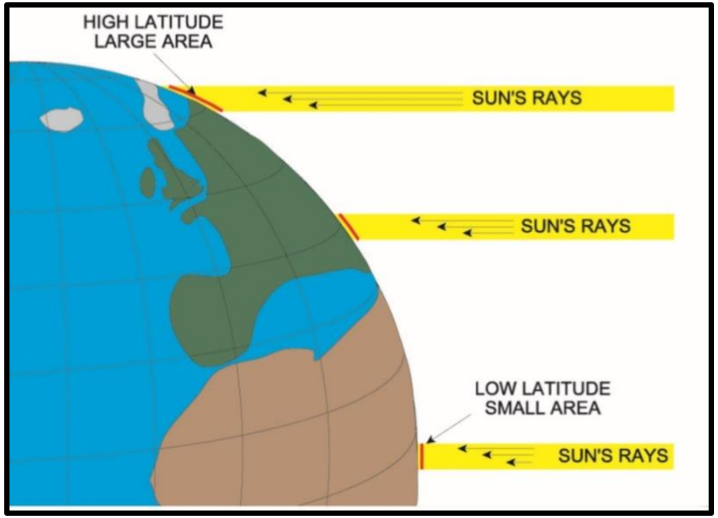

INVERSION
TROPOPAUSE
ISOTHERMAL LAYER
A TYPICAL EARLY MORNING INVERSION, AFTER A CLEAR NIGHT SKY
HEIGHT
TEMPERATURE

Surface Temperature

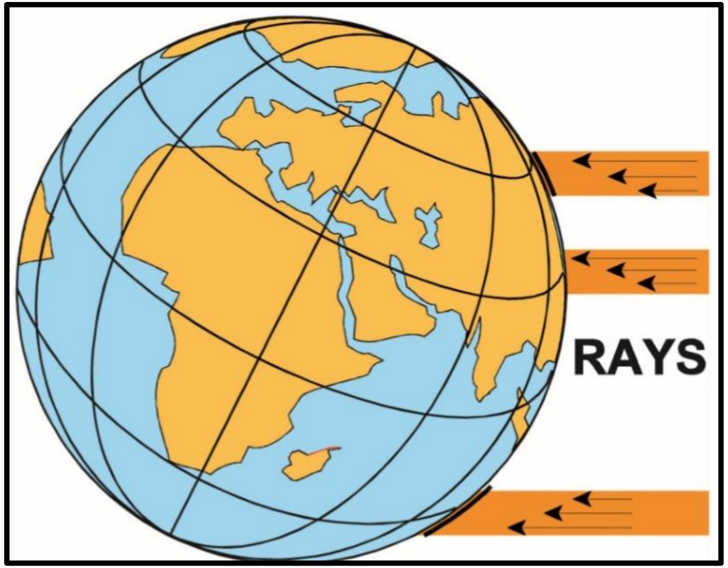
The surface air temperature measured in a Stevenson screen is subject to considerable variations: Latitude Effect, Seasonal Effect, Diurnal Variation and multiple effects due to cloud and wind.

The Angular Elevation of the Sun :

- **Latitude Effect**



- **Seasonal Effect**



Diurnal Variation :

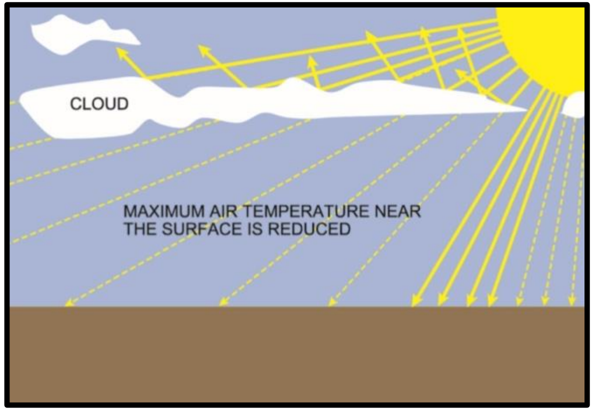
• The sun is at its highest elevation at noon, but for two to three hours after this time, the earth is receiving more solar radiation than it is giving up as terrestrial radiation. A balance between incoming and outgoing radiation is reached on average at 1500 local time when maximum temperatures can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

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

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

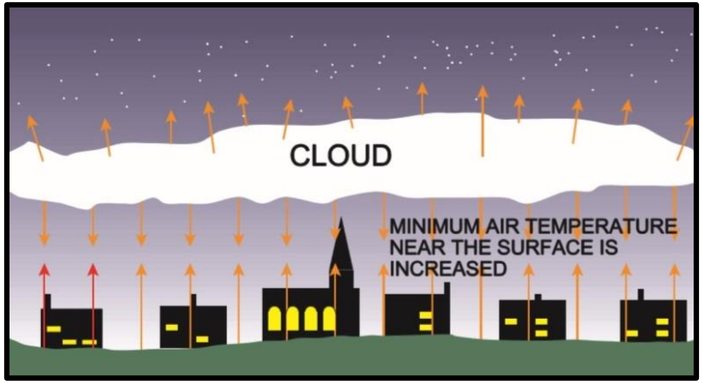
- **Cloud cover by day**

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



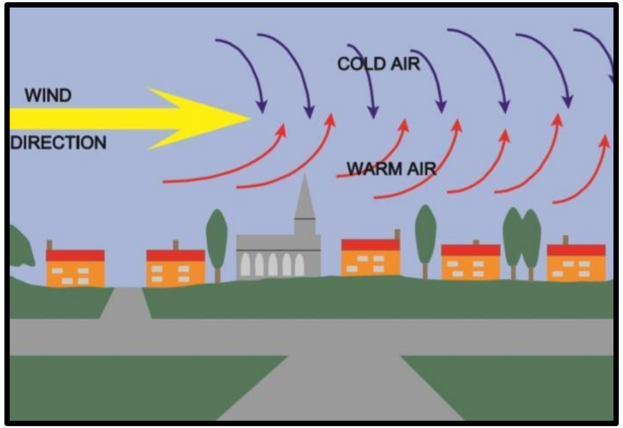
- **Cloud cover by night**

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



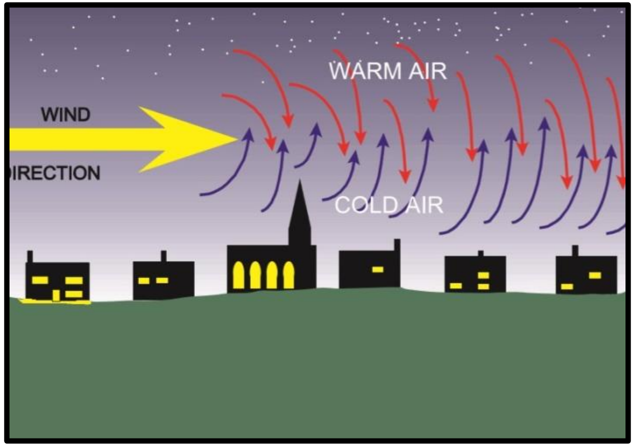
- **Effect of wind by day**

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



- **Effect of wind by night**

at night there will normally be an inversion above the surface and wind will cause cold air to be turbulently mixed with warm air above thus increasing T min.



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

Chapter 6

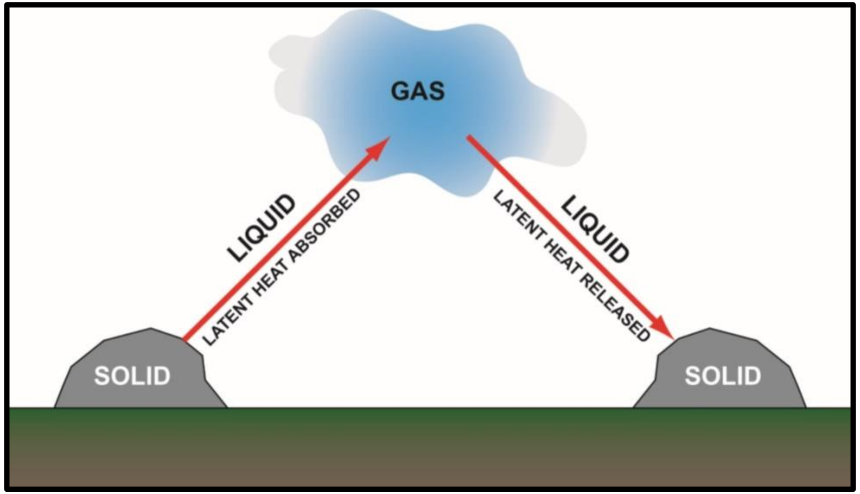
Humidity

Latent Heat

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

Evaporation

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



Saturation

Air becomes saturated by adding more water vapour to it. Alternatively, as warm air can hold more water vapour than cold, saturation can be achieved by cooling the air.
Air is saturated if it contains the maximum amount of water vapour that it can hold at that temperature.
If saturated air is cooled, condensation will occur

Condensation

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

Freezing

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

Melting

The opposite change of state, from solid to liquid, is called melting.

Sublimation

The change of state from ice directly to water vapour is also called sublimation.
The reverse process of sublimation is deposition.

Relative Humidity (RH)

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

RH 100% = SATURATION

Chapter 7

Adiabatics and Stability

Adiabatic Temperature Changes

An adiabatic temperature change occurs when a gas is compressed or expanded with no external exchange of heat.
In the atmosphere pressure decreases as altitude increases so if a parcel of air is forced to rise it will expand as it rises and hence will cool by the adiabatic process. Similarly if a parcel of air is forced to descend it will become compressed and hence heat up, again by the adiabatic process.

The Dry Adiabatic Lapse Rate – DALR

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

The Saturated Adiabatic Lapse Rate - SALR

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

The Environmental Lapse Rate (ELR)

This is the lapse rate of the air in the environment and varies with time and position.

Stability

Stability can be defined as being resistance to change. When dealing with atmospheric stability we are looking at what happens to air in vertical motion.
If a parcel of air is forced to rise, for example over a mountain, when it gets to the top of the mountain there are 3 things it can do.
It may return to its original height, it may continue rising or it may remain at the height of the summit.

- In the first case, in terms of the vertical position, the air is where it started so before and after are the same so we have a stable situation.

- In the second case we have continual change and hence instability.

- The third situation is a neutral or indifferent case, since the parcel of air is remaining where it was moved.

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

ELR > DALR : ABSOLUTE INSTABILITY

ELR < SALR : ABSOLUTE STABILITY

DALR > ELR >SALR : CONDITIONAL INSTABILITY

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

Chapter 8

Turbulence

Introduction

A dictionary definition of turbulence is a ‘disturbed state’ and so from the aviation point of view this would mean disturbed or rough air.

Windshear

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

- **Vertical Windshear**

change in speed and/or direction with change of height.

- **Horizontal Windshear**

change in speed and/or direction in the horizontal plane.

Locations

Turbulence occurs:

- In the friction layer .
- In clouds .
- In clear air .

The Friction Layer

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

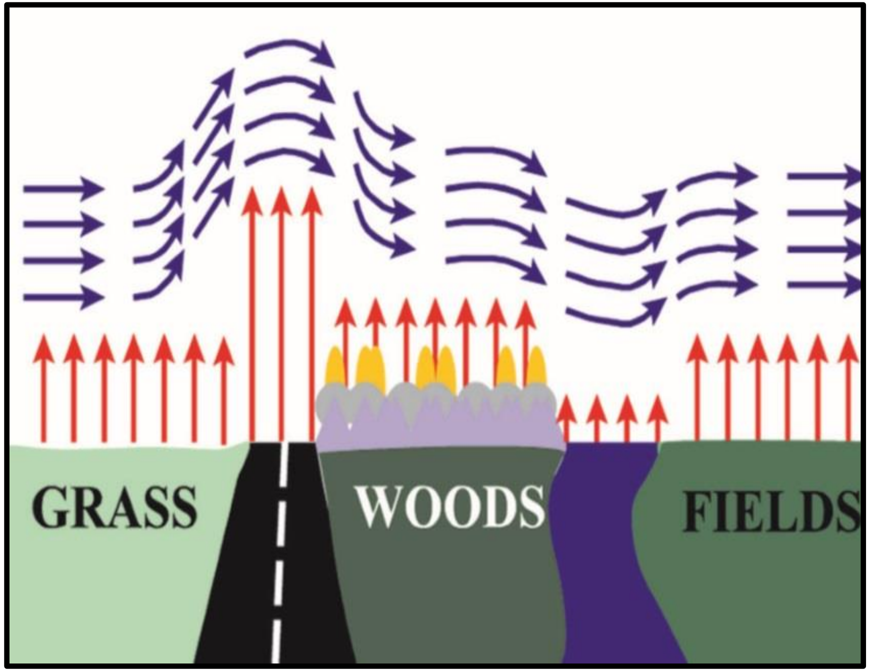
- The roughness of the terrain.
- The wind speed.
- The stability of the layer. Stable conditions will resist vertical movement and hence limit the depth.

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

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

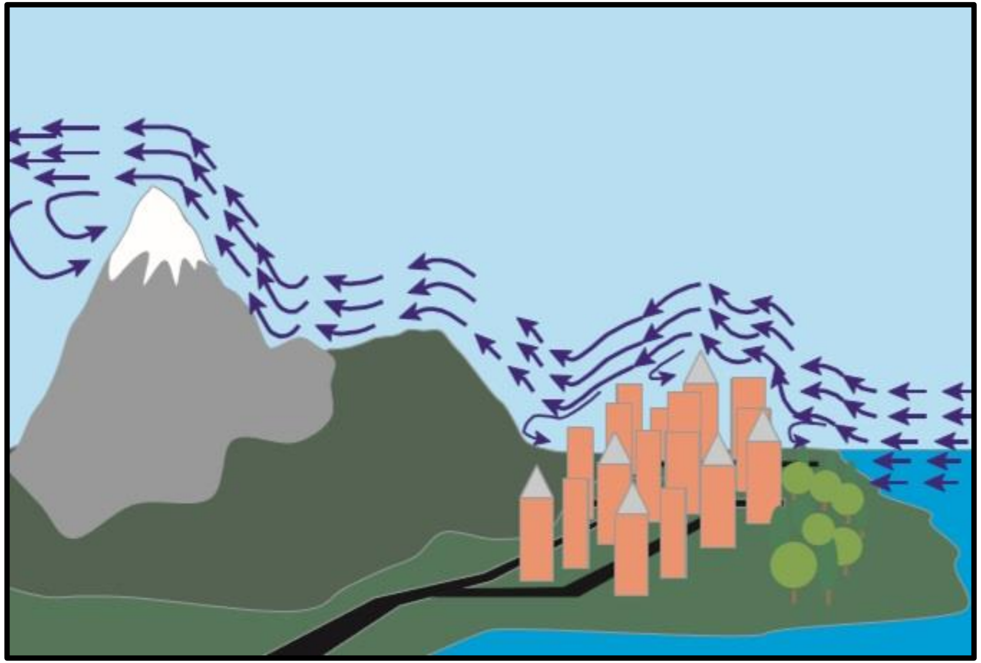
Thermal Turbulence

Insolation gives rise to convection currents. The intensity of these currents depends on the heating of the surface. So flight within the friction layer on a sunny day will be affected by variable speed vertical currents and hence windshear giving turbulence. Thermal turbulence is greatest around 1500 hrs on clear sunny days. There is no thermal turbulence over the sea.



Mechanical Turbulence

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

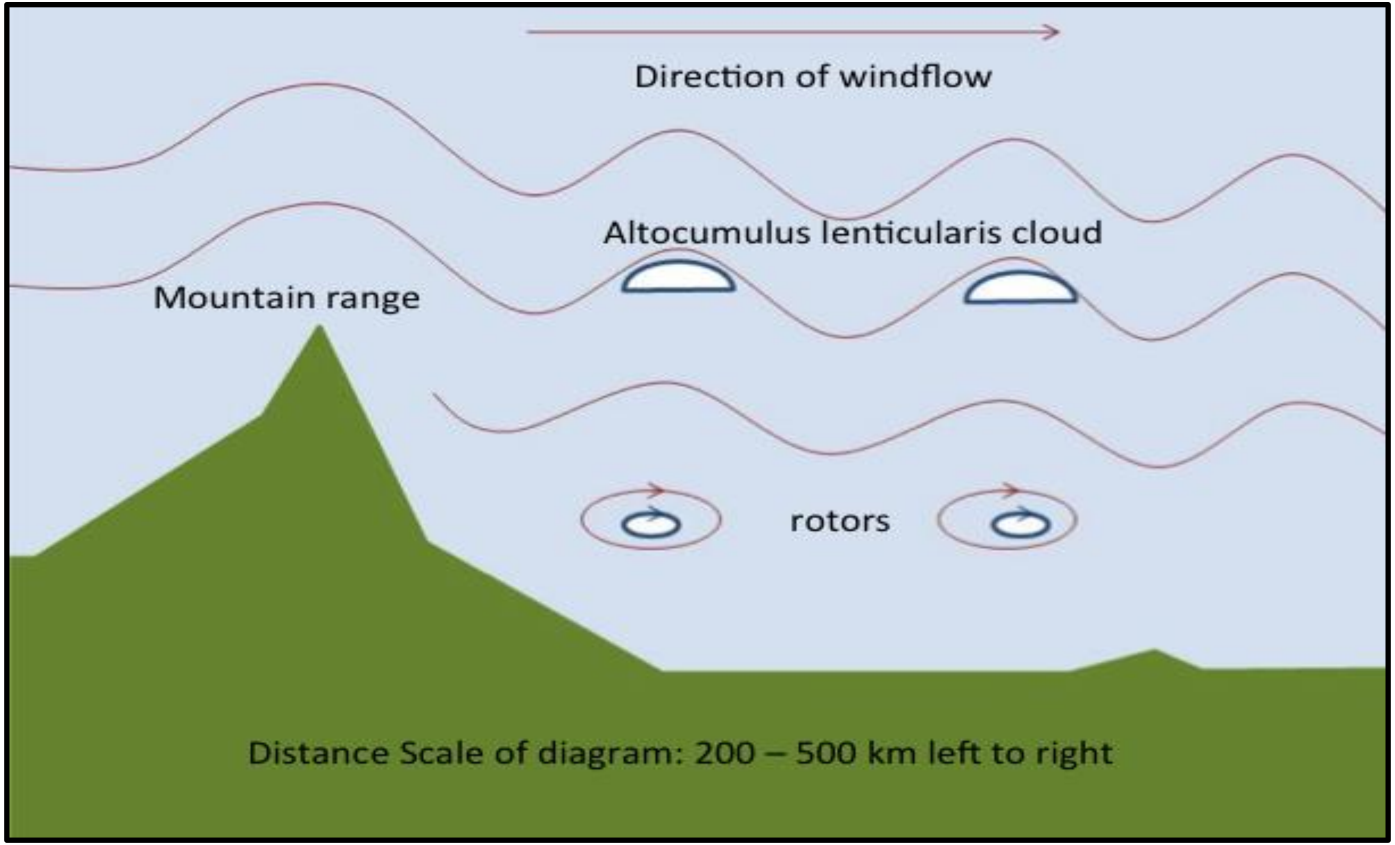


Mountain Waves (MTW)

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

- The wind direction is perpendicular to the mountain range (+/-30°) without significant change in direction as altitude increases.
- The wind speed at the summits is at least 15 kt with speed increasing as altitude increases.
- A marked layer of stability around the altitude of the summits.

The resultant waves can extend for hundreds of miles downwind of the range if suitable conditions prevail. The waves may extend well above the tropopause and the wave form may be seen in cirrus clouds high in the troposphere.


Direction of windflow
Altocumulus lenticularis cloud
Mountain range
rotors
Distance Scale of diagram: 200 – 500 km left to right

Turbulence Effects of Mountain Waves

Most severe turbulence can occur in the Rotor Zone lying beneath the crests of lee waves and is often marked by Roll Clouds. The most powerful rotor lies beneath the first wave crest (one wavelength downwind).
It has been found that turbulence caused in the troposphere due to mountain waves may continue well into the stratosphere. An aircraft flying close to its ceiling on these occasions might find itself in serious difficulty.

Visual Recognition Features of Mountain Waves

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

- **Lenticular, or lens shaped clouds**

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

- **Rotor, or roll-clouds**

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

- **Cap clouds**

form on the ridge and strong winds may sweep the cloud down the lee slopes.

The characteristic clouds above may be obscured by other clouds and the presence of standing waves may thus not be evidenced.
If the air is dry, clouds may not form at all, even though mountain waves are present.

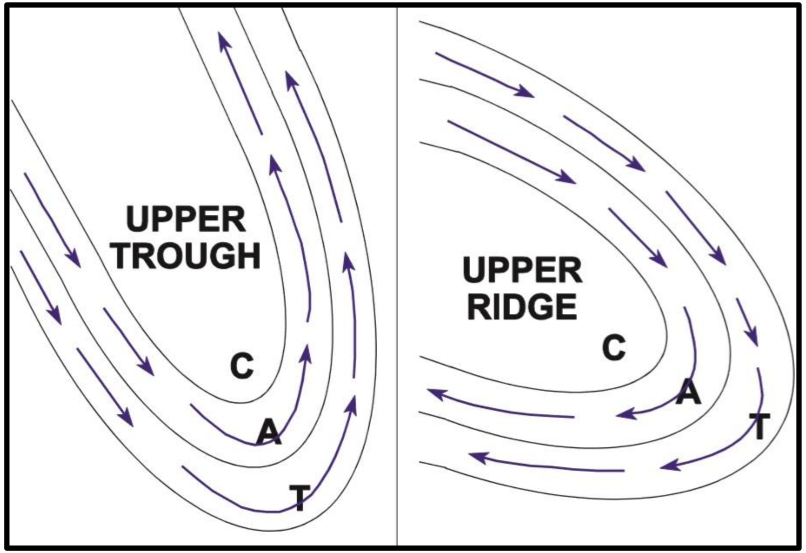
Jet Streams

- Jet streams are narrow fast moving currents of air which occur just below the tropopause and Generally the associated turbulence is found on the cold air side of the Jet Stream just below the core where the greatest windshear occurs, with a secondary area above the core extending into the stratosphere as the winds rapidly decrease in strength.

- The turbulence will be more severe with curved jets, developing and rapidly moving jets and in mountainous areas, particularly when mountain waves are present.

Turbulence around Upper Level Troughs and Ridges

Since upper level winds are stronger than those at the surface, the sharp changes in wind direction at upper level troughs are likely to produce considerable horizontal windshear and consequent disturbance which may be experienced as Clear Air Turbulence (CAT).
As upper level ridges tend to be more gently curved than troughs, the direction changes and consequent turbulence will be less severe.



Turbulence Reporting Criteria

- **Light Turbulence**

Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw).

- **Moderate Turbulence**

Turbulence that is similar to light Turbulence but of greater intensity. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times.

- **Severe Turbulence**

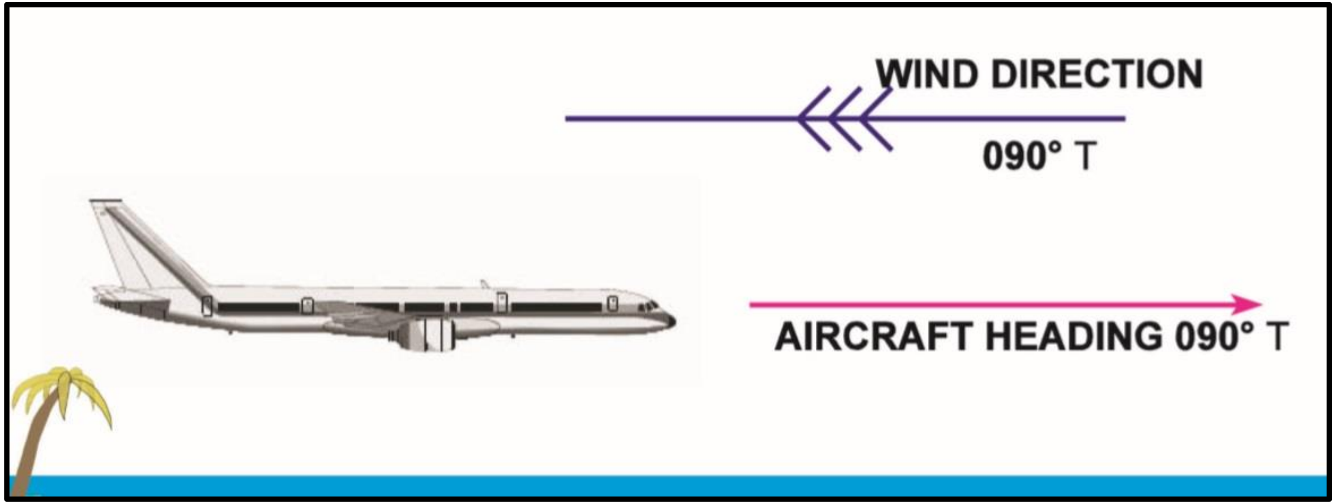
Turbulence that causes large, abrupt changes in altitude and/or attitude. Aircraft may be momentarily out of control.

Chapter 9

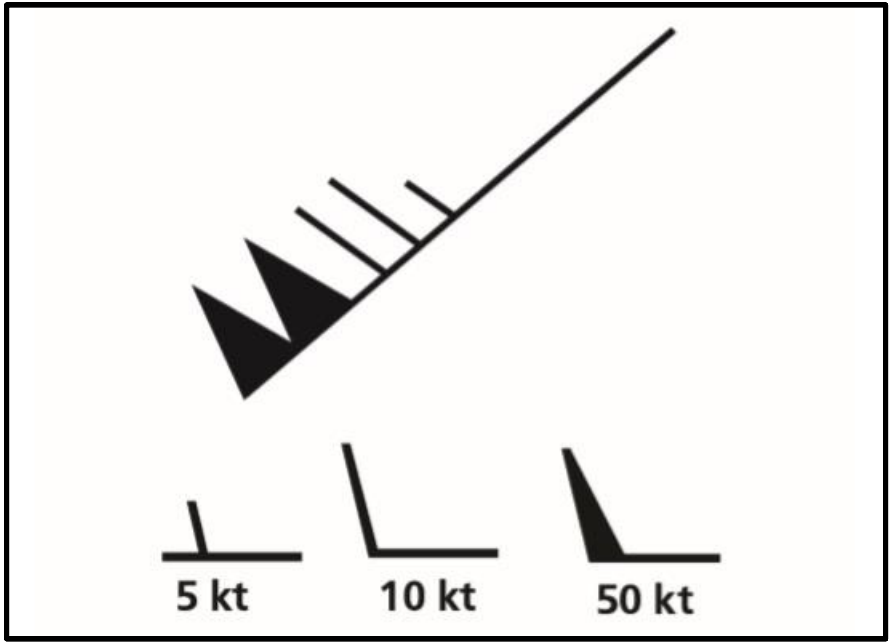
Winds

Introduction

• Wind is air in horizontal motion. Wind Velocity (W/V) has both direction and speed.
• Wind direction is always given as the direction from which the wind is blowing.
• It is normally given in degrees true, but wind direction given to a pilot by ATC will be given in degrees magnetic.



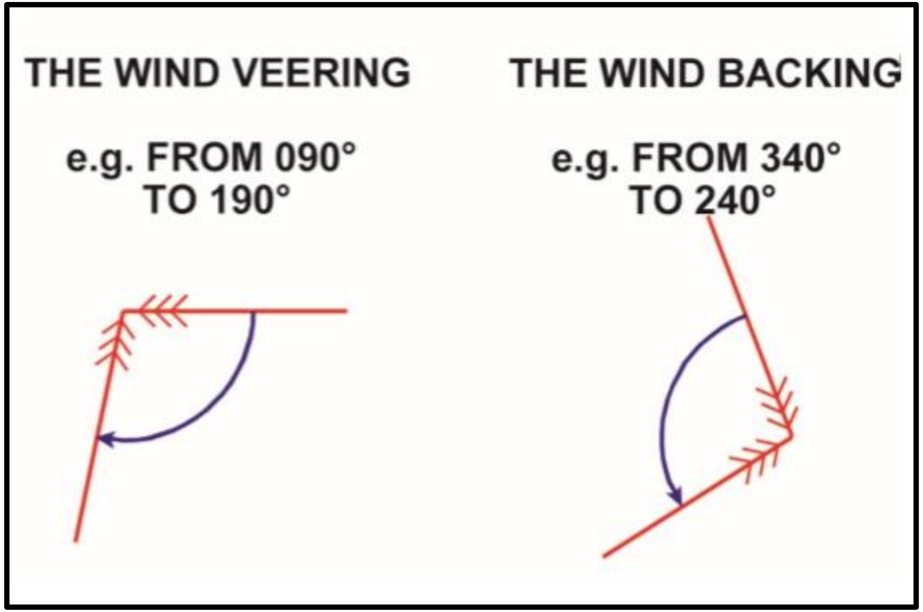
- Wind speed is usually given in knots
- On the wind vector the wind direction is from the feathers to the point which indicates the location of the wind. The illustrated wind Figure is 240° (true) at 125 kt.



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

- Backing is a change of wind direction in an anticlockwise direction.

This applies in both hemispheres



Gusts

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

Squalls

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

Wind

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

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

• Buys Ballot's Law tells us that if we stand with our back to the wind in the Northern Hemisphere low pressure is on the left (right in the Southern Hemisphere). This implies that the wind does not flow directly from high pressure to low pressure but parallel to the isobars.

There are two winds that we need to consider:

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

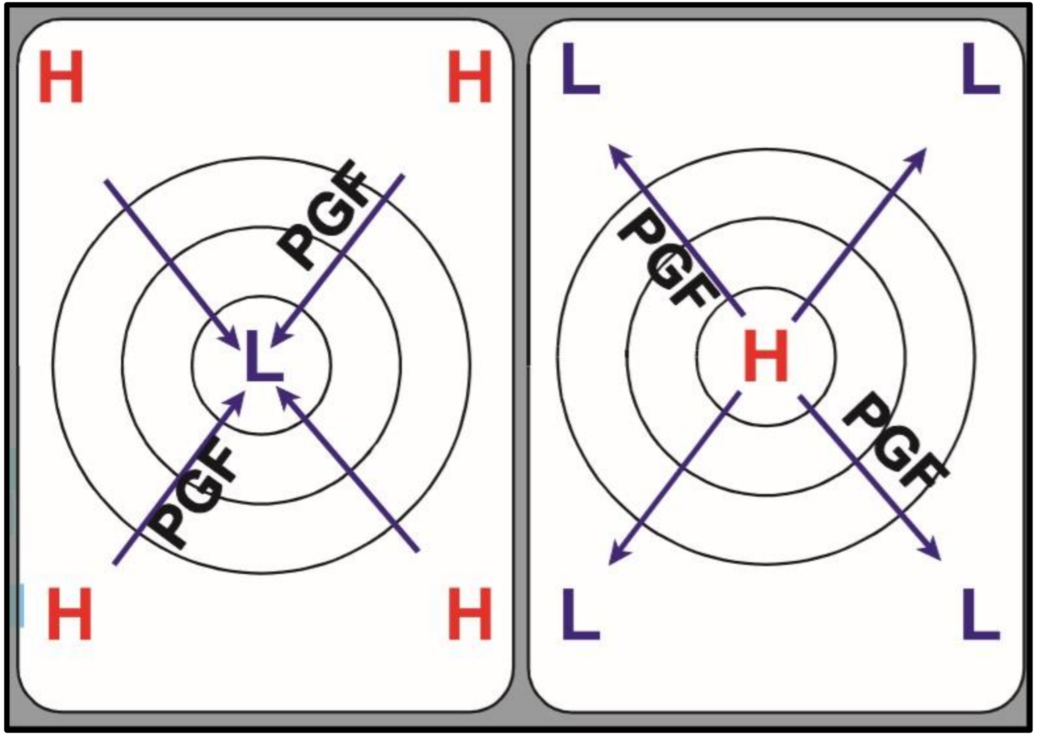
The Geostrophic Wind

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

These two forces are:

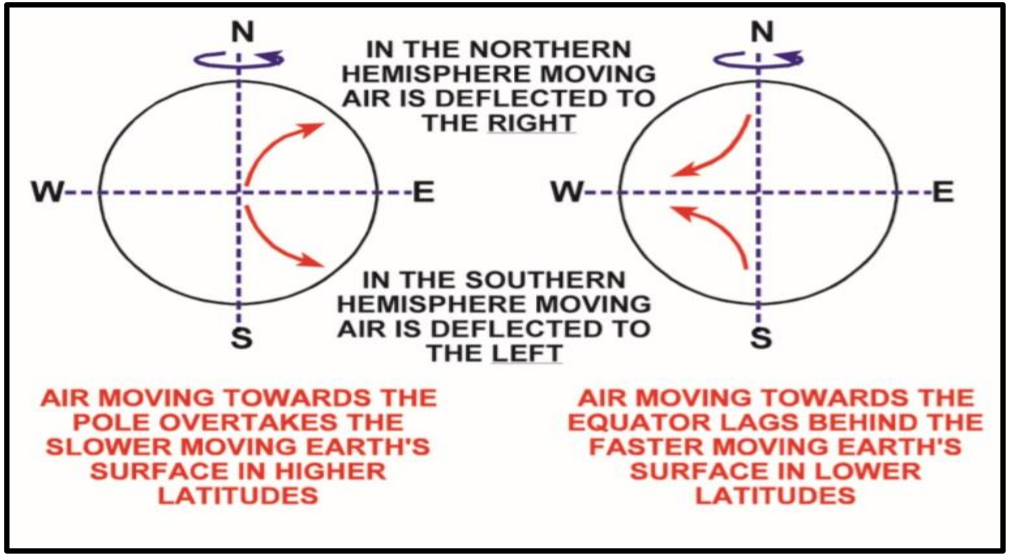
Pressure Gradient Force (PGF) :

• Pressure Gradient Force, (PGF), is the force that acts from a high pressure to a low pressure.
• Closely spaced isobars would indicate a large pressure gradient force. This is common in low pressure systems. Widely spaced isobars indicate a small pressure gradient force. This is common in high pressure systems.
• The Pressure Gradient Force, (PGF), controls the wind speed. A large pressure gradient force would create strong winds, whereas a small pressure gradient force would create light winds. Wind speed is directly proportional to the pressure gradient force.


H
H
PGF
L
PGF
H
H
L
L
PGF
H
PGF
L
L

Coriolis Force (CF) :

• Coriolis Force, (CF), is the force caused by the rotation of the earth.
• It acts 90° to the wind direction causing air to turn to the right or veer in the Northern Hemisphere and to the left or back in the Southern hemisphere. CF is maximum at the poles and minimum at the Equator.



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

It is the combination of 4 factors:

$$\mathbf{CF = 2\,\Omega\,\rho\,V\,\sin\theta}$$

where:

Ω = angular rotation of the earth

ρ = density

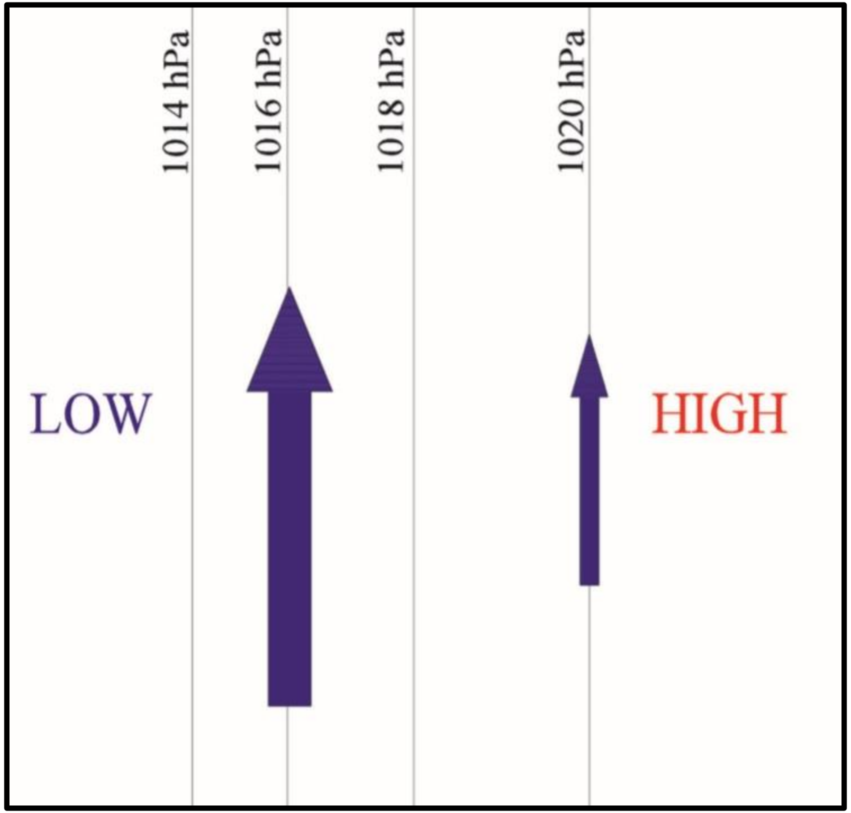
V = wind speed

θ = latitude

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

The Geostrophic Wind

- The Geostrophic Wind blows parallel to straight isobars. Therefore the geostrophic wind can only blow in a straight line. If the wind were to follow a curved path, it cannot be considered as a geostrophic wind because there will be additional forces involved, namely the centrifugal or centripetal forces.

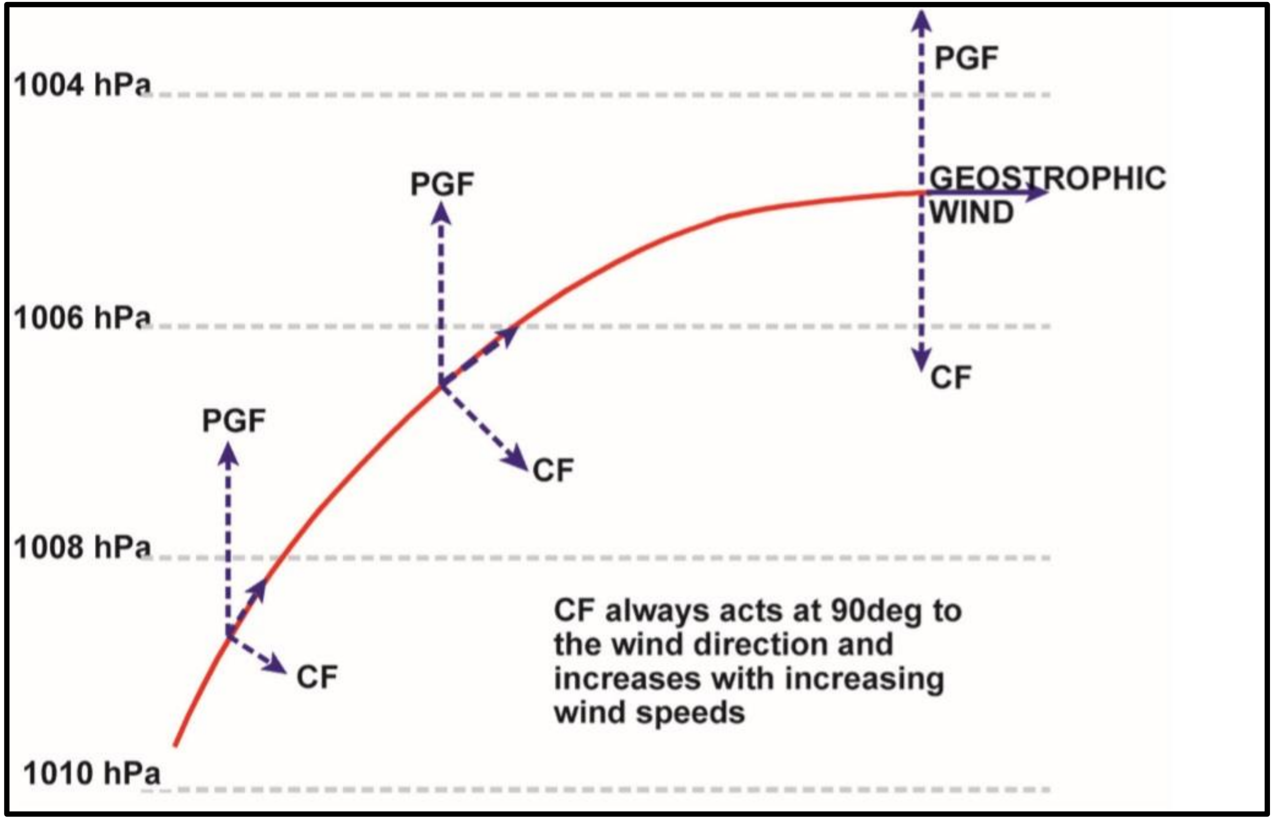


- The geostrophic wind only blows above the friction layer. Within the friction layer the wind speed is reduced because of surface friction. Therefore the Coriolis force will reduce, causing the two forces to be out of balance.

- latitude is inversely proportional to the geostrophic wind speed :

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

Construction of the Geostrophic Wind



Conditions Necessary for the Wind to Be Geostrophic

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

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

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

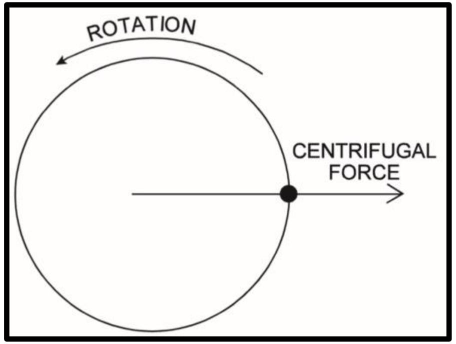
The Gradient Wind

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

- PGF
- CF
- Centrifugal Force

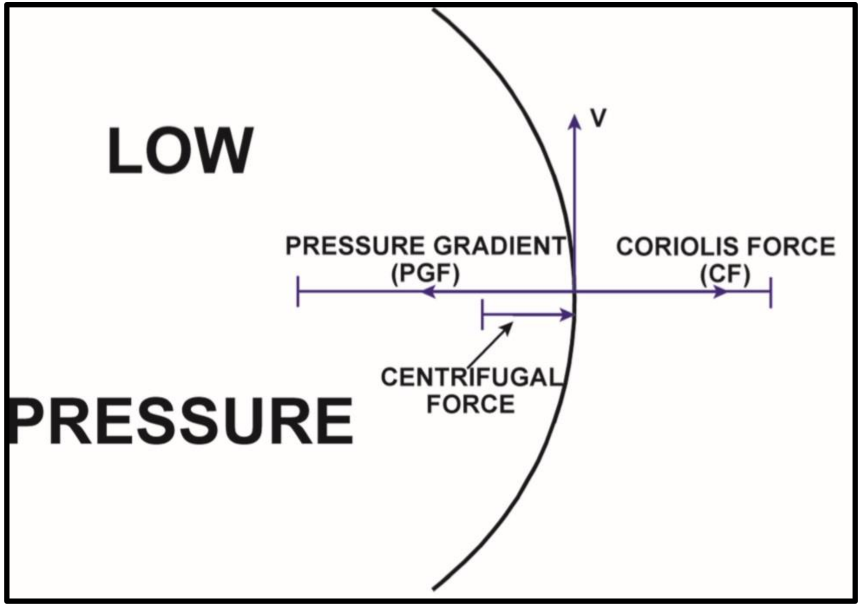
Centrifugal Force

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



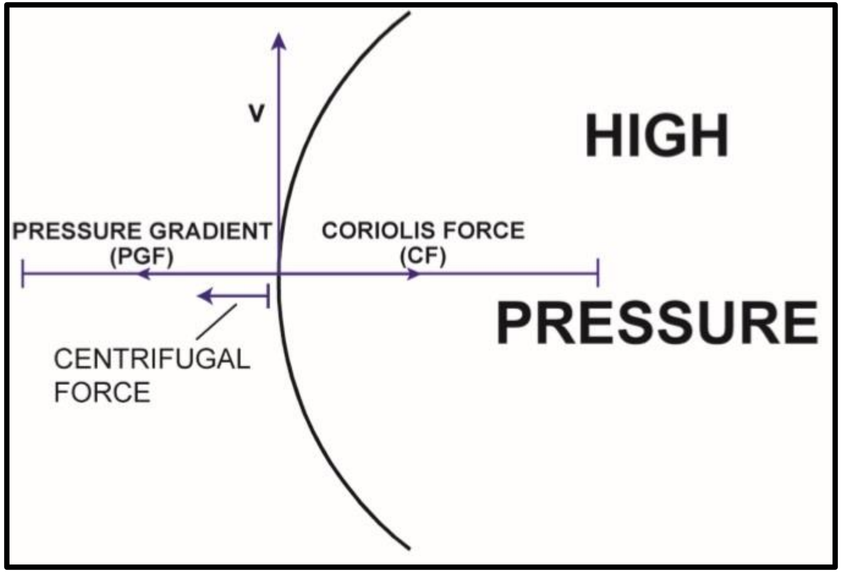
Gradient Wind in a Depression

If air is moving steadily around a depression, then the centrifugal force opposes the PGF and therefore reduces the wind speed.
The gradient wind speed around a depression is less than the geostrophic wind for the same isobar interval.



Gradient Wind in a High

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

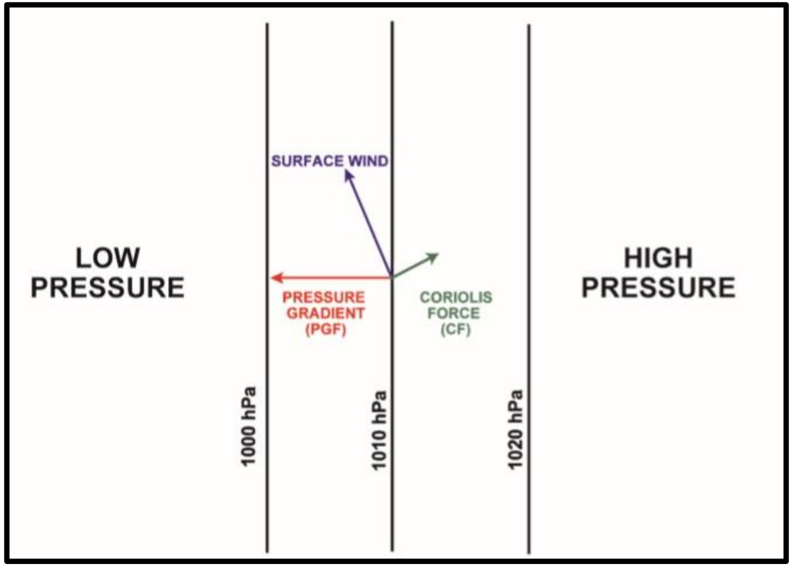


The Antitriptic Wind

The wind which blows in low latitudes where the CF is very small is called the antitriptic wind.

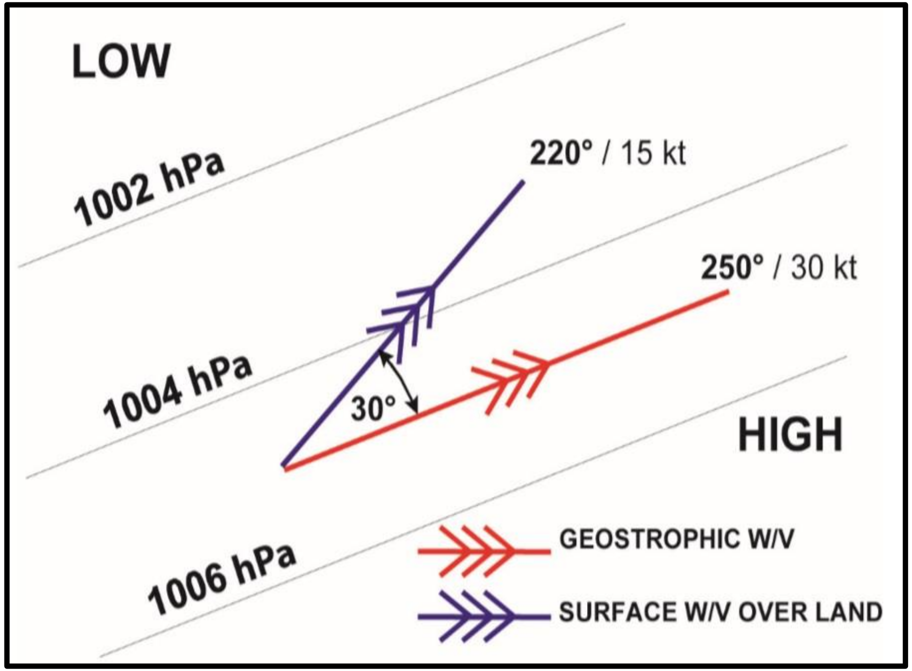
Winds below 2000 - 3000 ft (1 km)

Friction between moving air and the land surface will reduce wind speed near the ground. This reduction also reduces the CF. This will cause the two forces in the geostrophic wind to be out of balance since now CF is less than PGF. The wind is now called a surface wind.
Since surface friction has reduced the wind velocity, resulting in a reduction in the Coriolis force, the PGF is now more dominant. This causes the wind to blow across the isobars towards the low.

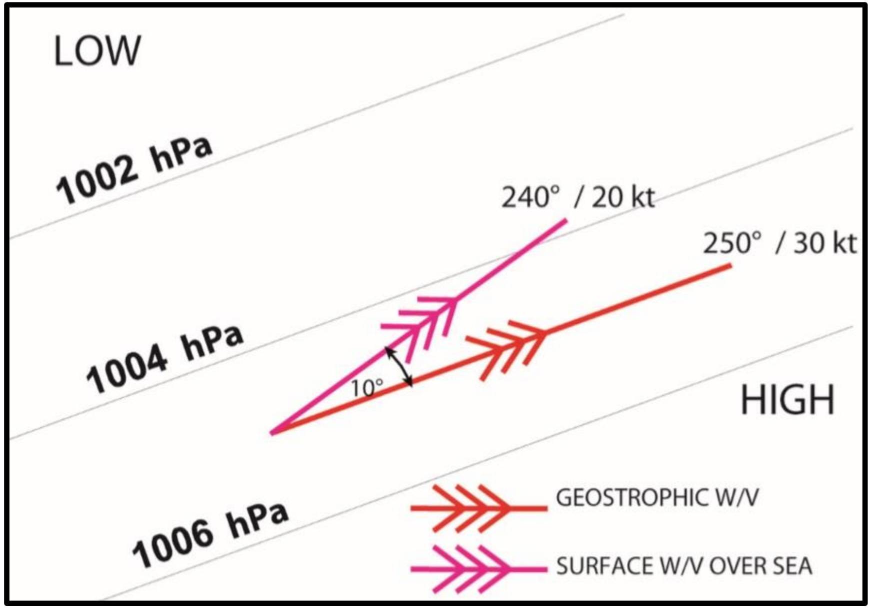


Rough Rules

- On average in the Northern Hemisphere the surface wind over land is backed by 30 degrees from the geostrophic, or gradient wind direction and its speed is reduced by 50%. In the Southern Hemisphere, because of the opposite effect of the Coriolis force, the surface wind is veered from the 2000 ft wind, but the numerical values are the same.



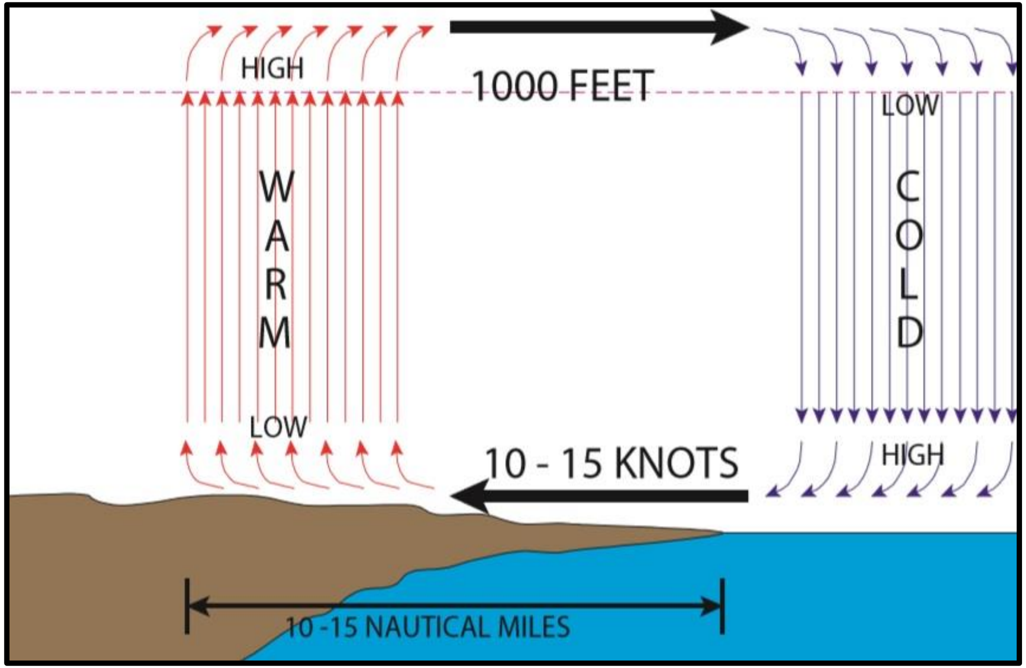
• Over the sea friction is very much less and the surface winds are closer to geostrophic values. Surface wind over the sea, in the Northern Hemisphere, is backed by 10 degrees from the geostrophic or gradient wind direction and speed reduced to 70% (surface winds will veer in the Southern Hemisphere).



Land and Sea Breezes

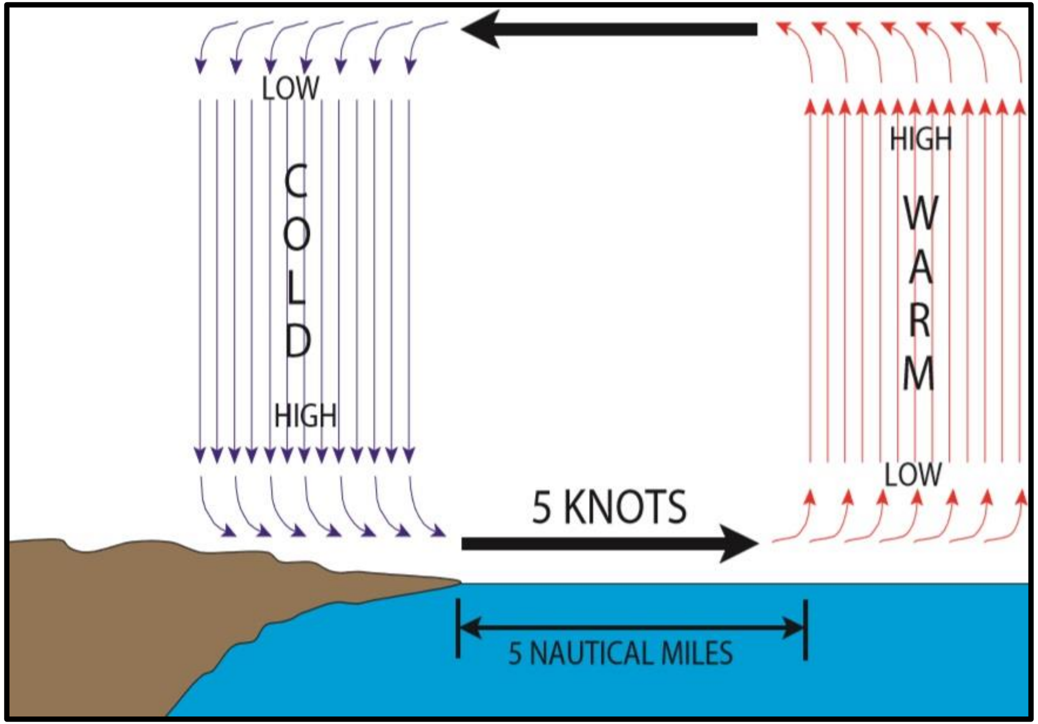
- **SEA BREEZE**

During the day, the land heats up more quickly than the sea. The air in contact with the land heats up and rises by the process of convection which leads to a decrease in pressure at the surface and an increase in pressure at approximately 1000 — 2000 ft agl.
This causes air at that height to move over the sea. Air then descends over the sea causing an increased pressure at the surface of the sea. Air then flows from the slightly higher pressure over the sea surface to the lower pressure over the land surface and creates the sea breeze.



- **Land breezes**

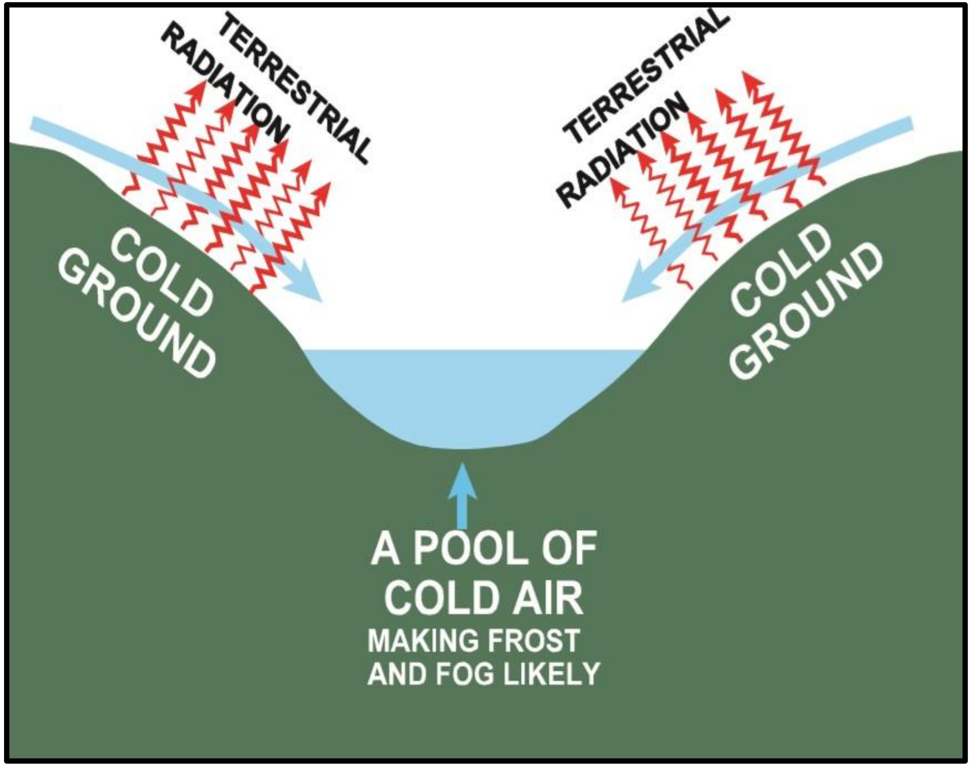
After sunset the land starts to cool down much more rapidly than the sea. This leads to a reversal of the above situation. The sea surface experiences a lower pressure and the land a higher pressure. The wind now blows from the land to the sea.



Sea breez : Day
Land breez : Night

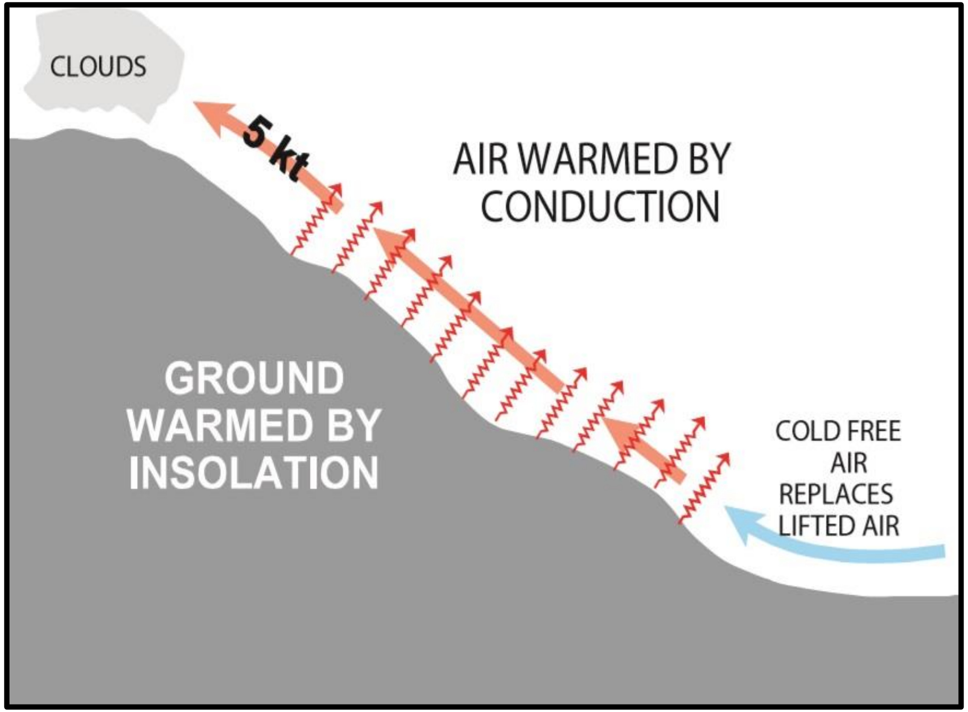
Katabatic Winds

A katabatic wind is caused by a flow of cold air down a hill or mountain side at **night**.
If the side of the mountain is cooled by radiation, the air in contact is also cooled, it will thus be denser and heavier than the surrounding air and it will therefore flow down the mountain side.



Anabatic Winds

On a warm sunny **day**, the slope of a hill will become heated by insolation, particularly if it is a south facing slope. The air in contact with the ground will be heated by conduction and will rise up the hill. Free cold air will replace the lifted air and so a light wind will blow up the hillside.



Föhn Winds

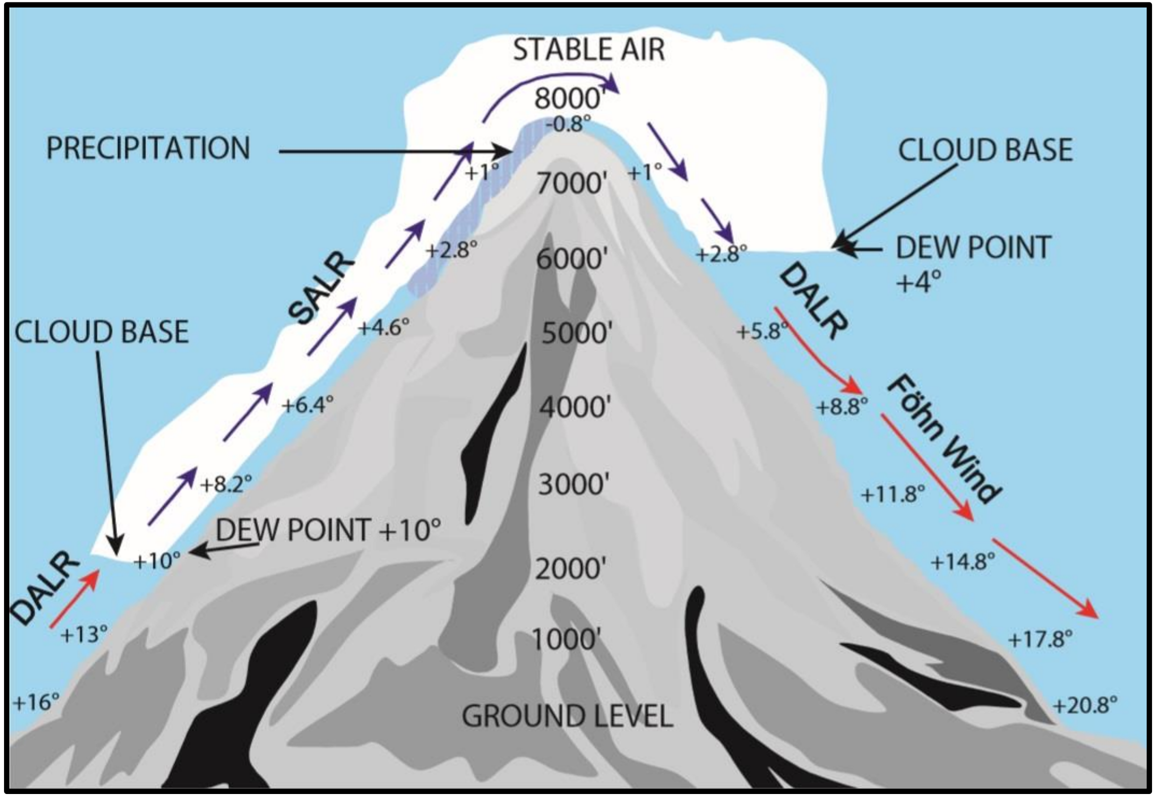
• The Föhn Wind is a warm dry wind which blows on the downwind side of a mountain range. It is a local wind in the Alps. A similar wind on the east of the Rocky Mountains in Canada is called the Chinook.

• When moist air is forced to rise up a mountain in stable conditions it will cool adiabatically at the DALR until saturated when it will continue cooling at the SALR.

• Precipitation will occur removing water from the air so the dew point will decrease.

• When the air descends on the leeward (downwind) side the cloud base will be higher so the air will warm at the DALR over a greater height than it cooled at the SALR on the windward side. Consequently the temperature at the base of the mountain will be greater on the downwind side than it was on the upwind side.

• So, on the windward side we can expect low cloud and precipitation whilst on the leeward side we will see clear turbulent conditions.


STABLE AIR
8000'
-0.8°
PRECIPITATION
+1°
7000'
+1°
CLOUD BASE
+2.8°
6000'
+2.8°
DEW POINT
+4°
SALR
DALR
CLOUD BASE
+4.6°
5000'
+5.8°
+6.4°
4000'
+8.8°
Föhn Wind
+8.2°
3000'
+11.8°
DEW POINT +10°
+10°
2000'
+14.8°
DALR
+13°
1000'
+17.8°
+16°
GROUND LEVEL
+20.8°

Chapter 10

Upper Winds

Introduction

• Upper winds are caused by Pressure Gradient Force (PGF), Coriolis Force (CF) and Centrifugal Force in the same way as the wind immediately above the friction layer.

The winds tend to be stronger because the density is less :

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

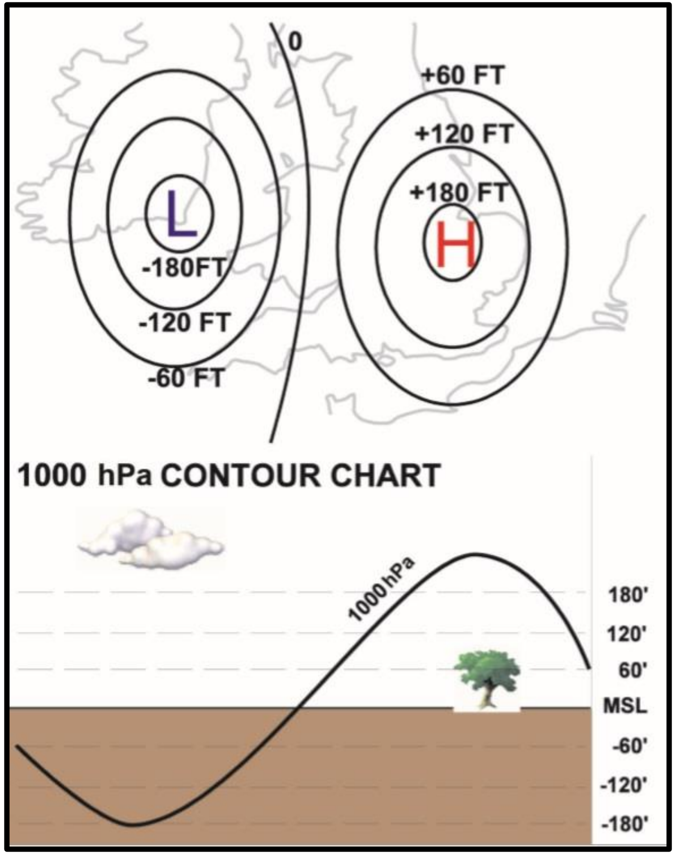
• At 20 000 ft, for the same PGF, the wind speed is double the surface wind speed, since density is half that at the surface.

Contour Charts - Constant Pressure Charts

• A Constant Pressure or Contour Chart is a chart where the pressure is constant everywhere.

• For example, as shown in Figure we can see that the 1000 hPa pressure level varies with height. These heights are plotted as contour lines (also known as isohypses) with the reference being MSL. The heights give us an indication of the distance that a pressure level is from MSL.

• If the contours are high values (in comparison to other values on the chart) then we can assume a high pressure exists. Conversely if the contours are lower values then we can assume a low pressure.



• If the contours are closely spaced we can assume a high pressure gradient exists.

• The upper winds will blow parallel to the contour lines.

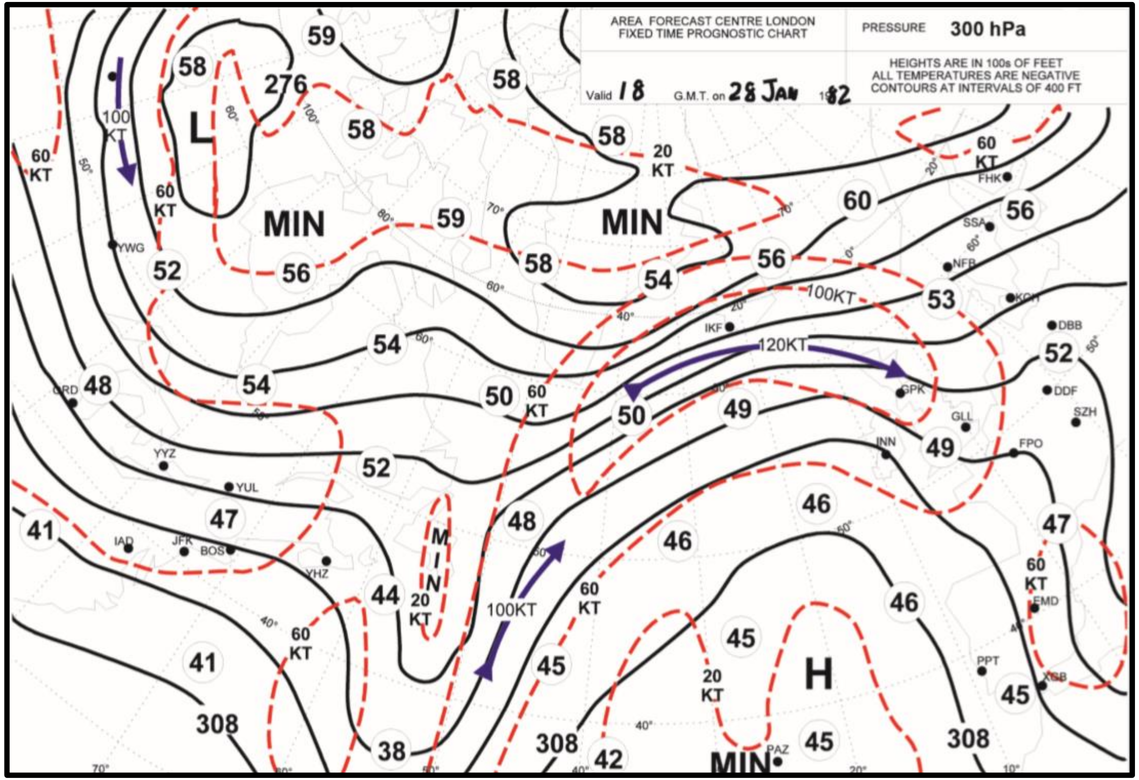
• This wind speed is proportional to the distance between the contour lines. The wind that we find from this are for the height of the constant pressure chart, e.g. 500 hPa chart is about 18 000 ft in ISA.

• The heights shown on contour charts are heights AMSL.
Charts are provided for:

Pressure (hPa)	Equivalent Pressure Altitude (feet)
700	10 000
500	18 000
300	30 000
250	34 000
200	39 000
150	53 000

Isotachs

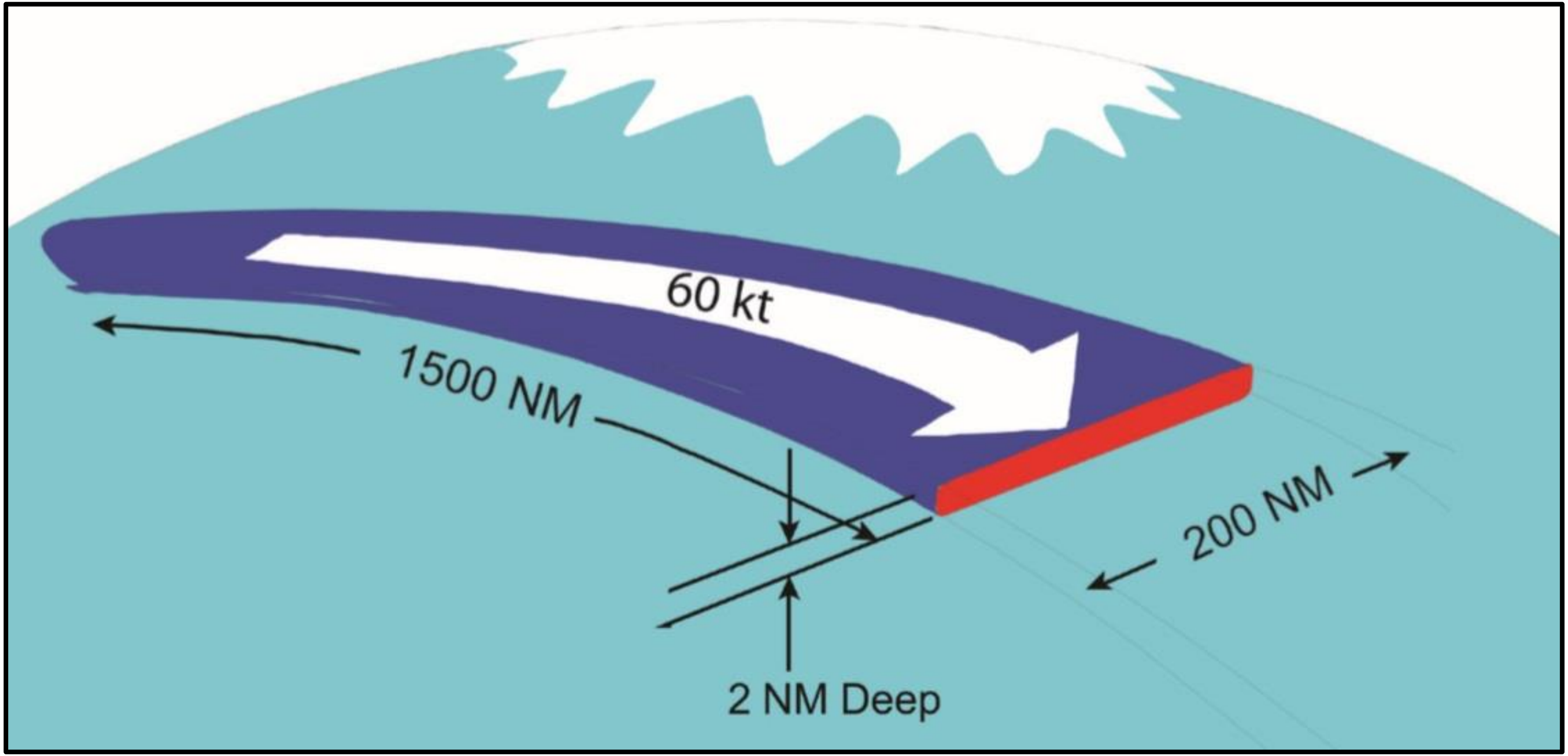
Isotachs are lines joining places of equal wind speed.



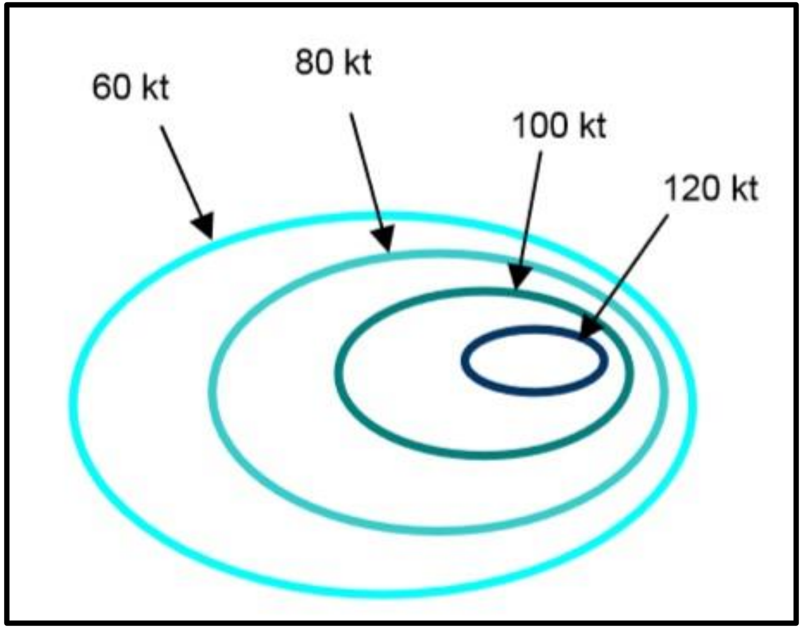
Jet Streams

- As we go higher in the troposphere, the density decreases so the wind speed increases.
- the upper winds will generally be westerly in both hemispheres.
- The strongest winds are to be found just below the tropopause.
- where these winds exceed 60 kt they are termed jet streams.
- we assume a jet stream to be about 2000 miles long.
- 200 miles wide .
- 2 miles deep(12000 feet) .
- a width to length ratio of 1:10.
- a depth to width ratio of 1:100 .
- a depth to length ratio of 1:1000.
- Speeds in excess of 100 kt are quite common, but it is rare for jet streams to be faster than 200 kt.

However, jets of 300 kt have been reported on occasion..


60 kt
1500 NM
200 NM
2 NM Deep

- The wind speed is fastest at the core and decreases with movement away from the core.



Causes

- Jet streams are caused by large surface temperature differences, i.e. large thermal components.

COMMON JET STREAMS

Polar front jetstreams

- 40° to 65° N/S
- 300 hpa-30 000 ft
- whole year
- winter-strong and summer-weak
- speed in jan 150 kt
- speed in jun,july,aug 135 kt

Subtropical jet streams

- 20° to 40° N/S
- 200 hPa – 45 000 ft
- whole year

Tropical Easterly Jet (Equatorial Easterly Jet)

- 10° to 15° N/S
- 45000-50000 feet
- easterly
- summer

Arctic Jet stream

- 60° N/S
- 400 hpa-20000 feet
- wnter

Different parts of jetstreams

Above the core

- Polar side
- Low pressure side
- Cyclonic side
- Cold side

below the core

- Equatorial side
- antiCyclonic side

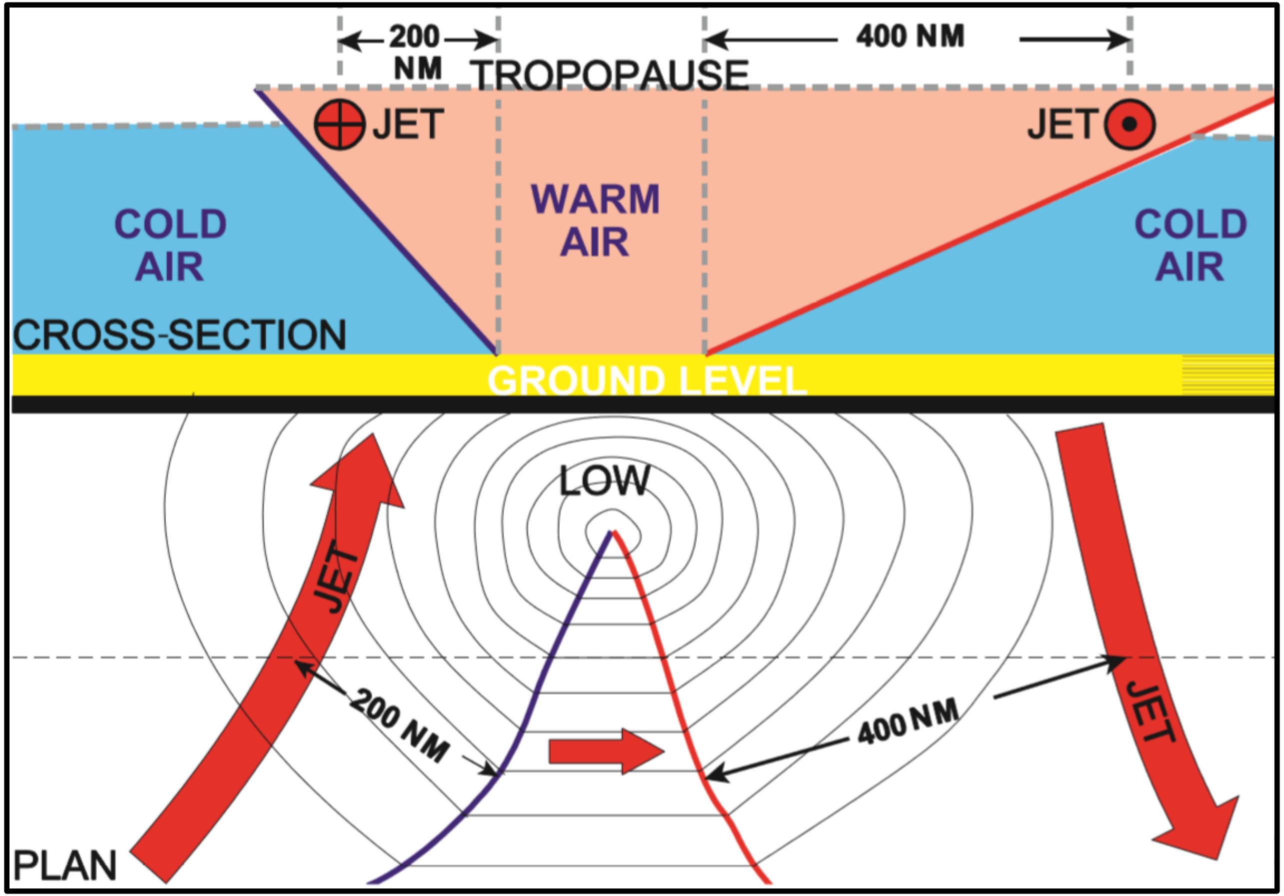
Clear Air Turbulence (TURB)

- Clear air turbulence (TURB) occurs around the boundaries of jet streams because of the large horizontal and vertical windshears.

- It is strongest near to, or just above, the jet axis on the cold air (low pressure) side with a secondary area above the axis.

- the most hazardous jet streams :

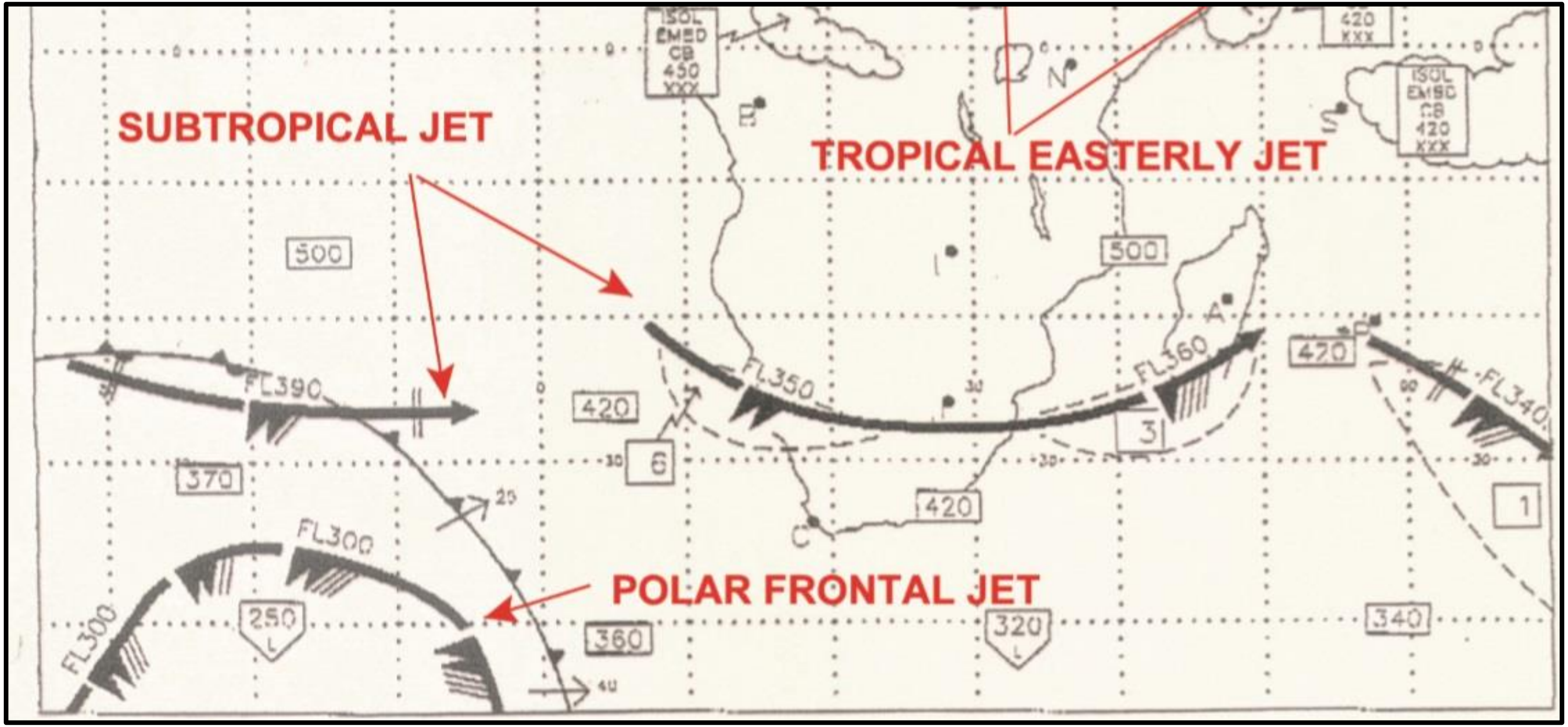
    - Jets with max 110 kt
    - Curved jets


200 NM
400 NM
TROPOPAUSE
JET
JET
COLD AIR
WARM AIR
COLD AIR
CROSS-SECTION
GROUND LEVEL
LOW
JET
JET
200 NM
400 NM
PLAN

Recognition

- From the ground, when the cloud amounts allow, jets may be recognized by wind blown wisps of CIRRUS cloud blowing at right angles to the clouds at lower levels.

- In the air, the presence of a jet will be difficult to see, but temperature differences, increases in wind speed, drift and clear air turbulence are all evidence of jet streams.


SUBTROPICAL JET
TROPICAL EASTERLY JET
POLAR FRONTAL JET
ISOL
EMBD
CB
450
XXX
ISOL
EMBD
CB
420
XXX
420
XXX
500
500
420
420
420
370
250
320
360
340
6
3
1
FL390
FL350
FL360
FL340
FL300
FL300

Chapter 11

Clouds

Introduction

Clouds may be regarded as signposts in the sky giving us warning of what the weather is or what it is likely to be. They are also a source of several hazards to aviation:

- Turbulence
- Poor visibility
- Precipitation
- Icing
- Lightning

Cloud formation

Cloud is formed by air being lifted and cooled adiabatically until the water vapour condenses out as water droplets. The height at which this occurs is called the condensation level. It is also the height of the cloud base.

The means whereby the initial lifting of the air occurs are as follows:

- Turbulence.
- Orographic Uplift.
- Convection.
- Slow, widespread ascent (frontal uplift).
- Convergence.

Note: The lifting processes above are strictly all 'convection'; the third process is free convection, the rest are forced convection.

The condensation level is the height at which the rising air, cooling adiabatically, has cooled to the dew point temperature. Any further ascent and cooling will result in condensation and the formation of cloud. This will be the height of the base of the cloud.

Calculation height of cumuluse base

$$HCU = \frac{TT - TdTd}{4.5} \times 1000$$ AGL $^{\circ}$F

$$HCU = \frac{TT - TdTd}{2.5} \times 1000$$ AGL $^{\circ}$C

Cloud Amount

Cloud amounts are reported in OKTAS (eighths). It is assumed that the sky is divided into 8 equal parts and the total cloud amount is reported by an assessment of the number of eighths of the sky covered by cloud.

FEW	1 to 2 OKTAS
SCT	3 to 4 OKTAS
BKN	5 to 7 OKTAS
OVC	8 OKTAS

Cloud Base

The cloud base is the height of the base of the cloud above ground - above official aerodrome level.

Cloud Ceiling

The height above aerodrome level of the lowest layer of cloud of more than 4 oktas .
The height above the ground or water of the base of the lowest layer of cloud below
6 000 metres (20 000 feet) covering more than half the sky.

Cloud Classification

Classification of cloud type is based, primarily, on the shape, or form of the cloud. The basic forms of cloud are **stratiform**, **cumuliform** and **cirriform**.

Clouds are also identified by reference to the height at which they occur. There are 3 distinct cloud levels within the troposphere.

Cloud Height Bands

Low-level clouds

- Surface to 6500 ft
- stratus, stratocumulus, cumulus and cumulonimbus.
- The prefix nimbo and the suffix nimbus imply “rain bearing.

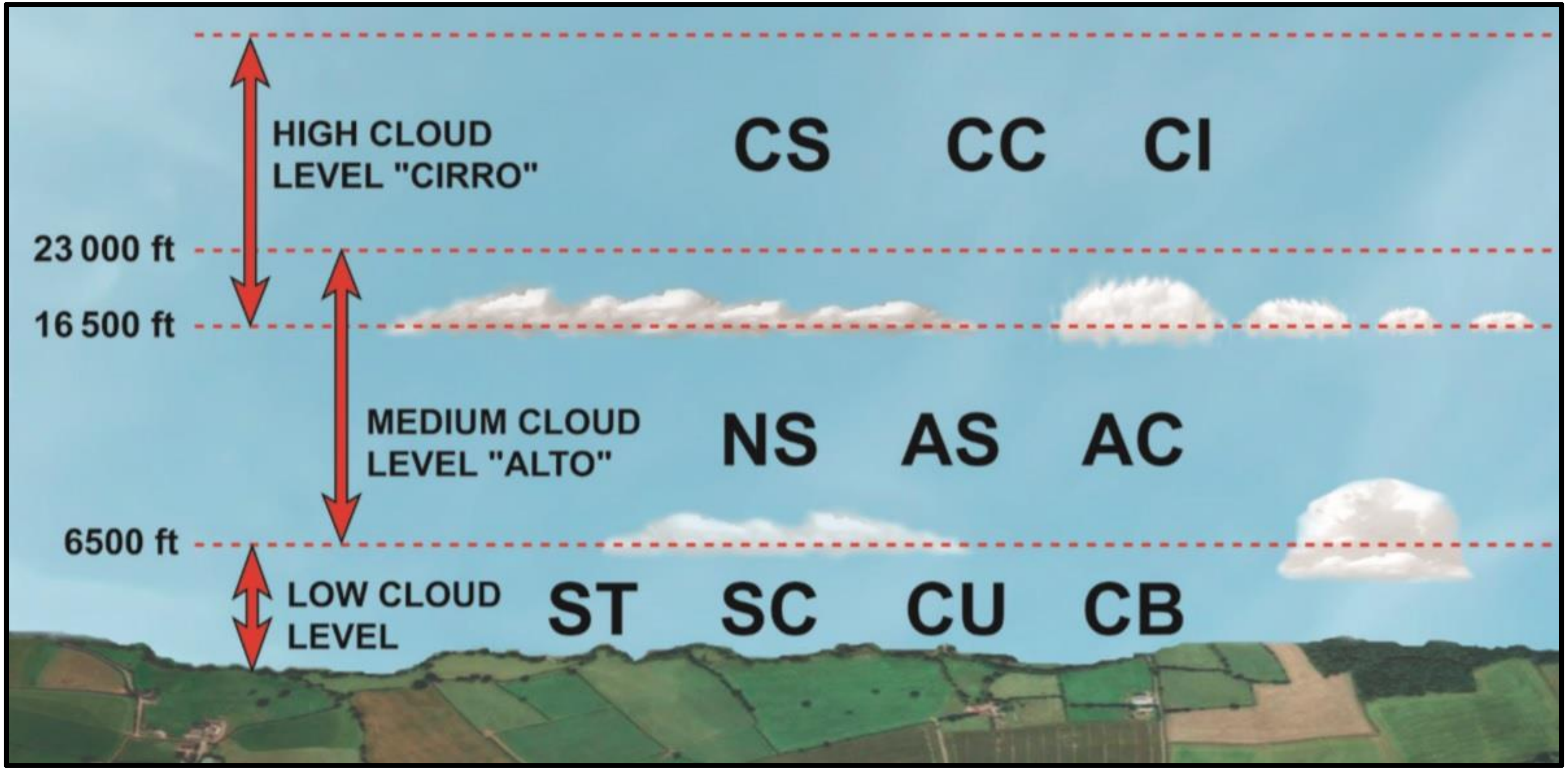
However, cumulus and cumulonimbus will have significant vertical development and will extend from low-level to higher levels. Cumulonimbus clouds may extend into the lower stratosphere.

Medium-level clouds

- are found between 6500 ft and 23 000 ft.
- The names of medium-level clouds are characterized by the prefix “alto-”.
- altostratus , altocumulus and Nimbostratus .

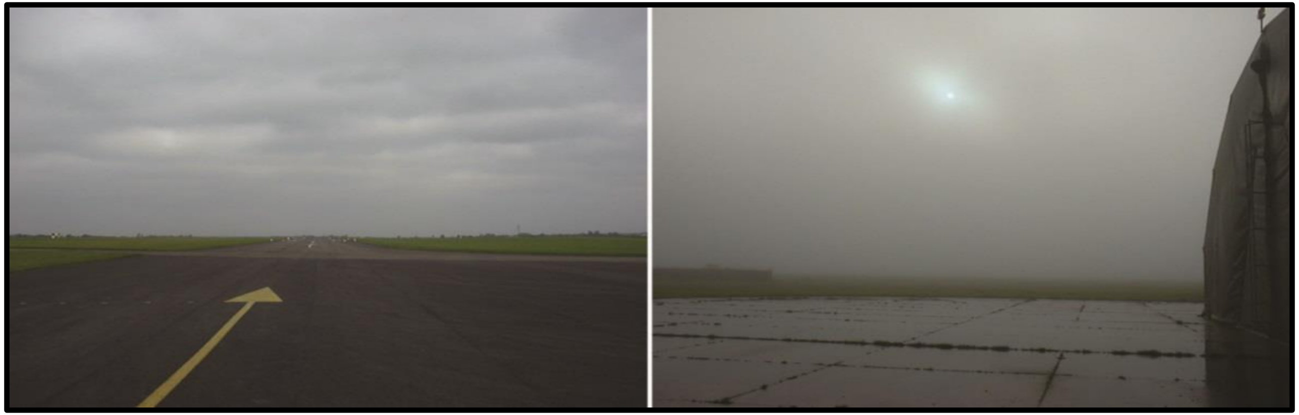
High-level clouds

- 16 500 ft to 45 000 ft
- The names of high-level clouds are prefixed by “cirro-”.
- cirrostratus, cirrocumulus, and cirrus.


HIGH CLOUD
LEVEL "CIRRO"
CS
CC
CI
23 000 ft
16 500 ft
MEDIUM CLOUD
LEVEL "ALTO"
NS
AS
AC
6500 ft
LOW CLOUD
LEVEL
ST
SC
CU
CB

Stratus (St or ST)

- generally a grey, layered cloud with a fairly uniform base, which may produce drizzle, or light snow.
- Water droplets
- No turbulence
- Stable air
- Light to moderate icing
- Poor visibility (<30 m)
- When stratus is at its thinnest, the sun can be clearly seen through the stratus layer.



Stratocumulus (Sc or SC)

- grey, or whitish, but usually has distinct dark parts. Stratocumulus can be seen as patches, or in a continuous layer.
- Water droplets
- Light turbulence
- Light – moderate Icing
- Poor visibility
- Stable air

Nimbostratus (Ns or NS)

- a dense, dark-grey, rain-bearing, stratiform cloud, producing extensive and long-lasting continuous or intermittent precipitation.
- Water droplets, ice crystals
- Moderate – severe turbulence
- Moderate - severe icing
- Poor visibility
- Warm front
- Heavy precipitation
- Stable air

Cumulus (Cu or CU)

• Cumulus cloud is the most common form of convective cloud.
• reliable indication of the presence of thermal upcurrents.
• below cloud base is turbulent, whereas, above the cloud tops, the air is likely to be very smooth.
• The sunlit parts of cumulus clouds are brilliant white, but their bases are relatively dark.
• the upper parts often resemble the head of a cauliflower.
• they can grow rapidly, when the atmosphere is unstable, and may develop into cumulonimbus clouds, with their tops reaching the tropopause.
• Unstable Air.
• Water droplets and ice crystals.
• Moderate to severe turbulance and icing.
• Poor visibility-Heavy showers.

Cumulonimbus (Cb or CB)

• Cumulonimbus clouds are clouds that the aviator should avoid.
• Cumulonimbus clouds consist of vigorous convective cloud cells of great vertical extent.
• The upper parts of a cumulonimbus cloud consist of supercooled water droplets and ice crystals.
• The base of cumulonimbus clouds is often very dark
• Unstable Air.
• Water droplets and ice crystals.
• Moderate to severe turbulance and icing.
• Poor visibility-Heavy showers.
• very strong upcurrents and downdraughts are continually at play, producing severe precipitation in the form of showers of rain and hail.
• Other hazards associated with cumulonimbus are lightning and static discharge which may lead to airframe damage, erroneous instrument readings .

Altocumulus (Ac or AC)

• Altocumulus takes the form of speckled white or grey cloud. The patches of cloud appear as rounded masses of fibrous or diffuse aspect.
• Water droplets, ice crystals .
• light – moderate turbulence and icing.
• Unstable air
• Fair visibility
There are two forms of altocumulus which are of particular significance, namely:

Altocumulus lenticularis
• also known as lenticular
• cloud, is found downwind of mountainous or hilly areas, and is indicative of the presence of mountain wave activity.
• moderate or even severe turbulence
• Water droplets and ice crystals.

Altocumulus castellanus

• “bubbly” form of normal altocumulus.

• These clouds are significant because they often herald a change to showery, thundery weather.

• Cumulonimbus clouds sometimes develop from altocumulus castellanus, when instability is present at medium levels of the troposphere.

• Indicative of medium level instability

Altostratus (As or AS)

- Altostratus is a grey or bluish sheet, or layer of cloud, which can be fibrous or uniform in appearance.
- altostratus is not a dense cloud, and the sun is usually perceptible through the cloud layer.
- light – moderate turbulence and icing.
- stable air
- Fair visibility
- Light to moderate rain
- Warm front

Cirrus (Ci or CI)

- Cirrus is the highest of all the cloud types and is composed entirely of ice crystals.
- Cirrus clouds take the form of white delicate filaments, in patches or narrow bands.
- They may also be described as fibrous or hair-like. They often herald the approach of a warm front.
- stable air
- No turbulence No icing
- Fair visibility

Cirrostratus (Cs or CS)

• Cirrostratus is a transparent, whitish cloud-veil of fibrous or smooth appearance, totally or partially covering the sky.

• Cirrostratus is made up of ice crystals, and the presence of CS usually indicates the approach of a warm front.

• CS often produces a halo around the sun or the moon.

• In tropical regions CS is often associated with the presence of tropical revolving storms.

• stable air

• No turbulence No icing

• Fair visibility

Cirrocumulus (Cc or CC)

- Cirrocumulus is a thin, white and patchy layer of cloud, with ripples, more or less regularly arranged.
- Cirrocumulus consists of ice crystals.
- unstable air
- Light turbulence
- No icing
- Fair visibility

Chapter 12

Thunderstorms

Conditions

Thunderstorms (TS) occur in well developed cumulonimbus (Cb) cloud, though not all Cbs produce thunderstorms. They are most likely to occur when there is:

- A lapse rate greater than the SALR through a layer at least 10 000’ thick and extending above the freezing level.
- Sufficient water vapour to form and maintain the cloud.
- Trigger * action to produce early saturation, thus enhancing instability.

* The so-called triggers or lifting forces are:

- Convection
- Orographic uplift
- Convergence
- Frontal uplift

Thunderstorms are classified as:

- Air mass type (more common in summer time).
- Frontal type (more common in winter time).

Air Mass Type Thunderstorms

Air mass type thunderstorms are:

- isolated - all triggers except frontal.
- most frequent over land in summer.
- usually formed by day, clear by night.
- formed in cols or weak lows.

Frontal Type Thunderstorms

Frontal thunderstorms are:

- most frequent in winter.
- formed over land or sea, day or night.
- usually formed in a line at a cold front or occlusion.
- found in active depressions or troughs.
- often accompanied by a line squall.
- the fastest moving.

Thunderstorm Development

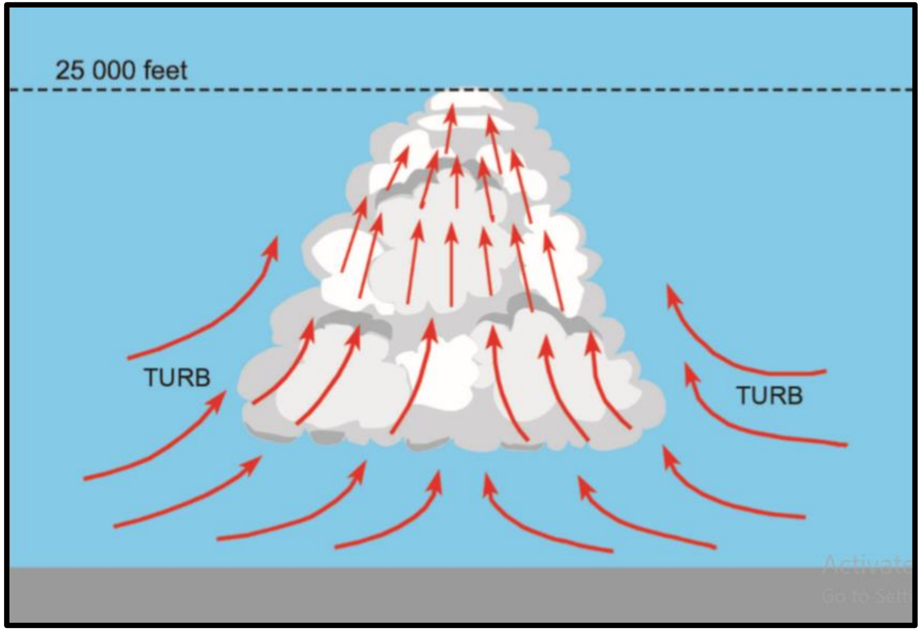
Initial stage :

- Several small Cu combine to form a large Cu cell about 5 NM across.

- There are strong upcurrents of 1000 to 2000 fpm (exceptionally 6000 fpm).

- Air from the sides and below is drawn in to replace the lifted air, thus causing turbulence.

- The initial stage lasts about 15 to 20 minutes.



Mature stage:

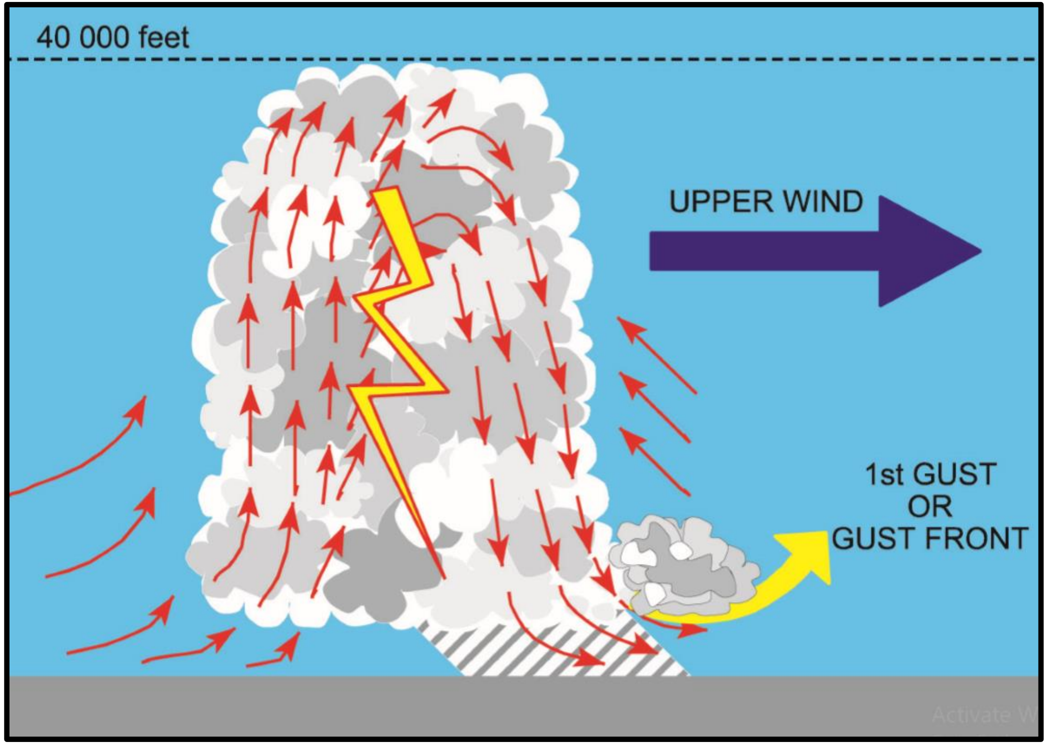
- When precipitation occurs, the storm has reached the mature stage.

- The rain or hail will cause strong down currents of up to 2400 fpm and will also bring cold air to lower levels.

- These down drafts will warm initially at the SALR causing the air to warm very slowly, thereby staying colder than the surrounding air causing it to sink faster. Another factor aiding these down drafts is that some of the rain will evaporate which will absorb latent heat from the air making it even colder and more dense. The intensity of this can lead to the formation of the **GUST FRONT**.

- Up currents remain strong and can be up to 10 000 fpm.

• Tops may rise at 5000 fpm or more. There can be moderate to severe turbulence in, under, over and all around the cloud.



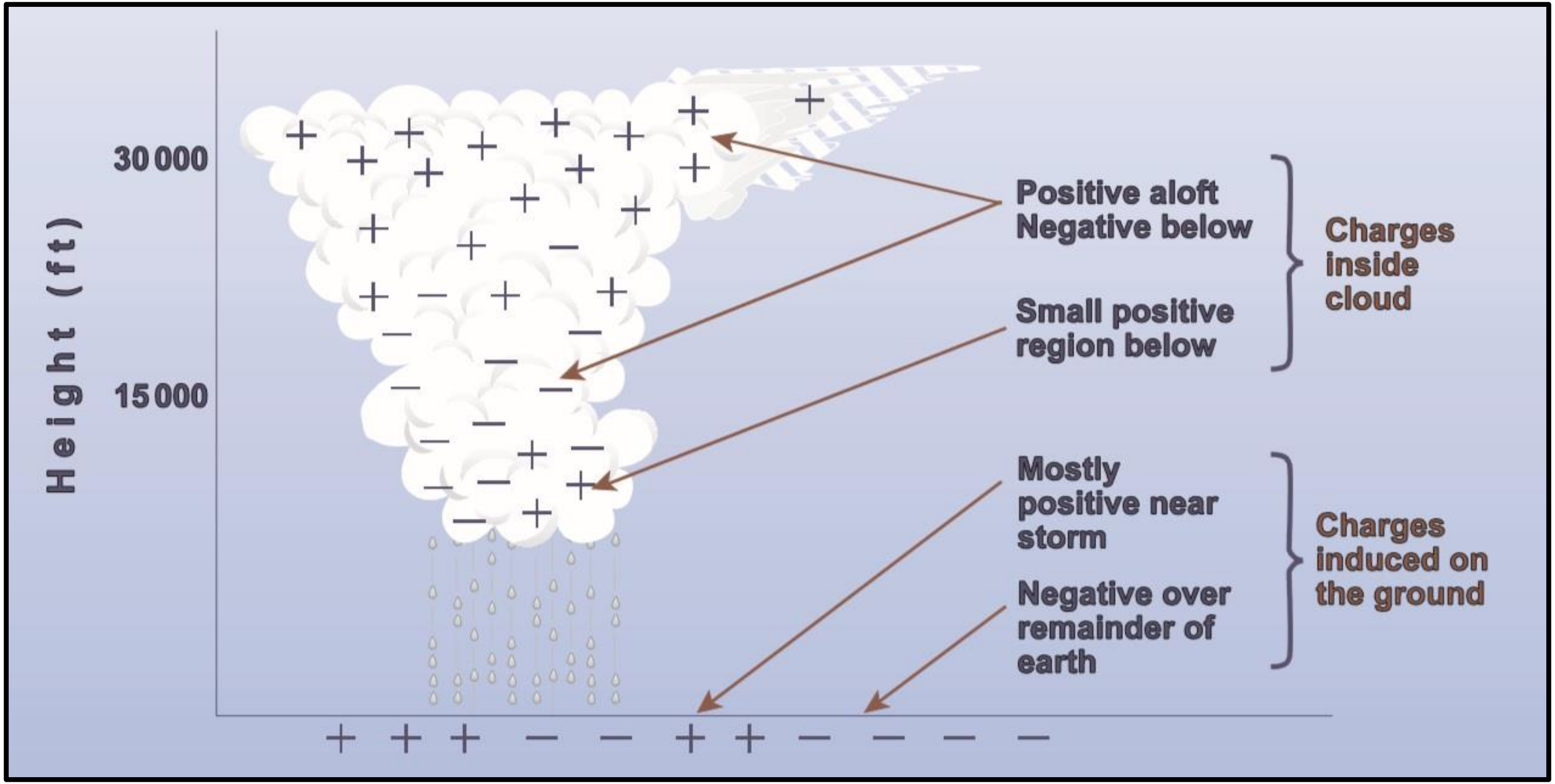
• At the bottom leading edge of the storm there can be a roll of Sc and a strong gust front can be experienced up to 13 to 17 NM (24 to 32 km) ahead of the storm and be up to 6000 feet in depth.
Below the cloud a squall and associated windshear can be expected.

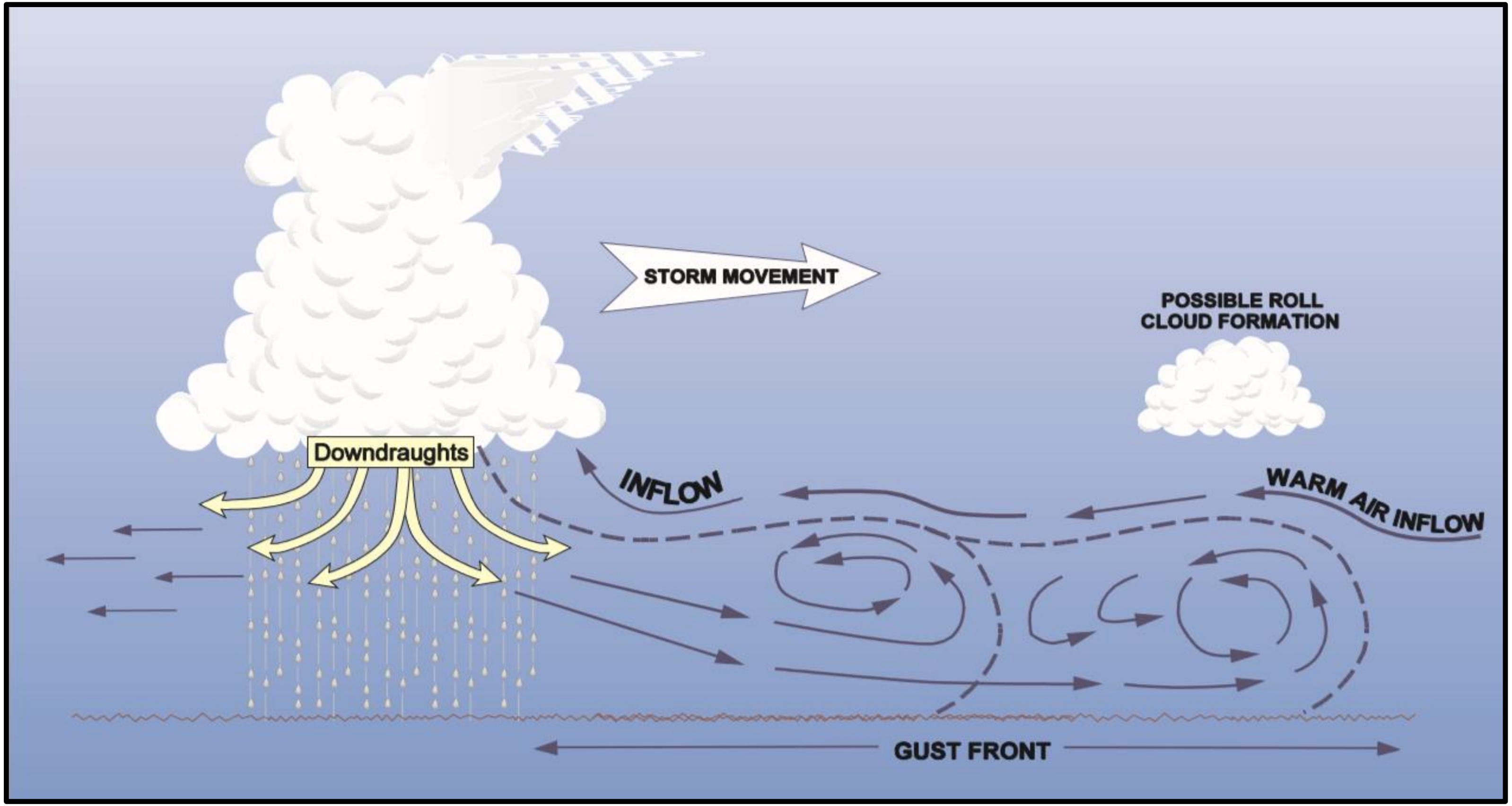
• **Downbursts (microbursts or macrobursts) may occur at this stage.**

• Rising and falling water droplets will produce a considerable build-up of static electricity, usually of positive charge at the top of the cloud and negative at the bottom. The build-ups eventually lead to lightning discharge and thunder.

• A characteristic of the mature stage is the GUST FRONT in advance of the storm produced by the force of the descending air. The gust front may extend 13 to 17 NM (24 to 32 km) ahead of the storm centre.

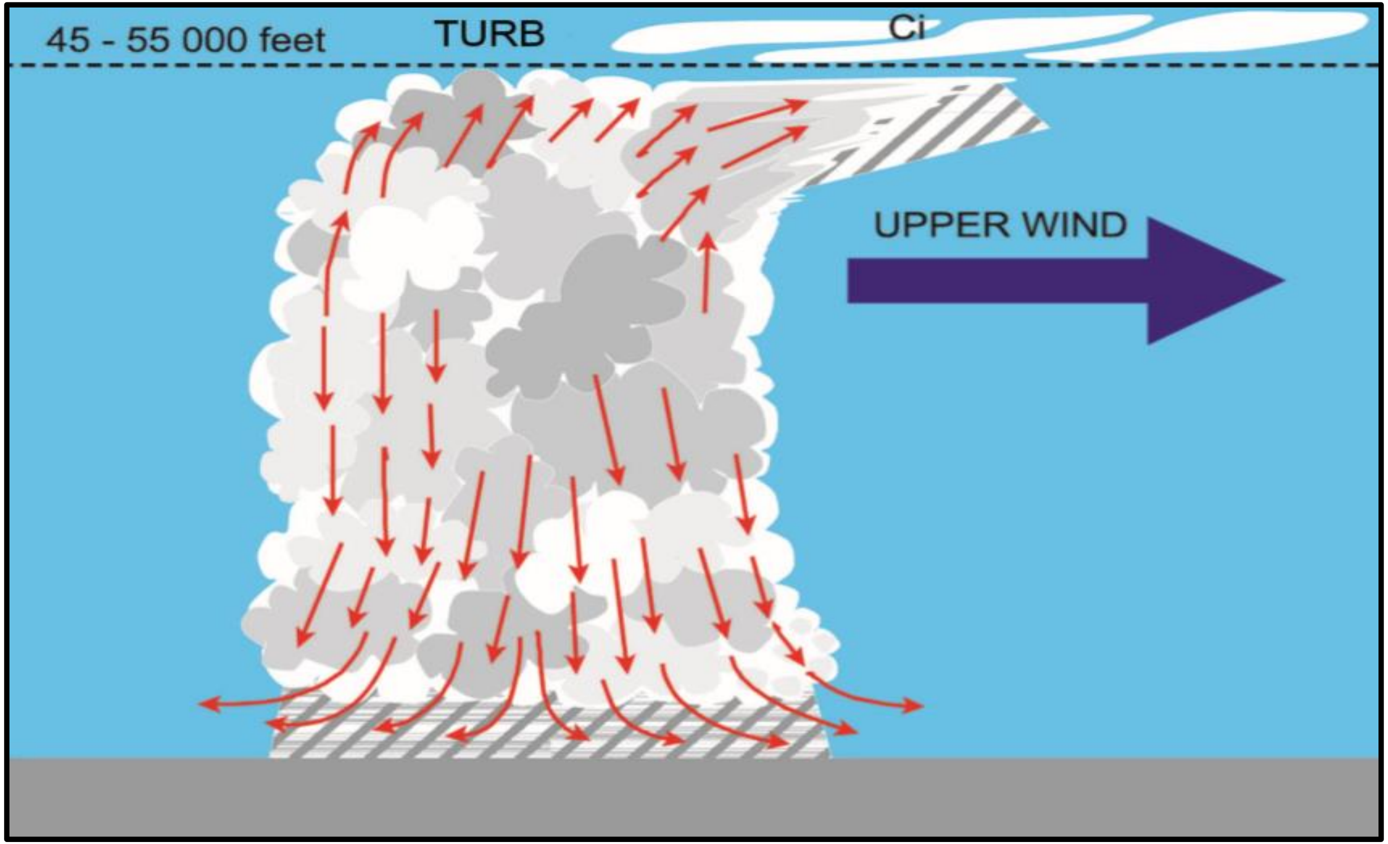
• The mature stage lasts for a further 15 to 20 min.


Height (ft)
30 000
15 000
Positive aloft
Negative below
Small positive
region below
Charges
inside
cloud
Mostly
positive near
storm
Negative over
remainder of
earth
Charges
induced on
the ground


STORM MOVEMENT
POSSIBLE ROLL CLOUD FORMATION
Downdraughts
INFLOW
WARM AIR INFLOW
GUST FRONT

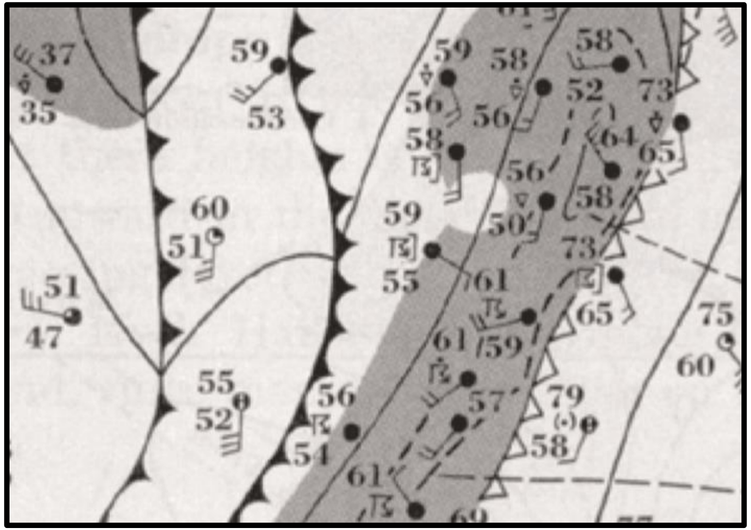
Dissipating stage:

- At this stage there is precipitation, which is heavy, and extreme turbulence.
- Thunder and lightning may possibly occur at this stage.
- The cloud extends to the tropopause, where it is spread out by the upper wind to form an anvil. At these levels the cloud thins to form Ci.
- Large variations in static charge in and around the cloud cause discharge in the form of lightning which can appear in the cloud, from the cloud to the ground, or from the cloud to the air alongside.
- The dissipating stage lasts about 30 minutes but the cloud can persist for 2 to 3 hours.


45 - 55 000 feet
TURB
Ci
UPPER WIND

Movement of Thunderstorms

• Single cell thunderstorms usually move in the direction of the 10 000 ft (700 hPa) wind, though large storms and newly developed ones may differ from this.
• Thunderstorm squall lines may occur at and some miles ahead of an active cold front.



Summary of Thunderstorm Hazards

- **Turbulence**

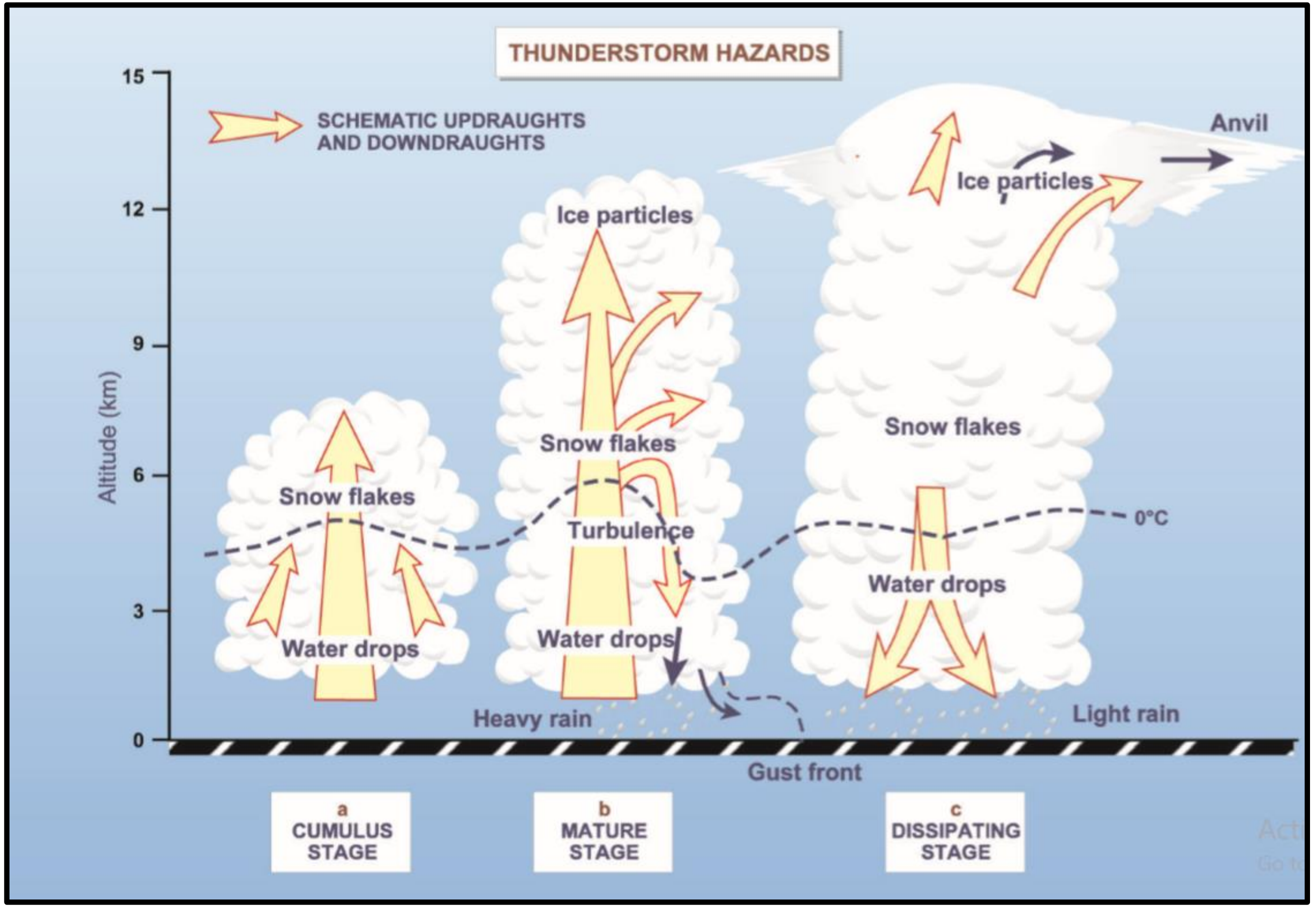
Turbulence can be violent both within cloud and at their sides. Below the cloud, turbulence can be dangerous during take-off and landing and there can be windshear. It is possible for a pilot to overstress the airframe in these conditions.

- **Hail**

Hail can be met at any height in the cloud, also below the cloud and below the anvil. Severe skin damage to the airframe can occur when the hail is large. Damaging hail can occur up to a height of 45 000 feet.

- **Icing**

This can occur at all heights in the cloud where the temperature is between 0°C and -45°C. Heavy concentrations of droplets and large droplet size result in severe clear icing.
Carburettor icing can occur at temperatures between -10°C and +30°C and it can be particularly severe between -2°C and +15°C.


THUNDERSTORM HAZARDS
SCHEMATIC UPDRAUGHTS AND DOWNDRAUGHTS
Altitude (km)
15
12
9
6
3
0
Ice particles
Snow flakes
Water drops
Turbulence
Heavy rain
Gust front
Anvil
Light rain
0°C
a CUMULUS STAGE
b MATURE STAGE
c DISSIPATING STAGE

- **Lightning**

The main effects of a lightning strike are:

- Temporary blindness of the pilots .
- Minor airframe damage .
- Magnetic compasses may be seriously affected .
- Disruption to electrical equipment .

- **Static**

This causes interference on radio equipment in the LF, MF, HF and VHF frequencies. St Elmo’s fire can be caused by static and it results in purple rings of light around the nose, wing tips and propellers. This is not a hazard, but it indicates that the air is electrically charged and lightning is probable.

- **Pressure variations**

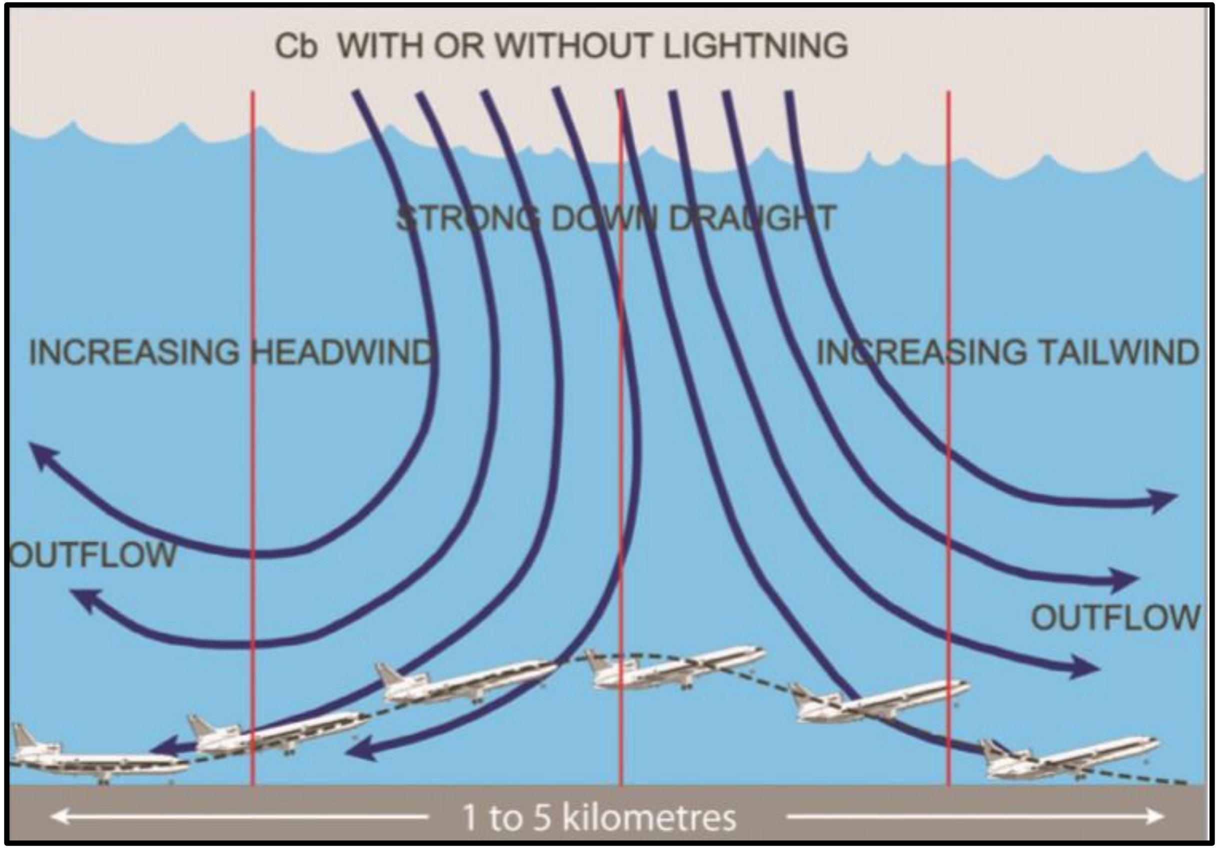
Local pressure variations covering only a very small region, in or close to, a storm can occur causing QFE/QNH to be in error, so that altimeter readings can be inaccurate by as much as ±1000’ at all heights. These, together with gust effects, can cause height errors at low level which can be dangerous.

- **Microbursts**

These are down currents in the cloud which also move outwards by reaction from the ground, having speeds considerably in excess of 1000 feet per minute downwards (up to 6000 fpm) and 50 kt horizontally. The windshear (headwind to tailwind) may be between 50 & 90 kt. They are largely caused by descending raindrops which cool the surrounding air by evaporation, the higher density accelerating the downdraught still further.

They are concentrated in a burst which is up to 4 km in horizontal length and have a lifetime of less than 5 minutes. (A macroburst is a similar event but over a bigger area.)

A warning sign is **virga**, which is streaks of precipitation from below the cloud which do not reach the ground.


Cb WITH OR WITHOUT LIGHTNING
STRONG DOWN DRAUGHT
INCREASING HEADWIND
INCREASING TAILWIND
OUTFLOW
OUTFLOW
1 to 5 kilometres

- **Water ingestion**

If updraught speed approaches or exceeds the terminal velocity of the falling raindrops, the resulting high concentrations of water can exceed the design limits for water ingestion in some turbine engines. The result can be engine flame-out and/or engine structural failure. Water ingestion may also affect pitot heads, even though heaters have been switched on.

- **Tornadoes**

Tornadoes are exclusively associated with CB and large CU clouds. They usually occur as a result of vertical windshear with warm moist air at low altitude and cool dry air coming from a different direction at high altitude. They are very powerful whirlwinds with small horizontal extent and very low pressure in the centre.
These tornadoes may have rotational speeds in excess of 200 kt and diameters up to 1 km.

Dust devils

are small whirlwinds usually occurring on hot and sunny afternoons when strong convective currents interact. In dry conditions they will draw up dust off the ground, hence the name. Whilst wind speeds may exceed gale force they have small diameter and will only extend up to a maximum height of around 2000 ft. As with tornadoes dust devils will be hazardous to aircraft and should be avoided.

SQUALL LINES

Squall lines are usually formed in the warm air mass ahead of a cold front. Squall phenomena are most frequent during the evening and early night. A squall line with thunderstorms also contains hail, and tornadoes can occur.
Although the CB along the squall can seem very small and insignificant compared to the frontal clouds behind, in reality the most intense weather phenomena are caused by squalls.

Chapter 13

Visibility

Introduction

Ground visibility is the visibility of an aerodrome as reported by an accredited observer.
Poor visibility is usually associated with stable conditions, anticyclones, cols, inversions and light winds.
The various types of reduction in visibility are:

- **Mist**

There is mist if the visibility is 1000 m or more and the relative humidity is greater than 95% with very small water droplets. The upper limit for reporting mist is usually 5000 m.

- **Fog**

There is fog if the visibility is less than 1000 m and the obscuring agent is water droplets. Relative Humidity (RH) will be near 100%.

- **Haze**

There is haze if the visibility is reduced by extremely small solid particles - sand, dust or smoke. If the visibility is reduced below 1000 m, it is shown on synoptic charts as  .

Radiation Fog

Radiation fog is caused by radiation of the earth's heat at night, and the conductive cooling of the air in contact with the ground to below dew point.
If there is a light wind, then fog will form, and in calm conditions the result will be the formation of dew.
Conditions necessary for radiation fog to form :

- **Clear sky**

to increase the rate of terrestrial radiation.

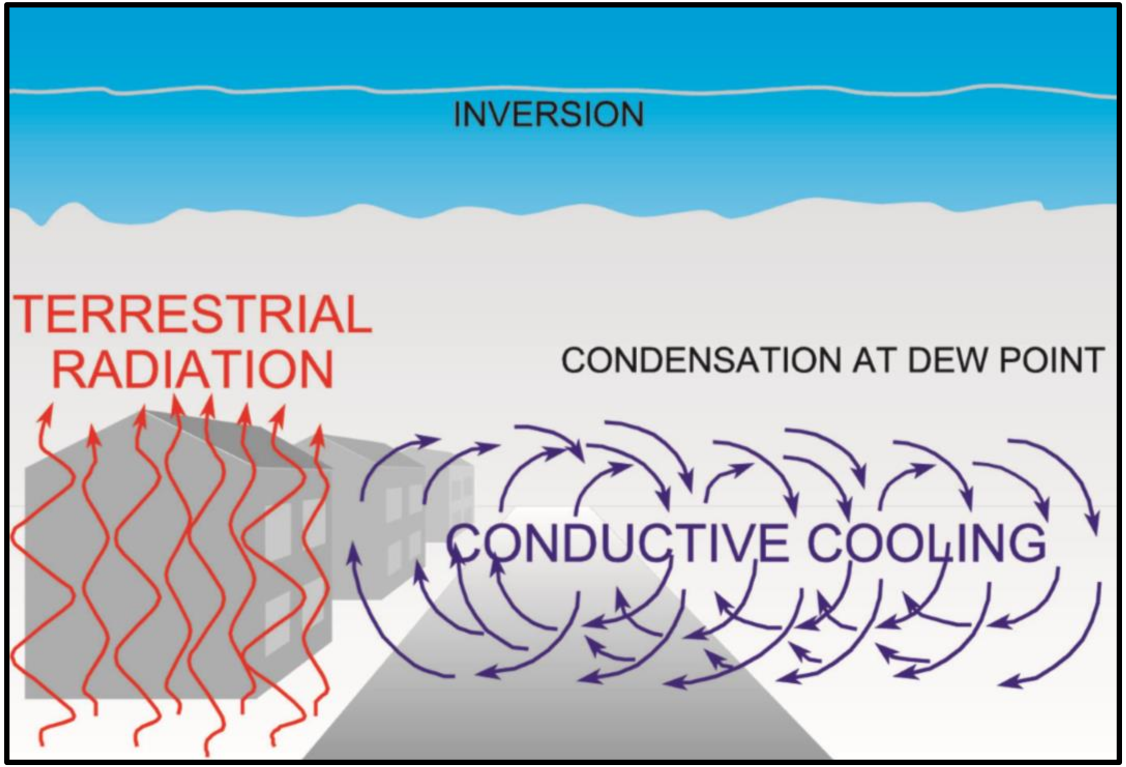
- **High relative humidity**

so that a little cooling will be enough to cause saturation and condensation.

- **Light wind**

of 2 - 8 kt to mix the layers of air causing turbulence so that droplets will be kept in suspension and so that warmer air from above can be brought into contact with the cold ground to thicken the fog.

A natural result of the radiative cooling at the surface will be an inversion above the fog layer (usually the friction layer).



Times of occurrence

• Predominantly in autumn and winter.
• Night and early morning. The lowest temperatures are early morning. Additionally, the first insolation provides thermal turbulence and light winds. The latest time at which radiation fog can form is about 30 minutes after sunrise.

Location

• Over land - not over sea because there is little DV of temperature.
• Firstly in valleys because of the katabatic effect.
• In anticyclones, ridges and cols.

Dispersal

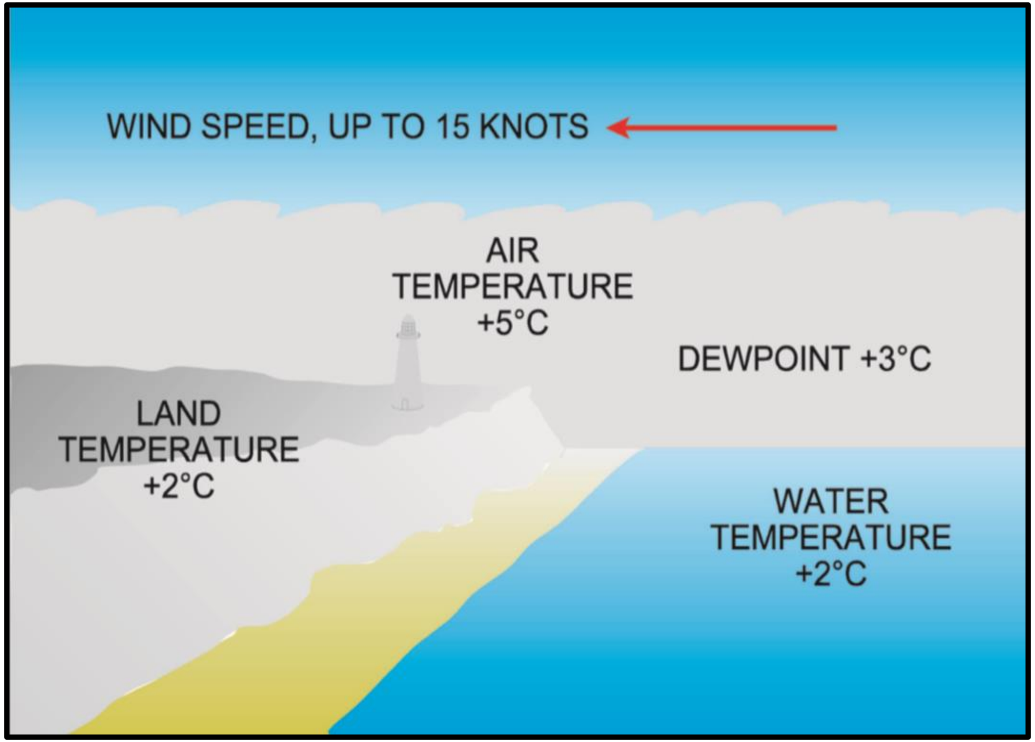
• By insolation causing convection which will lift the fog. It will also help to evaporate the lower layers.
• By a strong wind lifting the fog to form stratus cloud.

Hill (Orographic) Fog

Hill fog is (usually) stratiform cloud (ST, SC) whose base is lower than the summit of the hills. It may be generated when moist stable air is forced to rise over the hills (cap cloud) or by the normal turbulence action producing ST and SC.

Advection Fog

Advection fog is formed by the movement of warm, moist air over a cold surface. The surface can be land or sea.



Conditions necessary for advection fog to form

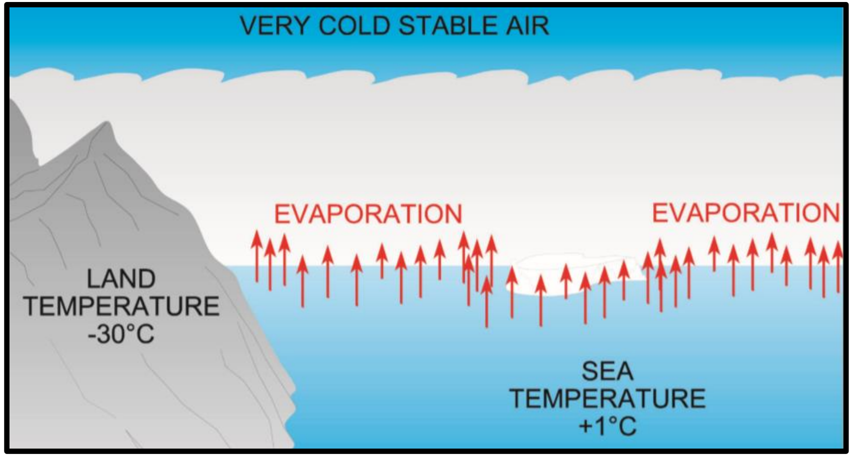
- Winds up to 15 kt to move the air. (May be stronger over sea areas)
- A high RH so that relatively little cooling is required to produce saturation and subsequent condensation.
- A cold surface with a temperature lower than the Dew Point (DP) of the moving air to ensure condensation.

Dispersal

- By a change of air mass. (Wind change).
- By a wind speed greater than 15 kt which will lift the fog to form stratus cloud.

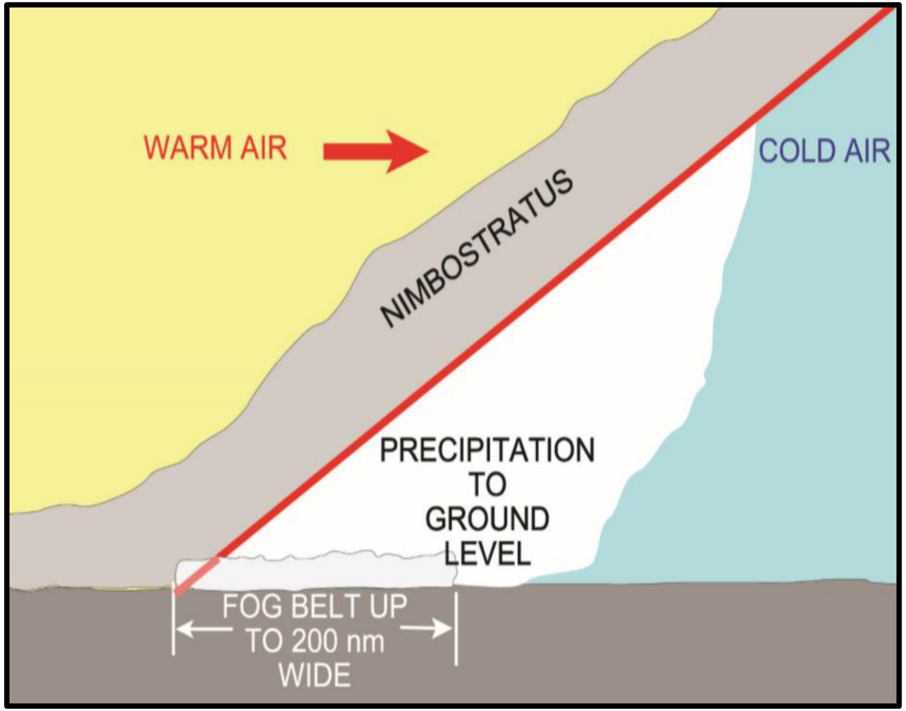
Steaming Fog (Arctic Smoke)

- It is caused by cold air from a land mass moving over a warmer sea.
- The small amount of evaporation from the sea is enough to cause saturation and condensation but the air itself must be very stable.
- The fog can be persistent and up to 500 feet thick - may drift inland.
- It Will be dispersed by an increase in wind speed or change of direction.



Frontal Fog

Frontal fog occurs at a warm front or occlusion. The main cause is precipitation lowering the cloud base to the ground.
The fog can form along a belt up to 200 NM wide which then travels with the front. Can be increased by orographic lifting. Will be dispersed by the passing of the front.



Freezing Fog

at temperatures below 0°C, the air becomes saturated for the formation of ice before it becomes saturated for the formation of water. Hence water vapour will go directly to the solid state at these temperatures. However, the rarity of freezing nucleii in the atmosphere means that when the dew point is below 0°C condensation will take place producing supercooled water droplets. These droplets will then freeze on contact with a solid object giving hoar frost (or rime ice).

Freezing fog will also occur when the dew point is above 0°C forming fog but the air then cools to a temperature less than 0°C.

Visibility Reducers

- **Smoke**

Smoke consists of solid particles produced by combustion. Conditions will be worse under STABLE (subsiding air) conditions.

- **Dust**

Dust is a particle less than 0.08 mm in diameter. Because of its lightness, it may be carried high into the atmosphere. The surface wind speed is likely to exceed 15 kt and as the speed increases, so will the height to which the dust will rise.

- **Sand**

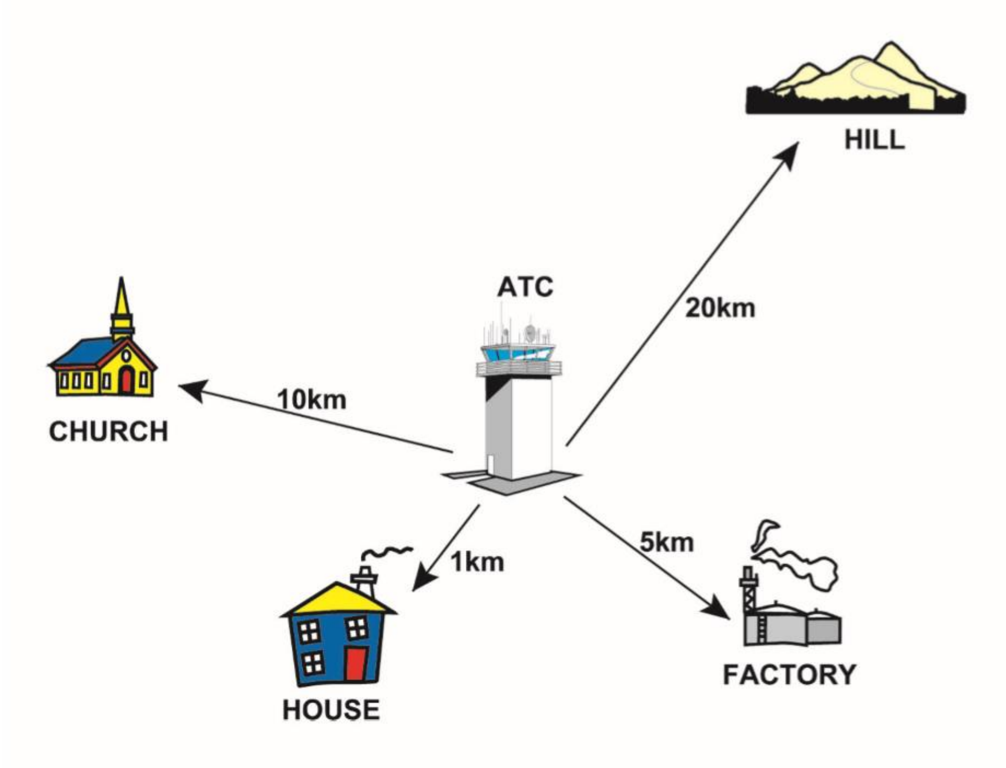
Sand consists of particles between 0.08 and 0.3 mm in diameter. Wind speed will be 20 kt or more. The greater weight of sand particles means that they will only be carried a few feet above the surface.

- Drizzle 500 to 3000 m
- Rain
- Moderate: 3000 m to 10 km

- Heavy: < 1000 m
- Snow
- Moderate 1000 m
- Heavy: 50 to 200 m

Visibility Measurement

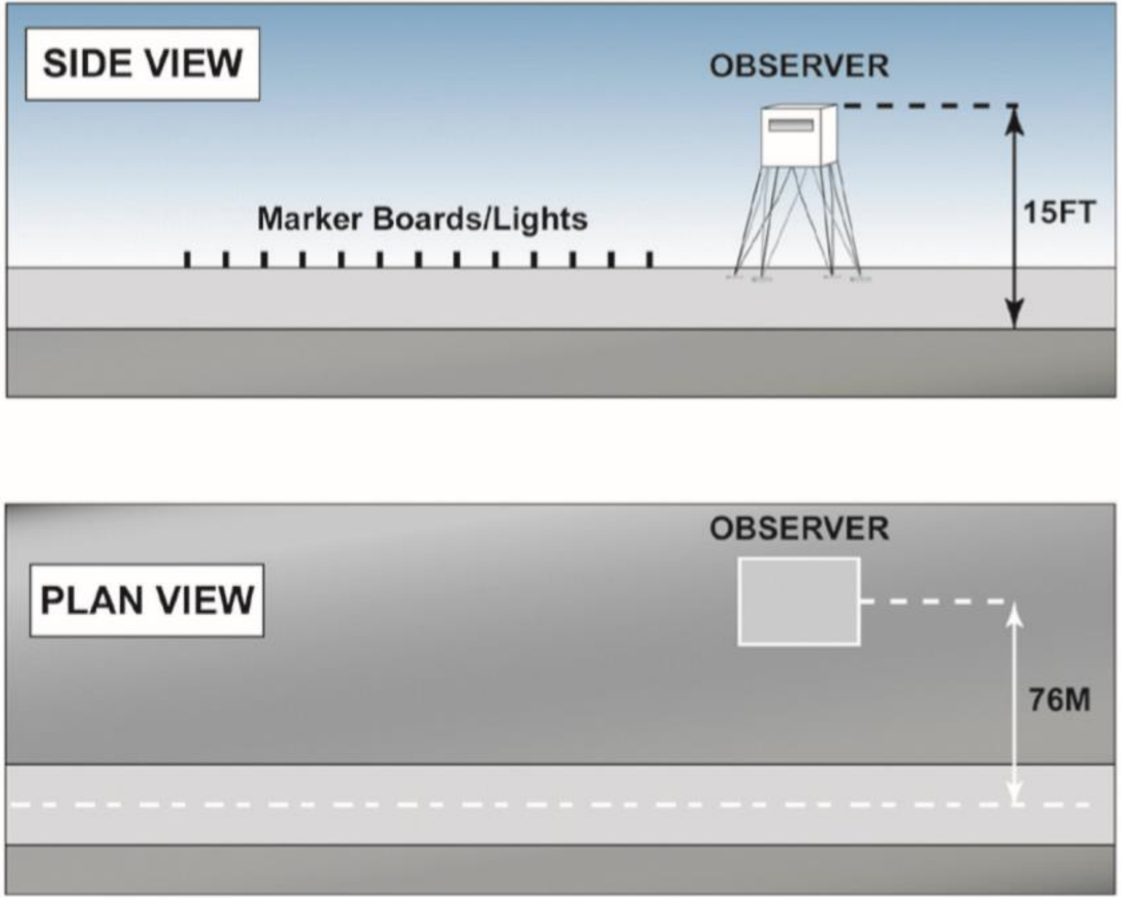
- **By day**



Runway Visual Range (RVR)

RVR is the maximum distance that a pilot can see marker boards by day or runway lights by night when looking in the direction of take-off or landing. The RVR can be assessed by positioning an observer 76 metres from the centre line of the runway in the touchdown area to sight the number of marker board or lights in the appropriate direction. RVR is reported when meteorological optical range (MOR) or (I)RVR falls to less than 1500 m, or when shallow fog is reported or forecast.

If traffic is light, readings are taken 15 minutes before a take-off or landing. RVR is never forecast. There is no connection between RVR and MOR. Generally, RVR is greater than MOR.

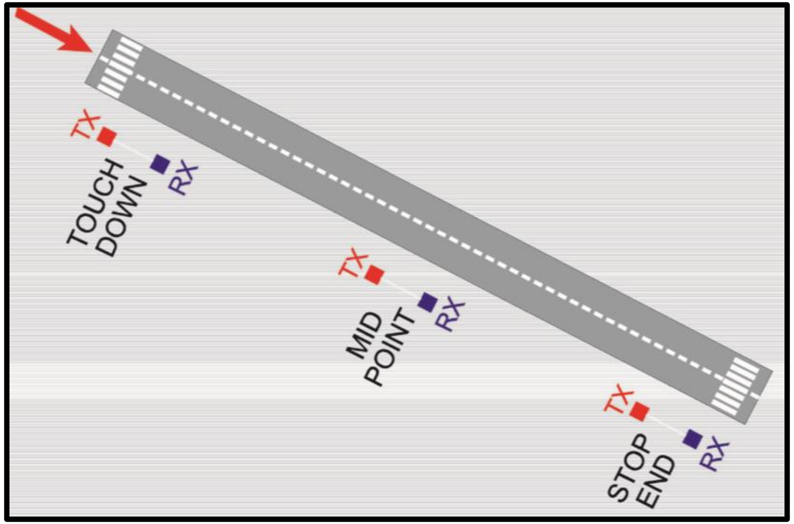

SIDE VIEW
OBSERVER
Marker Boards/Lights
15FT
PLAN VIEW
OBSERVER
76M

Instrumented Runway Visual Range (IRVR)

• Three Transmissometers are positioned alongside the runway.

• IRVR is reported when the normal visibility is 1500 metres or less, or when shallow fog is reported or forecast.

• Readings are sent to ATC. Three readings can be given, one each for touch-down zone, midpoint and stop-end, e.g.: R28L / 600 400 550.



Chapter 14

Icing

An Introduction to Icing and Its Basic Causes

Airframe icing can cause a serious loss of aircraft performance and this will frequently result in a large increase in fuel consumption and some difficulty with aircraft control.

Ice will form on an airframe if there is:

- Water in a liquid state (supercooled water droplets).
- Ambient air temperature below 0°C.
- Airframe temperature below 0°C.

Supercooled Water Droplets (SWD)

A supercooled water droplet is a droplet of water still in the liquid state although its temperature is below 0°C.
If the SWD contains a freezing nucleus then the droplet will start to freeze.
Supercooled water droplets can exist in clouds at temperatures as low as -40°C. However, when an aircraft strikes a supercooled water droplet, it will start to freeze.
Supercooled water droplet size is dependent on the size of the basic cloud droplet, (controlled by cloud type) and the temperature. As temperature decreases the water droplets size decrease.

- Large supercooled water droplets 0°C to -20°C, CU, CB and NS clouds

- Small supercooled water droplets:
    - Upper levels of CU, CB and NS clouds, -20° to -40°C
    - ST, SC, AS and AC clouds 0°C to -40°C

- Below -40°C only very tiny supercooled water droplets can exist

The Effects of Icing

- **Weight.**

In severe conditions, ice can form at a rate of 1” in 2 minutes.There will be a loss of stability due to the weight of ice not being uniform across the airframe.This can lead to a displaced C of G. Similar uneven weight of ice on propeller blades can cause severe engine vibration.Ice breaking off propellers can cause skin damage.

- **Instrument effects**

Ice can block pressure heads and the readings of ASIs, VSI, altimeters and machmeters can be in error as a result.

- **General**

Windscreens and canopies can be obscured.A thin film of ice/frost can cause skin friction.
Ice in landing gear wells can affect retraction. Ice on aerials can cause static interference.

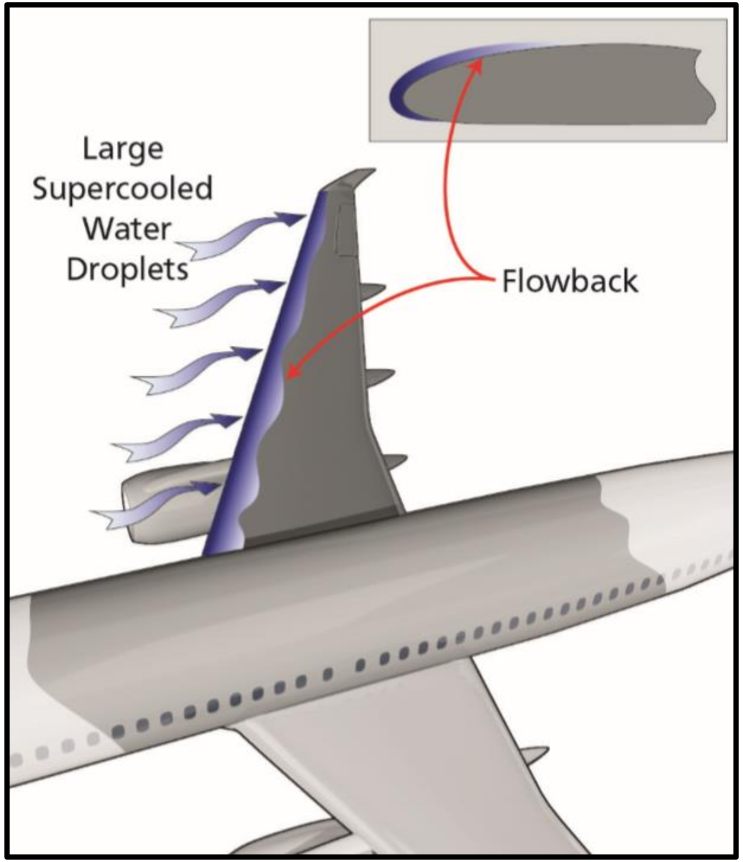
Clear Ice

• If a large supercooled water droplet strikes an aircraft, it will start to freeze and this will release latent heat . This will delay the freezing process whilst part of the supercooled water droplet will flow back over the impact surface forming clear ice.

• ice appears transparent because there is no air trapped under the flowback icing.

• Clear ice forms in Ns, Cu and Cb at temperatures from 0 to -20 °C.

• This is the most dangerous form of icing because of the speed at which it can build up on the aircraft.



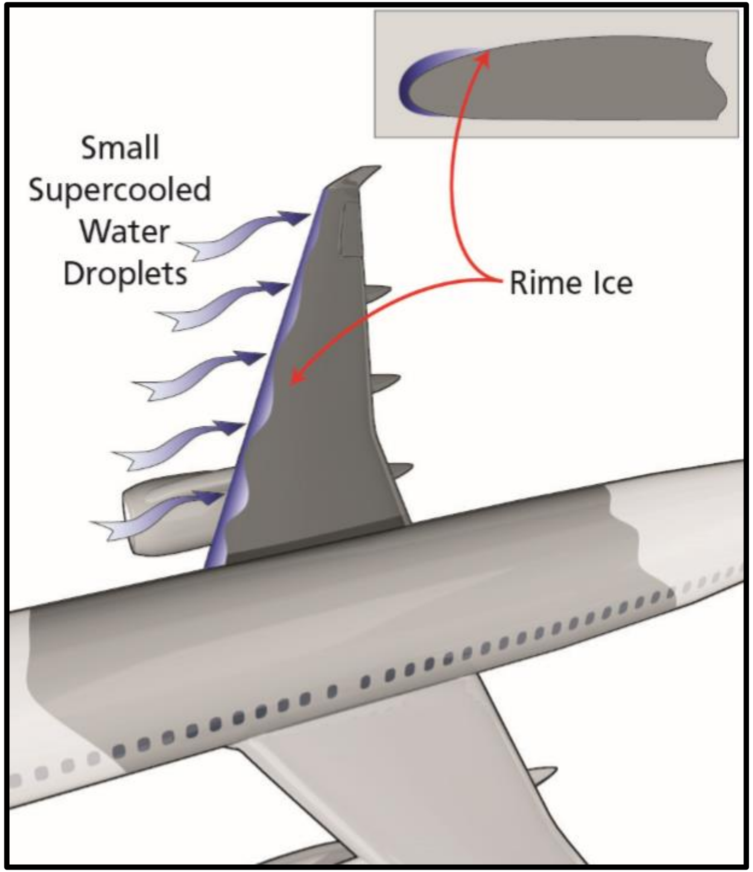
Rime Ice

• When the supercooled water droplets are small (at very low temperatures) or when cloud droplets are small, the whole droplet freezes on impact, each droplet sticking to the surface it strikes and becoming solid almost at once.

• Air becomes trapped between each frozen droplet, which makes the ice opaque. Rime ice, is a white opaque deposit with a light texture. It is caused by small, supercooled water droplets freezing quickly.

• There is little or no flowback. The ice grows out from the leading edges and is compacted by the airstream.

• Rime ice can occur in any cloud where there are small supercooled water droplets



*Rime Ice: Rough, milky, opaque ice formed by the instantaneous freezing of small supercooled water droplets.
*Clear Ice: A glossy, clear, or translucent ice formed by the relatively slow freezing of large supercooled water droplets.

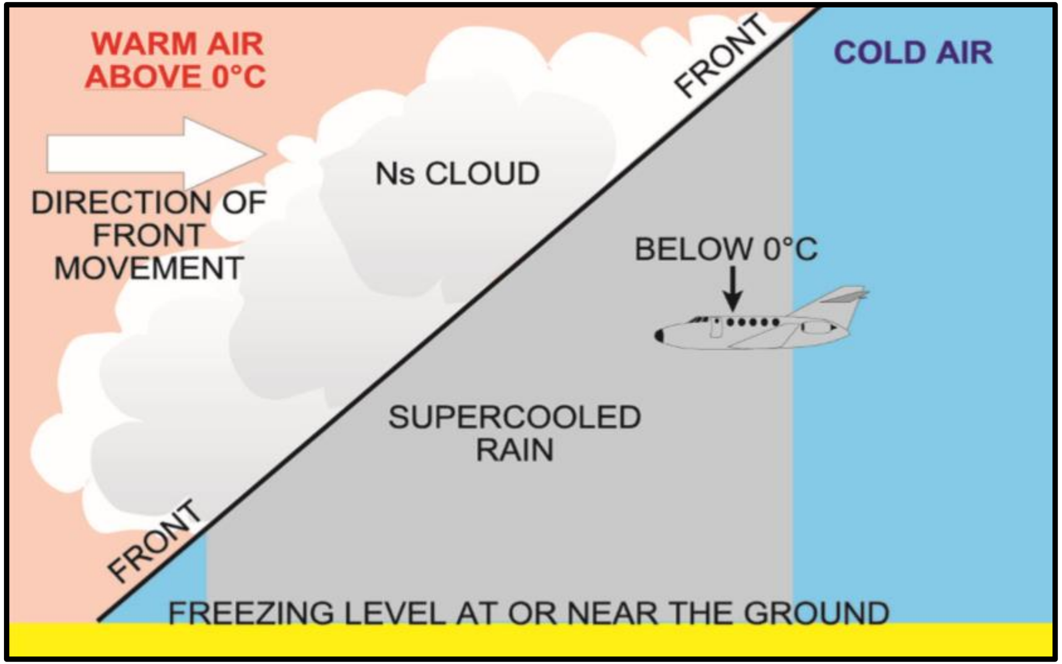
Mixed Ice

Very often in cloud, at temperatures between 0° and -20°C we find a mixture of both large and small supercooled water droplets. This produces a build-up of ice on the leading edges from the small droplets and the flowback from the large droplets giving a combination of the worst effects of both clear and rime ice.

Rain Ice

- Rain ice occurs in rain which becomes supercooled by falling from an inversion into air below 0°C.
- The rain does not freeze immediately in the air but can impact the aerofoil to form clear ice or rime ice.

• Rain ice builds up very quickly and a pilot's action should be to turn onto a reciprocal heading immediately.
• Rain ice occurs in a narrow range of altitudes at low level, about 1000 ft, ahead of a warm front or occlusion and is associated particularly with the moderate continuous rain which often falls from nimbostratus cloud.



Hoar Frost

Hoar frost is a white crystal deposit which appears similar to frost on the ground. It occurs in clear air. This type of icing occurs when air is cooled to the temperature at which saturation occurs and the airframe is below 0°C. The frost forms by sublimation, that is, water vapour turns directly to ice without passing through the liquid state. This process requires the presence of another type of ice nucleus, the sublimation nucleus.

There are two situations where hoar frost can occur:

- **on the ground**

This usually occurs at night and is similar to the frost which forms on a car.

- **in flight**

Hoar frost can occur in flight in the following cases:

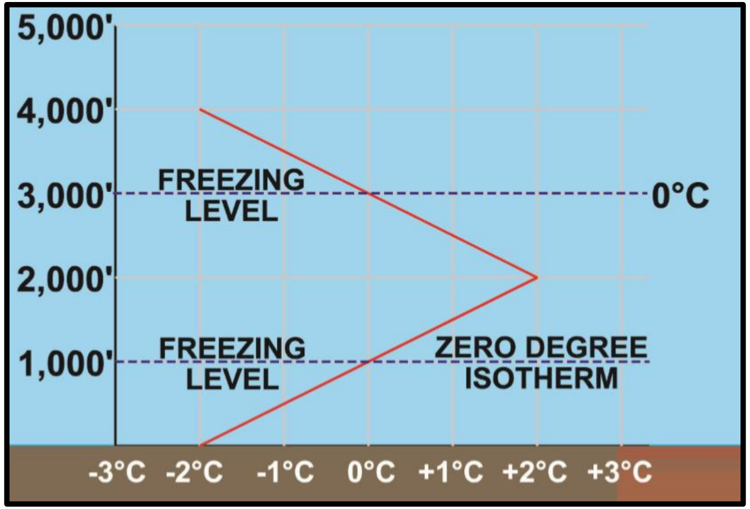
  - If a rapid descent is made from a very cold region to a warm moist layer.
  - If a climb is made from a temperature below 0°C through an inversion.

Icing Forecasts

Forecasting airframe icing is a matter of forecasting clouds, both by type and vertical extent. The degree of airframe icing is classed as light, moderate, or severe.

Freezing Level

The height where ambient temperature is zero is called the freezing level.
It is usually given in forecasts on an area basis by reference to the height of the Zero Degree Isotherm.
With an inversion, two freezing levels are possible.



Airframe Icing

All pilots encountering unforecast icing are requested to report time, location, level, intensity, icing type and aircraft type to the ATS unit with whom they are in radio contact.

Intensity	Ice Accumulation
Trace	**Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation.** It is not hazardous even though de-icing/anti-icing equipment is not utilized, unless **encountered for more than one hour.**
Light	The rate of accumulation might create a problem if flight in this environment **exceeds one hour. Occasional use of de-icing/anti-icing equipment** removes/prevents accumulation. It does not present a problem if de-icing/anti-icing equipment is used. (ICAO: Less than moderate icing)
Moderate	The rate of accumulation is such that even short encounters become potentially hazardous and **use of de-icing/anti-icing equipment,** or diversion, **is necessary.** (ICAO: conditions in which change of heading and/or altitude may be considered desirable)
Severe	The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. **Immediate diversion is necessary.** (ICAO: conditions in which immediate change of heading and/or altitude is considered essential)

Piston Engine Induction Icing

- **Impact icing**

Ice in intake areas caused by snow, snow and rain mixed or supercooled water droplets.

- **Fuel icing**

This is caused by water in the fuel freezing in bends in the induction piping.

- **Carburettor icing**.

This is caused by:

  - The sudden temperature drop as latent heat is absorbed when fuel evaporates.
  - The temperature drop due to the adiabatic expansion of the air as it passes through the venturi.

Carburettor icing is most dangerous within a temperature range of -10°C to +25°C, in cloud, fog or precipitation at any power setting.

Chapter 15

Air Masses

Introduction

An air mass is a large volume of air where the humidity and temperature in the horizontal are more or less constant.
The temperature and humidity properties are obtained by the air remaining roughly stationary over a surface where conditions are generally constant for some length of time - a high pressure area.
Therefore at source, all air masses must be stable.
The basic properties of stability, temperature and humidity can change as an air mass moves over surfaces with different properties.

An air mass moving to a warmer area will become heated in the lower layers and should become:

- Unstable.
- Warmer.
- Lower relative humidity.

An air mass moving to a colder region should become:

- More stable.
- Colder in the lower layers.
- Have an increased relative humidity.

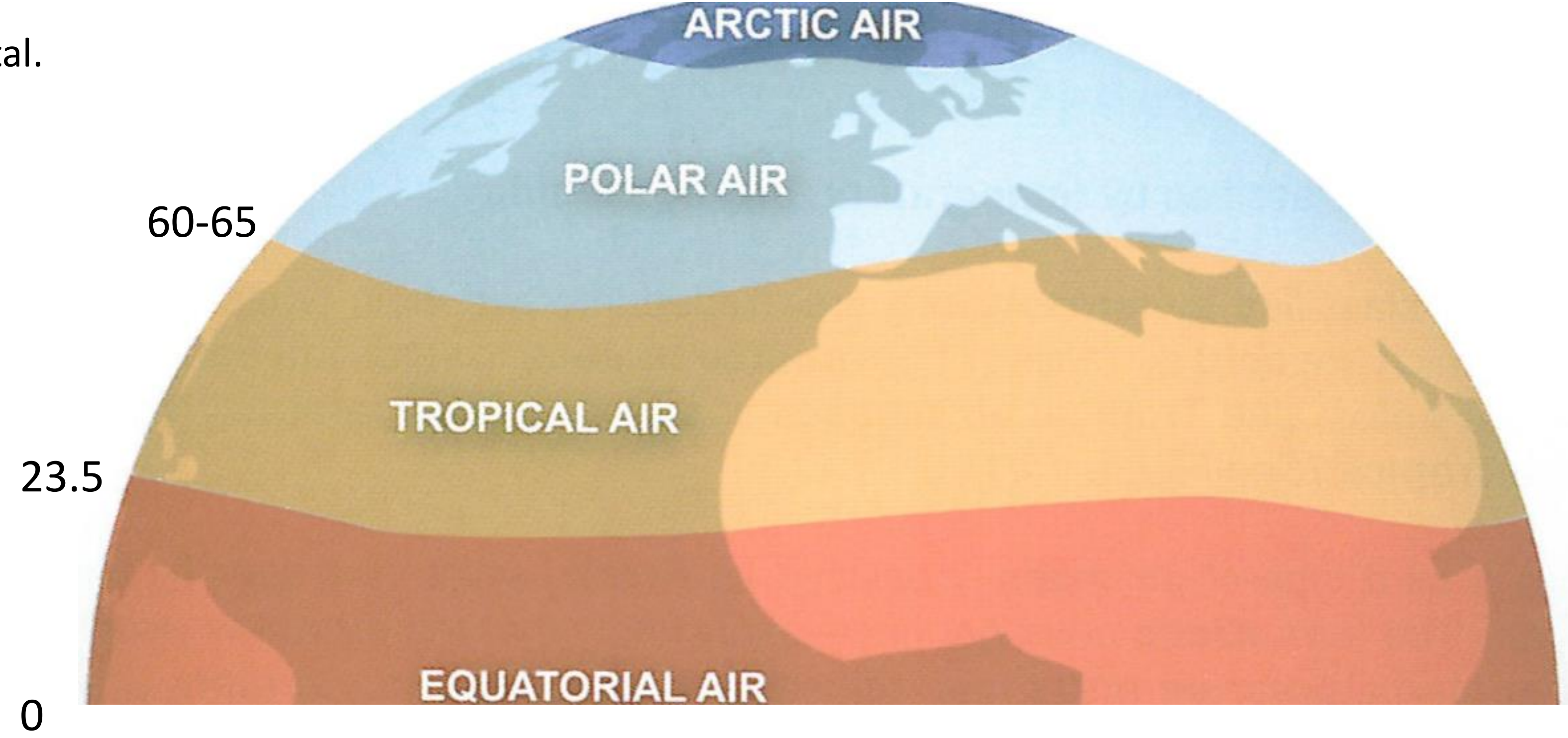
Identification

Air masses are identified by temperature/latitude:

- Equatorial.
- Tropical.
- Polar.
- Arctic.

and by humidity or sea/land source:

- Maritime.
- Continental.



Fronts

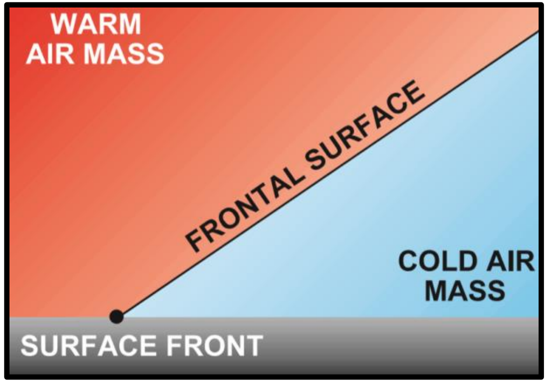
• A front is a zone or surface of interaction between two air masses of different temperature.

• When the two air masses meet, the warmer will rise over the top of the colder because of the difference in density.

• A front is usually only a few miles wide. If the term ZONE is used, then the region of interaction is much wider (up to 300 NM).

The main global fronts are:

• The Polar Front.
• The Arctic Front.
• The Mediterranean Front.
• The Intertropical Convergence Zone (ITCZ).



The Polar Front

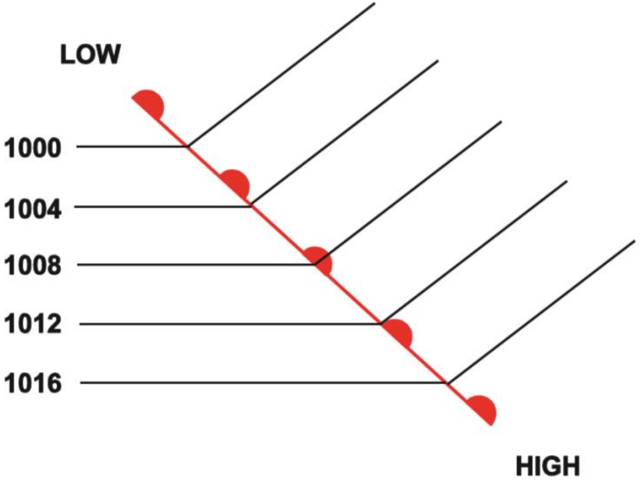
- The Polar Front is the boundary between polar and tropical air masses.
- In the Northern Hemisphere the polar front is found between latitude 35°N and 65°N.
- In the Southern Hemisphere it is found between about 50°S and 55°S throughout the year.

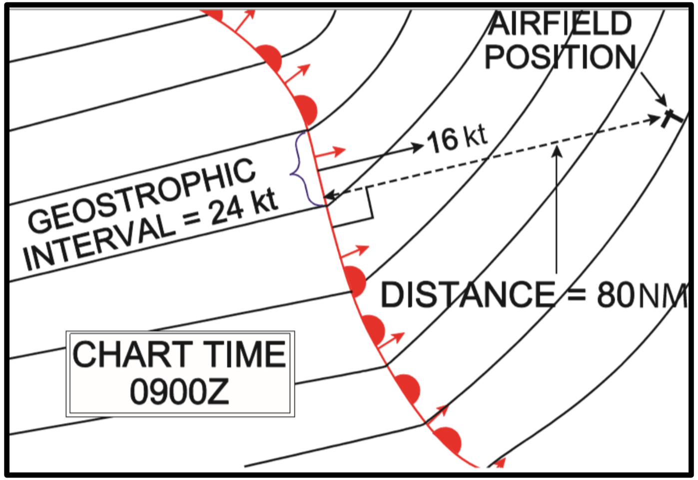
The Arctic Front

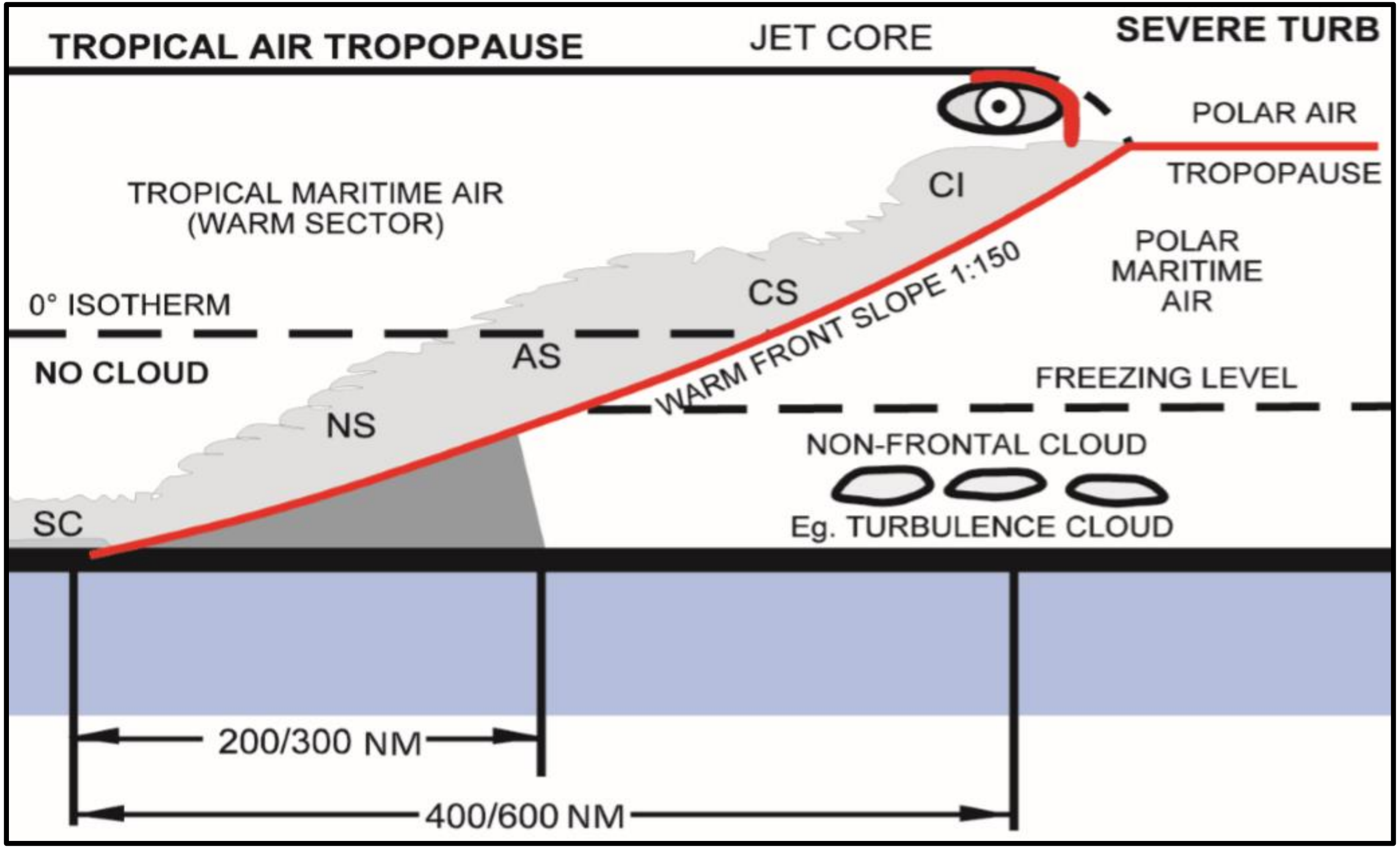
The Arctic Front is the boundary between the Arctic and the Polar air masses and may have an associated jet stream. It lies at higher latitudes than the polar front but sometimes moves into temperate latitudes in winter and spring.

Warm Fronts

- If warm air is replacing cold air, then the front is called warm.
- A warm front has an approximate slope of 1:150
- The front moves at right angles to itself at a speed equal to 2/3 of the geostrophic wind speed.





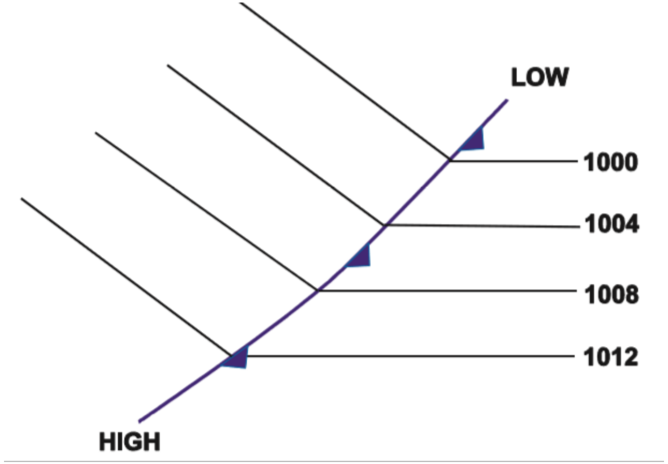

TROPICAL AIR TROPOPAUSE
JET CORE
SEVERE TURB
POLAR AIR
TROPOPAUSE
TROPICAL MARITIME AIR
(WARM SECTOR)
CI
CS
AS
NS
SC
WARM FRONT SLOPE 1:150
POLAR
MARITIME
AIR
0° ISOTHERM
NO CLOUD
FREEZING LEVEL
NON-FRONTAL CLOUD
Eg. TURBULENCE CLOUD
200/300 NM
400/600 NM

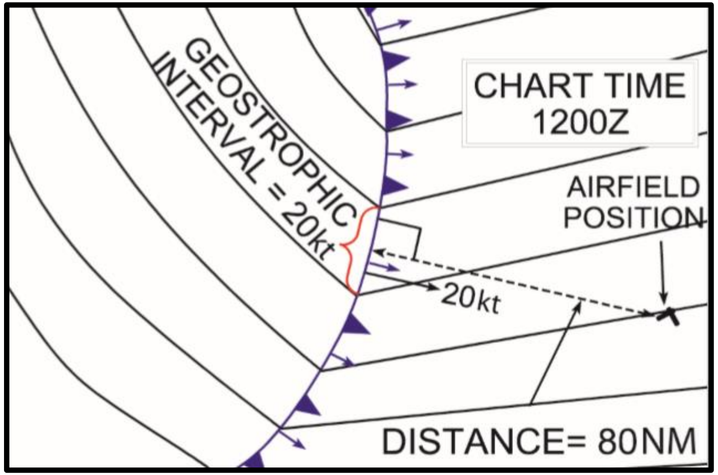
Cold Fronts

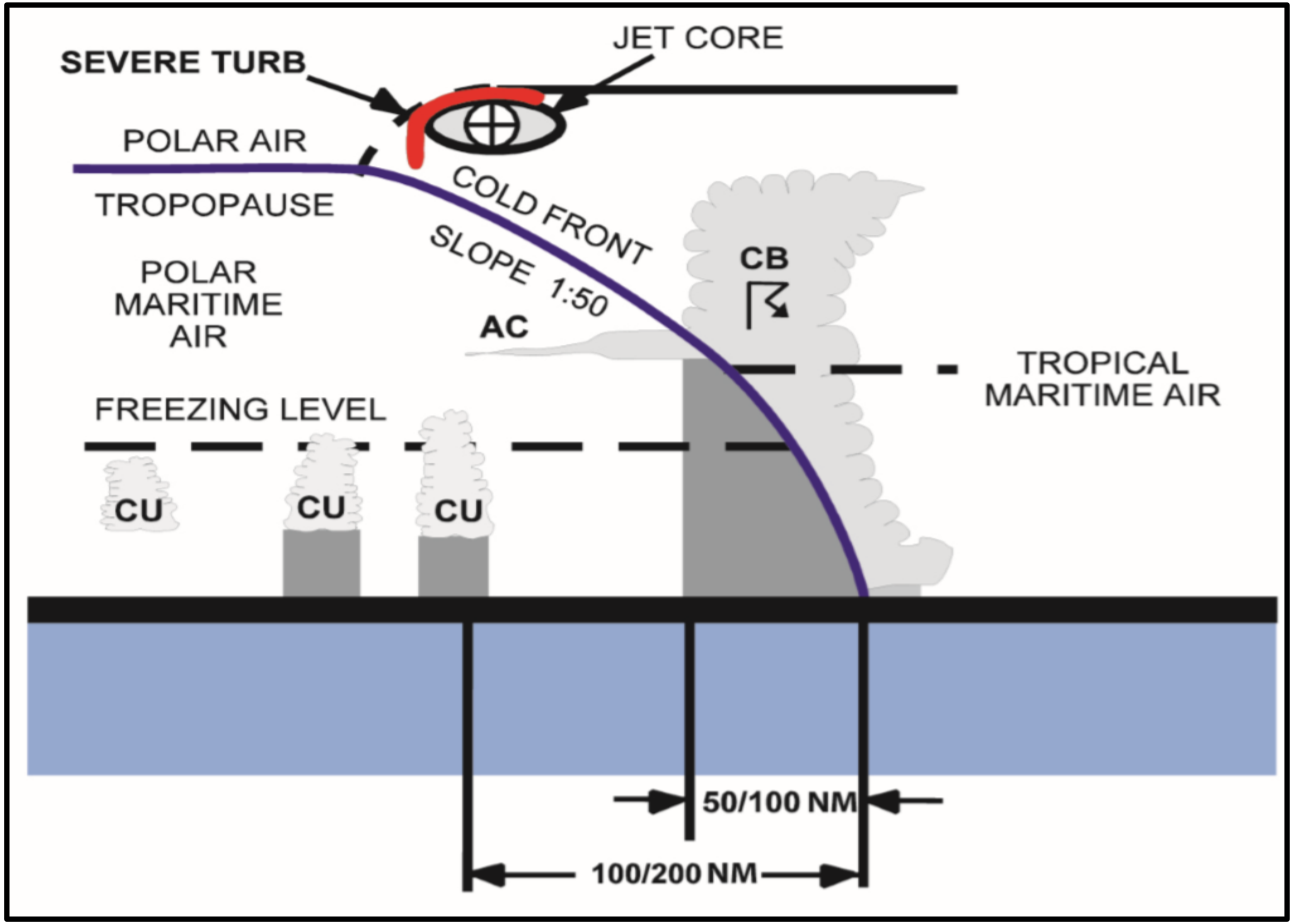
• If cold air is replacing warm air, then the front is called a cold front.

• The slope of a cold front is approximately 1:50 to 1:80 .

• The front moves at right angles to itself at a speed equal to the geostrophic interval (full) measured along the front.



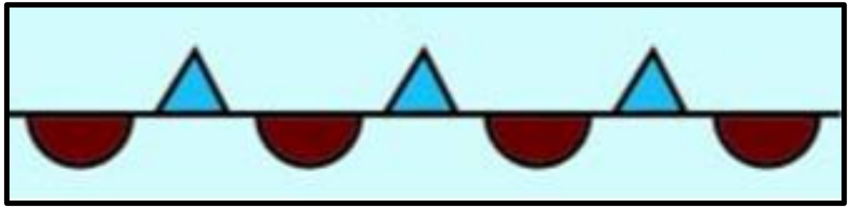



SEVERE TURB
JET CORE
POLAR AIR
TROPOPAUSE
COLD FRONT
SLOPE 1:50
POLAR
MARITIME
AIR
CB
AC
TROPICAL
MARITIME AIR
FREEZING LEVEL
CU
CU
CU
50/100 NM
100/200 NM

Quasi-stationary Fronts

- When the front has little or no movement it is known as a quasi-stationary front.

- Since there is little frontal movement, weather conditions are likely to be comparatively quiet, though longer lasting.



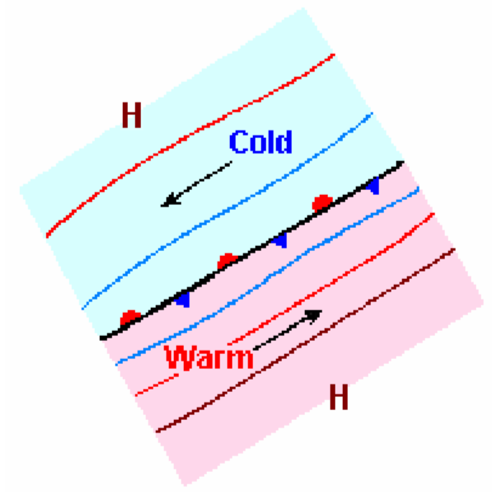
POLAR FRONT DEPRESSIONS

- These form on the polar front – the boundary between polar and tropical air.

- At the front the pressure is lower as the warm air rises up over the cold air (fronts associate with LP).

- Moving away from the front on either side the pressure increases.

- Obeying Buys Ballots Law the wind flows along the isobars with the low pressure to the left. As the diagram below illustrates the wind on either side of the front flows in opposite directions.

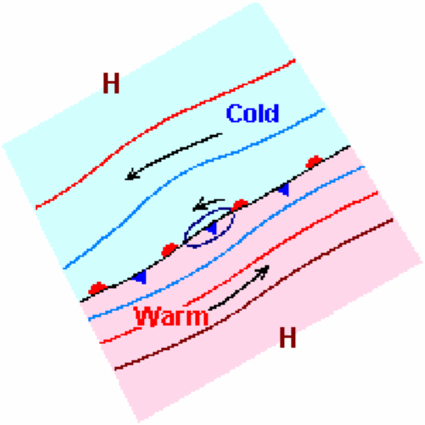


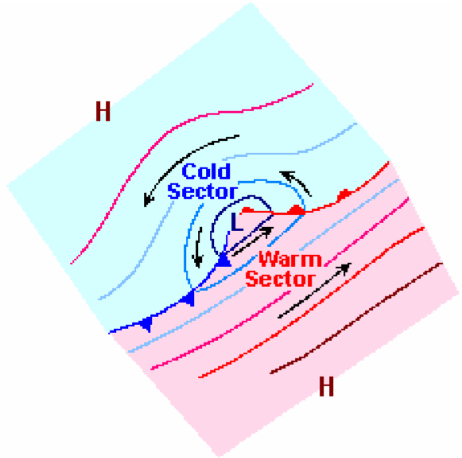
• The opposite direction of wind causes friction which leads to the formation of waves or ripples along the front.

• As the size of the ripples increases with increasing wind speed, the warm air bulges into the cold air .

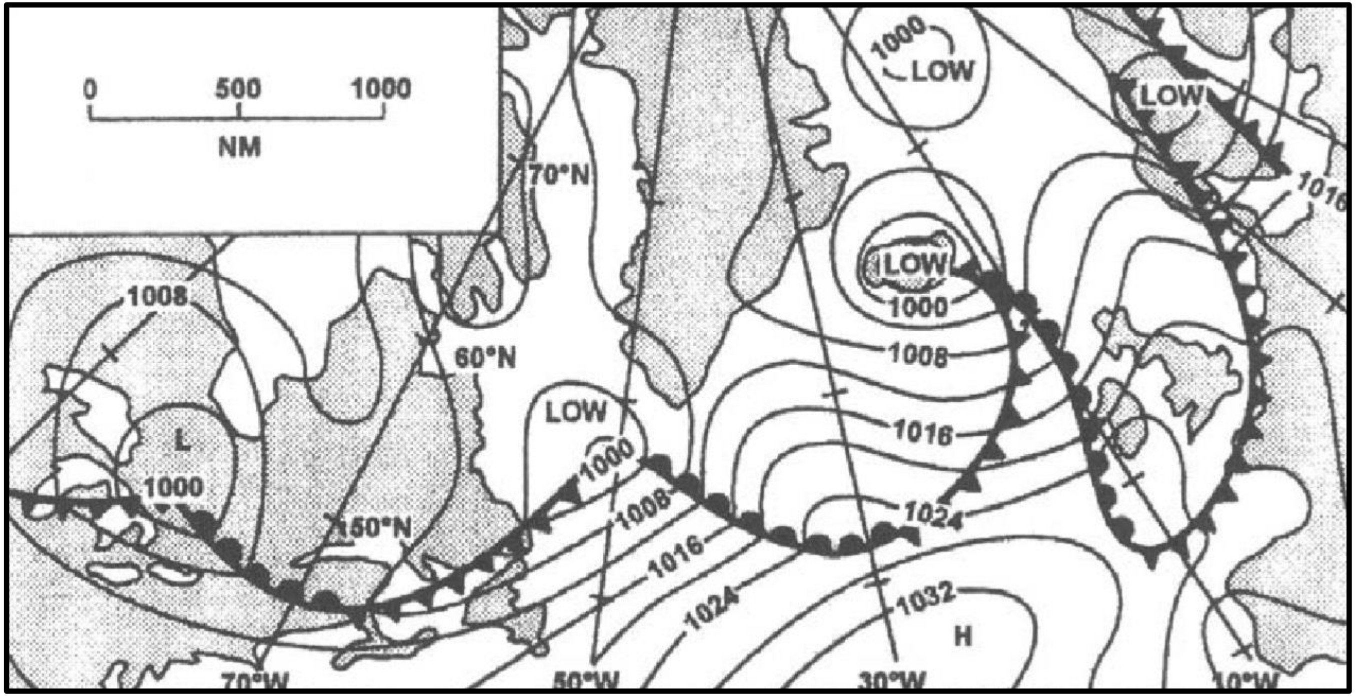
• More warm air flows into the depression, causing the depression to deepen.

• The result is a system shaped like a shark fin, with a warm front followed by a cold front. The tip of the shark fin is a low pressure centre.





• Growth of a polar front depression takes about four days. The depression dies away as it fills which typically takes ten days.
• The system moves in an easterly direction, forming an overall picture like that shown on the synoptic chart below.

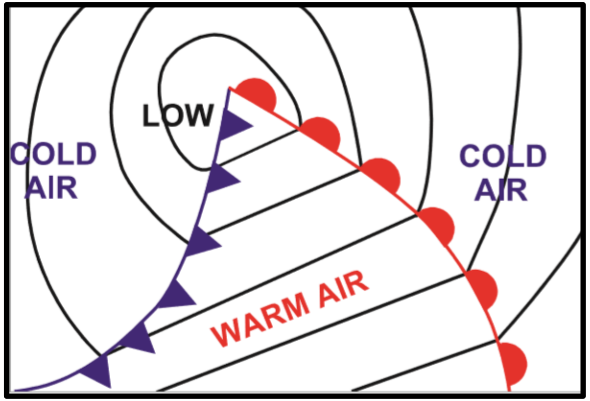


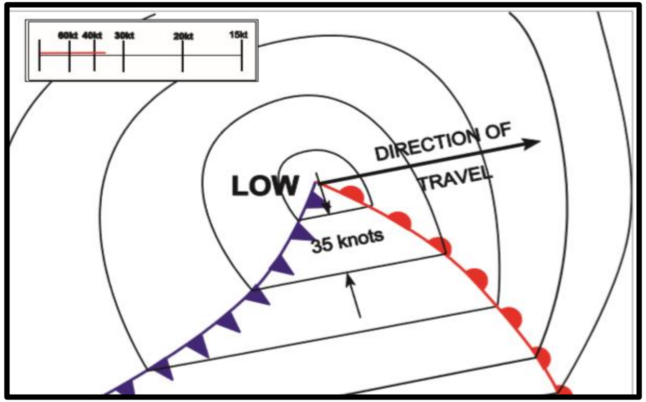
The Warm Sector

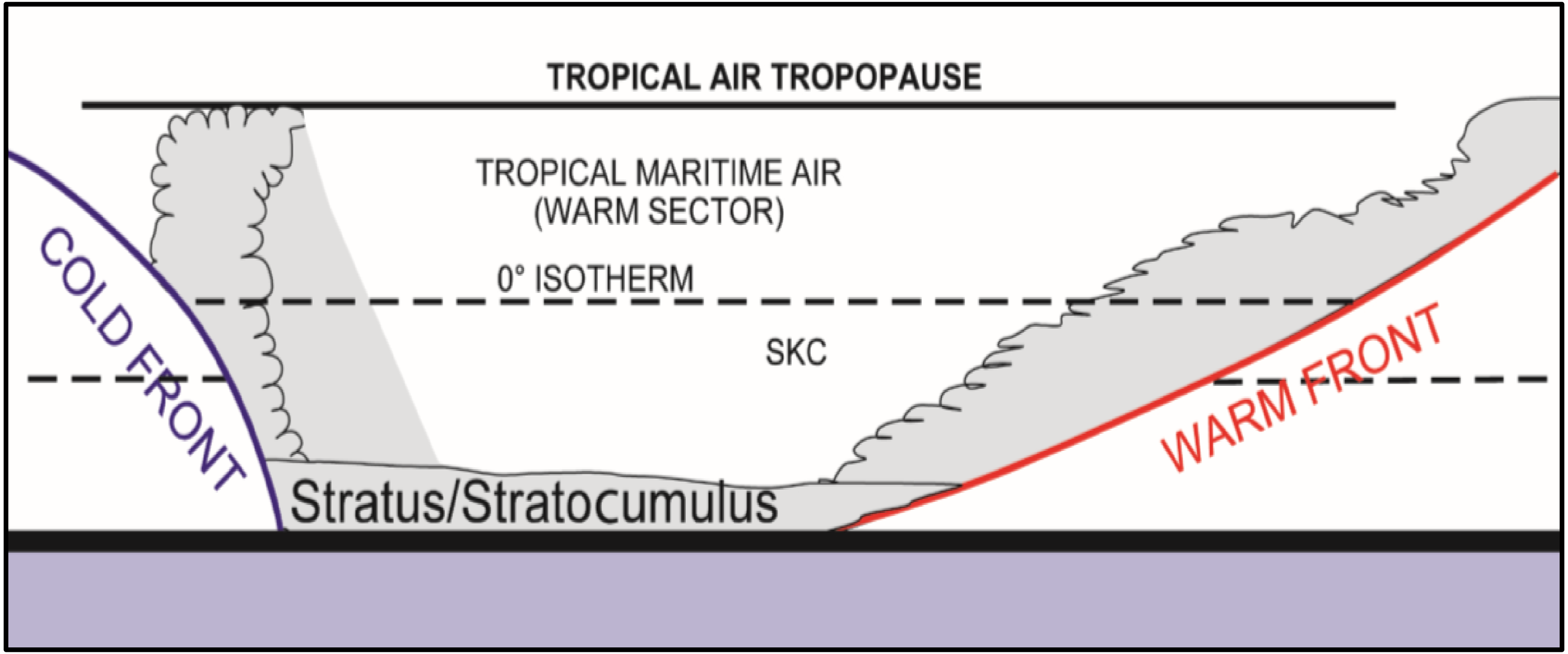
- The area lying between the two fronts is known, since it is covered by tropical air, as the warm sector.

- The warm sector will move as the warm front and cold fronts move and will in fact narrow, as the cold front moves faster than the warm.

- The depression at the tip of the warm sector will move parallel to the isobars in the warm sector at a speed given by the distance between the first and second isobars.

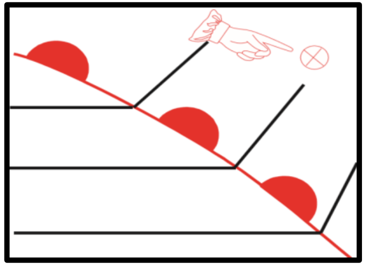





TROPICAL AIR TROPOPAUSE
TROPICAL MARITIME AIR
(WARM SECTOR)
0° ISOTHERM
SKC
COLD FRONT
WARM FRONT
Stratus/Stratocumulus

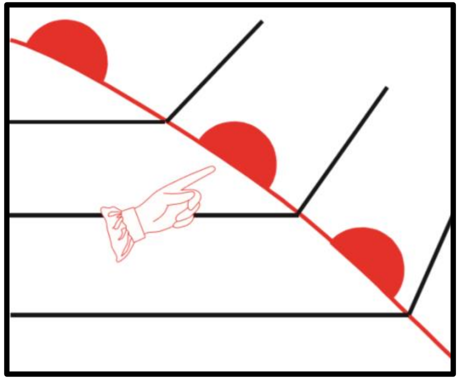
Weather with the Passage of a Polar Front Depression

- **Ahead of a warm front**



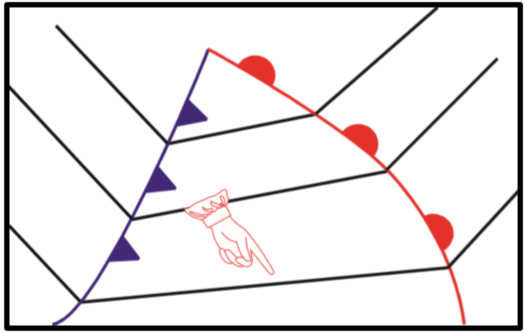
• Surface W/V	Speed increasing, slight backing, usually southerly.
• Temperature	Steady low.
• Dew Point	Steady low.
• Pressure	Steady fall.
• Cloud	Increasing to 8/8, base lowering, Ci, Cs, As, Ns.
• Precipitation	Light continuous from As becoming moderate to heavy continuous from Ns.
• Visibility	Reducing to poor.

- **At the warm front**



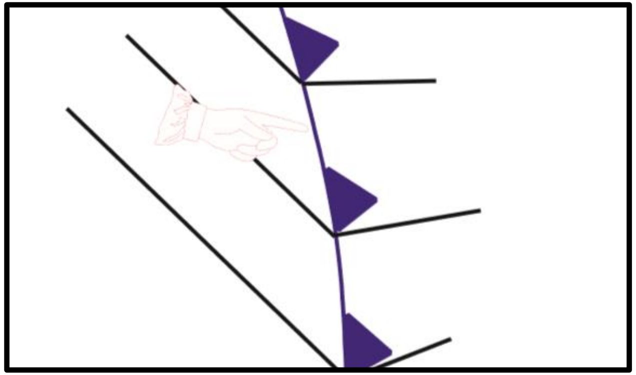
• **Surface W/V**	Sharp veer.
• **Temperature**	Sudden rise.
• **Dew Point**	Sudden rise.
• **Pressure**	Stops falling.
• **Cloud**	8/8, base very low, Ns, St.
• **Precipitation**	Moderate or heavy continuous.
• **Visibility**	Very poor, fog can occur

- **In the warm sector**



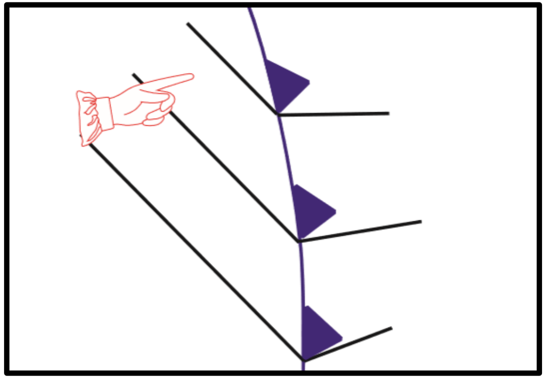
Surface W/V	Steady, usually from the SW.
Temperature	Steady.
Dew Point	Steady.
Pressure	Slight fall.
Cloud	6/8 to 8/8, some large breaks may occur, base low, St, Sc.
Precipitation	Light rain, drizzle
Visibility	Poor, possibly advection fog in winter.

- **At the cold front**



Surface W/V	Sharp veer, gusts and squalls likely.
Temperature	Sudden fall.
Dew Point	Sudden fall.
Pressure	Starts to rise.
Cloud	6/8 to 8/8, base low but rising, Cu, CB, sometimes Ns.
Precipitation	Heavy rain or snow showers, thunder and hail possible.
Visibility	Good, except in precipitation.

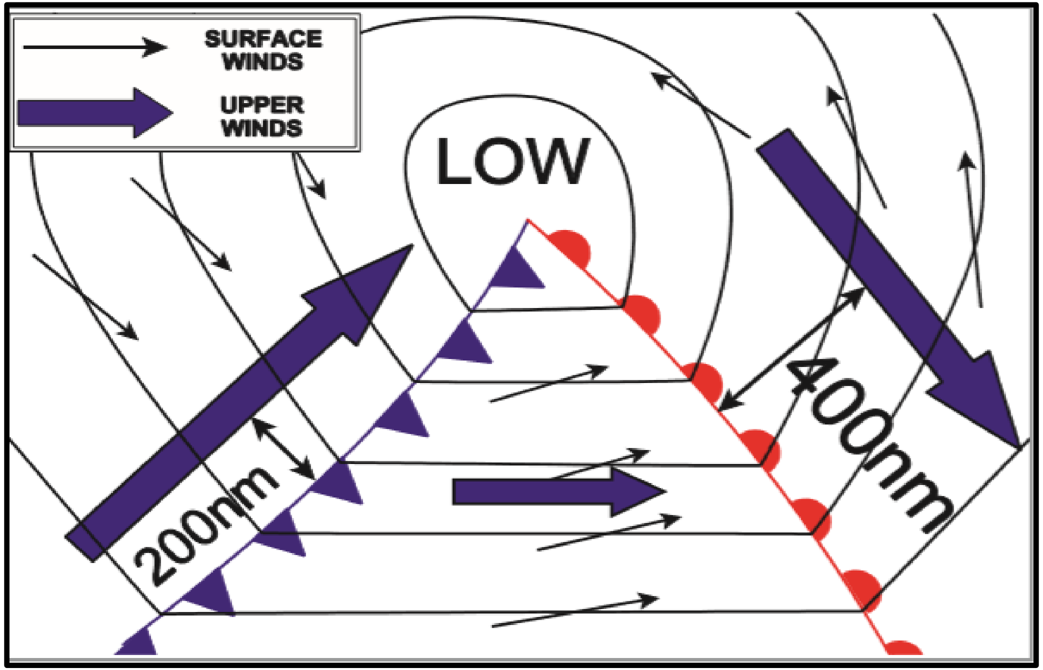
- **Behind the cold front**



• **Surface W/V**	Steady or slight veer to NW.
• **Temperature**	Steady low.
• **Dew Point**	Steady low.
• **Pressure**	Rises slowly.
• **Cloud**	6/8, base lifting, Cu, Cb.
• **Precipitation**	Showers, heavy at times, hail and TS possible.
• **Visibility**	Very good, except in showers.

Upper Winds in a Polar Front Depression

At the height of the jet stream (about FL300) the cause is directly related to the temperature gradient so the jet streams generally will be parallel to the fronts. The winds are:



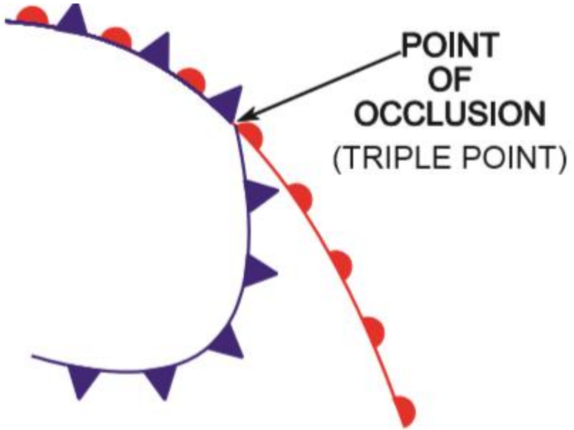
Chapter 16

Occlusions

Introduction

• As the cold front is moving faster than the warm front the surface position of the cold front will eventually catch up with that of the warm front. When this occurs we have an occlusion.

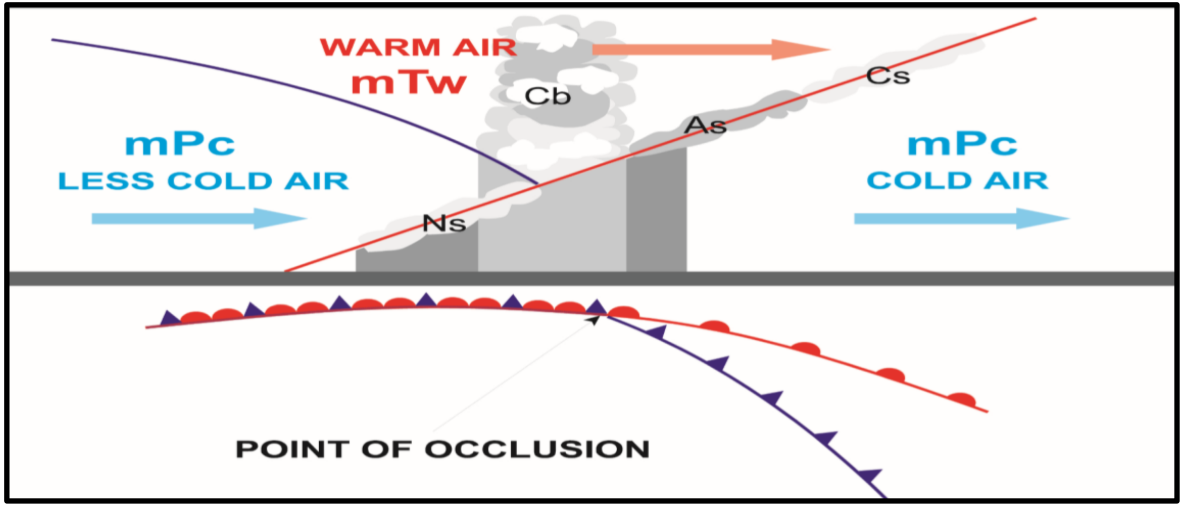
• The position where the occluded front meets the warm and cold fronts is known as the point of occlusion or triple point.



Warm (Front) Occlusion

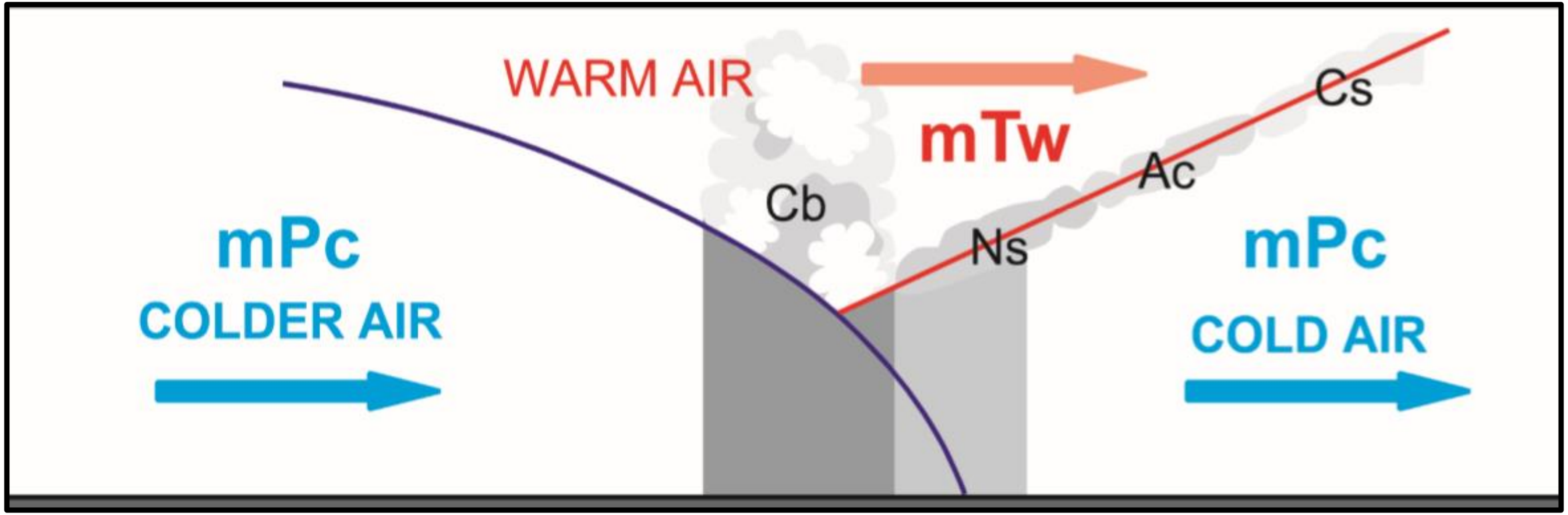
• If the air ahead of the warm front is colder than the air behind the cold front, then a warm occlusion will be formed.

• The warm sector is now raised off the ground and the cumuliform cloud at the cold front is pushed into the stratiform cloud at the warm front, giving the hazard of embedded CB. Most of the precipitation in the warm occlusion occurs ahead of the surface position.



Cold (Front) Occlusion

• If the air behind the cold front is colder than the air ahead of the warm front, then a cold occlusion will be formed.
• Once again the warm sector is raised off the ground and we have the hazard of embedded CB. Most of the precipitation is behind the surface position of the occlusion.



Chapter 17

Global Climatology

IDEAL GLOBAL CIRCULATION

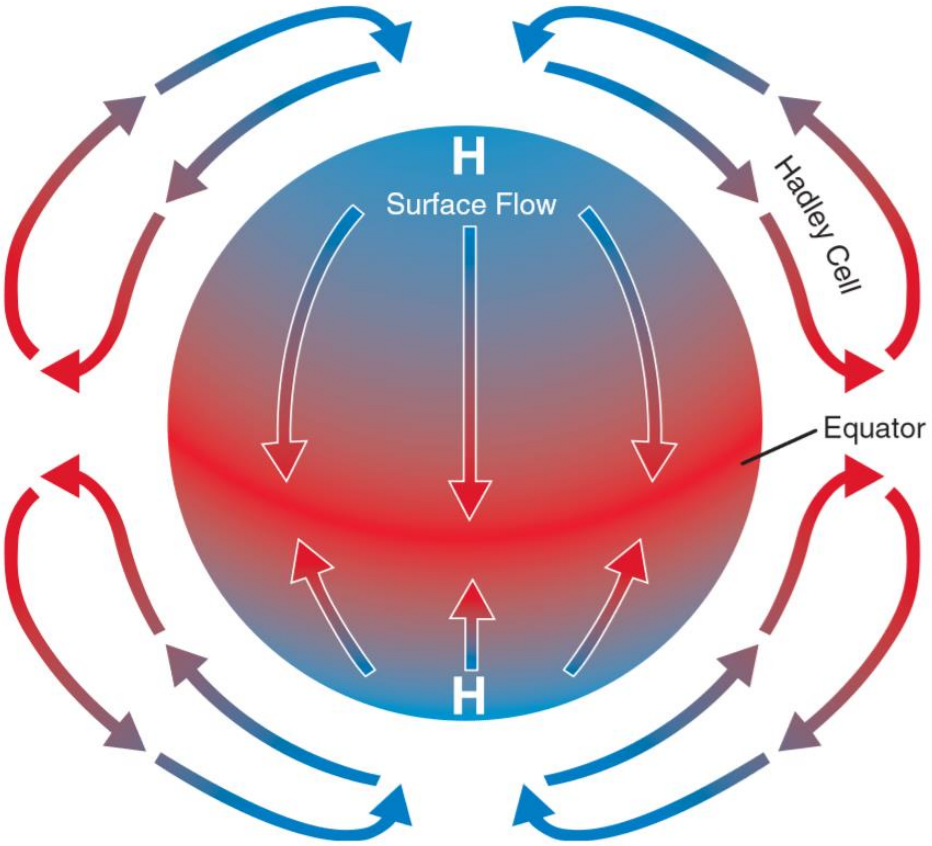
• Initially, assume that the Earth has a uniform surface, that it is not rotating, and it is not tilted.

• The circulation of the air resembles a large scale sea breeze.

• The Equator receives more insolation than the poles. This insolation causes the Equator to have a higher temperature than at the poles.

• The air at the surface is warmed, expands, and rises. This rising air creates a high pressure at altitude over the Equator. This flow starts an outflow of air from the high pressure at height. A low pressure system is formed at the surface which draws air in.

• At the poles the low temperature causes a high pressure system at the surface and subsidence occurs. The subsidence allows a low pressure system to form at height drawing air from the Equator.


H
Surface Flow
Hadley Cell
Equator
H

ROTATION OF THE EARTH

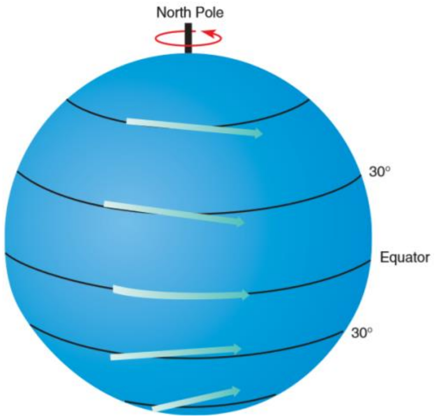
• Because of the Earth's rotation, take into account the geostrophic force or Coriolis.

• In the upper levels as the air travels towards the poles from the equator it comes under the influence of Coriolis. In the:

Northern Hemisphere	The air is deflected to the right
Southern Hemisphere	The air is deflected to the left

• The deflection means that the flow is eastwards in both hemispheres. The air is cooled as it moves parallel to the Equator and eventually subsides to the surface. The falling of the air causes a high pressure to form at the surface. Known as the Sub-Tropical High these are recognisable on the average pressure charts.

• This movement takes place at approximately 30° from the Equator.



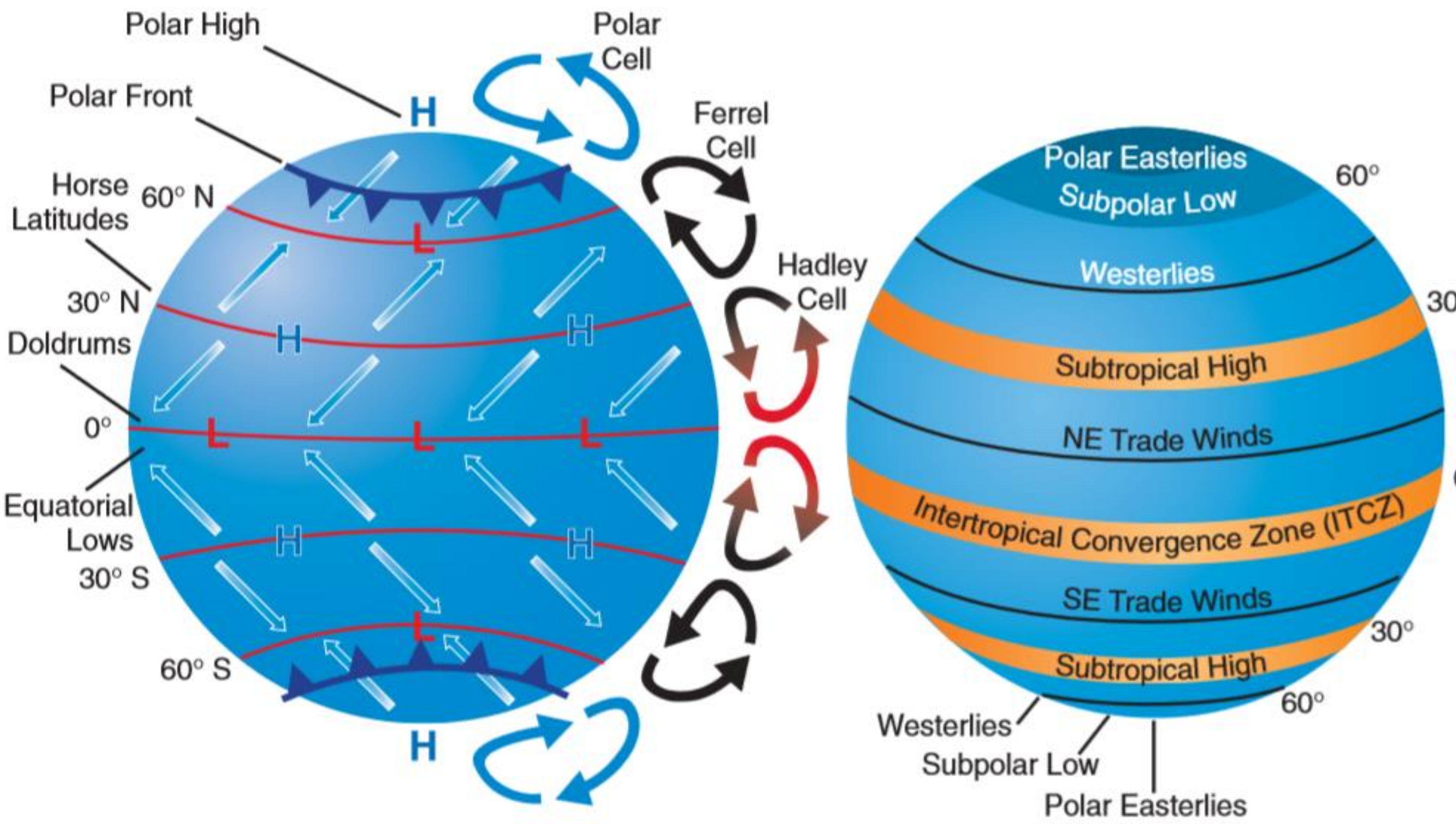
IDEALISED PRESSURE ZONES

- The Coriolis effect forms the first of three cells in the idealised circulation. This first cell is known as the Hadley Cell.

- The sub-tropical high pressure system has an outflow of air to both the Equator and towards the poles.

- The flow of air from the poles and the flow from the sub-tropical high meet in the temperate latitudes. Convergence occurs and air rises. A surface low pressure forms with a high pressure area at height.

- The three distinctive cells are:
  - The Hadley Cell
  - The Mid-Latitude Cell (Ferrel Cell)
  - The Polar Cell


Polar High
Polar Cell
Polar Front
Ferrel Cell
Horse Latitudes
60° N
Hadley Cell
30° N
Doldrums
0°
Equatorial Lows
30° S
60° S
H
L
Polar Easterlies
Subpolar Low
60°
Westerlies
30°
Subtropical High
NE Trade Winds
0°
Intertropical Convergence Zone (ITCZ)
SE Trade Winds
30°
Subtropical High
60°
Westerlies
Subpolar Low
Polar Easterlies