Meteorology summary

/the general term used to describe the mixture of air

CH 1

The composition of the air:

- 78% nitrogen
- 21% oxygen
- 0.95% argon
- Trace amounts of other gases:
    - CO_2, water vapor, trace gases, helium, etc.

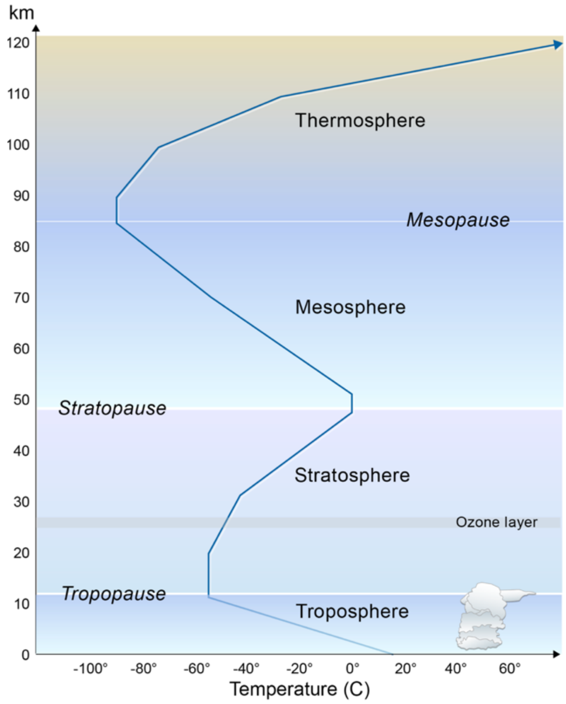
CO_2 although small amounts it significantly affects the global climate

- It strongly absorbs long-wave radiation; re-radiated by the earth

Ozone; absorbs short wave radiation + acts as a heat source in the ATM

Without water vapor in the ATM, there would be no weather

- When gas cools down and becomes liquid or solid it gives rise to meteorological phenomena such as clouds
    - Lower ATM can contain as much as 4% of the total volume of water vapor



Different layers of the ATM has different properties, though pressure decreases with increasing altitude

- We use temperature lapse rates to identify different layers
    - A pause is mostly indicated by a pause

The Troposphere

- temperature decreases with height
    - Lapse rate, 2°C per 1000 ft
- Where most visible weather happen
- Gravity compresses the gasses
    - Almost 75% of all the mass of air is contained here
    - Almost all water vapor is contained here
    - Thicker at the eq. thinner at the poles, average is 11km; 36 000 ft

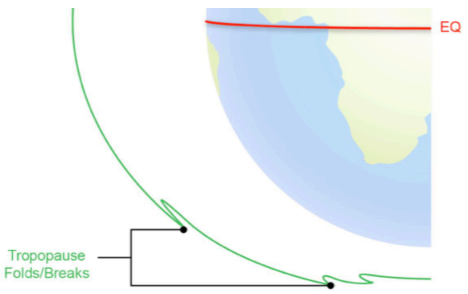
Where the temperature changes with less than 2°C per 1km/3300ft is where the next defined layer starts

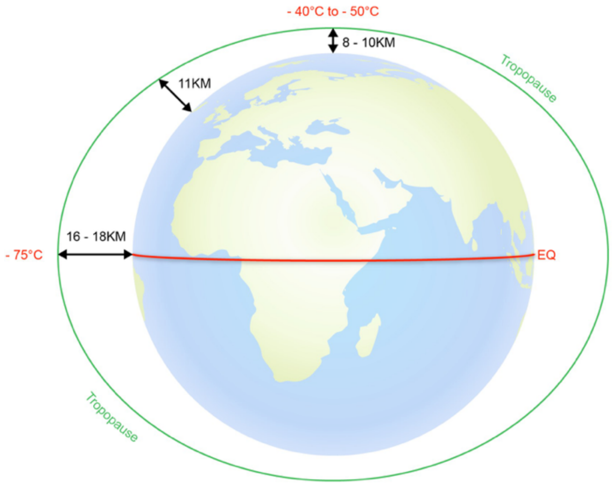
$$\cos(latitude) \times 16km$$

+3000ft in the summer and -3000ft in the winter
Formula only **valid for mid latitudes**

The top of the troposphere marks the tropopause, no change in temperature, isothermal

- Described as air being stable
  - Resulting in no heating/cooling of air → resisting further vertical expansion of gases→ causing clouds to spread horizontally instead
- The height of the tropopause is determined by the temperature of the air in the troposphere near the surface
  - The warmer the air the higher the tropopause





There are 2 regions in the s.hemisphere and 3 in the n.hemisphere where large temperature changes occur over short distances
→ causing the tropopause to fold

- It breaks at the places where fast-moving air currents are found

The stratosphere

- Temperature increases with altitude, not uniformly
  - Caused by absorption of the sun's UV by the ozone layer
    - Ozone is created when short wave solar radiation interacts with O_2 to form O_3
  - Ozone is usually found at 25km
  - Ozone absorbs harmful ,UV-C, and releases longer wave radiation
    - Temperature rises to a steady 0°C
- Some local/temporary convections may occur, caused by volcanic eruptions/ vigorous thunderstorms
- Good place to fly
- Planes need to have ozone converters, otherwise it could harm the respiratory systems

Mesosphere

- Temperature decreases with height
- 50km to 80-90km AMSL
- Coldest layer
- Only clouds of interest; noctilucent clouds, illuminated by the sun
  - Seen at high lat. During summer nights, illuminated by the sun below the horizon
  - About 80km AMSL

Thermosphere

- Temperature increases with height
- 90km to 700km, exosphere
    - Space from 120km

Ionosphere

- Not classified by temperature
    - Rather unique property of ionised ATM by UV and X-ray radiation from the sun
- Creates high concentrations of positive ions and free electrons creating an electrostatic force
    - Influences radio wave propagation
- Usually found between 85km and 600km AMSL

Because of gravity, air is much denser towards the surface

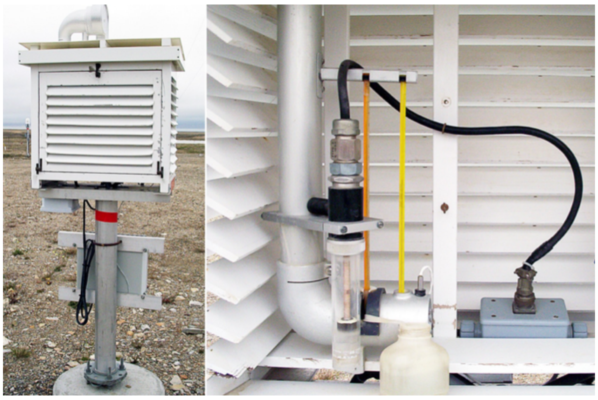
- Air pressure is determined by the mass of the overlying air
- Air pressure and air density decreases with altitude

CH 2

Temperature is the measure of the heat of the energy associated with the movement, kinetic energy, of molecules

Temperature drives the development of all forms of weather because it creates pressure differences; in turns creating winds

- Fahrenheit = 9/5 × n°C +32



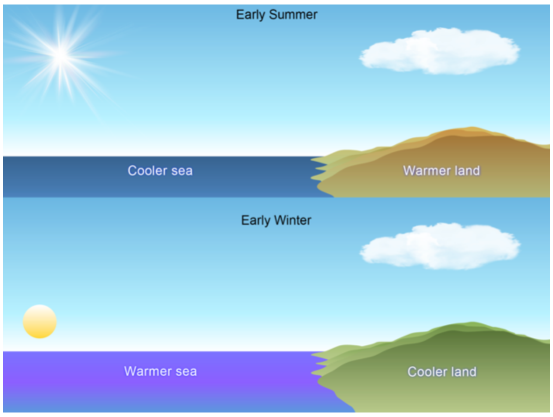
Nowadays, temperature is measure with a thermometer inside a Stevenson screen
- Various altitudes is measured by radio sondes attached to weather balloons

Radiation

everything which has mass and a temperature greater than absolute zero emits energy in the form of electromagnetic radiation
- Normally hotter objects emit greater proportion in the shorter wavelengths
    - The sun is a good example
- When an object absorbs radiation it heats up
    - Causing it to re-radiate; but at a much longer wavelength, ex. Earth

How much is absorbed/reflected depends upon:
- Colour
- Mass
- Texture
- Angle of incidence

Objects which reflect a lot of radiation is said to have a high **albedo**, ex snow
- Scale 0 to 1



When a mass absorbs radiation its increase in temperature depends on its specific heat capacity
- How many joules is required to heat 1g, 1K
    - **Water is 4,18 J K^{-1} kg^{-1}**

The different heat capacities of water and earth leads to land masses being relatively warmer during early summer, and colder during winter, than the surrounding water/sea

The difference between radiation at the top of ATM and ground level is due to the ozone and water vapour

- The radiation which reaches the earth's surface is called insolation, about 85%
  - Some is also reflected by the earth's surface
  - The amount of insolation depends on time of day and the season

As the Earth absorbs solar radiation it heats up

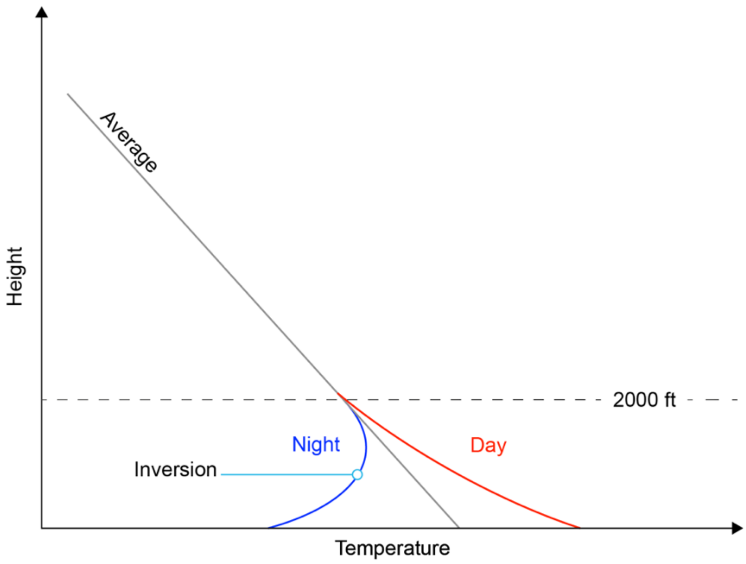
- This causes the earth to release its terrestrial radiation
  - Longer wavelength, but less intense
    - Longer wavelength is more readily absorbed by gases
  - Primary heating source of our planet

Because the ATM is denser near the surface, this is where most of the terrestrial absorption takes place

Greenhouse gases are very effective at absorbing and trapping long-wave terrestrial radiation

Air, ATM, is a poor conductor of heat as to why most of the heat transfer by conduction is down by the surface where the ATM is the densest

- Usually below 2000ft
  - During the winter, northern lat. The land cools for such a long period it thickens the layer
  - Summer causes turbulence and lots of mixing → thinner



Notice that at night the temperature increases, the first 2000ft, with altitude

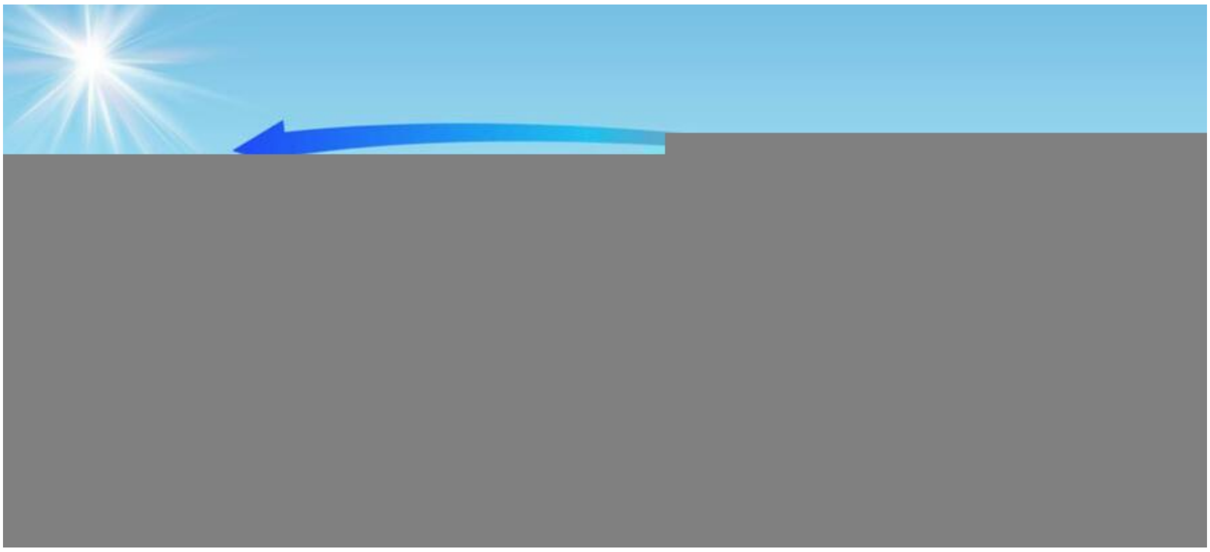
- Called inversion; nocturnal/radiation inversion

Convection; vertical transfer of heat/cold

- An area with a significantly warmer surface than the surround heats up by conduction, causing air to become less dense, causing the pocket/bubble/parcel of air to rise
    - The most air cools down and forms a cloud
        - Sometimes at speeds of 10 000ft/min.
        - Can be dangerous
- Over a cooler surface, it's density will increase and the air will sink

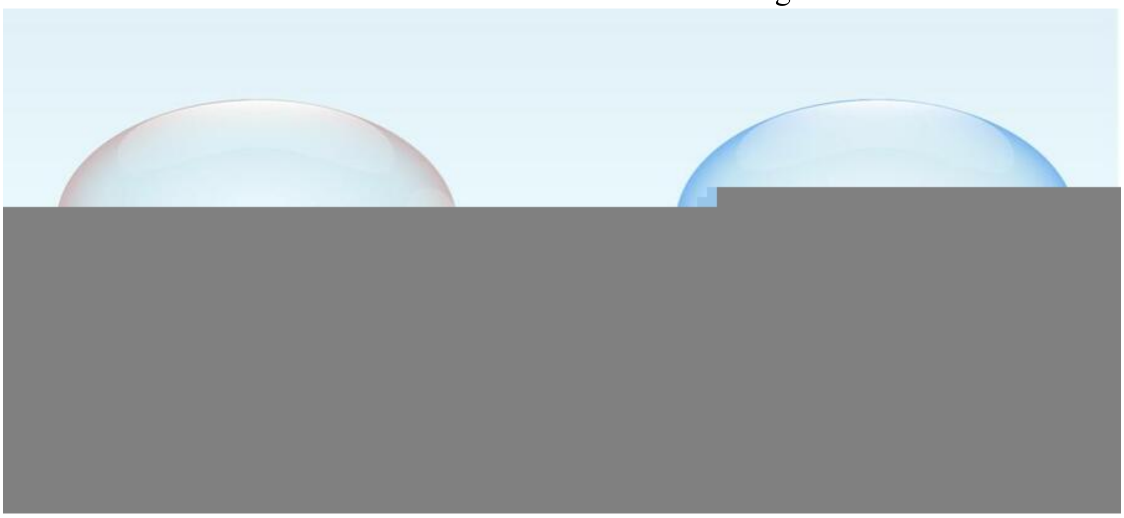
It can occur at a small scale, 10s of meters, to hundreds of miles

On a continental scale, land masses in summer are much warmer than the adjacent oceans, consisting of an upstream and a downstream creating heat transfers; advection



Advection; horizontal transfer of heat; a product of convection

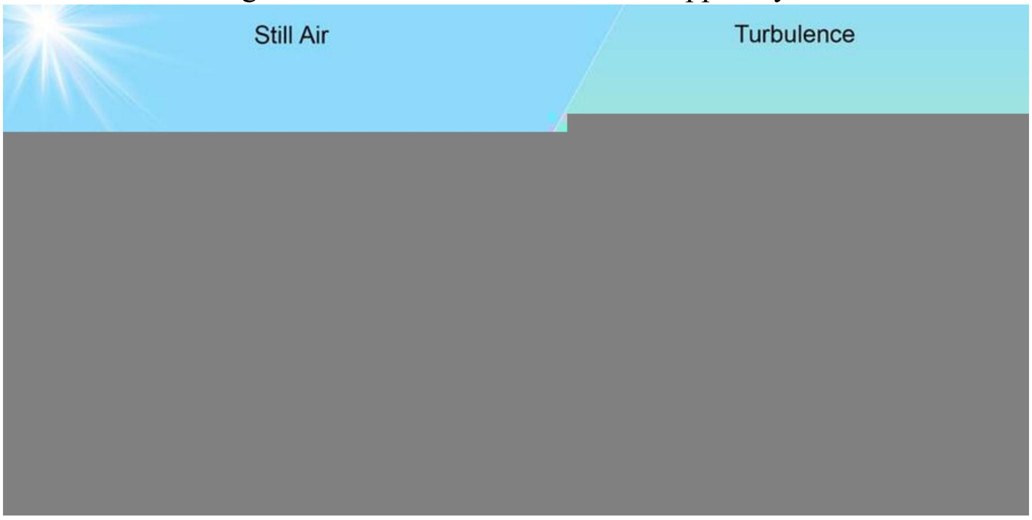
- Major contributor to weather
    - Ex. Winter, temperate lat; warm air from the seas may blow in over cooler land, creating a horizontal transfer of heat
        - Resulting in warmer coast than inland
        - Can lead to the formation of advection fog



- Advection takes place whenever the wind is blowing
    - Whenever the airflow is from the south it will feel slightly warmer

Turbulence; the chaotic interference between airflows

- Ex. During the day, the surface might heat up much more so than the overlying layer, turbulence exchanges heat between the surface and upper layers



Latent heat; is the energy released or absorbed by a body without any change in temperature

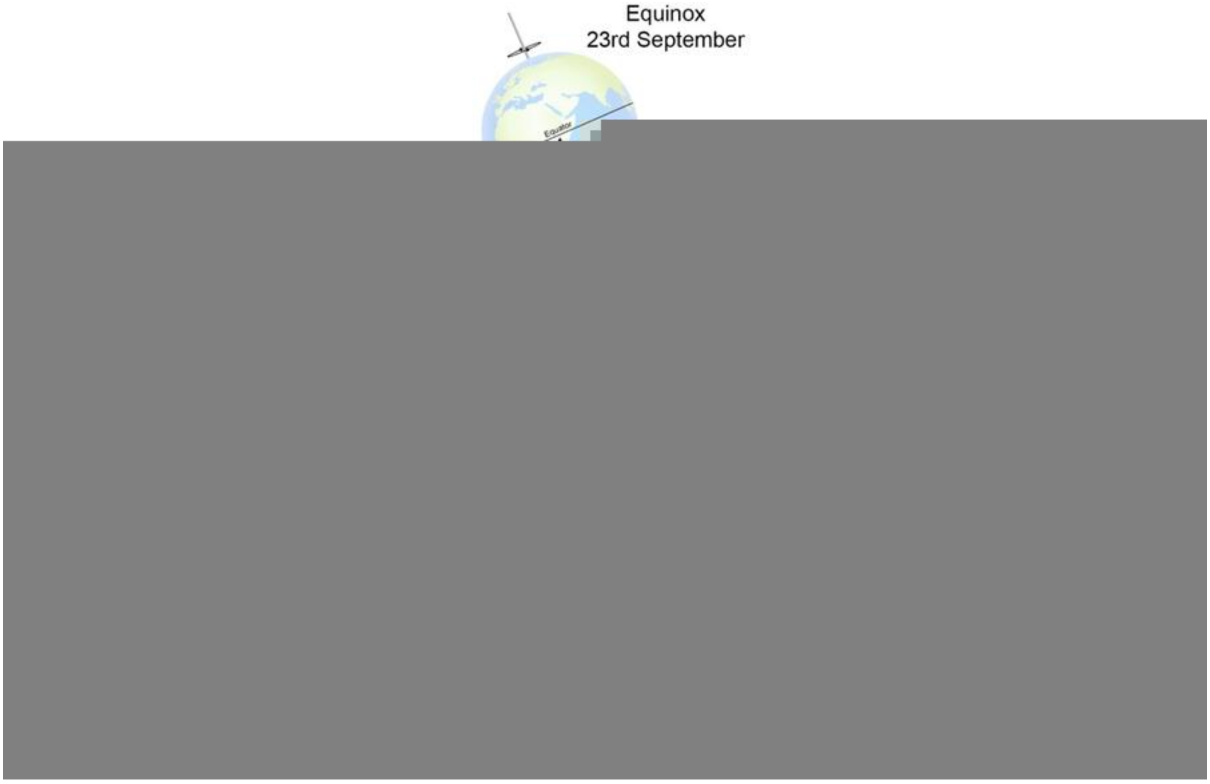
- Happens when elements change state
  - Breaking or creating hydrogen bonds, for water
- When water vapour evaporates it takes energy from the surrounding, making the surrounding cooler, to "heat up" itself, the opposite when it's condensed
  - This mechanism is a major supplier of energy in weather systems

The amount of insolation varies accordingly to the reflectivity of the earth's surface; its albedo. And the angle of incidence

- The path of the earth around the sun is rather ecliptic with 23, 5° of tilt
    - ≈ 4 Jan the closest to the sun; **Perihelion**
    - ≈ 4 Jul furthest from the sun; **Aphelion**
- On approximately 21 Jun the n.hemisphere is maximally tilted towards the sun
    - 23, 5°N received the most insolation, **tropic of cancer**
    - Maximum surface temperatures are usually experienced 1-2 months after this date

- 21 Dec is when the s.hemisphere experiences the most insolation
    - 23, 5°S; **Tropic of Capricorn**
- **Equinoxes** occur at 21 Mar and 23 Sep

The position of the heat equator is important as it dictates the seasonal movement of jet streams, pressure systems and surface winds

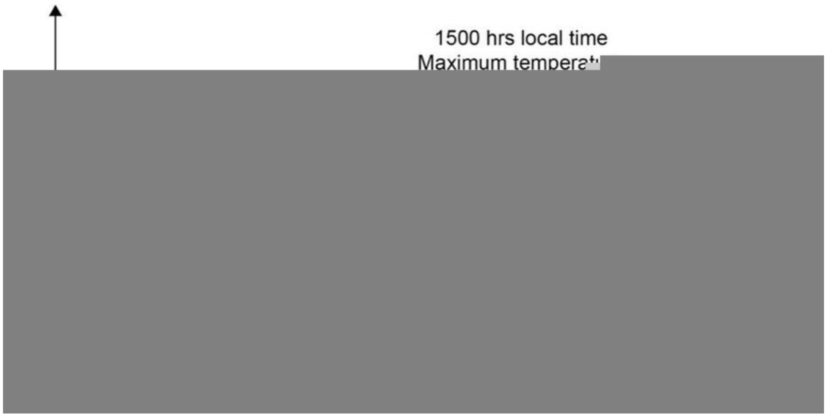


Diurnal variation of surface air temperature; temperature variation as per day

- During the day insolation from the sun causes energy to get absorbed by the earth, reaching its maximum at noon
  - During the day there's more incoming than "outgoing" causing surface air to increase
  - At night, there's no incoming but the earth continues to radiate

The maximum temperature occurs at around 15: 00 and the coldest at 30 minutes after sunrise

- Because it receives radiation at an angle making the outgoing bigger
- The 3 hour delay is due to thermal inertia; time to warm up

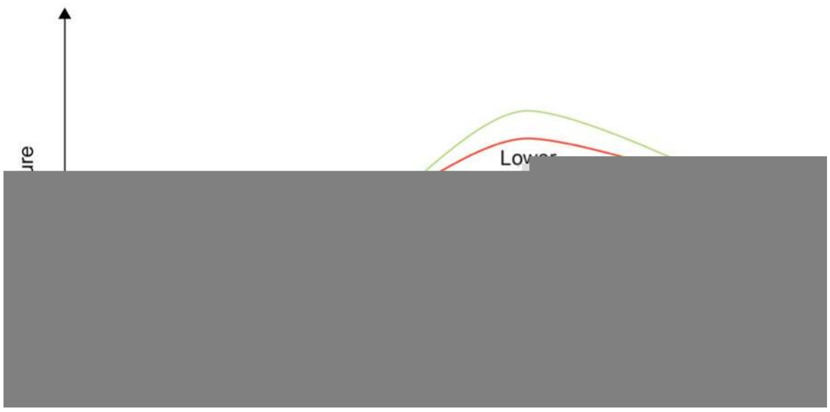


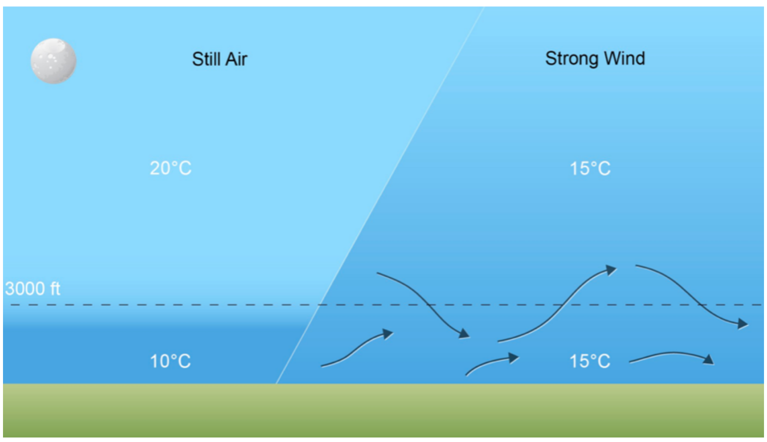
The cycle of diurnal variation does not change but the min. and max. depends on surface conditions; factors:

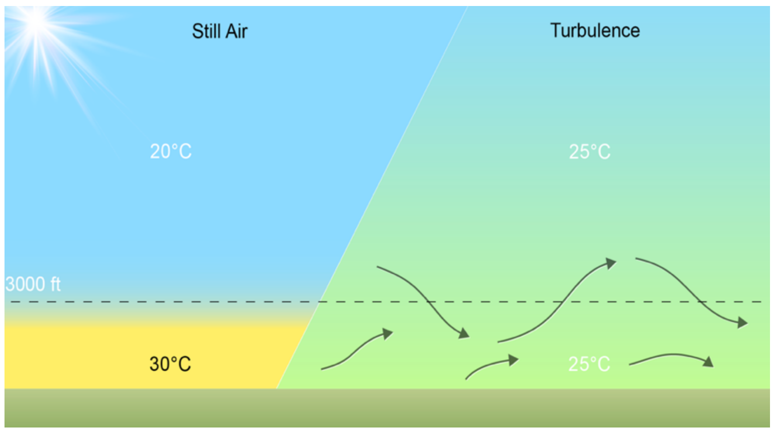
- Type of surface; albedo
- Wind
- Cloud cover

A strong surface wind reduce the diurnal variation by turbulent mixing in the lower ATM

- During the day the warmer surface mixes with the colder overlying layer
  - Temperature on ground decrease
- During the night; the ground being the better conductor of heat cools down below ATM air temperatures causing the ground to be the cooler one, turbulent mixing causes the surface air to warm up







Cloud cover

during the day clouds reflect a greater proportion of solar radiation

→ less insolation → cooler max. surface temperature

Night clouds have a different effect

- Vapour easily absorbs terrestrial radiation
  →acts as a heat source, re-radiating the earth's terrestrial radiation

Vertical temperature variation
the earth is mostly heated from below. Usually therefore temperature decreases with altitude

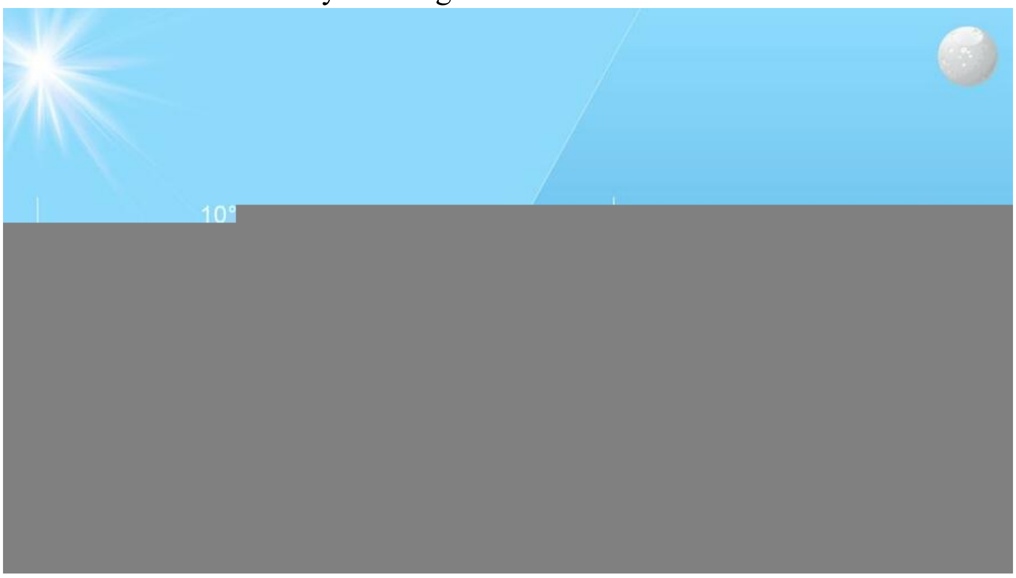
- This general change of temperature is called environmental lapse rate, ELR.
    - Being highly variable, depending upon surface conditions
- If temperature remains constant with height it's called an isothermal layer
- If the temperature increases with height, in the troposphere, it's known as an inversion

Inversions can occur anywhere in the ATM it's important as they signify areas of turbulence and/or wind shear or freezing rain; alter the stability of air

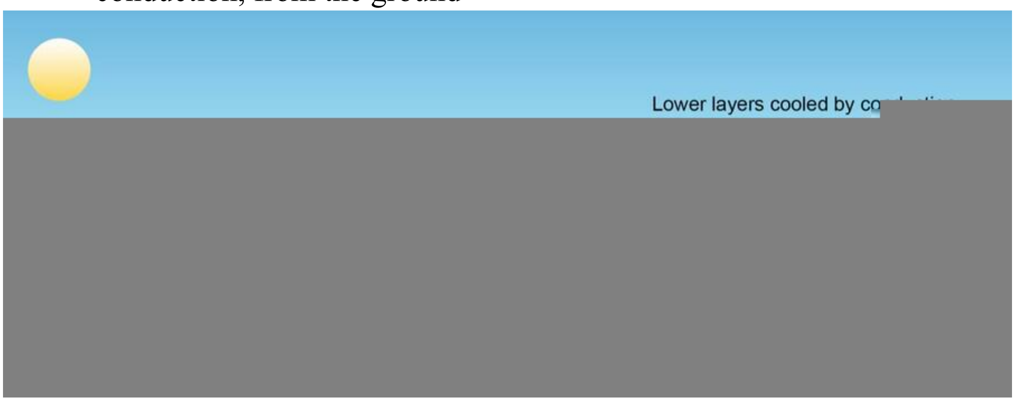
- Can be recognised by a trapped layer of dirty air, as they trap pollution

Ground inversions caused by 2 mechanisms

- Nocturnal/radiation inversion, happens every night over land
    - As the ATM cools overnight, the lower layers often becomes colder than the overlying causing inversion
    - Usually only a few thousand feet thick, above 3000ft it returns to normal
    - The inversion reaches its maximum strength just after sunrise
    - During the colder months, it's been noted, under the right conditions, as condensation takes place and fog form; radiation fog
        - almost never happen over the sea as the temperature does not decrease sufficiently over night

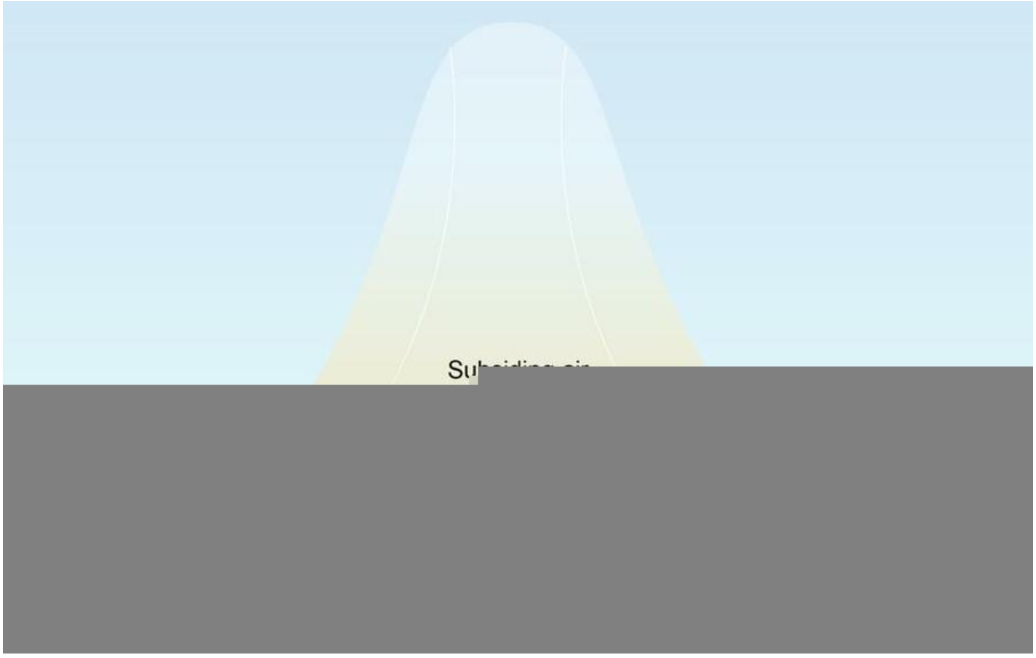


- By creating a ground inversion by the advection of air
    - When warm air flows in over a colder surface the lower layer cools by conduction, from the ground



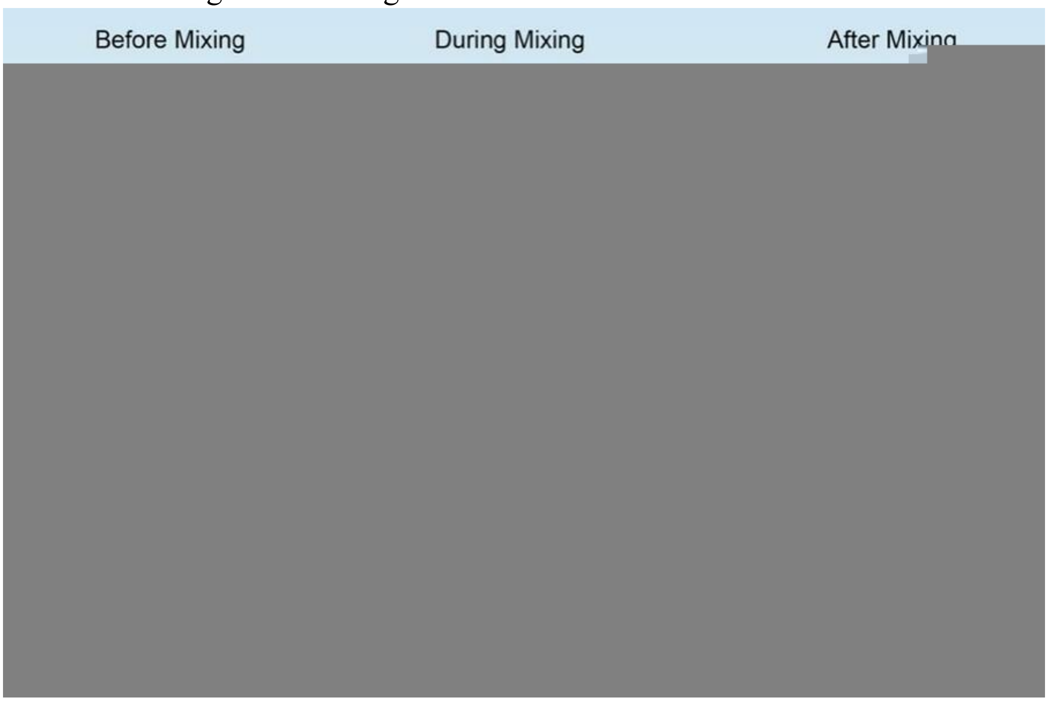
Subsidence inversions, form as a result of air gradually sinking over a wide area

- Descends and compresses
    - Lower ATM compresses warming the air adiabatically
- Generally warms at a faster rate than the surrounding air



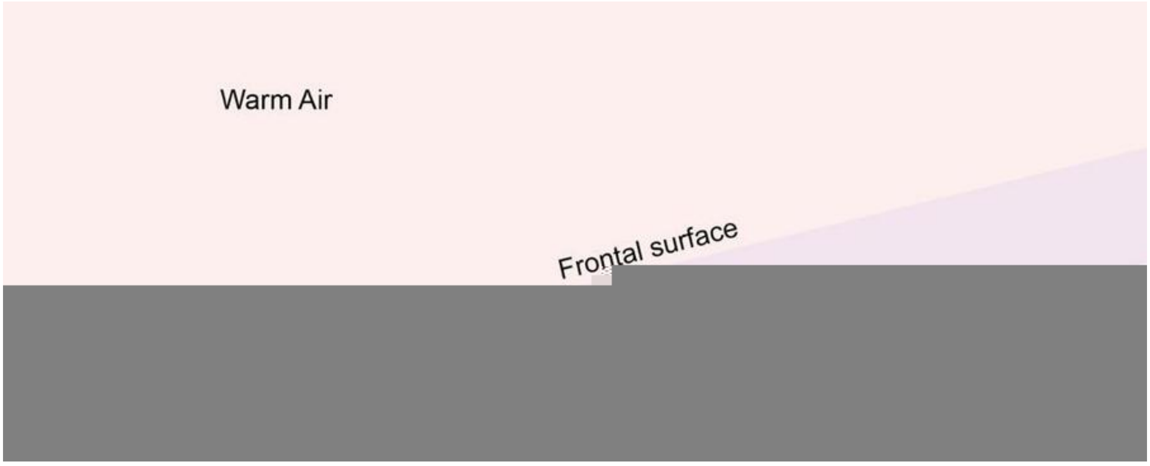
Turbulence inversions, created by the mixing of air in the lower ATM

- When air is forced to move vertically, it changes the rate it warms/cools
    - Creating a new average rate



Frontal inversions, form at the boundaries between warm and cold air

- Due to different densities, the colder slides under



Valley inversions

- works the same way as Nocturnal/radiation inversion with the exception of
    - the terrain causes the colder air to move downslope
        - forming a katabatic wind

CH 3

Atmospheric pressure

- early forecasts noted
  - high pressure for "good weather"
  - low pressure for "bad weather"
- pressure is a force applied over an area
  - the force acting is the gravity
    - which is for the sake of the course assumed to be constant
- air is a fluid making the "weight", static pressure, feel equal in all directions

Pressure measurements:

- mercury barometer
  - Hg put into an evacuated tube drives the content up as the pressure increases
- Aneroid barometer
  - Uses a flexible, partially evacuated capsule
  - An increase in pressure causes it to contract
- Barograph
  - Aneroid which records the different pressures on a piece of rolling paper
- Solid state
  - For professional use
  - Uses a sealed evacuated chamber on one side with a diaphragm in between, flexing with miniscule pressure differences

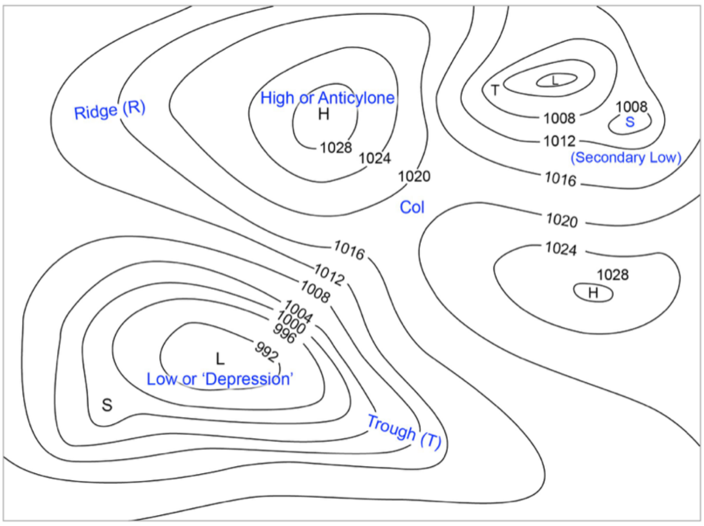
Units of measurements:

- Europe: hPa which coincide with bars
- Northern America: in Hg

1013.25 hPa = 29.92 in Hg

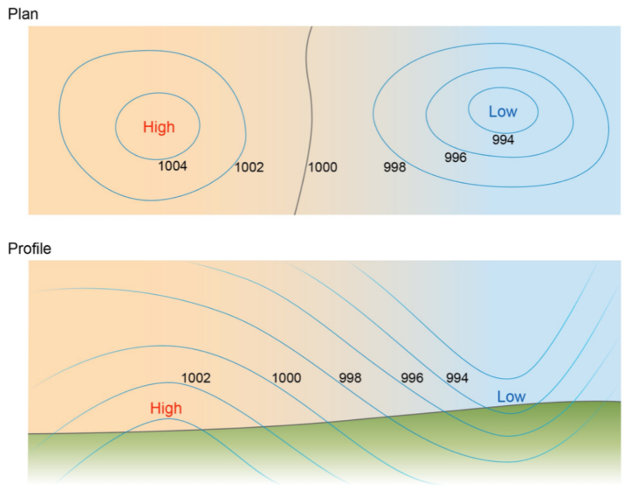
Diagrams of variations in surface pressure are called pressure surface charts, or **synoptic charts.**

- First developed in 1863, by Francis Galton
- To obtain an accurate surface pressure chart, pressure reading must be made with respect to a common datum
  - Most common, MSL pressure charts
    - QFF
- Lines of equal pressure are known as isobars



Relatively speaking:

- Low-pressure areas are known as depressions or lows, cyclone
    - Pressure increases with distance away from the centre
    - An extension of a low is called a trough
        - Weather in such features are often more severe than the parent system



- High-pressure areas are known as anticyclones or highs
    - Pressure decreases with distance away from the centre
    - An extension of an high is called a ridge
        - Weather in such features are often more severe than the parent system
- Between highs or lows is an unique area called a col
    - Usually characterised by widely spaced isobars
    - A variety of weather may occur here

Whenever a pressure variation exists, a force is created that tries to drive air from high pressure to a low pressure area

- This is known as the pressure gradient, PGT
    - The greater the difference, and the narrower the isobars, the higher the gradient
        - Creating wind

Horizontal pressure variations

- There's an underling semi-diurnal in surface pressure
    - Highest occurs around 1000h and 2000h
    - Lowest at around 0400h and 1600h
- The size of the diurnal variation varies with latitude, highest in the tropics, ≈4hPa, maybe 1 hPa at mid latitudes

This distribution is characterized by the presence of distinctly identifiable zones of homogeneous pressure regimes, "pressure belts"

Vertical pressure variation, pressure decreases with height at a decreasing rate

- At least half of the ATM lies below 18 000ft, 500 hPa
- The higher up we go, the greater the distance between the pressure readings
- Below 10 000ft it's generally true to assume pressure changes with 30 ft per 1hPa

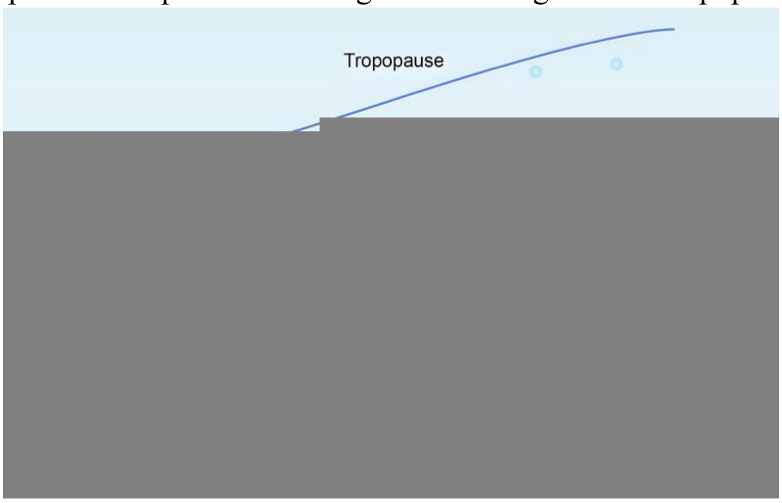
Height in feet	Pressure in hPa
40 000	200
30 000	300
20 000	480
18 000	500
10 000	700
5 000	850
MSL	1013

Calculating the change in height in feet for 1hPa change of pressure

$$\frac{(\mathbf{96} \times \boldsymbol{temp.}(\boldsymbol{K}))}{\boldsymbol{pressure}\ (\boldsymbol{hPa})}$$

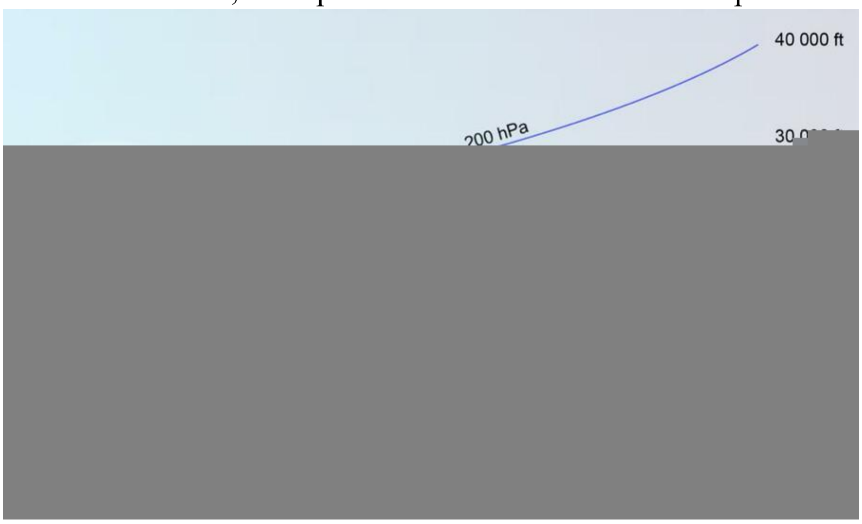
- Aircraft altimeters use this relationship to calculate and display height

The effect of temperature on pressure readings and the height of the tropopause:



- Pressure in a cold column falls more quickly with height
- Cold air causes pressure to change more rapidly with height
  - Above cold air, the pressure is lower than at the same level in warm air

By assuming 0°C at the surface, the lapse rate would be closer to 25 ft per hPa than 30

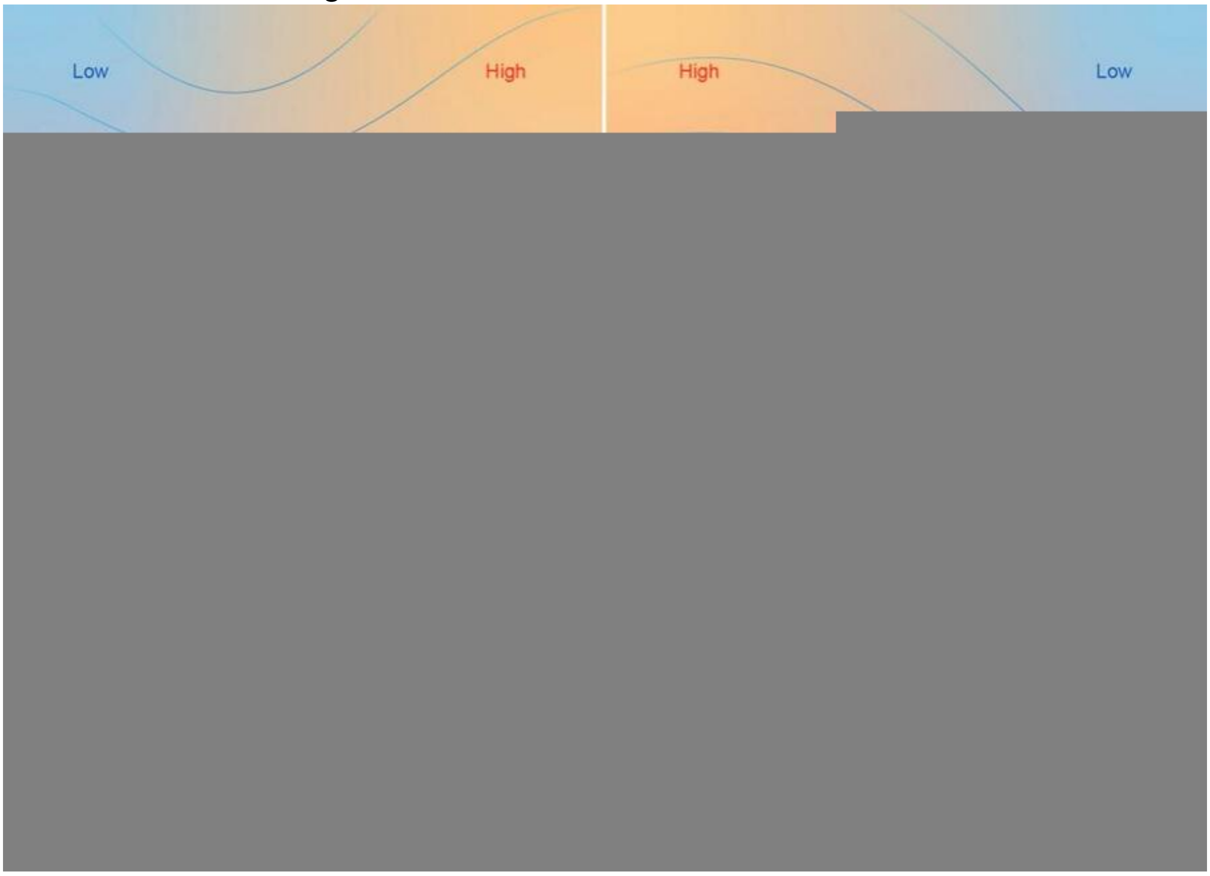


Charts showing the topography of pressure levels is used by meteorologist to illustrate the conditions in the middle and ATM

- Constant pressure, or contour charts, usually the 500 hPa pressure level
  - isohypse are lines on a map connecting points of both equal height and equal barometric pressure

When looking at pressure patterns from a profile view

- Pressure levels always slope downward to the low pressure
- However, depending on the **temperature** the pressure levels becomes progressively modified with height



Pressure datums

- All aviation charts uses MSL as their datum

QFE is the barometric pressure at the aerodrome reference point

- “field elevation”

QNH is QFE mathematically adjusted down to the MSL

- QNH = QFE + (elevation/27)

QFF is similar to QNH but it’s NOT mathematically adjusted, it’s the actual pressure at sea level depending on the actual temperature; rather than ISA

- For airfields above MSL
    - Warm air: QFF is lower than QNH
    - Cold air: QFF is higher than QNH
- *The reverse is true for below MSL

CH 4

Air density; has a significant effect on the performance of an aircraft, aerodynamic force generated

Influencing factors:

- Temperature:
    - As temperature increases, the kinetic energy of the molecules takes more space and thus reducing the density
- Pressure:
    - Air is compressible; as pressure increases, the air becomes more compressed→ more dense
- Humidity:
    - As the water vapour is added to dry air it displaces some of the heavier, molar mass, oxygen and nitrogen molecules→ making the air less dense
        - Cold air is more reluctant on holding on to water vapour causing it to be more dry and usually more dense

The density of air decreases with altitude, much faster at lower levels than higher up

- The rate at which it changes is affected by temperature

The density is lower above cold air than above hot air above same the same elvelation

- Due to the distribution of mass of the air

altitude	hPa	Density altitude	ISA density g m^{-3}
40 000	200	40 000	302; 25% of MSL
30 000	300		
20 000	480	22000	609; 50% of MSL
18 000	500		
10 000	700	10 000	903; 75% of MSL
5 000	850		
MSL	1013	MSL	1225; 100% of MSL

Density altitude; the pressure altitude corrected for temperature variations

- 120 ft per 1° ISA deviation
- When you take off at a density altitude of 10 000ft you can expect your aircraft to perform as it would at 10 000ft

Relative density; compares the prevailing density against the ISA MSL density and expressed as a percentage

- Ex. If the measure density is found to be 903 g m^{-3} the density would be 75%

CH 5
Pressure systems

A depression, Low, is a region of relatively low pressure

- Shown by concentric isobars
- Varies from few feet to thousands of miles in diameter
- characterised by rising air; terrestrial heating
- Cyclone is technically correct term but usually confused with tropical revolving storm

When the air rises in the ATM it expands the surrounding pressure drops

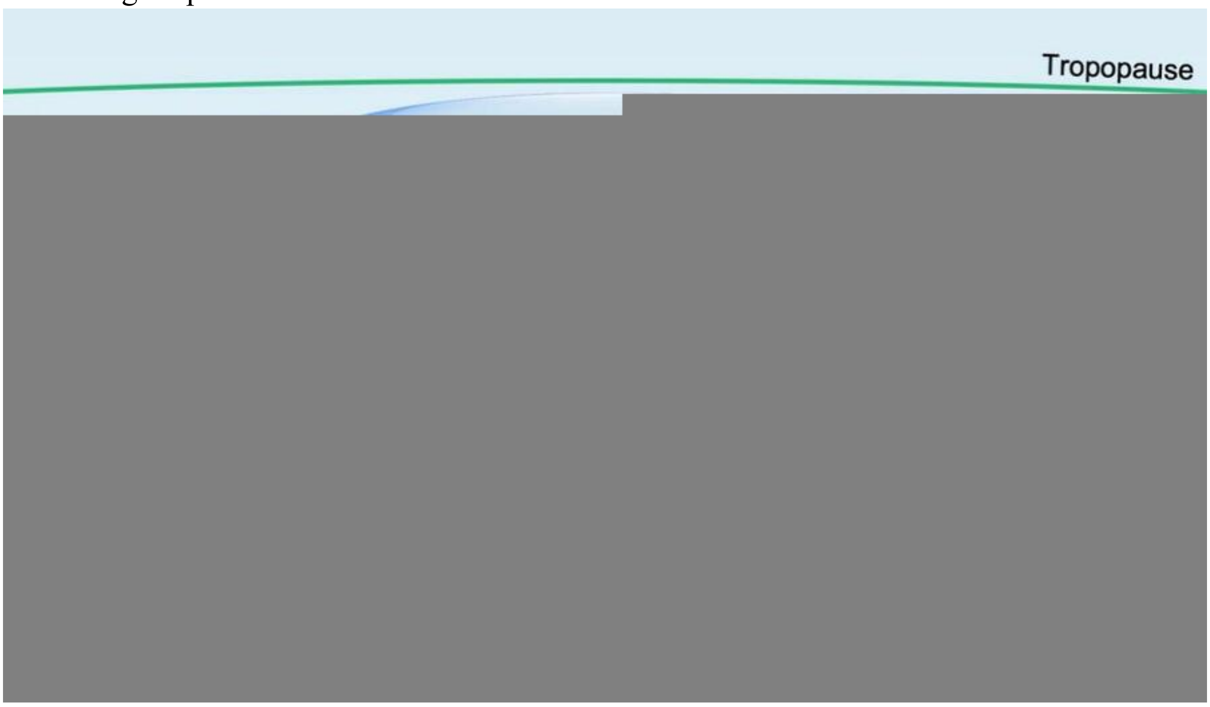
- Causing the rising air to cool and condense → fog/ clouds
  - Always accompanied by clouds and precipitation

The rising air helps clear the surface from pollution → good visibility

Formation; mainly due to differential heating and buoyancy, air can rise in the ATM. Once it hits the tropopause the temperature is constant and can no longer rise → spreads outwards; reducing the total mass of the ATM at that point→ surface pressure falls and a low pressure system is created

Air moving from high pressure to lower, moving towards the low to replace “lost” air

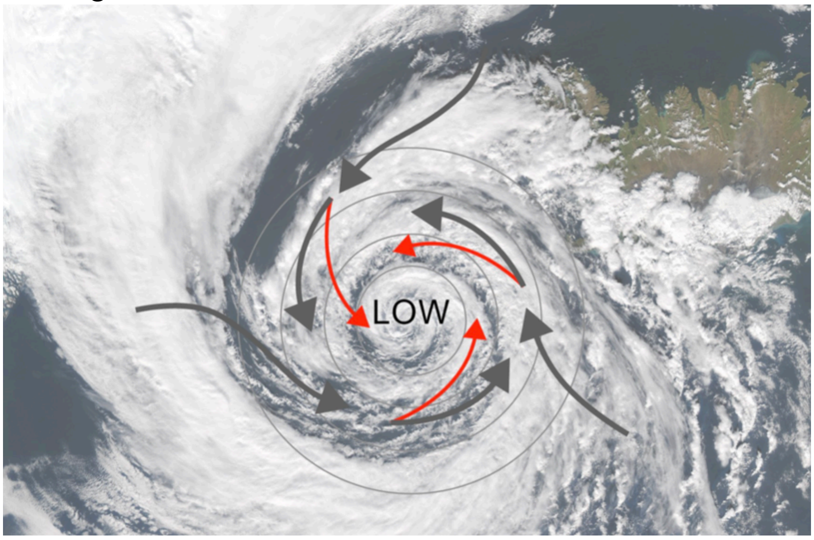
- Air entering is slowed by surface friction
  - Creating a net loss (suction)→ continued reduction in ATM mass→ sustained and deepened it the flow continues
- As the air mass approaches the tropopause it bottlenecks at the top creating slightly higher pressure



Accumulation of a depression; air near the surface is initially drawn directly towards the "eye", immediately being modified by the Coriolis force, deflecting the flow to the right in the n.hemisphere

- As a result 3000-5000ft AMSL, the winds are deflected so much it flows parallel to the isobars
- Producing an anti-clockwise flow, in the n.hemisphere
    - Clockwise in the s.hemisphere

Below 3000ft the surface friction dominates Coriolis force → the wind vector is not parallel to the isobar, it converges towards the centre



Small scale heat low

Land warms much more rapidly than sea, across land some surfaces heat up faster → warms up and becomes less dense in that area → convection→ if conditions are right → low pressure airflow forms

The rising air associated with these lows is vertical and usually strong

- Also producing vertical cloud, cumuliform cloud
    - Producing rain showers
        - Size of a thunderstorm, too small to appear on a surface pressure chart

Large scale heat lows

Having many small scale lows over a large are they begin to show on pressure charts in fact they add up. Most noticeably are north American and Asian lows

Global distribution of heat lows
Heat lows generated around the equatorial region form the equatorial low-pressure belt, varies from Cancer to Capricorn.

- Characterised by strong thermal up streams diverging at the tropopause
    - The influx along the surface from both south and north creates the inter tropical convergence zone, ITCZ
        - Usually comprises isolated but severe tropical thunderstorms

In some circumstances tropical thunderstorms can break loose of the ITCZ and grow to become the largest and most destructive weather phenomena on the planet; tropical revolving storm (>27°C)

- Depending where they originate from:
    - Hurricanes: Caribbean and china sea region
    - Cyclone: Indian ocean and south pacific
    - Typhoon: west pacific

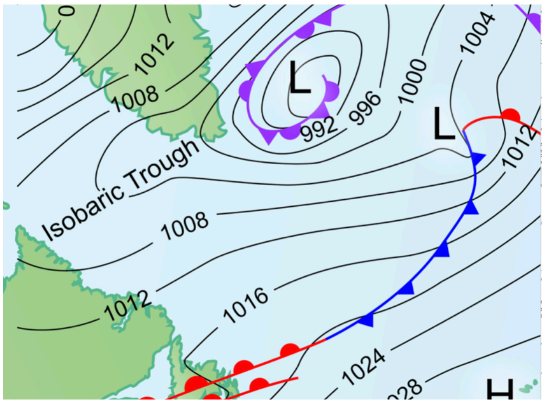
Large scale low; commonly referred to as *mid-latitude depressions* or *polar front depressions*
Each depression is hundreds of miles in diameter and contains a large number of tightly spaced isobars. Occasionally, smaller secondary depressions can form along the polar front within the confines of a larger one

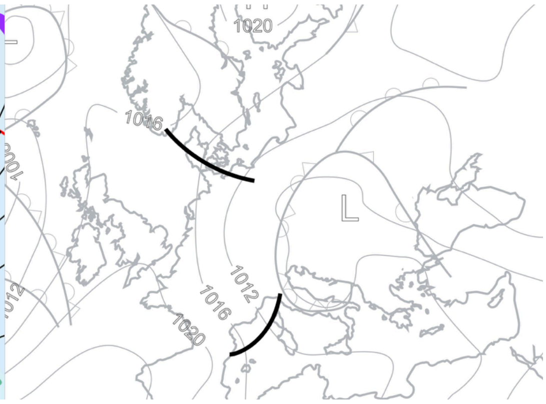
Polar front depressions have the same cross sectional flow of air as other depressions, however, the triggering mechanism is different and more complex. They are also responsible for generating much of the weather in the mid latitudes, bringing abundant cloud, wind and rain

Troughs ("truff"); is an elongated area of low-pressure. There are 2 types:

- Isobaric trough
    - A portion extends from an area of low-pressure into another region
- Trough line
    - A black line drawn on a surface pressure chart
    - Not necessarily associated with any parent low but are more common with flows of air that become unstable, tendency to rise
    - Expect; heavy showers of rain/hail and strong wind gusts

Generally throughs of low-pressure have stronger than normal surface convergence and increased could and rain





Anticyclone; an area of relatively high surface pressure

- Air is subsiding and flowing outwards at the surface
- Air that sinks in the ATM becomes compressed
- Subsiding warm air as it descends towards the surface

Since it originates at the tropopause, subsiding air is very dry→ cannot form clouds.

Descending warm air creates an inversion; the air closest to the surface is not the same air as the one moving hence, it retains its temperature. The air in the descending column has been warmed by depression.

- Thus making the air increase with altitude for the first few thousand feet
    - Subsidence conversion

Descending air also causes pollutants to become trapped near the surface → low altitude poor visibility.

Cloudless skies and light winds associated with anticyclones→ temperature falls significantly during the night

Unlike low pressures, the isobars stent have much wider spacing→ pressure gradient force is weaker→ the winds are weaker

A high pressure system is created when the mass of air immediately above the surface is greater than the surroundings

- Air at high altitudes may start to descend by a variety of mechanisms
- Air is drawn in from either side; conically→ surface pressure increases→ low altitude moves away from the high pressure

The diverging air at the surface is slowed due to surface friction→ air cannot leave the system as fast as it enters.

Air near the surface diverges and flows away from the high-pressure; Coriolis force causes this flow to be deflected to the right in the n.hemisphere→ airflow rotates clockwise

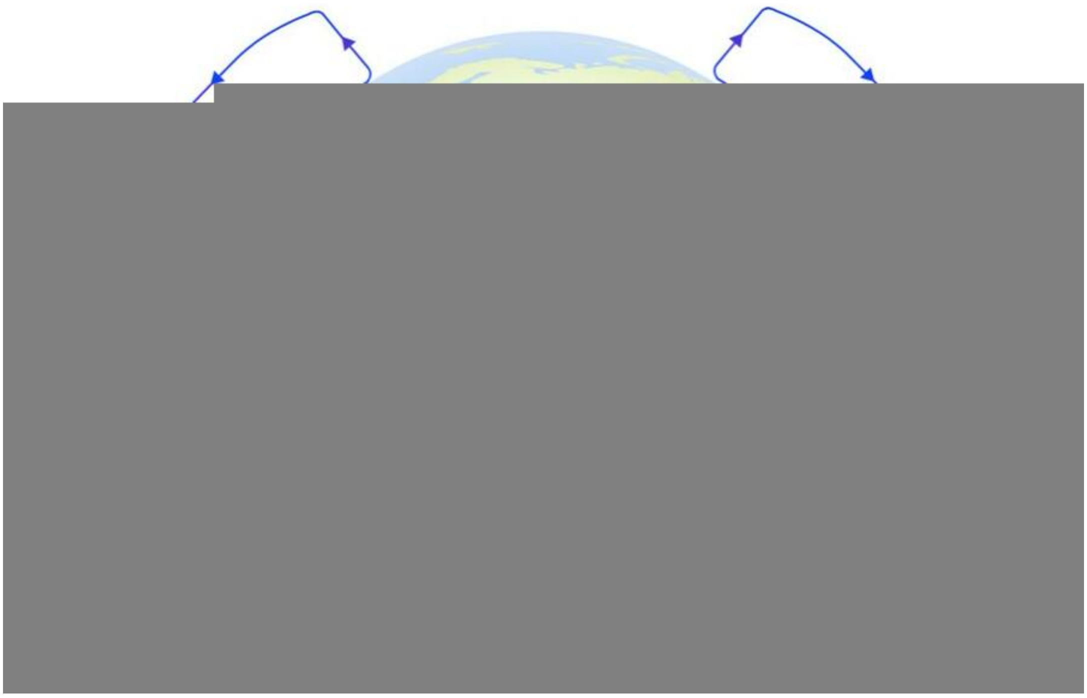
- Because of surface friction, the flow parallel to the isobars doesn't establish itself until above 3000ft

Surface winds in red arrows:

Warm anticyclones; occurs at approximately 30° latitude either side of the equatorial low-pressure belt, forming a belt of sub-tropical highs

Warm air rising at the equator calls and spreads outwards at the tropopause, as it cools further it becomes denser and starts to sink → giving rise to the belt of warm, dry anticyclones producing some of the world's greatest deserts

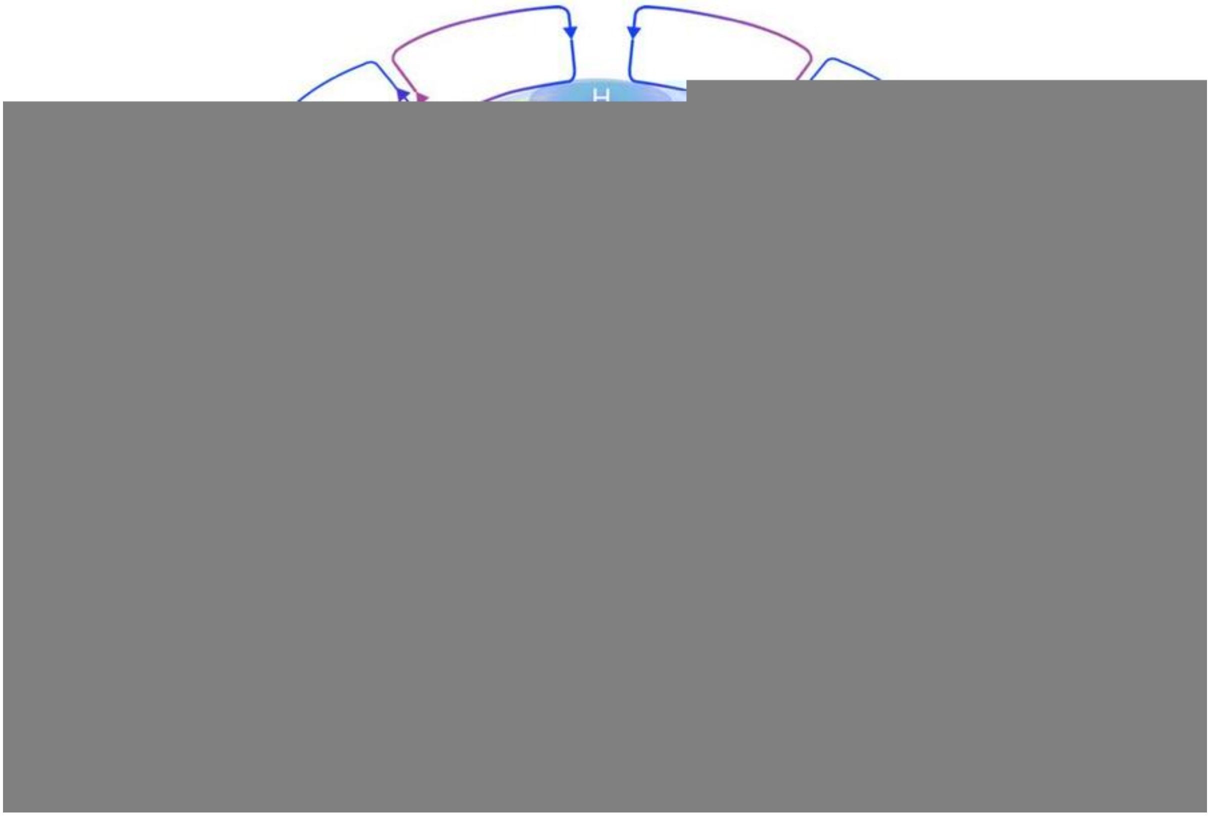
- Azores high
- Bermuda high



A **blocking anticyclone** describes one of the effects of a warm anticyclone. Under certain conditions, the sub-tropical highs expand into the latitude band normally occupied by the polar front depressions → deflecting the depressions northwards

Cold anticyclones; the pattern of high pressures repeats itself however, the polar regions receive very little insolation → cold anticyclones

- Formed by large scale cooling of air at the surface→ denser→ sinks



In the winter over land, this high pressure belt can cause extremely cold conditions

- Serbian high over Asia
- Canadian high over north America

cold anticyclones occur more or less permanently over the polar regions; polar highs

- In western Europe during the winter, is affected by the Serbian high
    - Airflow from the east

Cold temporary anticyclones; can be identified between the polar front depressions, mid-latitudes, because the pressure in the area between 2 large low-pressure systems is relatively higher

Ridge; an area of high-pressure which protrudes outwards into other pressure regions

Col; occur between 2 areas of high pressure surrounded by 2 lows

- Widely spaced isobars
- Weather depends on the time of year
    - Little movement of air→ heating significantly during the summer
        - Can lead to thunderstorms
    - Accumulative cooling during the winter leading to formation of fog

	Depression	Anticyclone Summer or cold winter	Anticyclone winter or warm anticyclone	Col summer	Col autumn-winter
Pressure, relatively	Low	High		Average	
Defining character	Rising air	Sinking air		Widely spaced isobars	
formation	Heating of an area*	Mass of air above the surface is greater than the surroundings		Middle area between 2 highs and 2 lows	
Sustainment	Divergence at the tropopause; faster flow in the upper regions	When air comes closer to the surface it's slowed by surface friction; suction is created		As long as it's surrounded by the 4 systems	
Clouds	Clouds may extend all the way to the tropopause	None, except on the edge of the system	Extensive stratus with low base	Thunderstorms are common	fog
Precipitation	Continuous, intermittent	None	Possibly drizzle	Depending	
Visibility	Poor in precipitation, otherwise good	Moderate with haze	Moderate to poor, mist/fog	Depending	poor
Temperature	Pending on origin and air mass	Dependent on type	Generally warm	Depending on changing pressure	
Winds	Usually strong	Light		By far the calmest	

*other types of depressions exist, this only reflects the most basic scenario

CH 6

Altimetry

Because the altimeter is a type of barometer, ATM changes in temperature, only ISA ±0, and pressure affect the behaviour and accuracy of the instrument

Aneroid barometers are the ones mostly used in aircrafts

- By selecting a pressure setting in the Kollsmann window we can define a datum

QFE; when the pressure is set to the aerodrome reference point

- Giving a reading of 0 ft at touchdown
- Expressed as height

QNH; QFE reduced to MSL using ISA lapse rates

- Expressed as altitude
- Always rounded down to the nearest whole number
  - To ensure “safer” separation

Reginal QNH, RPS; is the lowest pressure for a certain region

- Valid for up to 1 hour
- Used for cross country flights below the transition altitude

QNE; used for landings at aerodromes having a higher altitude than possible to be set on the subscale

- Uses SPS, 1013,25hPa
- given the elevation from SPS the aerodrome reference point is

SPS;

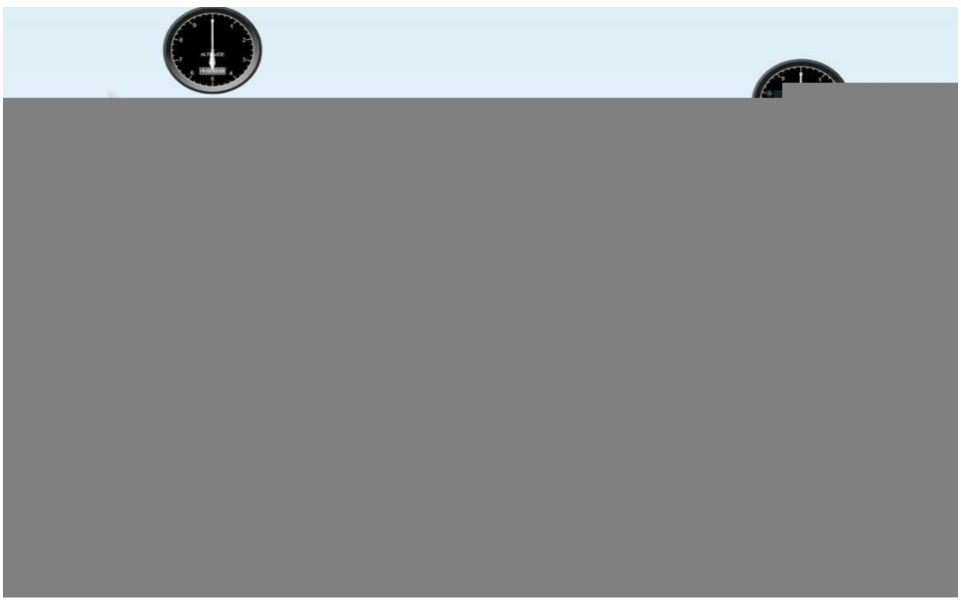
- 1013.25hPa
- Used for flights above the transition altitude
- Flight levels

Below 10 000ft assume a lapse rate of 30ft/1hPa

The altimeter suffers from errors, horizontal pressure variations and temperature variations

- Leading to “false/inaccurate” height readings

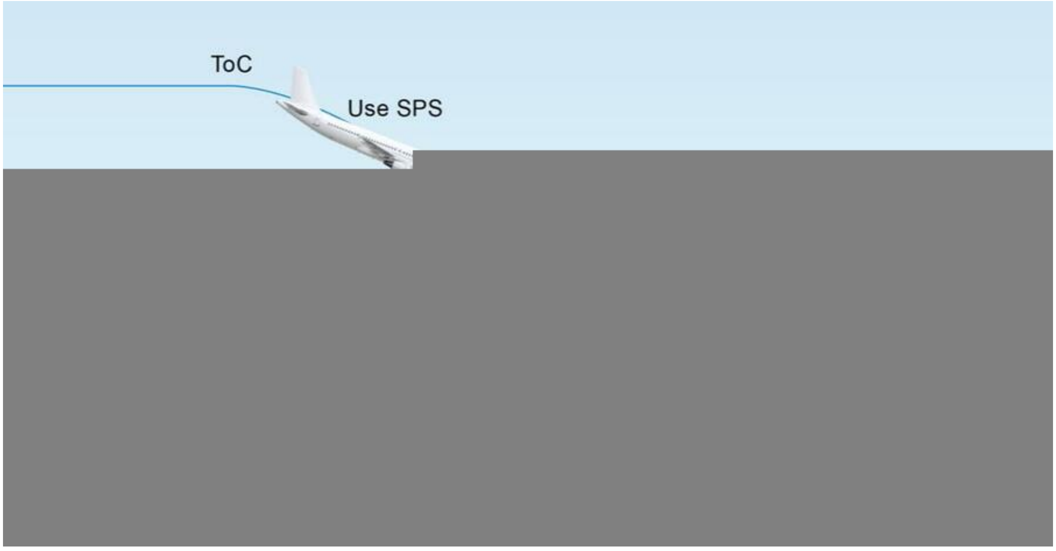
When flying from a higher pressure are to a lower pressure area→ true altitude reduces while indicated remains the same. And vice versa



Adjusting the altimeter to the aerodrome QNH is vital for the following reasons:

- Ensuring the altimeter is showing the correct altitude
- Ensuring safe separation from other aircrafts and terrain/minima

Whenever an aircraft flies above the transition altitude the crew must set the SPS to 1013.25hPa



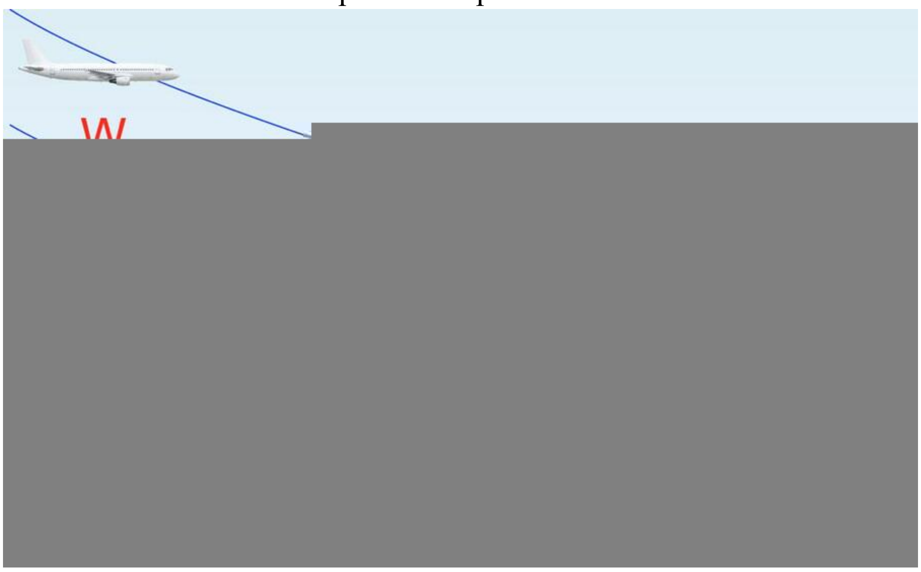
The transition level is the lowest available flight level, it guarantees minimum vertical separation of 500ft; transition layer

- Transition level varies with QNH

Accelerated airflow; can cause altimeter errors

- Terrain can squeeze the horizontal winds over the peaks of undulating terrain through narrow valleys increasing the velocity of the airflow
    - Causing the altimeter to over-read

The temperature of the air affects the pressure lapse rate



- Flying from cold to warm, constant altitude, causes the altimeter to progressively under-read

Whenever the temperature is colder or hotter than ISA, altimeter temperature error will be present

- COLD air; true altitude is less than indicated
- WARM air; true altitude is more than indicated

Cold operation pose a unique threat to pilots because they can cause altimeter to over read; temperature correct more important during sub-zero temperatures.

- During radar controlled approaches , the controller issues altitudes corrected for temperature
- Procedural approaches and without radar control, it's the pilot's responsibility to correct for temperature deviations
    - Some approaches even require you to program the FMS

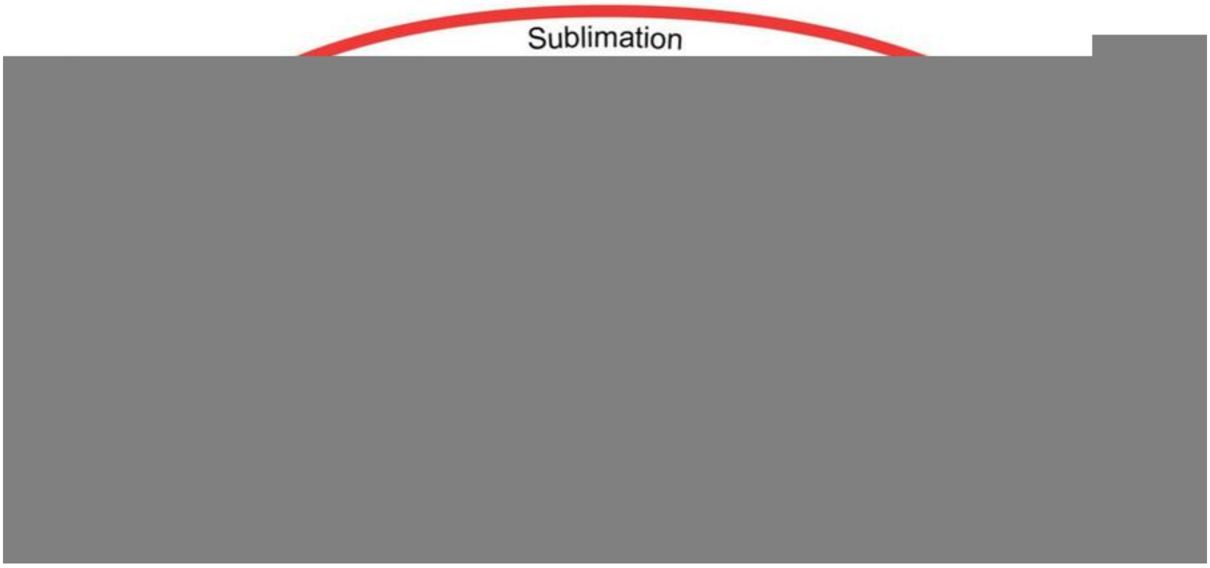
The indicated altitude/height changes by 4% for each 10°C temperature deviation from ISA

CH 7

Humidity; is the term used to describe the water vapour in the air

Knowing the humidity is important as the greater the humidity the more likely it's for weather to form

During phase change, significant heat transfer takes place. Every phase change requires either absorption or release of latent heat



- Melting; latent heat is absorbed
  - Hydrogen bonds are broken down to make the molecules move around freely
- Evaporation; adding heat give the molecules the needed energy to break apart into individual molecules
  - When the air is full of water vapour, the air is saturated
    - In certain, rare circumstances supersaturation may occur

As temperature increases the pressure in the surrounding air eventually reaches the point where it physically prevents further molecules from separating from the liquid

- It's said to be saturated
- 100% relative humidity is when the pressure exerted on a parcel of air by its surroundings is equalised by the pressure exerted by the water vapour within it
- **For any given temperature and pressure, the air can only contain a certain amount of water vapor**
- **Warm air can hold more water vapour than cold air**

Condensation; latent heat in the water vapour is released to the surroundings

Once this happens we begin to see it in the form of steam, dew, fog and clouds

For condensation to occur:

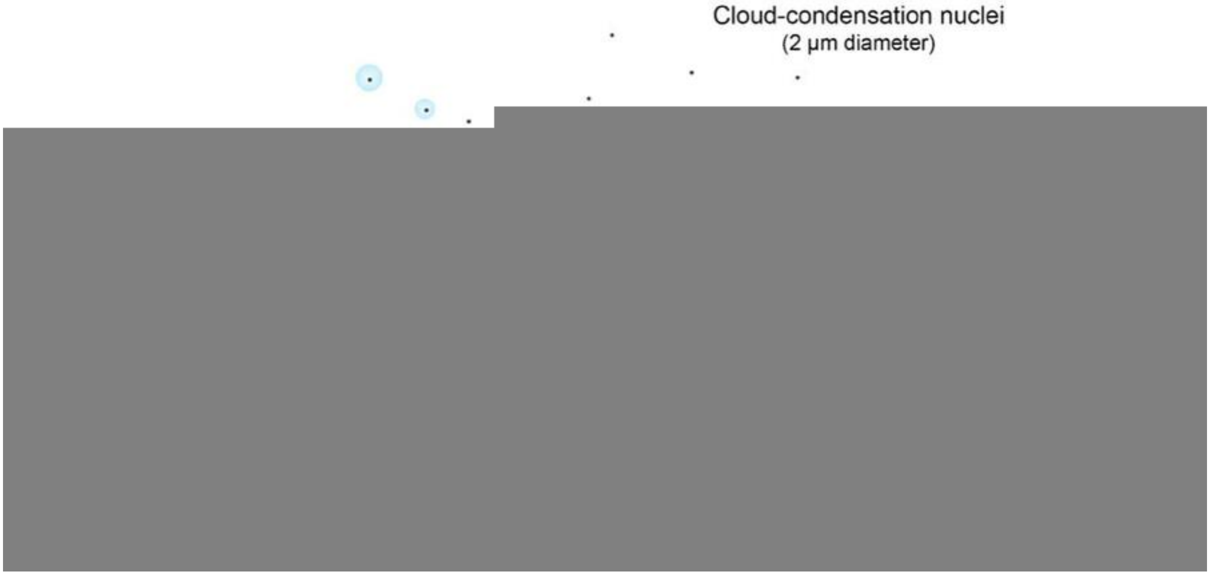
- The air must be cooled
- There must be a nucleus of matter around which water vapour can cluster into

When warm moist air is cooled, it must eventually reach a temperature where it's incapable of holding all the water vapour molecules

- This is known as the dew point

In normal circumstances, the water vapour molecules needs tiny particles of matter, cloud condensation nuclei, to begin the condensation process; the nucleus must also be hydrophilic

The condensing water vapor forms microscopic water droplets around these particles, colliding and merging with others



It's possible for condensation to occur without a cloud condensing nucleus; for this to happen the temperature must be at least -40°C

When water freezes it releases latent heat to the environment, for it to occur as high as 0°C, a freezing nucleus is needed to initiate the process

Whenever water exists in liquid form below 0°C it's said to be supercooled

- Supercooled water droplets are common in clouds
  - But less so in -50°C, below that temperature they spontaneously begin to form ice crystals

Flying into an area containing SCWD can result in instant and severe airframe icing

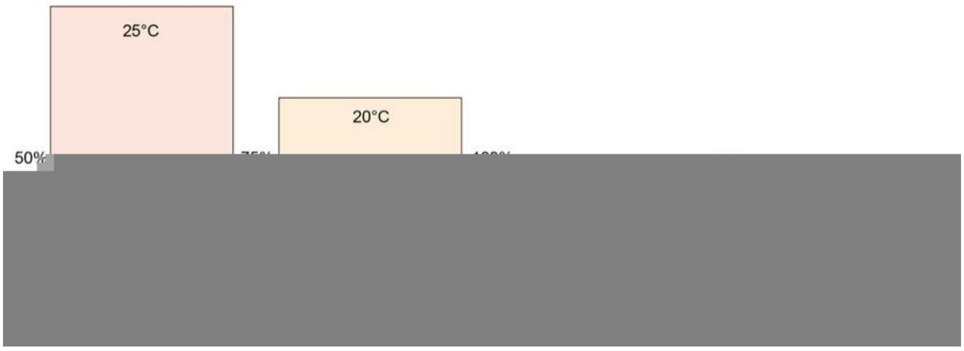
Sublimation, solid to gas, and deposition, gas to solid, is one of the ways hail grows. And seen as contrails

Measurement of humidity:

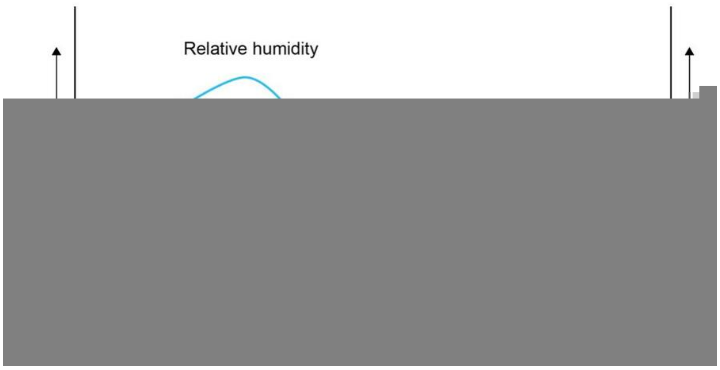
- Digital hygrometer:
  - Measuring capacitance between 2 plates, the more humid the greater the capacitance
- Psychrometer:
  - Uses 2 thermometers; one dry bulb and a wet bulb, wrapped in a cloth
    - The distilled water in the cloth will gradually evaporate, if the air is very dry a lot of evaporation takes place causing a large drop in the wet bulb temperature
    - If the air is already full of water then no evaporation takes place, giving two similar readouts

Units of humidity:

- Absolute humidity g m^{-3}
  - The mass of water vapour per unit volume
  - Rule of thumb; 30°C contains about 30g of water; and 10°C contains about 10g
- Specific humidity
  - Expresses humidity as a ratio of mass of water vapour mixed in whit mass of air; g/kg
  - The saturated humidity mixing is maximum when the air is saturated at any given temperature and pressure
- Relative humidity
  - Defined as the percentage ratio of the partial pressure of the water vapour to the saturated vapour pressure



When the temperature of the air decreases, relative humidity increases and vice versa



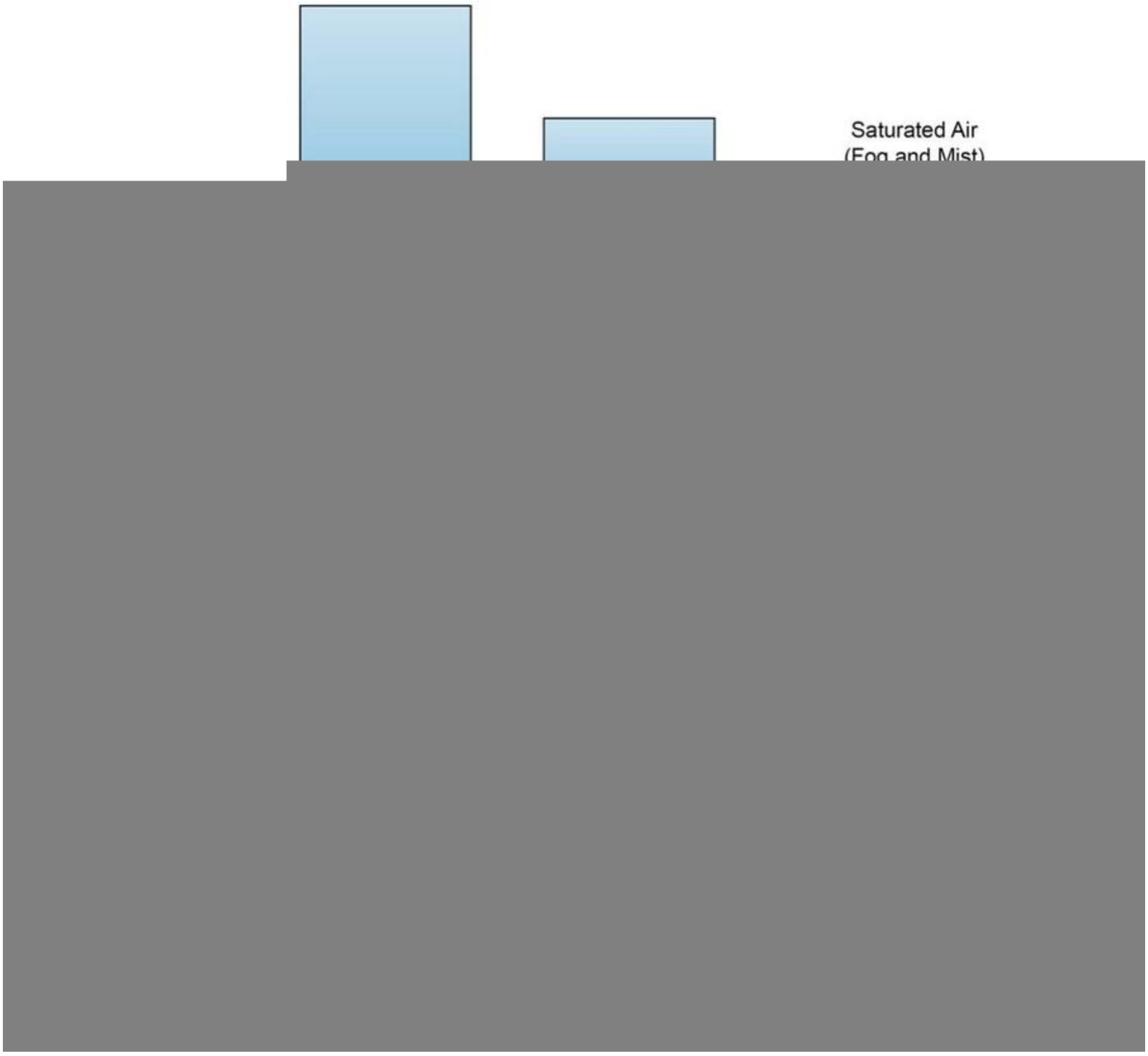
The dew point is the temperature to which air must be cooled in order to become saturated

- Dry air → low dew point

Surface air whose temperature and dew point are close together indicates a high risk of fog or low clouds

To approximate cumuliform cloud base:

- $\frac{temperature\ (n°C) - dew\ point°C}{400}$= cloud base in feet
    - During the winter the difference is much lower resulting in less lifting needed and lower cloud base



CH 8

Adiabatic processes and stability

Atmospheric stability describes the ability or otherwise of a parcel of air to resist vertical motion

- When a parcel has a natural tendency to rise it's said to be buoyant, "float"

An adiabatic process is a thermodynamic process of warming or cooling in which no heat is transferred to, or from the system

- **Only by compression and expansion**

Air that is caused to rise in the ATM cools by adiabatic expansion

→As it cools the RH increases, eventually leading to saturation. Rising further causes condensation and formation of clouds

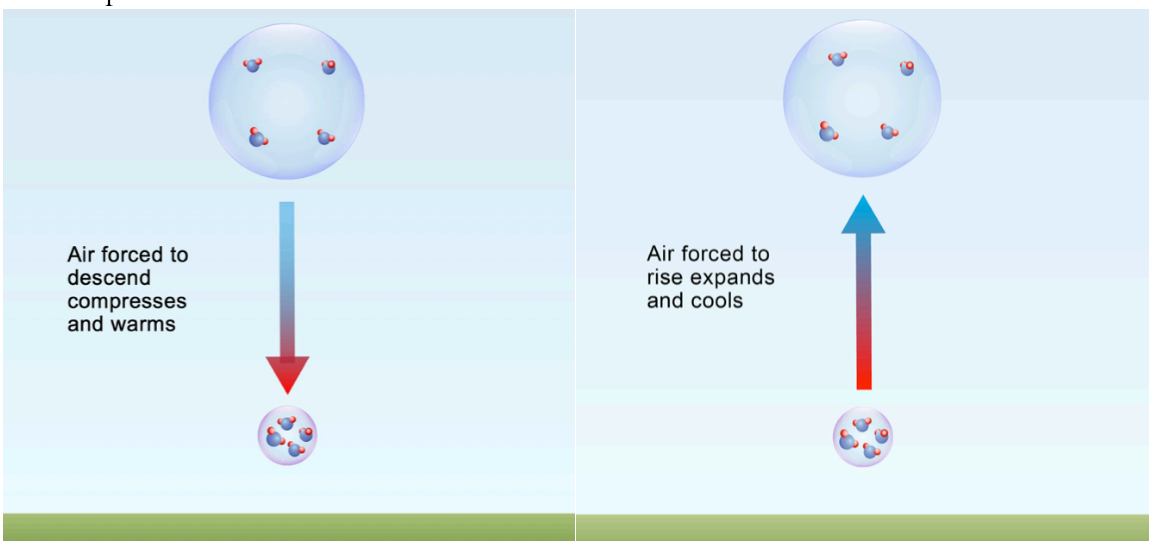
Air that is caused to descend in the ATM warms by adiabatic compression

→ when the air is forced to descend, the warming will cause it to become drier, because of the water vapour carrying capacity

Air which rises or descends in our ATM changes temperature adiabatically

The rate of the adiabatic temperature change is called the adiabatic lapse rate, ALR

- Dependent on the moisture content of the air



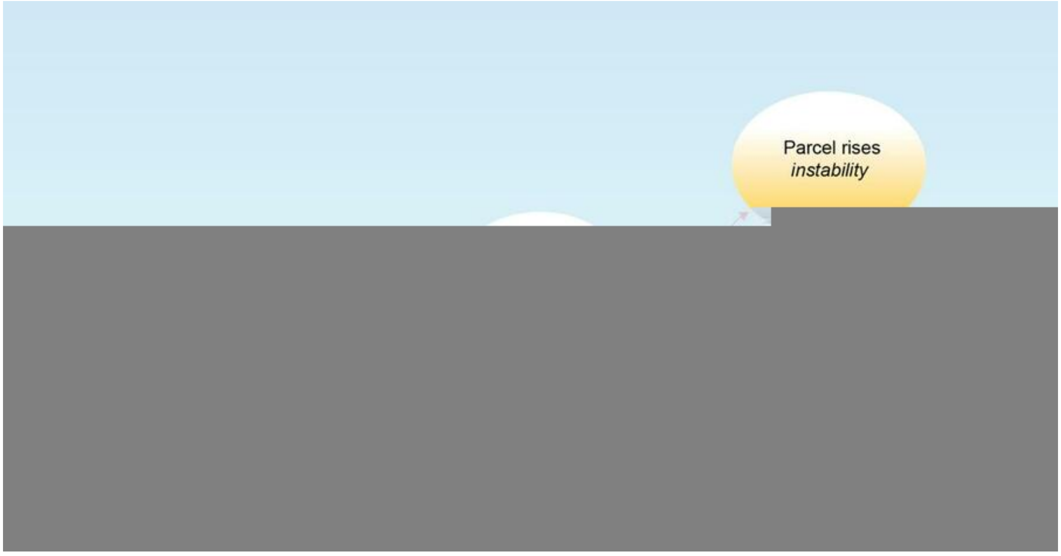
Dry air, less than 100% humidity, when caused to rise/descend, changes temperature at a rate of 3°C per 1000 ft; DALR

Saturated air, when caused to rise or descend, changes temperature by an average of 1,8°C per 1000 ft; SALR

- Saturated air changes by a smaller fraction because of the latent heat; when saturated air has cooled, condensation takes place. Condensation causes latent heat to be released into the parcel of air, adding thermal energy to it

When the ATM is in a state of hydrostatic equilibrium the vertical pressure gradient force is exactly balanced by gravity

Atmospheric stability describes the tendency of a parcel of air to rise, remain level or to sink

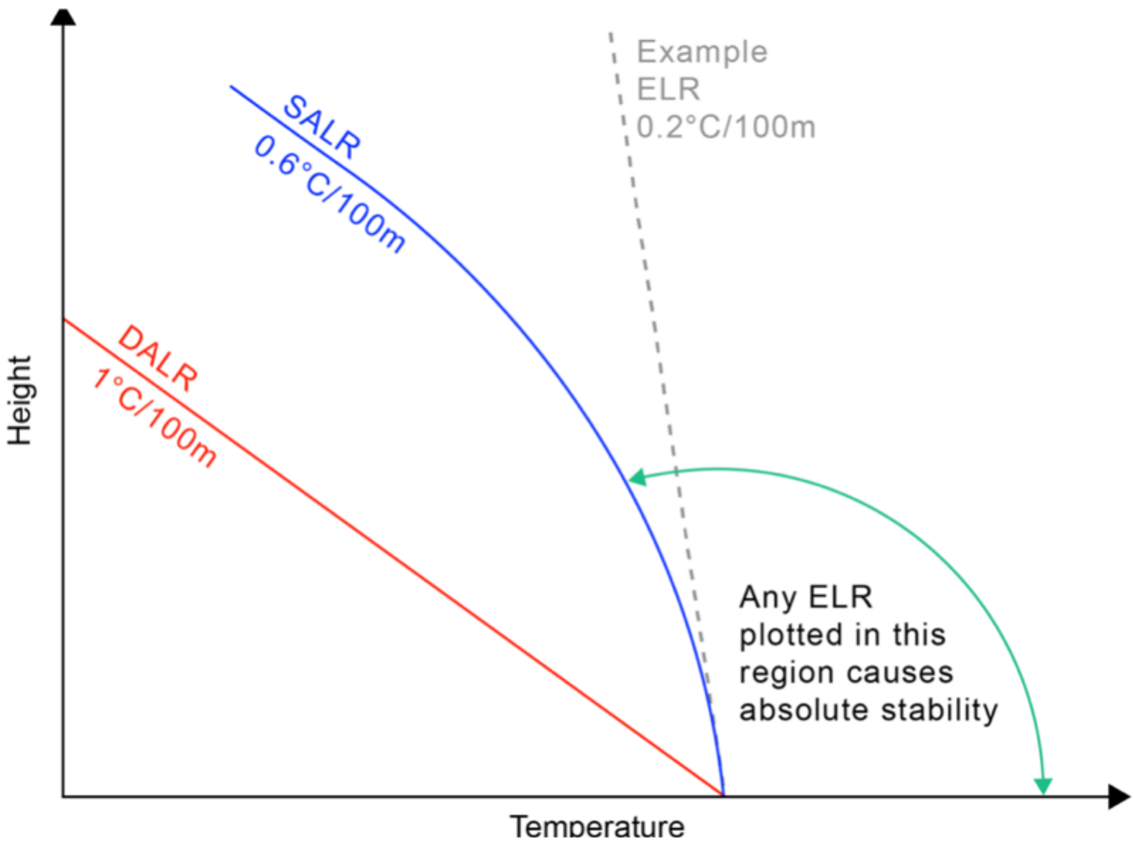


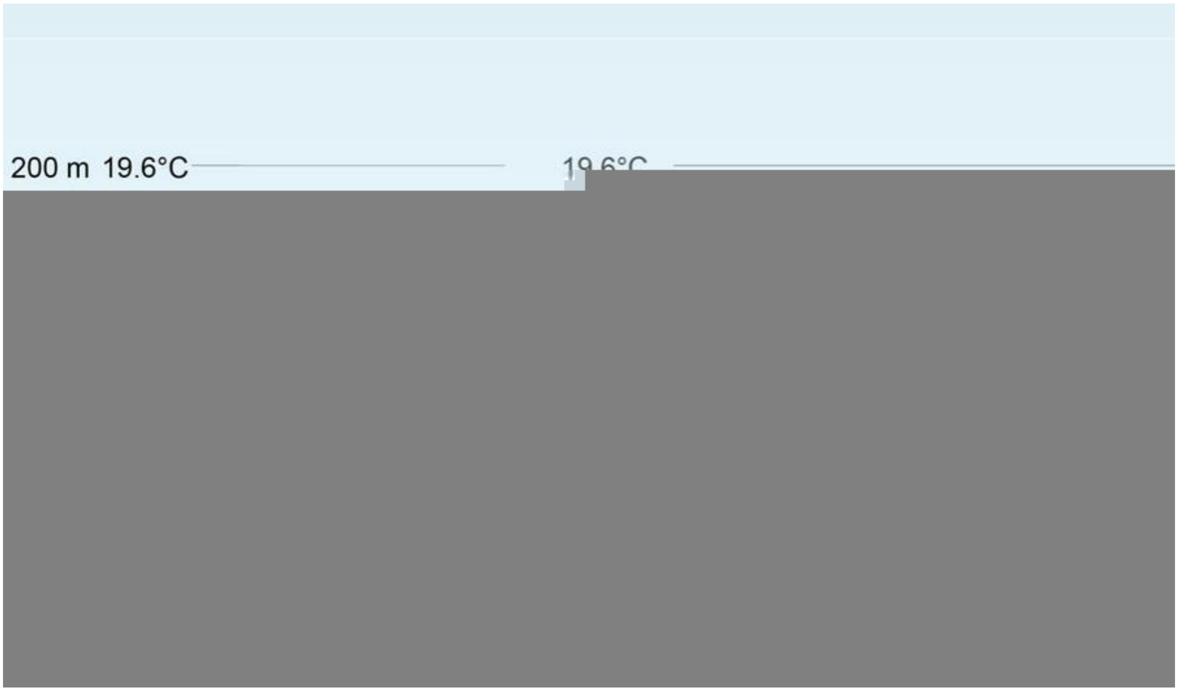
ATM stability depends on the rate of adiabatic cooling compared with the ELR.

- If a lifted parcel of air cools faster than the surrounding air then it will become colder than its surroundings
    - Making it denser than the surrounding air→ sinks back down

This is an example of stability

Absolute stability describes the tendency of a displaced parcel of air to return to its original position once the initial displacement force has ceased; the greater the displacement the greater the tendency to return





A parcel of air will resist vertical motion because parcels are cooling down faster than the environment, dry or saturated; in other words when ELR is less than DALR and SALR

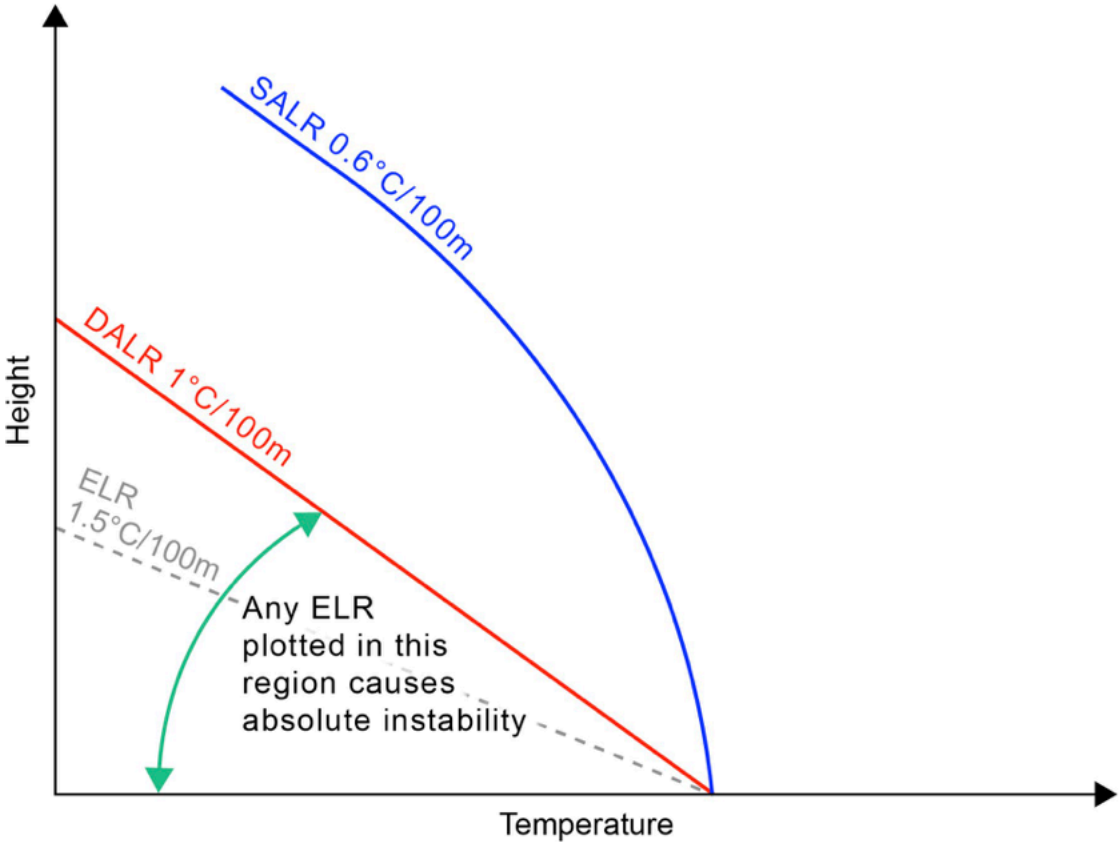
Inversions and isotherms produce ELRs which are much lower than the DALR and SALR so they produce very stable atmospheres

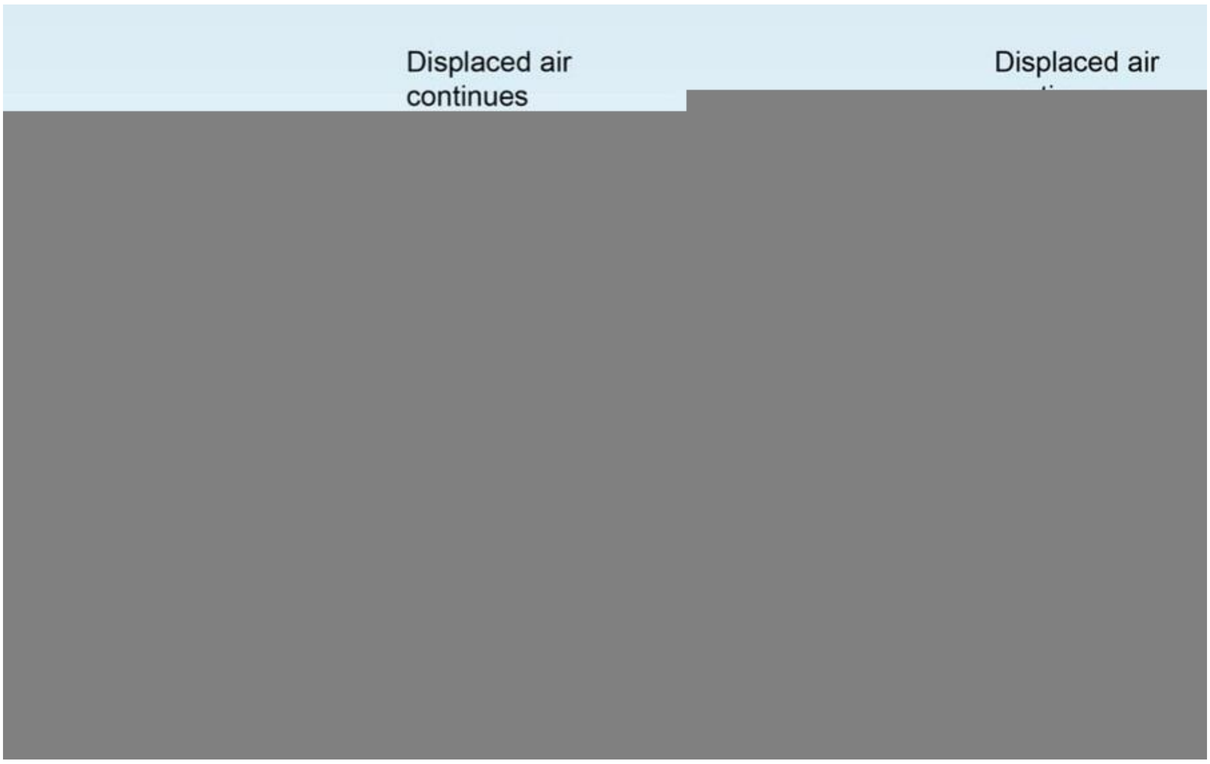
Any time there's surface or low-level cooling, the ELR will decrease and promote stable conditions

Weathers to expect in absolutely stable conditions:

- Any cloud produced will be flat or layered; stratiform clouds
- Lack of vertical movement makes it hard to produce large rain droplets or hail
- Visibility is kept poor as the pollutants is kept close to the surface
- Little or no turbulence due to motionless vertical airflow

Absolute instability is defined as the tendency of a displaced parcel of air to continue in the direction of the displacement once the displacement has ceased





Worth mentioning that the parcel temperature differenced is progressively increasing, causing it to accelerate

- Unstable air causes significant vertical cloud development , thermal and thunderstorms

There are several mechanisms which lead to the ELR being higher than DALR. In general, any time the surface or lover layers are warmer the ELR will increase

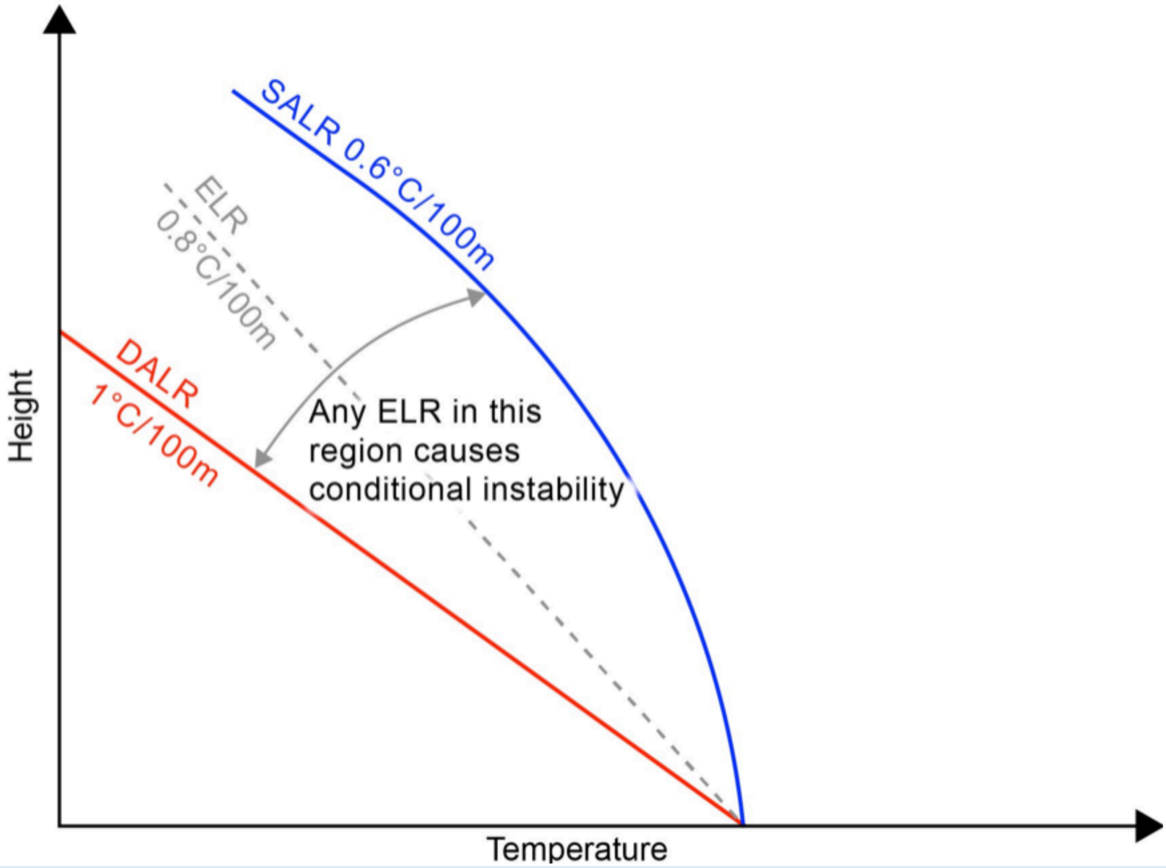
- Most common being summer afternoons over land masses in the topics; as the surface warms through the day and the upper air temperature remaining approximately the same, no mixing→ greater environmental lapse rate
- Another example is advection, having colder air move in over a warmer surface

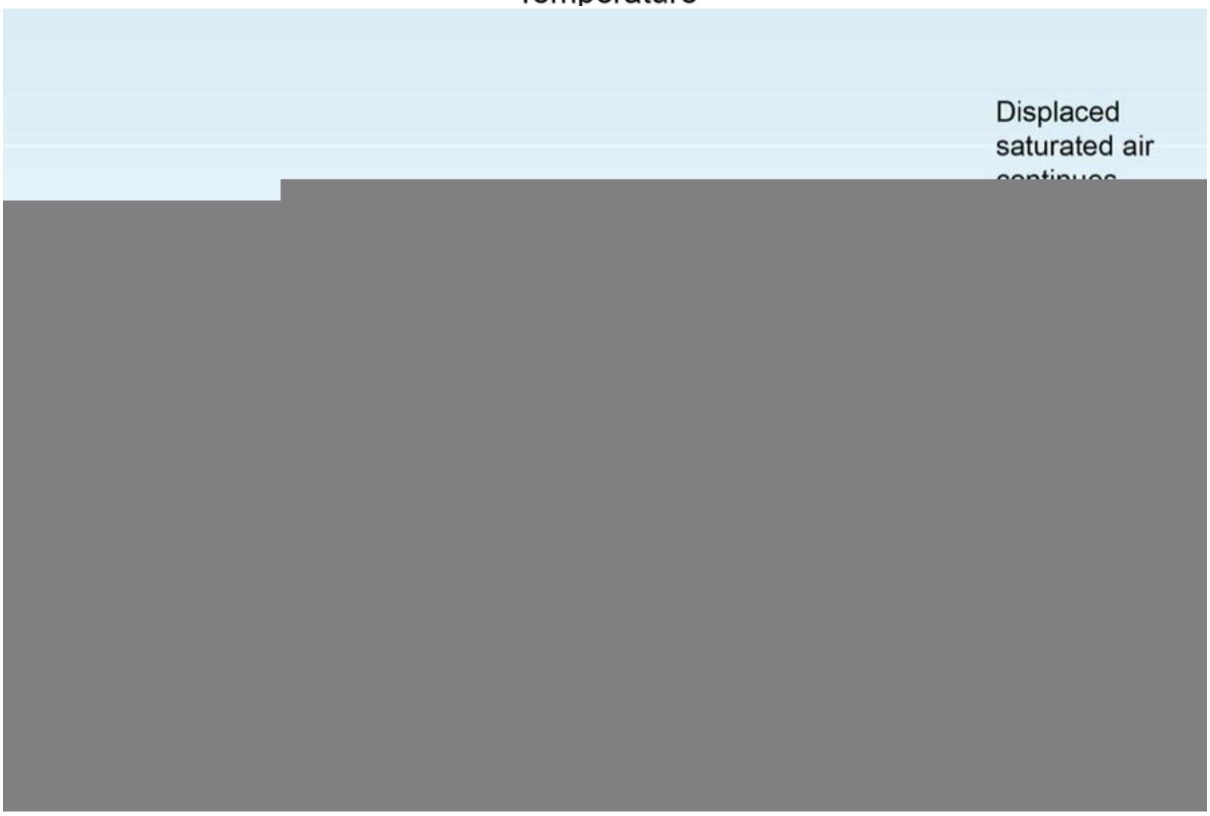
Weather in absolutely unstable conditions:

- Strong rising air currents produce clouds with considerable vertical extent, cumuliform clouds
- Precipitation is likely to be intense, comprising large droplets of rain/hail; short intensive showers, as the clouds does not have much of a horizontal extent
- Visibility is good, during precipitation poor
- Moderate to severe local turbulences

The instability will normally stop at the tropopause

Conditional Instability is when the air is either stable or unstable depending on whether or not it is saturated/dry



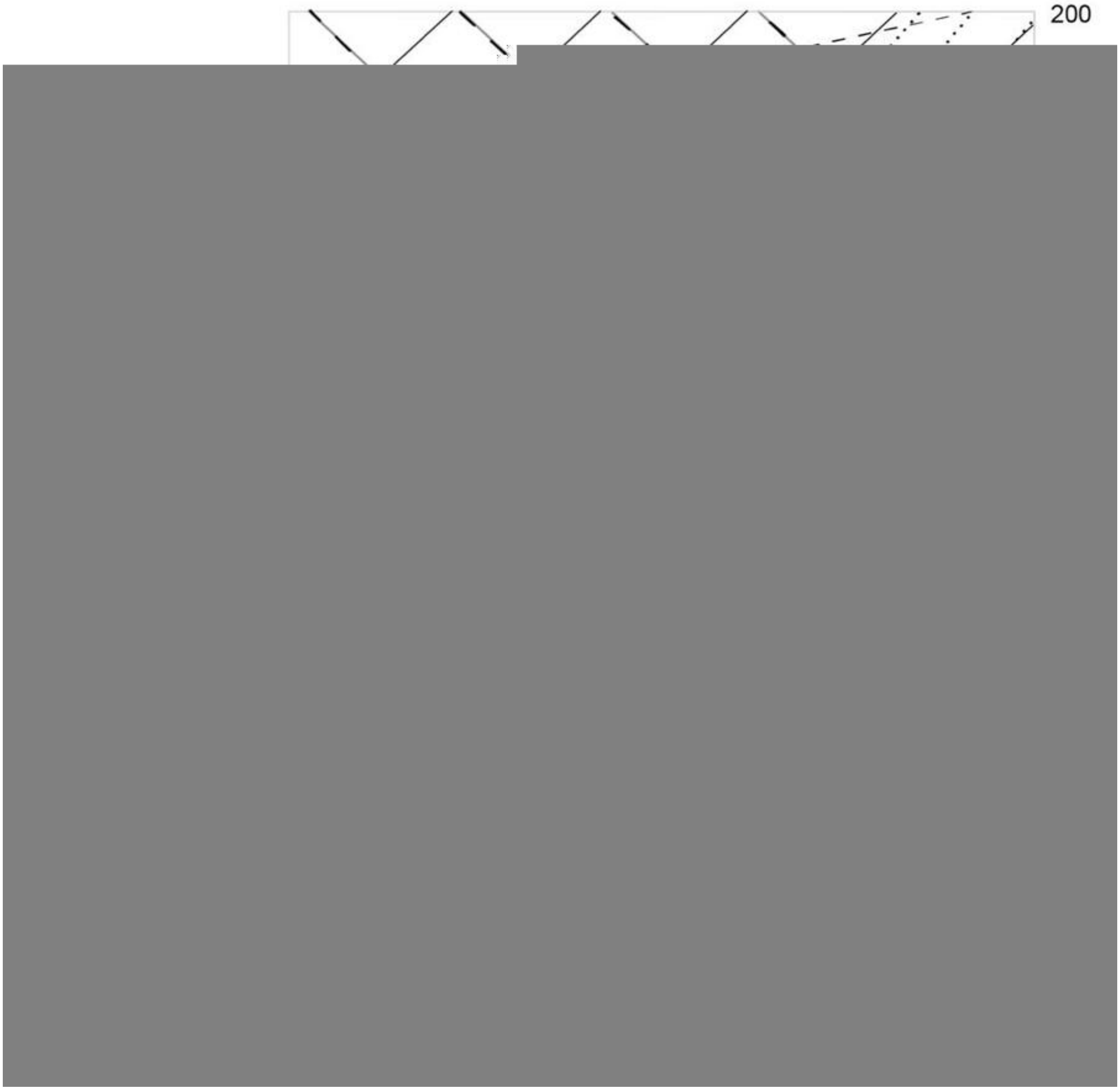


During conditional instability saturate air is unstable

Neutral stability is the tendency of a displaced parcel of air to remain in its displaced position when the initial disturbing force is removed; this can only occur in 2 situations:

- When the ELR is equal to DALR and the disturbed air is dry
- When the ELR is equal to the SALR and the disturbed air is saturated

A **Tephigram** is a thermodynamic diagram designed to aid in the interpretation of the temperature and humidity structure of the ATM



This can be used for:

- Finding the liquid water content and RH of the air
- Finding the convective cloud bases and tops
- Identifying layer cloud
- Identifying the wet-bulb potential temperature
- Forecasting the temperature at which radiation fog could form

CH 9
Turbulence and windshear

Turbulence describes disrupted air whose sudden change in velocity cause air to move abruptly

- Generally only disrupts the attitude of the aircraft not the altitude

It's often better to let the aircraft to be disrupted than to try and fight it

Windshear is a more serious phenomena causing disruptions in both attitude and altitude

- Requires substantial urgent control
- Many modern transport aircraft are fitted with windshear alert systems

It's mandatory to make reports when encountering moderate or severe turbulence and windshear to ATS. High level, FL150 and above, turbulence should be accordingly to this table:

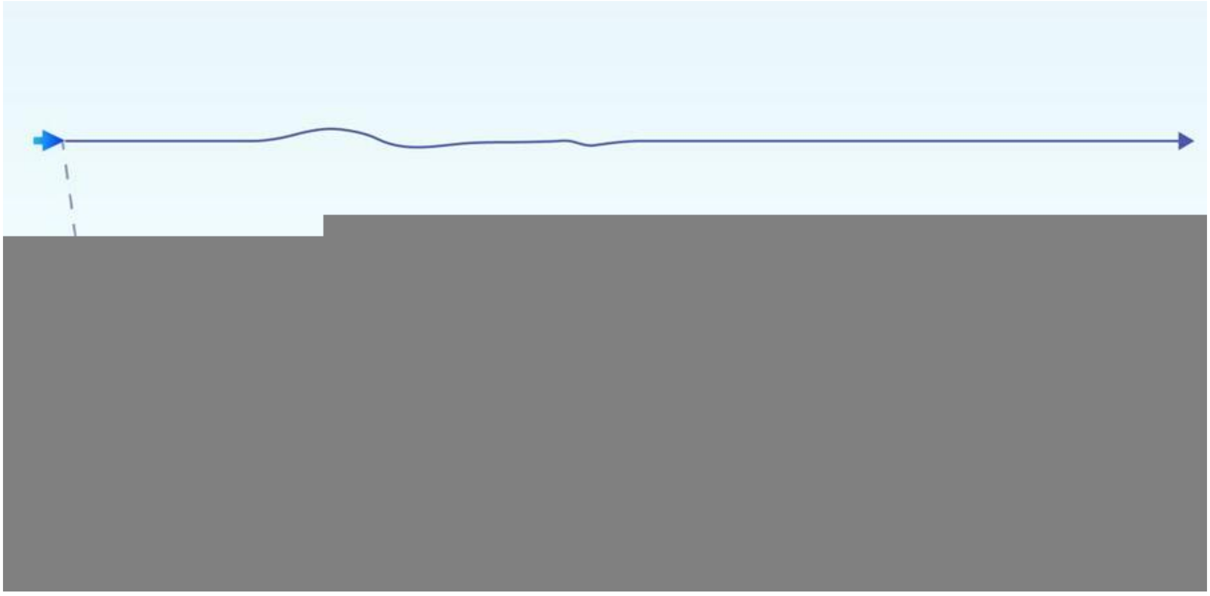
	Aircraft			In aircraft	
Intensity	a/c IAS	g-force	Other	Occupant feel	Service feel
Light	±5-15kts	<0.5g	Momentary change in attitude/altitude	Slight strain against seat	Food service with little or no difficulty
Moderate	±15-25kts	0.5-1.0g	Same as light and still able to have positive control	Definite strain against seat	Service and walking is difficult
Severe	>25kts	>1.0g	Can be momentarily out of control	Forced violently against seat	Service and walking is impossible

It's very difficult to forecast turbulence and even then somewhat unreliable; this is the reason for special air reports, must be heeded

There are 2 types of turbulence:

- Mechanical/frictional turbulence:
  - Caused by physical obstructions like mountains
- Thermal turbulence:
  - Caused either by rising air or, in and around cloud formations

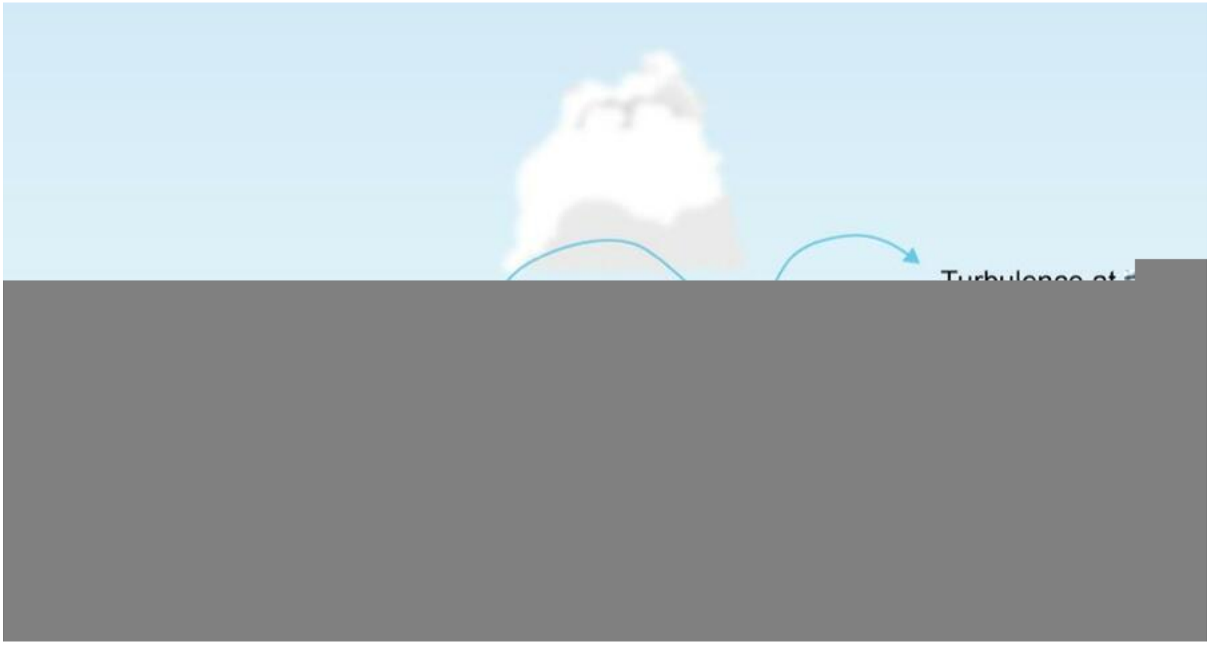
Mechanical turbulence; air flowing over the earth surface encounters an obstruction, at moderate or severe speeds, >15kts, as it flows over the top and unable to sustain smooth flow causing the streamlined flow to become turbulent



Any object that protrudes into the airflow will cause turbulence

The more uneven the surface and the stronger the wind, the deeper and stronger the turbulent layer. (more turbulent flow around than laminar flow)

Thermal turbulence; rising air obstructs the horizontal movement of air→ turbulence at and downwind of the thermal



Thermal turbulence can be indicated by cumulus clouds; within and especially underneath such clouds moderate to severe turbulence can be expected

The friction layer and low-level turbulence

Most low-level turbulence is caused by the interactions between the wind and the earth's surface

- The greater the thermal activity and the mechanical disturbance the higher the thicker the friction layer
- Surface friction slows the surface winds→ change of wind direction→ mild windshear

On hot days and an uneven surface the friction level is about 1 km above the surface

Mountain waves; are turbulent undulating, up and down, waves of air which can form above and downwind of a mountain range

- Also called standing waves or lee waves
- Can extend 50 – 100 nm downwind, and all the way up to the tropopause
- Can be visually identified by the presence of lenticular clouds, "pringles clouds"
- just like the waves at sea, the crest can break

the vertical movement of the air within the waves can exceed 2000 ft per minute

The conditions which lead to mountain waves are:

- wind speed at mountain must be at least 15-20kts and increasing with height
- wind direction must be perpendicular to the range of the mountains ± 30°
- there must be a region of marked stability
    - isothermal or preferably inversion layer by the top with less stable air above and below
        - Fueling from below and maintaining above

At high levels undulations are gentle with increasing severity towards closer to the surface; the most severe turbulence occurs in the rotor zone, first rotor at the crest, often marked by roll clouds

Most low-level and mechanical turbulence can be avoided by flying a higher at a higher level and/or flying upwind of the obvious influencing topography

- Lenticular clouds may have ragged edges which may indicate breaking waves→ avoid
- Cap clouds are also indicators of standing wave activity
    - Exceptionally forming on the windward side of the mountain

If you find yourself in areas of mountain wave activity, cross mountain range at 90° and as high as possible, no less than height of ridge plus its elevation DON'T fly parallel or downwind

Windshear; is a large change in wind direction and/or speed including up and downdrafts

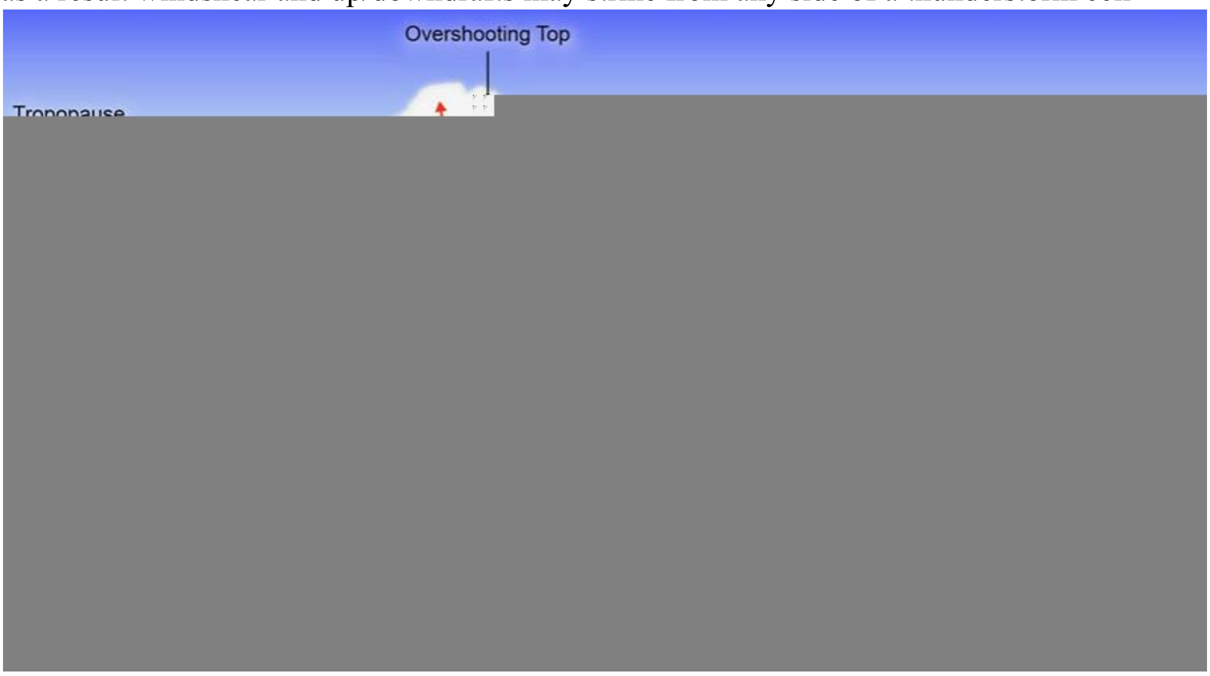
- Low altitude windshear
    - Along the final approach path, runway and take-off and initial climb-out flight path
- Vertical windshear
    - Change of horizontal wind vectors with height
    - Typically measured by 2 or more anemometers at different heights in kts per 100ft
- Horizontal windshear
    - Change of horizontal wind vectors with horizontal distance
    - Typically measured in kts per 1000ft
- Up/downdraft shear
    - The changes in the vertical component of wind vector with horizontal distance
        - Can reach up to 10 000ft per minute in thunderstorms

The only SURE countermeasure against windshear is to avoid it

The most dangerous windshear is **caused by thunderstorms**, CB clouds, but can also be caused by:

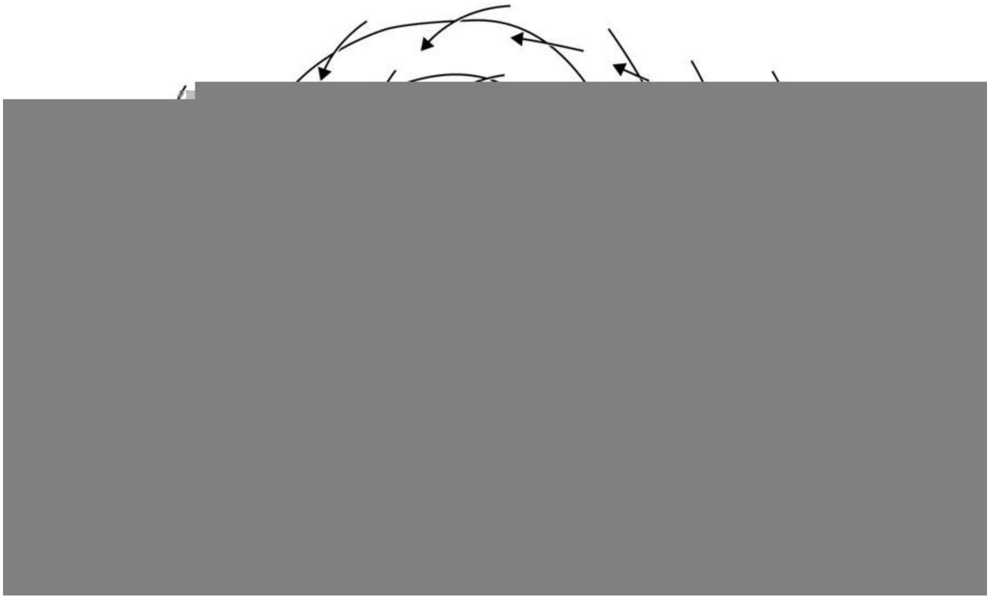
- **a passage of a front**
- **a strong temperature inversion**
- **a strong low-level wind**
- **a turbulent boundary layer**
- **even terrain and buildings if the winds are strong**

Thunderstorms are always associated with severe turbulence, hail, windshear and lightning, as a result windshear and up/downdrafts may strike from any side of a thunderstorm cell



Frontal passage; weather fronts are the boundaries between different air masses, often associated with changes in wind direction.

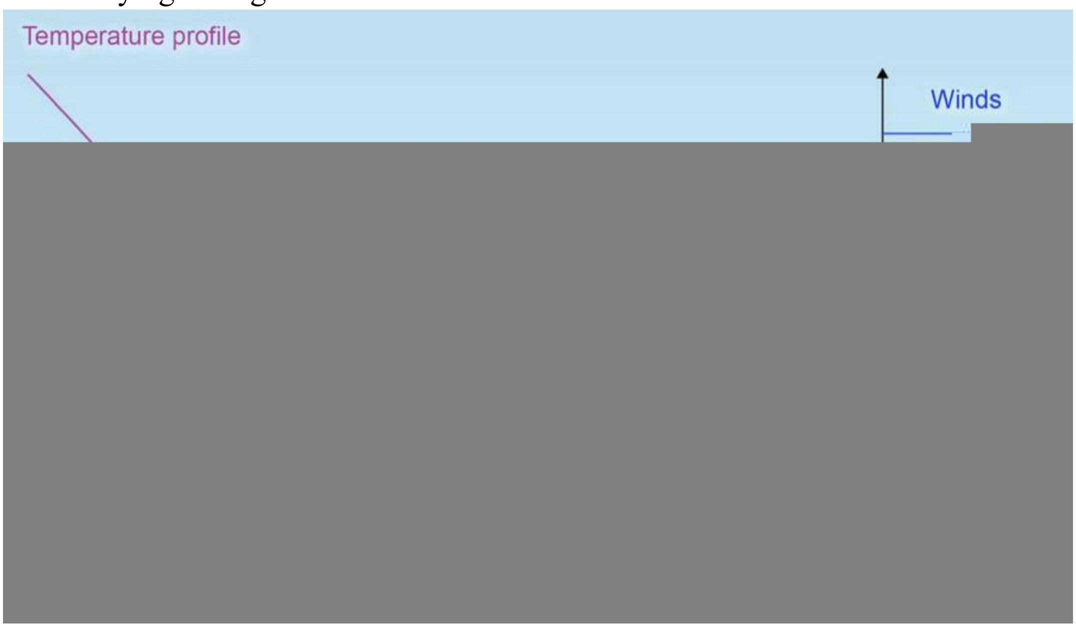
Well developed, narrow surface frontal zones, large temperature differences, are likely to carry a risk of windshear. Illustrated by picture below:



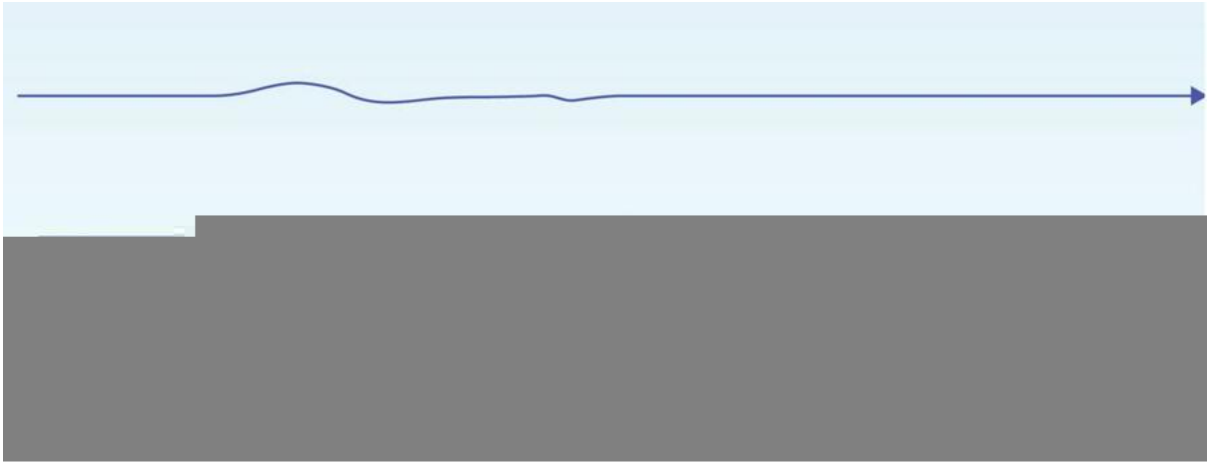
Also beware of:
- temperature differences ≥5°C across the frontal zone
- frontal movements >30kts

a vigorous cold front has a more rapid onset than a warm front, expect the windshear zone juts behind the surface position of the front

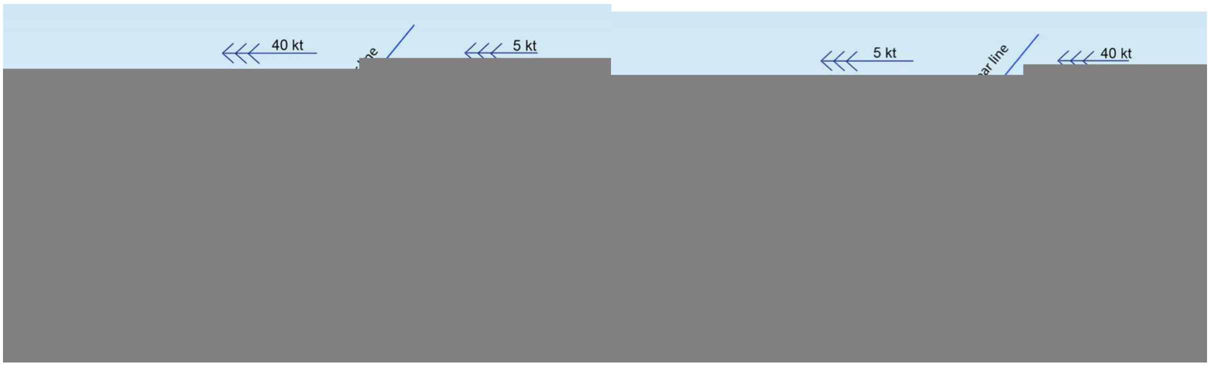
Inversions; when temperature changes by >10°C between the surface and 1000ft, MTI, marked temperature inversion warning is issued, as they are commonly associated with windshear
Visually identifiable, as the inversion tarps pollutants beneath it. Turbulence is often also encountered flying through it



Topographical windshear
Natural or artificial can affect the steady-state wind flow and cause windshear of varying severity



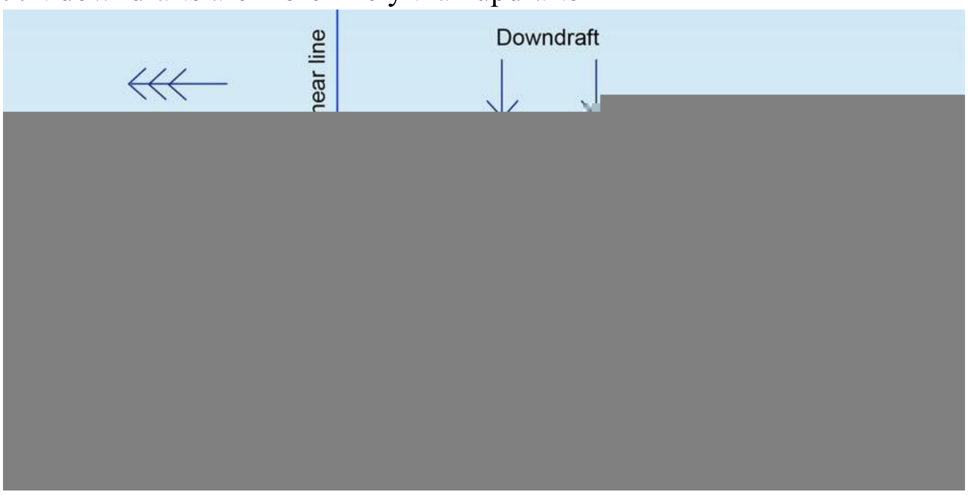
The effect of windshear of aircraft in flight is highly dependent on its design, mass and phase of flight. In a windshear encounter it's not only the magnitude of the wind vector change but also the onset rate



A significant vertical current of air changes the angle of the airflow approaching the wing, this has 2 effects:

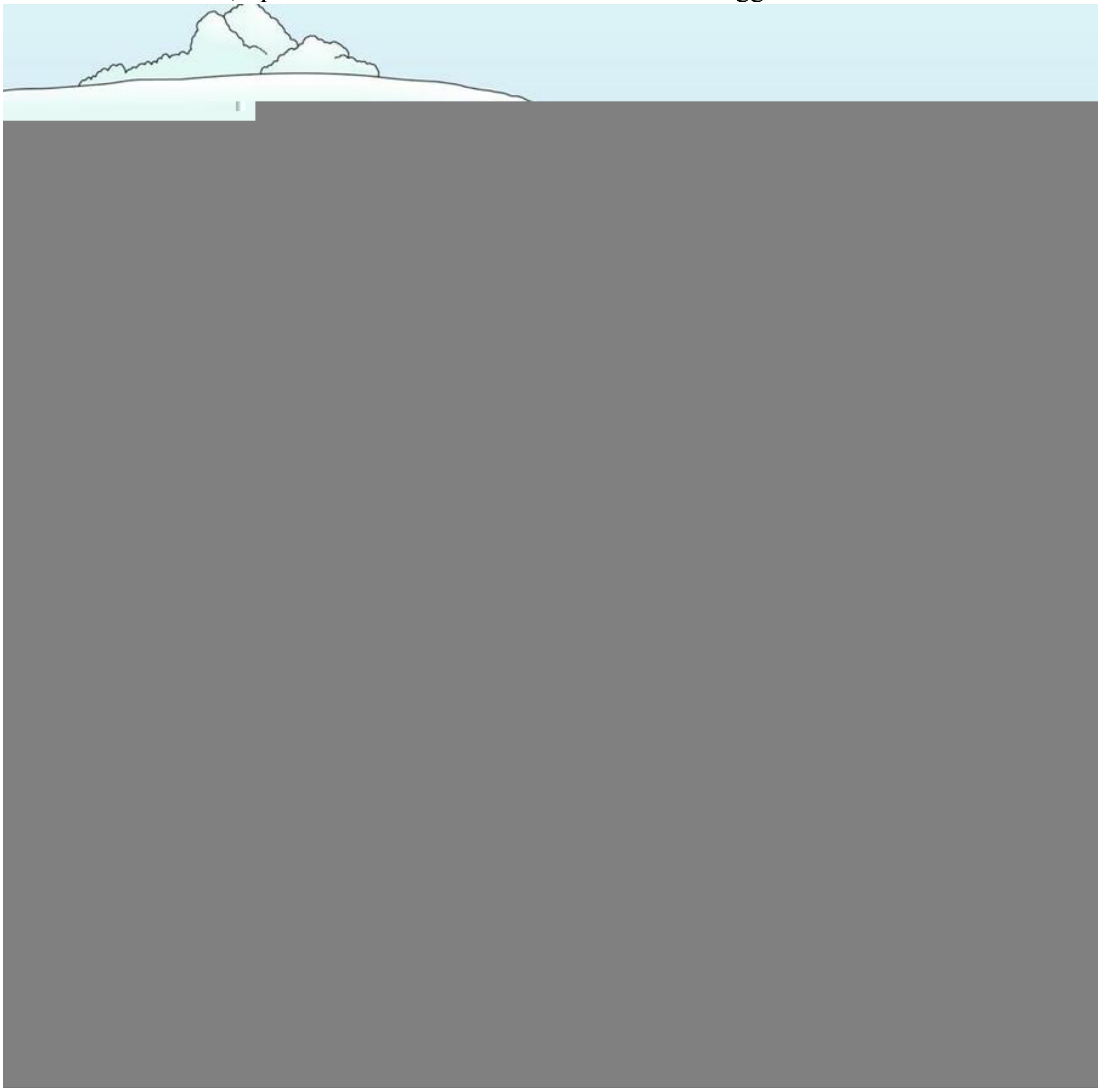
- airspeed change
- angle of attack change

below 1000ft downdrafts are more likely than updrafts



As the downdraft impact the ground, the air is forced outwards in all directions and also curls backwards this results in extremely severe winds close to the surface of the ground.
Depending on the size and duration, downdrafts are either called microbursts or macrobursts

- **microbursts**; 5min or less and usually less than 4km in diameter
- macrobursts; up to 20 min or more and affect an area bigger than 4km in diameter



When dry air mixes with precipitation in a thundercloud it causes the weather droplets to evaporate → rapid drop in temperature due to latent heat absorption→ starts to sink gaining momentum as it sinks → spreads out

The cool, dry air can further get pulled down by the sheer weight of precipitation; water loading; known as a microburst

Microbursts are exceedingly dangerous at low levels

Countermeasures: don't enter

Encountering a microburst:

A. abrupt energy gain, sudden increase in headwind, rate of descent reduced or reversed
B. abrupt energy loss, sudden decrease in headwind, increase in rate of descent
C. energy loss, increasing tailwind, airspeed still falling

Turbulence in jet streams
Jet streams are very long narrow bands of fast moving air which can occur just beneath the tropopause. The shear lines are created when there is a marked change in wind velocity

- the highest change of speed occurs on the side of the jet stream adjacent to the cold air, this is where the clear air turbulence is
  - clear air turbulence has no visual warning signs
- areas of forecast CAT are shown on the significant weather chart

Turbulence in jet streams is most severe:

- with stronger winds
- with curved jet streams
- above, and to the lee of very high mountain ranges
- in the primary area for maximum CAT
- with developing and fast moving jets

if you encounter CAT at high altitudes due to jet streams, descend and move to the warmer side of the jet stream

Windshear countermeasures:

- during approach, if such has to be made, increase the approach speed

to counter loss of airspeed close to the ground:

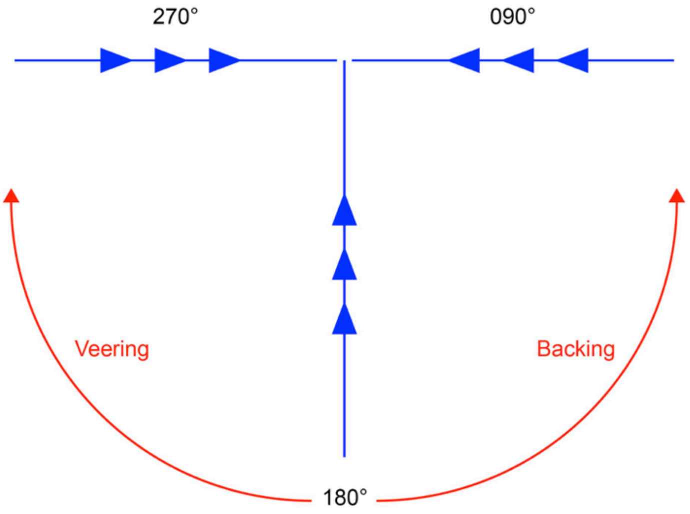
- briskly increase power
- raise the nose to check descent
- coordinate power and pitch
- prepare to carry out missed approach rather than a risky landing

CH 10
Low-level winds

Wind is the sustained horizontal movement of air

Wind velocity describes direction AND magnitude
- a wind direction of 270° is a westerly wind, coming from the west
  - aviation weather is usually given to true north
  - reports describing aerodrome wind conditions, relative to magnetic north

when the wind changes direction clockwise it's said to be veering; backing anticlockwise



Describing changes in wind speed
- gust, sudden increase in wind speed, often with a change in direction, lasts for a few seconds and are very localised
- squall is similar to a gust but can last for some minutes and often a wider area
- Lull is a sudden decrease in wind speed; can change direction as well

Representing wind velocities on charts
- Using barb symbols

Measuring surface wind

- Defined as the wind measured at 10 meters agl
- Cup anemometer to get intensity
- Wind vane to get direction

Every meteorological reporting station and local air traffic unit are equipped with these devices

New technologies such as sonic anemometer and acoustic resonance anemometer provide more accurate measurements than the mechanical anemometer

Reporting surface winds, measurements are averages over a time period, except at take-off and landing, those are instantaneous measurements

- 2 min. for local routine and special reports and for wind displays in ATSU
- 10 min. for METAR and SPECI, except if during that time period there's a significant change in speed/direction
    - 5kt or more when local routine and special reports, when noise abatement procedures are applied
    - 10kt otherwise
- TAF, when the forecasted maximum speed, gust, is exceeded by 10kt, the forecasted maximum is indicated

Estimating wind speed

The pressure gradient force, PGF, is the force that acts from areas of high-pressure towards areas of low-pressure. The relationship between the isobar spacing, the PGF and the windspeed is set out on a geostrophic wind scale; hence changes with latitude

To measure the geostrophic wind speed:

- Measure perpendicular distance between 2 isobars
- Read off from the scale for the specific latitude

This is a good start but it does not account for the Coriolis effect…

Coriolis is the effect caused by the earth's rotation

- It affects objects free from the surface
    - Deflecting to the right in the n.hemisphere
    - To the left in the s.hemisphere

Since it appears to cause the wind to turn we can think of this as a force acting on the wind

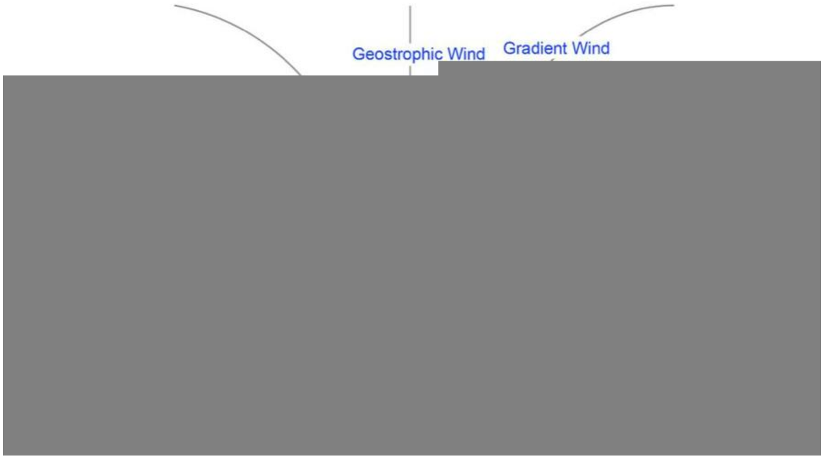
The effect of latitude on Coriolis

- No effect at the equator, maximum at the poles
    - Assume no effect ± 15°N/S of the equator

$$CF = 2\Omega\rho V\ sin\theta$$

Angular rotation of the earth, density, wind speed, latitude

The geostrophic wind model; explains wind behavior in terms of simple vector forces



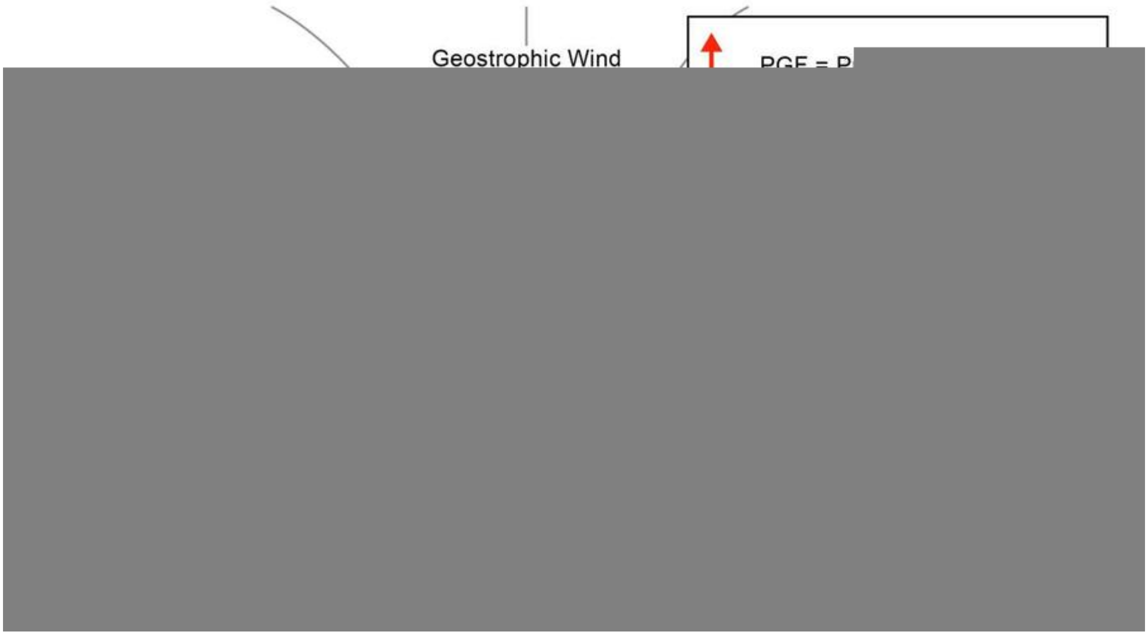
Assumptions made by the geostrophic wind model, this is the backbone for wind speed predictions

- Model only blows above the friction layer; not accounting for surface friction
- It blows parallel to straight isobars

Assuming 2 forces:

- PGF
- CF

These 2 forces act opposite from each other and are in balance, not applicable ±15°N/S of the equator



Stage 1. When a pressure gradient exist, it starts to accelerate air towards the low pressure, they are slow and therefore Coriolis effect weak

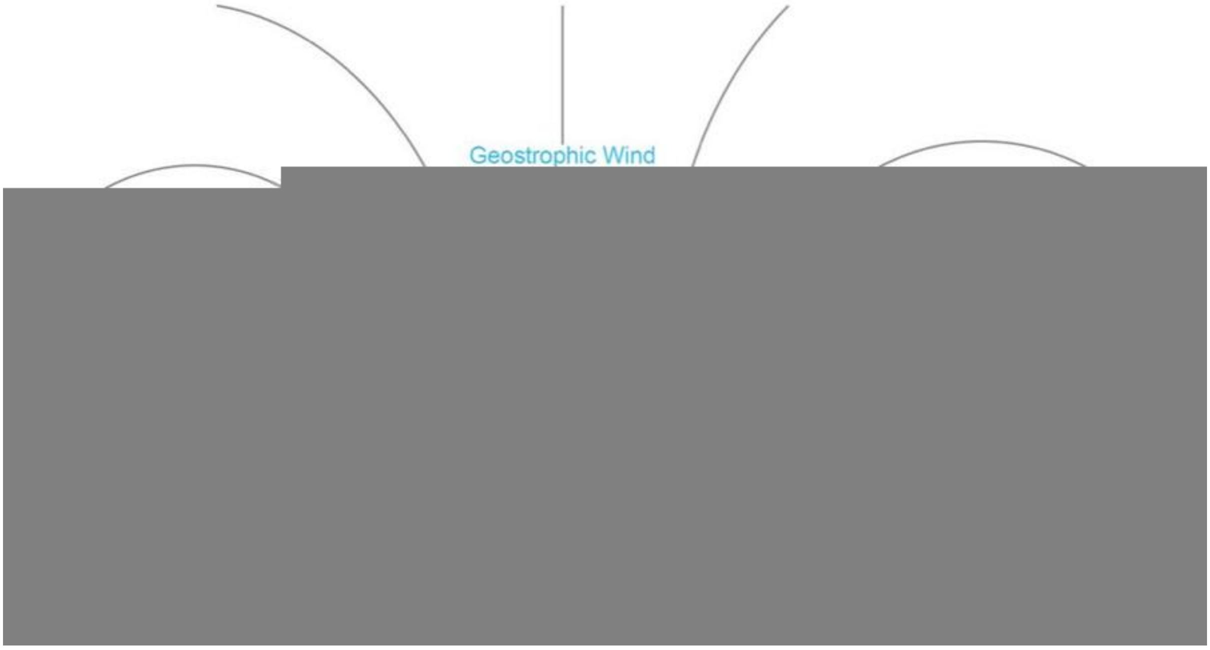
Stage 2. The air particles have gained some more speed as the PGF is still the bigger force, Coriolis also increases → deflecting the particles further to the right

Stage 3. Eventually the forces balance out stopping further acceleration or deflection to the right, n.hemisphere. the wind ends up blowing parallel to the straight isobars

The gradient wind model, same as the geostrophic except it takes account of turning air flow.

- Assuming the additional centrifugal force, acting outwards from the rotating body

For a particular PGF the gradient wind speed increases as latitude decreases



When air moves around a depression, the centrifugal force opposes the PGF, it therefore reduces the wind speed, this reaction also causes a reduction in Coriolis force

The gradient speed around a depression is less than the geostrophic wind for the same isobar interval

Around an anticyclone the centrifugal force acts in the same direction as the PGF → wind speed increases

In theory the gradient wind in the anticyclone is greater than in the depression but in practice depressions have more tightly spaced isobars and therefore have a much higher PGF than anticyclones

The surface wind model

the wind that occur in the friction layer

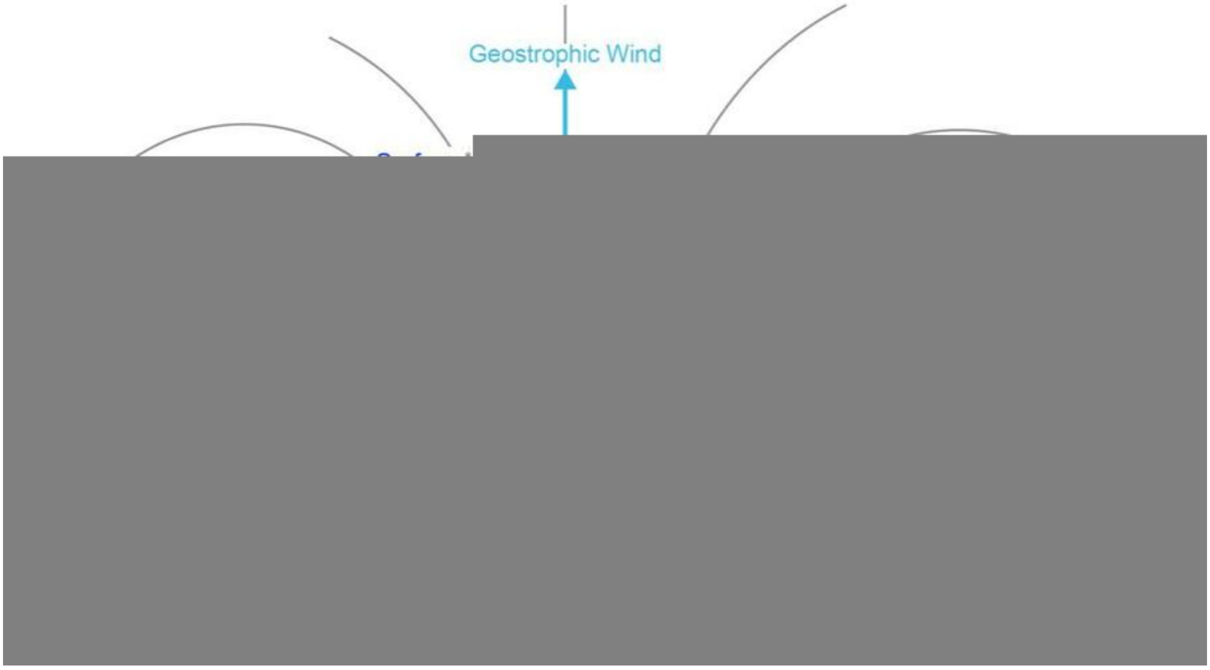
Again we will build on the geostrophic model assuming:

- The surface wind in the friction layer, height less than 1000m, stronger closer to the surface
- The wind blows across the isobars towards the low pressure

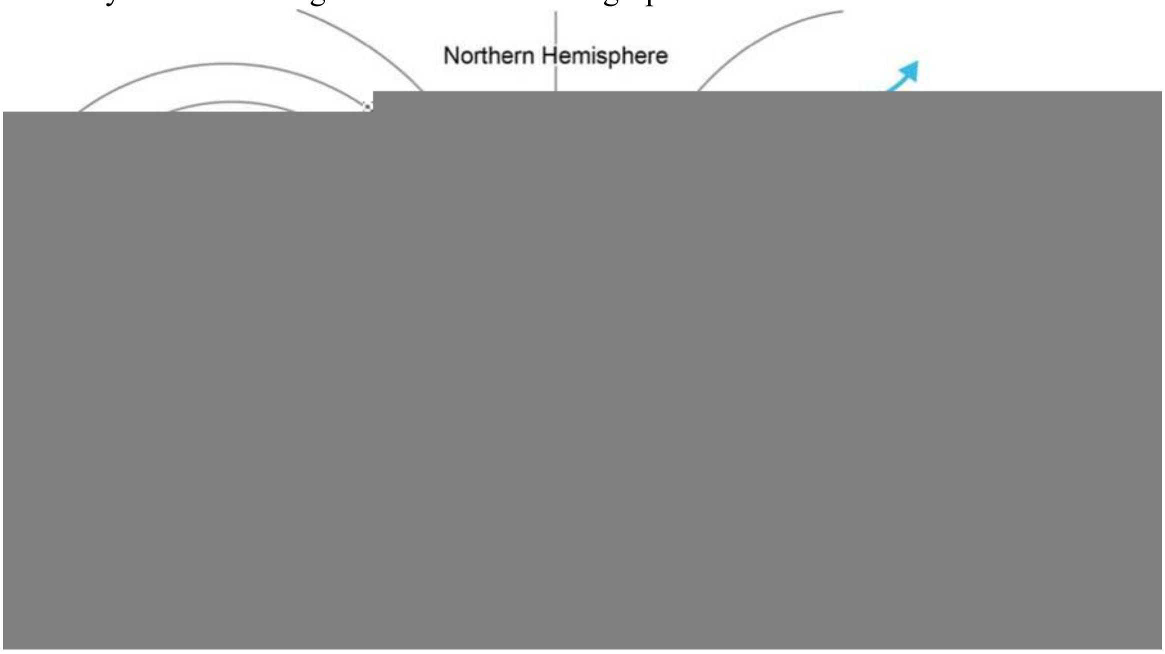
3 forces are considered:

- PGF
- CF
- Friction force

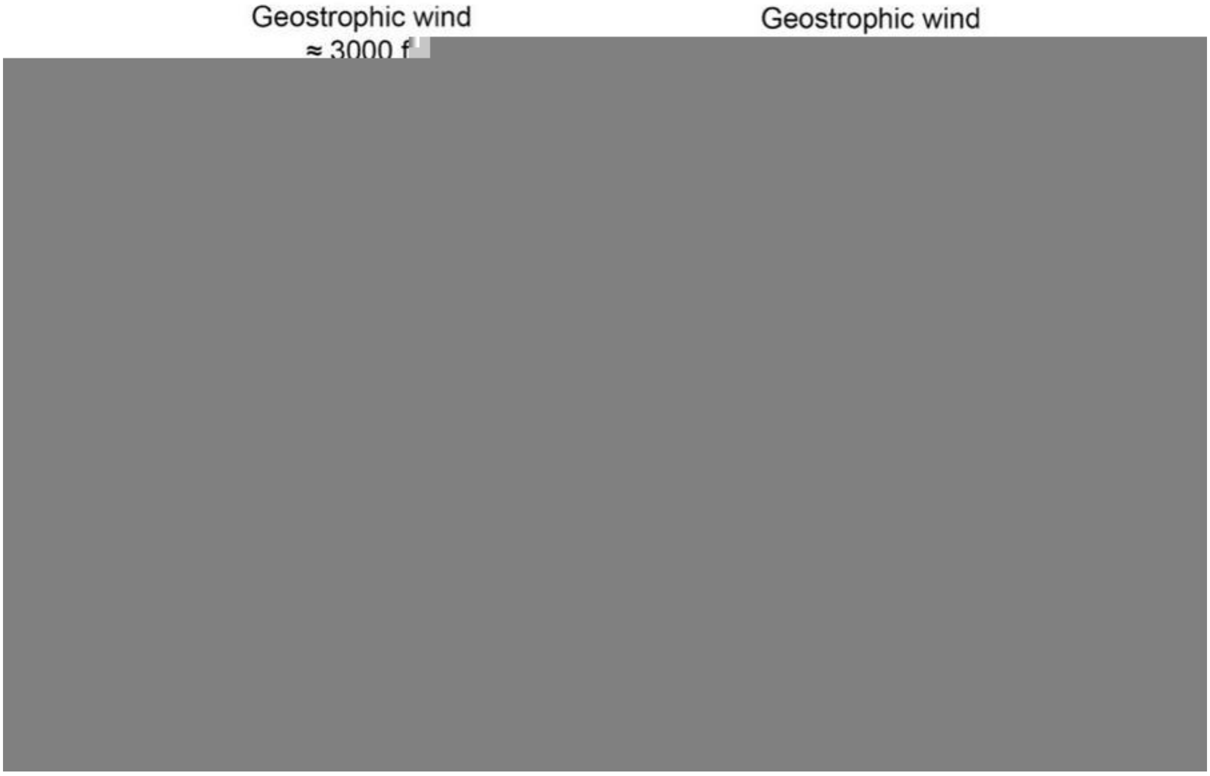
For a particular PGF, the surface wind speed increases as latitude decreases



The surface airflow in a low-pressure system converges at the surface towards the low-pressure system and diverges outwards from a high-pressure

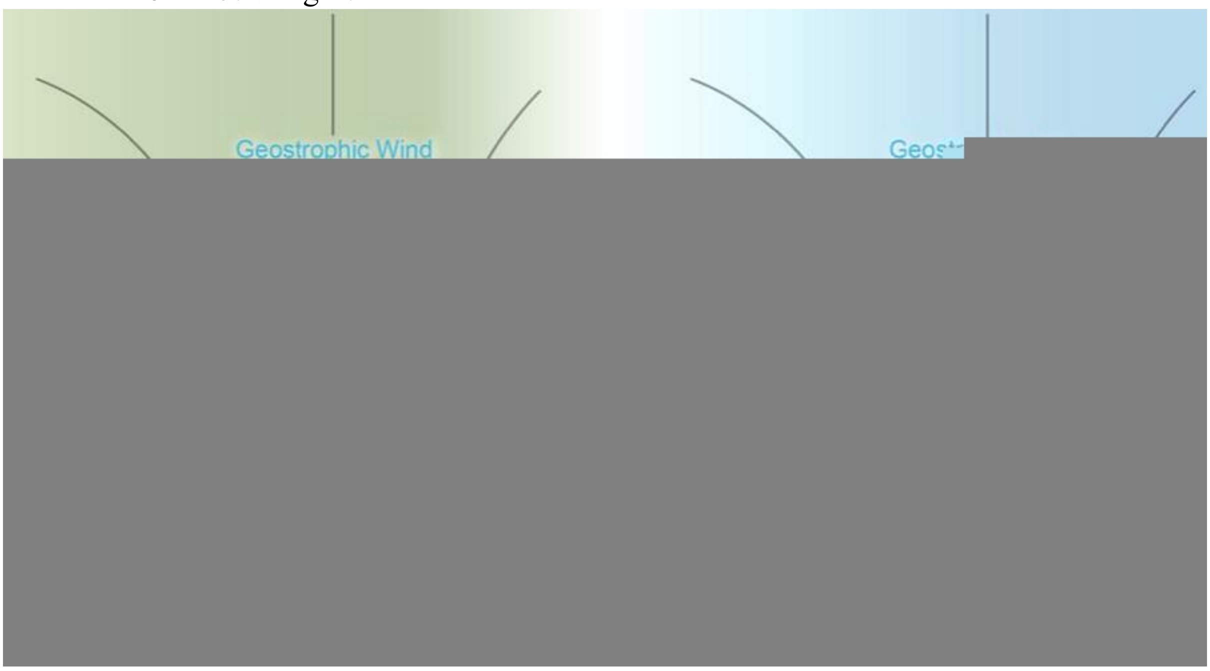


A simplified version can be seen below:



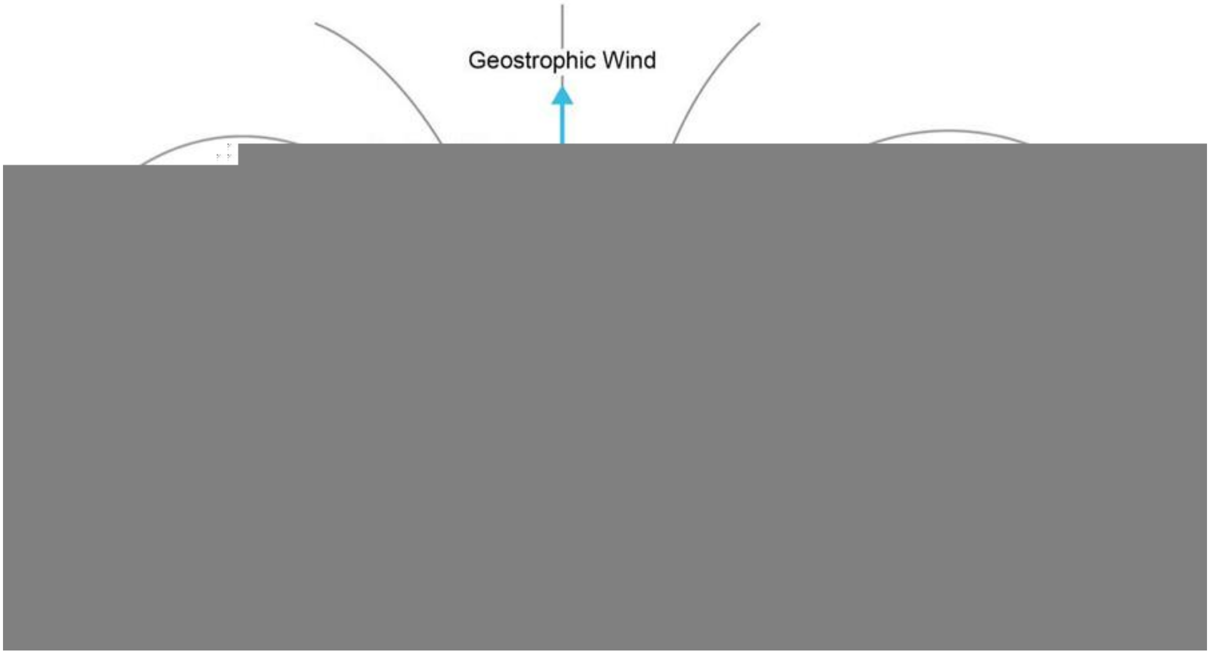
The amount of surface friction varies depending on the underlying terrain

- Over land, 50% of the geostrophic wind speed, this leads to CF also reducing by 50% →change in direction
    - The wind deviates from the geostrophic by as much as 30°
- Over sea it's about 70% of the geostrophic wind
    - Deviating 10°



Diurnal variation of the surface wind
Is the earth surface warms up, the normal flow of air is distributed by rising thermal currents, mixing takes place→ the average surface wind is higher during the day than the night

The stronger surface wind during the day means a stronger CF and therefore less deviation from the geostrophic wind

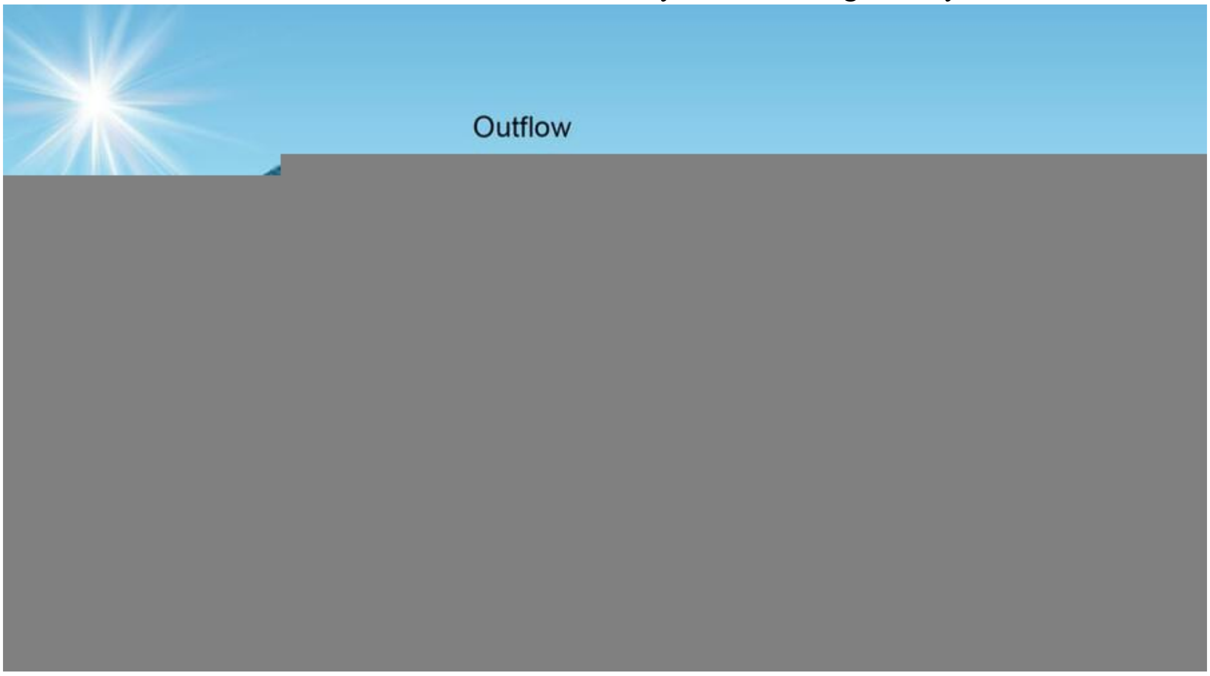


Land and sea breezes mainly occur around the coastal areas where there's a slack pressure gradient, or when there's no major pressure system influencing the coastal region

On a warm day with few clouds the sun quickly heats the land, but not the sea

- air is heated by conduction
- When rising air reaches about 1000ft its vertical movement slows and the flow diverge
- The portion of the diverging air which travels over sea, slowly cools down causing it to sink

This is the mechanism that cause sea breezes. It only occurs during the day



Rising air over land can lead to vertical cloud formation, they can often develop into thunderstorms

Land breezes occur during the night and are generally weaker

- During the night the land cools down more rapidly, while the sea remains fairly constant

Mountain and valley winds, some are so common they are given local names

Anabatic winds, winds which flow upsloping terrain, caused by daytime heating of the mountain slopes.
On slopes facing the sun the temperature of the surface rises rapidly after sunrise, air in contact warms by conduction → warming less dense air→ flows upsides the slope

Frequently the rising air condenses to form cumuliform clouds

These valley winds only develop in the mid to late afternoon

Katabatic winds, winds flowing downslope terrain. At night the surfaces of the mountain slopes cool. Colder and denser air starts pooling at the centre of the valley floor.

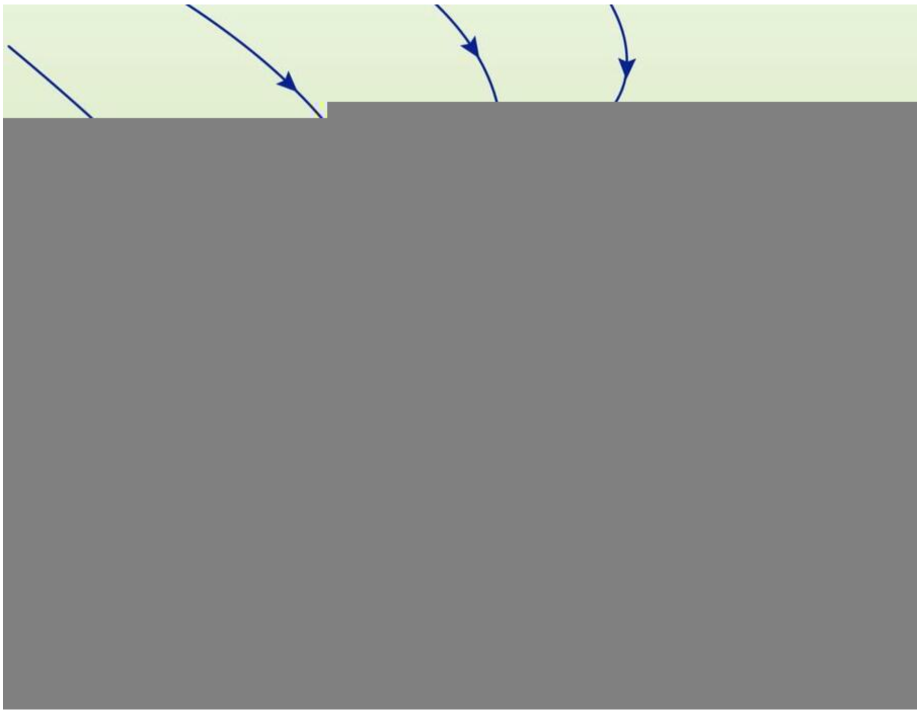
- If it falls below its dew point, valley fog forms
- Warmer air left at higher levels, causing temperature inversions

Over antarctica, extensive cold katabatic winds persist. Winds slip off large elevated ice masses and push towards the sea with huge energy. They are deflected by CF to form polar easterlies

The mistral, well known for being strong, relatively cold wind. Driven by high-pressure over NW Europe

- In the winter the air is cold and dry
- Wind can come from 2 different directions
    - Acts as a natural venturi, amplifying the wind speeds
- The mistral can extend up to the tropopause
- The NW version usually causes a period of cloudless skies, clearing any weather in a matter of hours

Further to the west lies a similar one called Tramontara



The Bora, is a cold area with strong NE winds found along the coastlines east of the Adriatic

- Strongest in the winter but can strike anytime
- It forms when an area of high pressure sits over the cold central European land masses while low pressure develops over the warmer Adriatic sea

This forces the cold dense air, which has accumulated in the basin to topple over and run down through the valley

Foehn/Föhn winds, is a local warm and dry wind which blows on the downwind, leeward, side of the mountain

When moist air is forced to rise up a mountain side, it cools adiabatically as it rises and quickly becomes saturated
After reaching the condensation level, cloud and precipitation forms; the air continues to rise but SALR to the top of the mountain; as it rises some of its moisture is deposited on the slope

If conditions are stable the flow will then sink on the lee side of the mountain. The saturated air warms up so quickly it becomes unsaturated→ the cloud base on the lee side is higher than on the windward side

On descent on the lee side the air warms at the DALR for much longer than it cooled at the DALR on the windward side→ much warmer and drier air blowing down the downwind side

With Föhn winds, expect cloud and rain on the upwind side, warm, dry clear skies on the downwind side

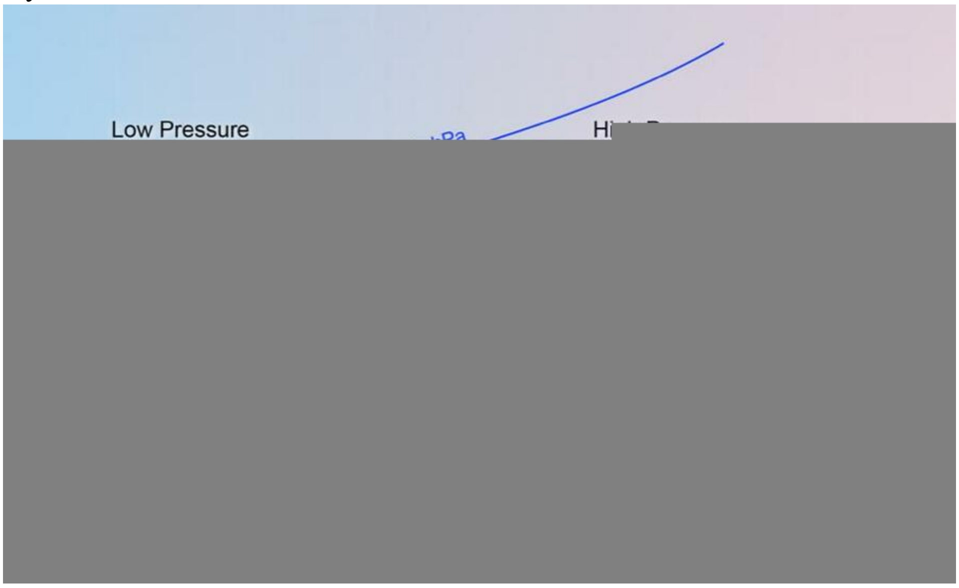
CH 11
Upper winds and the jet stream

The winds at higher levels, up until the tropopause, are generally much faster, this is because:

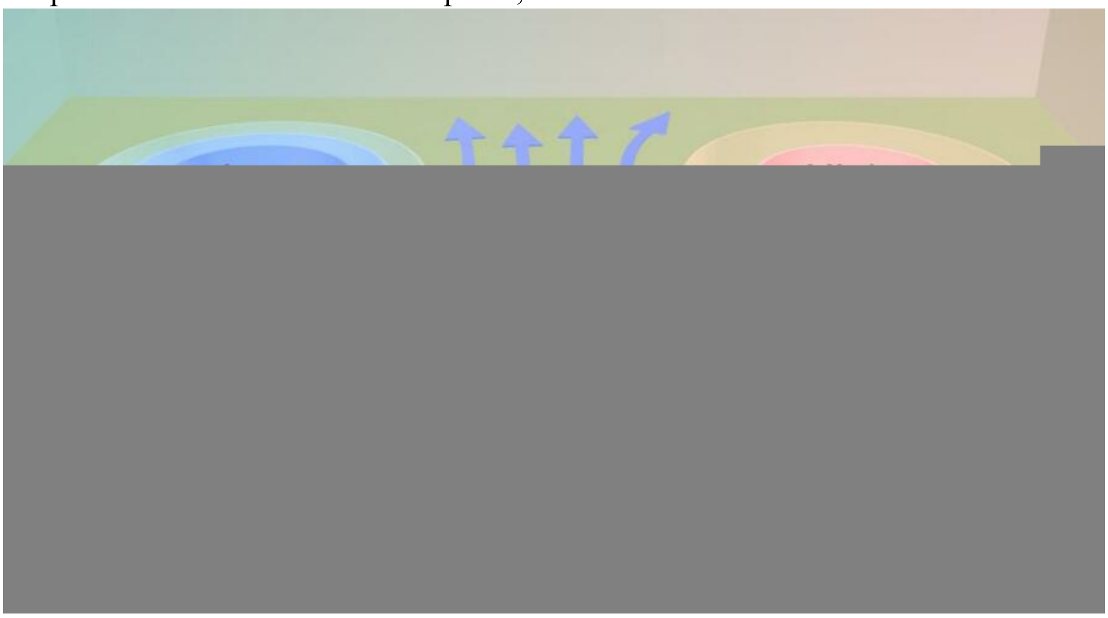
- The pressure difference between columns of different temperature air increases with altitude
- The reduction in air density increases the windspeed

The causes of pressure differences in the lower ATM are different from the causes of pressure differences in the upper ATM

The pressure differential produced by the temperature differential causes the air at height to flow initially from the warm column towards the cold column



Because of the Coriolis force the initial flow direction is deflected to the right in the n.hemisphere and to the left in s.hemisphere; this flow is known as the **thermal wind**



n.hemisphere; with your back to the upper wind, the cold air is to your left

contour and thickness charts, a way of displaying indirect measurements of the upper level conditions indirect measurements requires either thickness or constant pressure charts, these charts plot the height/thickness of pressure levels

- Usually given in decameters, dams

The **contour chart** below is showing the elevation of the 500hPa pressure level AMSL.

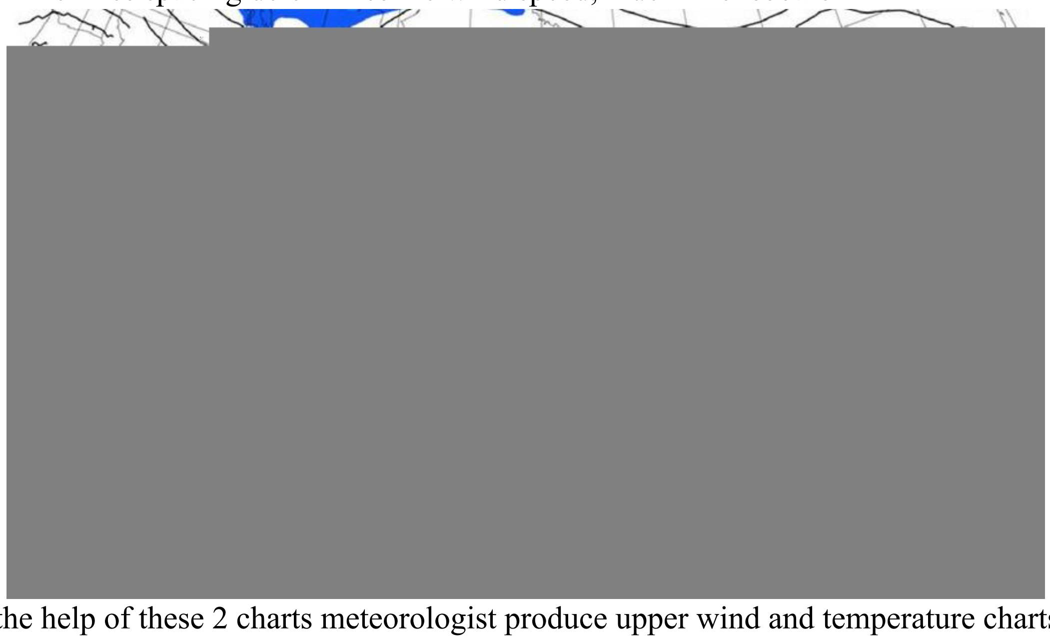
- Marked with yellow we see 518 dams, suggesting cold air at the surface and relatively low pressure at altitude.
- The bottom yellow marking shows 590 dams, warm air and relatively high pressure

A thickness chart plots the thickness between 2 pressure levels, also measured in dams

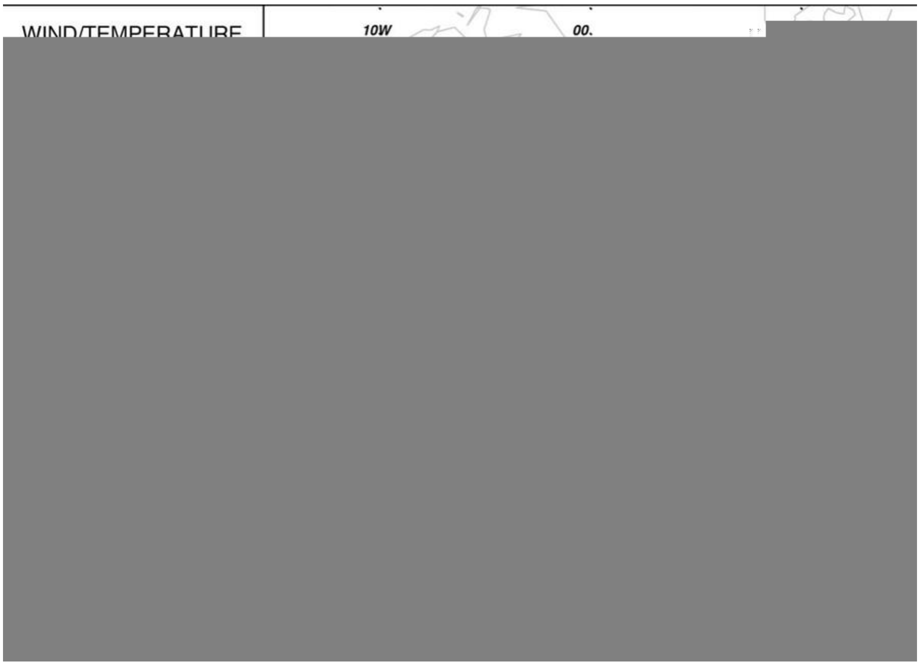
- Warm air forces the pressure levels further apart, increasing the thickness
    - This signifies high pressure

The image below shows lines of equal vertical spacing, between 200hPa and 850hPa level

- These lines are called isohypses or isopleths
- The lines spacing determines the wind speed, much like isobars



With the help of these 2 charts meteorologist produce upper wind and temperature charts for various altitudes

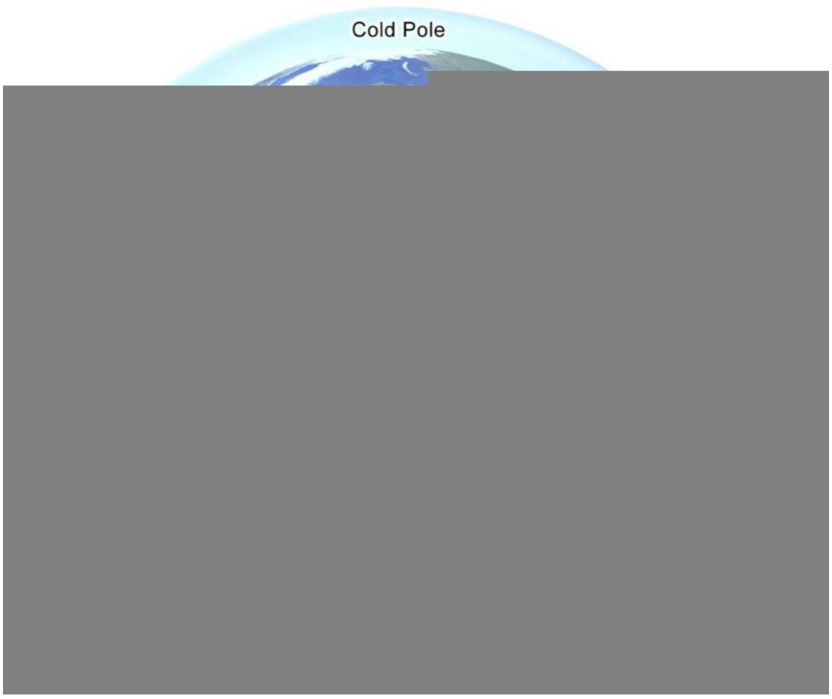


At this FL we expect temperature to be negative, hence the negative sign left out. In the case of a positive value a PS prefix would be added

The upper wind pattern is driven by temperature differences → around the earth we should expect to find the strongest winds at the boundaries between warm and cold air masses.

There is a relatively steady global pattern in the distribution of warm and cold air → stable global pattern of upper winds

In the northern hemisphere with your back to the upper wind, the cold air or low-pressure is to your left



→Air is colder at the poles than at the equator→ the general global upper wind pattern is westerly

- This can greatly benefit long-haul flight coming from the west*

Easterly flows; the n.hemisphere, June/summertime. the heat equator sits at latitude 23.5°N making this warmer than the equator; the temperature difference between the two creates an upper easterly wind

- With your back to upper wind the cooler equator is on your left and the heat equator on the right → easterly flow
- By December the heat equator is at 23.5°S

Generally around the equatorial regions, weather patterns are moved by the easterlies

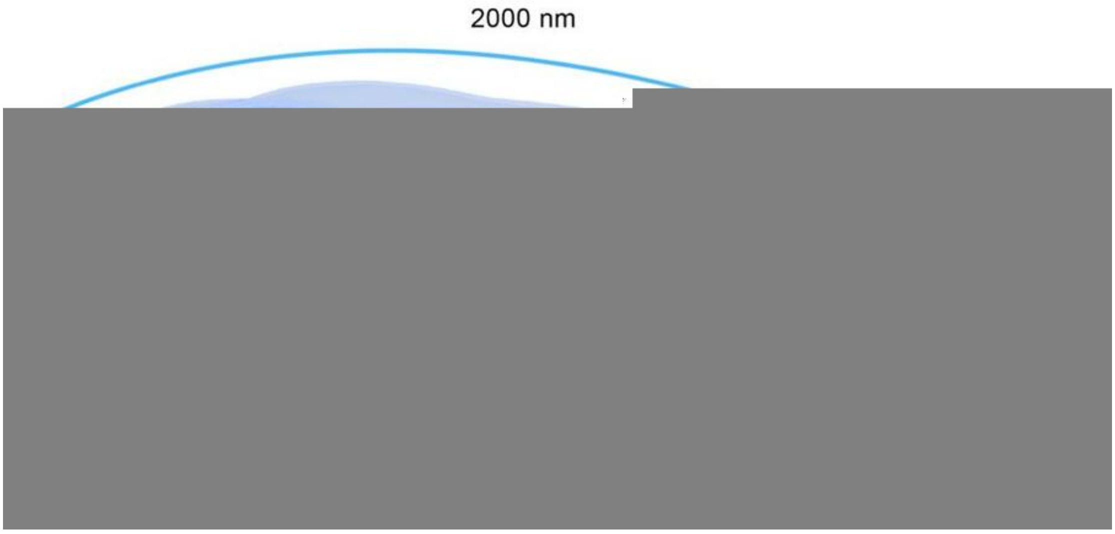
Because the temperature difference between the heat equator and the equator is not as great as the difference between the polar and temperate air→ upper easterlies are not as strong as the upper westerly flows

→ outside the equatorial regions the general weather tends to follow the westerlies

Jet streams

The upper wind pattern is driven by temperature differences. At the boundaries between hot and cold air, the temperature difference is large enough to generate high velocity winds, jet streams

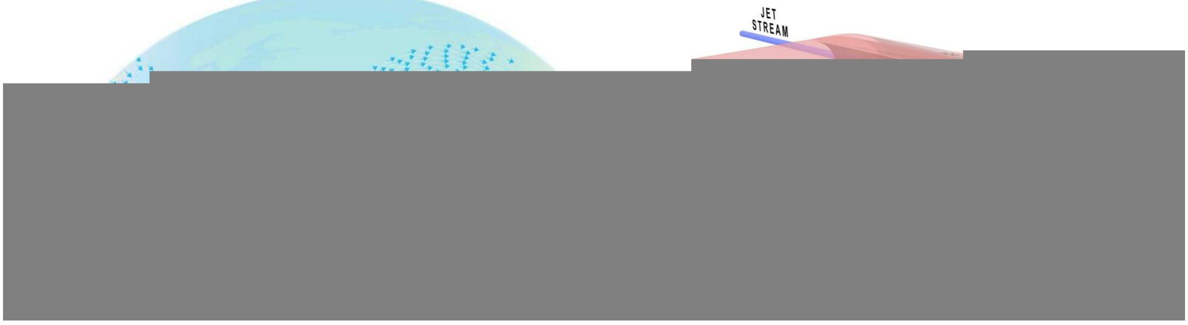
- Jet stream; a narrow band of airflow with a velocity greater than 60kt
- The most abrupt differences in temperature are found at the boundary between polar and tropical air, found in mid-latitudes
- The jet lies at the position of maximum pressure gradient



Jet streams can extend for hundreds or even thousands of miles but EASA approximates are shown above

This is a typical pattern of strong winds at the boundary of cold and warm air in the n.hemisphere

The jet stream is always located in the warm air



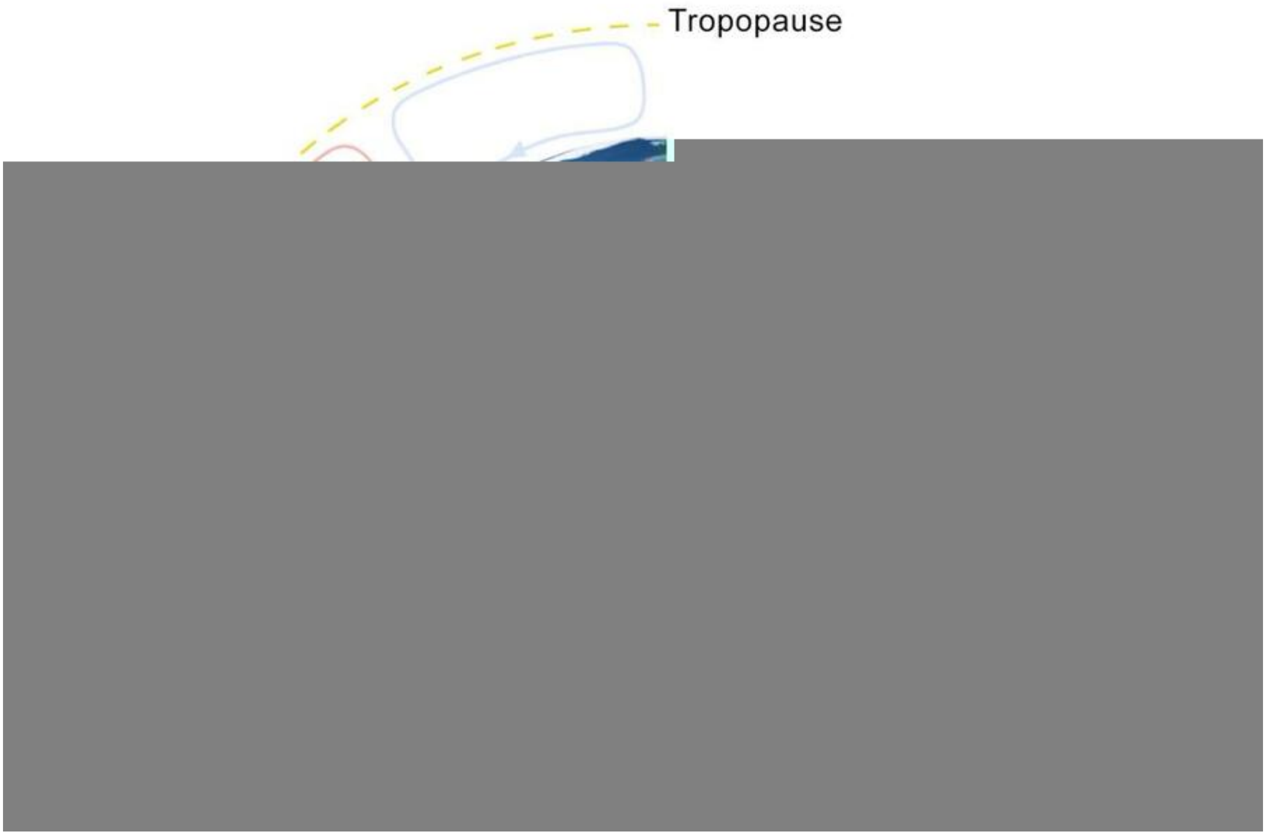
There are 4 notable jet streams:

- The sub-tropical jet stream
- The polar front jet stream
- The seasonal arctic front jet stream
- The seasonal tropical easterly jet stream

The movement of the heat equator can produce large changes in the shape of the temperature boundaries → large distortions in the paths of the jet streams

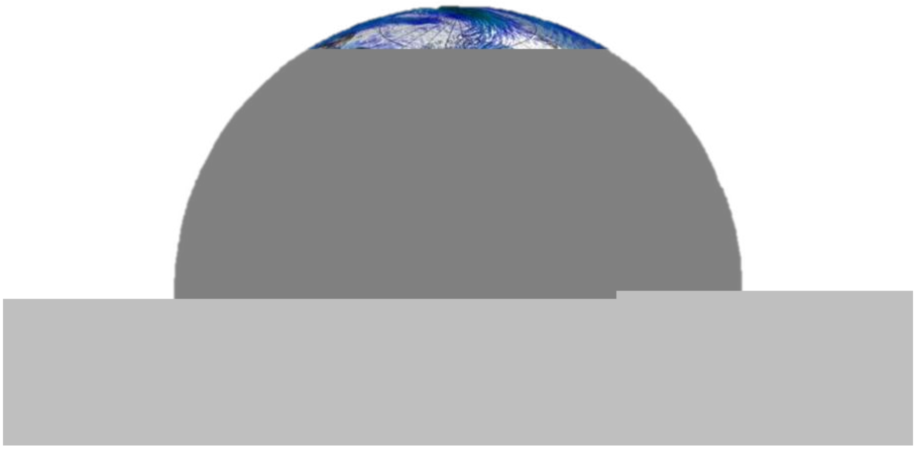
The sub-tropical jet streams are permanent and occur in both hemispheres

- Almost completely encircles the globe
- Created by temperature differences between global air circulation cells
    - At the boundary of Hadley and Ferrel cells
- In December the jet streams are found in the latitude bands 25° to 40°, in June 40° to 45° latitude
- The het core occurs at the 200hPa level
    - Lower in the winter, higher in the summer



The Polar front jet streams are permanent and occur in both hemispheres

- Created by the temperature difference between the warmer Ferrel cell and much colder Polar cell
- The thermal boundary on the surface between these air masses is called the polar front
- The polar front jet streams don't quite circumnavigate the globe, frequently start and stop, especially over land masses
- One of the recognizable features is the presence of streaky or streaked cirrus clouds
- Occurs between 40° and 60°N and 50°S
- Jet core is at 300hPa
- The jet streams become faster in winter



The arctic jet stream is a seasonal jet stream found only in the northern hemisphere, not even common

- Only forms in the winter in the north Atlantic ocean
- Typically positioned at around 60°N
- The core varies between 300hPa and 400hPa
- Driven by intense cold of the winter arctic compared with the relatively warmer polar air in the south

The tropical easterly jet stream is a seasonal jet found only in the northern hemisphere

- It occurs in the summer when sufficient temperature difference is reached between hot west African countries and their relatively cooler oceans to the south
- Typically found between 10° and 20°N only
- Occurs at about 150hPa

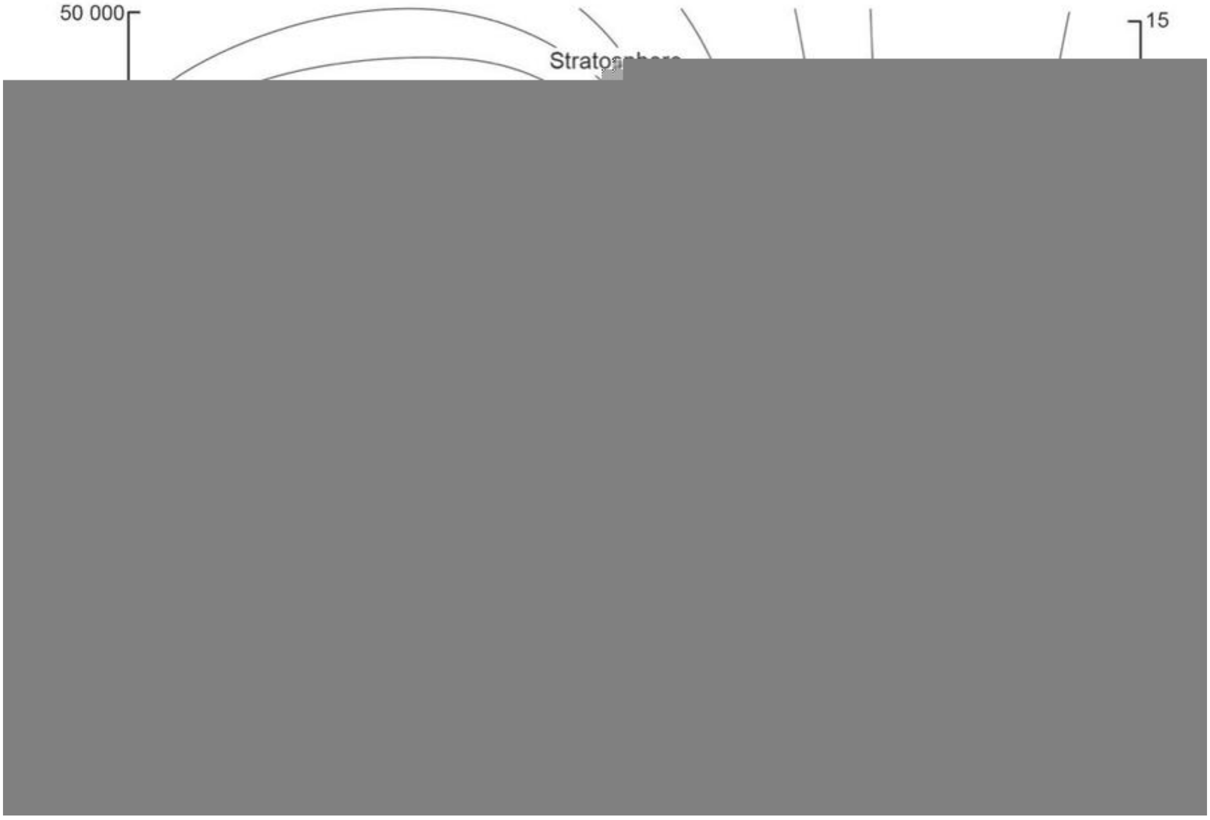
Clear air turbulence

Jet streams have a significant impact on navigation as they offer they offer the opportunity to much reduced cruise times and fuel expenditures, but they also create CAT

- CAT occurs whenever there's a rapid change of wind speed and/or direction

The figure below shows a cross-section through a typical polar front jet stream

- Isotachs show lines of equal speed



The most pronounced change of speed occurs on the cold air side where isotachs are closest, this produces the greatest windshear

It's generally true to say that the cold side of the jet stream has the greatest risk of CAT→ descent further onto the warm side

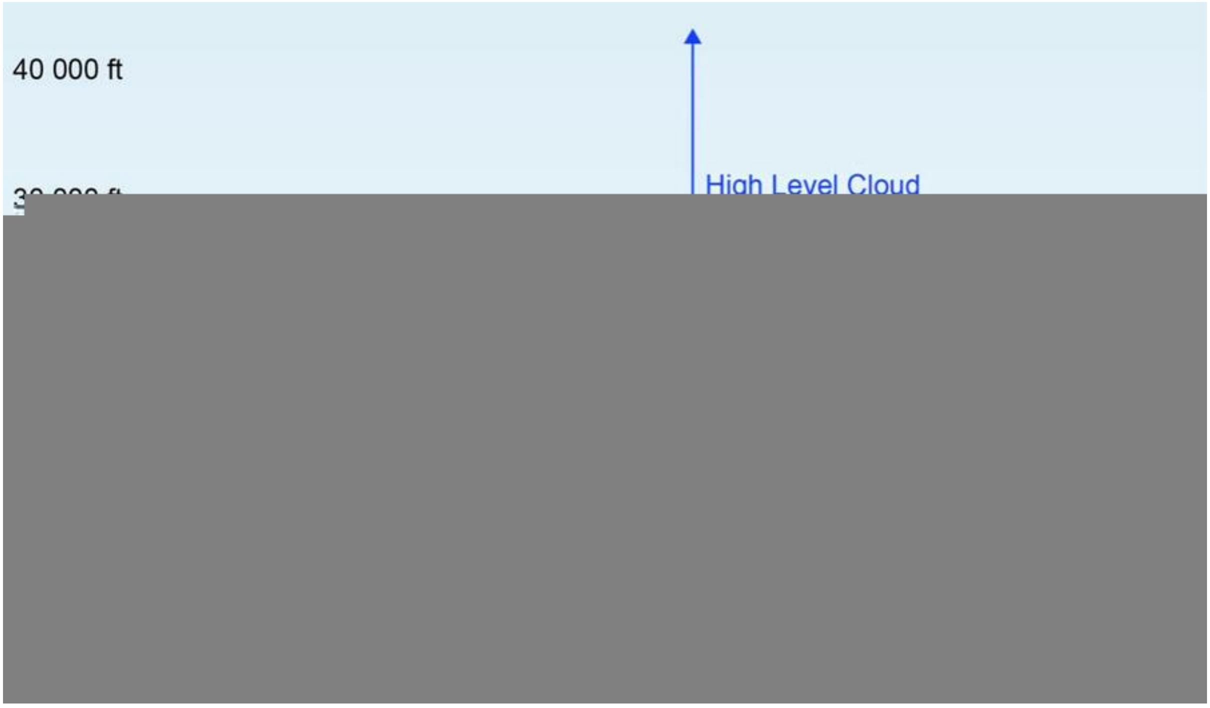
On a significant weather chart, CAT is marked by a dashed line

CH 12

Cloud classification is not an exact science it's mainly done by observing the cloud:

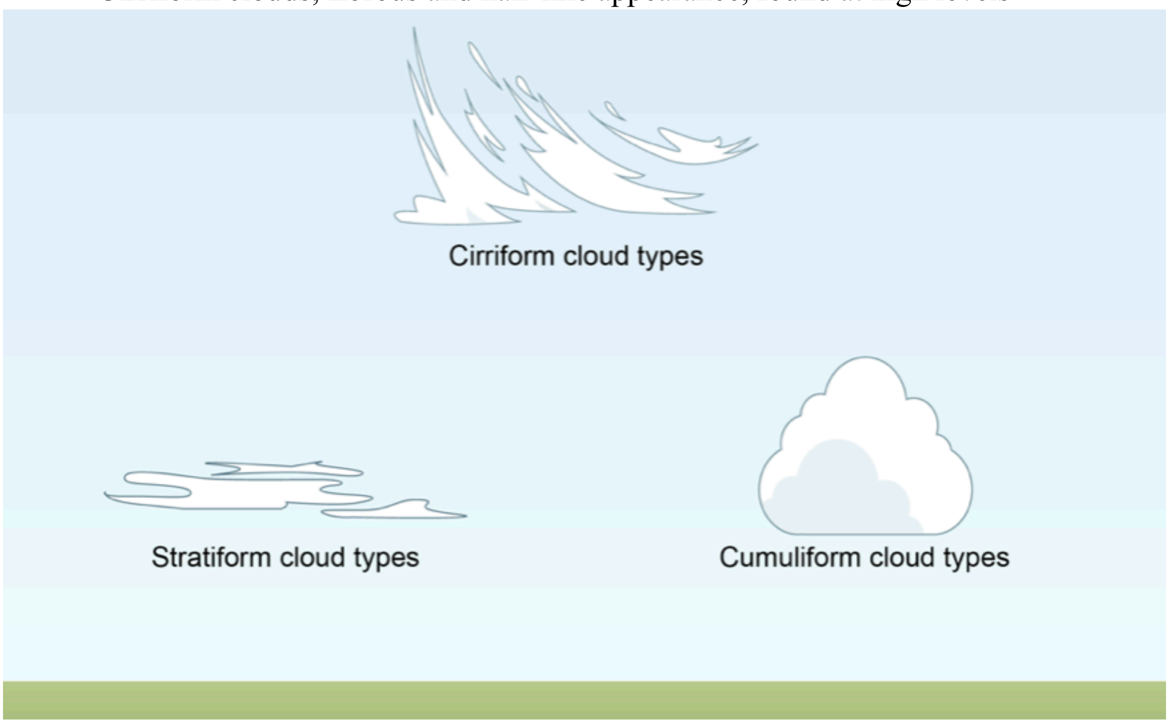
- Base
- Shape

For this purpose the tropopause is divided into 3 levels; low, medium and high. The heights wary with latitude and season. EASA uses the following; note the prefixes:



There are 3 basic cloud shapes:

- Stratiform clouds; flat or stratified with large horizontal extent
- Cumuliform clouds; tall butt relatively little horizontal extent
- Cirriform clouds; fibrous and hair-like appearance, found at high levels



Cloud species:

- Nimbus, Latin for rain shower, usually much darker in colour. Rain producing clouds
- Fractus, broken/fractured, usually applied to low-level clouds, common beneath heavy rain clouds
- Castellanus, castle, clouds with tops like castle turrets
- Mammatus, boobs, a cloud with a base containing softly curved protuberances
- Lenticularis, lens shaped
- Capillatus, usually applied to a very large well spread anvil shaped cloud
- Calvus, Cb where the sprouting of the upper parts are indistinct and flattened, appearance of a white-ish mass without sharp outlines
- Congestus, strongly sprouting cumulus, generally sharp outlines and often great vertical extent
    - AKA towering cumulus

High level clouds: (properties are found in the table below)

Ci, Cirrus

Cs, Cirrostratus

Cc, Cirrocumulus

Medium level clouds

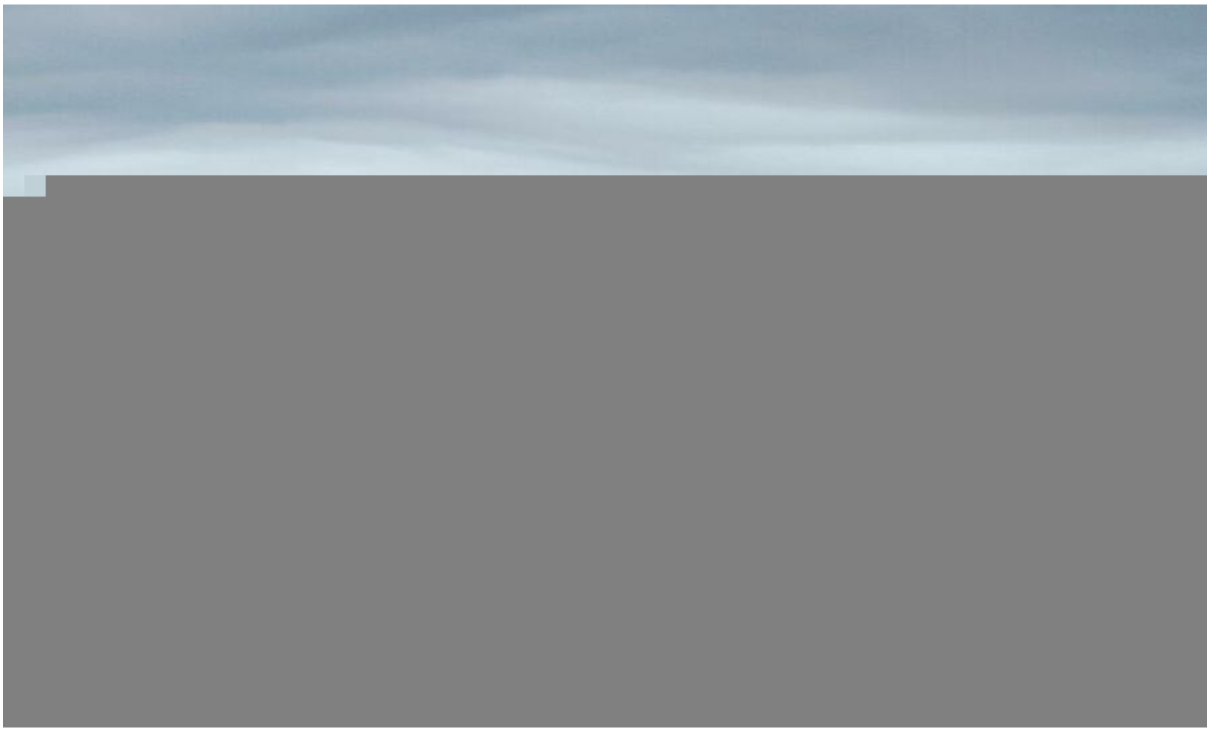
As, Altostratus

Ac, Altocumulus

Ns, Nimbostratus

Low level clouds

St, Stratus



Sc, Stratocumulus

Low vertically **developed** clouds

Cu, Cumulus

Cb, Cumulonimbus

Properties:

Name		Height, 1000ft	Composition	Turbulence	Icing	Visibility (meters)	Significance
Ci	Cirrus	16-45	IC	NIL or S	*[4]NIL	1000+	Found 400-600nm ahead of warm front
Cs	Cirrostratus	16.5-45	IC	NIL or S	*[4]NIL	1000+	Found 400-600nm ahead of warm front
Cc	Cirrocumulus	16.5-45	IC	NIL or S	*[4]NIL	1000+	Found 400-600nm ahead of warm front
Ac	Altocumulus	6,5-23	WD/IC	NIL or S	S to M	20-1000	can indicate approach of warm front
As	Altostratus	6.5-23	WD/IC	NIL or S	S to M	20-1000	Warm front 200nm ahead. Merges w/ Ns as the front is approached
Ns	Nimbostratus	*[1]0-6.5	WD/*[2]IC	M to X	M to X	10-20	Warm front adjacent
Sc	Stratocumulus	1-6.5	WD	S to M	S to M	10-30	Turbulence cloud often associated with Cu
St	Stratus (/fog)	0-6.5	WD	NIL or S	*[3]S to M	10-30	Turbulence cloud. Light precipitation
Cu	(towering) Cumulus	1-25	WD/IC	M to X	M to X	<20	Instability cloud. May develop into Cb
Cb	Cumulonimbus	1-45	WD/IC	M to X	M to X	10-20	Instability cloud. Thunderstorms, lightning, hail

Composition: WD = water droplets, IC = ice crystals
Turbulence: S = slight, M = moderate, X = severe
Icing: S = light, M = moderate, X = severe

*1; can be found at 10000ft to 15000ft when it's merging into Altostratus
*2; ice crystals only at medium levels
*3; only occasional icing
*4; can be associated with ice crystal icing, serious condition which affects gas turbine engines

Cloud species

Lenticularis;

- applies mainly to Cumulus clouds
- avoid, since they indicate mountain waves

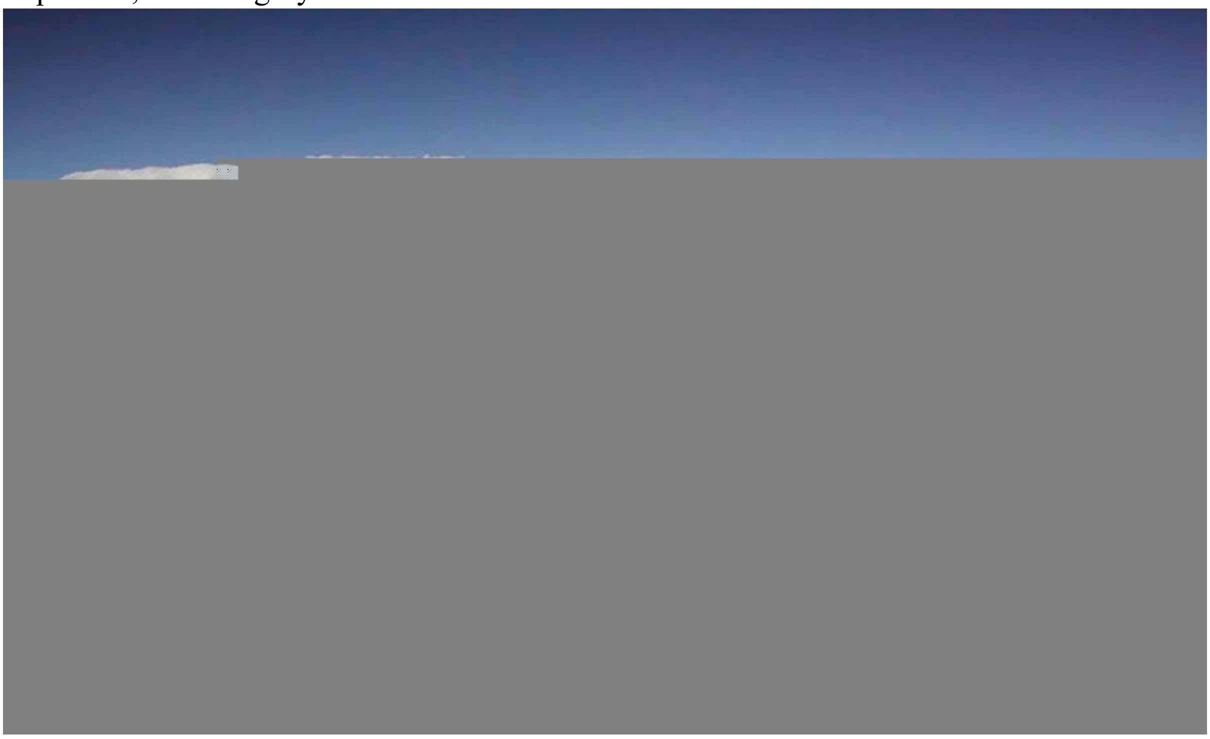
Castellanus

- indicates middle level ATM instability, possibility of thunderstorms developing
- applies only to Cirrus clouds

Fractus

- applies only to stratus and cumulus
- found beneath a storm in turbulent mixing air
- quickly break apart and reform

Capillatus; sub-category for Cb



Mammatus

- often seen beneath super-cell storms

Virga

- trails of precipitation falling but not reaching the ground
- AKA fallstreaks

Cloud covering the sky is reported in oktas:

Coverage	Description
0 oktas	SKC, Sky clear
1-2 oktas	FEW
3-4 oktas	SCT, Scattered
5-7 oktas	BKN, Broken
8 oktas	OVC, overcast

Summary of cloud types:

CH 13
Cloud formation and Precipitation

Conduction is the transfer of energy by direct contact

If the dew point is reached condensation will occur and cloud will form; textbook example of radiation fog, as does lots of low level stratiform clouds

Advection is the horizontal movement of air, not in direct mechanism of cooling but it does have a significant effect

When sufficient water vapour is cooled and the visibility along the surface is reduced to less than 1000m it's classified as fog

- Wind and rising temperature can lift fog so it becomes stratus
- Continued cooling over a long period can deepen the cloud layer → Nimbostratus

When a body radiates its heat, it cools down; happens every night

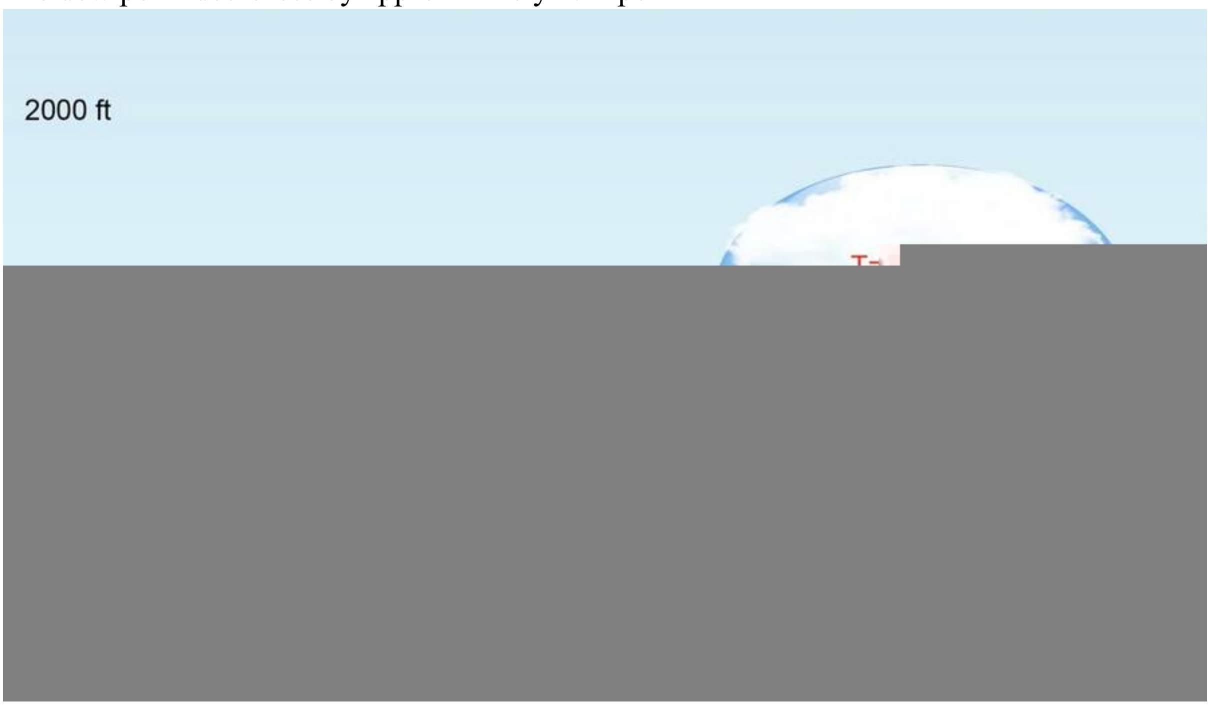
- If it cools below it dew point radiation fog can form
  - High-pressure system, clear sky and light/no winds are favourable

Radiation fog can lift when the temperature rises

Uplifted air is by far the most significant cause of cloud formation

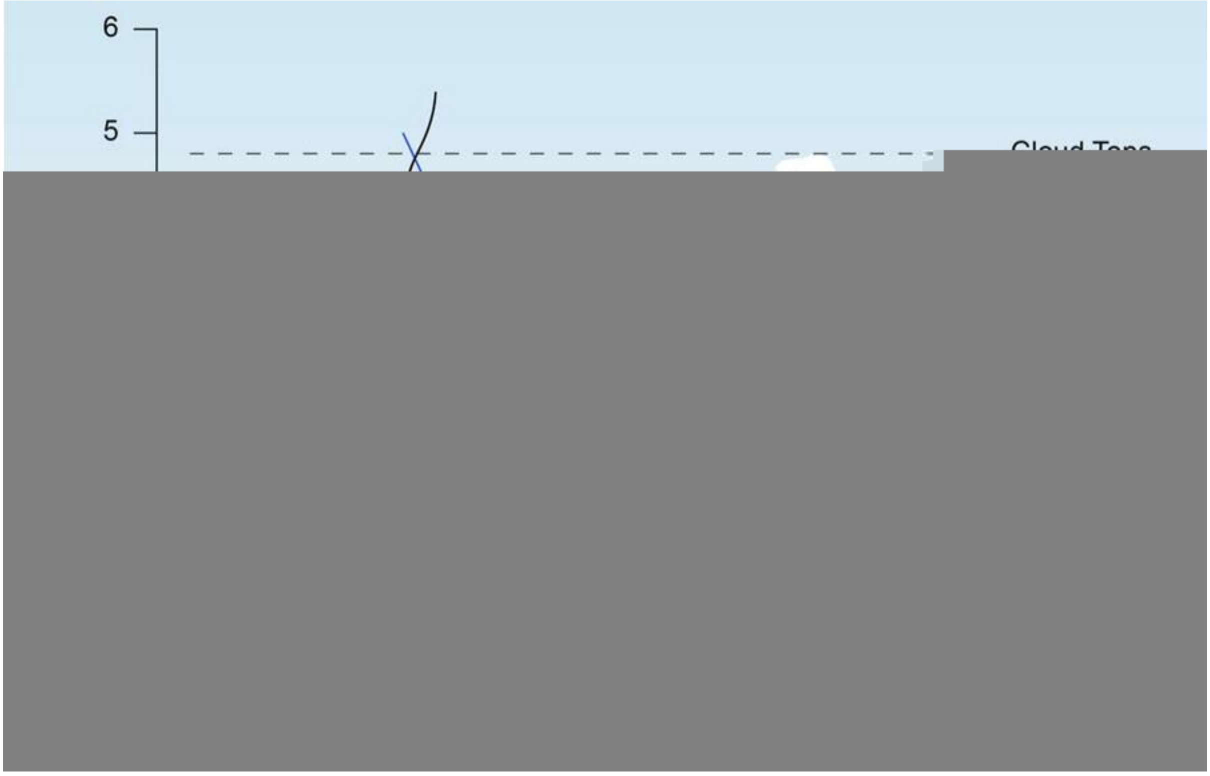
- Air which is forced to rise cools adiabatically

The dew point decreases by approximately 0.5° per 1000ft



(Temperature - dew point) × 400 = cloud base in ft

We can calculate the cloud tops as well if we know the ELR, and the cloud base:



Clouds start to form when the ELR is less than the SALR and continues until ELR becomes warmer than SALR.

- Can happen if there's an isothermal layer or an inversion

Clouds for when uplift or horizontal movement causes moist air to cool below its condensation point; the clouds will dissipate when the reverse happens

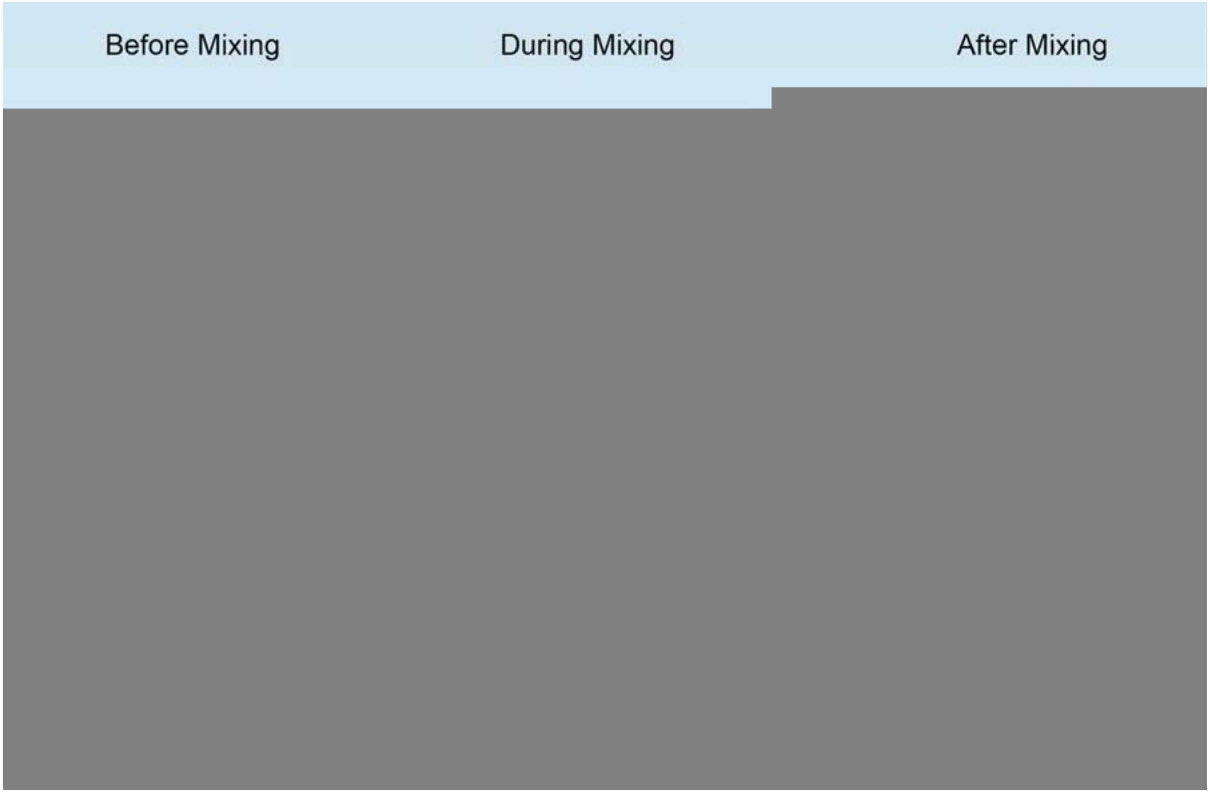
- Increased warming in stable ATM conditions will cause clouds to dissipate
- Changes to the ELR can mean that there's no longer a layer of instability to react to thermal and orographic triggers

Initial causes of vertical cloud motion, causing air to rise:

- **Turbulent uplift and mixing**
- **Orographic uplift**
- **Convection**
- **Frontal uplift**
- **Convergence**

Turbulent uplift and mixing
Turbulence near the surface is caused by the disruption of smooth airflow by mechanical effects and thermal effects

- Producing a turbulent layer of air, in the friction layer up until 3000ft
- Air mixing modifies the temperature so the top of the layer reaches its dew point
  - This type of cloud is called turbulent cloud



Turbulent clouds tend to be stratocumulus, above the air is smooth for flight

This type of uplift is generally shallow; any precipitation that falls will be light

Orographic uplift

When wind meets a physical barrier the air is forced to rise and thus begins to cool adiabatically

- As a general rule: hills and mountains are pro-lific cloud producers

The type of orographic cloud produced depends on the stability of the ATM

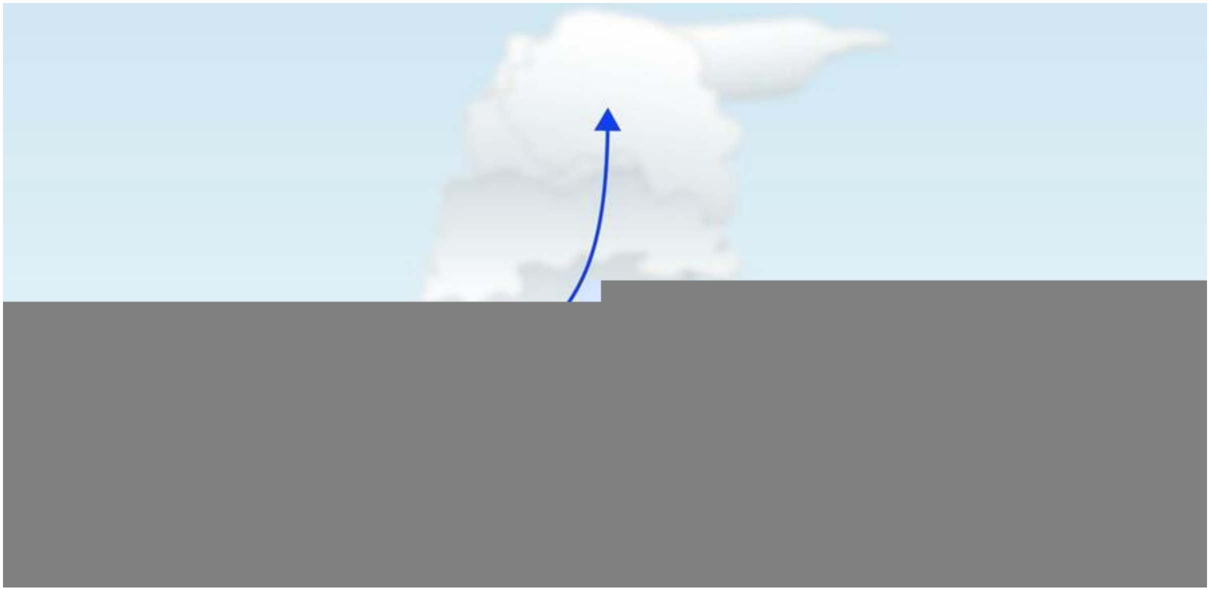
Unstable:

The initial uplift triggers a continuous rise, rapidly growing cumuliform clouds

Vertical support can cause severe turbulence, icing, lightning and hail

→ avoid

This type of cloud may be embedded inside another more innocent looking cloud forms



Stable:

Air forced to rise on the windward side is cooled to its dew point and clouds form. The air cant ascend much higher than the terrain so it tends to hug the tops, producing cap clouds

On the leeward side, the initial trigger no longer has an effect; air sinks.

- This causes adiabatic warming
    - The cloud evaporates

Long lasting drizzle or snow may occur over the windward side if conditions are right

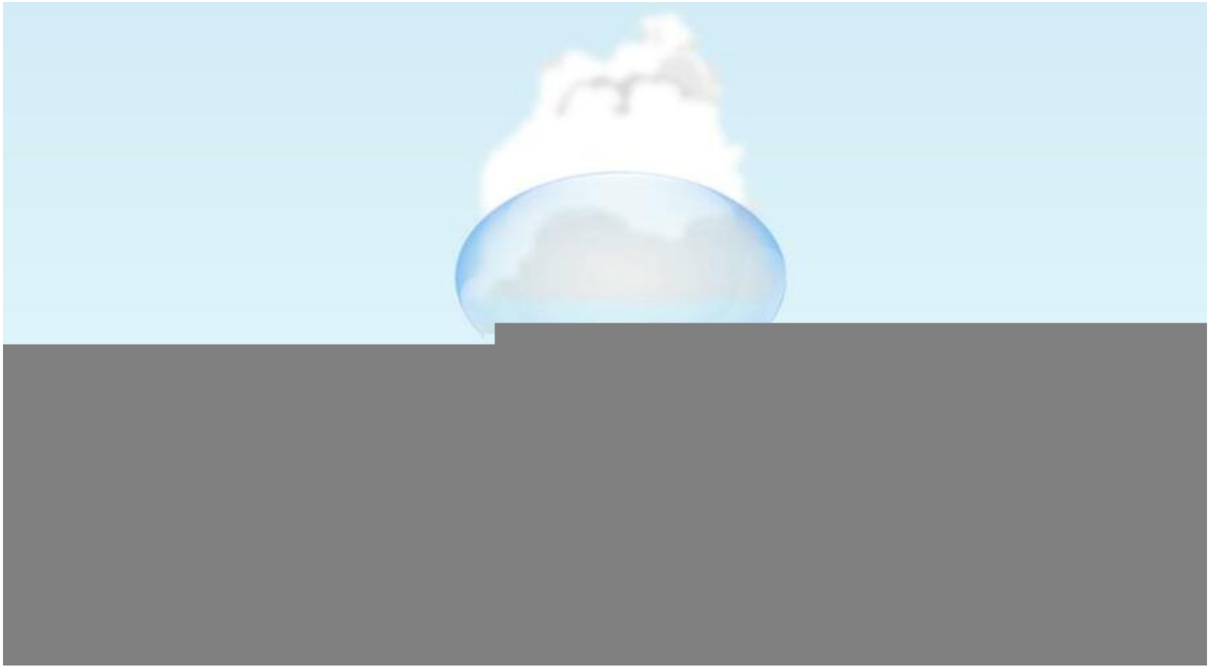
When the wind is strong, orographic effects in a stable ATM can produce mountain waves, lenticular clouds and dangerous rotor clouds; it may also cause the Foehn effect

Convective uplift

When air at the surface is warmed it heats up and expands

- A reduction in density → becomes buoyant and rises
- It will rise as long as it's buoyant and ATM conditions are unstable

As it rises it cools adiabatically; at the condensation level clouds begin to form



Conditions lead to cumuliform clouds but may develop into Cumulonimbus

Intemperate regions this is common in the summer, but may also occur over large lakes in the winter; water tends to be warmer in the winter than surrounding land masses

Frontal uplift
Most common in the temperate and mid latitudes

A front is a boundary between a cold and a warm front relatively speaking

- When a cold mass of air moves is slides underneath the warmer, less dense air. This known as a cold front
- When a warm mass moves, it slides over the colder, more dense air. This is a warm front

In both cases warm air is lifted at the front; as air rises is cools adiabatically, condenses and forms clouds.

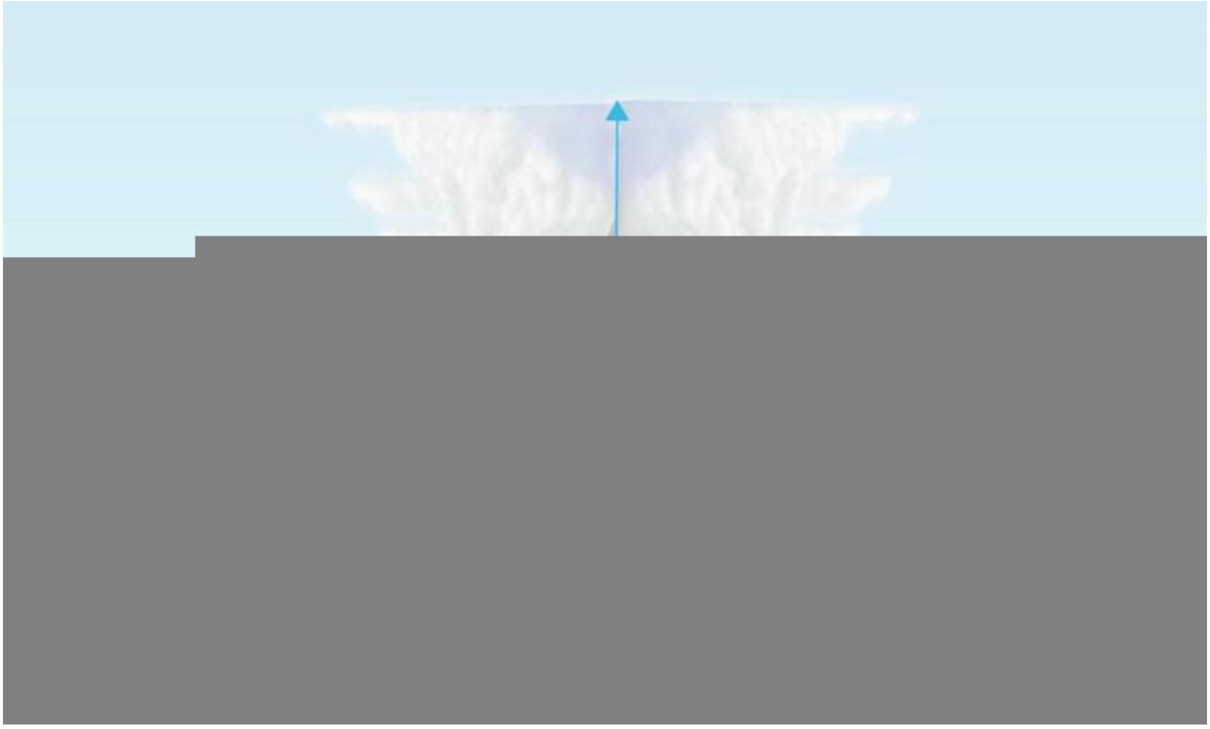
It rises gently the warm front is about 1 up 150 forward producing stratiform with light to moderate continuous drizzle, rain or snow

The cold front slopes backwards because the heavy, cold air is forcing itself underneath; slopes at 1 up 75 backwards also causing stratiform cloud

The cold front also has a cold nose, this is a very unstable region, triggering rapid vertical uplift embedding cumuliform clouds within the stratus

Convergence uplift
When wind coming from opposite directions meet thy are forced upwards

- Common in low-pressure troughs



It also happens on a global scale; ITCZ, giving rise to intense cumuliform cloud formation

Potential hazards with precipitation

- Reduced visibility
- Airframe icing
- Sensor blockage/malfunction
- Flame-out
- Structural damage
- Runway contamination

As air cools below the dew point the water vapour changes state either to liquid or ice crystals, when they grow in size they overcome the uplifting air current

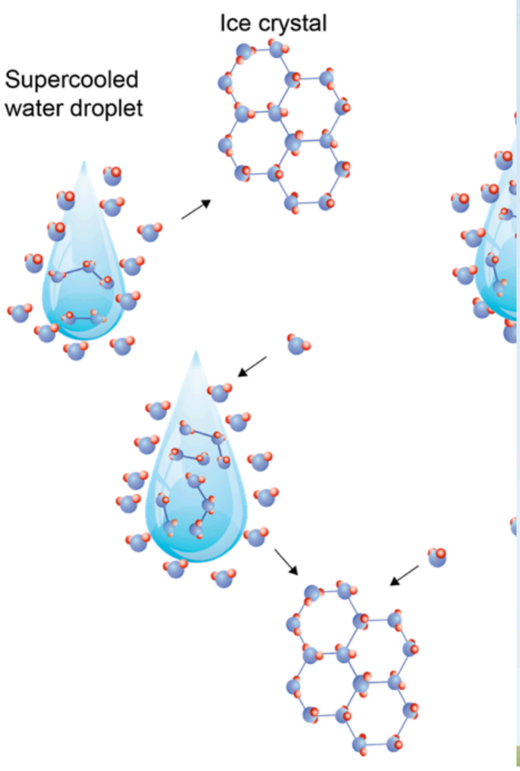
The type of precipitation depends on the cloud structure and the speed of the ascending air

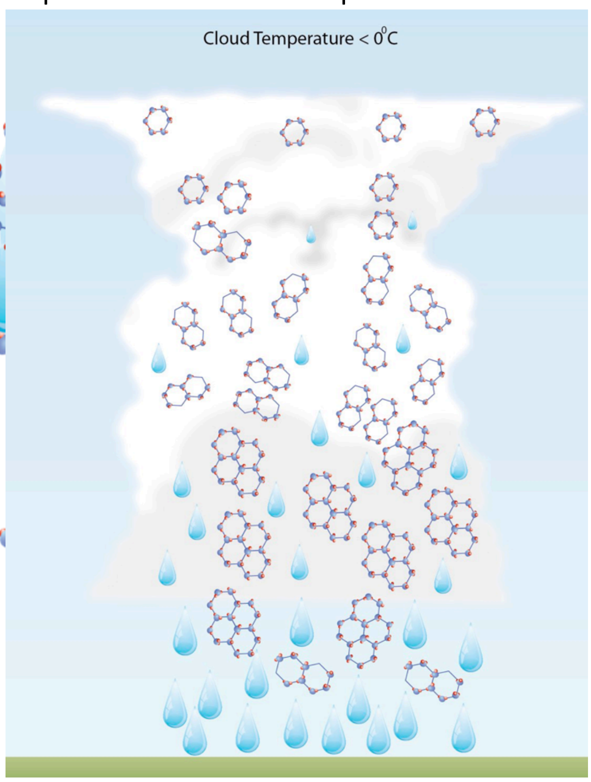
Precipitation processes

The **Wegener-Bergeron-Findeisen process**, the ice crystal process
Ice crystal growth in clouds which are below 0°C and which contain a mixture of supercooled water and ice

The vapour pressure around the ice nuclei is much less than around the water molecules making it easier for molecules losing energy to attach themselves to an ice crystal

As a result, ice crystals build up rapidly at the expense of the water droplets





As the crystals grow and fall, they pass the base of the cloud, if it’s above freezing the crystals melt and fall as rain instead. Sub-zero layer of air below the cloud would cause the rain to freeze in the form of ice pellets. Sleet if you get both snow and rain reaching the ground

Coalescence theory explains the formation of precipitation in clouds warmer than 0°C

When condensation takes place; the updraft in the cloud lift the water droplets causing them to collide and join until the size overcomes the suspension and fall

- The greater the updraft the greater the size of the droplets

When condensation or sublimation takes place, the water droplet or ice crystal is initially about 0.02 mm in diameter with a terminal velocity of 0.012 m/s in still air

DZ, drizzle

- Comes from stratiform clouds only

RA, Rain

- Nimbostratus or cumulonimbus are the only ones big enough to produce such big water droplets

Ice crystal / diamond dust

- Fall as needles, columns or plates of ice

SN, Snow

- Ice crystals that are branched
- Above -5°C these crystals often bind together into larger snowflakes
  - The colder and the lower moisture content, the smaller the flake
- Precipitation can fall as snow as long as the surface temperature does not exceed +4°C

SG, Snow grains

- Very small, diameter less than 1 mm
- Does not bounce or shatter

GS, Snow pellet

- Easily crushable
- AKA soft hail
- Diameter about 2-5 mm
- Bounces and breaks on contact with hard ground

PL, Ice pellet

- Larger than snow pellets
- Comprise clear ice
- Bounce when hitting hard ground

GR, Hail

- GS for soft hail
- Large, structured like an onion
- Formation requires much ascending and descending within the cloud
- The opaque layers are caused by trapped air within the ice, liquid water content of cloud is low

Reporting intensity of precipitation:

	Rain, mm/h	Rain, hail mm/h	Snow, cm/h
Slight	< 0.5	<2	< 0.5
Moderate	0.5 to 4	2 to 10	0.5 to 4
Heavy	> 4	10 to 50	> 4
Violent		> 50	

Continuity of precipitation:

- Continuous, no breaks in the precipitation for more than 1 hour
    - Stratiform cloud types
- Intermittent, falls from time to time, with no marked clearances less then 1 hour
    - Stratiform cloud types
- Showers, rain, snow, sleet or hail
    - Always associated with cumuliform clouds
    - Marked SH in METARs

Precipitation type	Cloud type
Drizzle	ST, SC, NS
Freezing drizzle	ST, SC, NS
Snow grains	ST, SC, NS
Rain, continuous	Thick AS, NS
Snow, continuous	Thick AS, NS
Rain, intermittent	Thick AS, SC
Snow, intermittent	Thick AS, SC
Hail	CB

CH 14

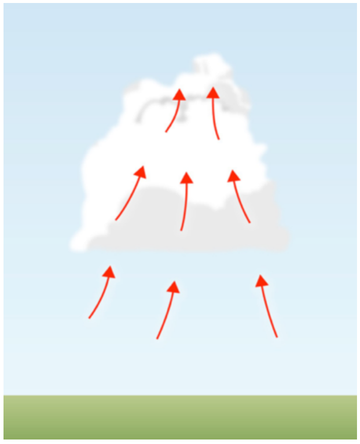
Thunderstorms, caused by highly developed Cb clouds strong enough to produce lightning

- The presence of thunder defines it

Requirement for a thunderstorm to develop:

- The air must be unstable throughout at least 10 000ft above the freezing layer
- Adequate supply of moisture to allow the development of a large cloud
- Must be a trigger to initiate the uplift
    - Convection
    - Orographic uplift
    - Convergence
    - Frontal uplift

A thunderstorm is normally a complex mixture of individual Cb cloud cells in various stages of development

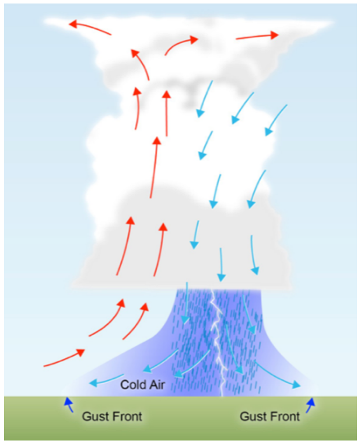


The life cycle of a single cell thunderstorm has 3 stages:

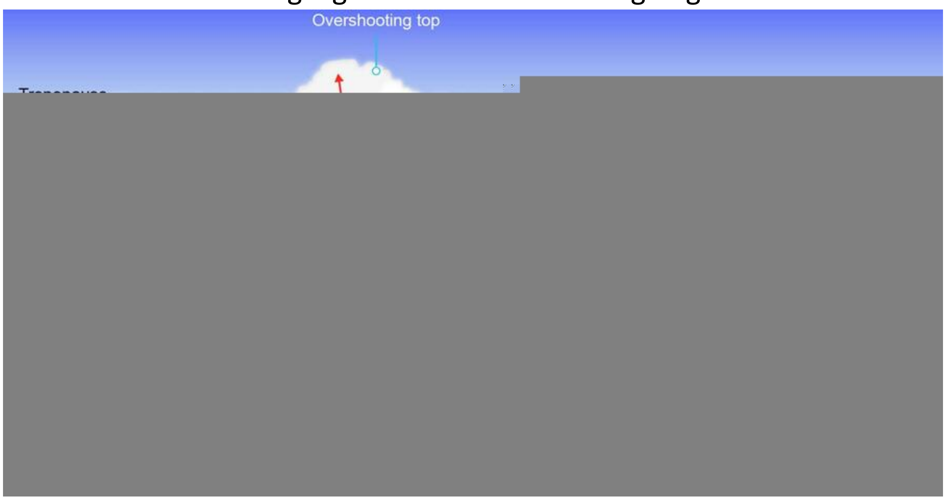
Stage 1. Building stage; updrafts are predominant

- If there's a deep layer of instability and plenty of moisture, a small cumulus cloud will grow into a larger cumulus cloud
- Vertical velocities at $30m\ s^{-1}$
    - Difficult/impossible to climb over
- The cell is fed with moist air
- 15 to 20 minutes

Stage 2. Mature stage; up and downdrafts coexist



- The weight of the water droplets becomes greater than the updraft forces
    - The falling precipitation partly evaporates during the descent; this absorbs latent heat from the surrounding air→ cooler surrounding air
- When the cold downdrafts hit the ground they spread outwards
    - Creating a gust front at the leading edge of the cold air



the cold air from the gust front sinks under the warmer surface air, causing it to rise.

- Lifting causes the warmer air to condense and form clouds; roll/wall/shelf cloud

Gust fronts can appear 15nm ahead of the storm and up to 6000ft deep. Below the cloud a squall with windshear can be expected

Microbursts are possible when the down currents are very strong

- And macrobursts when the entire cold air outflow leaves a thunderstorm(s)

Rising and falling droplets and hail produce a considerable build-up of static electricity

- Positive at the top
- Negative at the bottom

The current involved in a discharge is so large it superheats the surrounding air to the point where it radiates light intensely

- Also causes the air to expand so rapidly it creates a pressure shock wave
    - Heard as thunder

in a single-cell thunderstorm, the downdraft eventually disrupt the updraft and begin to kill the storm

- The mature stage usually lasts 15 - 20 minutes

Stage 3. Dissipating stage, downdrafts predominant
Signalled by the cessation of updrafts, this occurs when:

- No more moist air left to feed the cell
- Initial trigger no longer exists
- When the cold downdraft becomes so intense it overcomes the updraft

The cloud base tend to rise during this stage
Lasts 1h30 to 2h30

Anvil formation
The inversion above the tropopause prevents further vertical formation. With light upper winds the anvil spreads out evenly in all directions

- A unidirectional anvil indicates the direction of upper wind

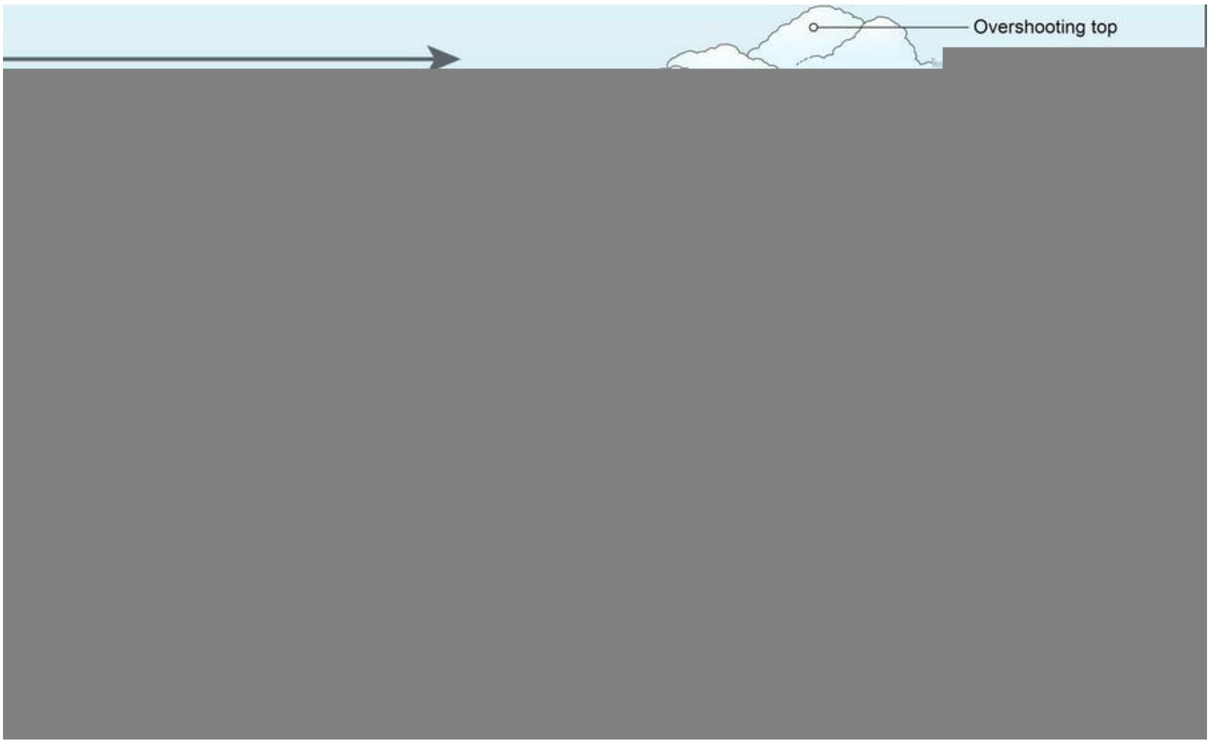
A **supercell** is a thunderstorm characterised by the presence of a deep persistently rotation updraft, called a mesocyclone

A thunderstorm can self-propagate with moist if the upper wind conditions are suitable

The winds vary with height so the storm doesn't develop straight but leans to one side

- The cloud continues to develop as long as there is moist air and a suitable trigger action
- Descending air spreads out and adds to the air being fed into the updraft, creating a daughter storm which feeds the main storm

There are 4 stages; the initial, supercell, tornado and dissipating stage



Types of thunderstorms:

- Heat thunderstorms
- Air mass thunderstorms
- Frontal thunderstorms
- Squall thunderstorms

Heat storms are caused by a combination of heat, humidity and instability

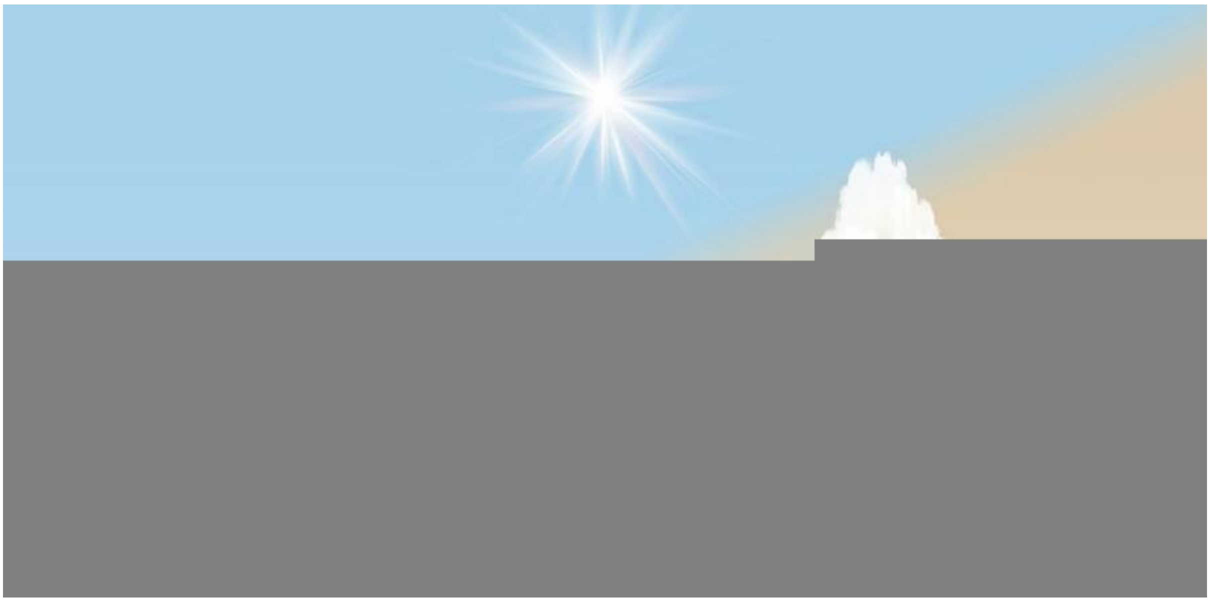
- And ELR which results in a deep layer of instability
- Ready supply of moist air

Add a trigger mechanism such as; thermal uplift or convection → thunderstorm

Air mass thunderstorms
If a cool air mass moves towards an area with a warmer surface→steepens the lapse rate → triggering thunderstorm development

Rising air caused by depression or convergence at a col may also produce thunderstorms

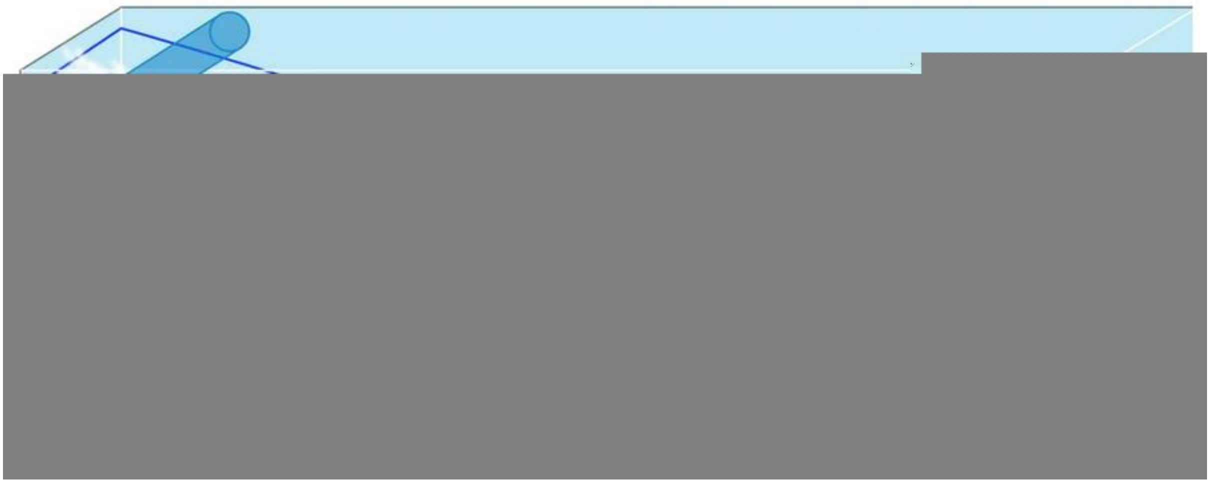
Clouds such as all the Altocumulus Castellanos, Acc, are signs of middle level instability AKA thunderstorms



frontal thunderstorms
occur where a cold air mass undercuts a warm air mass

- Thunderstorms most likely to develop just ahead of the cold front at the point where the cold front curls under itself

The cold noes puts warm air under the cold air which greatly increases the lapse rate and leads to instability



Squall line

Is a line of thunderstorms that can be several hundred miles long, it usually forms just ahead of a cold front

Squall line is very active he may have no option but to abandon your flight and wait until the weather clears

Diurnal and seasonal variation

- Heat thunderstorms are likely to occur in the early afternoon
- Storms generated by air mass movement can occur at any time

Thunderstorms formed in a Col or slack PGF move unpredictably

Hazards:

- Tornados can occur with both isolated and squall line thunderstorms
    - The updraft retains the spin as it bends to flow upwards in the cell
- Always assume hail exists in a thunderstorm

- Turbine engines have a limited amount of water it can ingest before it flames out
    - Watch out for heavy rain
        - This may give false airspeed indications
- Icing is bad
- Lightning
    - Intra cloud
    - Cloud to cloud
    - Cloud to ground

Areas of potential lightning strikes:

Static electricity is often noticed as noise on the high and medium frequencies radio bands

ADF must be used with extreme precaution since they tend to point towards the area of discharge rather than radio stations

Magnetic compasses can be strongly affected by lightning

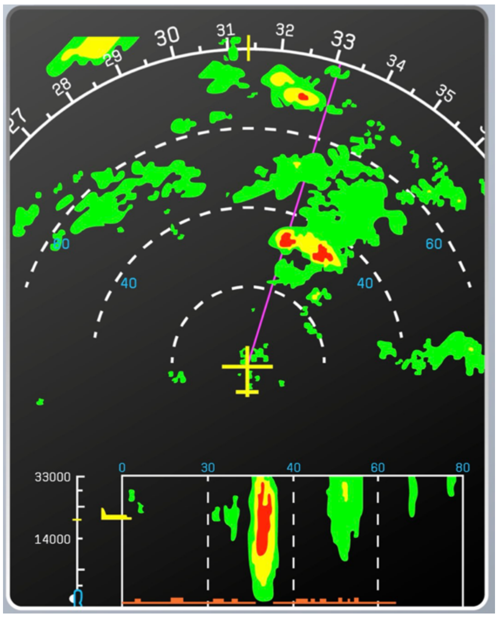
Airborne weather radar is used to navigate around active weather including thunderstorms

- They are not good at detecting ice in the top of clouds, but wet precipitation
- 8-12 GHz, 2.5 -4 cm wavelength

The water phases listed in descending order of reactivity:

- Wet hail
- Rain
- Hail
- Ice crystals
- Wet snow
- Dry hail
- Dry snow

The intensity of the return shown on the display depends on the amount of electromagnetic amplification given to the receiver



Dense clouds close to the aircraft may disguise the radar return from active cells behind it

Clouds containing rain or hail can produce identical radar returns

Guidance on the safe distance from thunderstorms are:

- If cloud tops are above 20 000ft it should be avoided by a minimum of 20nm
- Cloud tops below 20 000ft by a minimum of 10nm

If storm clouds have to be overflown, always maintain at least 5000ft vertical separation

If you have to penetrate a thunderstorm/ Cb cloud do the following:

- Fasten seatbelts/harnesses, secure loose objects
- One pilot flies, the other monitors continuously
- Set recommended speed for flight in turbulence
    - Adjust trim and note the position
- Ensure pitot heaters
- Check anti/de-icing
- Disregard radio navigation indications when being affected by electrical interference
- Turn up cockpit lightning, lower set and sun visor
- Follow manufacturers recommendation for autopilot/manometric locks
- Navigate using weather radar
- In turbine powered aircraft; turn on continuous ignition system
- Avoid flying over the top of a thunderstorm

Flight manuals and maintenance documents may quantify levels of turbulence which would trigger a maintenance inspection

CH 15

Icing

Threats:

- Increased stalling speed
- Increased drag
- Alters lift characteristics
- Build-up by the air intake for turbine engines, loss of power or flame-out
- Build-up on fan blades
- Jam control surfaces
- Cover windscreen
- Malfunction sensors

For airframe icing to occur the airframe temperature must be below 0°C and it must come in contact with moisture

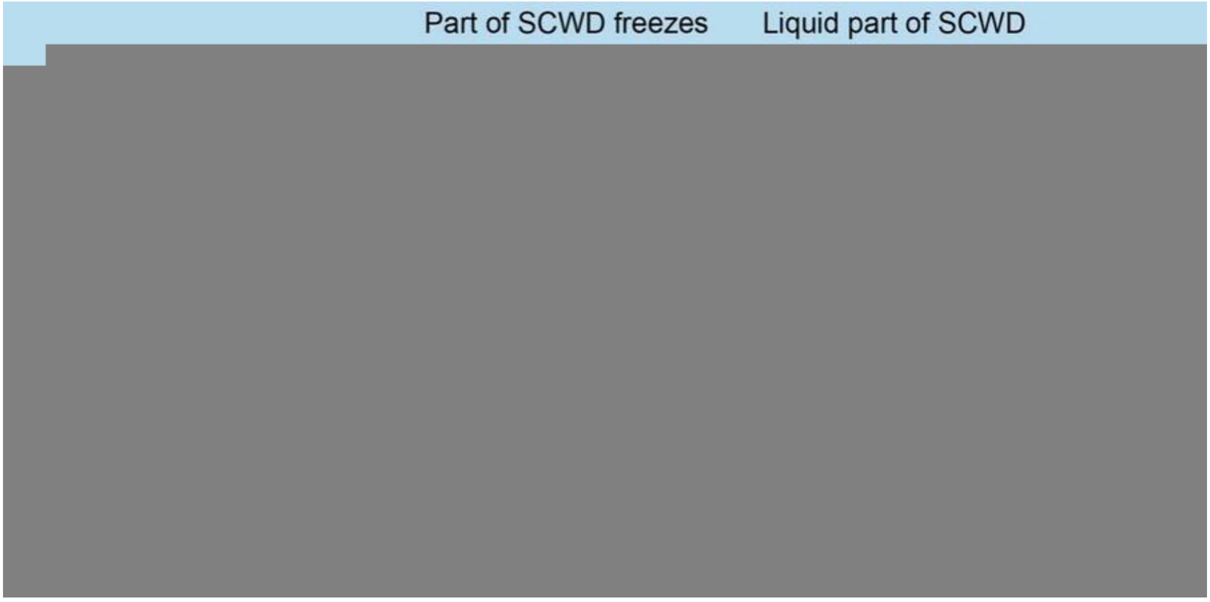
- Hoar frost is the exception

Supercooled water droplets, SCWD, are liquid droplets of water whose temperature is below 0°C

- They can exist between 0°C and -40°C
    - The colder and the less moist, the smaller the droplet
    - The “newer” the cloud the more likely the SCWD is to be in the liquid form; giving it less time to change state
    - At lower levels closer to the freezing level the cloud may contain very large SCWD
- Very unstable

Larger SCWD freeze relatively slowly; when it comes into contact with the airframe it flows backwards along the surface, leaving a trail of ice behind

“for every 1°C below 0°C, 1/80 of an SCWD freezes instantly on impact”



Airframe icing can to be encountered whenever an aircraft flies through visible moisture below 0°C but above -40°C

It is also possible to encounter super cold water droplets in clear air when flying through a certain type of rain

No de-icing or anti-icing system can cope with prolonged flight into severe icing conditions

Hoar frost
Forms on cold surfaces when moisture is present in the ATM

- Common on an early morning after a cold winter night
- Must be cleared completely from all critical surfaces before flight

Hoar frost can also occur in-flight in clear air when an aircraft descends through warm, moist air, after a long period cold soaking at altitude

- May also accumulate temporarily when flying across a front from a colder region to a warmer region

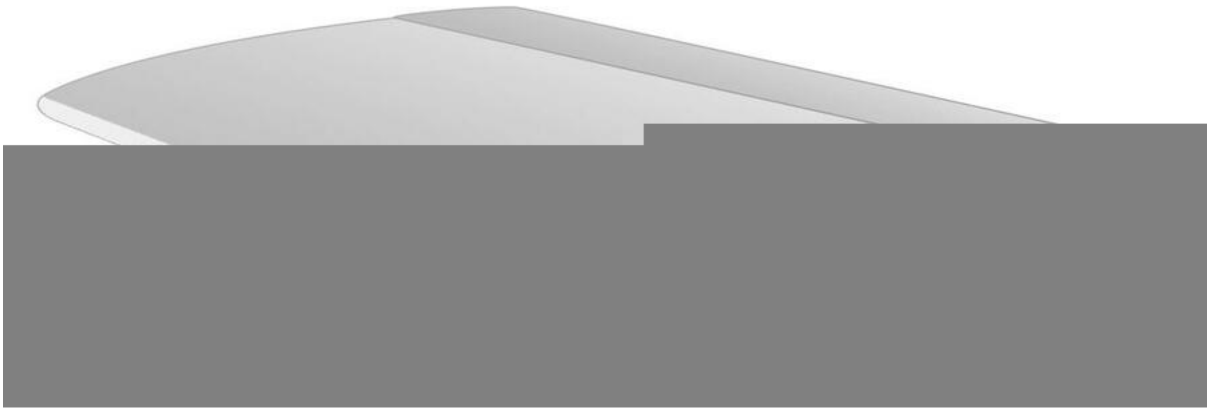
After landing you may notice ice on top and below the wing. Ice forms as the fuel inside the wing is cold

Rime ice
Forms when small SCWD come into contact with an airframe surface colder than 0°C

The rapid freezing traps tiny bubbles, making it look opaque and white

The rapid freezing makes the ice accumulate on the leading edge

Rime ice is quick and easy to remove using de-icing and anti-icing systems



Rime ice on the ground can form in freezing fog and on the windward side of the exposed object

Clear ice
Heavier and harder to remove then rime ice
Clear ice is almost transparent and has a glass like appearance
It's forms when the leading edge of the airframe, sub-zero temperature, comes into contact with large SCWD

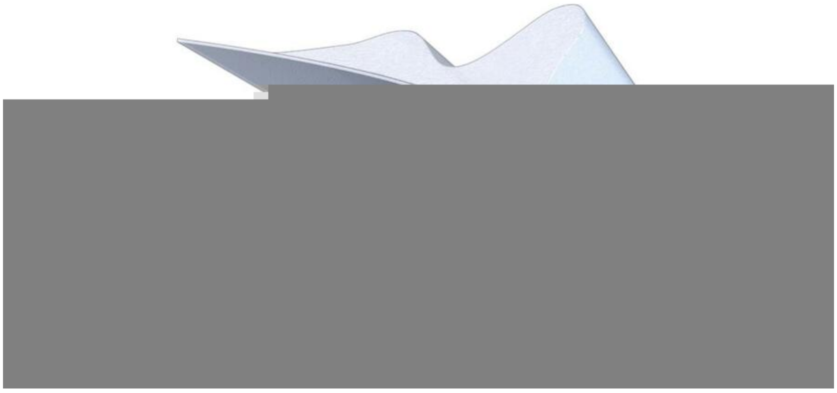
- Air bubbles have time to escape
  - Creating a smooth surface
  - Sticks strongly to the airframe

Clear ice can also be created by cold rain, freezing rain, supercooled large droplets; airframe sub-zero

Mixed ice
Rime and clear ice
Mixed ice shares the characteristics of clear and rime ice

- Some forward and some flow-back build up

Severe such build-up can lead to formation of a double horn on the leading edge



Freezing rain/Drizzle

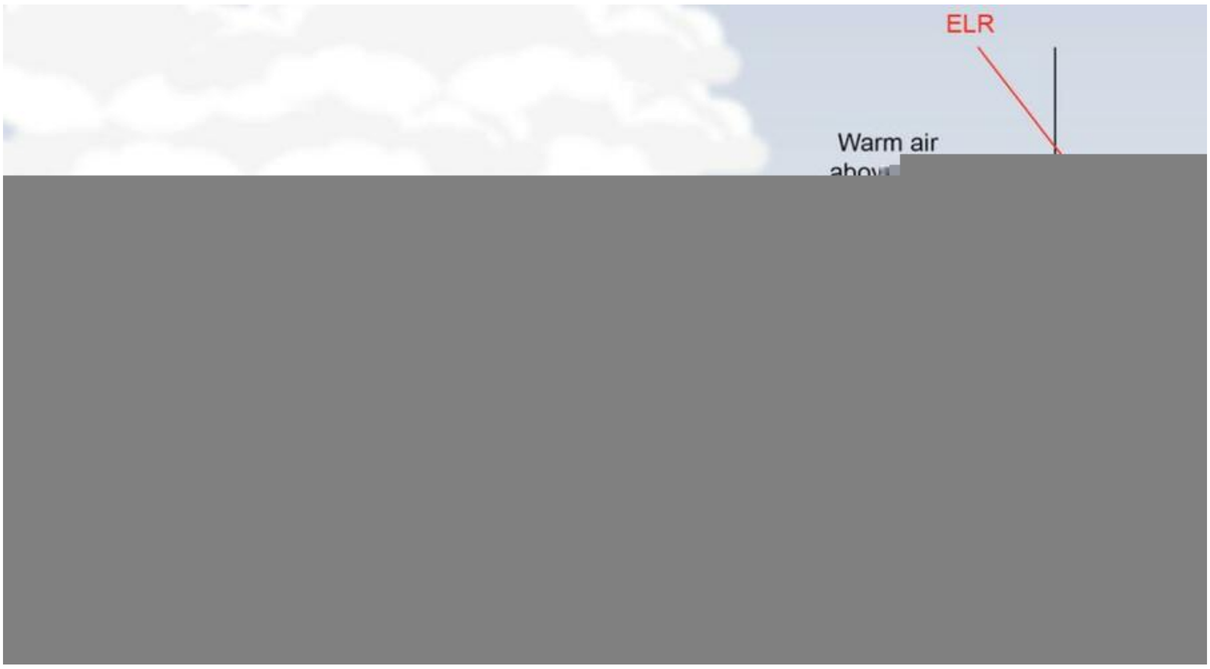
- No aircraft can safely fly through freezing rain/drizzle

Visual cues include:

- Extensive ice accumulation in uncommon places
- Ice on the upper/lower surface of the wing, aft of the protected area
- Ice on sensor probes
- Water splashing on windscreen, even though OAT is sub-zero

Freezing rain requires a unique set of metrological circumstances:

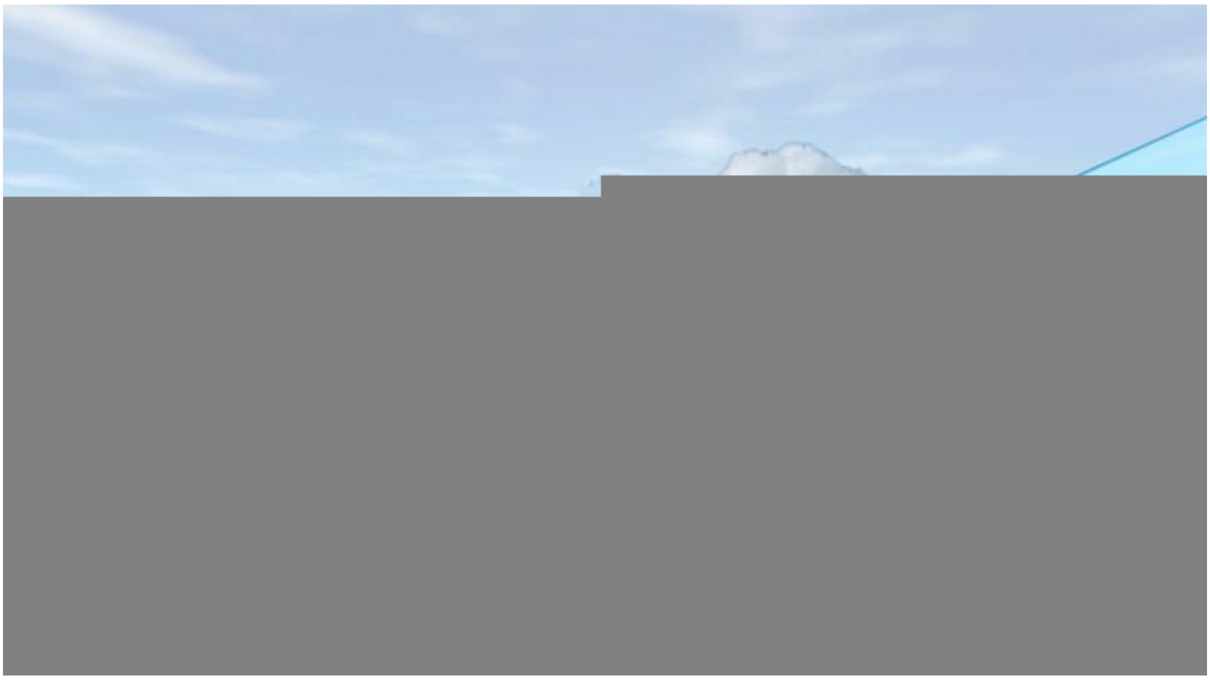
- Droplets must be cooled close to 0°C
- Airframe must be cold
- The drops must form in a relatively warm cloud before falling before falling through a very cold layer



The rain ice triangle

Icy conditions mostly occur just ahead of a warm front over a very cold land mass in winter, this creates a triangular danger area perfectly suitable for rain ice conditions

- If you find yourself here, CLIMB! Don't try to outrun horizontally



Ice crystals can stick to the aircraft if the airframe is wet

- The crystals then freeze with the water to form rough, cloudy ice

The most serious hazard on the ground is from freezing precipitation in the form of rain or drizzle. De-icing will probably not be sufficient, delay!

Factors affecting how much the airframe is affected by icing:

- Size and quantity of SCWD
- Shape of wing; thinner wings pose a smaller risk
- Orographic intensification
    - Increased vertical flow of droplets
    - The 0°C isotherm lowers, increasing the depth of the potential freezing zone
- Kinetic heating, compressed air warms the airframe
- Concentration of liquid water
    - Light 0.11 - 0.6 g m^{-3}
    - moderate 0.61 - 1.2 g m^{-3}
    - severe >1.2 g m^{-3}

if you encounter icing conditions, reported according to the following table:

intensity	Ice accumulation
Optional reporting	
Trace	Rate of accumulation is slightly greater than the rate of sublimation. Not hazardous even without de/anti-icing
Light	The rate of accumulation might create a problem If flight in this environment exceeds one hour. Occasional use of de/anti-icing
Mandatory reporting	
Moderate	Short Encounters become potentially hazardous and use of de/anti-icing is necessary
Severe	Rate of accumulation is such that de/anti-icing fails to reduce or control the hazard
Rime/clear ice	Rough milky opaque ice formed by instantaneous freezing. Glossy, clear ice forms by slow freezing

Cloud types and icing

Cumuliform cloud:

- mostly temperatures down to -20°C
    - containing mostly liquid water droplets or ice crystals
- it has cellular structure, some cells are developing, while some are decaying

Stratiform cloud:

- mostly temperatures down to -15°C
    - risk of moderate icing
- contains relatively small amounts of water droplets

Altostratus/ altocumulus

- extensive layer depth
    - producing larger SCWD
- mostly temperatures between 0° to -15°C
    - moderate to severe icing

nimbostratus

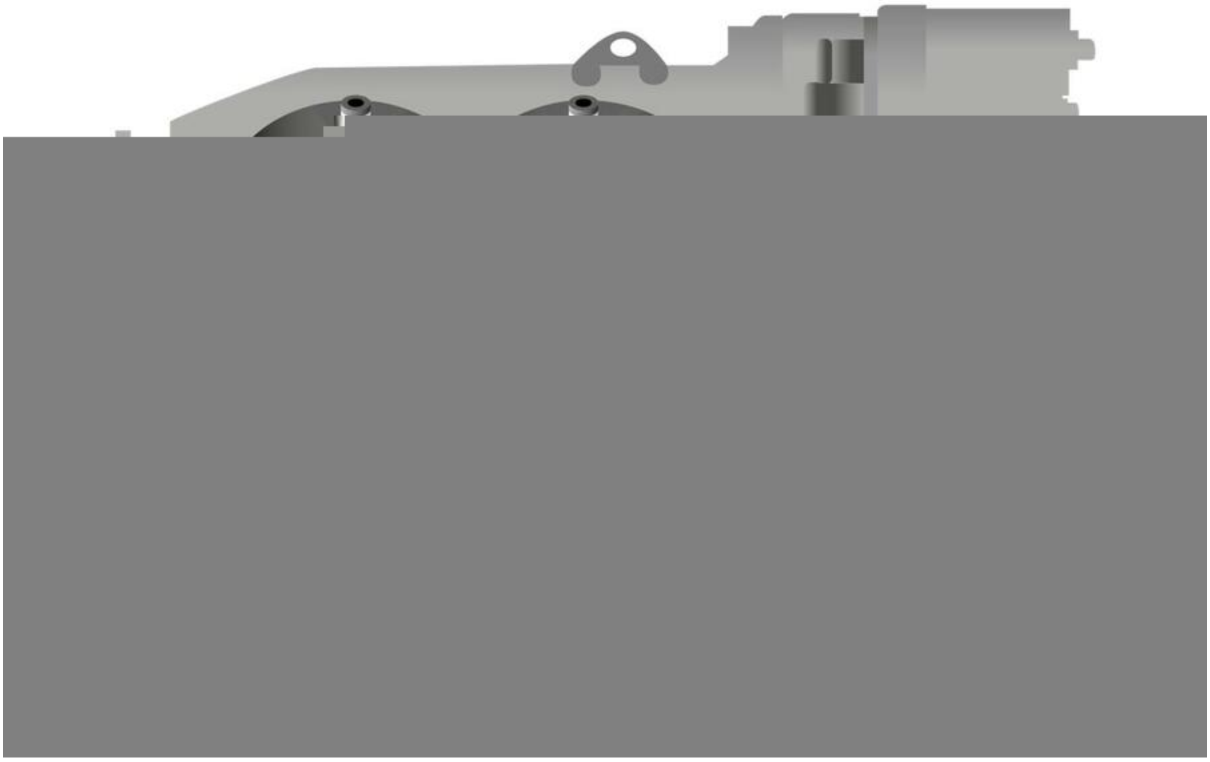
- similar to altostratus with the exception of being able to form at lower altitudes
    - increases the water droplet concentration

Cirrus clouds

- usually only ice crystals
- airframe icing unlikely

there are 3 main types of icing that can affect piston-engine aircraft:

- carburettor icing, fairly common
- (air) intake ice, fairly common
- Fuel (line) icing



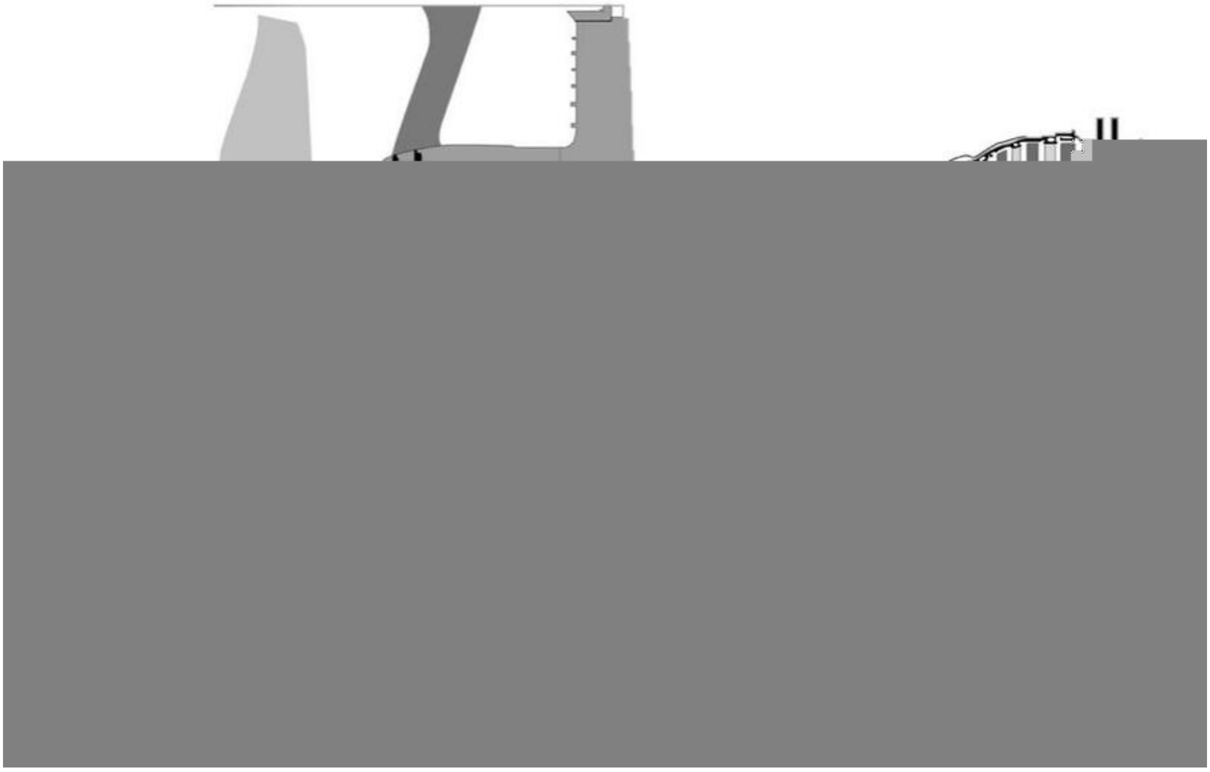
Carburettor icing is most likely to occur in warm humid conditions when throttle butterfly is only partially opened.

Carburettor icing areas:

The main danger for turbine aircraft is ice accumulation around the intakes and fan blades

At high power settings and low speed intake icing and start to occur before the onset of airframe icing

Ice crystal icing is a threat because in the hot conditions inside a gas turbine engine these crystals partially melted, cooling the compressor blades until they become sticky enough to accumulate ice



CH 16
Visibility

Meteorological visibility is:
- The greatest distance at which a black object situated near the ground, can be seen and recognized when observed against a bright background; or
- The greatest distance at which a light of 1000 candelas can be seen and identified against an unlit background

Today most synoptic observing stations have forward scatter visiometer sensors automatically measuring visibility, meteorological optical range

Non-atmospheric causes of low visibility:
- Glare from the sun or a windscreen
- Contaminated windscreen
- Scratches
- UV damage

Atmospheric causes:
- Water droplets
- Ice crystals
- Smoke
- Dust
- Chemical pollutants
- Volcanic ash

The distance one can see through atmospheric air is determined by the number of particles suspended in the air

Causes of lowest ability or separated into two groups, those caused by precipitation and those that aren't:

- FG, fog
  - Visibility less than 1000m
- BR, Mist
  - Visibility less than 5000m more than 1000m
- HZ, Haze
  - Visibility less than 5000m
- FU, Smoke
  - Visibility less than 5000m
- VA, Volcanic ash
- DU, widespread dust
  - Visibility less than 5000m
- SA, Sand
  - Visibility less than 5000m

Fog comprises water droplets or ice crystals
Fog can start to form whenever the difference between the dew point and the temperature is less than 2°C

Ice fog is fog composed of tiny solid ice crystals that were previously just tiny water droplets

Fog is classified according to the physical process which produces saturation or near saturation of the air:

- Radiation fog
- Advection fog
- Evaporation/steam fog
- Frontal fog
- Hill/up-slope fog

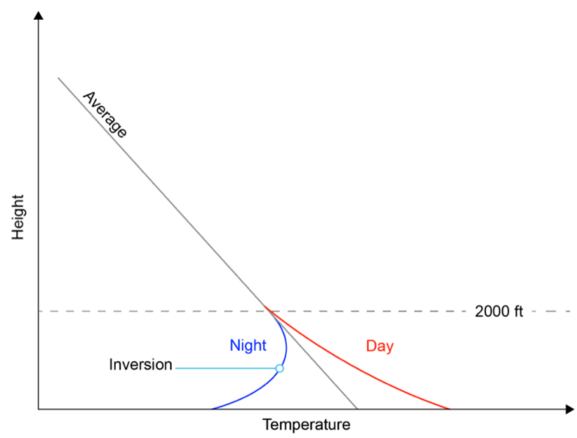
In non-tropical regions and away from coasts the most common type of fog is **radiation fog**

- It forms overnight over the land when the ground loses heat by radiation

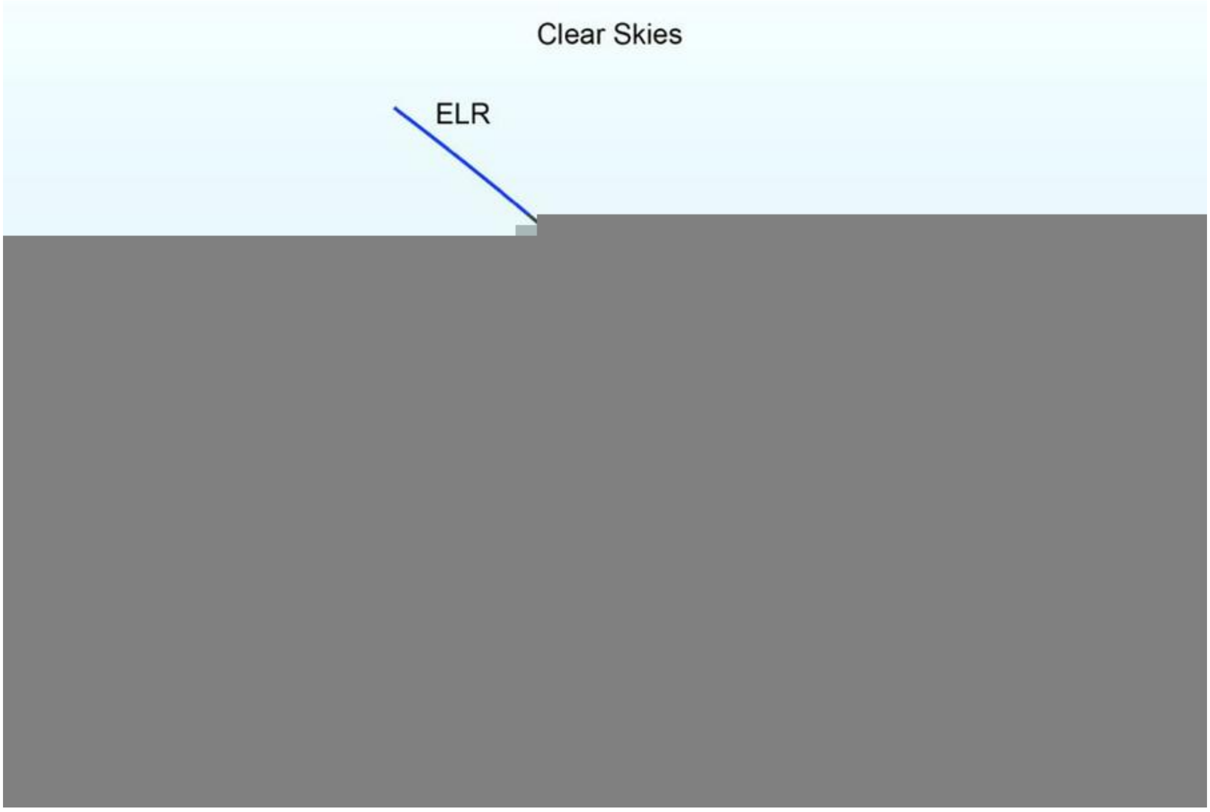
Ideal conditions:

- High relative humidity
- Light winds
- Clear skies and long nights

These conditions often prevail in temperate regions when there is a high-pressure system or a col over the land
As the ground cools overnight the layers closest to the surface become colder than higher layers → nocturnal inversion



As the fog forms the lapse rate becomes approximately isothermal from the ground upwards. Loss of heat by radiation from the ground is almost completely prevented by a layer of fog



Radiation fog often clears during the early mornings thanks to the warmth of the sun

Diamond dust is a special type of radiation fog comprising ice crystals

- It forms in clear skies in the very cold winter months over large land masses
- Formed by sublimation

Advection fog, is formed when relatively warm, moist, stable air moves over a cool surface

- The colder surface cools the warmer air from below

Steam fog, arctic smoke, evaporation fog; forms when very cold, stable dry air lies over a relatively warmer, moist surface

- The cold air causes the evaporating moist air to condense
- It forms in the same way vapour from a warm coffee

Frontal fog forms near a weather front when rain falling from relatively warm air above a frontal surface saturates the cooler air close to the earth's surface

- It disperses when the front passes

Hill/up-slope fog
It describes the surface visibility found in cap cloud conditions
When air is forced to rise up a hill it cools adiabatically, eventually a dew point is reached and clouds form. To an observer on the hill this would seem like fog

Snow can also reduce visibility to less than 50m, even snow being artificially blow can have an impact on visibility

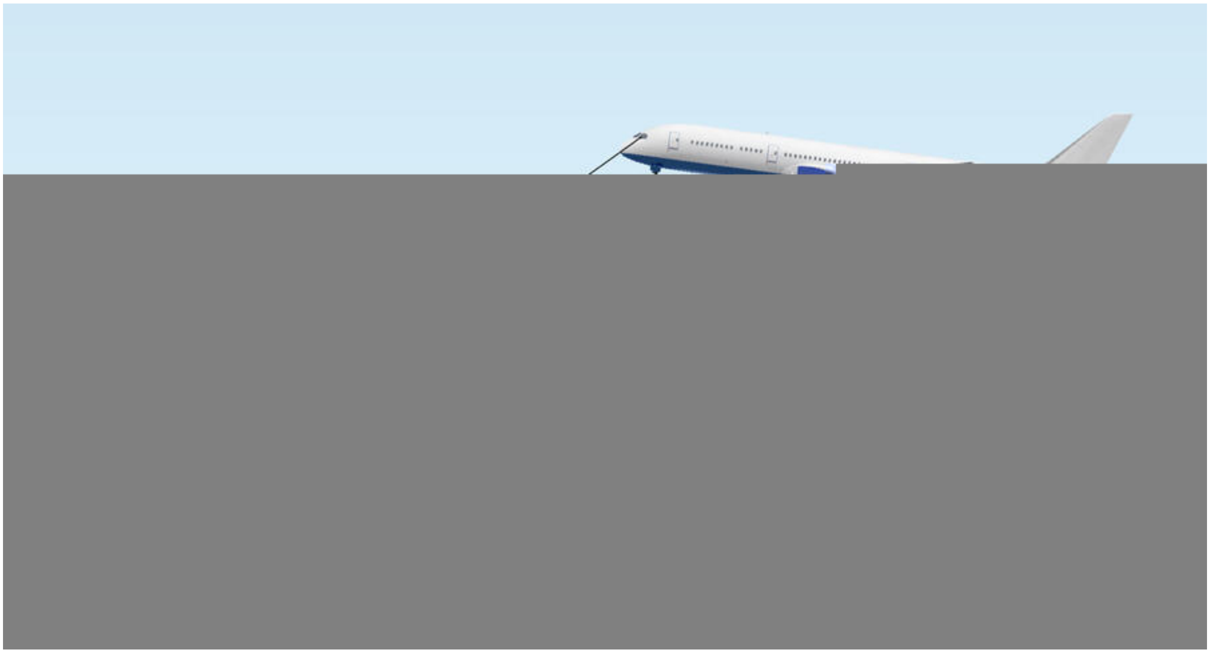
The meteorological name given to the reduction invisibility by solid particles is **haze**; when the particles are mixed with visible moisture this can form a particular dense from of pollutant known as **smog**

Volcanic ash can cause extreme reduction in visibility and may extend hundreds of miles, alongside posing a great risk to gas turbine engines

In dusty or sandy areas where the wind exceeds 15-20 kt, the particles may get picked up and carried upwards by turbulence to the full depth of the turbulence layer; 3000ft, smaller particles may rise all the way to 15 000ft in a dust/sand storm

When the sun is being reflected off the tops of clouds, haze or fog can cause adverse perspective of depth

When looking through a layer of fog, the air-to-ground visibility depends on the angle of view



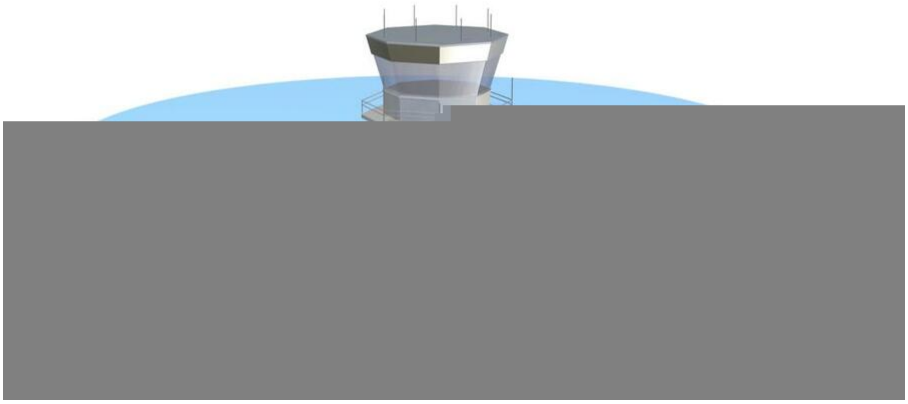
- The higher the aircraft, the greater the maximum forward visibility

Sometimes when the fog has lifted it might be nearly impossible to distinguish between fog and low stratus clouds

Reporting the visibility at ground level

The prevailing visibility is defined as:
The greatest visibility value observed which is reached at least halt the horizon circle or within at least half of the surface of the aerodrome

This case; 6km



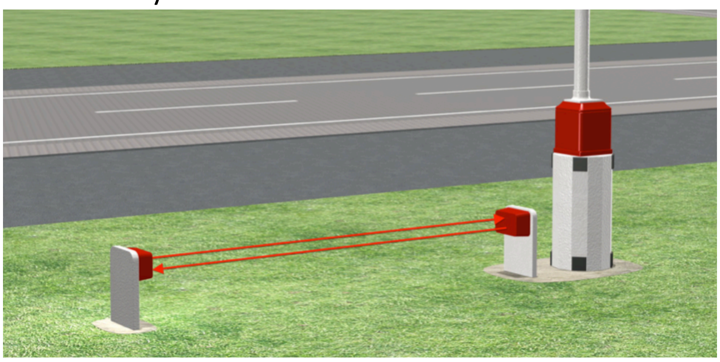
In local routine and special reports the visibility is reported in:

- Steps of 50m below 800m visibility
- Steps of 100m above 800m but below 5km
- Steps of 1km above 5km but below 10km

It's given as 10km if the visibility is 10km or more or CAVOK if clouds allow

Runway visual range, RVR, is the visibility at the surface near a runway in direction of landing

- Measured at 3 points along the runway, 2,5m above ground,
  - Threshold
  - Mid-point
  - Stop end
- When instrument systems are used, IRVR is updated at least every 60 seconds
  - Forward scatter meter and transmissometers
  - METARs and SPECI however s updated every 10 minutes
    - Reported in steps of 25m, below 400m; 50m, below 800m; 100m, above 800m
    - If the values fluctuate more than 100m between the first 5 minutes and the last 5 minutes it's indicated
    - U suffix means upward tendency, D = downward tendency; N = stable tendency



Vertical visibility is defined as:

- The distance one can see **upward** into a surface-based obstruction; or
- The maximum **height from which** a pilot in flight can recognise the ground through a surface-based obstruction

The conditions under which vertical visibility must be reported are:

- Whenever the sky is obscured by fog; or
- Heavy precipitation and the height of the cloud base cannot be measured

VV followed by a 3-digit indicated the height in hundreds of feet

CH 17

Air masses

The weather depends on the local characteristics of the air

An air mass is a large body of air which has approximately uniform characteristics of temperature, moisture and pressure horizontally

- Little pressure difference across the mass above the friction layer

This makes it move as a coherent entity

Air masses obtain their initial properties from the surfaces over which they originate

- Properties may be altered when the mass is moving over new surfaces
- Surfaces transfers their heat and humidity properties to the air above them
    - Hence, Warm water evaporates more readily

Weather conditions depend on what happens when a air-mass moves across the new area

For an air mass to assume the uniform properties of its underlying surface it must remain there for a significant period of time; days or weeks

- There are certain areas that allow for this:
    - The large high pressure zones, subtropical belt
    - High pressure, Polar areas
    - Seasonal, winter, High pressure areas

Air mass classification

It's 3-parted, 1st letter describing the humidity

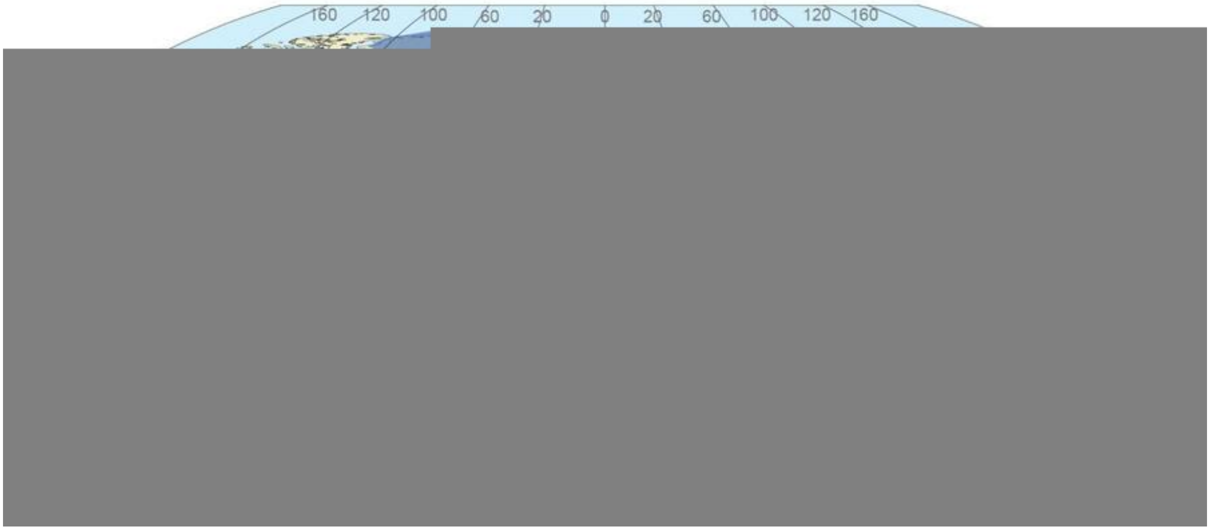
- Maritime, m
- Continental, c

The 2nd letter describes the thermal properties of the source region

- Equatorial, E
- Monsoon, M
- Tropical, T
- Polar, P
- Arctic, A
- Antarctic, AA

The 3rd letter is used to indicate if the air mass is warmer or colder relative to the surface which it moves over; may often be omitted

- Warmer, w
- Colder, k



General principles:

- An air mass moving to a warmer location is warmed from below
    - Increasing the ELR, and makes the airmass unstable
- Airmass moving to a colder region is cooled from below
    - Decreasing the ELR, making the airmass more stable
- If an airmass overflow the sea → it will gain moisture
    - Traveling over land causes it to become more dry

If you know the initial source region you can make a good estimate of the general characteristics of the weather

The principal source region which determines the European weather:

Tropical maritime, mT

- Source region; sub-tropical high pressure belt, particularly Azores
- Air is cooled from below
  - → more stable air
- High humidity levels
  - → condensation occurs readily
- Fog or low clouds with drizzle and poor visibility occur in the winter
- If the airmass passes land in the summer, surface heating usually disperses any cloud

Tropical continental, cT

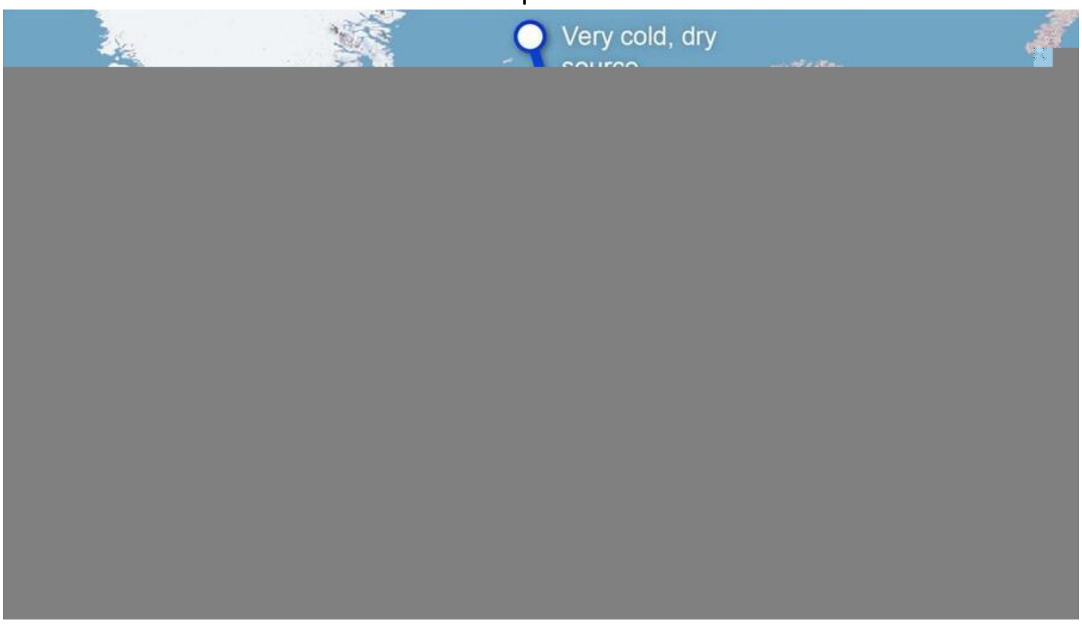
- Source region; northern Africa
- Air moving to higher latitudes is cooled from below
  - → increasing the stability
  - Very low dewpoint → hardly any clouds created
- Air is generally dry but may increase if it picks up from the Mediterranean
- Visibility is often reduced by dust particles

Polar maritime, mP

- Source region; polar region
- So far up north the temperature is low→ cold and dry air
- Heated by the warmer sea from below
  - As it heads southwards it warms and increases in humidity
  - Makes the airmass unstable
  - Showery precipitation and generally good visibility
- Most of the unstable weather in Europe comes from this
- In the summer as this air crosses much warmer land, heating from below is intensified→ more uplift→ thunderstorms

Arctic maritime, mA

- Seasonal, winter airmass
- Much colder, making it hold less moisture
- Air is unstable
  - Cumuliform clouds will develop



Returning polar maritime, rmP

- It has taken an extended route across a long sea track
    - Moving southwards it becomes unstable but when it turns north it becomes stable in the lower layers
    - Middle layers maybe unstable and have unstable characteristics

Polar continental, cP -summer

- Source: warm dry air from central Europe
- Little modification to the mass as it moves in over Europe
    - Produces warm dry, hazy conditions
- By the time it reaches UK it might have accumulated some moisture and small amount of instability

Polar continental, cP -winter

- Source: cold dry air from Russia
- The track is over land producing cold dry conditions
    - Often leading to hard frosts overnight
- The airmass might pick up moisture over the north sea causing the UK to gain some instable masses

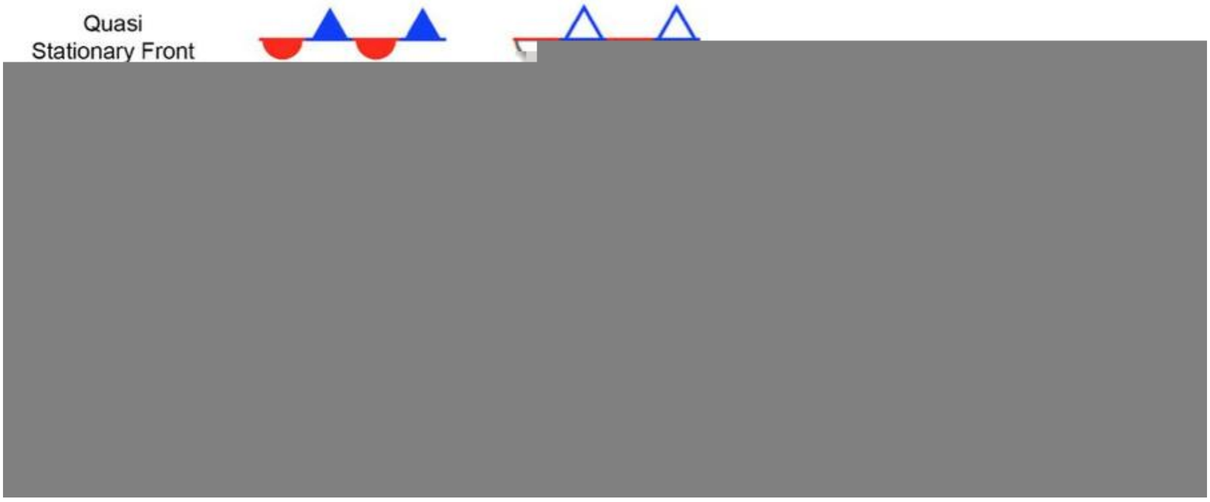
In practice, no two air masses are the same, nor is it truly uniform in its contruction

CH 18

Because of different densities airmasses tend not to mix or merge

- The boundary between one airmass to the next is not sharp
  - It occurs over typically a few kilometres
- The conjunction zone is called a front

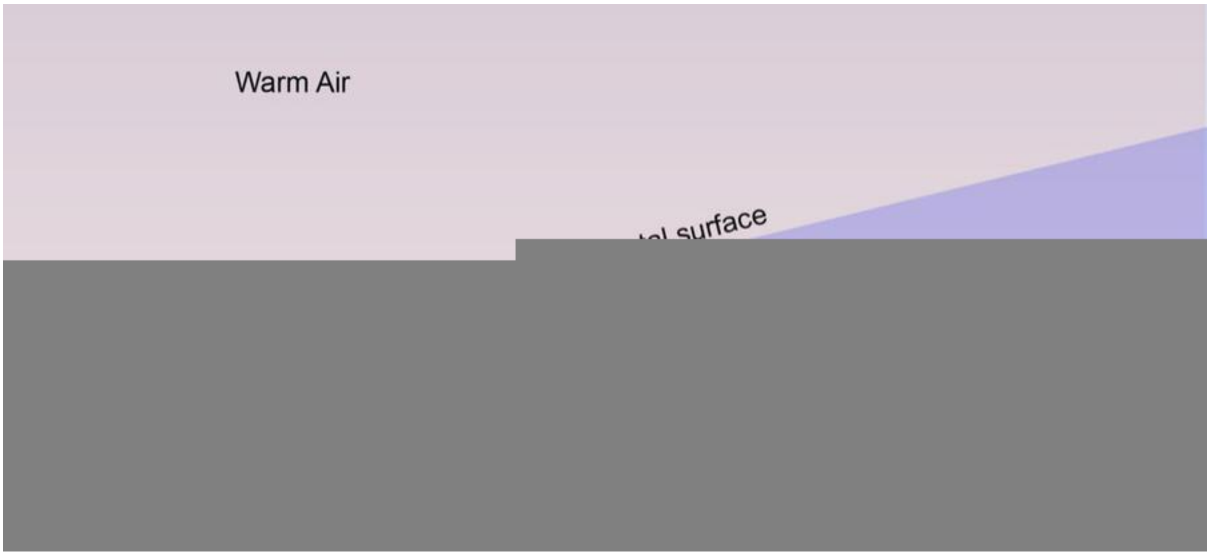
Fronts produce significant amounts of cloud and precipitation; surface positions are usually marked:



When a transition between 2 airmasses occurs gradually, usually 200-300km, it's known as a transitional zone rather than a front, usually calm weather

General properties of fronts:

- Most significant being the temperature, therefore the identification; warm/cold front
  - When warmer air displaces colder air it creates a warm front
  - When colder air displaces warmer air it creates a cold front
  - If there's little movement of either airmass then the front is stationary/ quasi-stationary
- The sloping boundary between airmasses is known as the frontal surface
  - This defines the position of the front

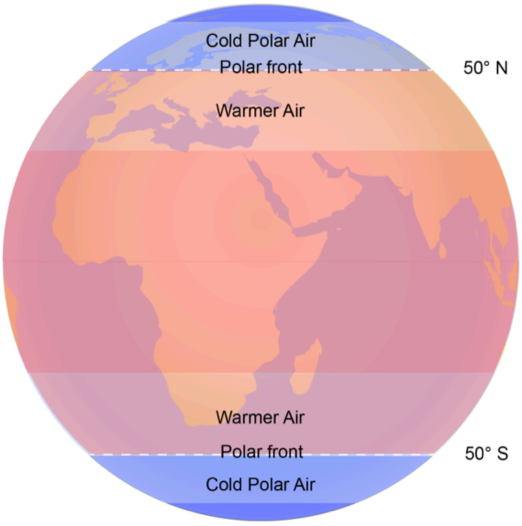


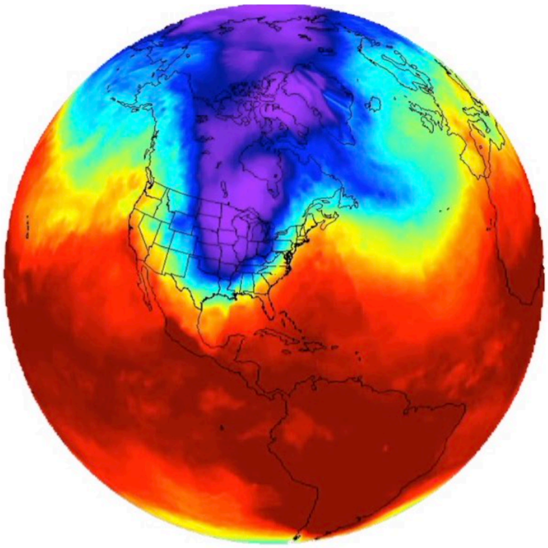
- Cold air is denser than warm air → it undercuts the warmer air mass
    - This produces a local inversion called a frontal inversion
- Warmer air rides over a cold dense airmass
    - Very different frontal slope gradients are created

Fronts form relatively sharp temperature boundaries which is why they create jet streams

The polar front; marks the boundary between the polar maritime and tropical maritime airmasses

- most pronounced over the oceans
- almost completely circumnavigates the globe
- between the polar cells and the Ferrel cell





- in reality, the n.hemisphere zigzags considerably around its position
    - found as low as 35°N, winter; and high as 65°N in the summer
- the s.hemisphere is more stable in place

the front is clearly identifiable in the north,

- mid-winter it extends from Florida to the SW of UK
- summer, from Labrador to northern Scotland

notice how depressions are formed along it; **these are the polar front depressions**

The arctic and Antarctic fronts mark the boundary between cold polar air and relatively warmer polar air mass

- winter phenomena
- the temperature boundary at this front creates the arctic front jet stream
- the fronts may move into lower latitudes in the winter months

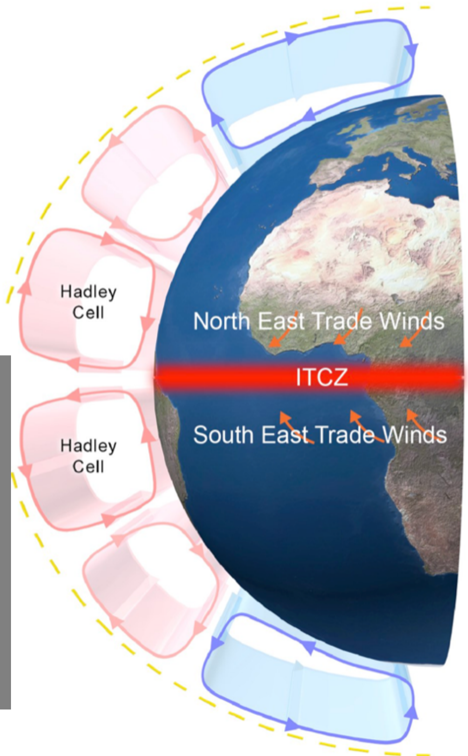
The Mediterranean front

- exists only in the winter
- is created because the sea is relatively warmer than the land surrounding it
    - creating a low pressure zone
- some of the winds are so regular they have local names
- this front often produce large active weather with large convective storms and strong winds

The inter-tropical front, ITCZ

Is the global zone of convergence between air masses carried by trade winds

- intense heating causes air to rise and draw in surface air from either side
- ITCZ varies significantly with season→ shifting the heat equator and therefore also the inter-tropical front



Polar front depressions

Whenever there is relative movement between 2 fluid streams then the turbulence, in the form of whorls and waves, is created

- This phenomena applies equally to air as it does to any other fluid

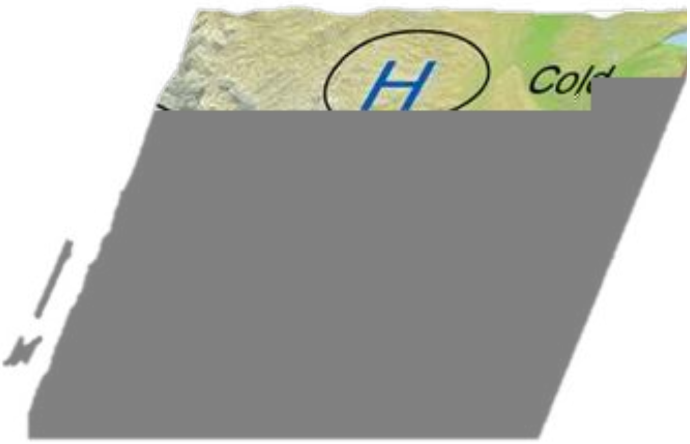
The trigger for a polar front depression is that it's caused by the turbulence at the boundary between the 2 airmasses

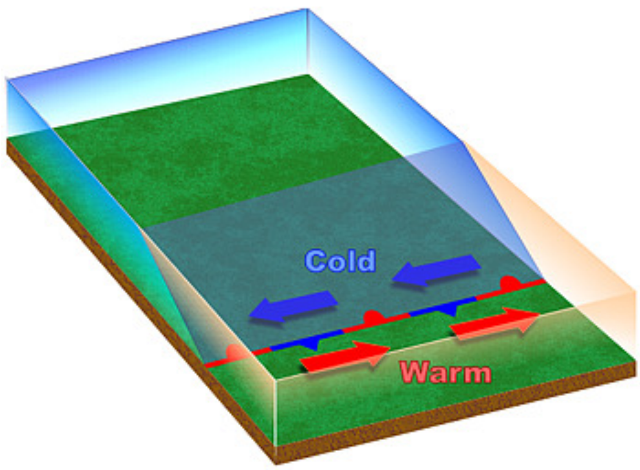
Polar front depressions are generally accepted to follow 6 stages of development:

- Stage, cyclogenesis/frontogosis
    - The formation of depressions, and anticyclones, along the polar front
    - Driven by the flow dynamics of the polar front jet stream and airmass movement
    - Once airmasses form, they may be put into motion by the large scale weather pattern and the jet stream
    - Development of polar front depressions most often occur underneath areas located downstream of 500hPa throughs; blue X; the jet stream diverges as this point pulling air vertically beneath it→ surface convergence
    - This creates a low pressure; blue line, red X describes converging air creating a high-pressure
    - Making colder air flow in a southernly direction; leading edge forms a cold front; warm air is pushed northwards creating a warm front

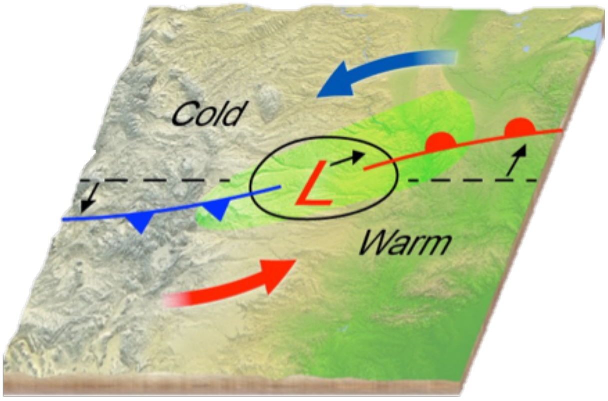
.

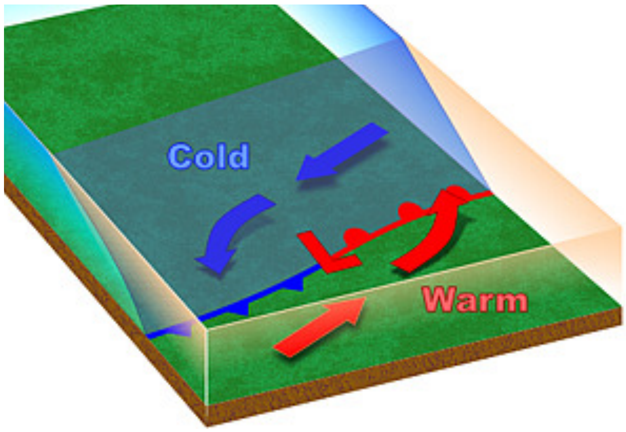
1. Stage, cyclogenesis/frontogosis
    a. Considering the initial stage, the isobars are parallel, wind blows parallel to the front; unique feature of a quasi-stationary front
    b. Partly because of the jet stream, unstable wave-like disturbances occur along the front's axis, crest to crest ≈ 650-1600nm



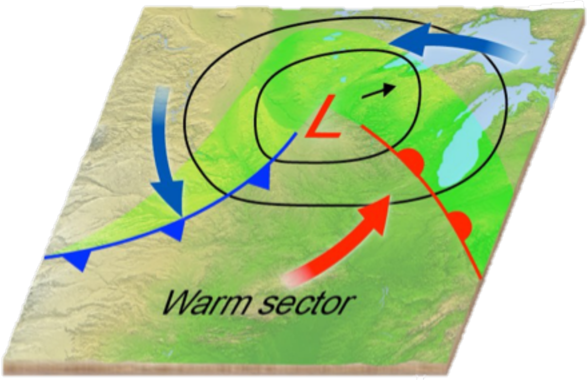


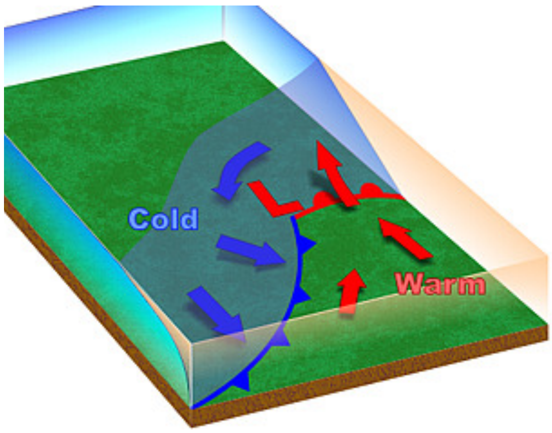
2. Frontal wave (The mature stage)
    a. A small low pressure area develops as a result of the wave
    b. A wedge of warm tropical maritime air starts to push into the cold air at the surface



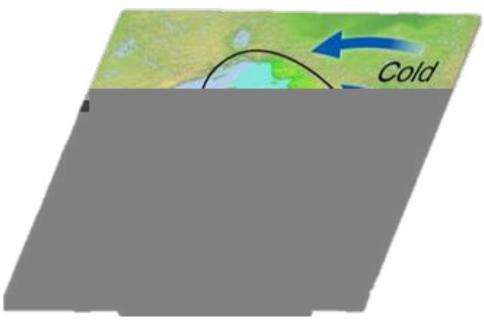


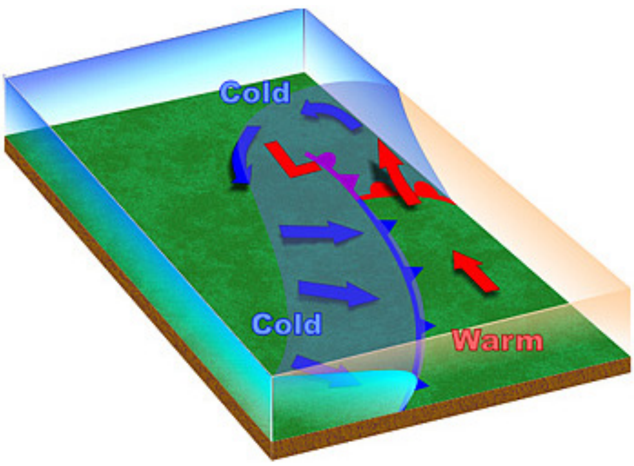
3. open wave (The mature stage)
    a. The low pressure draws in surface air from either side
    b. →the wind starts to curve towards and around the tip of the wedge
    c. →this circulation converges so air rises



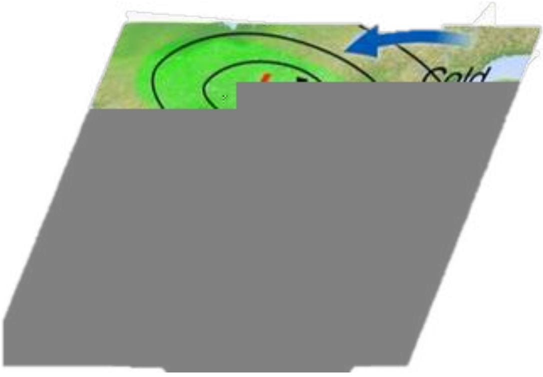


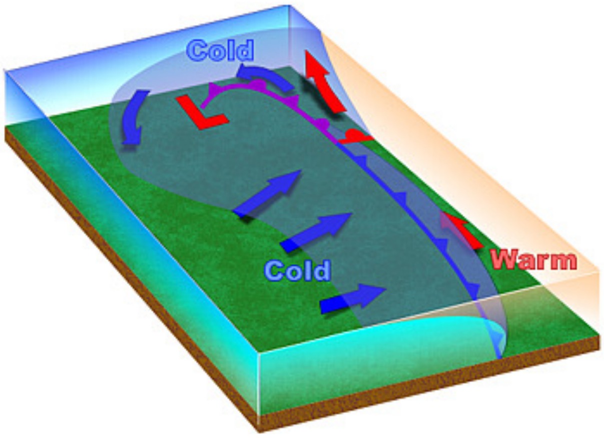
4. Initial Occlusion stage
    a. as the pattern of circulation develops the airmasses begins to move
    b. the cold polar maritime air moves SE pushing the warm air to create a cold front
    c. the warm air within the wedge moves NE pushing against the cold air to create a warm front



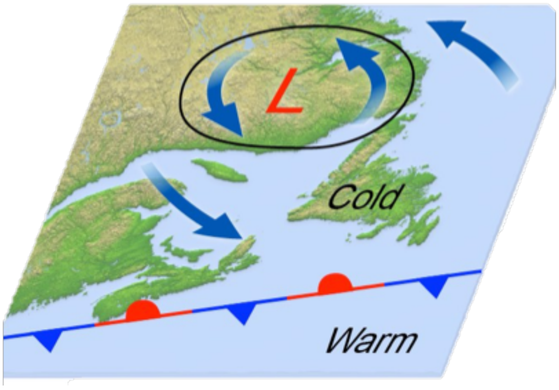


5. Advanced occlusion
    a. Eventually the wave develops into a mature polar front depression

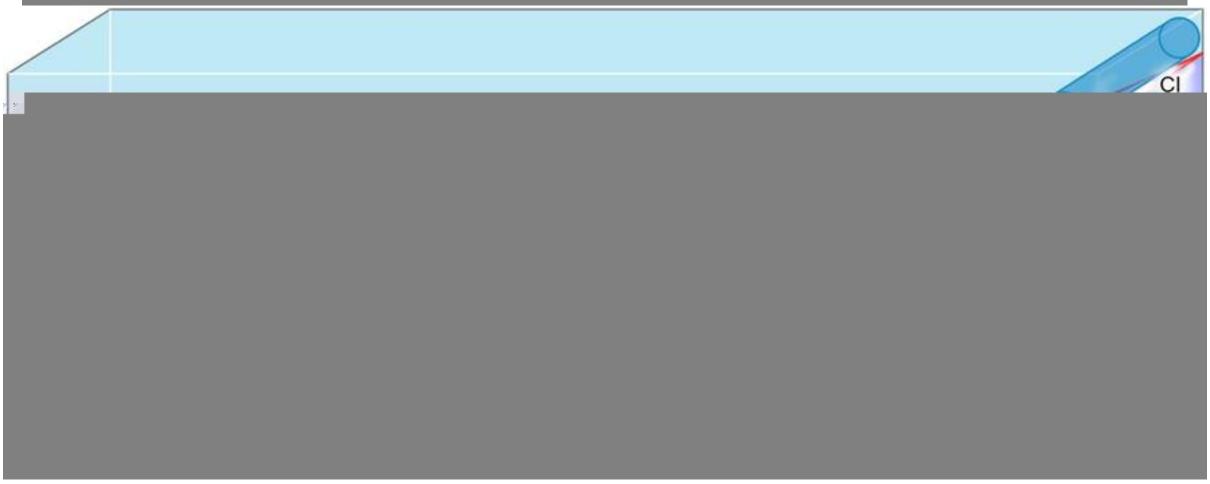




6. Cut-off cyclone (Dissolving stage)



The warm front



- The tropical maritime air in the warm sector is being forced towards the polar maritime air
- It slides up and over it, causing the warm front to lean forward; slope 1 up, 150 fwd
- As the air slowly rises it cools adiabatically
    - Condenses to produce stratiform clouds

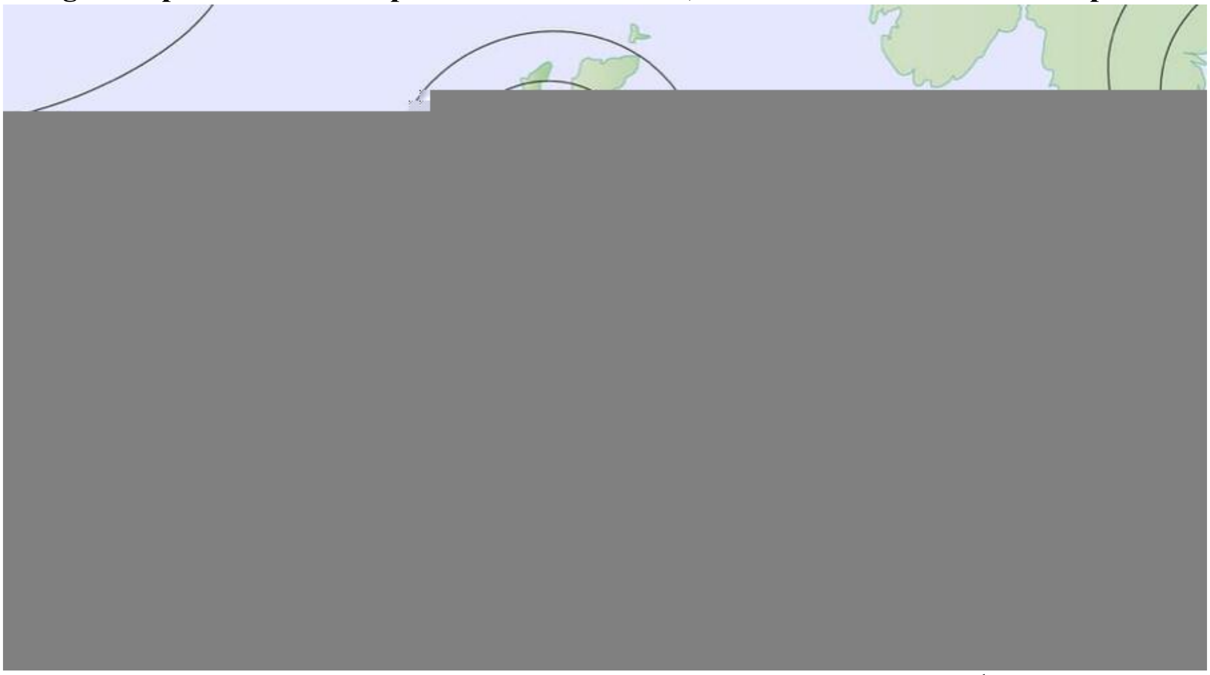
- At position A, the first sign of the warm front is the arrival of high cirrus clouds
- As the front gets closer the cloud base lowers and the cloud thickens into altostratus
- About 200nm ahead of the front, the clouds are thick enough to be rain bearing, NS
- Rain falling from the AS evaporates and can saturate the air just ahead of the front
    - The front might take a day to pass and can cause freezing rain/drizzle when it passes over cold land masses in the winter
    - Extensive periods of rain in the summer

Because of the lowering cloud base and increasing precipitation the visibility steadily worsens

The jet stream, or the strongest wind, occurs between A and B

- Found beneath the polar air tropopause
    - 300-400nm ahead of the warm front

The geostrophic wind blows parallel to the isobars; low to the left in the n.hemisphere



The warm front usually moves parallel to the isobars behind the front at 2/3rd of the geostrophic windspeed; about 10-15kt

The air within the warm sector is typically tropical maritime/continental

- Winter; widespread low stratus/stratocumulus may predominate
    - Clear skies may occur if humidity levels are low
- Summer; fair weather cumulus can form over land
    - If it's cT→ generally clear skies

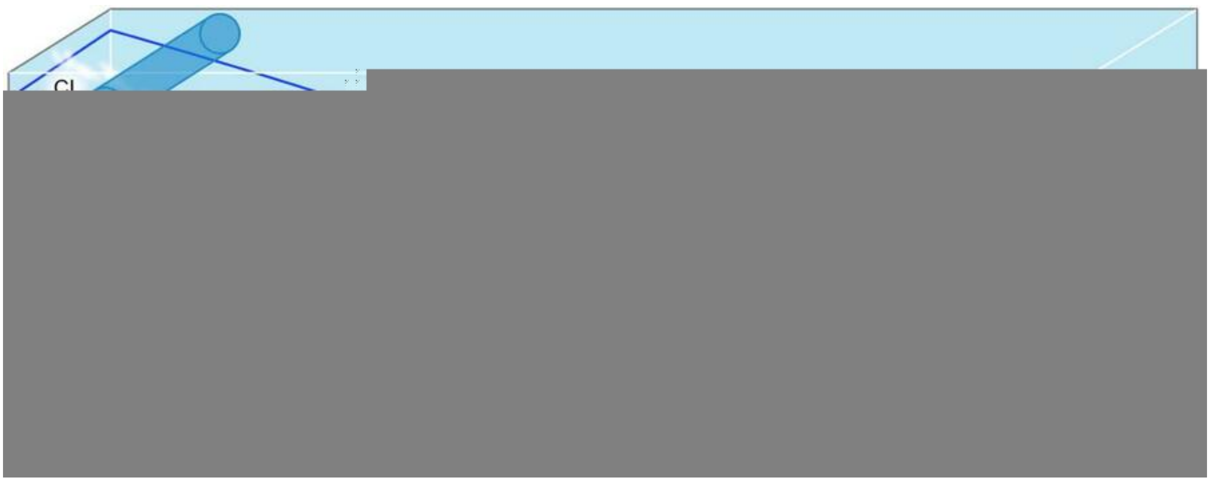
The surface pressure falls slightly within the warm sector up until the cold front arrives

The cold front

- It slides underneath lifting warmer tropical maritime air
- The rising maritime air cools adiabatically
    - Cools and condenses forming clouds along the front
- The cold nose steepens at the cold front 1:50 or 1:75
    - This dramatically increases the ELR leading to marked instability and creating an intense line of CB clouds
    - An additional problem is that the thunderstorms are embedded with more "kind" NS and AS clouds
- The front can produce intense downpours in the summer
    - Heavy snowfall in the winter
- When the front has passed, expect the cloud base to rise, clouds to reduce and precipitation to reduce, pressure to rise and wind to veer sharply

Behind the front, the southward moving air is warmed from below making it unstable

- Producing scattered, isolated Cu behind the front

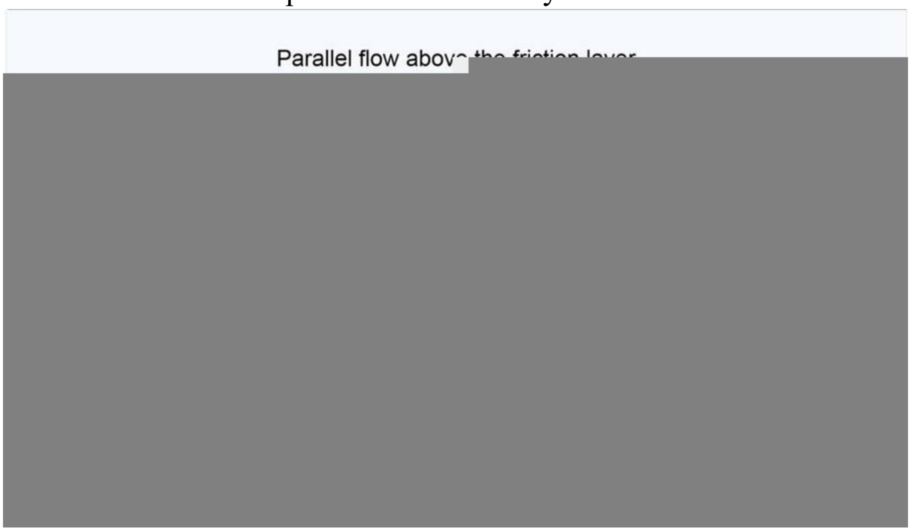


The likely position of the jet stream, or strongest wind, is between C and D; found beneath the polar air tropopause about 50-200nm behind the surface position of the cold front

The cold front moves parallel to the isobars behind the front, however, it moves faster than the warm front; at the geostrophic wind speed

When a front is **quasi-stationary** it's moving <5kt, with respect to each other

- weather usually persists for longer periods
- On a chart the isobars are parallel to the front
- Wind above the friction layer blows along the front
  - In the friction layer there's a slight inflow of warm air causing uplift; weather formation trigger
    - Weather depends on the stability



Stable stationary front

- Stratiform clouds form in the warm air above the front
  - Drizzle or light rain in the summer
  - Light sleet or snow in the winter
    - Above the freezing level, icing conditions may be present

Unstable stationary front

- Cumulus will form, often embedded within other stratiform clouds
- A shallow sloping quasi front results in a wide area of showers and frontal fog
  - In the winter this may be showers of snow

Over the Atlantic and western Europe, mature depressions move approx. SW or NE. more accurately in the direction of the isobars in the warm sector

If the warm sector is rising more than the initial forced ascent along the front it's called an **ana front**

- The front is a lot more active because there's effectively twice the lifting
  - Bringing heavy precipitation and a deep layer of cloud

In the **kata front** the warm sector air is descending, the weather is less intense, with a shallower cloud belt

- This usually occurs when the depression is filling and weakening

Depending on the situation, mountains can strengthen, weaken, accelerate or decelerate fronts; **mountain effect**

- Channelling mountain ranges may accelerate
- A front might be blocked and therefore slowed

Occluded fronts

Since the cold front travels faster than the warm front, at the wedge extending outwards, it will sooner or later catch up

- The cold front undercuts the warm sector
- Along the occluded front the entire warm sector is squeezed up above the surface
  - This generally increases the amount of cloud and precipitation

Occluding process is the term used, occluded when it's finished after this it enters the dissolving stage, characterised by uplift

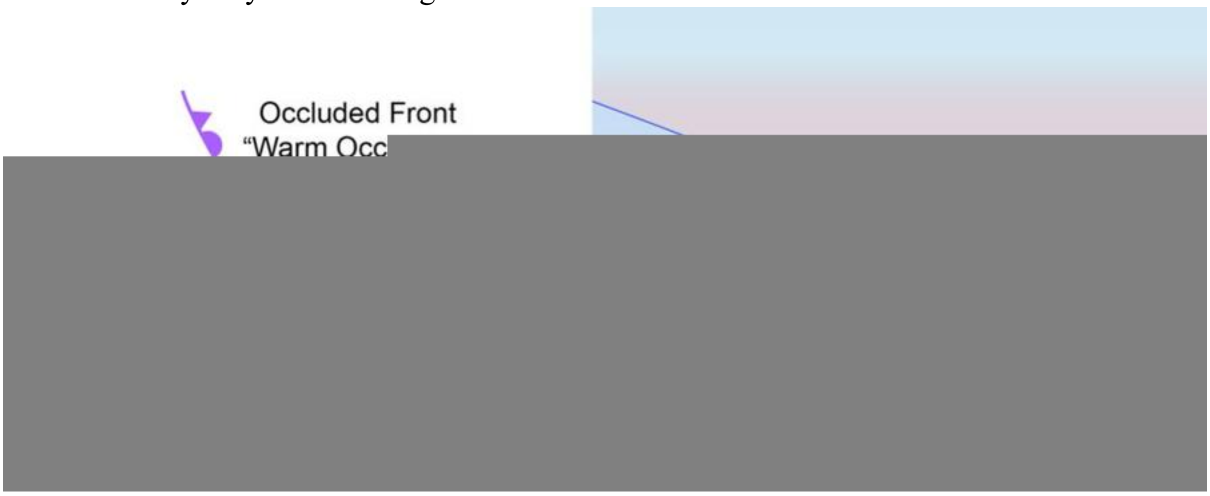
The position and shape of the line of occlusion is subject to many variations

- A bent back occlusion create an additional band of weather

One side of the cold polar maritime air either side of the warm sector is often colder than the other this determines the type of occlusion; warm/cold

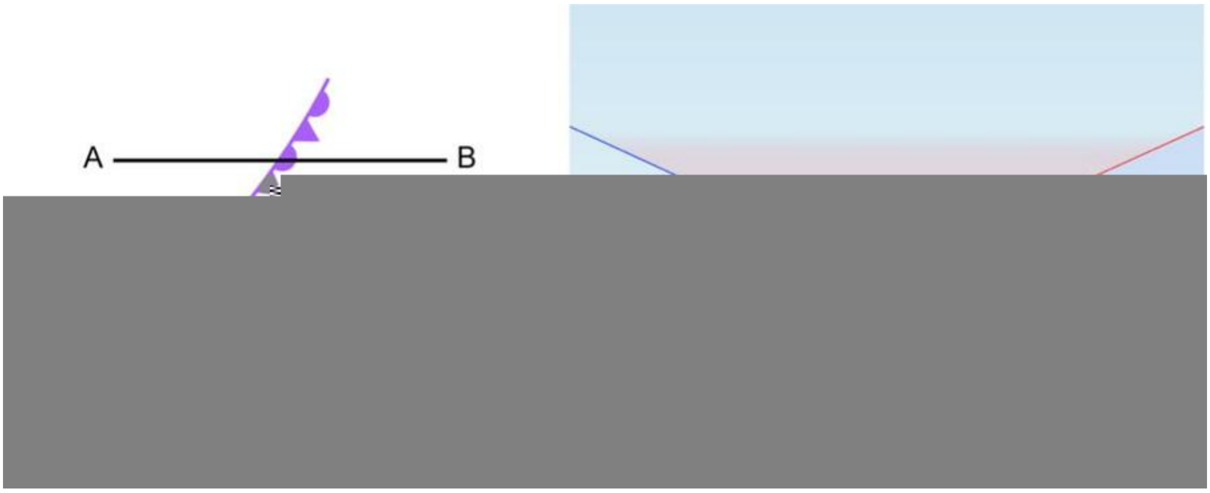
Warm occlusion occurs when the cold front rides up and over the warm front:

- Usually only found during the winter



Cold occlusion occurs when the cold front slips underneath the warm front:

- More common in the summer months



CH 19
Non-frontal depressions

Depression are frontal or non-frontal, the main causes of non-frontal depressions are:

- Thermal activity
    - Form when air warmed by the surface rises and diverges at higher levels
    - Can also happen on a really big scale, ITCZ, or heating of the Indian sub-content (Asiatic low)
- Orographic processes

The intense heating in the equatorial regions is the largest example of a non-frontal thermal depression

The Asian land mass is very large and extends into the tropics

- South of the Himalaya intense surface heating in the summer months reduces the surface pressure to from a huge thermal depression
    - It draws warm, moist air from the Indian ocean, as the air warms further it rises and condenses to produce enormous band of rainfall traveling from southern India up to the Himalayas; this is the southerly monsoon
        - Summer phenomena

Polar air depression; at high latitudes there may be a significant difference between the cold air masses and relatively warmer sea causing low-pressure systems to form

- They are generally weaker than other low-pressure systems

The waves of weather associated with the equatorial low-pressure belt, ITCZ, can under special conditions develop into large and most destructive weather on earth, TRS

Tropical revolving storm can produce extreme wind speeds, torrential rainfall, thunderstorms and tornadoes; diameter around 300nm

Pre-existent conditions:

- Large water mass at least 26.5°C
    - Energy source
- Unstable atmosphere, needs to be a deep layer
    - sustainment
- Moist mid-troposphere
    - Conductivity, thunderstorms
- A minimum distance of 500nm from the equator
    - Coriolis
- A pre-existing near surface disturbance
    - Trigger
- Low magnitude vertical windshear between the ocean's surface and the upper troposphere
    - Preventing the vertical flow of air leading to the formation of TRS

Most of the storm's energy is derived from the massive amounts of latent heat set free during condensation

Stages of development, based on the organisation of the storm and the sustained wind speed

Stage 1. Tropical disturbance
A cluster of showers and thunderstorms over the tropics typically 200nm diameter moving westwards; lasting for more than 24 hours; no closed wind circulation

Stage 2. Tropical depression
When the first appearance of lowering pressure and organised circulation in the centre of the thunderstorm occurs; winds 20-34 kts

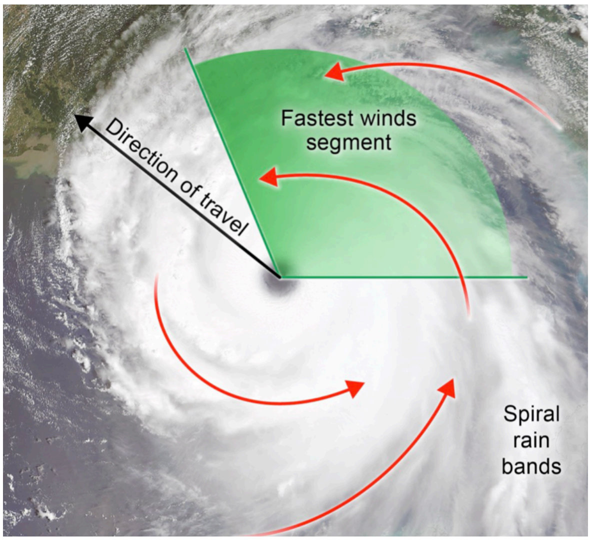
Stage 3-4. Tropical storm/ severe tropical storms
It becomes more organised; circular rotating appearances; wind speeds 35-63kt

Stage 5. Tropical Cyclone/Hurricane/Typhoon
Surface pressure continues to drop; wind speeds exceed 63kts; fully developed forms an eye and surrounding eye wall

Fully developed TRS are further classified into 5 categories; CAT 5 being the most violent with sustained wind speeds up to 170kts, and surface pressure as low as 860hPa

Fastest winds are usually found to the right of the track in the n.hemisphere; left in the s.hemisphere.

- This area pushes sea up to 30ft higher than normal
- When forced against land it creates a storm surge



- The most recognisable feature of a TRS is its eye
    - Diameter 20-50km
- Tightening of the eye signals that the storm is strengthening
- Within the eye are the lowest surface pressure and calmest conditions
- The enclosing eye wall is the most devastation region in terms of wind and rainfall

TRS originate within 5° to 15° of the equator and move westwards, curving away from the equator

They also travel at around 15kt lor less and at a reasonable predictable path

In the Atlantic, hurricanes begin as tropical easterly waves which get pushed westwards

- Created by an area of convergence at the African west coast
    - Causing huge uplift, generating intense convective cells
- Storm cells are then carried westwards across the Atlantic by the prevailing easterly winds

Typhoons, Asian TRS, are the most severe and frequent, commonly also the largest

TRS are a phenomena of the late summer and early autumn months

- Occurring between June and October in the n.hemisphere
    - December and April in the s.hemisphere

Basin	Season start	Season end	occurrences
N.atlantic	June	November	6
E.pacific	May	November	15
W.pacific	January	December	25
N.indian	January	December	6
SW.indian	June	July	10
Australia	November	April	11
S.pacific	November	April	7

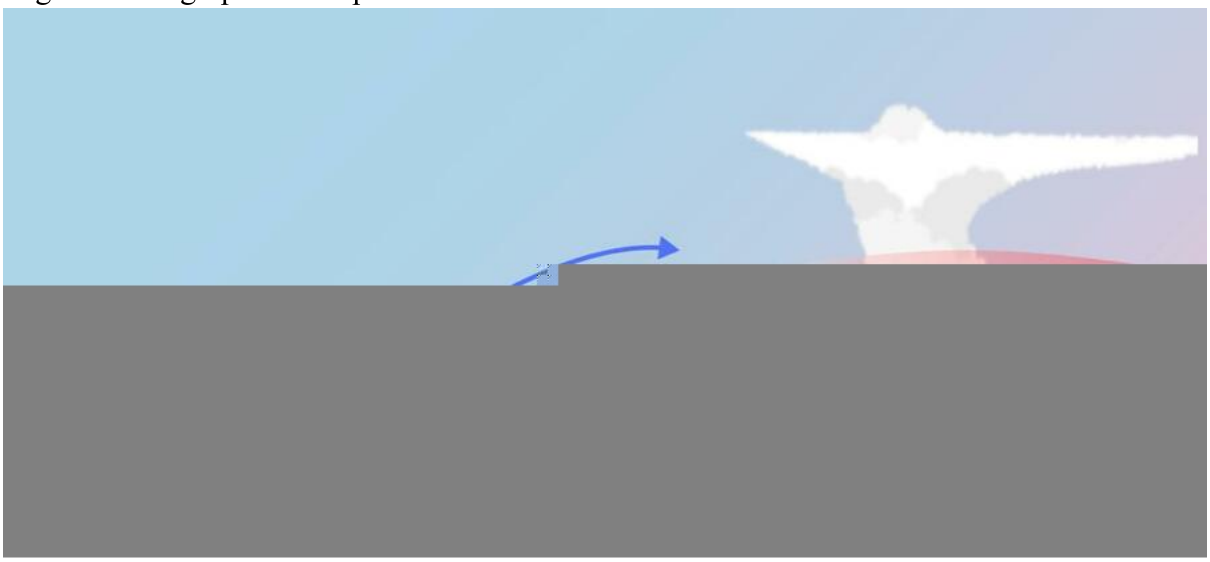
The first indication of an approaching storm is the thick high-level cirrus clouds formed by the air hitting the tropopause and spreading outwards from the eye

Dissipation

- If they stray over land their energy source is removed
- Hurricanes from the west Indies fade as they move into colder seas at higher latitudes

An orographic depression is a low-pressure area that forms on the lee side of a mountain/hill range

In general orographic lows produce little weather because of the Foehn effect



This produces a depression and great instability on the lee side, as the warm underlies the cold

Secondary depression are depressions that form within the circulation of the main depression

- They move with the primary depression
- Secondaries may grow large enough to swallow the primary
- Weather conditions are sometimes more severe in the secondary

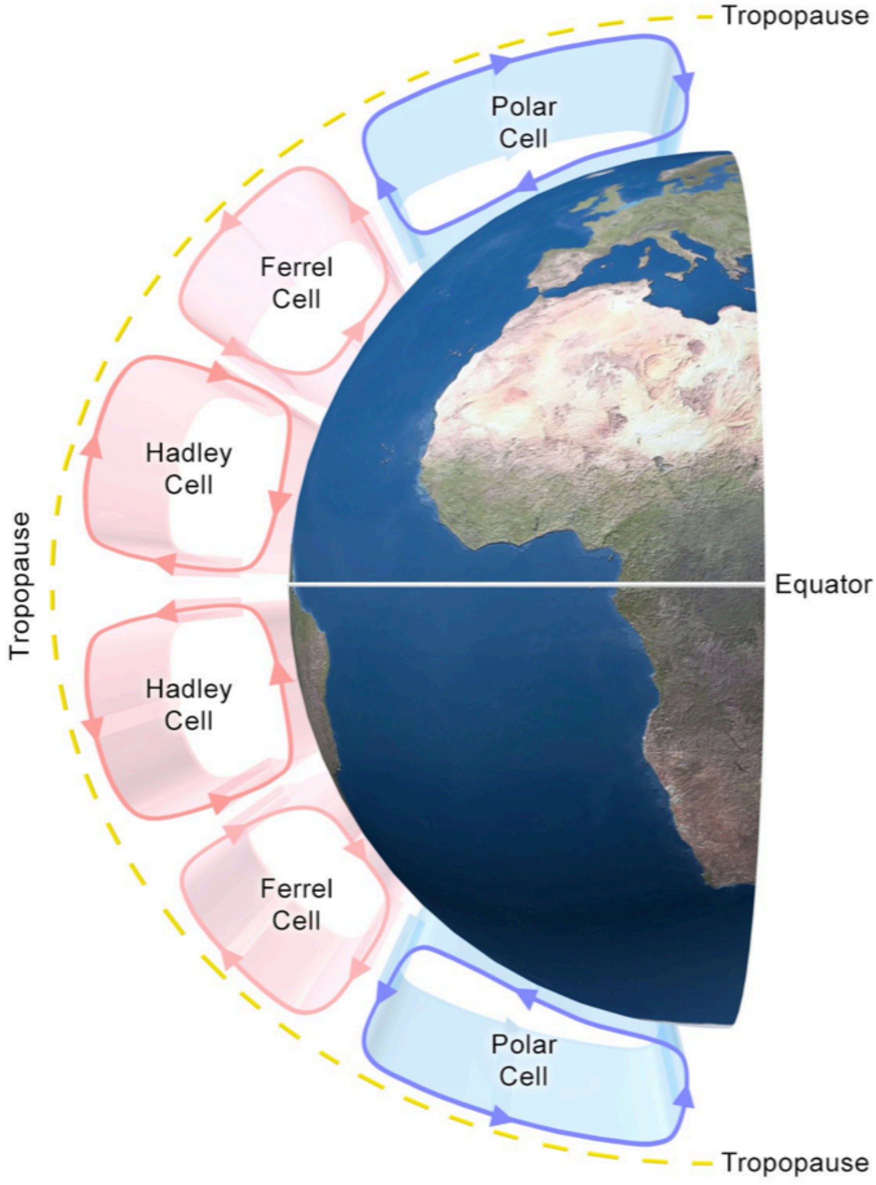
Frontal secondaries; A secondary depression may also form on a trailing cold front which in turns may from a new primary depression or rotate within the main system

CH 20
Climatology

The circulation of air in the troposphere drives global weather pattern

- The pattern begins at the heat equator, **equatorial low-pressure belt**, where hot air rises and spreads outwards at the tropopause
- After spreading out it's turned by Coriolis force then cools and sinks to create areas of mass descent, **subtropical high pressure belt**

This creates the first cells; Hadley cells

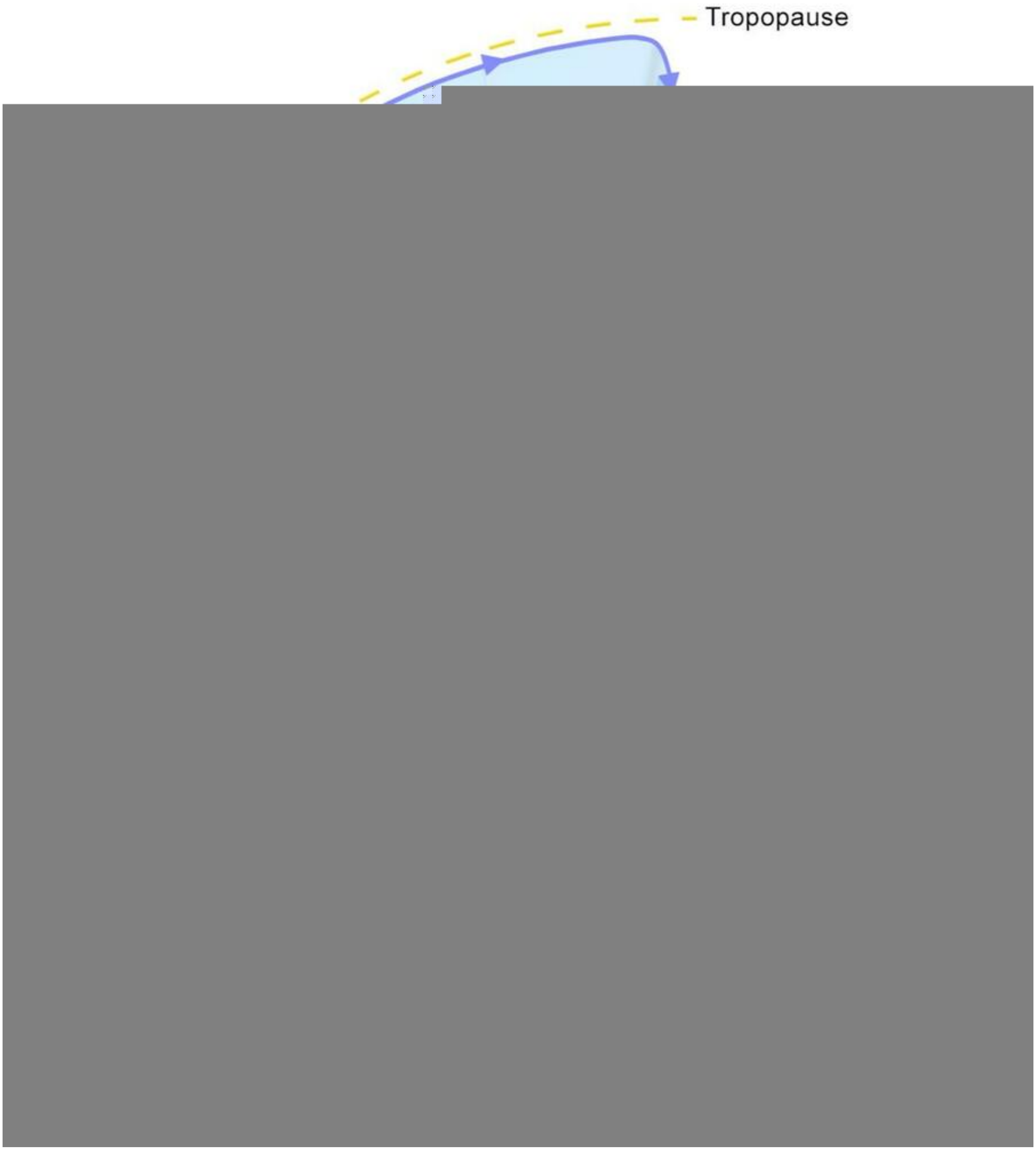


The sinking air splits at the surface, between Ferrel and Hadley, some going north and some south.

- The northbound flow meets the cold sinking air at the poles to form an area of converging thus rising air; this is the polar front. This creates the 2 other cells seen in the picture
- This area has relatively dry, cloudless skies
- As the air descends come return back to the equatorial low-pressure belt; these surface winds are called Trade winds

The descending air at the sub-tropical high also diverges to higher latitudes

- This area of convergence forms the polar front and creates polar front depressions affecting the temperate mid-latitude regions



Comparing this to the real world the model works quite well in the southern hemisphere however, the large landmasses in the northern hemisphere alter the pattern

During the winter in the northern hemisphere the land masses call down producing two major anticyclones, Siberian high and north American high →

Broadly stable distributions of highs and lows produces regular patterns of wind driving the movement of airmasses which in turn creates weather

The doldrums

- At the surface of the ITCZ converging winds cancel each other to produce areas of calm conditions persisting for days or even weeks

The trade winds

- When they cross the equator to get to the ITCZ, the Coriolis force changes their direction making them come from NW or SW
    - Instability is increased if they collect moisture from the sea
- Trade winds steer the path of tropical storms that form on the eastern side of oceans → pushing them westwards

The horse latitudes

- In the n.hemisphere in the Atlantic, the area where light and variable conditions prevail; due to widely spaced isobars in large scale high pressures
- 30 - 35°N

The roaring 40s and Furious 50s

- The strongest sustained winds created by the global weather patterns
    - Westerly flows, found between 40° and 50°, between sub-tropical highs and polar front lows
- Much stronger in the s.hemisphere as there are less land masses to disrupt the flow

Classification of climates

Based on the 5 vegetation groups characterising the zones:

- Equatorial zone; tropical rain climate; dark blue
- The arid zone; dry climate; orange and red
- Warm temperate zone; light green and light blue
- Snow zone; sub-arctic climate; Olive green
- Polar zone; snow climate; Grey

This coincides fairly well with the density of vegetation across the earth:

The equatorial zone

- Spans from the equator to 20°
- Highest annual rainfall of any area, and where the tropical forests are found

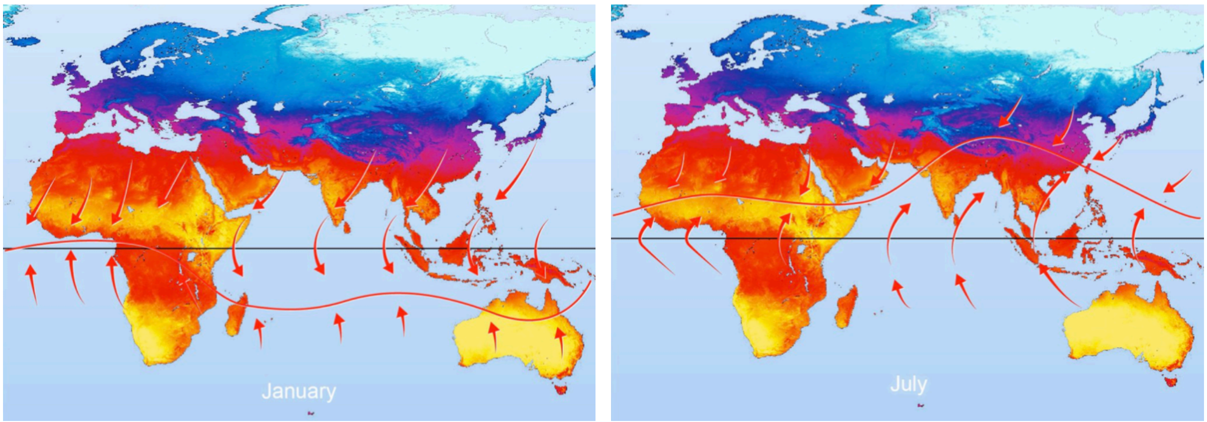
Sub-divided into 2 sub-zones:

- The tropical rain forest climate; 0° to 10°
- The tropical savannah; 10° to 20°

Significant weather characteristics:

- High temperatures, with little seasonal variation
- Very high humidity
    - Convective weather
- Always under the influence of the ITCZ which passes through it twice a year
- The trade winds dominate the region, slightly modified by Monsoon effect
- At the convergence zone winds are very light or non-existent; Doldrums (surface winds)
- The tropical rain forest climate is classified as monsoonal when the rain falls in distinct seasons

As a result of the moving ITCZ there's only one rainy season for the tropical savannah climate



The arid zone

- Spans from 20° to 40°
    - Sub-divided into desert and steppe (steppe being further away from the equator)
- The desert region having less precipitation
- Steppe regions having a slight amount of rainfall producing low-growing vegetation

Significant weather:

- Sub-tropical high pressure belt results in descending air and little cloud formation or precipitation
- Very hot summer with large seasonal variation
- Trade winds

The warm and cool temperate zones

- Between 40° and 70°
    - The warm temperate zone being the lower end of this latitude

Significant weather, cool temperate zone

- Predominantly westerly winds with the frequent passage of frontal depressions
- In the s.hemisphere there are strong, persistent westerly winds such as the roaring 40s
- No dry season
- Seasonal variation

Significant weather, warm temperate

- Transitional climate; large seasonal variations
- Winter; conditions are similar to the cool temperate zone
- Summer; the sub-tropical high pressure areas are associated with the arid zone predominantly
- Hot dry summers and cool wet winters

The snow zone

- Dominated by tundra and permafrost conditions

Significant weather

- Long cold dry winters and hot summers, seasonal temperature variations can be 60°C
    - Average temperature below 0°C

The polar zone, significant weather

- Extreme seasonal variation
- Extremely cold winters
- Periods of constant darkness
- Little or no precipitation
- Dominated by high pressure systems at each pole

The tropics, between Capricorn and cancer

- Usually defined as climate in which surface temperature does not fall below 18°C
  - Little annual variation
- Not the hottest places on earth
- Rain in the tropics sees both extremes
  - Ranging from 1mm per year in Atacama and 10meter per year in Hawaii
- Subdivided into 3 zones:
  - Tropical rainforest/equatorial
    - High monthly precipitation; no less than 6cm per month up until 2m per month
    - high humidity
  - Tropical monsoon
    - Greater than 1m of precipitation per year
    - Large variations in humidity
  - Tropical wet and dry or savannah
    - Less than 6cm of precipitation for any month and less than 1m per year

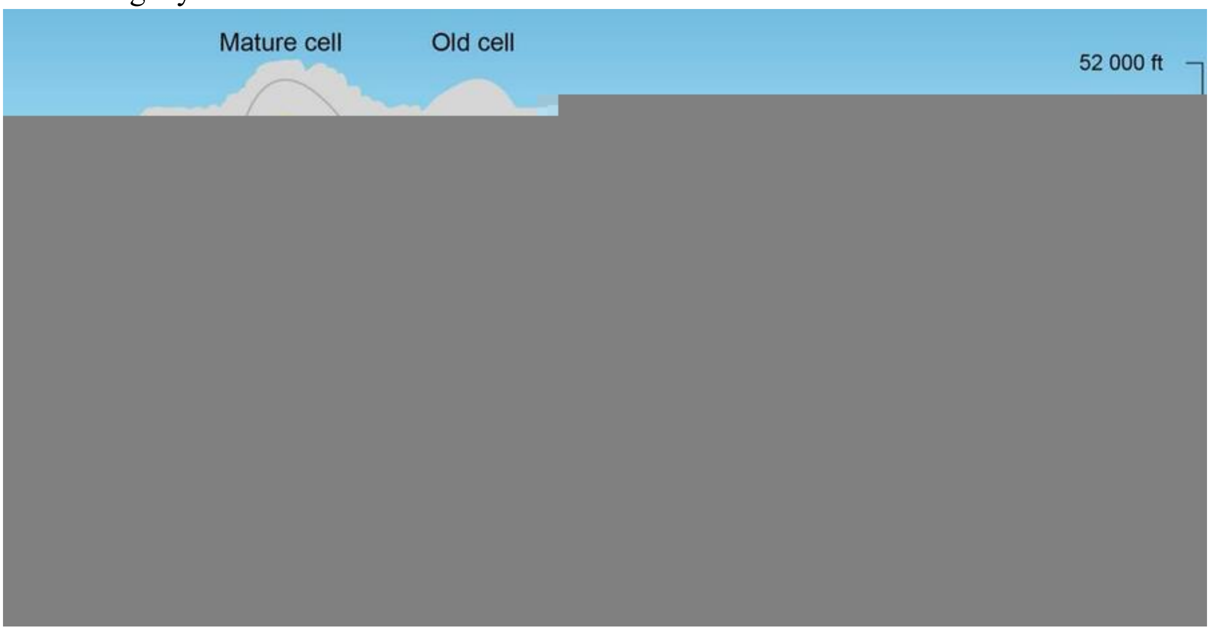
The general uplift at the ITCZ can trigger a mesoscale convective system

- MCS is a complex of thunderstorms that becomes organised on a scale larger than individual thunderstorms

Tropical squall lines

- MCS can give rise to this phenomena; a line of thunderstorms which is much longer than its width
  - Proceeded by Short, violent wind gusts
  - Up to 600km long
  - Intense downdrafts
  - Extremely heavy precipitation

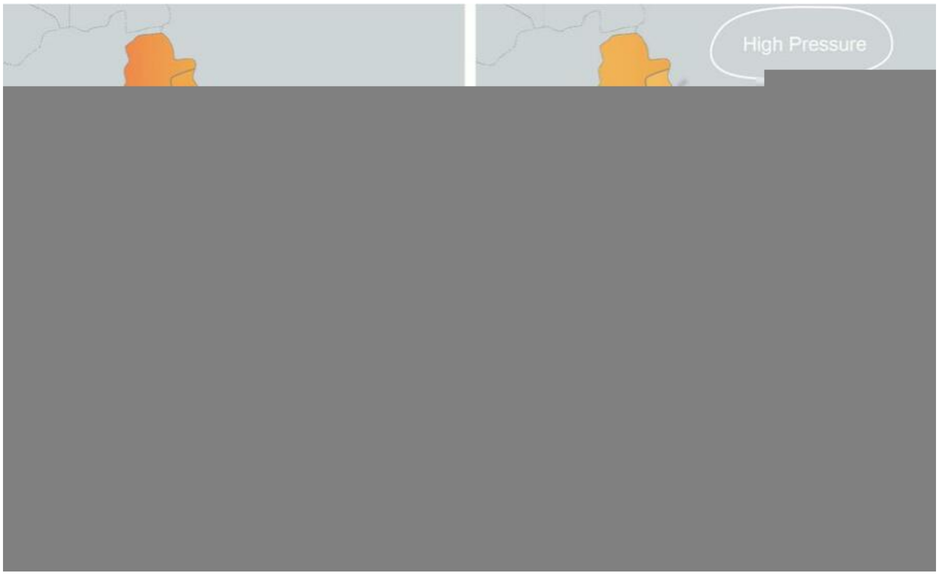
The strongest radar returns occur just below the freezing layer and immediately surrounding the melting layer



Regional weather characteristics
Indian subcontinent

- Dominated by monsoons
  - Seasonal changes in wind and rain caused by asymmetric heating of land and sea masses
- During the summer the land warms up drawing moist air from the sea as it travels over warm land it becomes unstable and heavy tropical thunderstorms develop
- The primary cause of the shift in wind direction is the differential surface heating between land and Sea
  - Like a sea breeze on a large scale
- During the winter the land cools down, the Siberian high develops, and the winds reverse direction
  - The air is cool and dry with little weather

Monsoons are also experienced in N.australia, W.african coast and regions of N.america and chile

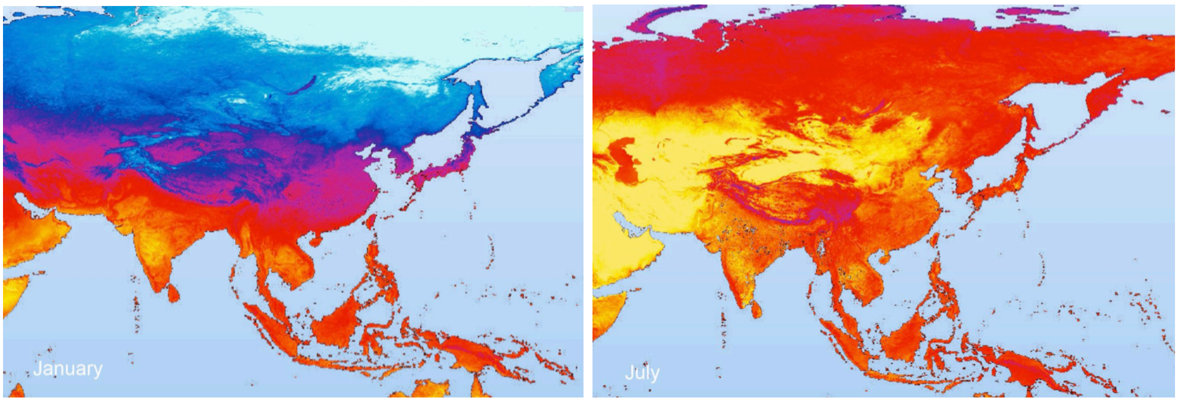


West Africa

- In august the ITCZ runs through the middle of the west African land mass
- Warm moist air combined with thermal and convergent uplift produces significant rain
  - This is the SW monsoon
- By January the ITCZ has moved to the S.coastline of west Africa this drives the monsoon ringing along dry, dusty air from the Sahara

East Asia

- They experience seasons
    - cold dry NE flow dominates in the winter, driven by Siberian high
    - northward movement of the heat equator in the summer produces hot and humid conditions



- In NE asia fog and low stratus can form along the eastern coastline in the winter
- During the summer NE trades veers right above the equator
    - This warm moist unstable wind is sustained by the warm land massand the asian low
        - Which in turns raises the ITCZ

Australasia

In December and January the ITCZ moves south bringing some NE trades across the equator to the northern part of Australia

- Driven by strong heat lows which form over N.Australia
- Not as strong monsoon as the Indian

In June and July the polar front moves into the bottom part of Australia bringing with it frontal depressions, and their associated warm temporary anticyclones

Mid-latitude weather is influenced by the position of the polar fronts

- These produce continuous wave of frontal depressions and their associated temporary highs
    - Driven by upper westerly winds
- The 2 major sub-tropical highs in the n.hemisphere are the Azores and Bermuda high

North American continent - winter

- The powerful pacific jet stream is bordered to the north by the polar air and the south by the sub-tropical air
- Conditions are stable but air coming from Canada mixing with the relatively moist warm tropical air can bring severe snow storms

North American continent - summer

- The cold polar air almost entirely disappears
- Intense heating of the land mass draws in warm moist air in the SW
    - This mixes with slightly cooler air at higher latitudes to produce a line of active thunderstorm conditions

South American continent - summer

- The northern parts of S.America is influenced by the trade winds but these quickly become modified
- Prevailing westerly winds in the Pacific are blocked by the Andes and turned north
- Intense heating in the Amazon basin produces very heavy rainfall

South American continent - Winter

- Cold Antarctic systems intrude on the southernmost part of the continent
- In the north the winds are modified by the northward movement of the ITCZ

A wind known as Pampero is driven by a sudden push of cold air from the SW across the Pampas

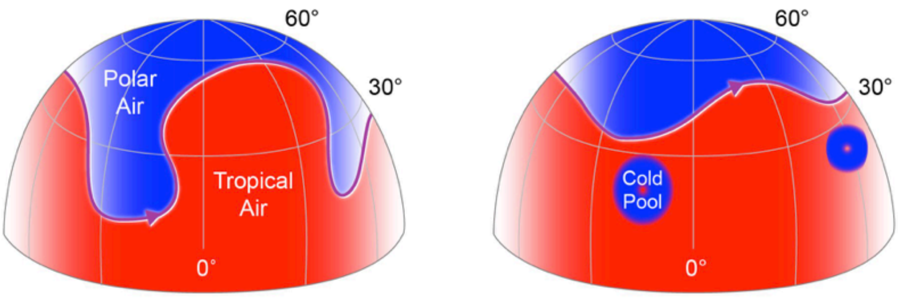
- Generated by the passage of cold front of an active low-pressure system giving rise to a squall line, producing a sudden drop in temperature after passing

Outbreaks of cold **polar air** occur in both hemispheres

- Can reach into the sub-tropic latitudes, bringing unseasonably cold weather
  - Heavy snowfall to the lower middle latitudes 30 to 50
- Are considered abnormal winter occurrences
- In extreme cases these outbreaks may lead to the formation of cold air drops

Cold air drops/pool

- They are deep cold cores aloft which are undetectable at ground level; 10 000-30 000ft
- A possible explanation to their existence is a pool of cold air remaining after a polar outbreak; diameter 300-1000nm
  - Unstable condition
  - Can produce significant areas of convective build-up



Highly convective thunderstorm cells and the largest volcanic eruptions may penetrate above the tropopause into the stratosphere otherwise it’s safe to say it’s advantageous:

- Higher cruising speed
- Reduced drag
- Reduced turbulence

Visible weather in the lower stratosphere is an exceptional condition

CH 21

Remote sensing

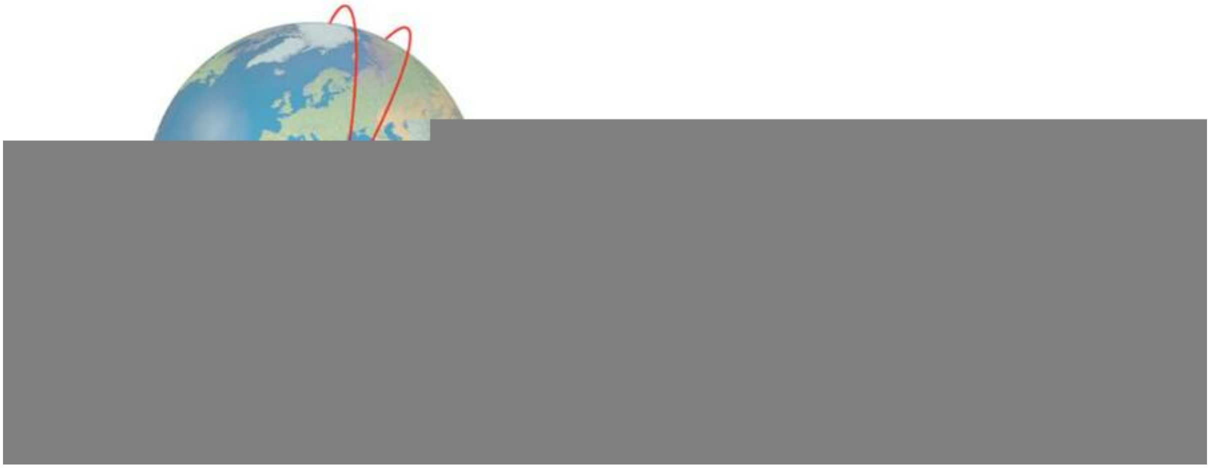
This deals with techniques to determine atmospheric conditions without physically sampling it

- Active sensors transmit a signal and analyse the reflection
- Passive sensors analyse the electromagnetic radiation emitted

Advantage of remote sensing is that large areas can be measure rapidly

Satellites observe visible and infrared portions of the spectrum

- Polar orbit
- Geostationary orbit



Geostationary orbit has the advantage of a wide field of view; 1/3 of the earth's surface; cons of having poor resolution

Polar orbiting satellites in low earth orbit passing over the pole, or close to the poles offer a higher resolution but can only sense a narrow band as they pass overhead

Radiometer detect radio-magnetic energy that is reflected or emitted by our planet:

- Measuring the amount of visible light from the sun reflected back to space
- Measuring the amount of infrared emitted by objects

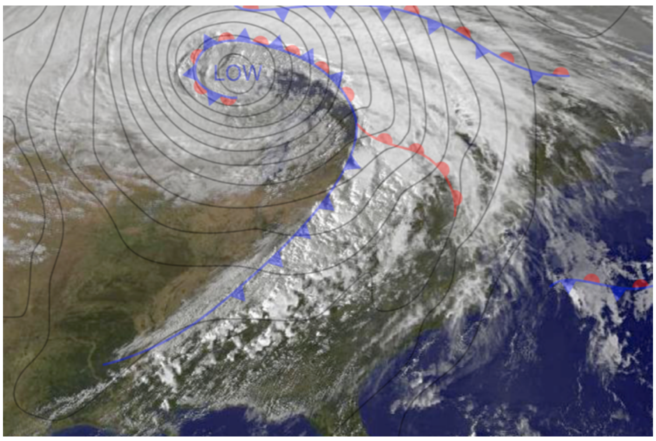
Other types of images include water vapour and false colour images

Visible light images

Useful for seeing basic cloud patterns, storm systems and monitoring snow covers

Disadvantages include:

- Only useful for daylight hours
- Difficult to distinguish between low and high level clouds
- Hard to distinguish snow from clouds



Infrared images
- Can be used during day and night
- A grayscale image
  - Hot objects appearing darker
  - Cold objects appearing more white
- False colour infrared images often use artificially created colour to depict the various temperature ranges

Combining visible and infrared imagery helps to overcome the disadvantages of each image type

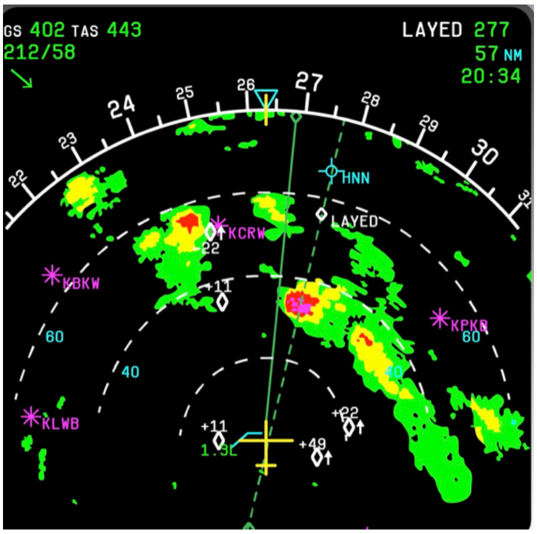
Atmospheric Motion Vectors images are derived by tracking clouds and vapour structures in consecutive images

Water vapour images show the amount of water vapour in the middle and upper atmosphere
- Useful for distinguishing between moist and dry air
  - This can give clues to jet streams

Weather radars use microwave wavelengths of 1-10cm because this is the optimal for detecting raindrops

- The reflectivity of precipitation depends on the diameter and its capacity to reflect

Airborne weather radars must be gyro-Stabilised to compensate for the aircraft's movements in pitch and roll

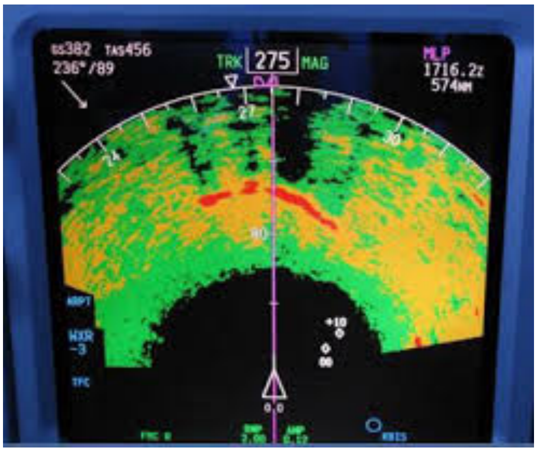


In modern installations false colour is used:

- Normally blue or green represents a weak return
- Red or magenta giving a strong return

Tilt control allows the crew to adjust the radar antenna so they look up or down at objects if interest

Modern radars have auto-tilt

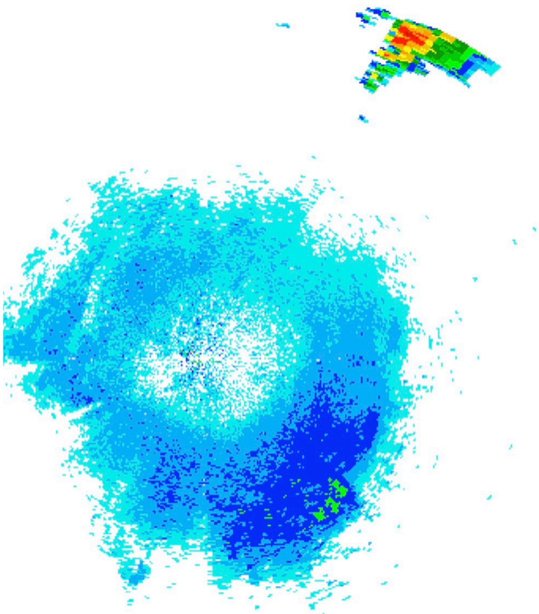


Weather radars cannot detect turbulence or reliably detect small ice crystals

The radar may also misinterpret birds, tall buildings and mountains for precipitation as well as not having sufficient strength to cloak weather behind an active cell; **blind alley effect**

Ground based radars/ weather surveillance radar

- Doppler radars isolate moving targets from ground returns

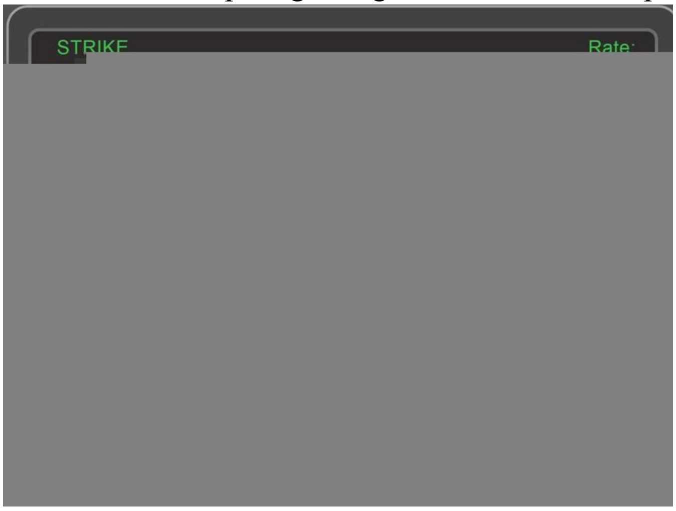


A burst of lightning produces a pulse of electromagnetic radiation, this can be measured using:

- o Ground based systems used to triangulate
- o Aircraft based systems using a direction and a sense antenna in the same location

All airlines must be equipped with weather radar, the latest systems also incorporate lightning detectors

General aviation aircraft often use simple lightning detectors; stormscope and strikefinder



CH 22

Reporting and Forecasting

ICAO annex 3's purpose is to ensure the adequate meteorological information is provided to operators, crew members etc.

MET offices and reporting centres are found worldwide

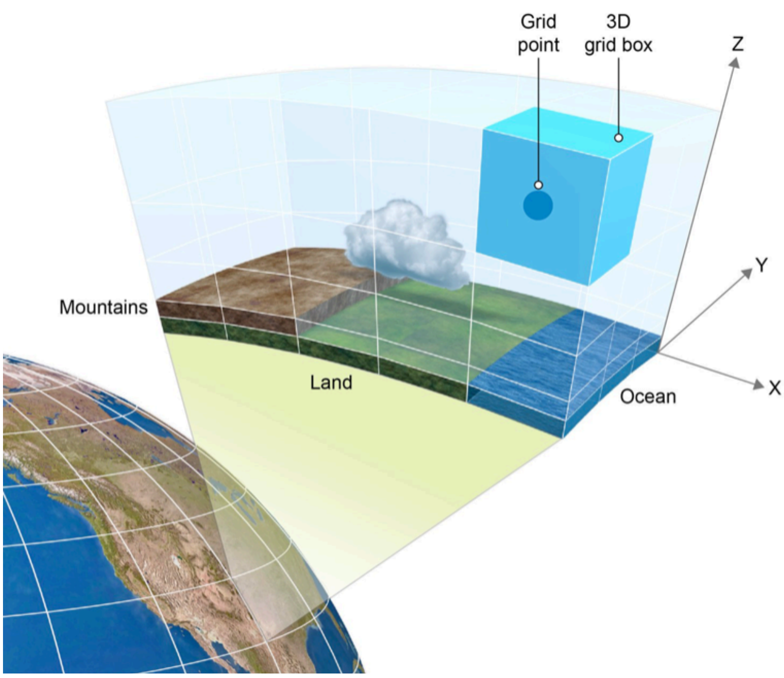
World are forecast system's objective:

To supply meteorological authorities and users with digital global aeronautical en-route forecasts; this is achieved through:

- WAFC, London and Washington
- Met offices, state
  - Aerodrome forecasts and regional briefing documents
- Meteorological watch offices
  - SIGMET
  - AIRMET
- Aeronautical meteorological stations
  - METAR
  - MET reports
- Volcanic ash advisory centre
- Tropical cyclone advisory centre
- Data collected in flight

Numerical weather prediction, NWP, is a method of predicting the weather based purely on mathematical principles and modelling

Model construction:



- Each grid represents an average value of data for a small volume
- Smaller grid cells lead to greater model resolution and more detailed forecast but longer processing time as well

GFS model outputs over 300 parameters

Responsibilities of WAFCs:

- Wind and temperature for FL 50 to FL 530
- FL and temperature of the tropopause
- Direction, speed and FL of the maximum wind
- Humidity at the various FL
- Horizontal extent and FL for base and top of CBs
- Icing layers
- CAT
- In-cloud turbulence

Meteorological information is supplied to operators and flight crew members for:

- Pre-flight planning
- In-flight re-planning

METARs, meteorological aerodrome report

- Issued every 30min by every major AD
- A SPECI is issued if necessary to update a METAR as there has been a significant change

In the format:

- Type of report
- Aerodrome identifier
  - 4-letter ICAO identifier
- Date and time of observation
  - UTC
- Wind
  - Degrees TRUE
- Visibility
  - meters
- Present weather
  - Reported as a minimum
- Cloud coverage
  - x/8
- Temperature and dewpoint
  - M indicates a negative value
- QNH
- recent weather
  - RE=recent
- Windshear warning
  - WS + rwy
- Trends
  - Valid for 2 hours from the observation
- Runway state
  - Contamination and info

Code	Remarks	Code	Remarks
DZ	Drizzle	VA	Volcanic ash
RA	Rain	VC	In the vicinity
FZ	Freezing	cloud	Up to 3 cloud groups may be reported
SH	Showers	**FEW**	1-2 Few
SQ	Squalls	**SCT**	3-4 scattered
TS	Thunderstorms	**BKN**	5-7 broken
FC	Funnel cloud	**OVC**	overcast
SN	Snow	NSC	No significant cloud
BL	Blowing, raised more than 2m	TCU	Towering cumulus
DR	Drifting	CB	cumulonimbus
GR	Hail	VV///	Sky obscured, base not discernible
GS	Snow pellets	NCD	No clouds detected, AUTO METAR
PL	Ice pellet	**CAVOK**	**9999, no TCU/CB, no cloud below 5000ft or highest minimum sector altitude**
IC	Ice crystals	NSW	No significant weather
SG	Snow grains	AT	At, time
FG	Fog	FM	From, time
BR	Mist	TL	Until, time
PR	Banks	TEMPO	temporarily
BC	Patches	BECMG	Becoming
MI	Shallow		
HZ	Haze		
FU	Smoke	PROB	TAF* probability, 30/40%
SA	Sand		
SS	Sandstorm		
DU	Dust		
DS	Dust storm		
PO	Dust devils		

Key differences between METAR and TAF are:

- Temperatures, dew points, QNH, recent weather, windshear and runway state are not mentioned in TAF
- Trends are replaced by forecasts

AIRMET reports are warnings in abbreviated plain language for a specified FIR or sub-area

- Compared to SIGMET, AIRMET covers less severe weather

AIRMETS are broadcasts on the ATIS and are referred to as weather advisories, valid for 6 hours, 3 types:

- AIRMET SIERRA; mountain obstructions or IFR, ceiling less than 1000ft and/or less than 3nm affecting 50% of the area at one time
- AIRMET TANGO; turbulence; sustained surface winds of 30kt or greater and windshear
- AIRMET ZULU; icing; moderate, detailing freezing level heights

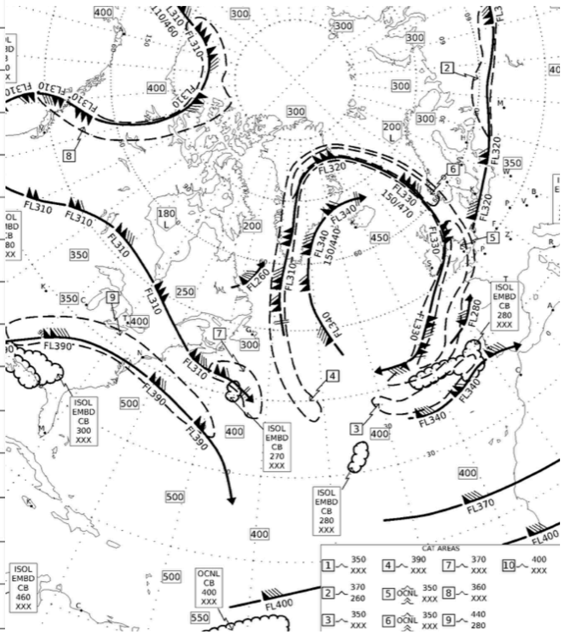
Phenomena in a SIGMET: thunderstorms, tropical cyclone, turbulence, icing, mountain waves, dust storm, sand storm, volcanic ash, radioactive cloud

Operators are the main users of SIGMETs; they also contribute to the effectiveness of the SIGMET since their crew transmit special air-reports to ATS unit

SIGMETs are valid for 4 hours; volcanic and cyclone SIGMETS are valid for 6 hours

SIGWX apply to pressure altitudes between 10 000ft and 63 000ft
Significant weather phenomena include:

- Jet streams, inc. speed and depth
- CAT
- Embedded CB cloud
- Tropopause levels
- TRS
- Volcanic eruptions generating ash clouds
- Widespread sand/dust storms
- Radioactive material accidentally released



The WAFC also publish wind charts which depict the wind at every 5° of latitude and longitude and at various pressure levels

VOLMET broadcasts are pre-recorded ground-to-air reports and forecasts, transmitted on HF and VHF, usually updated every 30 minutes

A GAMET is an area forecast published in abbreviated plain language and standard formats for low level flights, up to FL 100

Windshear warnings shall be prepared by the aerodrome meteorological office designated by the MET authority concerned for the aerodrome

Routine air reports shall be made during en-route and climb-out phases of the flight

Special air report shall be made if:

- Moderate or severe turbulence and/or icing
- Severe mountain wave
- Thunderstorms, windshear, squall lines
- Heavy dust/sand storm
- Volcanic ash cloud
- Pre-eruption volcanic activity

Should be made during flight ASAP