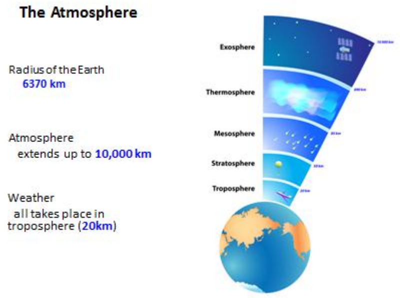
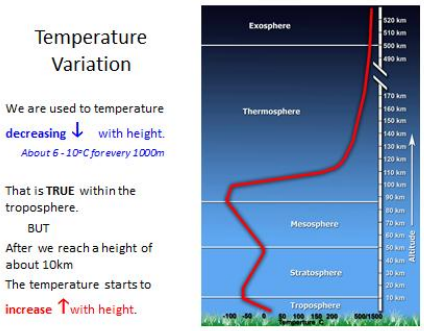
The Weather

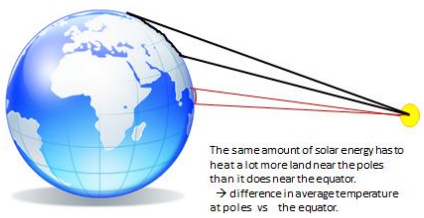
U3A : Popular science



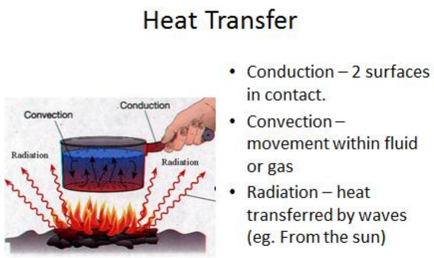
We live on the Earth – a planet which has a radius of 6370km (3980mi) [almost 8000miles in diameter]
It is surrounded by an atmosphere that extends up to around 10,000 km but the weather all takes place in the bottom layer – called the troposphere. This varies in depth from around 20km at the equator to just 10km at the poles.



When we climb a mountain, we are used to the fact that the temperature decreases with height. In normal atmospheric conditions, the temperature falls by 6 – 10 degrees C for every 1000m increase in altitude.
But this is only true in the tropopause – the bottom layer of the atmosphere. As we reach the top of this layer, the temperature first levels off (at the tropopause) and then starts to increase with height through the stratosphere. There are further layers of the atmosphere defined by their temperature properties – but we are not concerned with these.

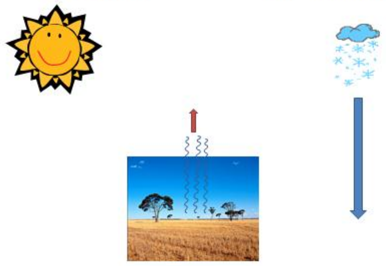


Why is it colder at the poles? If you consider a narrow band of solar radiation striking the earth at the equator and another similar sized band of solar radiation striking the earth near the pole, then the 1st one has only a small area to heat whilst the polar one has a large area – the heat has to be shared over a much bigger area of land.
Also the polar radiation has to penetrate a lot more atmosphere – this means a lot more opportunity for the energy to be reflected back into space.



A brief aside on how heat is transferred from 1 object to another.
If the 2 surfaces are in contact then heat is transferred by conduction – eg. If you touch the hot plate of a cooker it feels HOT.
Hot air of fluid rises up to be replaced by cooler air/fluid. This process is called convection
Heat can also be transferred by radiation – ie. transfer of heat by 'waves'
How does this affect the weather.
Heat is transferred from the sun to the earth by radiation. The air absorbs a little heat this way but it is mainly the Earths surface that is heated.
The lowest few cm of the atmosphere are heated by conduction from the Earths surface. Air is a poor conductor so it is only the lowest few cm heated this way.
Having heated the lowest cm of air by conduction, this warmer air then rises up by convection. Convection basically is the source of the weather.

Warm air rises   cold air sinks



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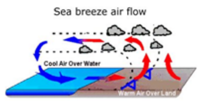
As the sun heats the earth, this also heats up the lowest layer of air in contact with the earth. → warm air rises and colder air sinks to replace the warm air.
Because the temperature levels off at the tropopause (top of the troposphere) the warm air stops rising. ie. convection & therefore weather stops at the tropopause.

Heating the land and Sea

- It takes a lot more heat (~ 3 times as much) to raise the temperature of 1kg of water by 1°C than it does to raise the temperature of the land by 1°C



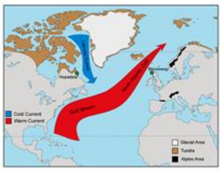
On average it takes about 3 times as much heat to raise the temperature of water by 1 degree C than to raise the equivalent quantity of dry rock or soil by 1 degree. This is the specific heat capacity [the amount of heat required to raise temp by 1 degree C]. This means that the land heats up more quickly → warm air over land → rises & flows out over the sea where it cools and sinks → sea breeze.
The distance of a location from the sea plays a large part in determining its typical temperature variation. In the middle of a continent the winters are COLD and the summers HOT.

Ocean currents

Ocean currents also affect the climate.

The **Gulf Stream** brings warm water to the UK

→ Warmer climate than other countries with same latitude.



Evaporation

- Water evaporates from lakes / oceans
- Higher temperature →greater evaporation
- Air that cannot hold any more water vapour is "**saturated**"
- **Relative Humidity** = $\frac{\text{Water vapour in air}}{\text{max.water vapour possible}}$
- Warm air can hold more water vapour than cold air
- As air rises, it cools and water vapour **condenses** out
  → Clouds

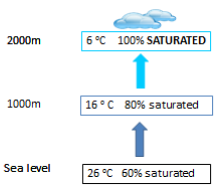
Water exists in 3 states : in order of increasing energy or heat these are solid, liquid and gas. When the sun shines on a lake or the ocean, it warms the water and causes some water molecules to escape from the surface becoming water vapour– ie. water evaporates. The higher the temperature the greater the evaporation.
But there is a limit to how much water vapour the air can hold. Air that cannot hold any more water vapour is said to be saturated.
Humidity or relative humidity is defined by .....

Dew Point

The temperature to which air would have to be cooled (without changing its total moisture content) for it to become saturated.

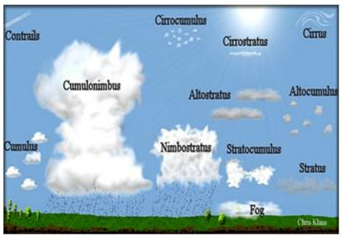
Dew point = 6°C

This is why clouds have flat bottoms



Because warm air can hold more water vapour than cold air, as moist air rises it cools and the humidity increases.
Eventually it cannot hold any more water, ie. 100% humidity or the air is saturated.
The dew point is he temperature to which air would have to be cooled (without changing its total moisture content) for it to become saturated.
Suppose we start at sea level with a packet of air with a temperature of 26 degrees and a relative humidity of 60%.
If we lift this up through 1000m then the temperature drops by ~10 degrees & this means the humidity increases (say to 80%).
Lift it up another 1000m & the temperature drops to 6 degrees & saturations increases to 100%.
If we lift it any further, there is more moisure than the air can hold and water droplets condense out → clouds

Clouds



High
Above 5000m

Medium
2000 – 7000m

Low
Below 2000m

Clouds are extremely variable but, for us trying to understand the weather, they are the most useful thing we have.
They are classified by their shape and the height of their base.
High clouds are those with a base > 5000m; medium level 2000-5000m and low clouds , 2000m
4 types of cloud :
Cirrus = ' curl of hair' wispy
Stratus - a layer of cloud
Cumulus – 'heap' for puffy clouds
nimbus – rain bearing

High Clouds (>5000m)

- Cirrus
Delicate / wispy / white; often called marestails

- Cirrostratus
Thin veil of cloud. Transparent white.
Sun visible through it.

- Cirrocumulus
Thin sheet of more or less separate rounded cloudlets in ripples.
Extensive cirrocumulus called 'mackerel sky'

Medium Clouds (2000-7000m)

- Altostratus
Sheet cloud with fairly uniform appearance
Greyish colour
Often cover entire sky.
Sun may be visible as if through ground glass

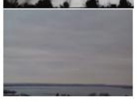
- Altocumulus
Broken patchy clumps of cloud – may have quilted appearance.
White or grey.

Low Clouds (<2000m)

- Cumulus
Puffy cauliflower shaped. Flat base / sharp outline.
Base white / top often brilliant white.
Usually well separated / a lot of blue sky between clouds.

- Stratocumulus
Sheet like but composed of rounded cloud elements. May form in rolls.
Light to dark grey.

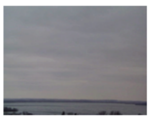
- Stratus
Uniform featureless cloud with a level base.
Often covers entire sky. Grey.
No precipitation – or only light drizzle.



Low Clouds (2) (<2000m)

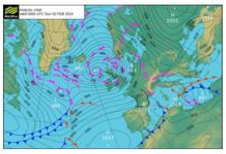
- Cumulonimbus
Very tall giant cloud often with anvil shaped top.
Very dark grey base. White sides and top.
Associated with heavy showers, hail and thunderstorms.

- Nimbostratus
Featureless thick layer of cloud.
Dark grey.
Associated with continuous steady rain or snow and poor visibility.



Air Pressure

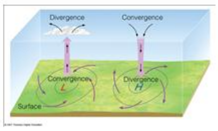
- The weight of the air above you
- Varies with height
- Pressure measurements are adjusted to show what the reading would be at sea level
- Isobars join places with the same pressure



Air pressure is used a lot in weather forecasting – so what is it?
It is the weight of the air above you – all 10000km or so of it. As you get higher, there is less air above you so air pressure decreases. To adjust for this change with altitude, all pressure measurements are adjusted so that they reflect the reading that you would get at sea level.
Isobars join places at equal pressure and we are all used to seeing weather maps like this in papers, on TV etc.

At ground level air
Converges at a low pressure
Diverges at a high pressure

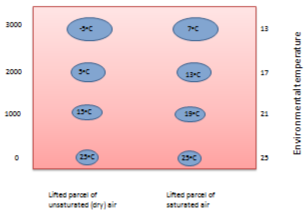
At altitude air
Diverges at a low pressure
Converges at a high pressure



Wind blows from high pressure areas to low pressure. Air then converges at a low pressure centre → air rising at the low pressure. At height, it then diverges.
Air diverges from a centre of high pressure. At height, air is drawn in (converges) and sinks.

Air stability

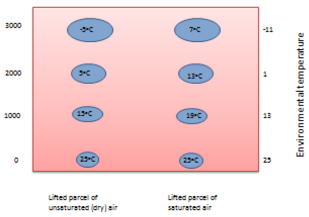
Stable environment



The temperature gradient in the environment varies from day to day. Suppose that the temperature gradient is as shown (ie. a fall of 4 degrees C for every 1000m increase in altitude.)
We imagine a parcel of dry air at sea level – isolated from its environment. It is at 5 degrees. If we lift it through 1000m, the temperature falls by 10 degrees (→ 15 ^{o}), at 2000m (→ 5 ^{o}), at 3000m (→ -5 ^{o})
If the air is saturated, when we lift it, it cools and water vapour condenses out (cloud). This releases energy so that the air is heated to some extent. The air temperature of the parcel falls by 6 ^{o}C for every 1000m increase in altitude.
Note that in both cases (dry and saturated air) the temperature of the air parcel at height is LESS than the environmental air temperature. Its colder so it should sink back to ground level. You lift it and it tends to go back to where it was originally. This is what we call a STABLE environment.

Air stability

Unstable environment



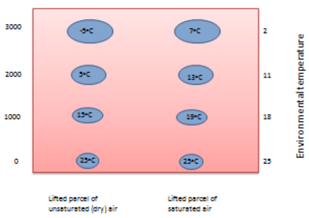
If the temperature gradient in the environment is steeper as in this case (12 degrees for each 1000m increase in altitude). The temperature of our imaginary parcels of air would behave in the same way as before [10 degrees for every 1000m for dry air & 6 degrees for saturated air]. But note that in this case, the temperature of the lifted parcel of air is always GREATER than the temperature of the environment. Because it is warmer it continues to rise. Once you start to lift the parcel it continues. This is called UNSTABLE

Air stability

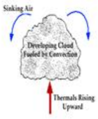
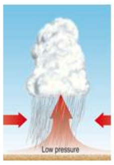
Unsaturated
Stable

Saturated
Unstable

Conditional Instabity



If the temperature gradient in the environment is intermediate as in this case (7 degrees for each 1000m increase in altitude). The temperature of our imaginary parcels of air would behave in the same way as before [10 degrees for every 1000m for dry air & 6 degrees for saturated air]. But note that in this case, the temperature of the lifted parcel of dry air is always LESS than the temperature of the environment so it is stable for unsaturated air.
But the temperature of the lifted parcel of saturated air is always GREATER than the temperature of the environment so it is unstable for saturated air.

Cloud Formation Conditions - Stable fine weather  Unstable - moist air  rain 	In stable conditions, as we have seen, warm air does not keep rising ⍰ this means that we get fine weather. With unstable conditions, warmed air will rise and will continue rising and cooling. If it is moist, it eventually reaches its dew point. Rising still further, water droplets condense out giving clouds.
Cloud formation Convection  Convergence  Orographic 	There are 3 ways in which clouds form. The first is what we have just described – Convection : warm moist air rising The 2nd way : when winds blow air in to an area of low pressure from several directions. That extra air has to go somewhere so it rises up. Cloud formation by convergence. The 3rd way. When the air is pushed upwards by the physical barrier of a mountain. This is called orographic lifting.
Clouds, Rain, Snow • Water droplets in clouds much too small to fall as rain • Droplets of different sizes fall at different speeds. • Droplets collide & coalesce. • Droplets move in updraughts, downdraughts, winds etc. until large /heavy enough to fall as rain. • If cloud is cold enough, the cloud consists of supercooled water droplets and ice crystals. • Collisions cause ice crystals to grow → snow flakes or hail (snow if most of the lower cloud is ice crystals, hail if it is mainly water)	Why don't the water droplets in clouds fall to earth? Most of them are much too small. They do start falling and droplets of different sizes fall at different speeds – the bigger the drop the faster it falls. This leads to collisions between droplets which then coalesce leasing to ever larger droplets. The droplets get buffeted around in updraughts, downdraughts, winds etc. until large /heavy enough to fall as rain. If cloud is cold enough, the cloud consists of super-cooled water droplets and ice crystals. (Water can exist in liquid form below freezing point – this is because, in order to freeze, it needs a solid particle of dust or ice called a freezing nuclei. Water below its freezing point is called super cooled). Collisions between ice crystals and water or other ice crystals cause the ice crystals to grow. snow flakes or hail (snow if most of the lower cloud is ice crystals, hail if it is mainly water)
Air Pressure and Wind  	Going back to air pressure. Remember that air pressure is effectively the weight of the air above us. Low pressure means that there is relatively little air above us, high pressure –a lot. This inequality means that air flows from the low pressure area to a high pressure area. Ie. wind blows from high to low pressure.
Wind • Wind speed – measured in knots Beaufort scale • Direction – from which the wind is blowing • Veering : Clockwise change in direction • Backing : Anticlockwise change in direction	Wind speed – measured in knots (nautical miles per hour). We use a scale called the 'Beaufort scale'. Apart from speed we need to know the direction of te wind. Direction – from which the wind is blowing Veering : Clockwise change in direction Backing : Anticlockwise change in direction

Beaufort scale

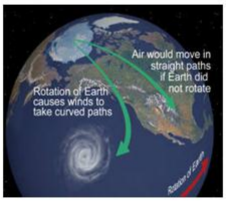
Force	mph	Beaufort name	Effect on land
0	< 1	Calm	Calm – vertical smoke
1	1-3	Light air	Direction shown by smoke
2	4-7	Light breeze	Weather vanes move; leaves rustle
3	8-12	Gentle breeze	Leaves & small twigs move
4	13-18	Moderate breeze	Small branches move
5	19-24	Fresh breeze	Small trees sway
6	25-31	Strong breeze	Large branches move; overhead wires whistle
7	32-38	Near gale	Whole large trees move; difficult to walk
8	39-46	Gale	Twigs break off trees; cars pushed off course
9	47-54	Strong gale	Slight structural damage (eg. Roof tiles)
10	55-63	Storm	Trees uprooted; considerable structural damage
11	64-72	Violent storm	Widespread structural damage
12	> 72	Hurricane	Extensive structural damage

This shows how wind speed is categorised. The force is defined by the wind speed but this table shows how to estimate the wind force by the effect of the wind on land.

Air Pressure and Wind

So we saw that wind is air blowing from high pressure to low pressure.
We would expect this to blow in a straight line.
If the Earth did not rotate, this is what would happen

Coriolus force



But the earth rotates. Suppose the high pressure area is near the north pole and low pressure in the USA as here. Then we expect the wind to blow here. But in the time it takes for the wind to blow down here, the Earth has rotated. So this point in the USA has now been replaced by this point here.

Air Pressure again

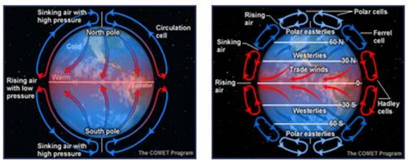
Northern hemisphere Winds are deflected to the right

Southern hemisphere Winds deflected to the left

This effect is due to the Coriolus force

It looks as if the wind has bent towards the right. We call this the Coriolus force – it means that winds in the norther hemisphere appear to be diverted to the right. In the southern hemisphere, they appear diverted to the left.

Global Air Circulation



Northern hemisphere : winds are deflected to the right
→ air blown S from 30°N to equator blows east to west [trade winds]
→ air blown S from pole to 60°N blows east to west
→ air blown N from 30°N to 60°N blows west to east

The general circulation of the atmosphere is driven by unequal heating of the Earth. Warm air rises at the equator. Colder air flows in from higher latitudes to take its place while the warmer air flows towards the poles at altitude.
This nice simple model doesn't work very well on Earth because of the Earths rotation. Instead we find that the warm air sinks again at around 30 ^{o} N/S forming a 'wind cell' between 0 & +/- 30o N/S.
At the poles, cold air sinks and then flows towards the equator. At around 60 o it has warmed and starts to rise again – giving the polar cells. Between these Hadley cells and the polar cells, there is yet another cell called the Ferrel cells.
This structure of weather cells explains the pattern of prevailing winds. Eg from 30 N a wind blows towards the equator, But because of the Coriolus force, this wind is diverted to the right so it blows from the N east. [the trade winds]
Between 30 & 60 N, the wind is blowing S to N: again it is diverted to the right so now it is blowing from the S west giving us our prevailing westerly winds.

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Air masses

Formed when a large body of air remains stationary over a fairly uniform part of the Earth's surface for long enough to acquire **uniform temperature & humidity**.

These form either

over continental land masses

or over **the oceans**

Movement of these air masses → **Fronts**

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Cold Front

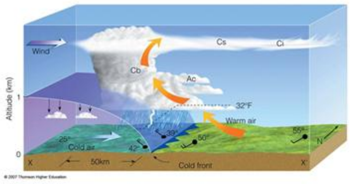
Cold air moves in to replace warm air at the surface.

Warm air rises up over the incoming cold air.

Moist unstable air → condensation / cumulonimbus clouds / heavy rain

Moist stable air → low level stratus clouds / drizzle

Dry air → no clouds but change in temperature



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A cold air mass is blown in.

Cold fronts typically move at around 40km/hr

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Warm Front

Warm air moves in to replace cold air at the surface.

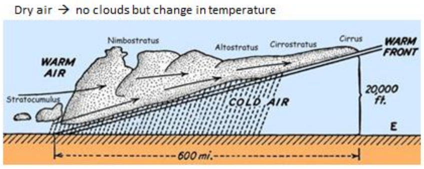
Warm air rides up over the cold air.

Moist air → Formation of clouds a long way ahead of the front

Clouds less deep than cold front.

Rain lighter but more persistent.

Dry air → no clouds but change in temperature



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Warm fronts typically move at 20km / hr (but variable speed). Slower than cold fronts

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Occluded front

Cold fronts move more quickly than warm fronts

Eventually catch up the warm front

→Occluded front (or occlusion)

3 air masses.

Original cold and warm ones either side of the warm front;

Additional cold mass that overtakes them

2 types of occlusion depending on whether the newest air mass is colder or warmer than the air that was originally ahead of the warm front.

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3 air masses : the original cold and warm masses either side of the warm front and the additional cold one that has overtaken them.

These occur because cold fronts move at a greater speed than warm fronts. Eventually they will catch up the warm front.

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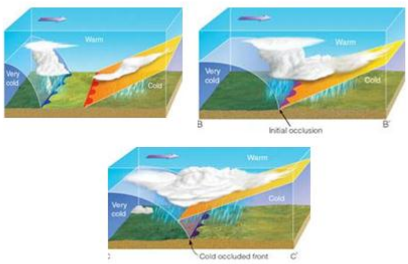
Cold Occlusion



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Cold occlusion occurs when the 3rd air mass is the coldest of all.

Initially you have the typical warm front with steady but light rain. Behind this there is the cold front moving in with a narrow band of heavy rain.

In the 2ns diagram, the cold front has caught up with the warm one. Being the coldest of the air masses, the incoming cold air undercuts both the warm and the cool air. The warm air is pushed up high above the ground.

Ahead of the occlusion, the weather is that of a warm front (precipitation ahead of the front). Once the occlusion arrives, it brings heavy rain typical of a cold front. The most extreme weather occurs just at the point of occlusion.

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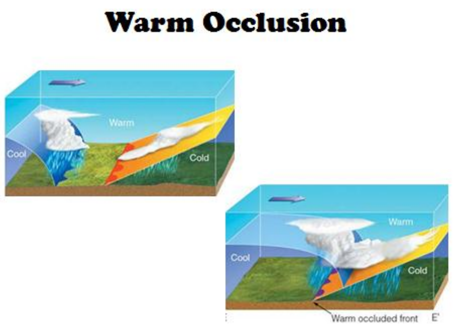	Warm occlusion occurs when the 3rd air mass is the warmer than the air ahead of the warm front. Initially you have the typical warm front with steady but light rain. Behind this there is the cold front moving in with a narrow band of heavy rain. In the 2nd diagram, the cold front has caught up with the warm one. The incoming cold air is not as cold so cannot undercut the orginal cold air mass. The cool air undergoes frontal lifting above the cold air and pushes the warm air ahead of it. Ahead of the occlusion, the weather is that of a warm front (precipitation ahead of the front). Once the occlusion arrives, the weather remains typical of a warm front.