MetLink
Royal Meteorological Society

Water in the Atmosphere

Background Information for Teachers

Water, water everywhere…

The water cycle moves water in its solid (ice and snow), liquid (water and cloud droplets) and gas (water vapour, a colourless gas) forms through the hydrosphere. In these notes, we will limit ourselves to considering the water cycle processes that occur in the atmosphere.

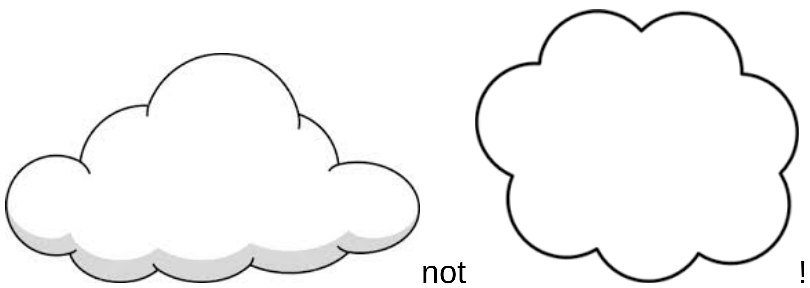
Most of the atmospheric processes ultimately depend on the balance between evaporation and condensation (and, in some very cold places, direct transfer between ice to water vapour or vice versa). Critically, the rate of evaporation of water from a liquid to a gas depends on temperature. The warmer it is, the faster water evaporates. On the other hand, the rate of condensation depends only on the concentration of water molecules in the air. Water is continuously evaporating and condensing from lakes, oceans, rivers, puddles, cloud droplets, vegetation etc. It is only the relative rates of the two processes that change.

So, consider some air which is cooling. As it cools, the rate of evaporation will fall but the rate of condensation will remain about the same. At some temperature, there will be more condensation occurring than evaporation. At this point, cloud droplets will form.

Find out how to make a cloud in a bottle.

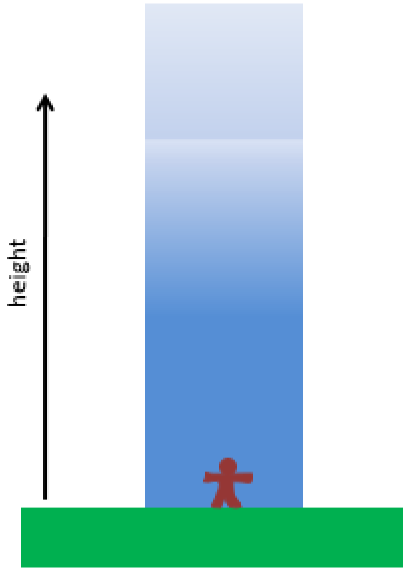
It is a common mistake to talk about how much water the air can hold, as if it were some kind of sponge. This misses the point that both evaporation and condensation are going on all the time.

Cloud base is a nice visual reminder of this process. Given that the temperature usually falls with height in the atmosphere, then the cloud base marks the height at which the temperature has fallen to the point when there is more condensation going on than evaporation. This is why the base of clouds is usually flat (unlike most primary school drawings of clouds!).



We can extend this thinking into looking at the different **types of rainfall**. For cloud to form, the air must have cooled.

One way that air can cool is by rising. As air rises up through the atmosphere, the pressure falls. Bearing in mind that air pressure is simply a measure of how much air there is above, then as air rises, there is logically less left above.

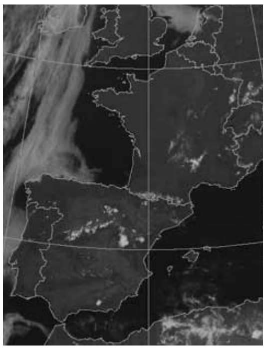


When we measure atmospheric pressure with a barometer, we are simply measuring the weight of the column of air above us. If the pressure reduces, it means there must be less air in the column above our heads.

As the pressure falls, the air expands. As it expands, it pushes against the surrounding air. As the air does work pushing the surrounding air out of the way, it loses energy and so cools. So, as air rises the pressure falls and it cools. At some level, it may reach the temperature at which cloud forms.

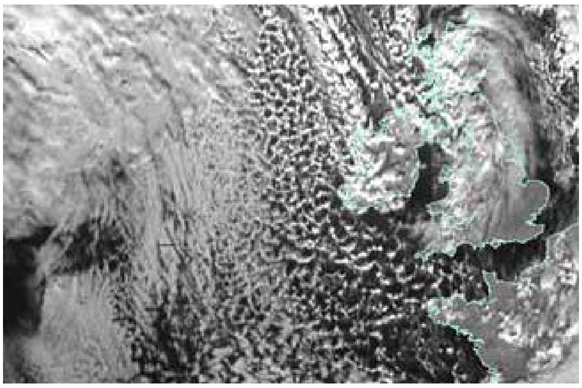
There are several ways in which air can be forced to rise:

1) At **weather fronts**: if a front is simply the boundary between air which is recognisably different, usually in temperature, then a front usually marks the boundary between warmer and cooler air. The warm air will always rise over the colder air (a teabag rocket is a nice way to demonstrate this). Cloud and rainfall may result.
2) On a clear, hot sunny day, some parts of the land surface may heat up more than others – maybe because of their aspect (facing the Sun) or the surface colour. The air in contact with the ground will be warmed in turn and subsequently rise – typically this gives late afternoon thunderstorms (cumulonimbus clouds). This is classed as **convectional** rainfall.

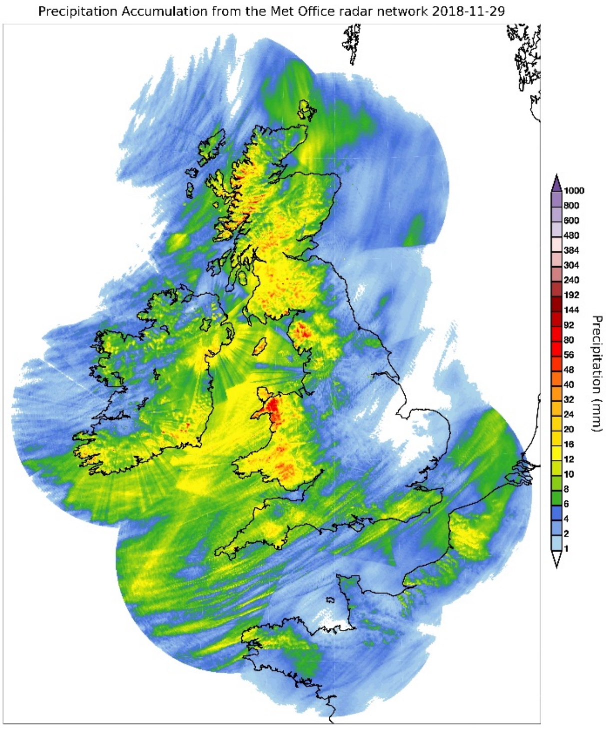


Convective thunderstorms over Spain and Portugal

3) Polar air: if air of polar origin is travelling south then it will gradually get warmer as it travels over increasingly warm land and sea. The air will eventually start rising, giving rise to puffy cumulus clouds – again, this is **convectional** rainfall. This satellite image, from the N. Atlantic in winter, clearly shows the puffy cumulus clouds typical for a polar maritime air mass:



4) Because of a change in the height of the Earth's surface – either a coast or hills or mountains. If air is forced to rise because of the underlying **topography** or **orography** (relief associated with hills and mountains), then it may reach the temperature at which cloud droplets form. Frequently, orography just **enhances** the rising that is already occurring – for example in the satellite image above, you can clearly see that the isolated patches of convection over the ocean come together into a blanket of cloud of the west coast of Ireland, Wales, Scotland and England as the westerly winds hit the west coast of the British Isles. There will be less rainfall downwind of the hills or mountains – an area known as **rain shadow**.



One day's accumulated rainfall over the UK on a day when Polar maritime air dominated

The wettest inhabited place in England is in Seathwaite where rising Polar maritime air is pushed further upwards by the Cumbrian Mountains. Annual rainfall at Seathwaite is 3552mm, Crib Goch in Wales receives over 4600mm and several places in India receive over 10,000mm.

Clive Giddis (cc-by-sa/2.0)

There will be less rainfall downwind of the hills or mountains – an area known as rain shadow.

The driest place in the UK, St. Osyth, is in the rain shadow of our prevailing westerly winds.

Paul Eccleston for CityandCountry.co.uk

If the air, rising up the side of a mountain, reaches the top of the mountain and is still warmer than the surrounding air, then it will carry on rising – leading to towering clouds over mountain ranges.

Sometimes air which has been forced to rise over a mountain ‘overshoots’ on the way down, leading to a downstream wave with lenticular clouds forming wherever the air is rising in the wave:

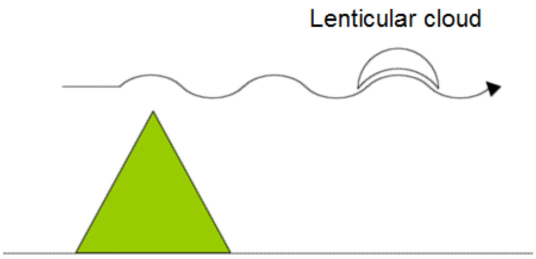
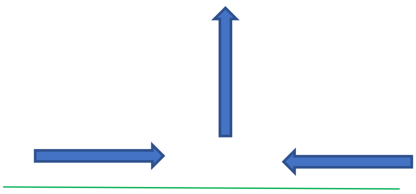


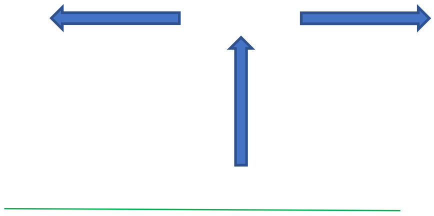
Image © Andy Cutcher, RMetS

When the clouds droplets in the cloud have grown big enough to fall as rain on the upwind side and top of the mountain, there is less liquid water left to evaporate again on the downwind side of the mountain: less heat is taken out of the air by evaporation than was released by condensation on the upwind side. The sinking air ends up warmer. This is the **Föhn** effect.

5) When air comes together near the surface of the Earth, squeezing the air together and pushing it up – for example because of sea breezes:



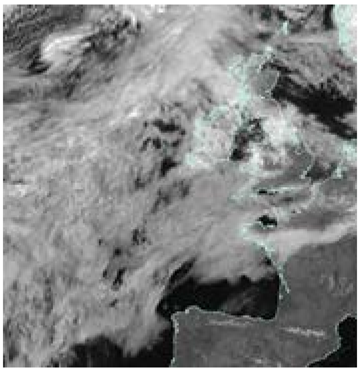
6) When air high in the atmosphere diverges and air rises from below to take its place – this can happen where the jet stream is slowing down.



When warm air rises the effect is enhanced by the release of latent heat. When water vapour condenses into liquid water it releases latent heat. This warms the air around it, causing the air to rise some more. (Conversely, when water is evaporated latent heat is used, this cools the surface it is evaporating from).

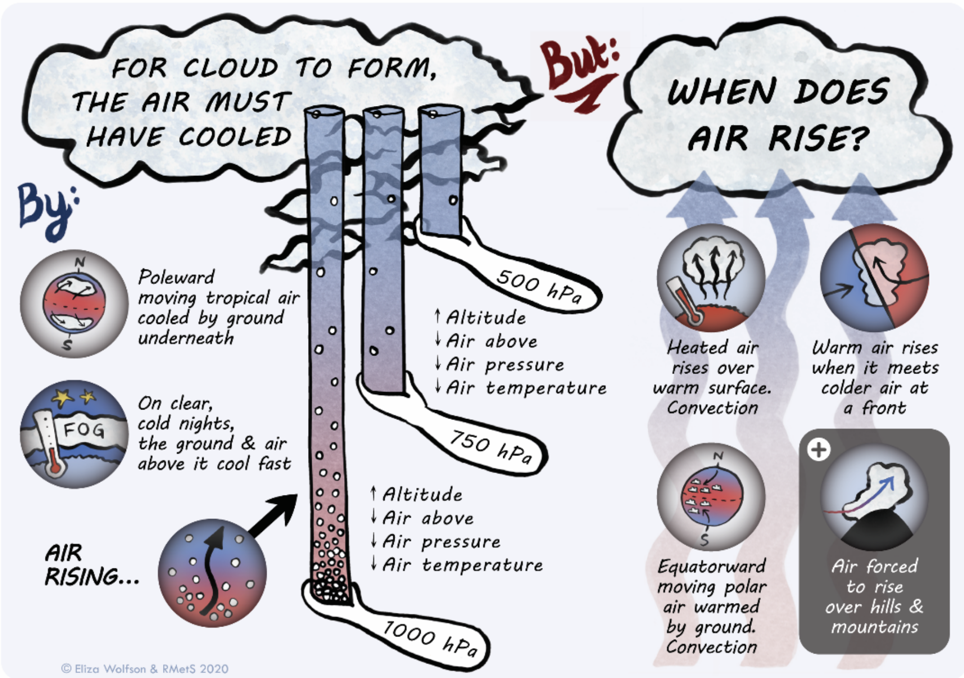
However, cloud, and therefore rain, can form when the air is cooled by other mechanisms as well:

1) Air travelling north from the Tropics, particularly over the oceans, is cooled from below as it travels north. It can be cooled to the temperature at which cloud forms. As this air is not rising, the cloud formed is of level sheets – stratus clouds, rather than puffy convective cumulus. The cloud droplets rarely get big enough to fall as anything heavier than drizzle.
   Here is a typical satellite image for Tropical Maritime air, clearly showing the swathes of featureless stratus over the North Atlantic:



2) The air can also be cooled from below in late autumn, winter and early spring when there are clear skies overnight – the Earth's surface loses heat to space, cooling and in turn cooling the air directly in contact with it. This can lead to **fog** or low cloud forming. This sort of cloud rarely produces anything more than a light drizzle.

Image credit: Sophie Richards



Simple weather apps, typically those embedded in cheap weather stations, watches etc. use pressure as an indication of when it will rain – when the pressure falls, the ‘rain’ symbol appears. But, considering all the different mechanisms for rain formation above, only frontal rain is associated with low air pressure (and convection when associated with summer thunderstorms). For many places in the UK, the prevailing wind direction is much more important. If air which is polar in origin has travelled over the Atlantic to reach us (Polar or Arctic Maritime air) then rain is likely on the west coast, particularly in winter. Similarly, the east coast can expect rain or snow when the wind is blowing from Siberia in winter, picking up moisture as it crosses the North Sea (polar continental air).

As water vapour condenses into liquid water, **latent heat** is released into the atmosphere. When air is warmed and begins to rise the effect is enhanced by the release of latent heat which warms the air further, enhancing the rising motion.This heat release is the energy source which powers developing storms – whether they are mid-latitude depressions or tropical cyclones. It is only while cloud droplets are forming that there is an energy source. Conversely, when liquid water evaporates, it takes heat from its surroundings – we all have experience of this, as skin feels cold when wet.

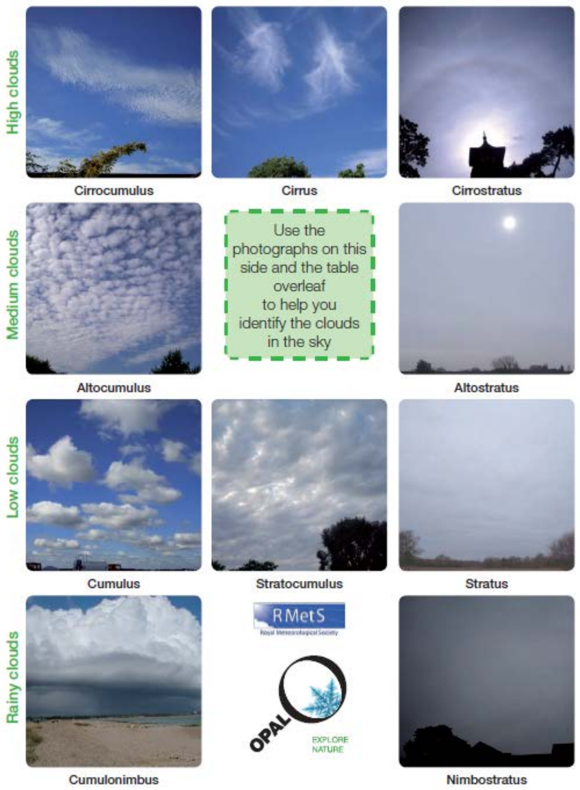
It is also worth noting that cloud cannot form in clean air – the cloud droplets need **Condensation Nuclei** to form on to. Typically, these might be soot, pollen, salt or even bacteria in the atmosphere. This can lead to it being cloudier when more polluted and forms the basis for **cloud seeding** experiments and even some proposed forms of **climate engineering** for mitigating climate change (see, for example, https://www.metlink.org/wp-content/uploads/2013/11/articles/catalyst_cloudseeding.pdf and https://www.abc.net.au/triplej/programs/hack/australias-daring-attempt-to-save-great-barrier-reef-has-begun/12155326).

Climate Change and the Water Cycle

- About 10% of the water evaporated from the ocean is transported over land by the winds and finds its way back to the ocean following condensation into clouds, eventual precipitation as rain or snow and subsequent surface runoff and sub-surface flows.
- As the climate warms, the water cycle intensifies. This is driven by an increase in evapotranspiration at the ground but is controlled by the temperature of the troposphere, which determines how much condensation, and hence precipitation, occurs.
- Over the last century, northern mid-latitude precipitation has increased and the number of heavy precipitation events over land has increased in more regions than it has decreased, particularly in Europe and North America.
- Globally, water vapour concentration in the lower atmosphere has increased by 3-4% since the 1970s.
- Water vapour is a strong and fast feedback that amplifies changes in surface temperature in response to other changes (for example increasing CO_2) by about a factor of 2.
- Many human and natural systems are highly sensitive to changes in precipitation, river flow, soil and groundwater.
-

More information is available at https://www.metlink.org/climate/ipcc-updates-for-a-level-geography/the-changing-water-cycle/.

Cloud Identification Chart



Cloud base	Bubbly appearance	Other sort of structure	Flat with few features
HIGH Above 6000 metres	**Cirrocumulus** Not a common type. Sometimes dappled or rippled. Sun visible.	**Cirrus** Sometimes delicate, hair-like strands. Sometimes thicker blobs.	**Cirrostratus** A veil of white thin cloud. Sun clearly visible with shadows. Often with halo.
MEDIUM 2000 to 6000 metres	**Altocumulus** Broken into small flat clouds, often regularly arranged. No rain or snow.		**Altostratus** Thicker than cirrostratus; sun visible as disc. No shadows or halo.
LOW Below 2000 metres	**Cumulus** Small cumulus have cotton wool shape. Often grow to bunch together. No rain.	**Stratocumulus** Common. Sometimes covering whole sky, sometimes more like flattened cumulus.	**Stratus** Grey, flat and boring, no sun visible. Drizzle may fall. Called hill fog on high ground.
LOW Rain falling	**Cumulonimbus** Cumulus grown tall and dark. Showers likely. Top can be very high, sometimes feathery or flat.		**Nimbostratus** Thick dark stratus, giving rain which is often heavy and prolonged. Difficult to photograph.