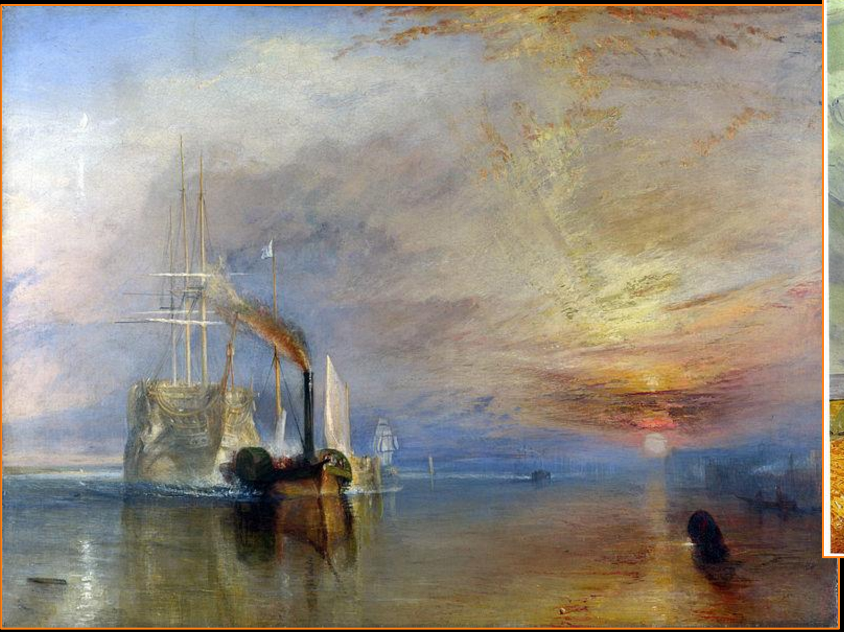
5. Clouds: Water in the Atmosphere

Clouds out of a Plane Window

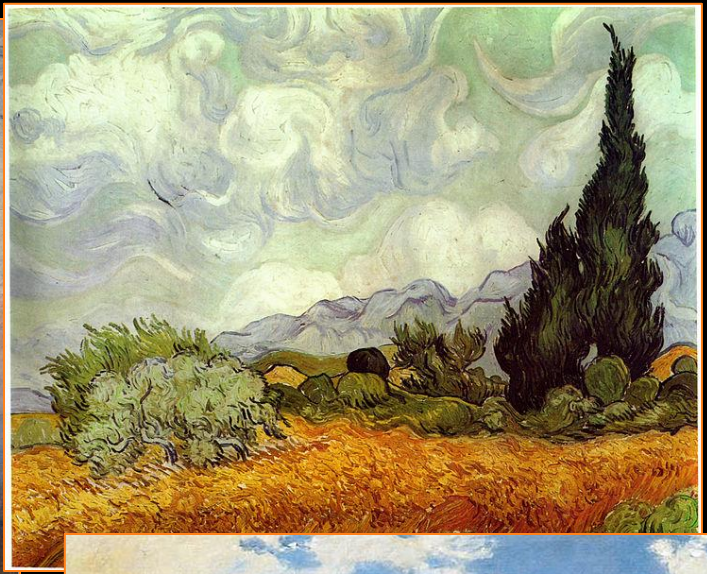
Clouds are one of the most picturesque aspects of the weather.

Convective clouds over Sweden.
Photo (c) 2012, Shonkimages.

Clouds have inspired artists, poets and authors for many centuries.



JMW Turner's "The Fighting Temeraire"



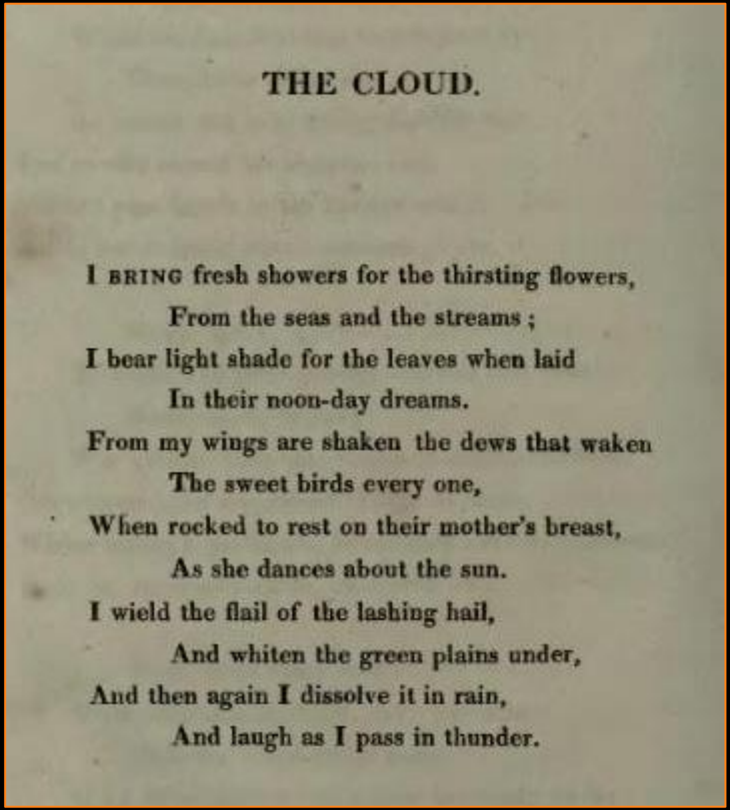
Vincent van Gogh's "Wheat Field with Cypresses"

Claude Monet's "Mouth of the Seine"

Clouds have inspired artists, poets and authors for many centuries.

I wandered lonely as a cloud
That floats on high o'er vales and hills,
When all at once I saw a crowd
A host of dancing daffodils;
Along the lake, beneath the trees,
Ten thousand dancing in the breeze.

William Wordsworth's – "I Wandered Lonely as a Cloud"



THE CLOUD.

I BRING fresh showers for the thirsting flowers,
From the seas and the streams;
I bear light shade for the leaves when laid
In their noon-day dreams.
From my wings are shaken the dews that waken
The sweet birds every one,
When rocked to rest on their mother's breast,
As she dances about the sun.
I wield the flail of the lashing hail,
And whiten the green plains under,
And then again I dissolve it in rain,
And laugh as I pass in thunder.

Percy Shelley's "The Cloud"

Clouds around the World

07 August 2012

Clouds occur at some point in nearly all parts of the world.

At any one time, they cover between 50% and 60% of the Earth's surface.

Different types of cloud dominate the weather in different parts of the world.

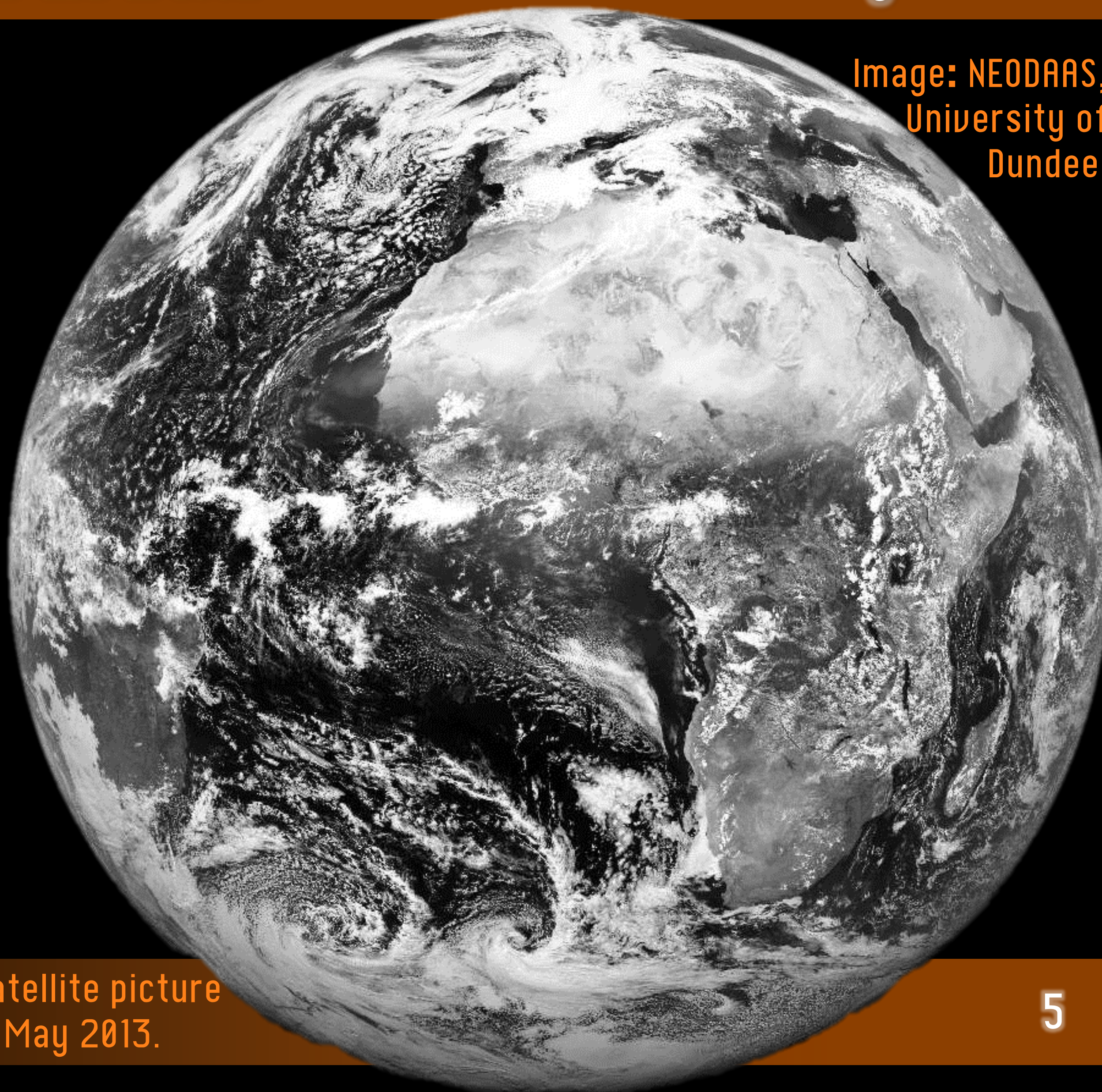


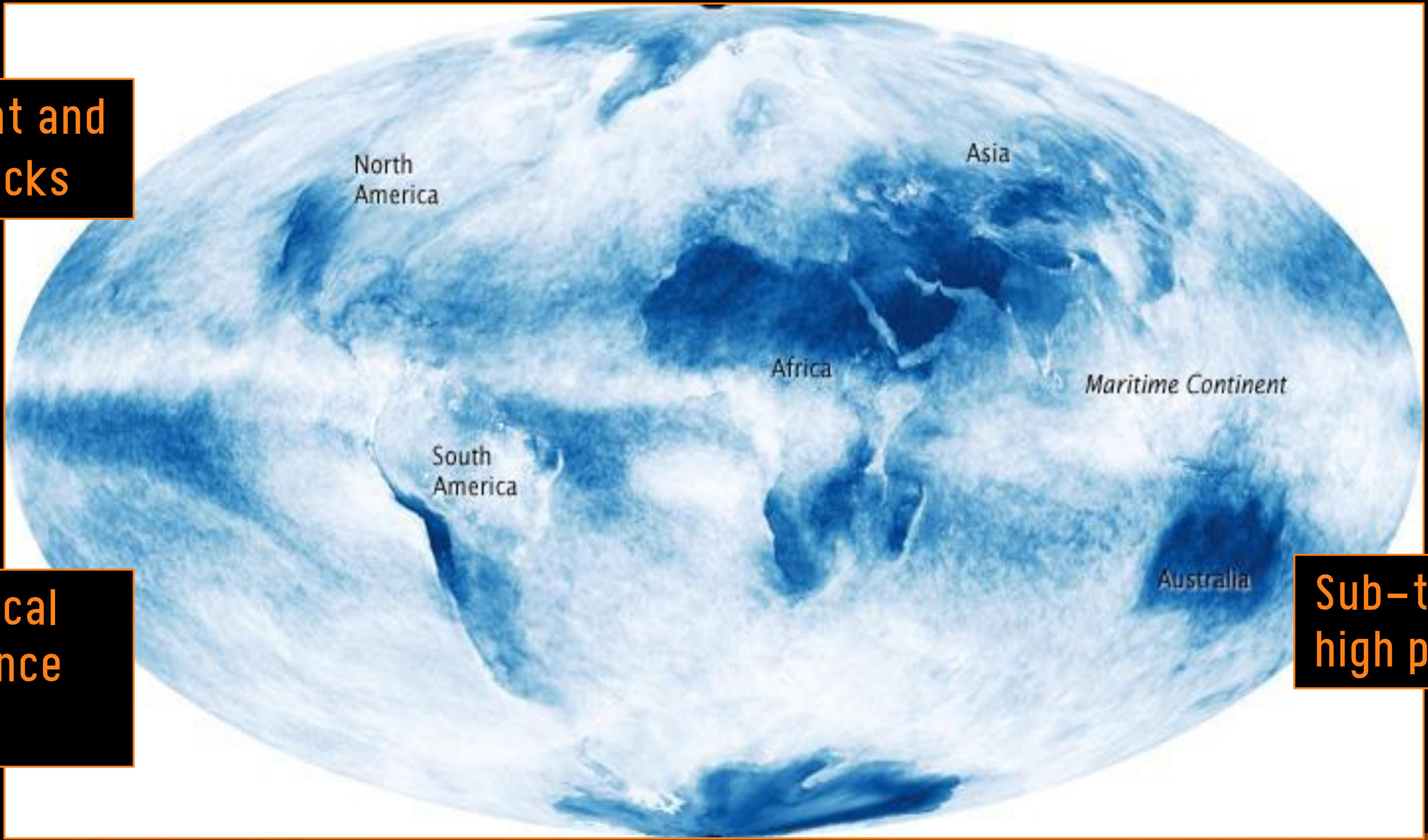
Image: NEODAAS, University of Dundee.

Geostationary satellite picture from 12:00 on 21 May 2013.

Clouds around the World

In a global climatology of cloud cover, key features of the circulation patterns of the Earth's atmosphere can be seen.

Polar front and storm tracks



Intertropical convergence zone

Sub-tropical high pressure

Global cloud cover data from NASA.

Precipitation around the World

A surprisingly small fraction of the world's clouds, however, are actually precipitating at any one time.

Rain and snow only falls from about 1% of the world's cloud cover.

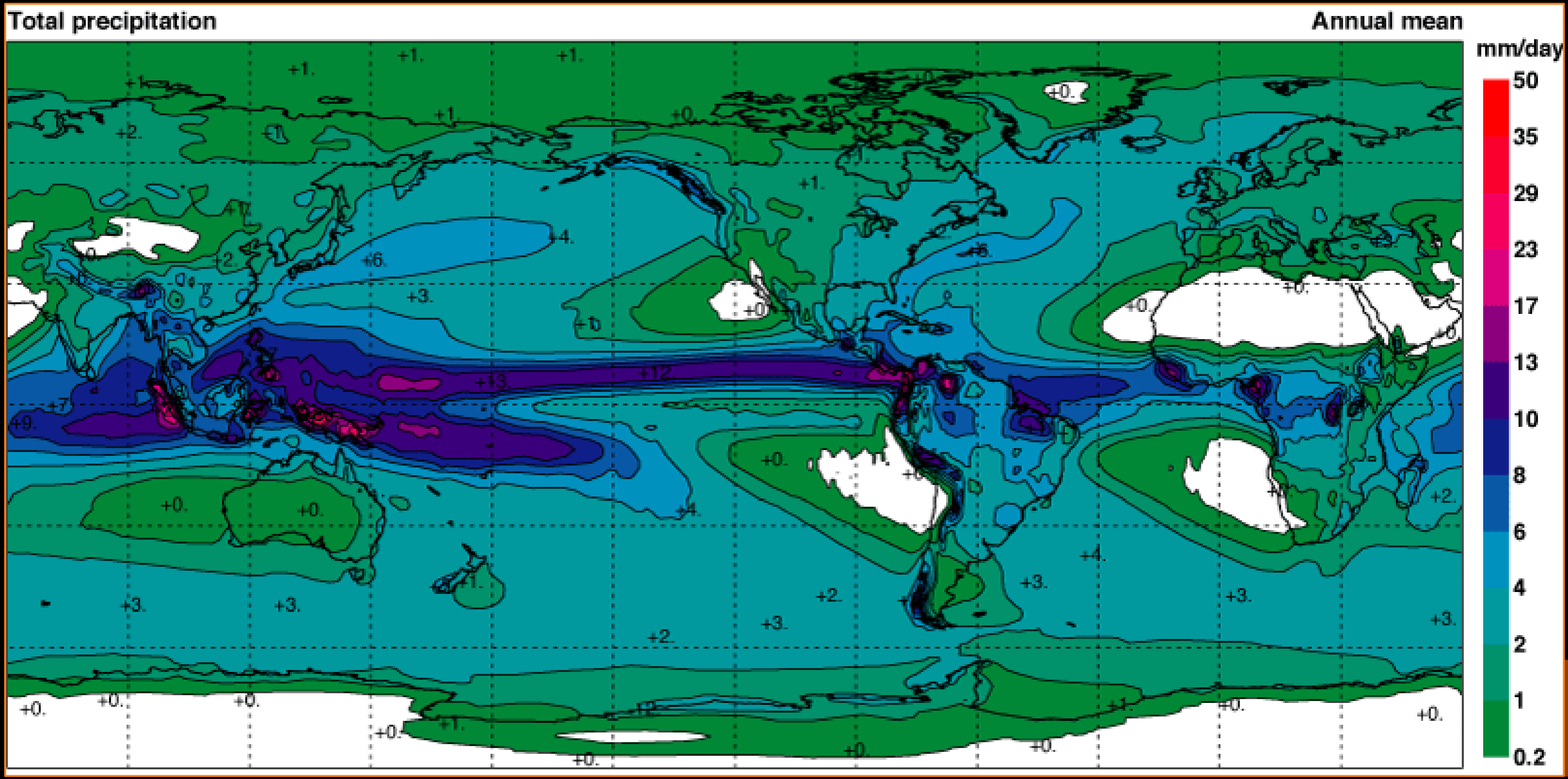


Image: ECMWF.

The traditional way to observe clouds is simply to look at them.

Cloud cover and cloud type is a part of the daily observation routine at a Met Office weather station. A standard cloud report consists of:

- cloud cover;
- low-level cloud type;
- mid-level cloud type;
- high-level cloud type.

Photo (c) Shonkimages.

Cloud cover is quantified in oktas, where 1 okta represents one eighth of the sky.

Cloud type is described using a cloud naming convention developed in 1802 (over two centuries ago) by English chemist and amateur meteorologist Luke Howard.

He based his cloud types on five words derived from Latin to give his system international appeal and used a Linnean naming style, similar to that used to categorise animals and plants.

- Cumulus: meaning ‘heap’ or ‘pile’.
- Stratus: meaning ‘layer’.
- Cirrus: meaning ‘wispy’ or ‘fibrous’.
- Nimbus: meaning ‘rain-bearing’.

Luke Howard

Combinations of these words are used to describe all the clouds that we see in the sky.

Since Howard's day, pairs of his words have become stuck together to describe clouds that have properties of both words (for example, cirrostratus, stratocumulus).

Other Latin-based words have also been included to divide the cloud type into subgroups. These are added after the main cloud type (for example, cumulonimbus capillatus incus; cirrus uncinus fibratus).

For cloud type observations, however, usually only the main cloud type is recorded.

Cirrostratus

Cirrostratus is seen as a milky, thin and tenuous layer cloud through which the Sun can be seen. Sometimes they create halos.

Photos (c) Shonkimages.

- Made of ice.
- High-level.
- Stratiform.

Cirrocumulus

Of the ten main cloud types, cirrocumulus is the rarest. It is a layer of small cloud cells that are thin and tenuous. The individual cells cast no shadows on each other.

- Made of ice.
- High-level.
- Transition.

Photo (c) Shonkimages.

Cirrus

Cirrus are wispy streaks of ice that can form in a wide range of patterns and shapes.

Photos (c) Shonkimages.

- Made of ice.
- High-level.
- Stratiform.

Altostratus

Photo (c) Shonkimages.

Altostratus appears as a thicker sheet of cloud than cirrostratus. Thicker layers may obscure the Sun.

- Made of ice and liquid.
- Mid-level.
- Stratiform.

Altocumulus

Altocumulus is a layer of cloud cells, like cirrocumulus, but the cells appear larger and do cast shadows on one another as the cloud is optically thicker.

- Made of supercooled liquid.
- Mid-level.
- Transition.

Photo (c) Shonkimages.

Stratus

Stratus is a uniform layer of cloud. Thick layers of stratus can bring drizzle.

- Made of liquid.
- Low-level.
- Stratiform.

Photo (c) Shonkimages.

Nimbostratus

Nimbostratus is a grey layer of rain-bearing cloud.

Photo (c) Shonkimages.

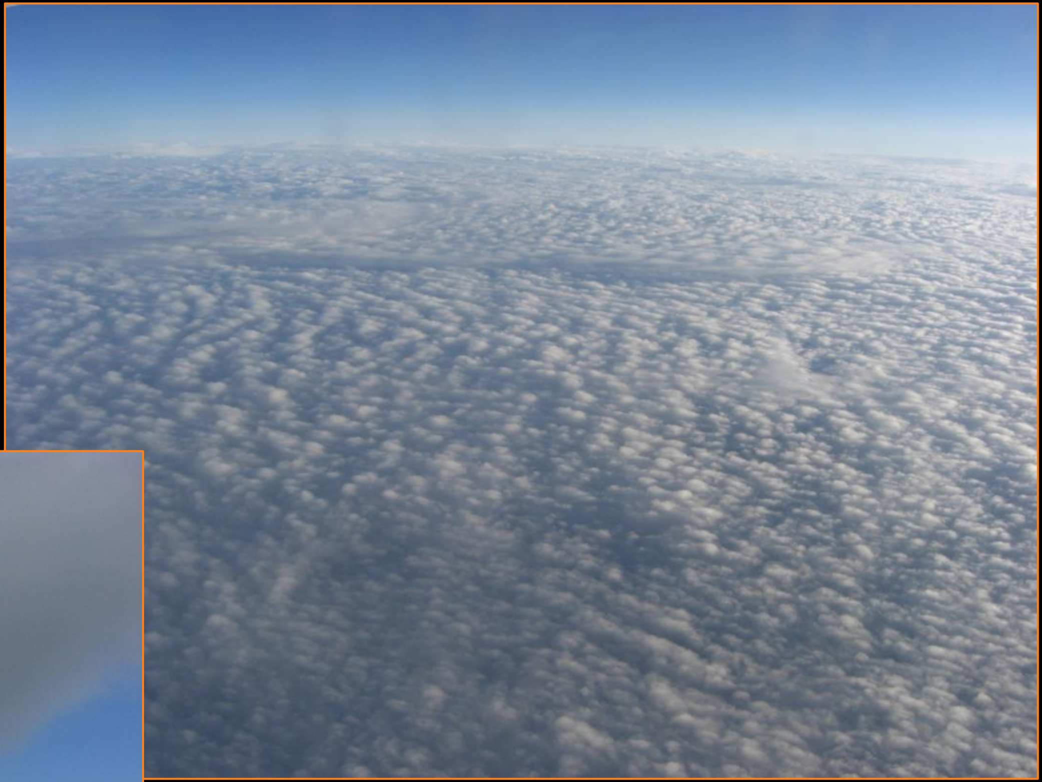
It brings prolonged periods of persistent rain, usually associated with weather fronts.

- Made of liquid.
- Low-level.
- Stratiform.

Stratocumulus

Stratocumulus is a layer of cloud cells. They can be separated by clear sky, or a continuous layer.

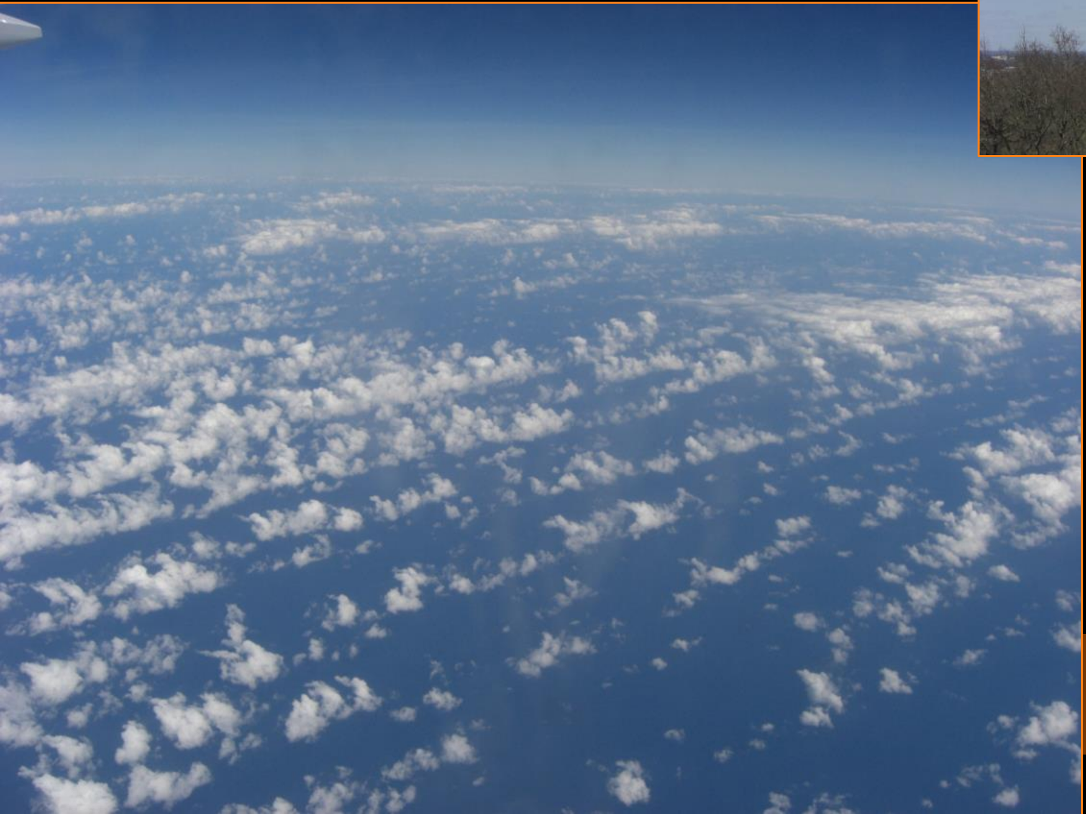
Photos (c) Shonkimages.



- Made of liquid.
- Low-level.
- Transition.

Cumulus

Cumulus clouds are the typical, fair-weather clouds. They start as small pockets of cloud. Sometimes they form in rows called cloud streets.



Small cumulus clouds are called cumulus humilis.

- Made of liquid.
- Multi-level.
- Convective.

Photos (c) Shonkimages.

Cumulus

Cumulus can extend through all levels of the atmosphere. Deep cumulus are called cumulus congestus and can bring rain showers.

Photo (c) Shonkimages.

Cumulus clouds become cumulonimbus when ice crystals start forming at the top. They are unmistakably anvil-shaped.

- Made of ice and liquid.
- Multi-level.
- Convective.

Photos (c) Shonkimages.

Contrails

Contrails are also a type of cloud left in the wake of jet engines. They can be short-lived, or can persist and grow over many hours.

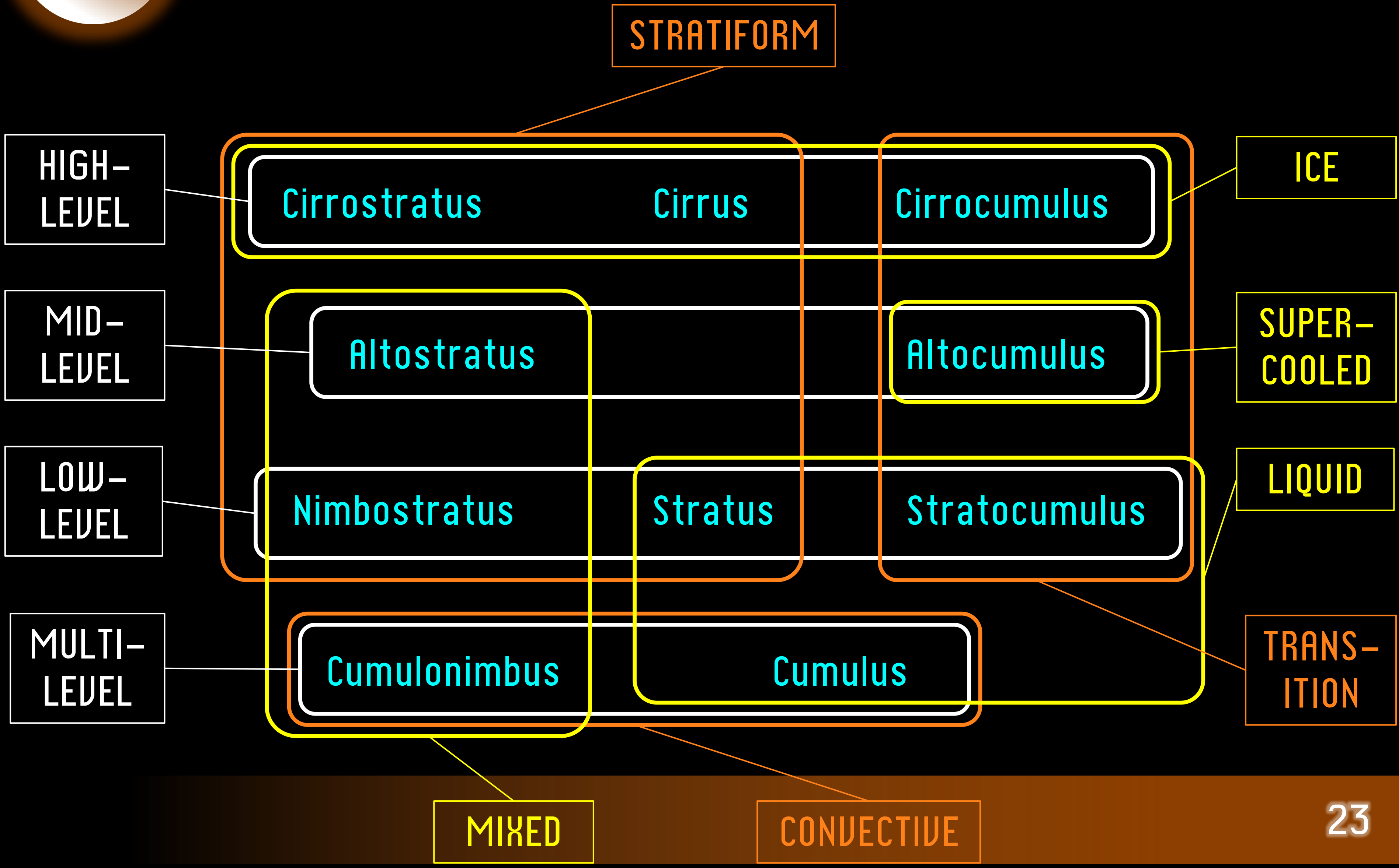
Contrails are, in composition, exactly the same as cirrus clouds.

- Made of ice.
- High-level.
- Man-made.

Photo (c) Shonkimages.

Summary of Cloud Types

07 August 2012



Cloud Challenge

07 August 2012

1

2

3

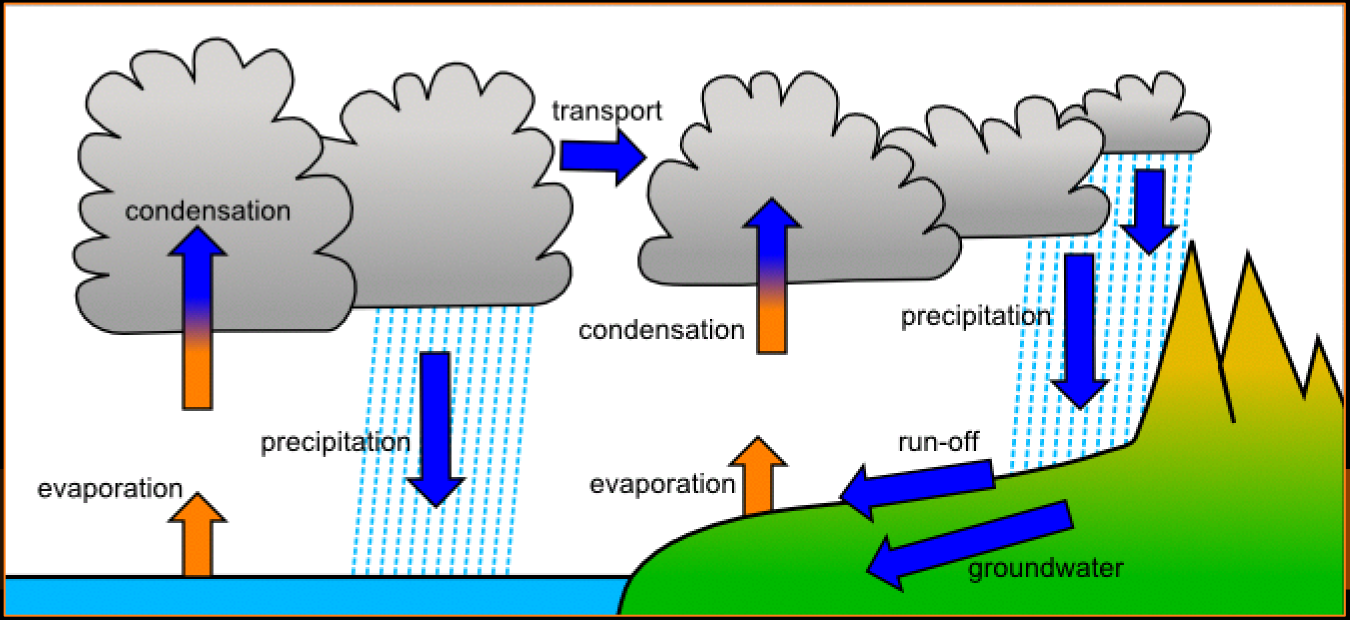
4

5

Now, we look at cloud formation in a little more detail.

Water in the system is constantly passing between the Earth, the atmosphere, the ocean and the ground as part of the water cycle.

Meteorology is concerned with the part of the cycle where the water is in the atmosphere.



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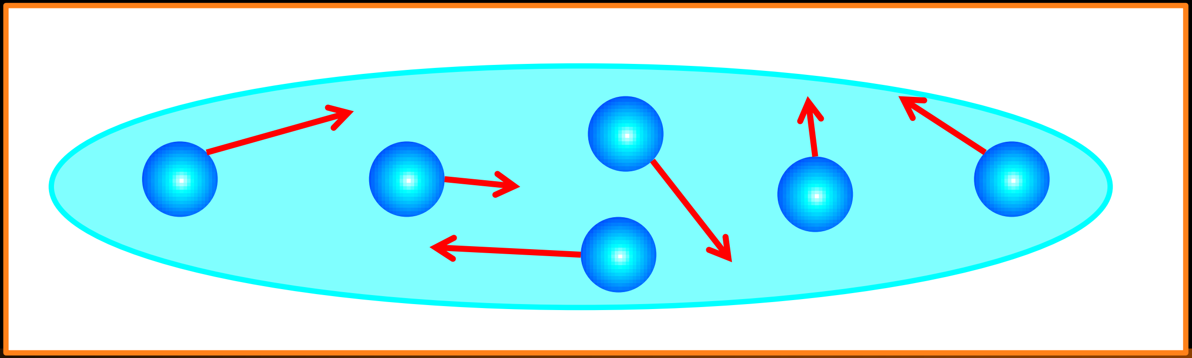
Water enters the atmosphere from the surfaces of rivers, lakes and the sea by evaporation.

Evaporation happens spontaneously. As long as the air above the puddle can hold it, water from a puddle will continue to evaporation until the entire puddle has evaporated.

The puddle is made up of a large number of water molecules, all of which are moving around at a range of different speeds.

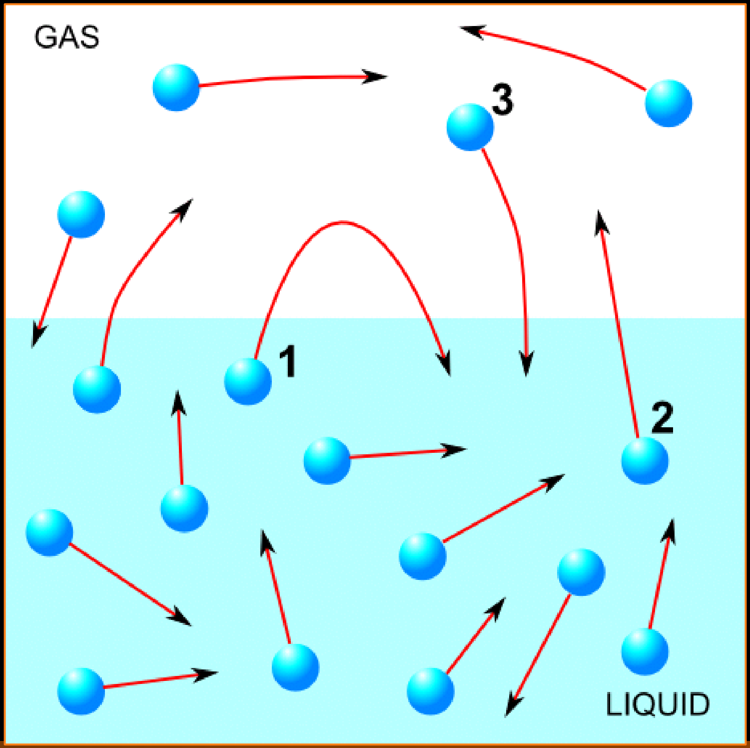


Evaporation

Some molecules have enough speed to break free of the liquid surface. Some fall back into the liquid (1), but some remain suspended in the air (2). At the same time, molecules are passing back into the liquid from the air (3).

If there is a net flow from liquid to gas, the liquid will continue to evaporate.

If the flow of molecules into and out of the liquid become the same, the air can hold no more water vapour. Then the air is said to be saturated.



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A number of factors affect the rate at which the puddle of water will evaporate.

- A warmer puddle contains faster moving molecules, hence more have the required speed to break free from the liquid.
- Warmer air has the ability to hold more water vapour.
- A breeze passing over the puddle can aid evaporation by constantly carrying the water vapour away, creating a supply of drier air for the puddle to evaporate into.

The amount of water vapour held in the atmosphere is described as humidity.

Humidity is a measure of the water vapour content of the air. It can be quantified in many ways.

- Specific humidity: mass of water vapour per unit mass of air.
- Mass mixing ratio: mass of water vapour per unit mass of dry air.
- Absolute humidity: mass of water vapour per unit volume of air.
- Vapour pressure: partial pressure exerted by the water vapour molecules in the air.
- Relative humidity: any of the above as a fraction of what it would be if the air were saturated.

Saturated air has a relative humidity of 100%; dry air has a relative humidity of 0%.

To get clouds to form from a parcel of air, we need to force the water vapour stored in it to condense.

We need to modify it so that its relative humidity rises. If we can force its relative humidity to above 100%, the air will no longer be able to hold the water vapour and condensation will occur.

The amount of water vapour that dry air can hold is dependent entirely on its temperature. Warmer air can hold more vapour than colder air. So, if we take a parcel of air and cool it down (but do not allow any water vapour in or out), the relative humidity will rise.

If we cool air down to the temperature where it saturates (its dewpoint temperature), condensation will start to occur.

Water vapour condenses to form water droplets in two ways. The first entails the spontaneous condensation of water vapour out of the air. This is called homogeneous nucleation.

This relies on water molecules clumping together in large enough numbers to form small droplets.

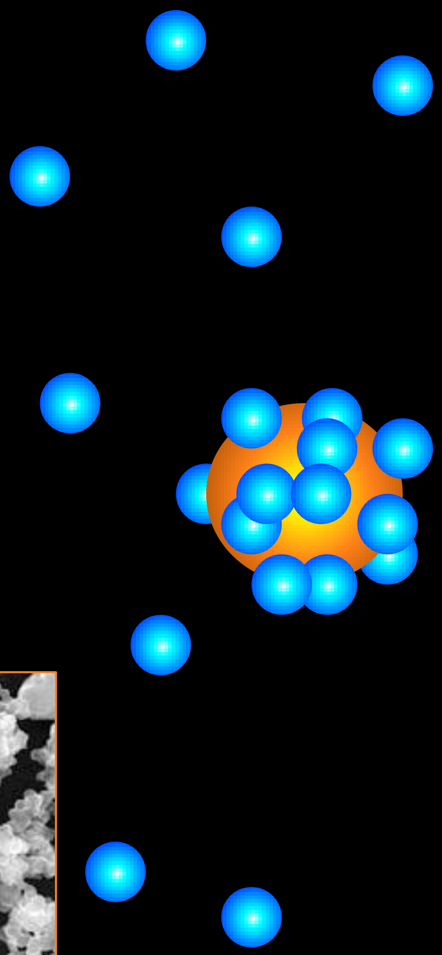
However, to get homogeneous nucleation to happen to any great extent in the atmosphere, relative humidity would have to be in the range 300% to 400%. In the atmosphere, it rarely exceeds 101%.

Heterogeneous Nucleation

A more efficient method is heterogeneous nucleation. This involves water droplets condensing onto small particles called aerosols.

Aerosols that water can condense onto are called cloud condensation nuclei.

Many types of aerosol exist in the atmosphere.



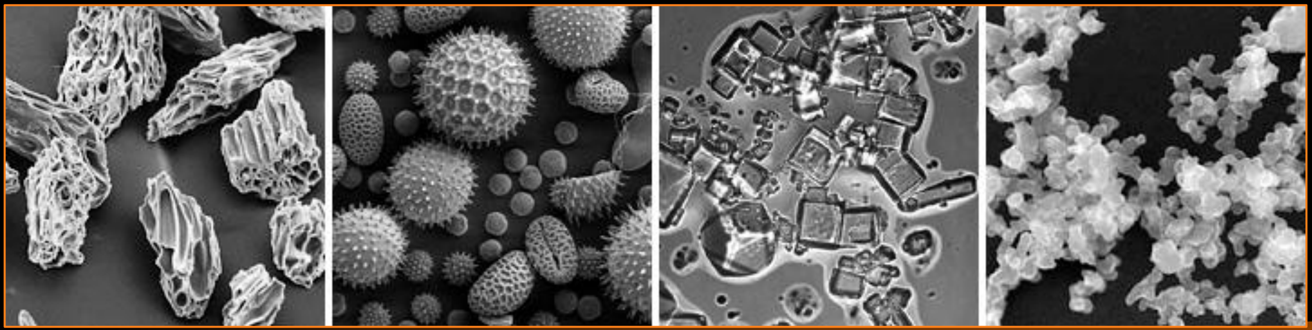


Image: USGS/UMBC/ Arizona State University.

Once a droplet has formed, it has the potential to grow.

Droplets grow in two ways:

- more water vapour condensing on their surfaces;
- their colliding and merging with other droplets (coalescence).

The smallest cloud droplets are a few tens of micrometres across; large raindrops can be a few millimetres across.

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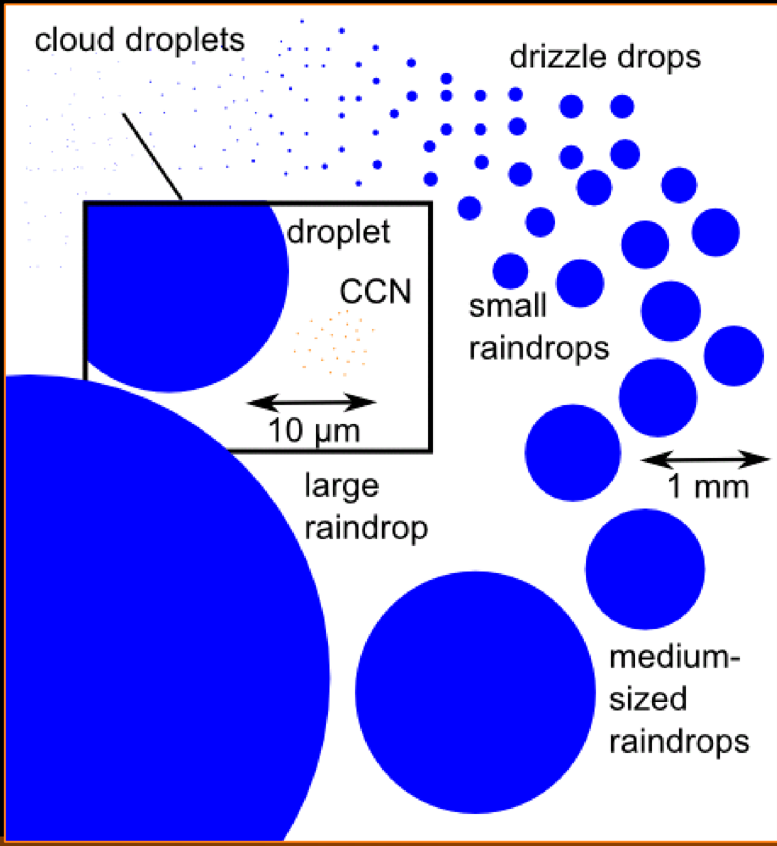


Condensation of Ice

Condensation does not just form liquid droplets in the atmosphere. If conditions are right, these droplets can quickly freeze to form ice crystals.

Most of the troposphere by volume is colder than 0°C, so ice crystal formation must be an important process.

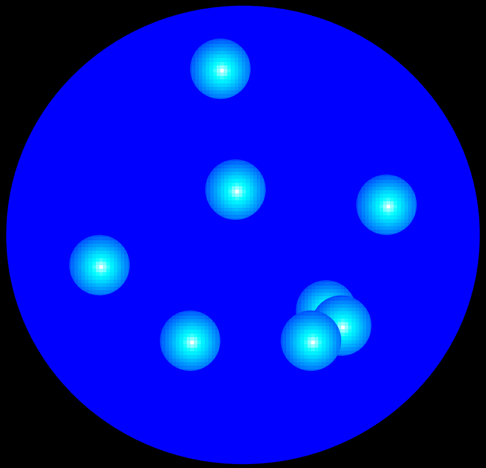
However, liquid water droplets can still form in the atmosphere at temperatures way below 0°C. In fact, they can form at temperatures as cold as –38°C (the "Schaefer Point").

Water droplets existing at temperatures below 0°C are called supercooled liquid droplets.

A supercooled droplet can freeze into an ice crystal in two ways.

The molecules within the droplet are in constant motion, in the same way as in the puddle of water we saw earlier. However, in a supercooled droplet, the temperature is much colder and the molecules are less energetic.

Some of these less energetic molecules might clump together to form a small ice particle within the droplet. Once this happens, the entire droplet rapidly freezes.



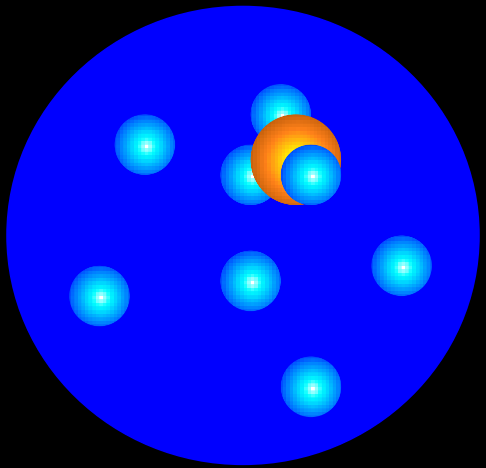
This is homogeneous nucleation.

Heterogeneous Nucleation of Ice

Alternatively, the formation of the ice crystal could be initiated by a particle within the droplet. Again, once an ice crystal forms within the droplet, the entire droplet will rapidly freeze. This process is referred to as heterogeneous nucleation.

At higher temperatures (near 0°C), most ice crystals form by heterogeneous nucleation. At lower temperatures (near −38°C), homogeneous nucleation dominates.

Ice crystals tend to grow by condensation; that is, more water vapour molecules freezing onto them.

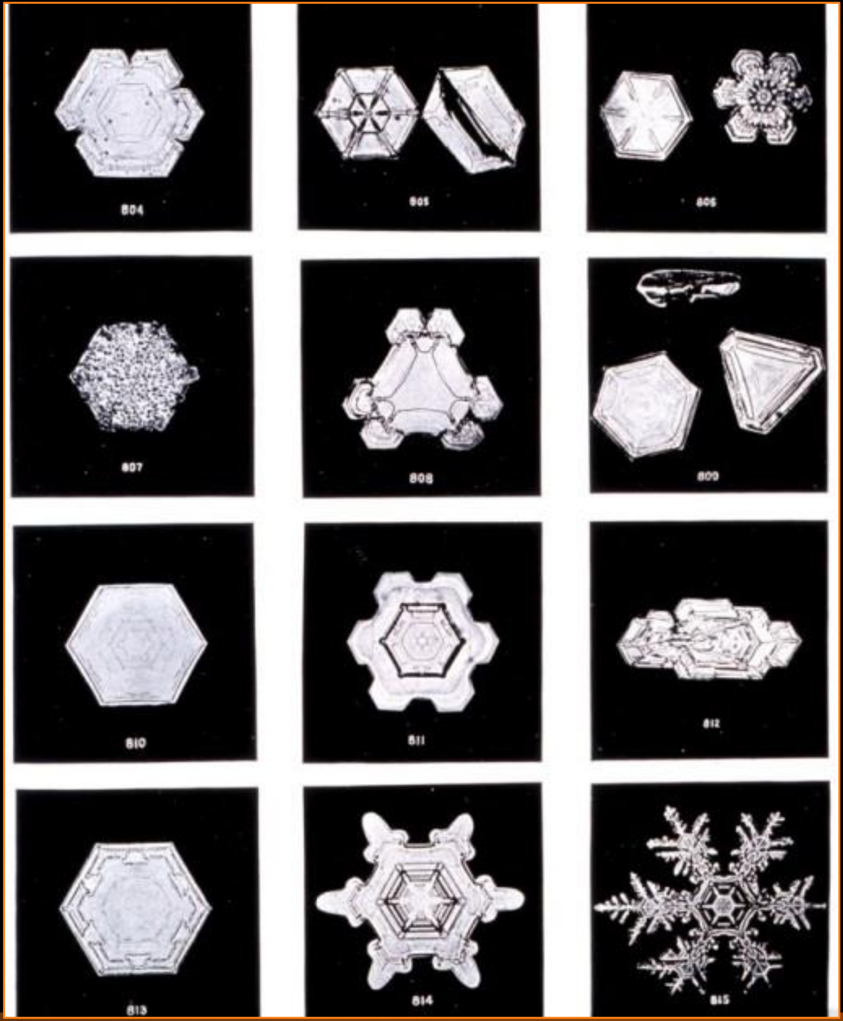


Ice Crystals

Water molecules in a solid state form a hexagonal lattice.

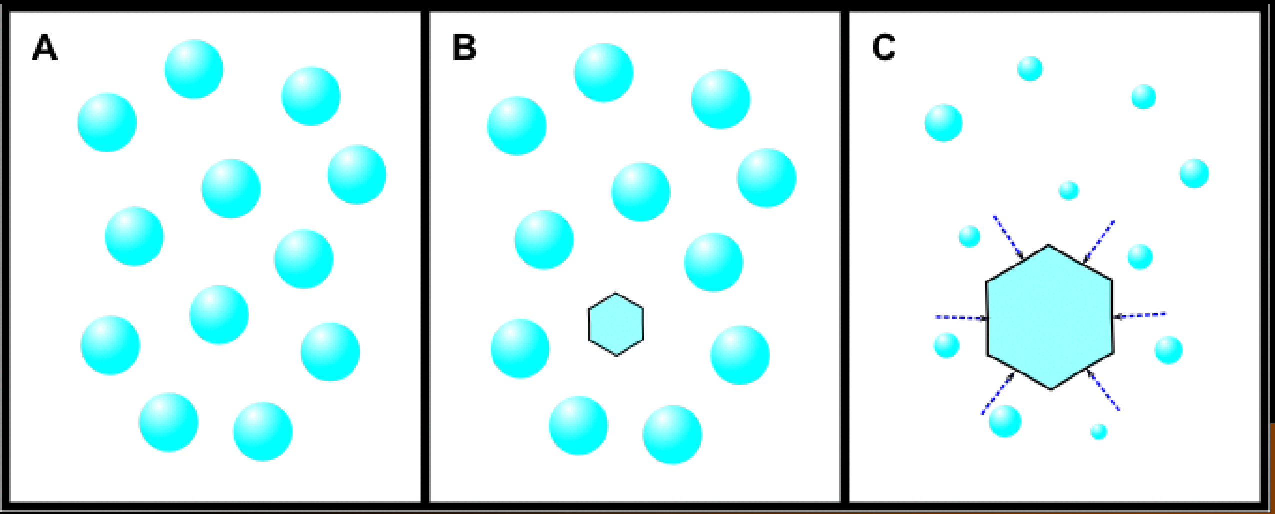
This leads to the six-fold symmetry we associate with ice crystals and snowflakes.

Depending on the conditions under which they form, ice crystals can take on a wide range of shapes.



Saturation occurs at different points for water and ice. Air in a supercooled cloud may be saturated (100% relative humidity) with respect to water, but could be supersaturated (150% relative humidity) with respect to ice.

Hence, if any ice crystals form in a supercooled cloud layer, ice crystals will rapidly form in great numbers at the expense of the supercooled liquid droplets.



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This is called the Bergeron—Findeisen process.

This process can sometimes be seen in action when an aircraft flies through a layer of altocumulus, producing a hole-punch cloud.

Hole-punch cloud observed near Linz, Austria. Photo: H Raab.

So the key to forming cloud is to cool moist air. The easiest way to do this in the atmosphere is to force the air to ascend.

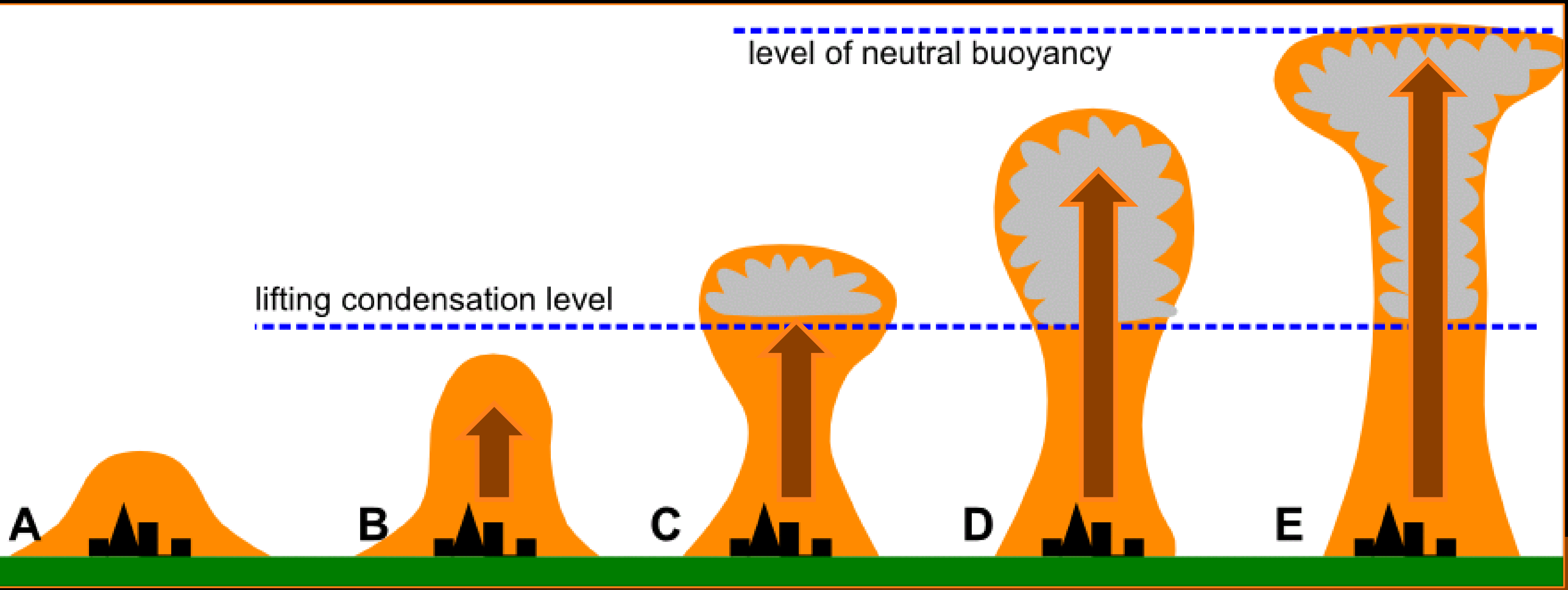
The pressure exerted on a parcel of air falls as the it ascends. This causes the air to cool. If we assume "adiabatic" ascent (meaning that no heat leaves or enters the parcel), it cools by 9.8°C for every kilometre.

There are three main ways ascent can happen in the atmosphere:

- convective ascent (associated with convection);
- frontal ascent (at a warm or cold front);
- orographic ascent (caused by air rising up over mountains).

The simplest of the three is convective ascent.

Say we have a warm spot on the Earth's surface. Air above this is heated and forms an ascending plume called a thermal. When it saturates, it forms a dome-shaped cumulus cloud.



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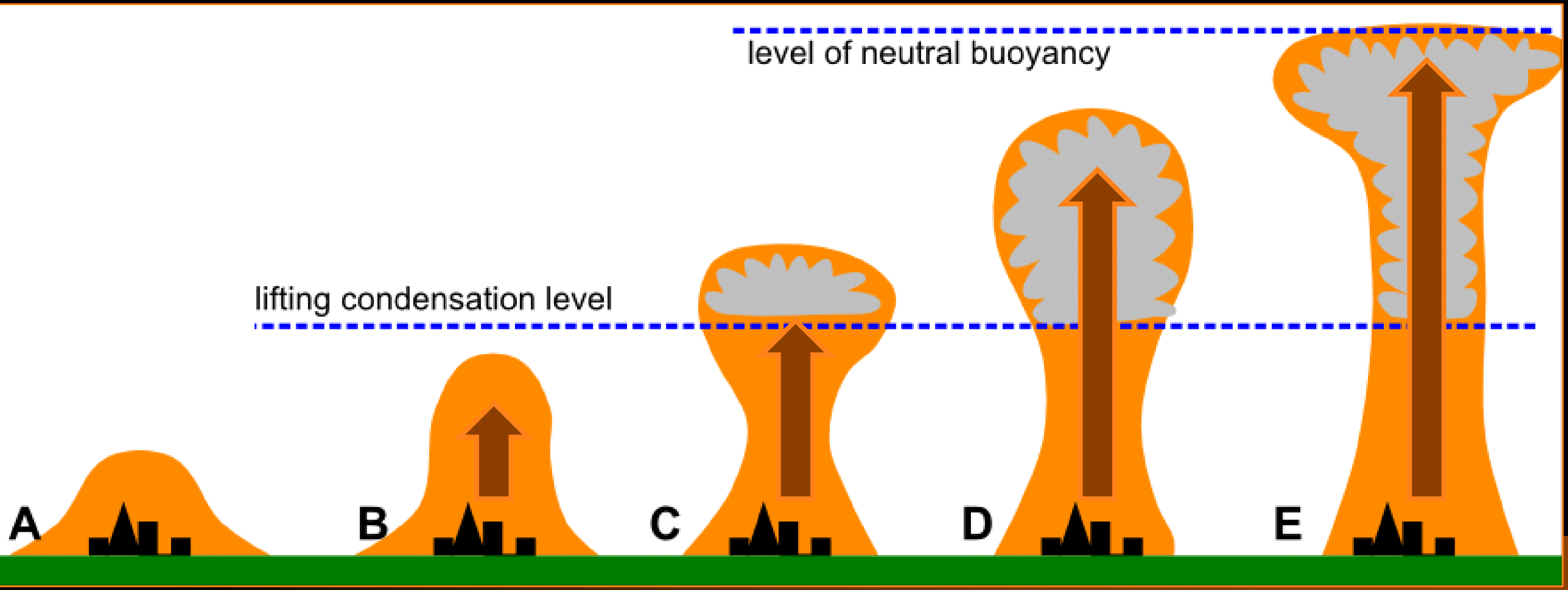
Cloud base forms when the temperature of the air is lowered to its dewpoint. The base of a convective cloud is usually fairly flat, but the top consists of billows and turbulence.

Clouds can contain many millions of kilograms of liquid water.



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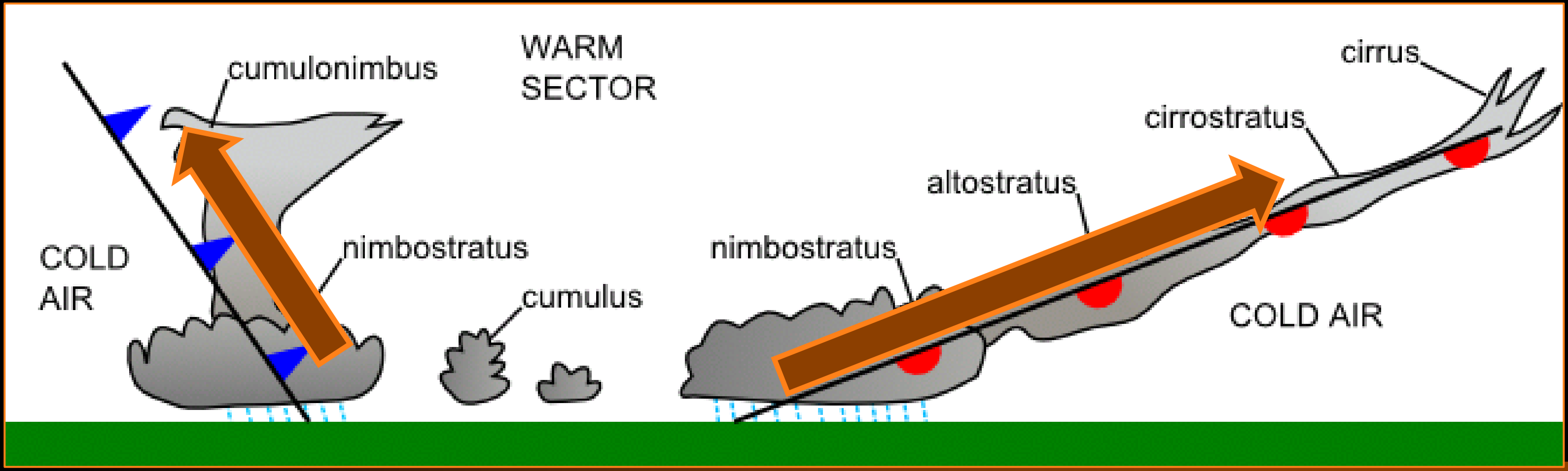
Frontal Ascent

A frontal surface is where warm air and cold air meet, with the result that the warm air is forced to rise.

As fronts form at very shallow angles, this generates a vast layer of uniform, stratiform cloud. This is particularly true at the warm front.



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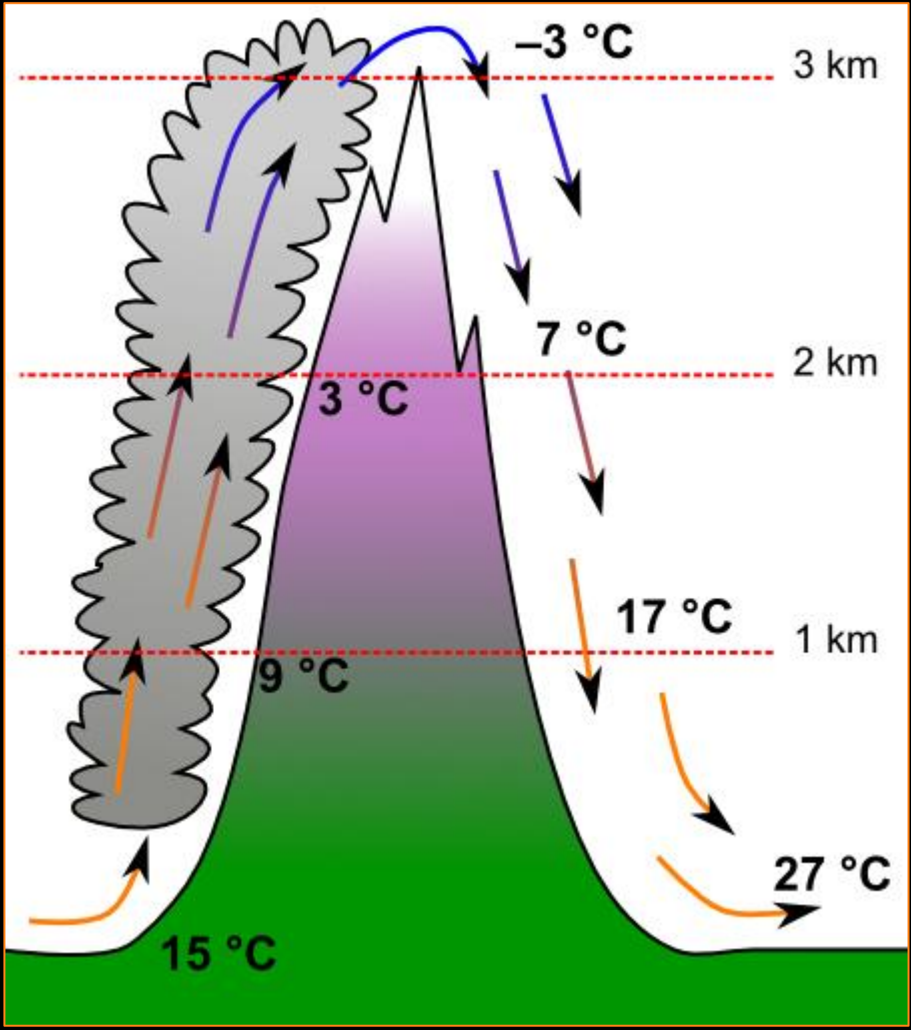
Orographic Ascent

When air reaches a range of mountains, it has no choice but to rise up over the top.

As air saturates, clouds form on the windward side of the mountains.

When the air descends the leeward side of the mountains, the air warms again and is no longer saturated. It is also warmer than on the windward side.



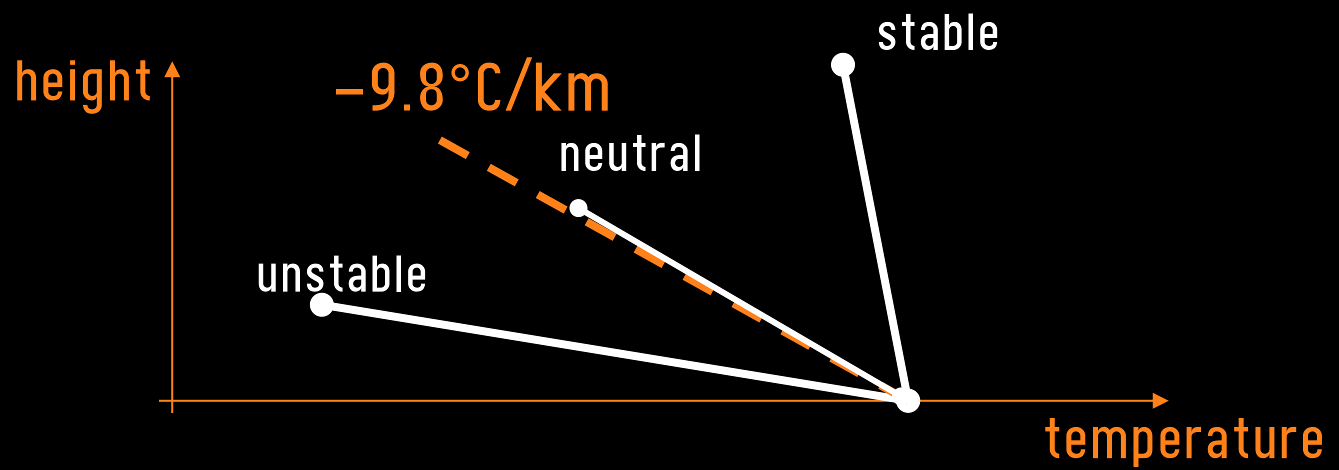
From Shonk, 2013.

If the layer of cloud base is high enough, the air being forced to ascend over the mountain can create wave clouds, called altocumulus lenticularis. These can form over the mountain, or in a chain downstream.

Altocumulus lenticularis over Iceland. Photo: Josvandamme.

A final property of the atmosphere that affects the shape of clouds that form is the stability of the atmosphere.

Dry air cools by 9.8°C for every kilometre it ascends. Stability is a way of determining whether a parcel of air is free to ascend by comparing this rate with the actual change of temperature with height in the atmosphere.



In a stable atmosphere, air displaced vertically is more dense than its surroundings, hence ascent is suppressed. If cloud forms in such conditions, they are flat sheets of cloud.

In an unstable atmosphere, air displaced vertically becomes less dense than its surroundings, hence is free to accelerate upwards, creating tall clouds.

Unstable conditions

Photos (c) 2011, Shonkimages

Stable conditions

SUMMARY

Clouds form in a range of shapes, sizes and compositions.

They can be categorised in many different ways, although the standard approach is to use the system based on Luke Howard's cloud classifications.

Water vapour enters the atmosphere by evaporation off liquid surfaces on the Earth. Clouds form when it condenses again aloft.

Condensation of cloud droplets is instigated by the cooling of the air caused by its ascent. This ascent can be convective, frontal or orographic.