MetLink
Royal Meteorological Society

Depressions

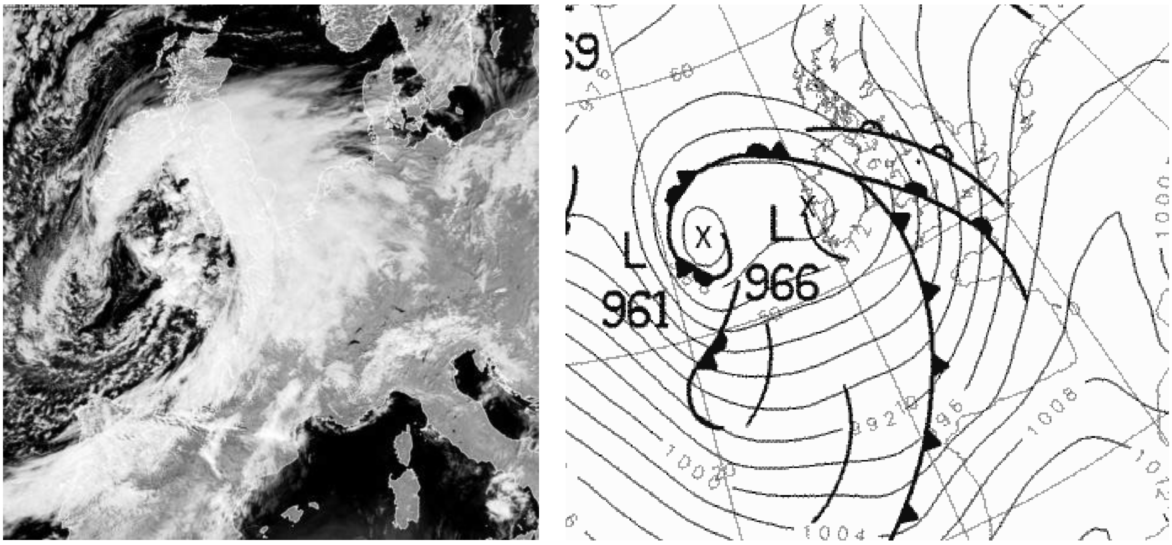
Background Information for Teachers

Stormy Weather

Mid-latitude depressions, extra-tropical storms, cyclones (in the mid-latitudes) or low pressure systems are all different names for the same thing. They all refer to the storms which bring the UK most of its weather, particularly in the autumn and winter. But what are they, why do they form in mid-latitudes, and why do they cause rainfall and winds?

These storms typically last several days, are a few hundred kilometres in size and travel approximately eastwards across the North Atlantic. They are characterised by a swathe of cloud the same scale as the UK, and when shown on a weather map (also known as a synoptic chart), are distinguished by low pressure in the middle and distinctive fronts.

They bring us both our ‘normal’ and our ‘extreme’ weather.

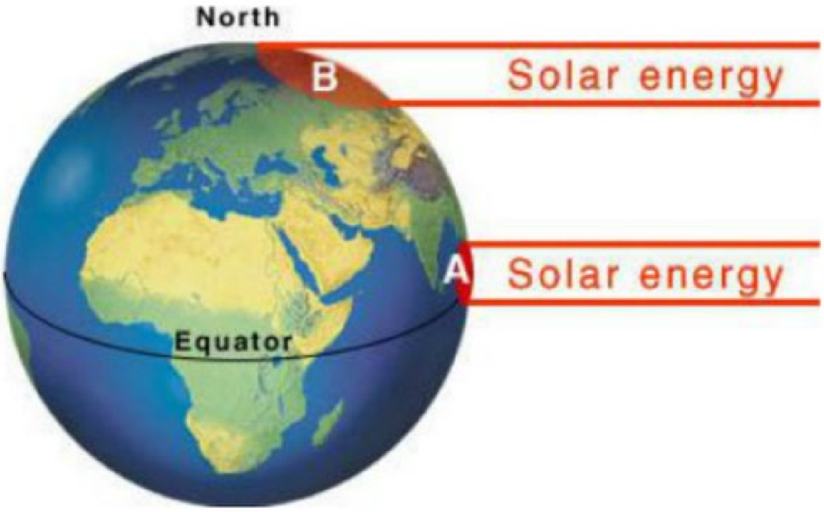


A satellite image (left) and synoptic chart (right) showing a characteristic depression over the UK.

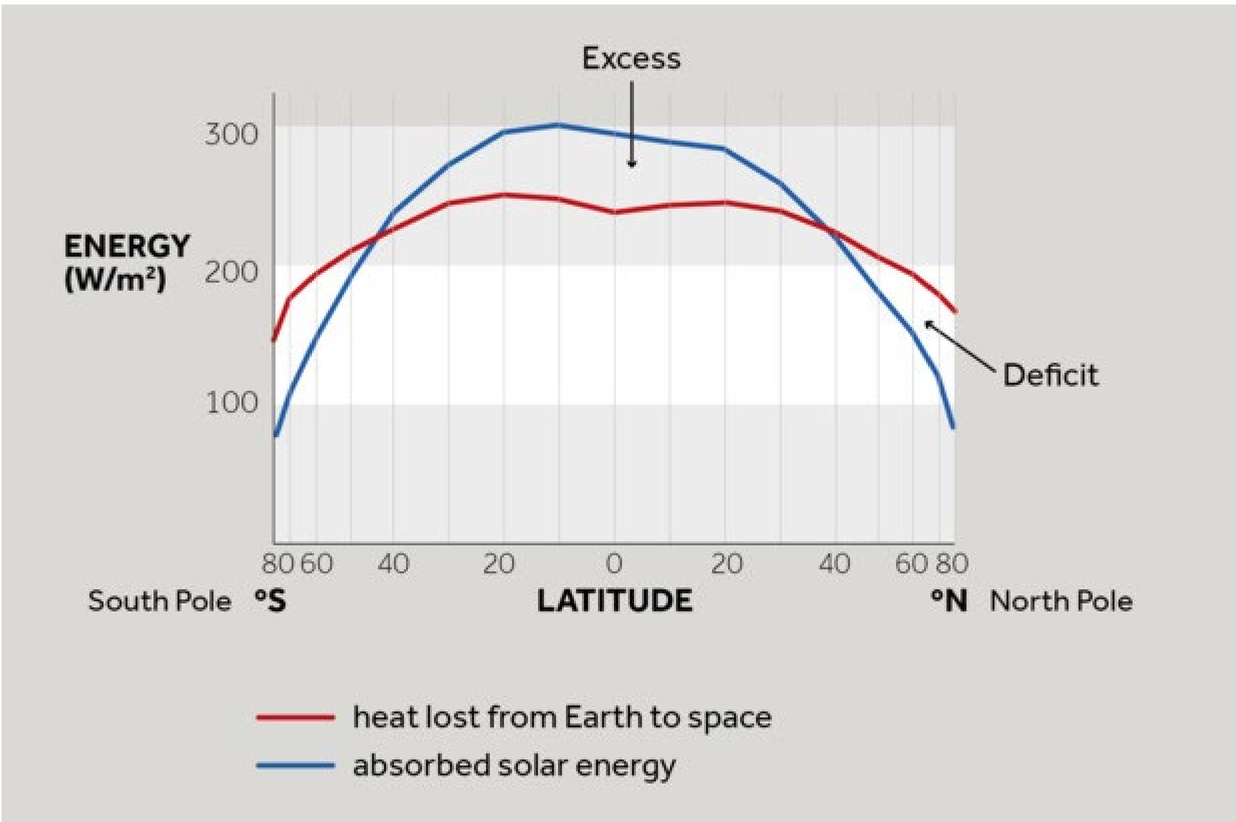
The first scientific study and classification of these weather systems was performed by a group of Norwegian meteorologists: the Bergen School. The location was no coincidence; Bergen experiences a lot of weather systems.

Working in the early 20th Century without the benefit of satellite and radar pictures, the tools we use to tell us about the atmosphere today, this group did a remarkable job of describing the nature of weather systems. Using only ground-based observations and information from weather balloons, they realised that depressions occur as a consequence of the pole-to-equator temperature gradient.

As we live on a spherical planet, you can see in the figure below, somewhere on the Earth’s surface will always be at right angles to the Sun’s rays, such that the Sun’s light is fairly concentrated (**a**). In contrast, in other areas on the Earth’s surface which slope away from the Sun’s light, the Sun’s light will be more spread out (**b**). As the Earth’s surface is warmed by the Sun, the more concentrated light falling on (**a**) will warm the surface more than in area (**b**). This is why the Tropics are always warmer than the poles.



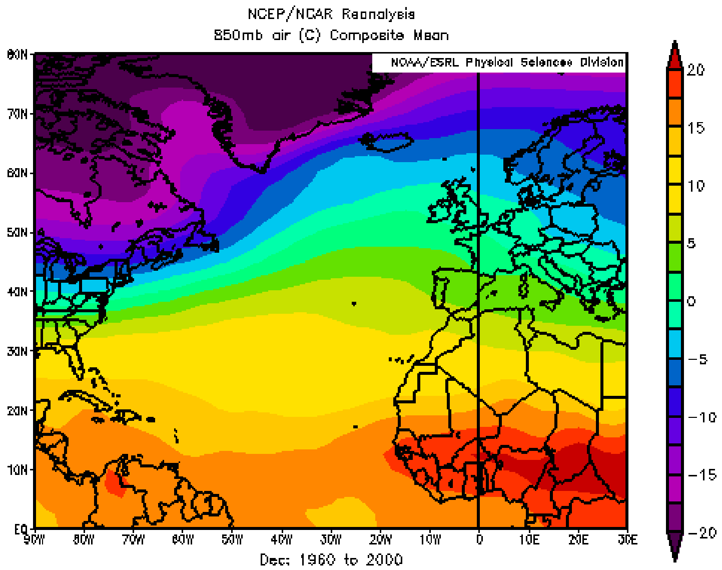
The graph below shows the latitude along the bottom (the x axis) and the amount of energy on the left (the y axis). The blue line shows that, over the course of the year, the Tropics receive more energy than the North Pole and South Pole.



The red line shows the amount of energy the Earth is losing to space. As you can see, the Tropics also lose more energy than the Polar regions, but the red and blue lines are not the same. The Tropics are absorbing more energy than they are losing, whilst the North and South Poles are losing more energy than they are absorbing. If energy absorption and loss are the only factors at play this would mean that the Tropics would be always warming and the Polar regions always cooling. However, this isn't the case, something else must be transporting heat from the Tropics to the poles.

Storms, such as mid-latitude depressions (and Tropical cyclones) are one of the ways the Earth transports heat from the Tropics to the Poles, maintaining the global climate. The rest of the heat is transported by the global atmospheric and oceanic circulations (Chapter 4).

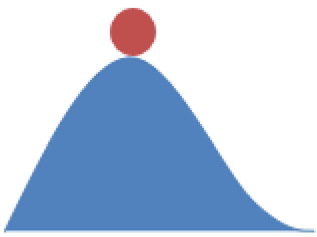
The map below shows changes in temperature from the Polar regions to the Tropics, the yellow/ orange colours indicate warm air and the purple/ blue colours indicate cold air. As you can see, the rate at which the Earth's temperature falls is not constant as you travel from the Tropics to the Polar regions. The colour bands are widest in the Tropics and Polar regions and narrowest in the mid-latitudes – the temperature is falling off fastest as you go north in these regions.



The Bergen meteorologists realised this temperature gradient was a key part of the formation of weather systems. They saw the mid-latitudes as being where the warm, Tropical air met and 'fought' the cold, Polar air. As they were working at around the time of the first World War when fronts were very much part of people's vocabulary, they referred to the temperature gradient as 'the Polar front'; a boundary separating warm Tropical air from colder air.

Mid-latitude depressions form on the polar front because it is unstable.

Consider a ball on a hilltop:

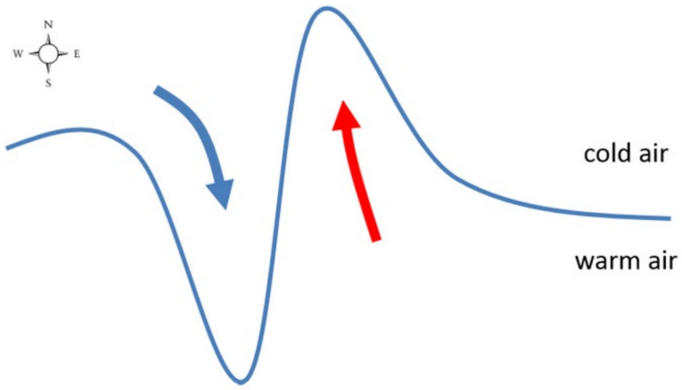


unstable

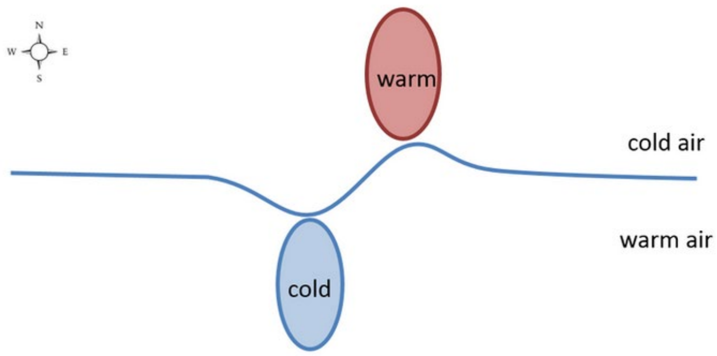
Even if you nudge that ball very slightly it will roll down the hill and end up a long way away from where it started – it is unstable. In exactly the same way, if something nudges the westerly winds blowing along the polar front from west to east, they end up a long way away from where they started.

Imagine something nudging the westerlies – maybe a hill which they blow around:

Because the polar front is unstable, the winds don't return to being westerly once passed the hill. Instead, the nudge grows into a wave:



Then, in the same way that an ocean wave approaching the coast eventually gets so steep that it can't hold together any longer and breaks, the atmospheric wave also breaks, stranding warmer air on the poleward side of the polar front, and colder air on the equatorward side.

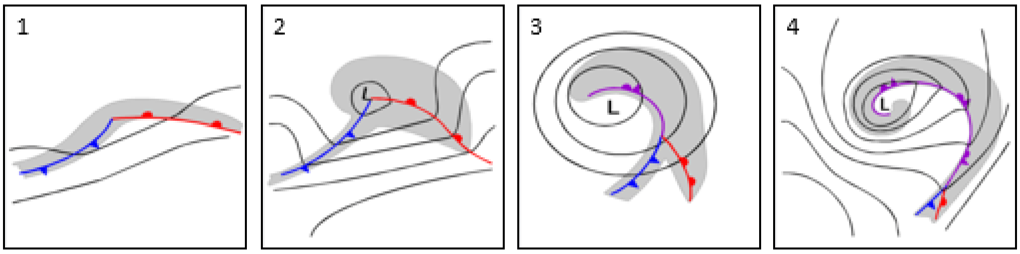


This is how depressions move heat from the Tropics to the Poles.

However, we now need to consider why we get weather associated with depressions. Most weather processes ultimately rely on the fact that warm air rises. So, where warm air meets cold air in a depression, the warmer air will rise. As it rises, cloud and eventually precipitation will form.

Remembering that air pressure is simply a measure of how much air there is above you (Chapter 8), as the warm air rises, there is less atmosphere left above it and so the pressure falls. The first law of thermodynamics tells us that as the air expands, it does work pushing the surrounding air out of the way, and this reduces its temperature. As the rising air cools, the rate of evaporation becomes less than the rate of condensation until eventually cloud droplets form. As water vapour condenses into liquid water, latent heat is released providing the energy source for the developing storm - for example, there is enough heat released in a small cumulus cloud to power an average home for 17 years! As the storm continues to develop, some of the cloud droplets will become large enough to fall as rain.

To look in detail at the weather associated with a depression, its useful to break the depression into 4 distinct stages. The images below are map views.



The Four Stages of a Depression. The grey shading indicates cloud.

Stage 1 shows the very start of a depression. There is warm air to the south of the front and cold air to the north. The winds are blowing from the west to the east, so to the left of the diagram we have cold (Polar maritime) air pushing into warm (Tropical maritime) air ahead. This is called a cold front and is usually drawn in blue and with triangle symbols (reminiscent of icicles). To the right of the diagram, the warm air is pushing into cold air ahead. This is called a warm front and is usually drawn in red with semi-circle symbols (reminiscent of the spherical Sun).

In **stage 2**, the wave has developed further. Taking a cross section through the stage 2 depression:

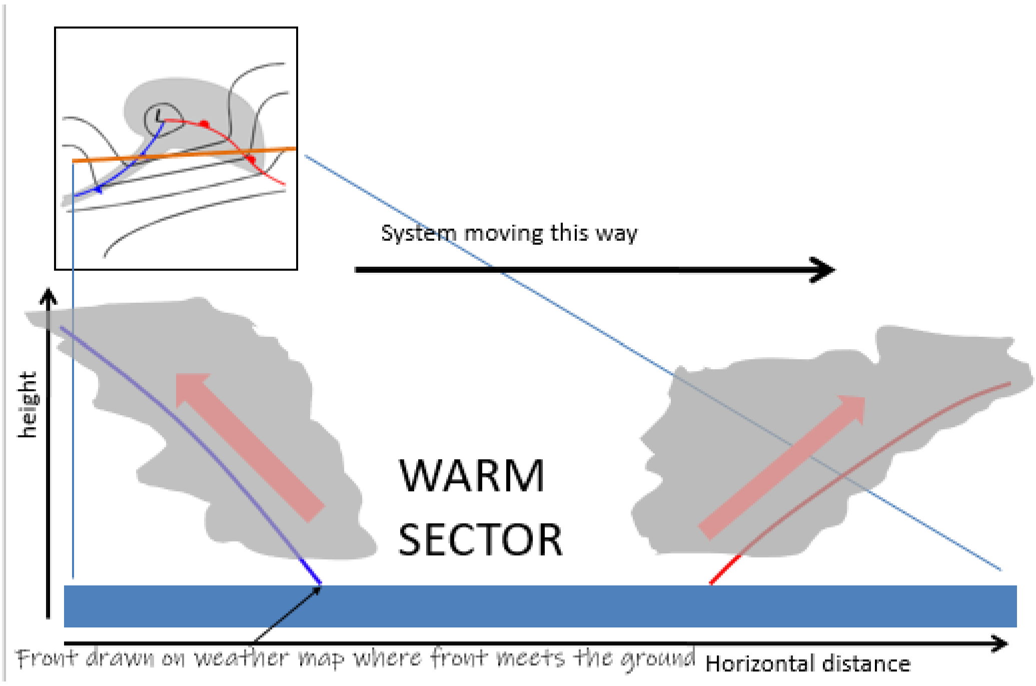
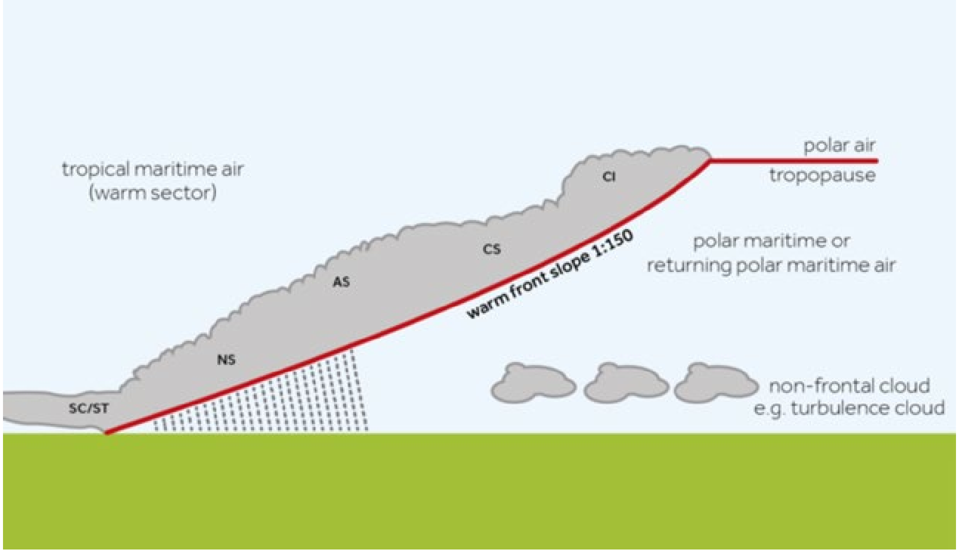


Image copyright: University of Reading

The first thing to notice is that the fronts are not vertical – as it's always warm air that rises. On the cold front, the cold wind blowing from the west pushes into and under the warm air in front of it, forcing the warm air to rise. On the warm front, the warmer air pushes into and over the colder air ahead of it. Cloud and rain are found on the fronts.

Looking at the warm front in more detail:



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(CI = cirrus, CS = cirrostratus, AS = altostratus, NS = Nimbostratus, Sc= stratocumulus, ST = stratus – see Chapter 9 for details)

It's worth noticing the very low gradient on the front – if the warm front is 5km high, then it may well cover 750km horizontally. On the ground, the front may be 1-20km wide.

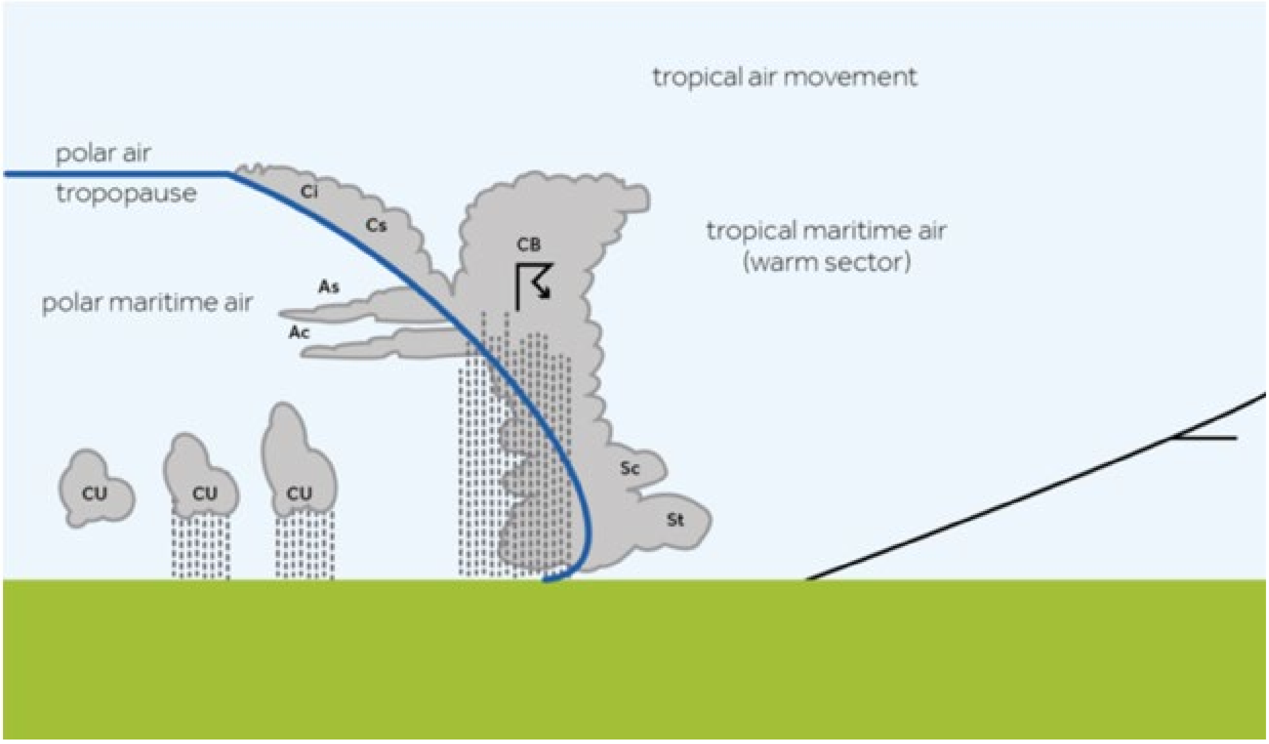
Wispy cirrus clouds form on the highest parts of the front – a good indicator of an approaching depression:

Cirrus (left) and nimbostratus (right). Images copyright RMetS

Closer to the ground, the cloud becomes featureless sheets – stratus – or nimbostratus when raining.

When the front passes you on the ground, the temperature may rise by a few degrees.

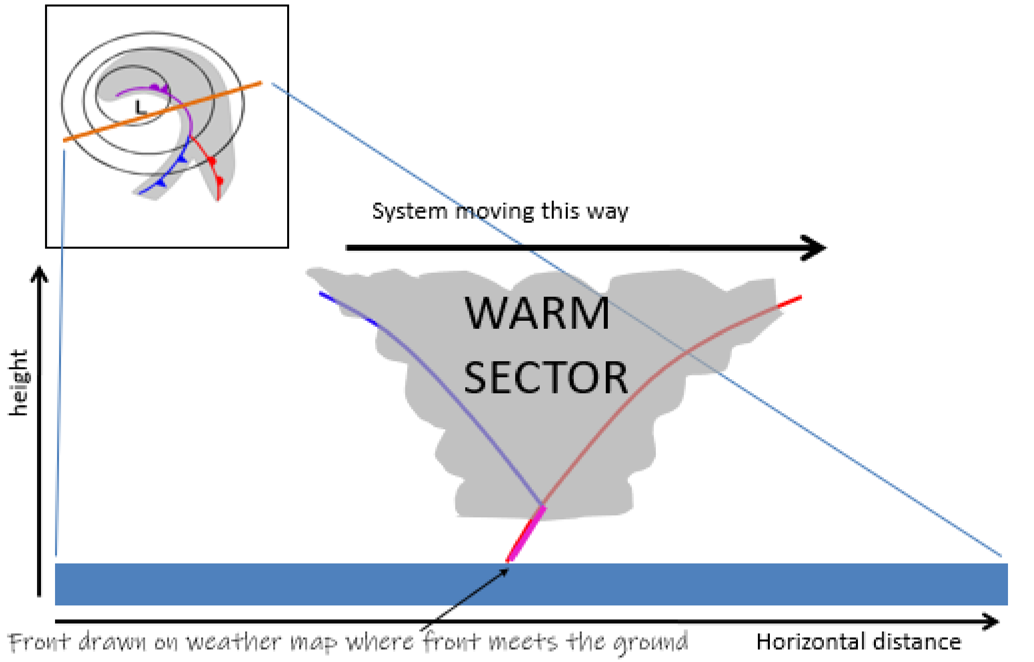
The cold front is much steeper than the warm front as it marks the boundary between extremely cold, dry air from high in the troposphere with the warmer Tropical air.



The weather on the cold front is therefore typically more extreme, with heavy precipitation and occasional hail, thunder, lightning and even tornadoes in the UK. Recent examples of tornadoes associated with cold fronts include the T6 in Jersey and T5 tornado in Stalybridge, Greater Manchester in late 2023.

(Ci = cirrus, Cs = cirrostratus, CU= cumulus, CB = cumulonimbus, Sc= stratocumulus, St = stratus – see Chapter 9 for details)

By **stage 3**, the cold front has caught up with the warm front. Conceptually, it is easy to imagine that it is easier for the colder, more dense air behind the cold front to push the warmer, less dense air out of the way than it is for the warmer, less dense air behind the warm front to push the colder, more dense air out of the way. As the cold front catches up with the warm front, the two fronts mix to produce an occluded front – usually drawn in purple and with both semi-circle and triangle symbols. Again, we can look at a cross section through this stage of the depression:



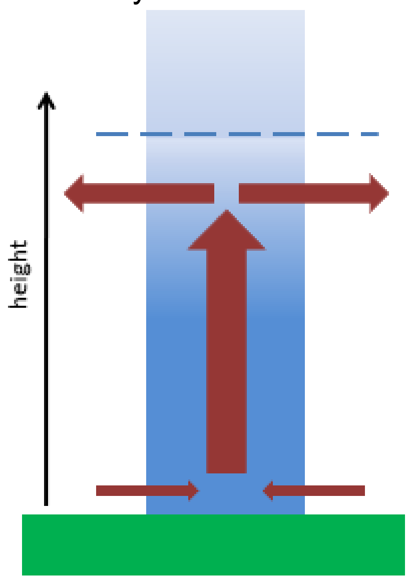
The cold front has caught up with the warm front and pushed the warm sector air off the ground. The warmer air in the warm sector is still rising and can produce cloud.

By **stage** 4, the wave has broken and the system is dying away.

The saying ‘red sky at night, shepherds delight; red sky in the morning, shepherds warning’ is linked to the passing of a depression. If the Sun, setting in the west, shines its light on a depression in the east giving a red sky, it is a sign that the depression has passed and better weather can be expected for a bit. On the other hand, if the Sun, rising in the east, shines its light on a depression in the west, then that depression has yet to hit the observer and is about to bring bad weather.

Image copyright: Sylvia Knight

Consider the rising air in the centre of the system:



The rising air cannot continue up into the very stable stratosphere above and so spreads out sideways along the tropopause (the boundary between the troposphere and the stratosphere). Air converges at the ground to replace the rising air – but this inflow is slowed down by friction. As a result, more air diverges at the top of the system than replaces it at the bottom, and the air pressure, the total amount of air, reduces. This is why depressions (and Tropical cyclones, which are also produced by rising air) are low pressure systems.
Winds blow around depressions in an anticlockwise direction, following the pressure contours, in the northern hemisphere. In the southern hemisphere, the winds blow in a clockwise direction (see Chapter 8).

What About the Jet Stream?

The polar front jet stream is a belt of westerly winds in the upper troposphere, with wind speeds up to 200mph. It sits at around 10km, the height at which aeroplanes fly. Trans-Atlantic pilots make use of the jet stream to minimise flight times.

The jet stream is found where the poleward surface temperature gradient is strongest, i.e. above the polar front – the same location where depressions form and intensify. The closer the temperature contours on the polar front, the faster the jet stream and the more rapidly depressions can intensify.

As depressions on average follow the same path as the jet stream it can be used to predict the path taken by an individual storm. Over a season, the clustering of the tracks followed by depressions produces a 'storm track' at the surface. The developing depression interacts with the jet creating continental-scale waves along its path.

See also chapter 4 for why there are westerlies and a jet stream above the polar front.

More detailed jet stream information: https://youtu.be/Lg91eowtfbw

The Difference between Summer and Winter

In the summer, the polar front, the jet stream and therefore the depressions tend to be further north than in the winter – usually, the North of Scotland still experiences depressions in the summer whereas the south of England doesn't. In addition, the equator to pole temperature gradient is less extreme in the summer – because the temperatures in the Tropics are relatively constant through the year, but the poles are far warmer in the summer. Therefore, the temperature gradient across the polar front is smaller, the westerlies are weaker and storms tend to be less damaging.

Naming Storms and Storm Warnings

Since 2015 the Met Office, together with the Irish and Dutch Met agencies, give storms which are expected to cause disruption or damage a name – and then, in addition, the Met Office issues weather warnings to specific areas, which are colour coded yellow, amber or red depending on how damaging the wind, rain or snow is likely to be.

The Environment Agency works with the Met Office to then issue warnings to places which may be affected by flooding as a result of the storm.

Depressions and Climate Change

In the Southern hemisphere, we know that, as the climate warms, the polar front and therefore the storm track and jet stream will shift to higher latitudes. There is less confidence in projections on what will happen in the Northern hemisphere.

In addition, we expect depressions to have faster winds and greater amounts of precipitation associated with them.

Sources of Information

http://Earth.nullschool.net is great for seeing current depressions – and comparing those in the northern and southern hemispheres.

Satellite images and rain radar can be found at https://en.sat24.com/en and https://www.netweather.tv/live-weather/radar

Synoptic charts can be downloaded from http://www1.wetter3.de/Archiv/archiv_ukmet.html

Passage of a depression animation: https://youtu.be/S8vKGMXE3tQ

Depression lecture by Pete Inness: https://youtu.be/2Wxoq_4K2IE