



MetLink
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Global Atmospheric and Oceanic Circulation

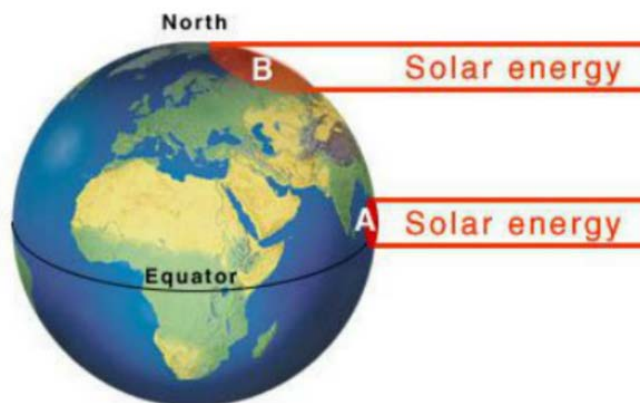


Background Information for Teachers

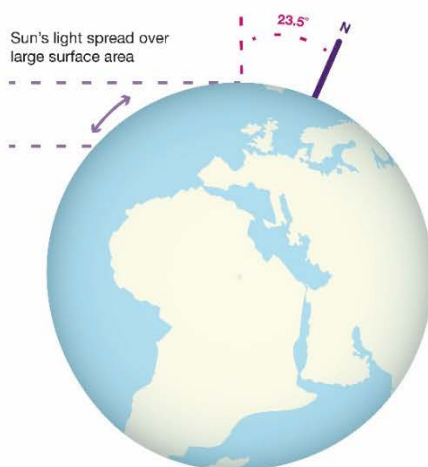
Global Atmospheric Circulation

What makes the whole atmosphere rotate and move? What gives us defined areas where it is generally dry or rainy, warm or cold, high pressure or low pressure?

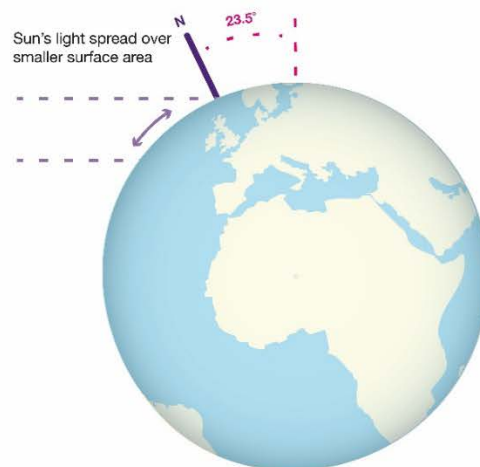
The answer to all these questions ultimately lies in the fact that we live on a spherical rotating planet, at some distance from the Sun. Some parts of the Earth's surface will always be pointing directly at the Sun, whereas other parts are slanting away. Which parts those are depend on the time of day, and the time of the year – the image below shows the Earth at an Equinox, when the Sun is overhead at the Equator.



Where the Sun is directly overhead, the Sun's light is focussed into a fairly small area (A) whereas where the Sun is low in the sky, the light is spread over a much larger area (B). Because it is the Sun's light which warms the surface of the Earth, which in turn warms the air above the surface, it will always be warmest where the Sun is highest in the sky.



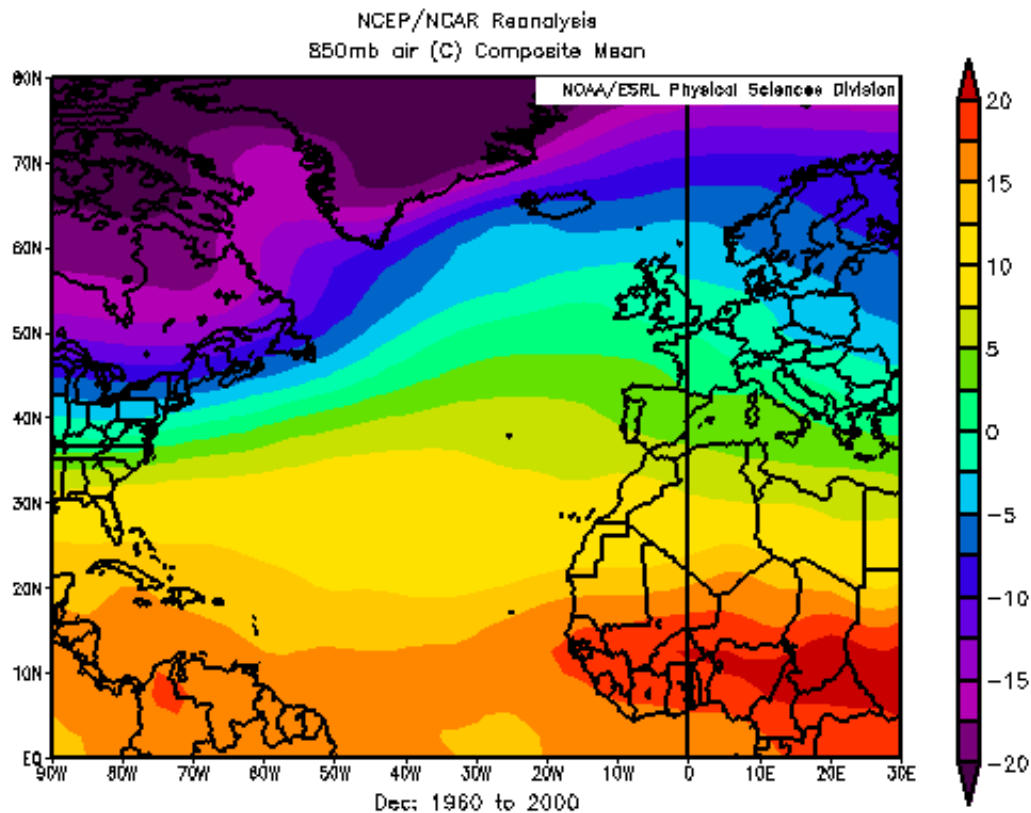
UK Winter



UK Summer

As the Earth's axis of rotation is tilted, as the Earth orbits the Sun through the year the

place where the Sun is highest in the sky moves from the Tropic of Cancer in June, past the Equator in September to the Tropic of Capricorn in December and then back to the Equator in March. So, you'd expect the warmest surface temperatures to follow the same pattern – maybe with a bit of a lag to give the water and soil etc. time to heat up.



A map of average December temperature of the atmosphere about 1.5km above the ground. © NOAA-ESRL Physical Sciences Division, Boulder Colorado. Data source [NCEP/NCAR Reanalysis 1: Summary](#)

Here is a typical temperature map for December and you can clearly see the warmest temperatures are in the Tropics, falling off with latitude. As soon as you have the situation where the air in some places is warmer than the air in other places, you'll see the warmer air rising. So, we'd expect to see something where the air was rising where surface temperatures are warmest and sinking where temperatures are coolest; something like:

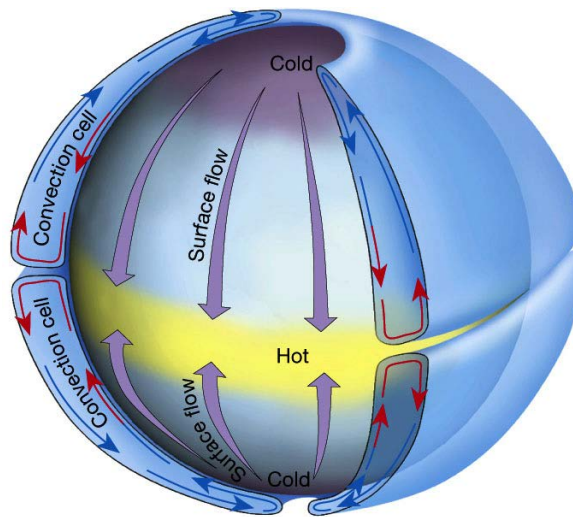


Figure 7.5 in *The Atmosphere, 8th edition*, Lutgens and Tarbuck, 8th edition, 2001.

However, things are complicated by the fact that the planet is rotating. This gives rise to the **Coriolis Effect** – the net effect of which is that anything moving in the Northern Hemisphere is pulled to the right of the direction it's moving in, and anything moving in the Southern Hemisphere is pulled to the left. We'll cover this in more detail in Chapter 8.

So, consider some warm air rising in the Tropics, through the troposphere. When the air hits the top of the troposphere it spreads out towards the poles (the troposphere is the bottom 10km or so of atmosphere which contains our 'weather' – it is very hard for air to move past the tropopause into the stratosphere above, because temperatures increase with height in the stratosphere making it very stable or resistant to vertical motion – just like fog trapped in a valley). In the Northern Hemisphere, it'll start off by moving from South to North (a southerly wind) but the Coriolis Force means it is pulled to the right, becoming ever more westerly until eventually the circulation breaks down, with the air sinking back down to the Earth and returning back to the tropics to take the place of the air which is rising there. However, the returning air (travelling from north to south) is also being pulled to the right by the Coriolis Force and now becomes easterly, forming the easterly **trade** winds (remember that we name winds by the direction they are blowing from). The trade winds converge at the **InterTropical Convergence Zone**.

This circulation is known as the **Hadley Cell**.

A similar thing happens at the poles – the coldest air is found at the poles and will sink and spread out towards the Equator. Air spreading south from the North Pole is again diverted to the right by the Coriolis Force, becoming ever more easterly, until again the circulation breaks down, the air rises and returns to the North Pole – the Polar Cell.

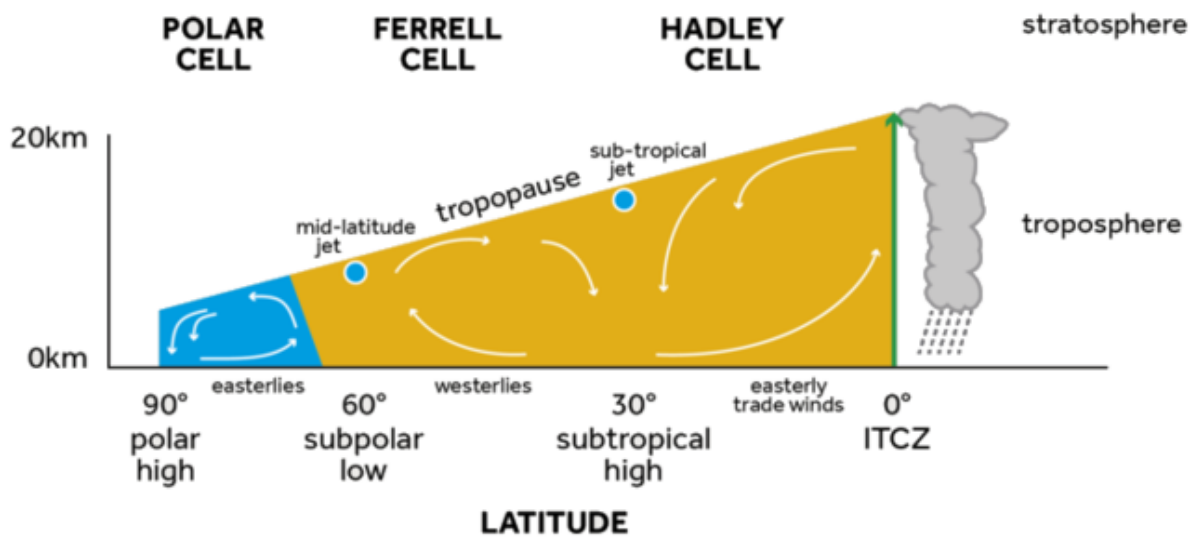
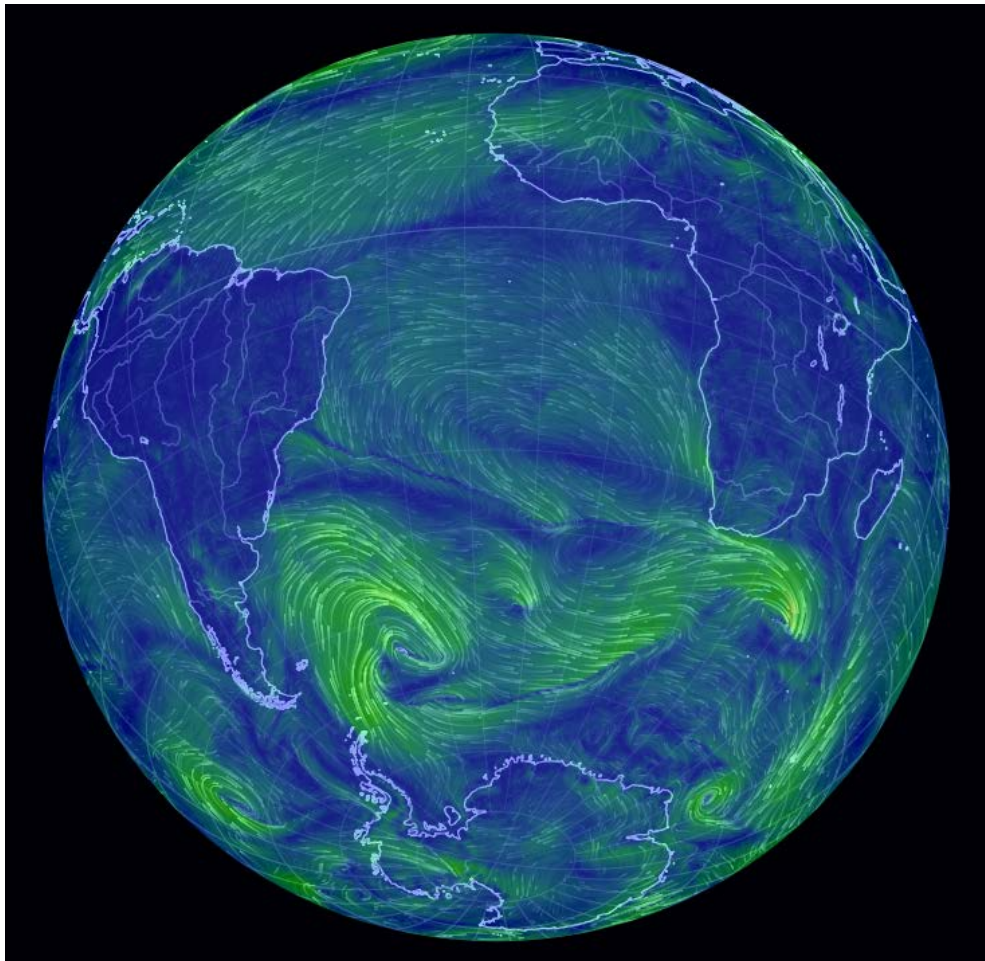


Image copyright University of Reading

Both the Polar and Hadley cells can be seen clearly on the snapshot below taken from the [earth.nullschool](http://earth.nullschool.net) website which shows near real time winds on the surface of the Earth. On this day (in March 2019) the Intertropical Convergence Zone is clearly just south of the equator, with easterly trade winds blowing in from either side. You can also make out the easterlies around the South Pole.



What happens in between the two cells is a lot less obvious – text books show a Ferrel Cell with sinking air in the subtropics and rising air in subpolar regions and surface westerlies – which can be visualised as a sort of gear between the Hadley and Polar cells. However, the **Ferrel Cell** is probably best thought of as the average of all the air motions caused by the mid-latitude depressions in this region. On the nullschool image above, these show up as swirling storms – clockwise in the southern hemisphere, anticlockwise in the northern hemisphere, all carried on surface westerlies.

It is the fact that our mid-latitude depressions tend to come from the west that makes the saying ‘red sky at night, shepherd’s delight’ one of the more accurate bits of weather lore (more on this in Chapter 17).

So how does this three-cell model of the Earth’s atmospheric circulation give rise to pressure patterns?

Consider a column of rising air (maybe at the ITCZ), ‘diverging’ or spreading out at the tropopause, and ‘converging’ or coming together at the surface. The friction at the surface is far greater than the friction at the tropopause where the air is thin and there are no trees or mountains etc. to slow the air down. This means that air diverges faster than it converges, and we are left with less air in our column and the air pressure falls – so rising air is associated with low surface pressure. Air pressure is simply a measure of how much air there is above a given point. Similarly, sinking air is associated with high surface pressure. So, we expect High Pressure at the poleward edge of the Hadley Cells, and at the Poles. We expect Low pressure at the ITCZ and where the Ferrel and Polar cells meet.

When there is air rising through the atmosphere, the pressure of that air falls as it rises up and there is less atmosphere left above it. As the pressure falls, the temperature of the air falls too, until eventually it reaches the point at which the rate of condensation exceeds the rate of evaporation and cloud droplets form – when these get big enough, they fall as precipitation. This is why we associate low pressure – be it in association with the ITCZ or in association with low pressure weather systems such as tropical cyclones or mid-latitude depressions, with cloud and rainfall.

Therefore, where there is predominantly rising air – at the ITCZ and in subpolar regions, there will be lower pressure, cloud and heavier precipitation.

Where there is generally sinking air – at the poles and in the sub-tropics, conversely the skies will be predominantly clear and the climate will be drier and the pressure higher. These High Pressure regions are the source of our air masses – tropical continental, tropical maritime, polar maritime and polar continental - which we will consider in chapter 7.

The whole pattern of cells and surface winds shifts to the North and South with the seasons - further north in June and further south in December.

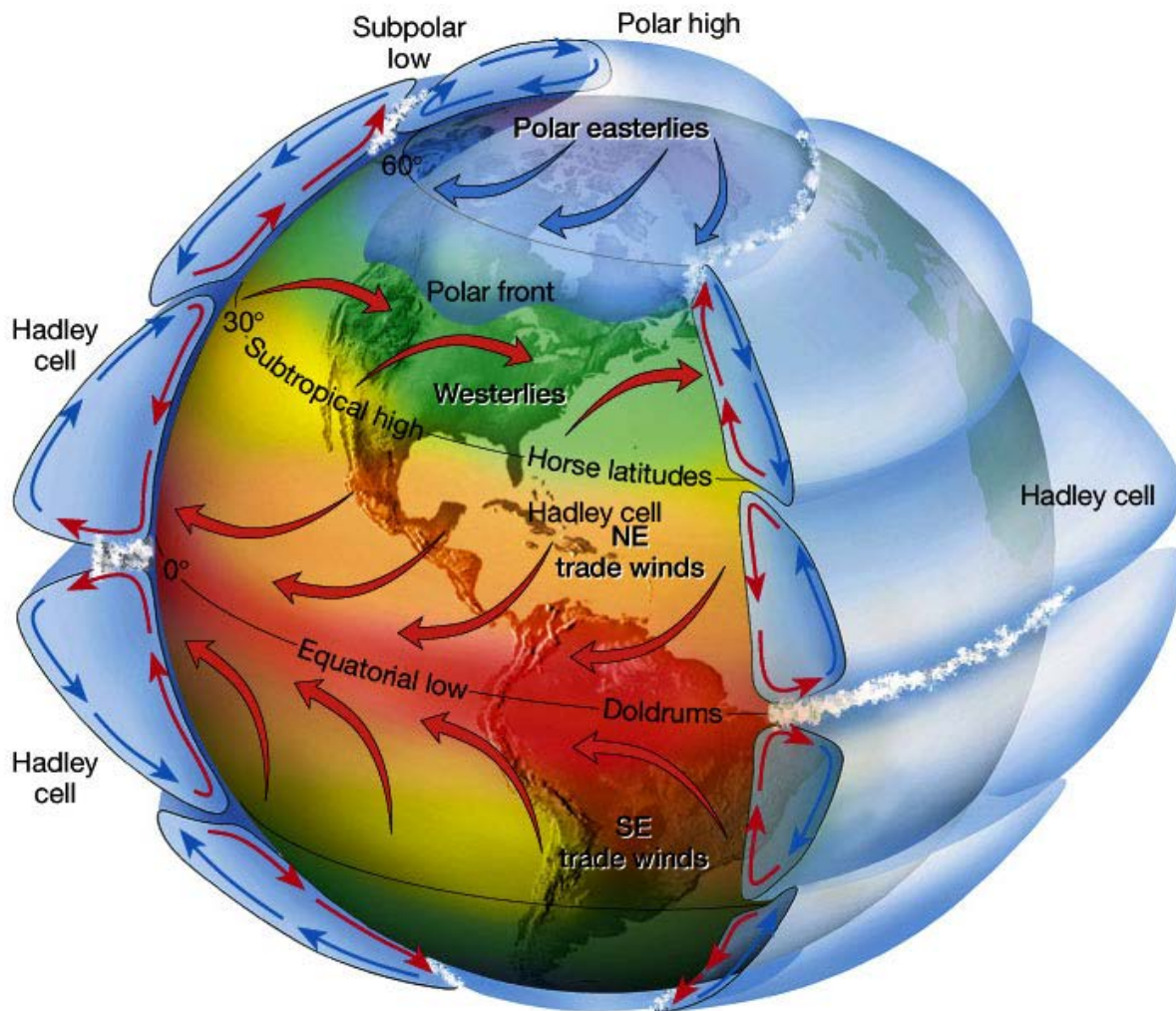
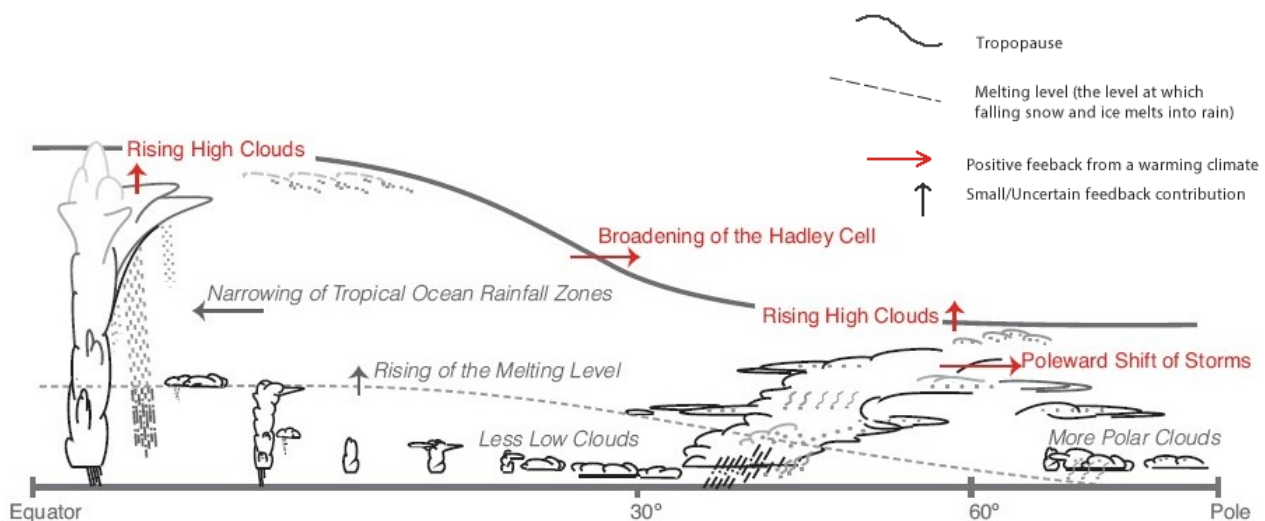


Figure 7.5 in *The Atmosphere, 8th edition*, Lutgens and Tarbuck, 8th edition, 2001

Changes to the Global Atmospheric Circulation

The 2013 Intergovernmental Panel on Climate Change report concluded that as the climate changes through the 21st century, we can expect to see the Hadley Cell broaden, the tracks that mid-latitude depressions take shift towards the pole and rainfall zones – such as the ITCZ, become narrower.



This is Figure 7.11 from the WG1 report for the 2013 IPCC 5AR.

Global Oceanic Circulation

The large-scale circulation of the oceans is similarly driven by warm water rising and colder water sinking. In addition, where ice forms in the polar regions, it forms from fresh water, leaving its salt behind to make the water even saltier and heavier. The sinking of water in the polar areas is therefore driven by both temperature and salinity and is known as the 'thermohaline circulation'.

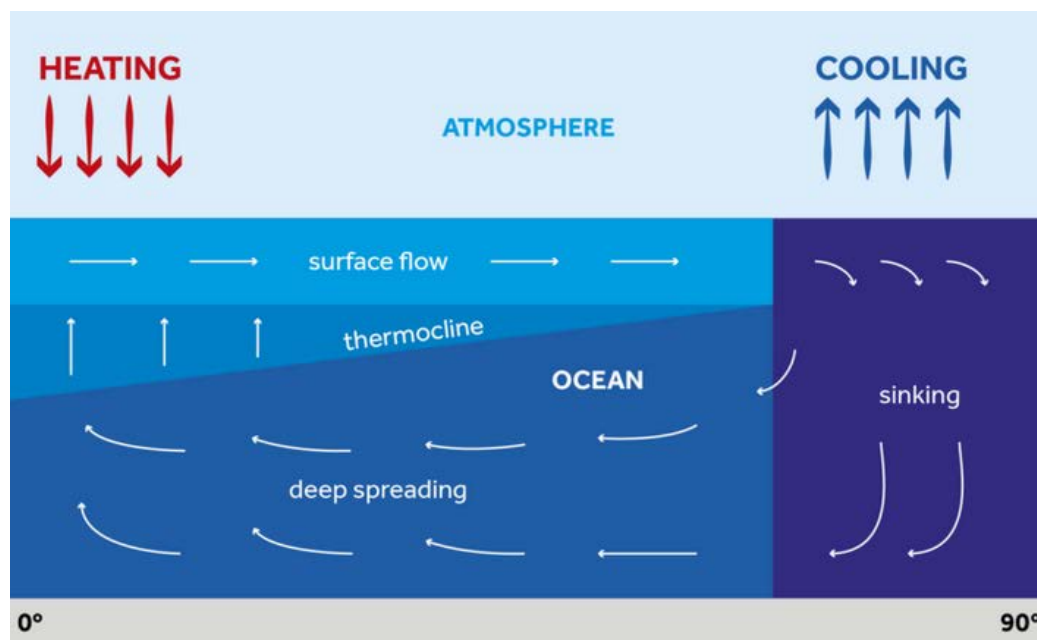
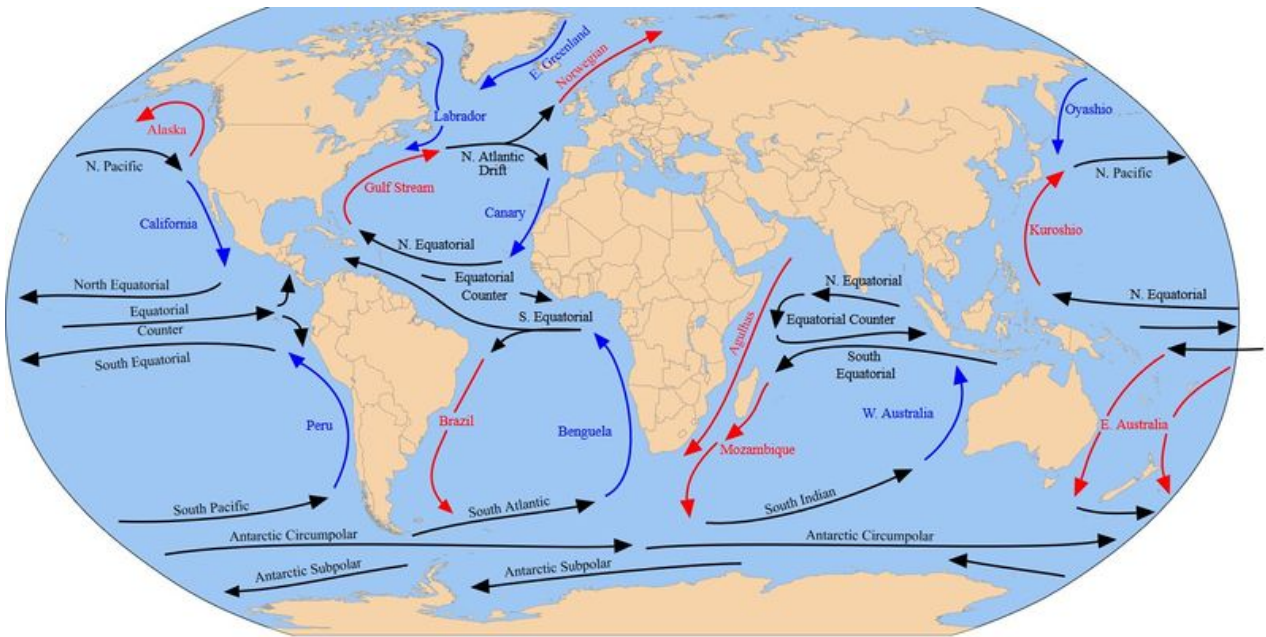


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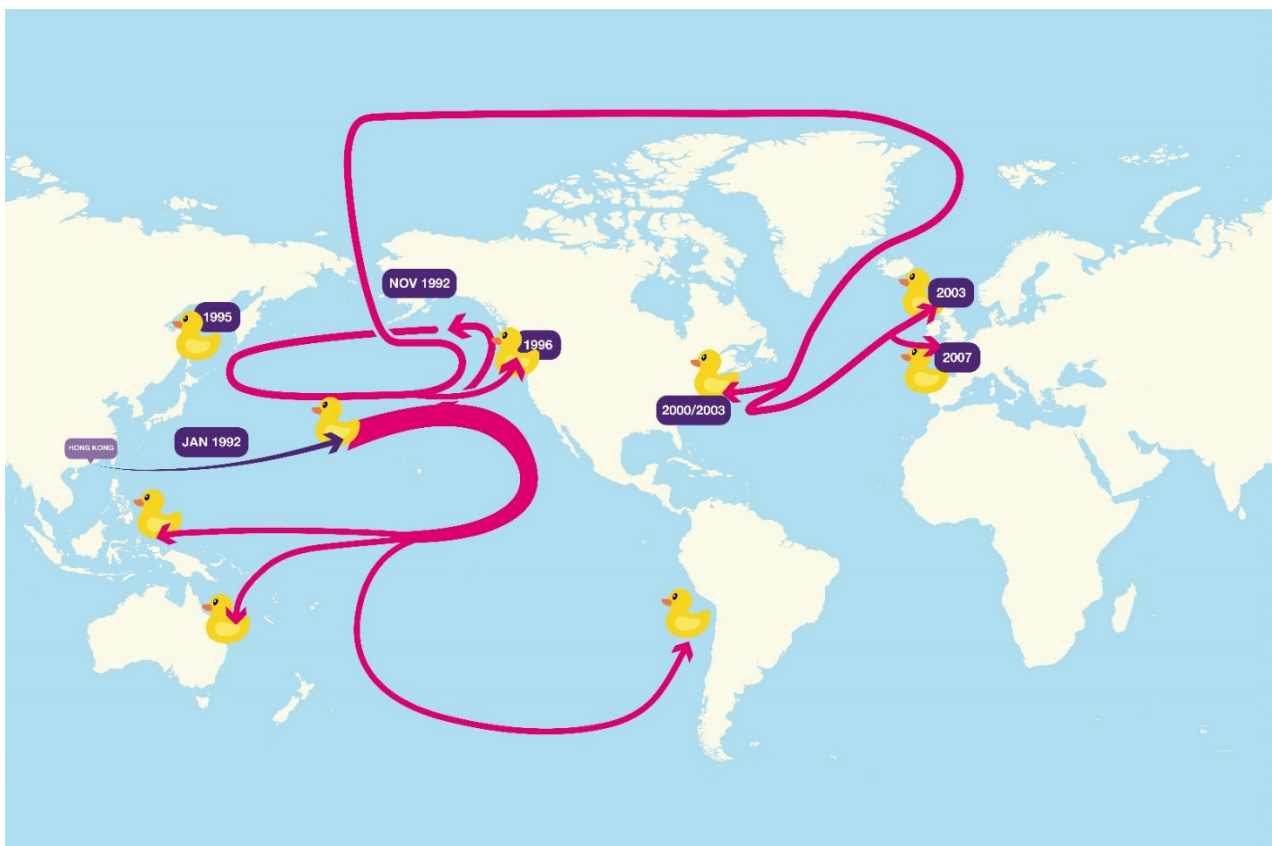
The full oceanic circulation is also complicated by the Coriolis Effect and the presence of continents. The wind blowing also carries surface water – the Gulf Stream, which carries warm water across the N. Atlantic towards the UK is a good example of this. Its polar

extension, the North Atlantic Drift, is more closely linked with the thermohaline circulation. Together, they keep the U.K. approximately 5°C warmer than it would otherwise be.



(image source http://www.coastalwiki.org/wiki/File:Ocean-Currents_gkplanet.jpg)

The loss of a container full of rubber ducks from a ship in the N. Pacific in 1992 provided an unintentional oceanic circulation experiment – the ducks have been washing up on shores around the world since, and some have remained trapped in the ‘great Pacific garbage patch’. (<https://youtu.be/AvchlWftt80>)



Changes to the Global Oceanic Circulation

The Intergovernmental Panel on Climate Change's 2019 Special Report on the Ocean and Cryosphere (<https://www.ipcc.ch/srocc/>) concluded that the effect of less sea-ice forming in the Arctic (as the climate there warms far more rapidly than most of the rest of the Earth) is expected to weaken the Atlantic Meridional Overturning Circulation – part of the thermohaline circulation.

As a result, there will be an impact on the North Atlantic Drift. It is very likely that it will weaken and/or move. Although this would imply that the UK and other western European countries would lose a source of warmth, the cooling is actually expected to be less than the warming caused by other aspects of climate change.

Sources of Information

This information is also available as a video: <https://youtu.be/fDs9MiHk3G8>

Nullschool for current atmospheric and oceanic conditions: <http://earth.nullschool.net>

Current global precipitation: <https://svs.gsfc.nasa.gov/4285>

Current global thunderstorms: www.blitzortung.org

Global weather maps: <https://earthobservatory.nasa.gov/global-maps>