MetLink
Royal Meteorological Society

Polar Climate

Background Information for Teachers

Polar Climate

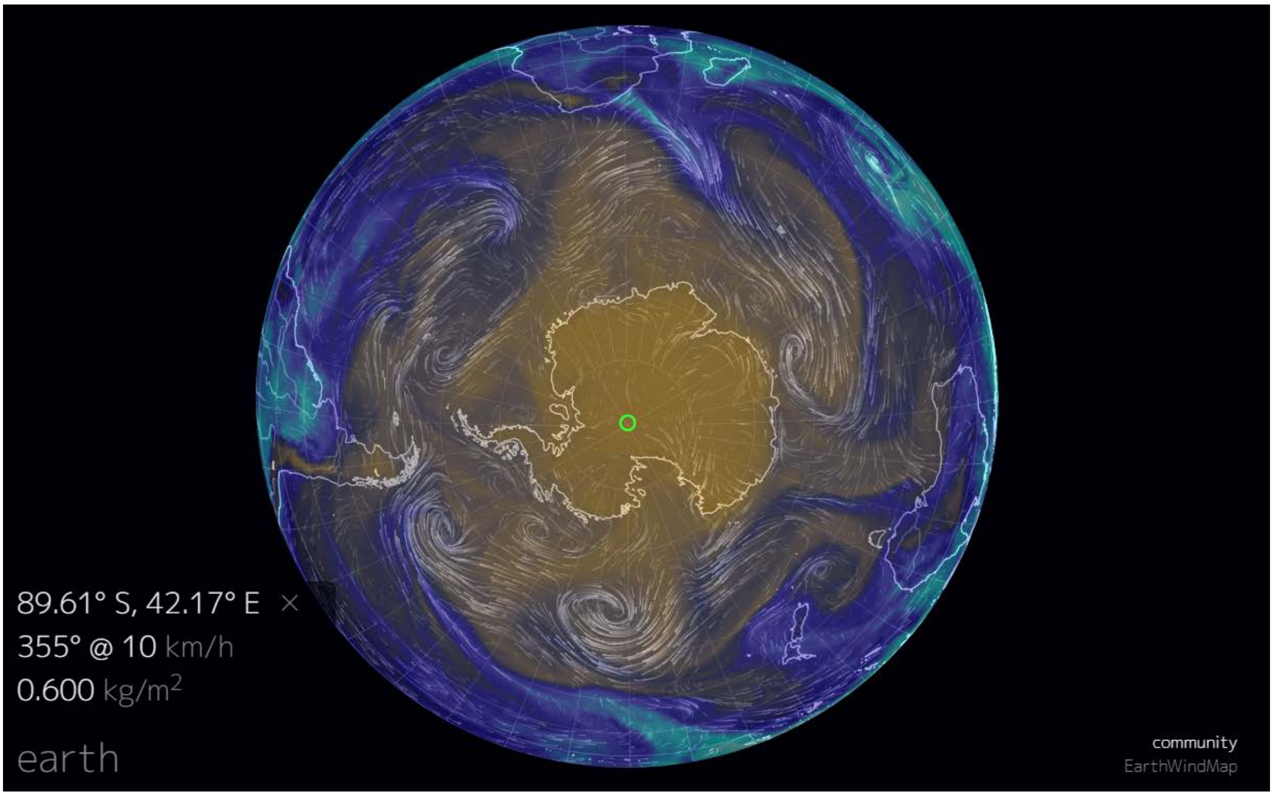
Some of the most extreme seasonal variations in weather can be found at the Poles, driven by the variation between Polar night in the winter, and 24 hours of daylight in the summer.

The Global Atmospheric Circulation (chapter 4) suggests that the polar regions should be dominated by sinking air, high pressure and clear skies. The Arctic is the source region for any polar continental or maritime air reaching the UK.

Too Cold for Snow

In the centre of the Antarctic, it can truly be too cold for snow. To explore why, we revisit what the requirements for snow are.

1) Moisture: there must be water vapour in the air for cloud to form. In the UK, surrounded as we are by sea, this is rarely a problem. As water warms up and cools down more slowly than land, the sea around us stays at a pretty constant temperature all year round and is a constant source of water vapour into the air above, through evaporation.
   It can be 'too cold for snow' in the centre of large land masses, such as Eurasia, Antarctica or N. America, where the wind has not encountered liquid water from which water can easily evaporate. It's really 'too dry for snow' – but it's too dry because it is so cold that the rate of evaporation from the lakes and rivers, which may be frozen, is very, very slow.



This image from earth.nullschool.net in February 2020 shows ‘precipitable water’ – defined as the total mass of water contained in a column of the atmosphere over a given area – in this case, there are just 600g, 0.6 litres, of water in the entire depth of atmosphere over each square metre on the surface in the green circled area.

2) Cloud: For cloud to form, the rate of evaporation must be lower than the rate of condensation. Evaporation and condensation are going on all the time, but the rate of evaporation falls as it gets colder. So, cloud can form when the air cools – there are several possible mechanisms for this
   - Where warmer air meets colder air at a front, causing it to rise. As the air rises, the air pressure falls and so the air cools (this is known as adiabatic cooling).
   - When air from somewhere colder than us (e.g. the Arctic or Siberia) approaches the UK, is warmed from below as it travels over relatively warm land or sea which causes it to rise and cool. This is the most common source of snow in the UK.
   - When air is forced to rise over the coast, hills or mountains and, as it rises, cools. This mechanism can add to, or enhance, the formation of cloud by either of the other mechanisms above.
   - If the ground cools overnight, the air in contact with the ground can cool to the temperature at which cloud forms. This is fog and is not likely to produce rain or snow.
3) Temperature: it has to be cold enough for the cloud droplets to grow as snowflakes and to not melt as they fall through the atmosphere and down to the ground. To see whether this is the case, forecasters look at the 528dam (=5280m) line. This line shows where the vertical thickness of the bottom half of the atmosphere (by mass) is 5280m i.e. the vertical distance between the 1000mb height (somewhere near the ground) and the 500mbar height (somewhere in the

middle of the troposphere). As warm air is less dense than cold air, the colder the air is, the less thick the atmosphere is – the smaller the distance from the ground to the 500mbar height.

If we are north of the line (i.e. the thickness is less than 528dam) then any precipitation can fall as snow, and if we are south of the line (i.e. the thickness is greater than 528dam) then we get rain.

If you look at the surface pressure forecast charts on the Met Office website https://www.metoffice.gov.uk/public/weather/forecast/map#?map=Pressure&fcTime=1574726400&zoom=5&lon=-4.00&lat=55.01 , then if you go more than 24 hours into the future the thickness lines are shown. The 528dam line is shown as a blue dashed line, and the thicker/ warmer 546dam line as a green dashed line.

Alternatively, look at the GFS charts (in the charts and data menu) at http://www.netweather.tv/index.cgi?action=nwdc;sess=
and select 'HGT 500-1000' from the 'choose chart type' menu. This clearly shows that the thickness is greater for warmer, tropical air and smaller for the colder, polar air.

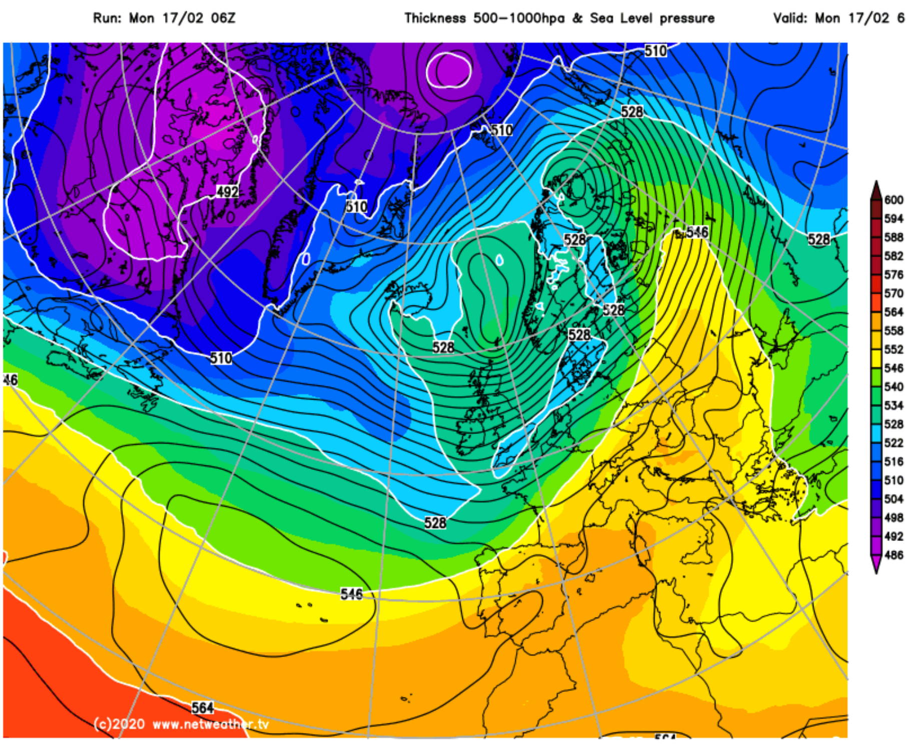
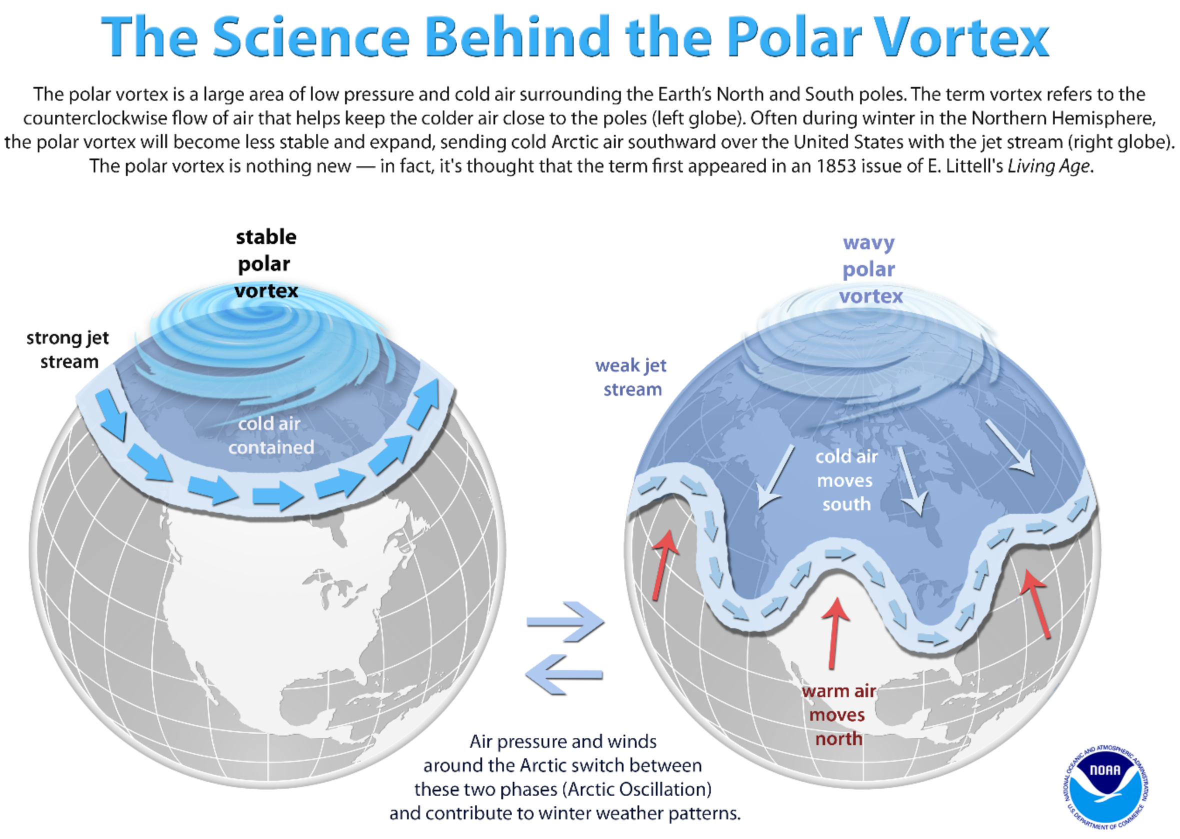


Image credit: Netweather

Polar Vortex

In wintertime, polar regions are incredibly cold due to the lack of sunshine. Although surface pressures may be high, associated with the Global Atmospheric Circulation, the temperature contrast between the Arctic and more southerly latitudes leads to very fast winds high up in the atmosphere. This results in a huge Low pressure system spinning anti-clockwise above the Arctic (or clockwise over the Antarctic) known as the polar vortex. From the side, you would be able to see this huge system reaching from the upper troposphere all the way into the stratosphere.

The Arctic polar vortex can change its shape as seen in the schematic diagram below:

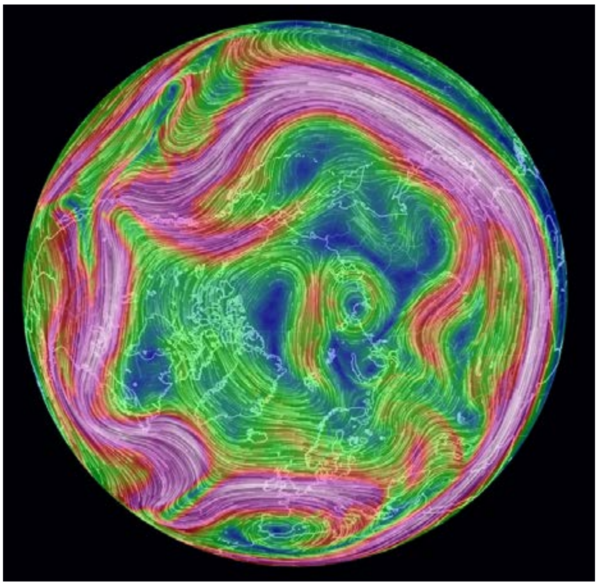


Comparison of a stable and instable polar vortex. Source: NOAA 2019

While a stable polar vortex confines cold air to the Arctic, an unstable or wavy polar vortex may cause cold air to spill further south. This is what we experience as cold snaps. A so-called sudden stratospheric warming event can lead to just such an unstable polar vortex. A disturbance in the polar vortex leads to sudden air compression and warming. It rapidly weakens the polar vortex and causes it to wobble. If these wobbles split off, they can make their way towards Europe and bring cold, Arctic air across Europe.

The 2019/20 Northern Hemisphere winter was an example of a very stable polar vortex.

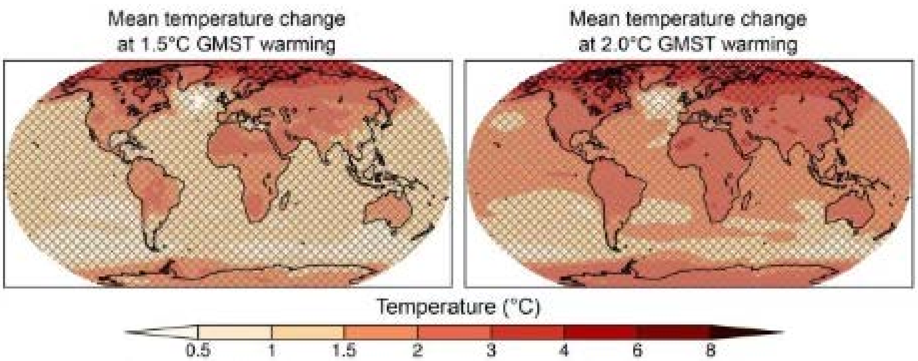
In the Southern Hemisphere, both Antarctica and the surrounding Southern Ocean are much more symmetrical than the continents in the Northern Hemisphere. This leads to a much more stable polar vortex – and, consequently, lower winter temperatures at the pole.



3/2/2020 Northern Hemisphere, 250hPa wind speeds, earth.nullschool.net

Climate Change in the Arctic – Polar Amplification

In general, climate change is more rapid in polar regions, particularly the Arctic, than in the rest of the world. This is referred to as 'Polar Amplification'. It is mainly due to the positive feedback mechanisms there. For example, as the temperature warms, sea ice melts exposing the ocean beneath. Water reflects less sunlight than ice, so more light and heat from the Sun is absorbed as the ocean is exposed. This further heats the polar regions. Other contributing factors include the transport of heat from the Tropics to the Poles by storms and the global atmospheric circulation, changes in cloudiness and another positive feedback mechanism through increasing water vapour in the air. Global temperatures from 2000–2009 were on average about 0.6°C higher than they were from 1951–1980. The Arctic, however, was about 2°C warmer.

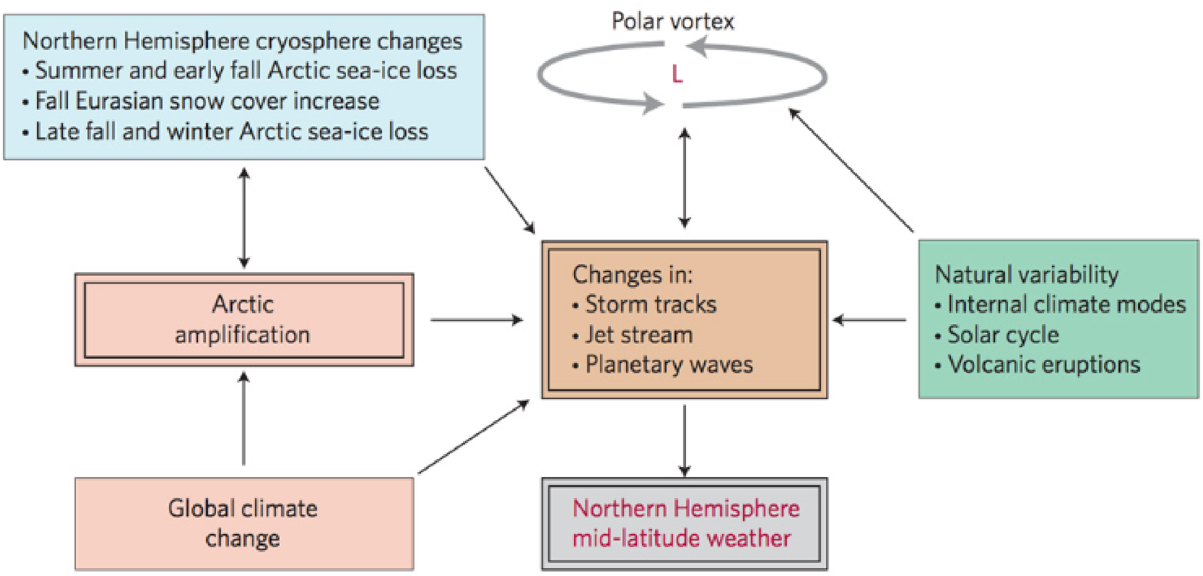


Projected changes in mean temperature at 1.5°C (left) and 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), From IPCC 2018 Special Report: Global Warming of 1.5°C.

For more information, see, for example, https://skepticalscience.com/What-causes-Arctic-amplification.html

Currently, the Arctic is warming faster than the Antarctic. This is partly due to the hole in the ozone layer over Antarctica – as the ozone recovers, Antarctica will warm faster.

Changes in Arctic temperatures may have an impact on mid-latitude weather, which are summarised in the schematic diagram below. There is some suggestion that with a warmer Arctic, the polar vortex will be weaker.



Schematic of influences on northern hemisphere mid-latitude weather. Source: Cohen et al. (2014)

Climate Change in Polar Regions – The Ozone Hole

Ozone, O_3, is a naturally occurring gas. Over 90% of the ozone in the atmosphere is found in the stratosphere – between 10km and 50km up in the atmosphere, in the 'ozone layer'. There, it absorbs ultraviolet radiation from the Sun which would otherwise reach the Earth's surface with harmful effects, including the destruction of chlorophyll in plants and a greater chance of skin cancers and eye cataracts in humans.

In the winter, the land and air inside the Antarctic circle does not receive any solar radiation at all and cools by emitting infrared radiation to space. As it does so, the air in contact with the ground is cooled by conduction and convection, as the air cools, it sinks, and the air pressure at the ground is relatively high. Conversely, the air pressure in the upper atmosphere is relatively low and it draws in more air. Because of the rotation of the Earth and the Coriolis effect (see Chapter 8), this sinking air develops a clockwise swirl. A vortex, known as the polar vortex, develops and wind speeds around the vortex may reach 100ms^{-1} in the middle to lower stratosphere. (in comparison, a low pressure system in the Tropics is termed a hurricane when surface wind speeds reach 30ms^{-1}). This vortex isolates the air inside it, making it very hard for it to mix with air outside the vortex.

The very low temperatures that can be reached in the centre of the polar vortex are low enough for polar stratospheric clouds (sometimes called Nacreous clouds but not to be confused with noctilucent clouds) to form. Polar stratospheric clouds form at temperatures below -78ºC. In July and August, temperatures in the Antarctic lower stratosphere can reach -90 ºC. Nacreous clouds can sometimes be seen bright in the night sky, because they are high enough to be illuminated by the sun long after sunset at the ground.

Polar stratospheric clouds over Antarctica. Copyright Renae Baker/ Cloud Appreciation Society

Chemical reactions on the surfaces of the cloud particles in the winter form molecules which destroy ozone as soon as the sunlight returns to the stratosphere. The rate of ozone destruction can reach 2 to 3% per day in late winter/early spring. However, when temperatures increase in the early spring, polar stratospheric clouds no longer form and the intense period of ozone depletion ends. As the Antarctic slowly warms through spring, the polar vortex breaks down and the relatively high concentrations of ozone that have accumulated at the edge of the vortex through the winter get mixed into the Antarctic air, rapidly raising the levels up again. The ozone hole disappears by December.

The greenhouse effect and the ozone hole are frequently confused. Although some ozone destroying gases, such as CFCs, are in fact greenhouse gases, the processes that result in the destruction of stratospheric ozone are entirely separate. However, at a deeper level, the greenhouse effect and stratospheric ozone are linked in several ways. Greenhouse gases such as water vapour, carbon dioxide and methane in the troposphere absorb outgoing infrared radiation (heat) from the Earth, warming the troposphere. This in effect means that less heat reaches the stratosphere, which then actually cools as the troposphere warms. A cooler stratosphere would extend the time period over which polar stratospheric clouds are present in polar regions and, as a result, might increase winter ozone depletion in the lower stratosphere. Another effect of an increasing greenhouse effect is that more water vapour gets into the stratosphere, again increasing the number of polar stratospheric clouds.

To complicate matters, because ozone is itself a greenhouse gas (it absorbs outgoing infrared radiation from the Earth) as the amount of ozone in the stratosphere begins to recover, it will in fact contribute to the warming of the Earth.

Aurora Borealis and Australis, Space Weather and our Climate

As well as emitting light, heat and ultraviolet radiation, the Sun emits charged particles. Solar flares and Coronal Mass Ejections (CME) send a plasma of charged particles towards the Earth as a solar wind. Forecasts for such 'space weather' are now routinely made because of their potential impact on satellite dependent communications and terrestrial power lines.

In the polar regions, a CME interacts with the Earth's magnetic field to give us the Auroras.
Space weather may have an impact on Earth weather too, making it generally cloudier and generating more lightning strikes.

Sources of Information

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

Antarctic web cams https://www.bas.ac.uk/data/our-data/images/webcams/

Current Antarctic weather http://www.antarctica.gov.au/about-antarctica/environment/weather/automatic-weather-stations/dome-a-details

Current Arctic webcams and sea ice graphs
https://sites.google.com/site/arcticseaicegraphs/webcams