

Weather and Climate

New A Level Subject Content Overview

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Introduction: “Weather is what we get, climate is what we expect”

Understanding the carbon and water cycles in our atmosphere, as well as their sources and sinks, is fundamental to many aspects of physical geography. In developing an understanding of the water and carbon cycle, geographers must understand: the processes that drive weather and climate, the differences between weather and climate, and the different physical scales of the processes from local to global. Some of the specialised concepts in weather and climate should be understood before they can be related to the water and carbon cycle or climate change - particularly the different scales involved and the difference between weather and climate. The study of weather and climate utilises a variety of geographical skills such as analysing weather data in the form of graphs, charts and statistics – in doing so, also learning how to draw conclusions by evidence. This also provides the necessary content to further explore the impact of human activities on physical processes relevant to weather and climate.

Weather transports water and carbon at various distance scales but on short timescales. However, climate dictates much of the long term picture of both cycles, and climate is usually measured on a rolling 30 year average (current climate maps show the 1981-2010 mean). Both the magnitude and location of water and carbon stores and fluxes are linked to climate change and its drivers – sometimes anthropogenic, such as land use change.

The processes of the water cycle are all key meteorological phenomena, including evaporation, transpiration, condensation (including cloud formation) and precipitation. We give a basic overview of the meteorological concepts underpinning weather and climate followed by some examples to illustrate their relevancy with the core content of the new 2016 specifications.

Geographical Concepts and Underpinning Theory

Air Pressure and Wind

The Earth's atmosphere extends hundreds of kilometres above its surface (see figure). The structure and transport of carbon and water within the atmosphere are governed by the way temperature and pressure varies vertically and horizontally and is largely restricted to the troposphere.

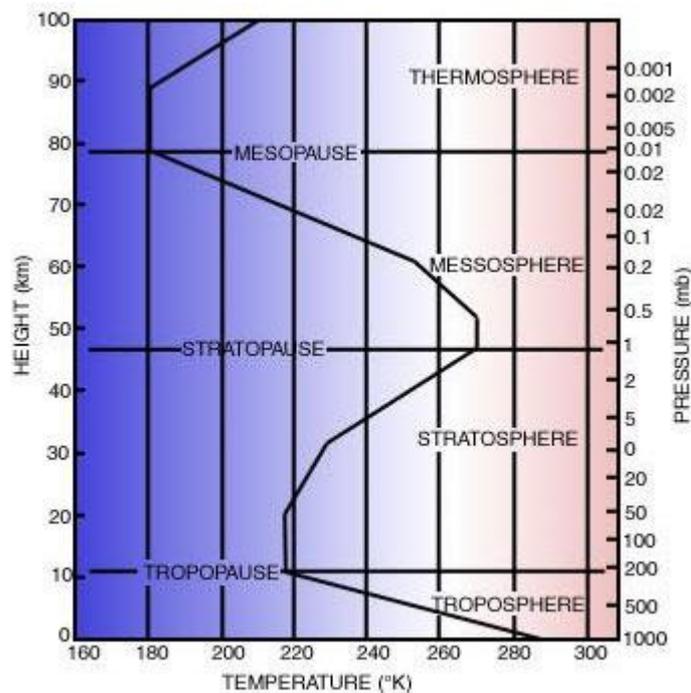


Figure 1: A graph showing how the temperature of the Earth's atmosphere changes with height above the Earth's surface © RMetS via <http://www.metlink.org/secondary/key-stage-4/atmosphere/>

The troposphere is the bottom 10km or so of the atmosphere in which our weather is found. On the whole, temperature falls with height. Above it, the stratosphere contains the ozone layer. This absorbs the sun's ultraviolet radiation, turning it into heat and warming the air. As a result, the temperature of the stratosphere actually *rises* with height, making it very stable and resistant to vertical motions.

Air pressure is the weight of the atmosphere above us. This means that air pressure generally decreases with altitude, as the higher we go; there is less air above us. The air pressure at the surface varies horizontally, caused by the top of the atmosphere being "lumpy" creating air pressure gradients. These gradients cause the wind to blow. At sea level the weight of air pressing down on your head is about the equivalent of about one tonne.

Wind is caused by air flowing from areas of high to low pressure. This occurs in the same way that water always flows until its height is equalised (See Figure 2).

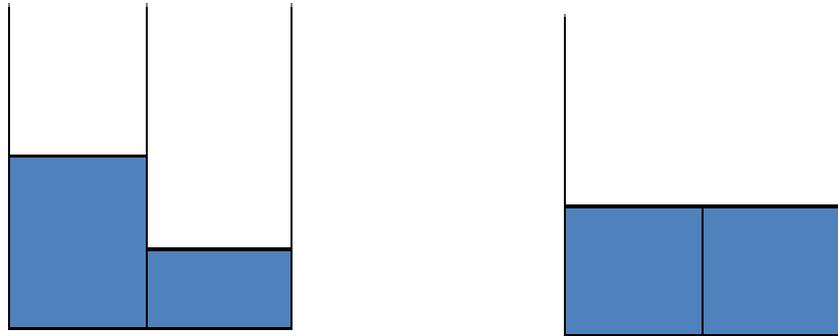
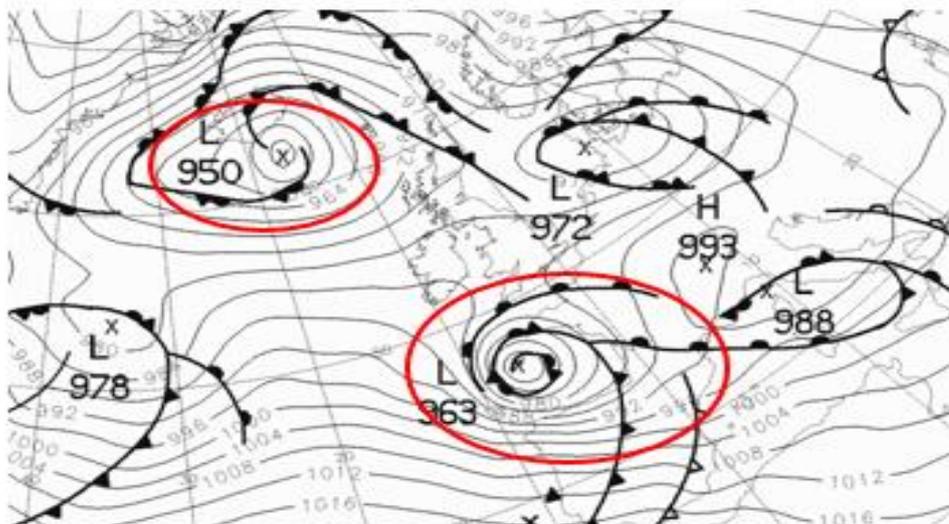


Figure 2: Two buckets of water, with more water in one than in the other, before (left) and after (right) the partition between them is removed.

The sea surface pressure chart below shows lines of equal pressure (isobars), these are the lines you will see on a weather map. An area of low pressure is known as a depression and an area of high pressure an anticyclone. Air tries to move from high to low pressure, creating wind.

If the isobars are closer together, then there is a strong pressure gradient (that is a big pressure change in a short distance) and hence stronger winds. The absolute value of pressure in the centre of the depression is less important than the difference in pressure between the centre and the edge of the system. The distance between the isobars on weather charts gives us an indication of how strong the wind will be.

When air moves across the Earth's surface, the rotation of the Earth causes a deflection to one side (to the right in the Northern Hemisphere and to the left in the southern) known as the Coriolis Effect. This balances the pressure gradient to give us winds that blow along the pressure contours – in an anticlockwise direction around low pressure regions in the northern hemisphere, and in a clockwise direction around high pressure regions.



NB there is no rule that says that anything over 1000mbar is high pressure!

Surface pressure chart. 0000. 24th Jan. 2009.

The depression in the Bay of Biscay has winds of hurricane force on its western and southern flanks

Figure 3: The depression in the Bay of Biscay © RMetS via <http://www.metlink.org/secondary/key-stage-4/>

Convection

Convection, or warm air rising, is the term used to describe the transfer of heat from a warmer region to a cooler region. In the atmosphere this often happens over warm oceans with evaporation driving the transport of water into the atmosphere. This is a significant part of the water cycle and determines the redistribution of water around the planet. Convection is one of the processes that form clouds, particularly cumulus clouds. When one part of the Earth's surface is warmer than another, the heat is transferred to the air nearest the ground, which starts to rise and continues to rise until it is colder than the air around it. The air cools as it rises; this is linked to the fall in atmospheric pressure when there is literally less air left above. Clouds form as the air cools and the rate of evaporation becomes less than the rate of condensation. As water vapour condenses to form water droplets, latent heat is released, locally warming the air a bit more and driving the convection. The convection and height of the clouds can reach the top of the troposphere.

You can find out more about lapse rates – the rate at which air cools as it rises, and the associated stability of the atmosphere, in the article linked to below.



Figure 4: 'Fluffy' cumulus clouds are a good indicator of convection © *RMetSoc* via www.metlink.org/wp-content/uploads/2014/05/Cu-300x264.jpg

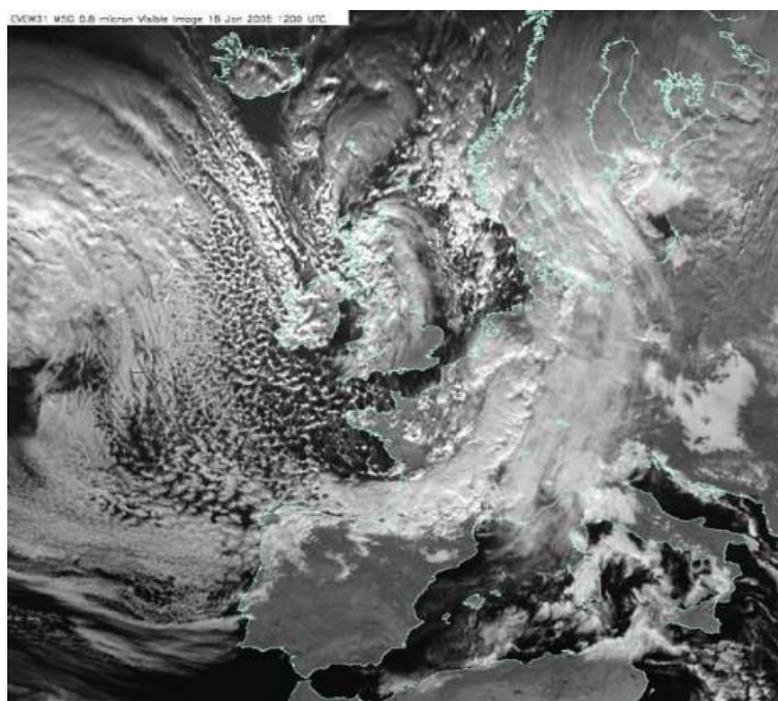


Figure 5: A satellite image showing convection over the ocean to the west of the UK-typical of a polar maritime air mass © NEODAAS/University of Dundee

You can see the small, 'fluffy' cumulus clouds in this satellite image, mainly over the Atlantic. Polar maritime air is travelling south-east, being warmed by the relatively warm ocean waters as it goes, and picking up moisture. Convective clouds form over the ocean and over the first bit of land the air reaches – typically the west coast of Ireland and the United Kingdom.

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Latent heat is another important concept as it is the heat energy required to change a substance from one state to another. Where there is a change of state (for example: from liquid to water vapour in evaporation or when water vapour condenses to liquid) there is a release, or uptake and storage, of energy. This helps move energy around the planet.

Clouds are made up of water droplets and in the case of higher clouds, ice crystals. They are another way that water is transported. They can remove pollutants and affect our weather by rainfall, as well as blocking out the sunlight. They also reflect the sun's light and absorb heat. Low level clouds can cool the globe whereas higher ones, such as wispy cirrus or aeroplane contrails, may actually warm the globe. An average-sized cumulus cloud could contain as much as 200 tonnes of water

Clouds form by *condensation* of water vapour. For condensation to occur the temperature needs to fall to the dew point, the temperature at which more condensation is occurring than evaporation. For clouds to form, there also needs to be suitable small particles for the water droplets to form on. These are known as *cloud condensation nuclei* (CCN) which can be: dust, soot from natural fires, sea salt, pollen and pollutants. In this way, pollutants can be mixed into our clouds. Cloud seeding and some climate engineering strategies are based on the need for CCN. As well as convection, cloud can be formed by air cooling without rising.

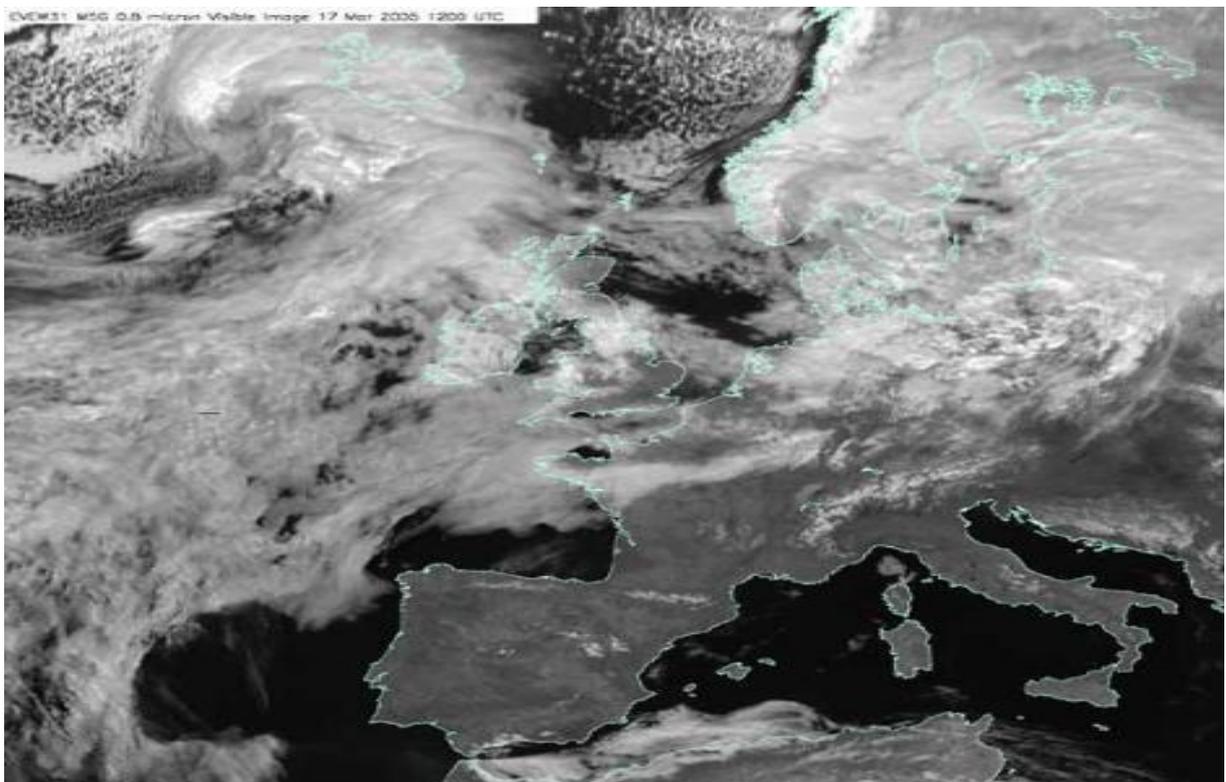


Figure 6: A satellite image showing sheets of stratus cloud over the Atlantic, typical of tropical maritime air
© NEODAAS/University of Dundee



This satellite image shows a period of time when tropical maritime air was approaching the UK from the southwest. As it moved north, the air passed over colder water and cooled, although still picking up water vapour. The cooler air does not rise, but eventually gets cold enough to reach its dew point anyway thus forming large sheets of layer cloud - stratus - typically bringing drizzle to the UK. Clouds can also form by *orographic uplift* when air is forced to rise over hills and mountains, again cooling as it rises. Examples of clouds that occur due to orographic uplift include lenticular clouds and cap clouds.



Figure 7: A spectacular lenticular cloud, formed by air rising over a mountain © Andy Cutcher, RMetS

Land Use

Land use and land type (for example: water, crops or forest) has very measurable effect on the meteorology. So the clearing of vegetation, or the change of a water course, can change the short term meteorology and affect the climate in the long term. Some of way the land use is measured is in terms of albedo (the fraction of incoming radiation that is reflected at the surface), vegetation type, soil moisture and surface roughness. Amongst other things these affect the amount of moisture available for evaporation, the depth of mixing in the atmosphere as well as wind flow. The amount of precipitation and speed of winds will be affected.

Global Atmospheric Circulation

As the earth rotates on an angle, different parts of the planet receive different amounts of energy (or radiation) from the sun. This causes a temperature gradient across the planet.

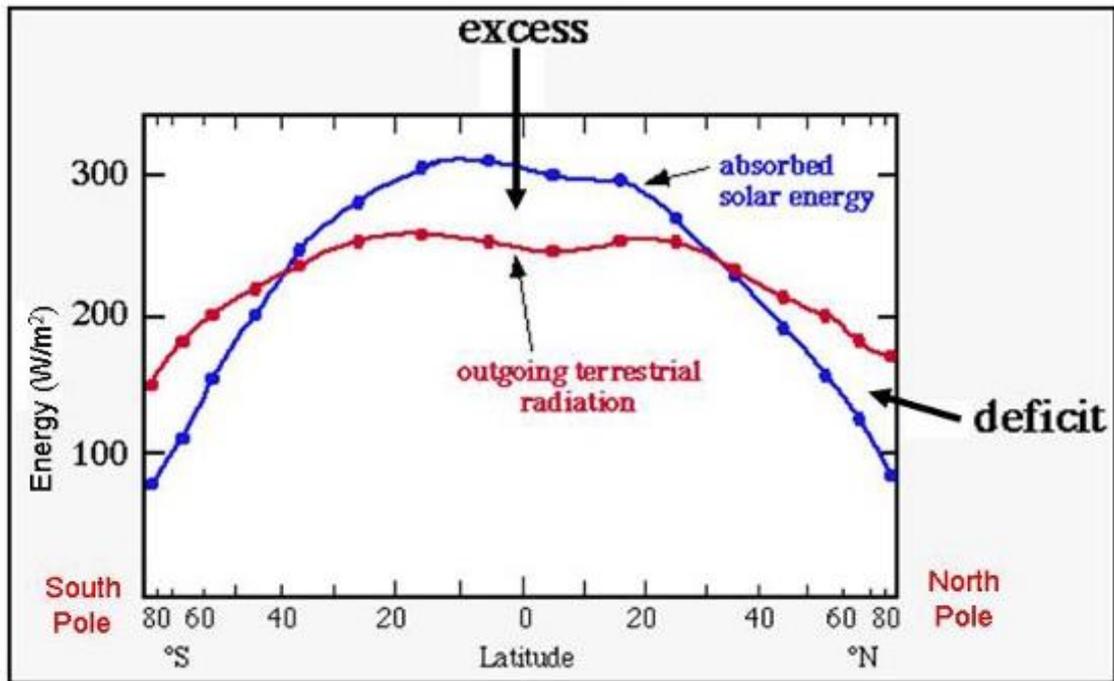


Figure 8: A graph showing the amount of energy the Earth receives from the Sun varies with latitude (blue curve) and similarly how the amount of energy the Earth loses to space varies (red curve) © Meteorology at University of Reading via: <http://www.met.reading.ac.uk/~sgs02rpa/CONTED/cl-intro.html>

The large scale movements of the atmosphere, or global atmospheric circulation, along with ocean circulation, distribute energy about the globe. Whereas individual weather systems are difficult to predict, the average circulation of the atmosphere remains relatively constant over time. This average circulation is driven by the fact that the tropics receive more solar radiation than the poles (see Figure 8) and this energy needs to be redistributed polewards. If it were not, the Tropics would be heating up and the Polar Regions cooling down. Weather systems (depressions and tropical cyclones) are responsible for about one third of the heat that is transferred from the equator to the poles and the global atmospheric circulation and ocean circulation account for roughly another third each.

The global atmospheric circulation is driven by hot air rising in the Tropics, specifically above the part of the Earth's surface which is at right angles to the Sun's light and therefore receives the most concentrated energy. This air reaches the top of the troposphere, the tropopause, and spreads out polewards, being deflected by the Coriolis force as it goes. Eventually, it sinks again, creating a belt of high pressure around 30°N/S and returns to the Tropics, again being deflected and giving us the easterly trade winds: this is the Hadley Cell. Similarly, in the Polar Regions cold air sinks, spreads out towards the Tropics, becoming ever more easterly and then rises to give the Polar Cell.

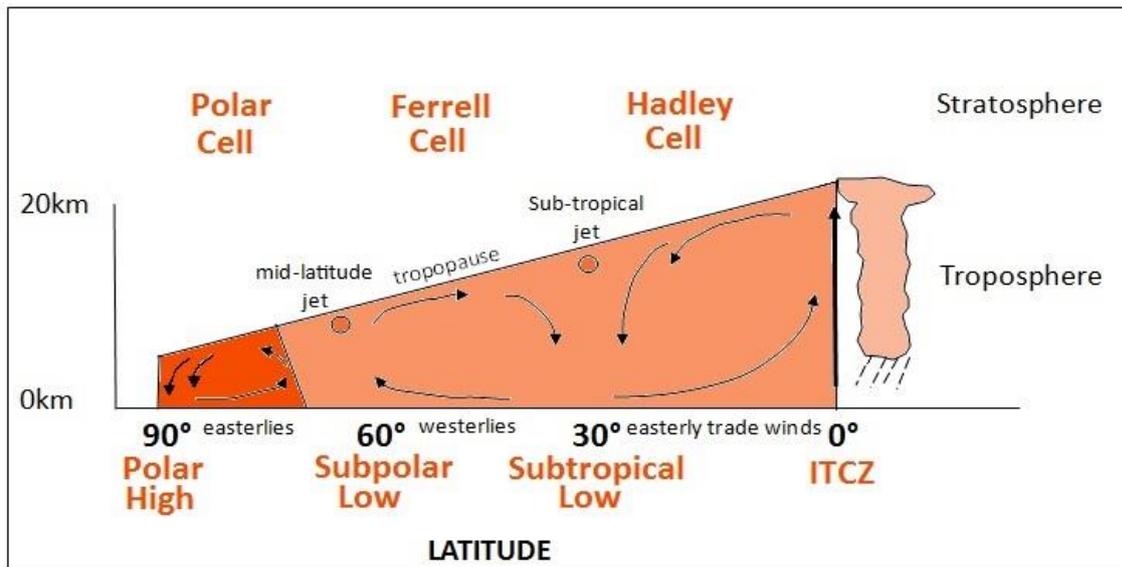


Figure 9: A simplified cross section through the Earth's global atmospheric circulation, showing the Hadley, Ferrell and Polar cells as well as areas of generally high and low pressure on the Earth's surface

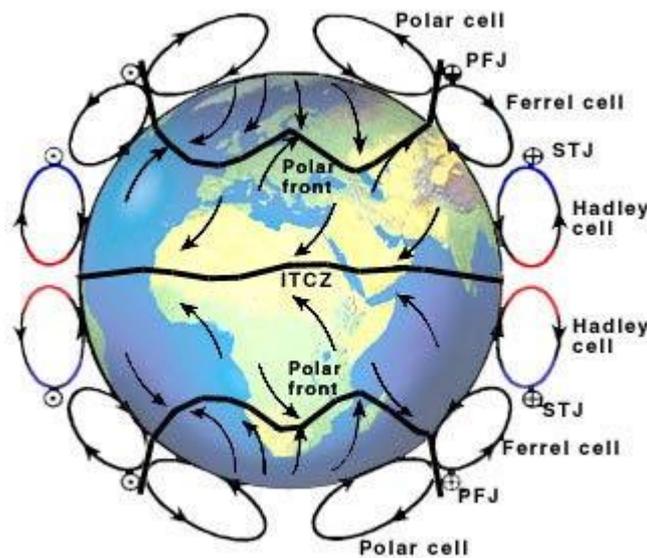


Figure 10: The 3D circulation of the Earth's atmosphere © RMetS via <http://www.metlink.org/secondary/key-stage-4/atmosphere/>

Rather than falling constantly with latitude, the south to north rate of change of temperature is greatest between 30 and 70 degrees north. This was called the 'polar front' by meteorologists working early in the 20th century, who saw the region hosting a 'war' between the warmer, tropical air and colder, polar air. All mid-latitude depressions form on this front.



Mid-latitude depressions

These form on the polar fronts in both hemispheres and tend to bring much of the weather – rain, wind etc. to countries such as the UK. This weather is both our ‘normal’ and our ‘extreme’ weather. Since the winter of 2015/ 2016, the UK and Irish Met Offices have been naming storms. The first storm to be named was Storm Abigale, which took place over 12-13 November 2015 and you can see the list of names storms, and future names which will be used on this link:

<http://www.metoffice.gov.uk/uk-storm-centre>.

Tropical Cyclones

Tropical cyclones may be called Hurricanes in the North Atlantic and Typhoons in the North-Western Pacific, but they are all some of the biggest and most destructive weather events in the world. They are intense low pressure systems which require a basic mix of components:

- A large expanse of warm water, with water temperatures over 26.5°C to a depth of 50m.
- Being at least 5° latitude from the Equator for the Coriolis Effect to make an impact on the motion of the air.
- An atmosphere which cools rapidly with height.
- High levels of humidity in the lower and mid troposphere.
- Low wind shear (change in wind speed and direction with height).
- A pre-existing disturbance.

They are reliant on the condensation of water vapour and subsequent release of latent heat as their energy source and, through transporting water and destroying vegetation, can have a significant impact on both the local carbon and water cycles.

Seasonal weather

El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO), which includes both El Niño and La Niña conditions, refers to changing patterns of sea surface temperatures in the South Pacific which have an impact on the weather of both the surrounding countries and worldwide. The effect of ENSO on regional precipitation is likely to increase in the future.

Monsoons

The major monsoon systems are associated with the seasonal movement of convergence zones over land, driven by the temperature difference between land and sea, and leading to profound seasonal changes in local water cycles. They are responsible for a large proportion of the annual rainfall in many tropical regions. In general, monsoons are expected to increase in area, intensity and duration through the 21st century.



Drought

We cannot yet say whether there has been a change in the amount of drought experienced globally as the climate changes. In current dry regions, the frequency of droughts will increase by the end of the 21st century. According to the 2013 IPCC report, carbon stored in the terrestrial biosphere is susceptible to loss to the atmosphere as a result of climate change, deforestation, and ecosystem degradation. The aspects of climate change with direct effects on stored terrestrial carbon include high temperatures, drought and windstorms; indirect effects include increased risk of fires, pest and disease outbreaks. Increased tree mortality and associated forest dieback is projected to occur in many regions over the 21st century, posing risks for carbon storage, biodiversity, wood production, water quality, amenity, and economic activity.

Climate

Urban climate

Many aspects of weather and climate, including temperature and wind patterns, humidity and air quality are affected by urban development. Action in urban centres is essential to successful global climate change adaptation. Urban areas hold more than half the world's population (WHO, 2014) and most of its built assets and economic activities. They also house a high proportion of the population and economic activities most at risk from climate change, and a high proportion of global greenhouse gas emissions are generated by urban-based activities and residents. Global climate risks are concentrated in urban areas. Rapid urbanization and rapid growth of large cities in low and middle income countries have been accompanied by the rapid growth of highly vulnerable urban communities living in informal settlements, many of which are on land at high risk from extreme weather.

Volcanic impact on climate

Volcanoes can have an impact both on the Earth's energy budget, by changing the amount of sunlight which reaches the Earth, on the carbon cycle, by releasing carbon dioxide and methane, and on the water cycle, by providing CCN and emitting water vapour.

Huge explosive volcanic eruptions in the Tropics, energetic enough to push sulphur gases up into the relatively stable stratosphere where they condense into aerosols (small particles), can have a cooling effect on climate by increasing the amount of sunlight reflected by the atmosphere – the albedo of the atmosphere. This sunlight never reaches the Earth's surface to warm it. For example, the 1992 eruption of Mount Pinatubo, in the Philippines, resulted in a global cooling of up to half a degree for a couple of years. Other recent energetic eruptions include El Chichon (1982) and Agung (1963) which were preceded by half a century of little volcanic activity. More historically, the

combined eruptions of La Soufrière (1812), Mayon (1814) and Tambora (1815) had catastrophic global effects, leading to a 'year with no summer' in 1816.

A more dramatic change in albedo is associated with the 'snowball Earth' hypothesis. It has been suggested that during the Proterozoic (850-630 million years ago) the climate was cooling leading to ice accumulating which in turn reflected more of the sun's light, further cooling the climate and ultimately leading to ice covering the whole Earth. Volcanoes, by emitting huge amounts of greenhouse gases, would be necessary for the Earth's climate to start warming again.

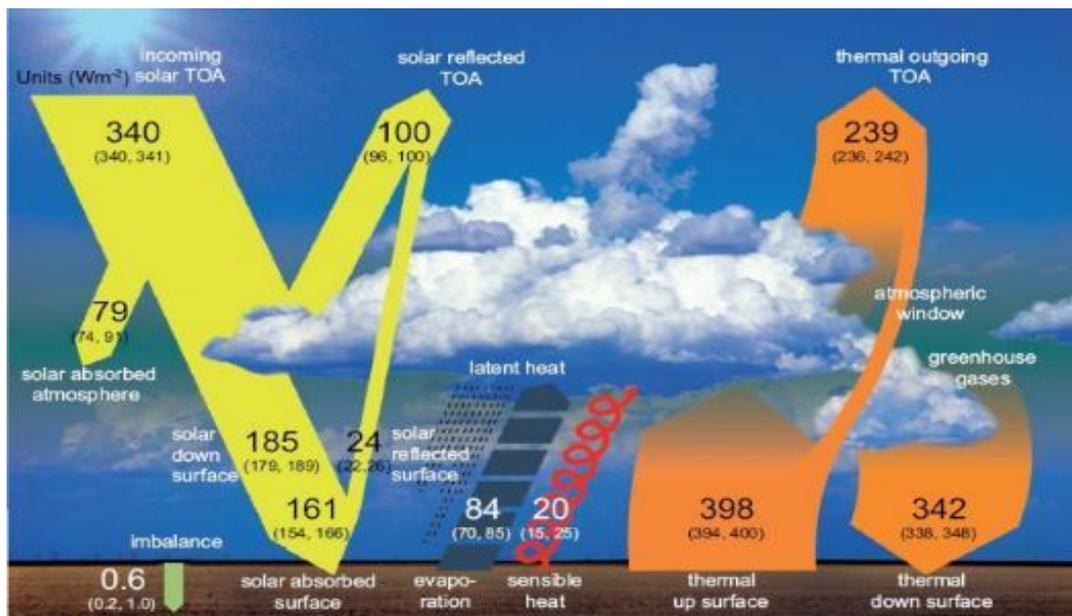


Figure 13: The Earth's energy budget © Professor Peter Read, with permission



Figure 14: A satellite image showing the ash cloud produced by Eyjafjallajökull erupting © NEODAAS/University of Dundee

The eruption of Eyjafjallajökull in 2010 was not powerful enough to push much gas or material into the stratosphere. However, the tropospheric ash cloud it emitted caused flight cancellations, which in turn 'saved' greenhouse gases which were probably in excess of the greenhouse gas emitted by the volcano itself. In addition, it is interesting to consider whether the cancelled flights led to a reduction in the number of contrails (high level clouds which warm the earth) in the atmosphere. If it did, it could have temporarily cooled the atmosphere locally.

Climate and Health

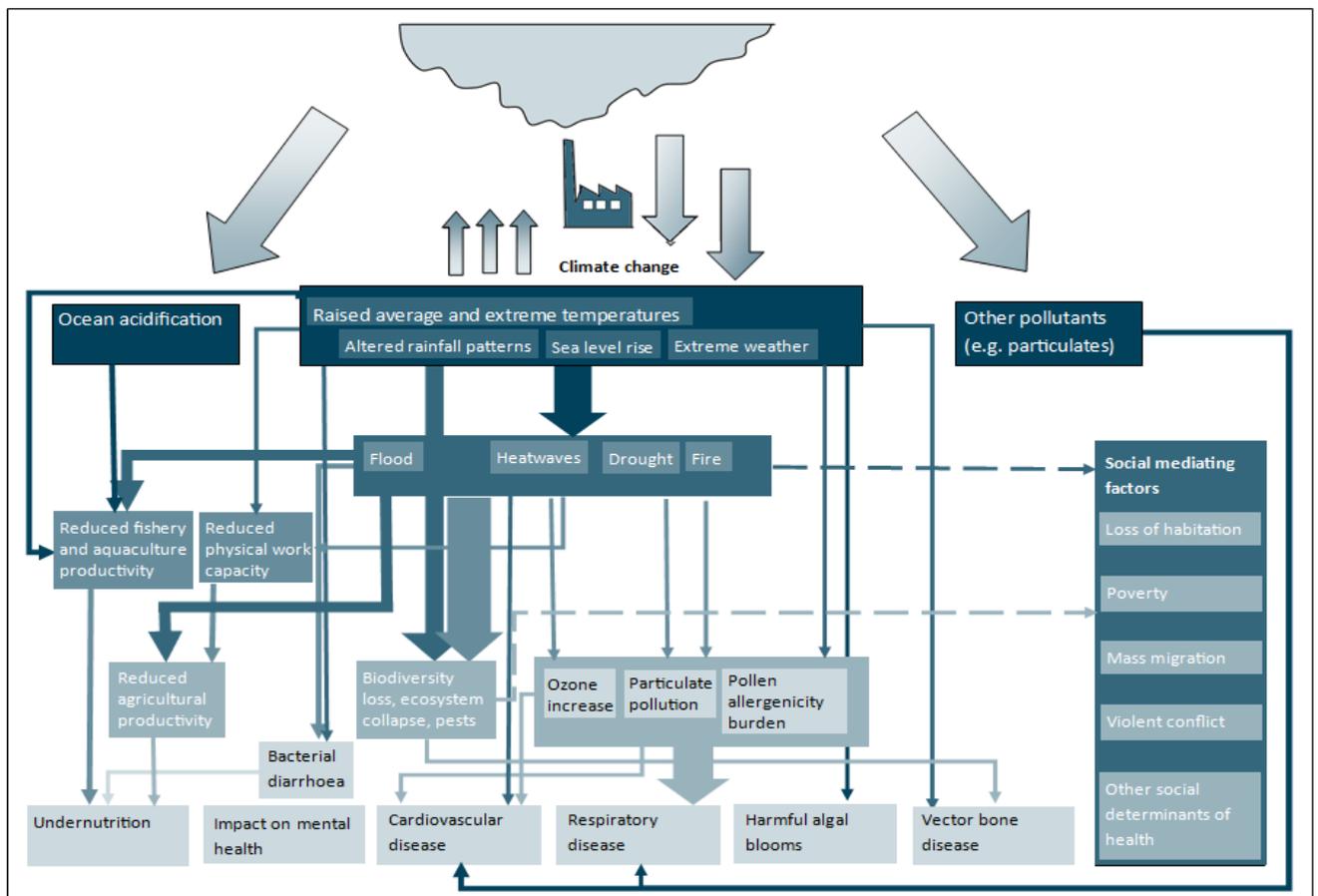


Figure 15: Many of the ways that climate change interacts with human health. Adapted from The Lancet (2015) via: <https://www.nbt.nhs.uk/sites/default/files/Sustainable%20Development%20Management%20Plan%202015.pdf>.

According to the World Health Organisation:

- Climate change affects the social and environmental determinants of health – clean air, safe drinking water, sufficient food and secure shelter.
- Between 2030 and 2050, climate change is expected to cause approximately 250 000 additional deaths per year, from malnutrition, malaria, diarrhoea and heat stress.

- The direct damage costs to health (i.e. excluding costs in health-determining sectors such as agriculture and water and sanitation), is estimated to be between US\$ 2-4 billion/year by 2030.
- Areas with weak health infrastructure – mostly in developing countries – will be the least able to cope without assistance to prepare and respond.
- Reducing emissions of greenhouse gases through better transport, food and energy-use choices can result in improved health, particularly through reduced air pollution.

Many of the ways that climate change interacts with human health are shown in Figure 16.

Weather events and climate also affect livelihood trajectories and dynamics in livelihood decision making, often in conjunction with cross-scalar socio-economic, institutional, or political stressors. Shifting in and out of hardship and well-being on a seasonal basis is not uncommon. To a large extent, the shifts from coping and hardship to recovery are driven by annual and inter-annual climate variability, but may become exacerbated by climate change.

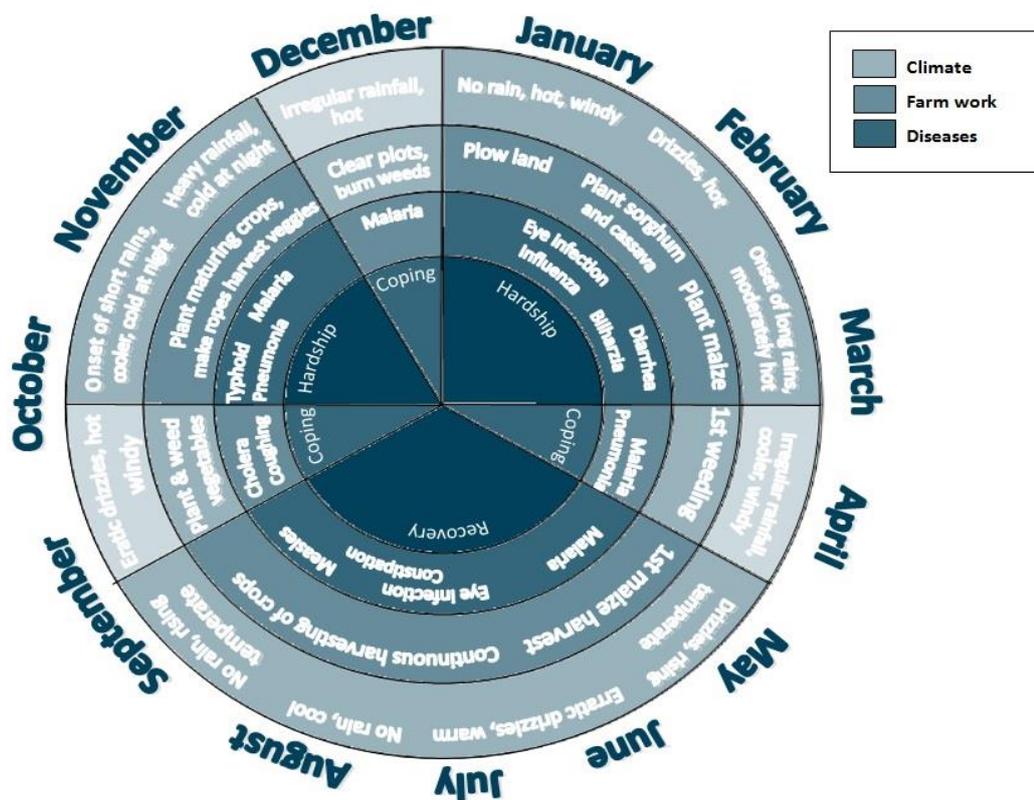


Figure 16: Seasonal sensitivity of livelihoods to climatic and non-climatic stressors for one calendar year, based on the experiences of smallholder farmers in the Lake Victoria Basin in Kenya and Tanzania. Adapted from: IPCC, 2014: *Climate Change 2014: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Useful Links

- Royal Meteorological Society
www.rmets.org/our-activities/education
- The difference between weather and climate
<https://www.youtube.com/watch?v=e0vj-0imOLw>
<https://www.youtube.com/watch?v=TQIHgGhYoF0>
- The structure of the atmosphere:
http://www.pbslearningmedia.org/asset/ess05_int_vertical/
- Experiments to demonstrate air pressure:
<http://www.metlink.org/experimentsdemonstrations/>
- The Coriolis Effect
<http://www.metlink.org/wp-content/uploads/2013/11/media/video/coriolis.mov>
- Hot air rises demonstration
<http://www.youtube.com/watch?v=YsCXw2bQU50&feature=plcp>
- The current surface winds – showing both the large scale atmospheric circulation and local weather features
<http://earth.nullschool.net>
- Annual Global sea level pressure and surface winds
http://geography.uoregon.edu/envchange/clim_animations/gifs/mslpwinds_web.gif
- Making clouds in the classroom
<http://www.metlink.org/experimentsdemonstrations/>
- Monsoons
<http://www.metlink.org/teachers/useful-links/#tropical>
- Drought
http://www.yourclimateyourlife.org.uk/a_drought.html
- Clouds
http://www.metlink.org/wp-content/uploads/2013/11/physics_review_clouds.pdf
- Atmospheric Stability and Lapse Rates
http://www.metlink.org/wp-content/uploads/2013/11/iop_atmospheric_stability.pdf
- Cold climates
<http://www.discoveringantarctica.org.uk/>
- Mid-latitude Depressions
<http://www.metlink.org/secondary/key-stage-4/>
<http://www.metlink.org/secondary/a-level/>
- The Met Office storm centre
<http://www.metoffice.gov.uk/uk-storm-centre>
- Tropical Cyclones



<http://www.metlink.org/teachers/teacher-development/extreme-weather-2/>

<http://www.metlink.org/teachers/useful-links/#tropical>

- El Nino/ La Nina

<http://rgsweather.com/2015/11/01/el-nino-how-does-it-impact-uk-winter-weather/>

<http://www.metlink.org/teachers/useful-links/#tropical>

- Climate

<http://www.metlink.org/teachers/useful-links/#climate>

- Climate Change updates for A level geography

<http://www.metlink.org/climate/ipcc-updates-for-a-level-geography/>

- The Changing water cycle

<http://www.metlink.org/climate/ipcc-updates-for-a-level-geography/the-changing-water-cycle/>

- Urban climate

<http://www.metlink.org/other-weather/urban-heat-islands/urban-heat-island-background/>

- Urban wind flow: a PowerPoint presentation

<http://www.metlink.org/pdf/teachers/urban-wind-intro.ppt>

- Introducing how the wind is affected by urban structures and notes for teachers

<http://www.metlink.org/pdf/teachers/urban-wind-teachers-notes.doc>

- Introducing simple fieldwork which can be carried out in the school grounds, using bubbles.

http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap8_FINAL.pdf

- Volcanoes and climate

<http://climatica.org.uk/volcanoes-and-climate-change1>

http://www.bbc.co.uk/science/earth/earth_timeline/snowball_earth#p00fzrcv

- Climate change and health

<http://www.who.int/mediacentre/factsheets/fs266/en/>

- When would we name a storm?

<https://www.youtube.com/watch?v=6uE7l6UkPFM>