Edexcel Geography GCSE

The World's Climate System

Hazardous Earth

Detailed Notes

Global Heat Transfers

The Earth's climate is influenced by **the atmosphere** and **the oceans**, which **transfer** and **redistribute** heat to different parts of the world. Without the transfer of energy around the globe, many parts of the world would be **uninhabitable**; the poles would be much colder, and the equator would be much hotter.

Heat is transferred around the Earth by **circulation cells** in the atmosphere (known as the global atmospheric circulation) and by **ocean currents**.

Global Atmospheric Circulation

The way our **atmosphere** circulates around the Earth impacts **global weather and climate patterns**, as the movement of air around the globe influences the **temperature** and **humidity**.

What is Atmospheric Circulation?

The **atmosphere** is the layer of air **surrounding the Earth's surface** which extends **hundreds of kilometres high**. Our atmosphere contains different **gases** (such as oxygen, nitrogen, water vapour and carbon dioxide), water droplets and particles.

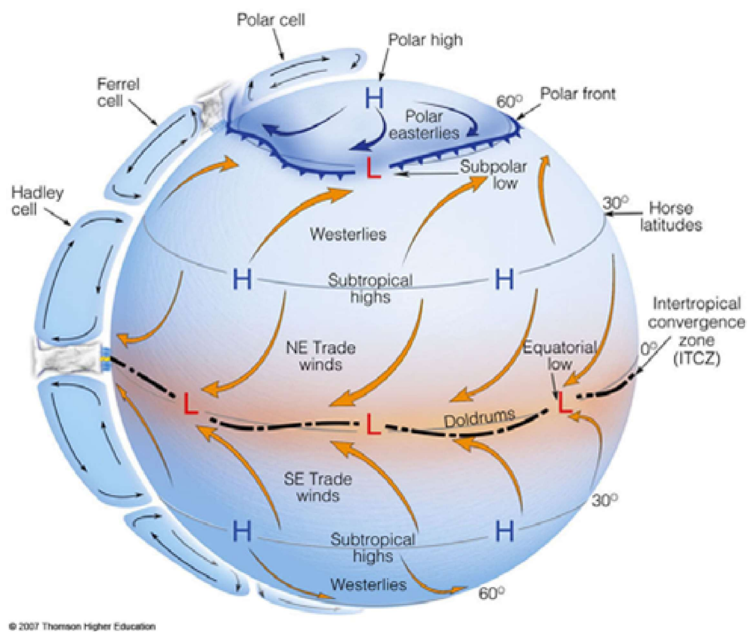
Within the Earth's atmosphere, the air is **constantly moving** in **different directions** because of the sun's **energy**, differences in **pressure**, and the **rotation** of our Earth. These movements cause air to **circulate** around our world, following generally quite **predictable** movements. These **patterns** can be **illustrated** by a model of **global atmospheric circulation**.

Atmospheric Circulation Model

The Global Atmospheric Circulation Model can be seen in the diagram below.

There are **three** distinct patterns of **air circulation** on either side of the equator (0°). These circular air movements are called **cells** (which are the blue sections with black arrows in the diagram). The three cells are:

- **The Hadley Cell:** At the **equator**, hot, moist air rises, moves to higher latitudes (30°) and sinks.
- **The Ferrel Cell:** At around **60°** either side of the equator, moist air rises, and travels to lower latitudes at around 30° where it sinks, along with air travelling from the equator.
- **The Polar Cell:** At 60° north or south of the equator, moist air rises, and travels to the poles (90°), where it sinks.



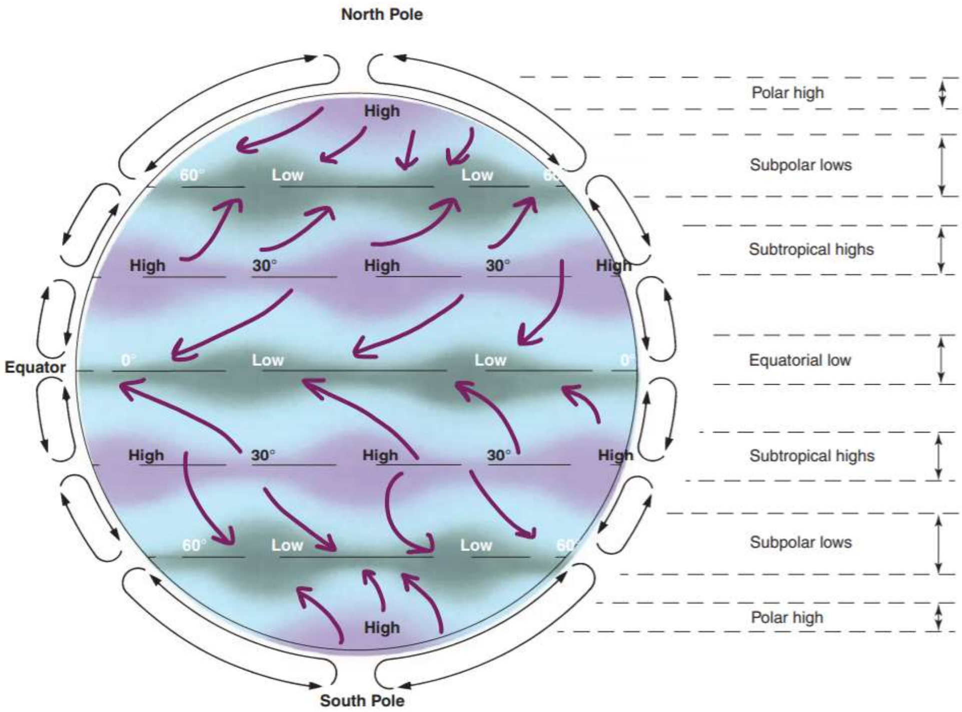
Pressure Belts

These air circulations create **different areas of pressure**.

When air **rises**, it creates an area of **low pressure underneath**.

When air **sinks**, it creates an area of **high pressure**.

A diagram of the **global pressure belts** can be seen below.



(Source: adapted from Cengage Learning)

One way to remember these patterns is to think of it like this - when the air is **sinking**, there are obviously more air particles **pushing downwards**, meaning there would be **higher pressure here**.

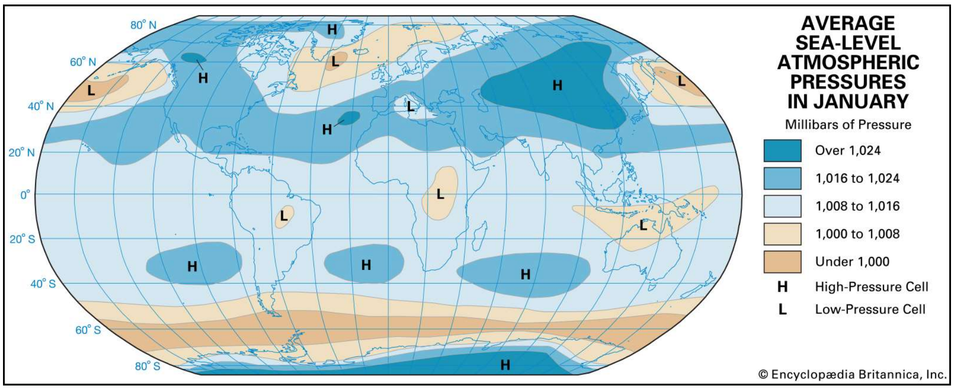
In contrast, if air is **rising**, the pressure will indeed be **lower** as the air particles aren't **pushing down**.

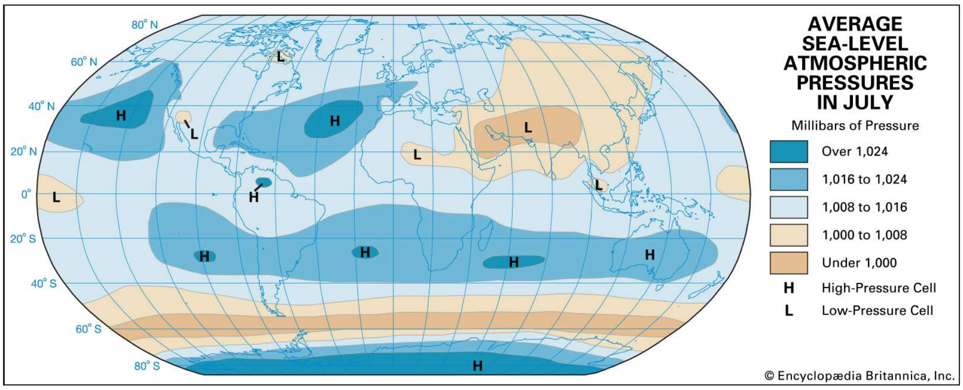
Pressure Differences in Land and Sea

Oceans behave differently to **land** when they absorb the Sun's energy and heat up, which causes **pressure differences** between the **land** and the **sea**.

Land generally absorbs sunlight more and heats up **quickly** in **summer months**, causing **low pressure over land** as the **hot air is rising.** The sea **reflects more heat** and therefore takes longer to heat up, forming areas of **high pressure**. The opposite happens in **winter**, as the land loses energy quickly causing **high pressure over the land**, whereas the seas take longer to cool, meaning they are relatively **low pressure**.

Maps showing the **differences in pressure between summer and winter** can be seen on the next page. Remember that in January it is winter in the Northern Hemisphere, but summer in the Southern Hemisphere (and vice versa in July) which is why the patterns are reversed.

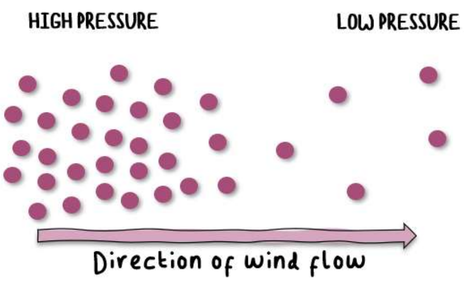




As a result of **atmospheric cells** and **pressure differences in the ocean**, **pressure belts** are formed across the globe. In general, there is **low pressure** at the equator and at 60° either side of it due to the **air rising** here. There is **high pressure** at the poles and 30° either side of the equator due to air sinking here. This can alter seasonally depending on the oceans.

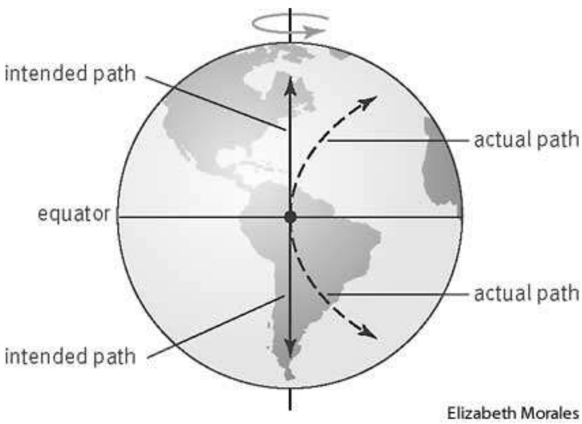
What about Wind?

Wind is created when air particles **move**. Air particles will always move from an area of **HIGH PRESSURE** to an area of **LOW PRESSURE**.



This pattern can be seen in the **atmospheric circulation diagrams above**; the arrows will always move **from high pressure areas to low pressure areas**. For example, the patterns of surface wind move **from** 30° which is high pressure **towards** the **equator** which is **low pressure**.

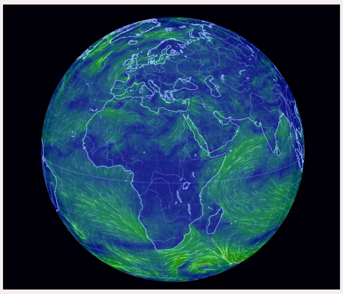
However, you may also notice that **these winds do not move in a straight line**. Instead, the winds are **deflected** in different directions. This is because the **earth is spinning**, so the winds end up travelling in a curved direction. This effect is known as the **Coriolis Effect**. So, the winds are **deflected right** in the northern hemisphere, and **left** in the southern hemisphere.



Thinking Further: Global Winds

[This website](https://earth.nullschool.net/#current/wind/surface/level/orthographic=-332.76,14.64,275) allows you to look at the **global surface winds** in real time. Try to spot the **overall patterns** that you can see on the **atmospheric circulation models**, but also spot any differences in these trends.

Hopefully you can see that **surface winds are not always that simple**, and sometimes don't stick to these patterns.

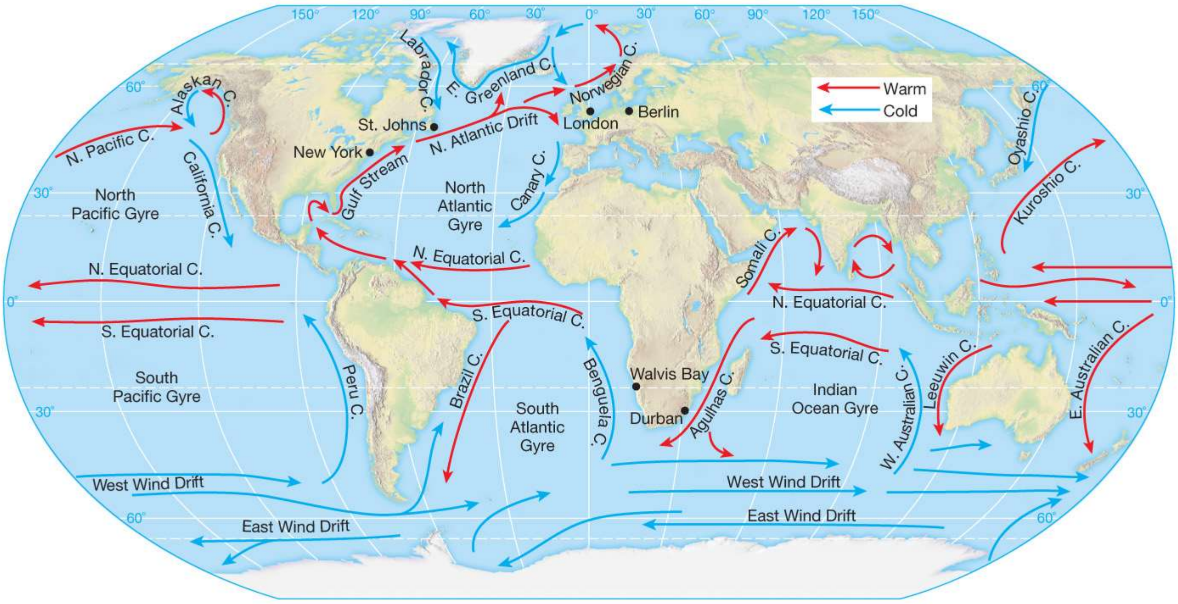


https://earth.nullschool.net/#current/wind/surface/level/orthographic=-332.76,14.64,275

Ocean Currents

Ocean currents are the **predictable**, **continuous** movements of water in the **ocean**. There are several **major ocean currents** that move around the world, transferring **energy** to other regions. Ocean currents can have major effects on the **climate** of a region, as they can transfer **warmer water to colder regions**, and **colder water to warmer regions**.

The Gulf Stream is an example of an **ocean current** that influences the climate. Warm water from the **equator** flows up to the **North Atlantic** via the **Gulf of Mexico**, which causes the climate in Europe to be **warmer**. Without this ocean current, Europe would be 5-10°C colder!



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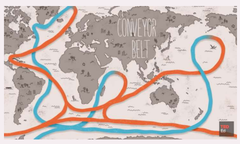
Thinking Further: Drivers of Ocean Currents

Ocean currents are driven by **winds**, the **Coriolis Effect**, the **tides**, and **density differences** (temperature and salinity). [This video](https://www.youtube.com/watch?v=p4pWafuvdrY) explains how ocean currents are set up and sustained around our world.
https://www.youtube.com/watch?v=p4pWafuvdrY



How Does Atmospheric Circulation Affect Climate and Weather?

Pressure belts and surface winds impact the **temperature** and **humidity** in regions throughout the world.

What's the difference between climate and weather?

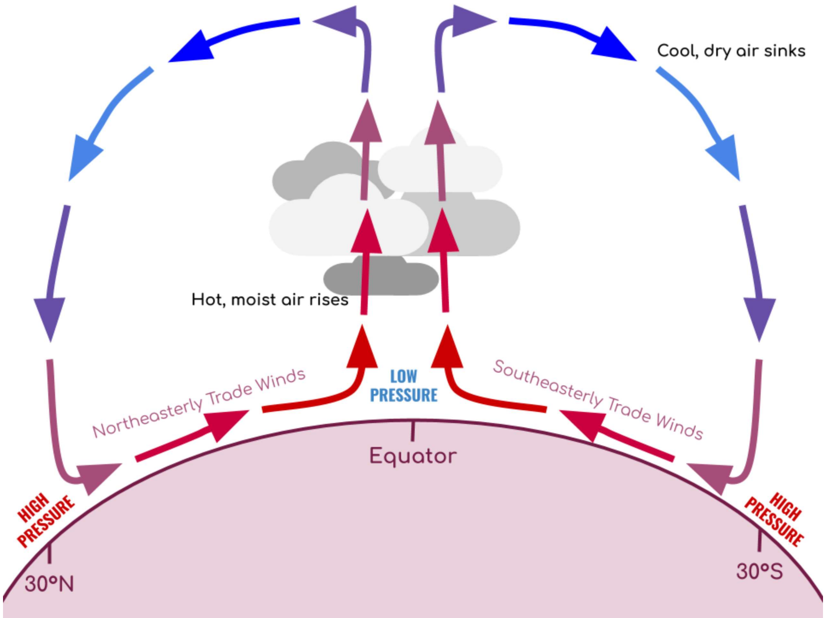
When we talk about the **weather** of a place, we are usually referring to the **daily conditions** that a place experiences, such as the **temperature**, how **windy it is**, **how much cloud cover** there is/ how **sunny** it is, and if there's any **precipitation** (rain, snow, hail etc.).

On the other hand, the **climate** is a **long-term trend** in temperature, humidity etc. (usually calculated over a 30 year period or longer).

High Rainfall Areas

High rainfall areas are found in areas of low pressure.

The sun **shines directly on the equator**, meaning it is consistently **warmer** than (as an example) the poles where the sunlight is less direct.



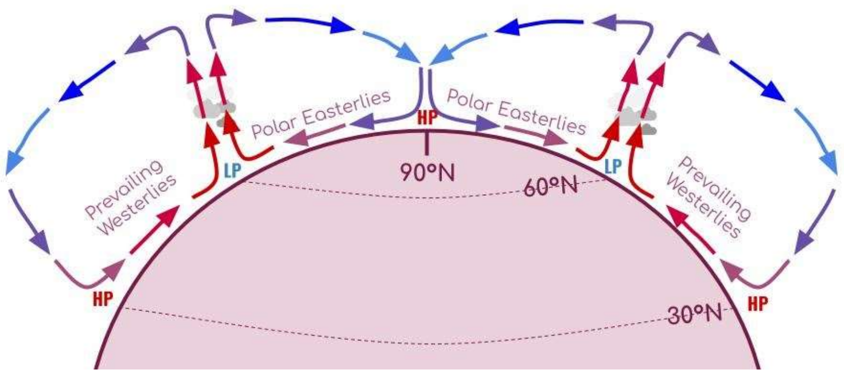
Hot, moist air rises here, creating an area of **low pressure (equatorial low)**. When the moist air rises, it condenses to form rain clouds. This causes the climate at the equator to be **humid** and **very rainy**. Tropical rainforests are found here due to the warm and wet weather.

At around 60° north or south of the equator there is another **low pressure belt**, causing the climate to be cloudy and wet. The climate here is **not as warm** as the sun shines **less directly** than at the equator.

Low Rainfall (arid) areas.

If a region is described as **arid**, it means that area receives **very little rain**, causing it to be **dry**.

Dry air sinks at the subtropics (around 30°), meaning it forms an area of **high pressure**. **Clouds do not form here** because the air isn't rising, so it is very **dry**. This is where we find many of the world's **deserts**.

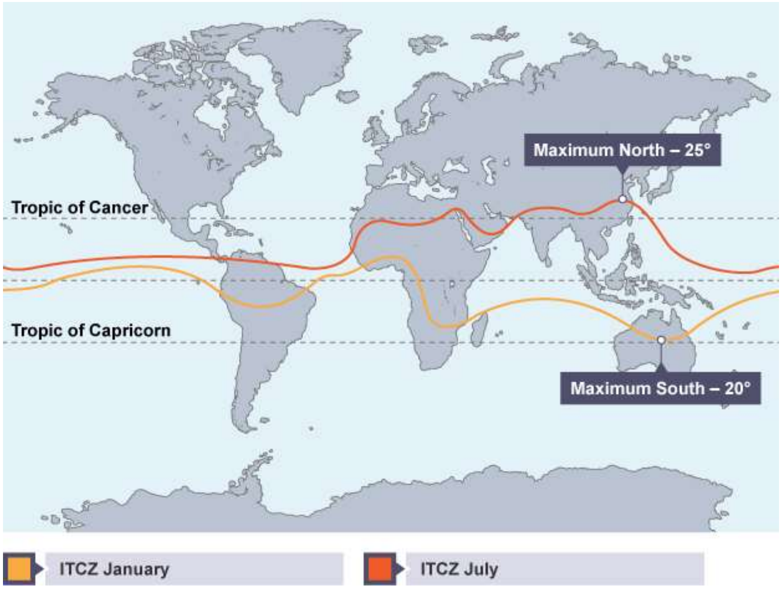


The Effect of The Inter-Tropical Convergence Zone (ITCZ)

The Inter-Tropical Convergence Zone is an area surrounding the equator where winds from the **northern** and **southern hemisphere** meet (**converge**) causing an area of low pressure with **rainy conditions**.

At the **ITCZ**, the northeasterly **trade winds** and southeasterly **trade winds** converge, creating an area of **lower pressure**. Moist air is forced upwards, which then **condenses**, forming a **band of clouds and heavy precipitation** on the ITCZ.

The ITCZ moves **seasonally**, causing patterns of **precipitation** to move with it. This causes **wet seasons** when the ITCZ is over an area **and dry seasons** when the ITCZ has left that area.



(Source:https://www.bbc.co.uk/bitesize/guides/z9yssbk/revision/2)

Natural Causes of Climate Change

There are several **natural factors** that have caused **changes in Earth's climate** for millions of years. The main natural influences on climate change are:

- **Asteroid** collisions
- Variations in the **Earth's orbit** around the Sun
- The effects of **volcanic eruptions**
- Changes in the **solar output** (amount of heat energy) of our Sun

Asteroid Collisions

Very large **asteroid impacts** can influence the climate. If an asteroid is **large enough** (a few kilometres wide) millions of tonnes of **ash** and **debris** would be ejected into the atmosphere when it impacted Earth. This material could **block out the sun** and therefore cause global temperatures to be much **lower**.

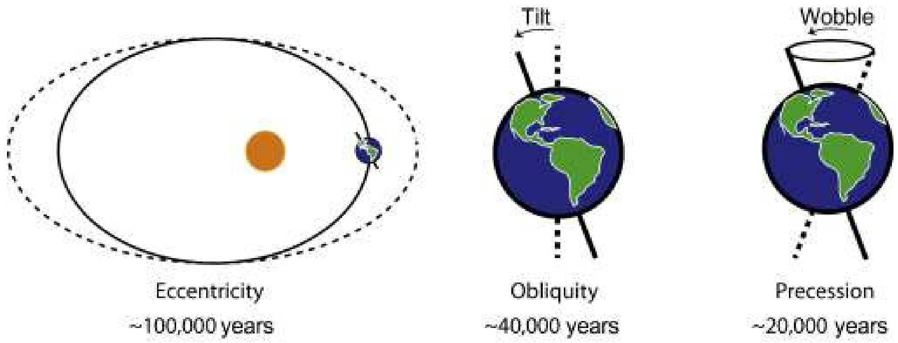
Some scientists **theorise** that it was a **huge asteroid collision** that led to the ice age and the extinction of the **dinosaurs**.

(Source: NASA)

Orbital Changes

The way in which the **Earth orbits around the Sun** changes over **thousands of years**. These orbital changes affect **where the Sun hits the Earth**, and how **intense** the Sun is, which in turn controls the seasons and affects the climate. Orbital changes follow **very similar patterns** to **glacial** and **interglacial** periods, and scientists theorise that orbital changes caused major **temperature fluctuations** throughout Earth's history.

The influence of Earth's orbit on the climate is known as '**orbital forcing**' and the cycles are commonly referred to as **Milankovitch cycles** after the Serbian geophysicist Milutin Milankovitch who discovered them. There are **3 distinguishable orbital changes** that the Earth goes through:



(Source: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/orbital-forcing)

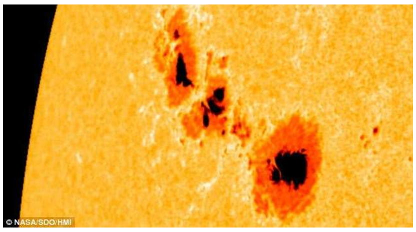
1. **Eccentricity:**
   - The orbit of the Earth around the Sun changes from a **near-perfect circle** to an **ellipse** (squashed circle/oval).
   - This affects how **intense** the Sun's rays are on Earth. If the Earth is orbiting in an **elliptical shape**, it will be **further away from the Sun** at certain points than if it was orbiting in a **circle**.
   - 1 cycle takes around **100,000 years**.

2. **Obliquity (tilt):**
   - The **tilt** of the Earth's **axis**, which changes from **21.5° and 24.5°** (currently 23.5°).
   - Affects the contrast between summer and winter **seasons**.
   - To change between 21.5° and 24.5° takes around **41,000 years**.

3. **Precession:**
   - Describes the **wobble** of the Earth's axis (imagine the movement of a **spinning top** when it starts to slow down - the Earth wobbles on its axis in a similar way).
   - Affects the **length of days**, especially in the poles.
   - A full cycle takes just over **20,000 years**.

Solar Output

There are **variations** in the amount of **solar energy** that the Sun **emits** which are thought to have an effect on the **Earth's climate**.



One example of a variation in solar output is the **sunspot cycle**. The **sunspot cycle** is an **11-year cycle** where the amount of **sunspots** on the Sun's surface (darker spots with reduced temperatures) varies from a **minimum** to a **maximum**, and then back to a **minimum**.

At the sunspot cycle's **minimum**, there is **reduced solar output**. At the sunspot cycle's **maximum**, there is an **enhanced solar output**.

There is an identifiable **relationship** between **the Earth's climate** and the **amount of sunspot activity present** on the Sun. There have been incidences of **temperature change** on Earth that are linked to these **cycles**, so it appears that **solar output variations** do affect the temperature on Earth, although this is only a **theory**. It has been hypothesised that temperatures during a cold period called the '**Little Ice Age'** plummeted further during sunspot minimums (1450 to 1534, and 1654 to 1715)

Volcanic Activity

Very large **volcanic eruptions** have had an effect on the **Earth's climate** in the past. The **ash** and **gas** that is **erupted** into the atmosphere when there is a huge eruption can cause a **cooling effect** on the Earth's climate. This reduction in surface temperatures caused by an eruption is known as a **volcanic winter**. Volcanic eruptions do this in two ways:

- Large amounts of **volcanic ash** can stay in the atmosphere and **block out the sun**. This is usually a **short term cooling**.
- Volcanic eruptions can emit **sulfurous gases** which react to form aerosols which **reflect solar radiation**. This effect can last several years.

Thinking Further: Volcanic Winters

There have been many examples of large volcanic eruptions causing **volcanic winters**.

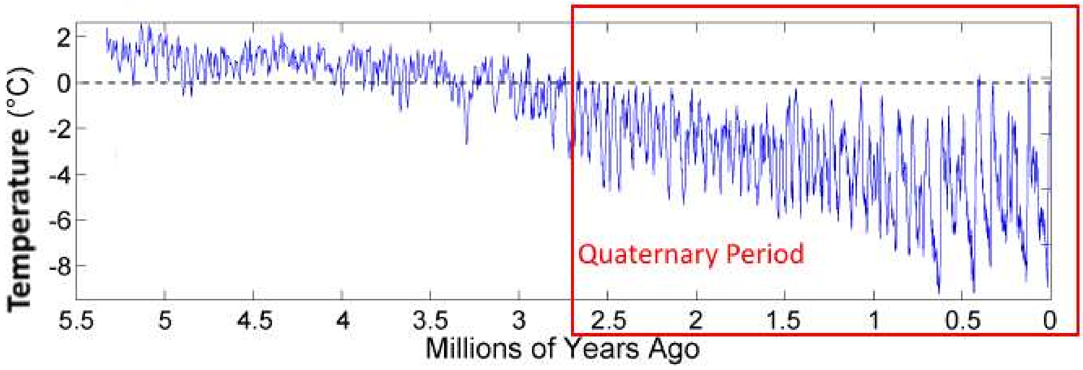
- **1783 - Laki, Iceland**. The year after the eruption, Northern Hemisphere temperatures fell by about **1°C**, resulting in severe weather. 8,000 additional deaths in the UK were recorded in the winter of 1783-1784. **Severe weather** continued for several years in Europe.
- **1815 - Mount Tambora, Indonesia.** The eruption caused global temperatures to fall by **0.4-0.7°C**, resulting in crop failures and famines. 1816 was commonly referred to as **'The Year Without a Summer'**.

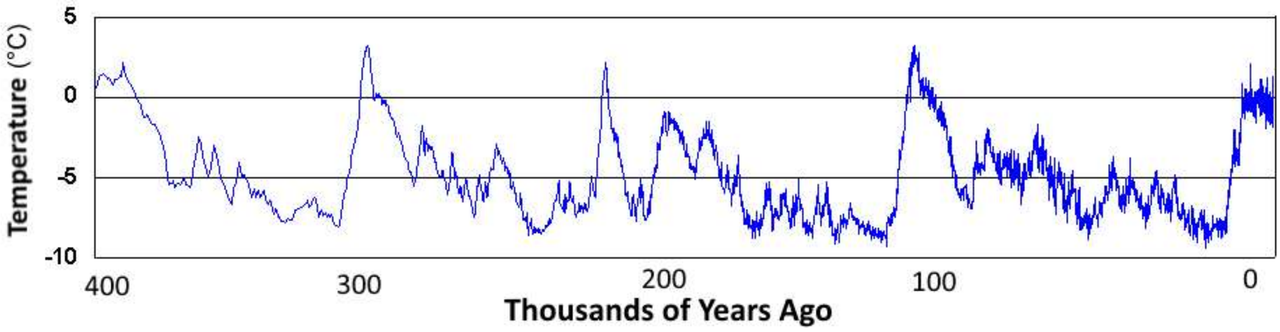
Artistic representation of the 1815 eruption.
(Source: Greg Harlin/Wood Ronsaville Harlin)

Climate Change During Earth's History

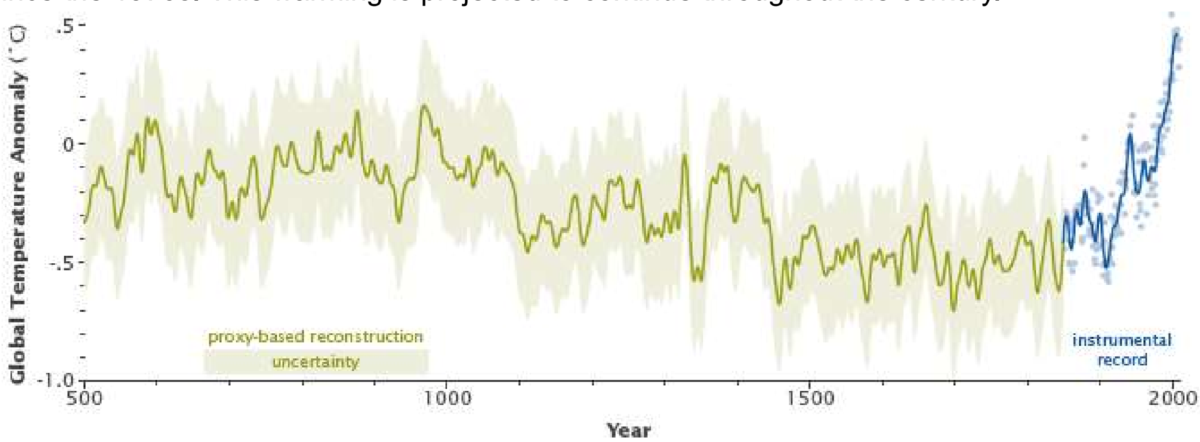
When we hear the phrase **'climate change'**, we might think about the changes in our climate **over the last few decades**: rising **temperatures** in the **air** and the **sea**, more **intense tropical cyclones**, severe **droughts** etc. However, the climate of the Earth has gone through **dramatic changes** throughout its **history**. Some **major fluctuations in temperature** have occurred in the ***Quaternary Period.***

The **Quaternary Period** is the **geological time period** that started **2.6 million years ago**, and extends into the **present**. During the Quaternary period, there have been many fluctuations between the colder **glacial periods** and warmer **interglacial periods**. We can see these fluctuations on the graphs below, which show the temperature relative to our current average temperature (which is displayed as 0°C on the graphs).





Over the last few hundred years, our climate has been warming **rapidly**. Average global air temperatures have risen by **0.85°C since 1880**, and the majority of this warming has occurred since the 1970s. This warming is projected to continue throughout the century.



(Source: https://earthobservatory.nasa.gov)

Evidence for Climate Change

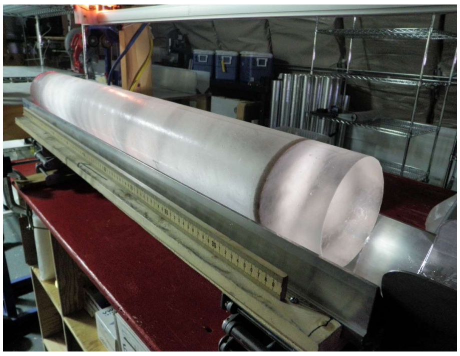
In the present day, we measure **air** and **sea** temperatures using **thermometers**. Scientists started taking these measurements around 100 or so years ago, meaning we have a **reliable record** of global temperatures starting around the late 1800s (which is known as the **instrumental temperature record**). The instrumental temperature record is shown by the **blue line** on the **graph above**.

However, this means there is **no instrumental data** of global temperatures **before people started taking these readings**. Scientists have therefore had to discover other ways to **indirectly** calculate global temperatures **in the distant past**.

Ice Cores

The Antarctic ice sheet and the Greenland ice sheet are the largest **and the oldest** ice sheets in the world. They contain ice crystals that were formed **hundreds of thousands** of years ago.

When snow falls on top of these ice sheets, it buries and **traps older snow** below. Over thousands of years, this snow builds up and compacts into **thick ice**.



(Source: icecores.org/about-ice-cores)

Scientists have been able to **drill down** inside the ice sheets and extract **large cylinders** of ice called **ice cores**, which can be seen in the image to the right. Scientists use these ice cores to calculate **gradual changes in temperature** over thousands of years. Right at the top of the ice core is the **youngest ice**, and as the scientists work down the ice gradually becomes **older**.

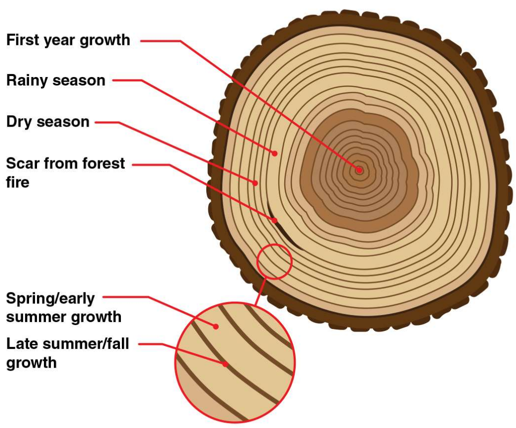
The **composition of water** can be analysed to calculate (with extreme accuracy) what the **temperature of the atmosphere** was when that water fell as snow. Air bubbles **trapped in the ice** can also be analysed; levels of CO_2 and other gases can tell us more information about the climate at that time.

Ice cores provide evidence of the climate stretching back **hundreds of thousands of years**. The furthest back in time an ice core has been able to go was 400,000 years!

Tree Rings

Tree rings can be used to **reconstruct** the climate that those trees **grew in**. Each year, a tree gains another **ring** when it grows; if a tree ring is **larger**, it means the tree grew **more** that year. Scientists can use tree rings to work out when temperatures were more **favourable for growth** (warmer, wetter), and therefore **reconstruct past climates**.

Although the majority of trees only last a few hundred years, **data from the distant past** can be gathered using fossilised tree trunks that have been preserved (e.g. in peat bogs).



(Source: NASA)

Historical Sources

Historical records and sources that **people** have created can be used to gain an understanding about climate **before accurate temperature measurements** were taken and recorded. These sources are especially relevant from the past 2000 years when civilisation began to develop.

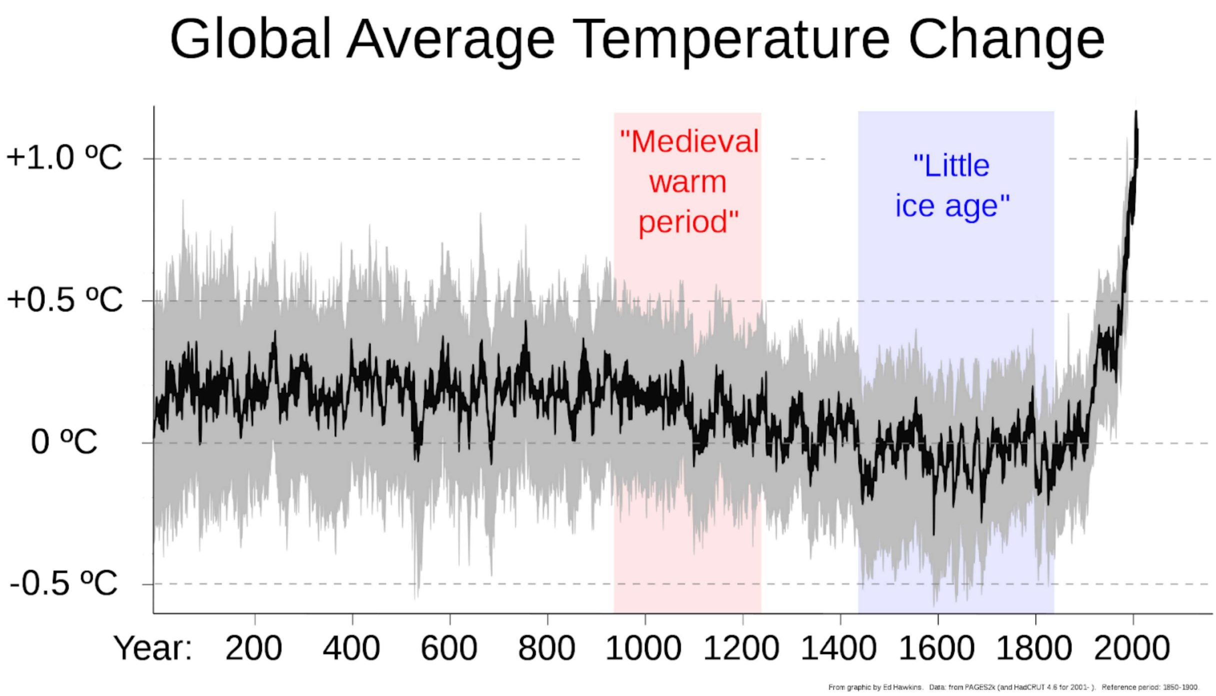
For example:

- Photos, illustrations and paintings can show what the **past landscape** was like. There are many paintings of the period around the Little Ice Age that depict a **cold** climate, with **lakes** and **seas** frozen over.
- Records of **animal behaviour/migrations** or the dates that trees **flower** can indicate temperatures at the time.
- Books, journals and newspapers can be used to understand the climate, or date any weather events such as extremely cold winters.

Historical sources can not be used as **accurate** sources of climate data as they were not **intended to be reliable sources**, but they can be used to gain an idea of temperature trends.

A painting during the Little Ice Age, H. Avercamp, c. 1620.

These sources of information have made it possible to reconstruct temperature changes throughout Earth's history



(Source: By RCraig09 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=87832845)

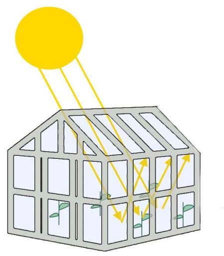
Human Causes of Climate Change

There is **overwhelming evidence** to suggest that **humans** have been a major cause of **climate change**, especially the **rapid warming** since the 1970s. This is due to **human activities** that influence how much **energy is in the Earth's atmosphere**. The main ways that humans are thought to have caused global warming are:

- The **burning of fossil fuels** during **industrial processes, transport, and energy production** which has released **greenhouse gases.**
- **Different farming methods**, which release **methane** (a powerful **greenhouse gas**).
- **Deforestation**, which has **reduced the CO_2** taken up by trees, contributing to higher levels of **greenhouse gases in the atmosphere**.

The Greenhouse Effect

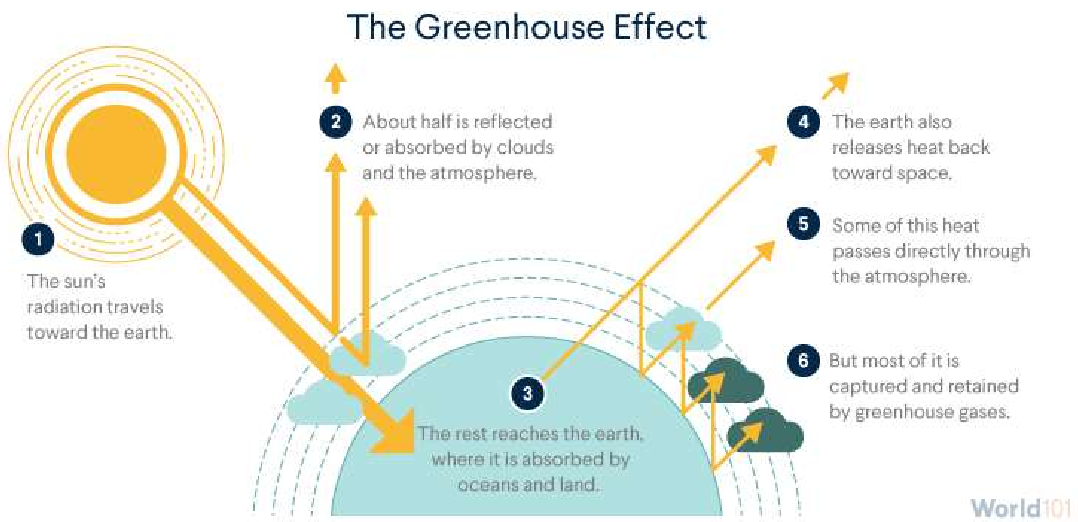
Human activities have contributed to global warming through the release of **greenhouse gases**, but **how has this caused recent climate change?**



The Greenhouse Effect is a natural process where **greenhouse gases** (mainly carbon dioxide, methane, water vapour, and nitrous oxides) trap the energy from the Sun inside the Earth's atmosphere, which heats the Earth. This effect is similar to what happens in a **greenhouse**. In a greenhouse, the **Sun** shines through the glass, which **heats up the air** inside. This heat cannot escape as it is **trapped** by the glass, which keeps it **warm** inside.

A similar effect happens when the **Sun** shines on our **Earth**:

- **Solar radiation** from the Sun (short-wave radiation) travels to our Earth and **heats up the Earth's surface.**
- The Earth **gives off heat** (long-wave radiation) when it cools.
- Some of this heat **leaves our atmosphere and goes into space.**
- Some of this heat is **trapped by greenhouse gases**, which keeps our Earth warm.



The Greenhouse Effect is the reason the Earth is **warm enough** to live on. Without it, Earth would be far too cold for life as we know it.

The Enhanced Greenhouse Effect

Human activities release **greenhouse gases** into the atmosphere at a **higher rate than natural processes**, which has resulted in an **enhanced greenhouse effect**.

As there are higher amounts of **greenhouse gases** in the atmosphere, more heat is **trapped** and cannot escape into space. This heat is **reradiated around the Earth** and causes the air to heat up more and more. This process has led to **increased warming** in recent years.

The main human activities that have caused an **increase in greenhouse gas levels** in the Earth's atmosphere are outlined below:

Fossil Fuels

Fossil fuels - such as coal, oil and gas - are fuels that are made up of **the remains of organic material**. We burn fossil fuels for **energy**, which produces our **electricity**, fuels our **cars**, and heats our **homes**.

When fossil fuels are burnt, **greenhouse gases** are released, such as carbon dioxide, nitrous oxides and methane. These greenhouse gases concentrate within the atmosphere, contributing to the **enhanced greenhouse effect**.

The vast majority of **CO_2** comes from the burning of fossil fuels.

Agriculture

Another source of **greenhouse gases** is due to **farming** activity.

Agricultural activities produce a lot of **methane**. **Methane** is a **more effective greenhouse gas** than CO_2, so it is **better at trapping heat**. About **25%** of global warming is thought to be caused by methane emissions, despite there being **much** less methane in the atmosphere than CO_2.

Rice Farming

In a paddy field (a flooded field where they grow rice) there are the right conditions to release a **lot of methane**. As rice is **heavily cultivated** across the world, rice farming is a **large contributor** to the levels of methane in the atmosphere.

Livestock

Some **farm animals**, such as cows and sheep, **produce methane** when they digest food. One of these animals on average produces 250-500 litres of methane a day!

Animals are kept all over the world **as livestock** to meet the population's demand for **meat and animal products**, which contributes to **huge methane emissions**.

(Source: https://www.nationalgeographic.org/encyclopedia/ranching/)

Agricultural fertilisers also produce **nitrous oxides**, which can be up to **300 times** more effective in capturing heat than carbon dioxide.

Deforestation

Deforestation is the process of **cutting down trees**. Deforestation occurs all over the world, mainly to **make space** for **agriculture**, or to **collect wood** to use for other means or to **burn** as fuel.

Trees take in **CO_2** from the atmosphere and store it inside them as **carbon**. Deforestation removes **large amounts of trees**, which in turn **reduces** the amount of **CO_2** that is being taken in and stored, resulting in higher levels in the atmosphere.

Also, forested areas are often **burnt** to make space quickly, and chopped wood is also burnt for fuel. The burning of wood **releases CO_2** that was originally stored in the trees and puts it in the atmosphere.

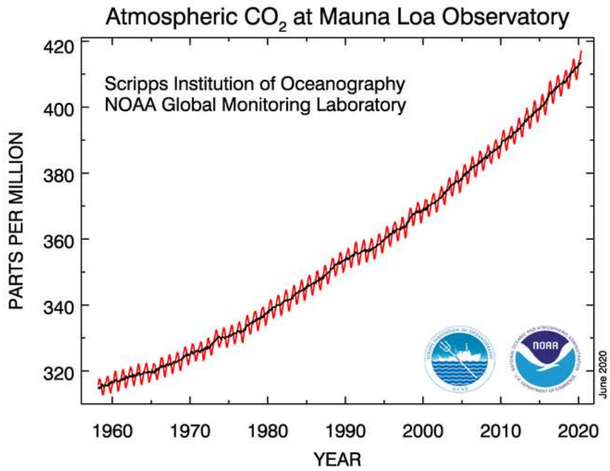
(Source: AFP via Getty Images)

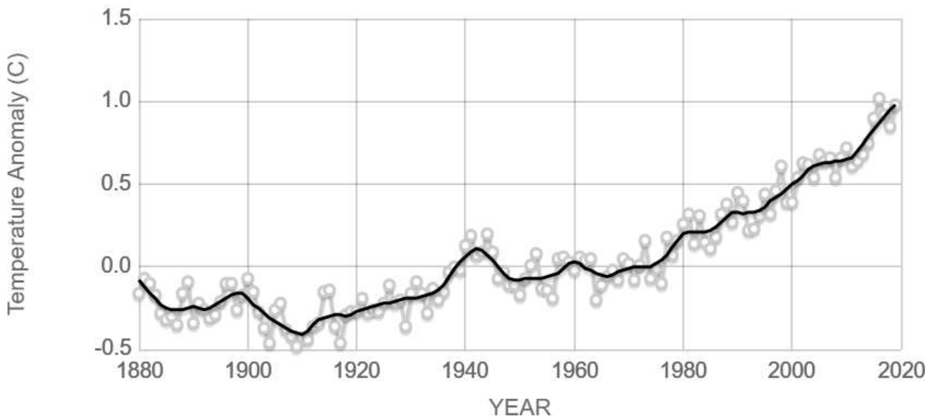
Greenhouse Gas Levels and Climate Change

Emissions of greenhouse gases due to human activities is thought to be a **bigger influence** on **current global warming** than **natural causes of climate change**.

Average global **temperatures** are projected to increase by as much as **4°C** by the end of the century (projected between 1.8°-4°C) due to human activities.

Below is a graph of the amount of **atmospheric CO_2** recorded since **1958**, and a graph of **average temperature difference** (anomaly) since **1880**. Notice how the global temperatures are rising in a similar pattern to the levels of CO_2 in the atmosphere.





Source: climate.nasa.gov

Evidence for Human Induced Climate Change

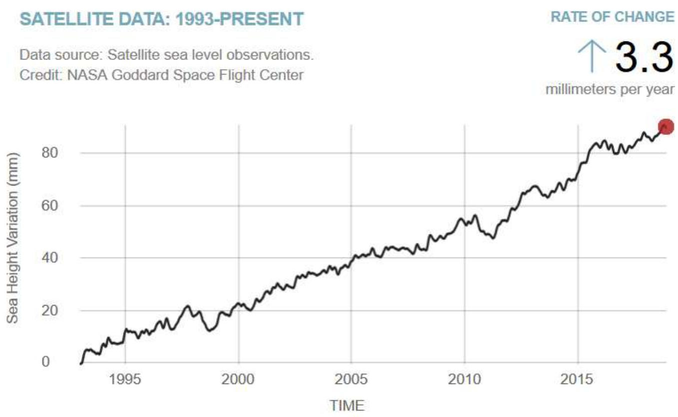
We know that our climate **has been warming** in recent years due to our temperature records, but we can also see **more evidence** of our changing climate in different parts of the world.

Sea Level Rise

The average **global sea level** has risen by **21-24cm** since the 1800s, and **a third** of this rise has occurred within the **last 25 years**.

Sea level rise has been occurring because **higher temperatures** have caused glaciers and ice sheets to melt, and this **freshwater** then flows into the sea.

Furthermore, water **expands** when it gets warmer (known as **thermal expansion**) so as the Earth warms, the whole sea is expanding and **rising**.



Decay of glaciers and ice

Glaciers and ice sheets are **melting** all around the world, which is evidence that **the climate is warming**. Some glaciers are projected to **completely melt** by 2035. The majority of glaciers are shrinking and thinning.

Sea ice is also **thinning** and not **extending as far**, especially in the Arctic Ocean. Sea ice has thinned by up to 65% since 1975 in the Arctic Ocean.

(Source: www.flickr.com/photos/wasifmalik)

Increased extreme weather

There has been an increase in **extreme weather events,** which is evidence that the climate is changing.

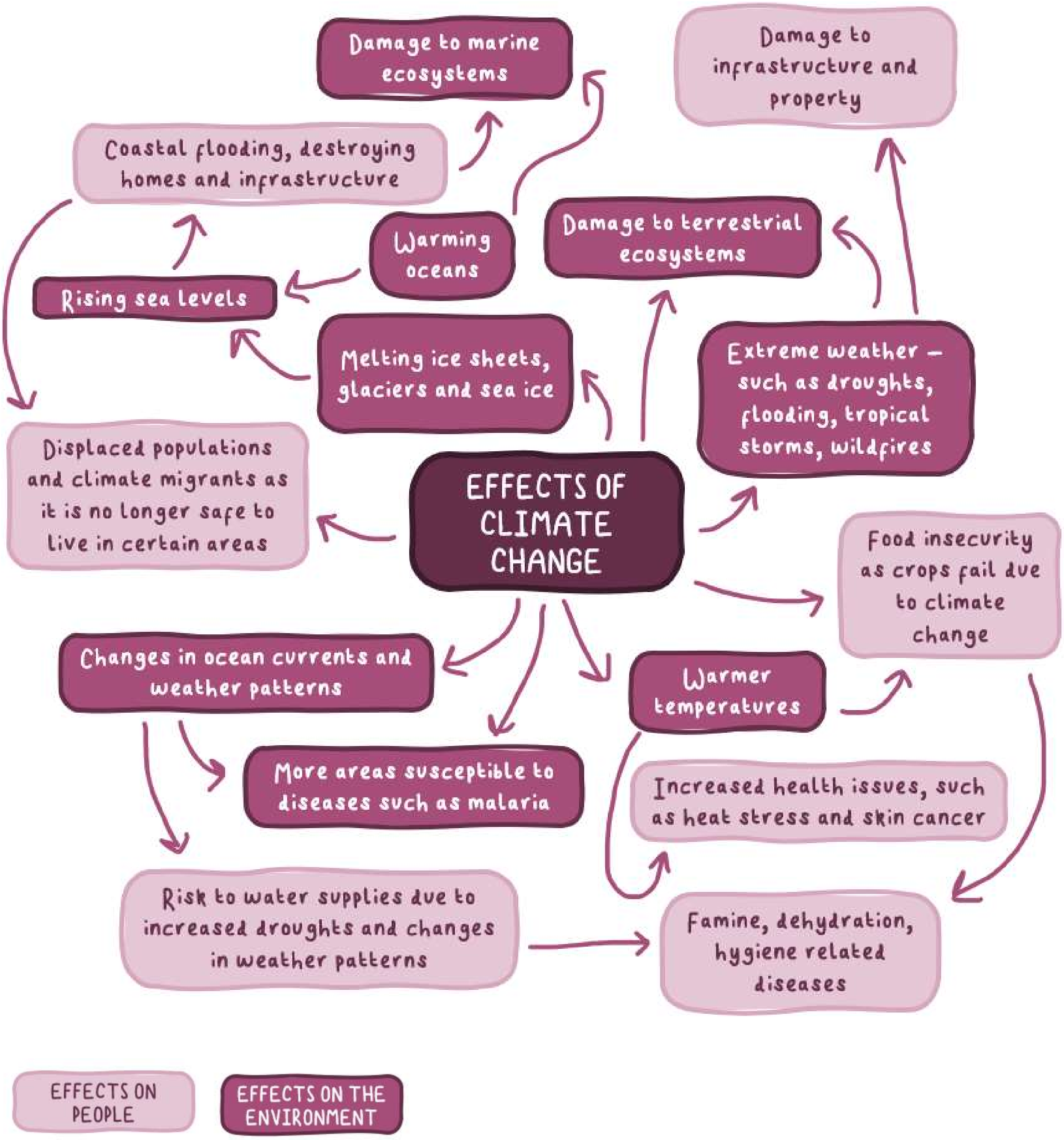
Nine out of ten of the warmest years on record have occurred in the 21st century. Prolonged periods of **hot, dry weather** are becoming more common in parts of the world. **Precipitation** is also becoming **more intense**, increasing **flooding risk**.

Tropical storms are becoming more **intense**, and **forest fires** are happening more frequently, which is thought to be because of the changing climate.

Effects of Climate Change

There are many potential **consequences** of climate change on the **population**, including issues with **food**, **water**, and **land availability**.

Below are some examples of these effects. Many are **interlinked** and **related** to each other, and many **environmental effects** can cause **human effects**.



Climate Change Projections

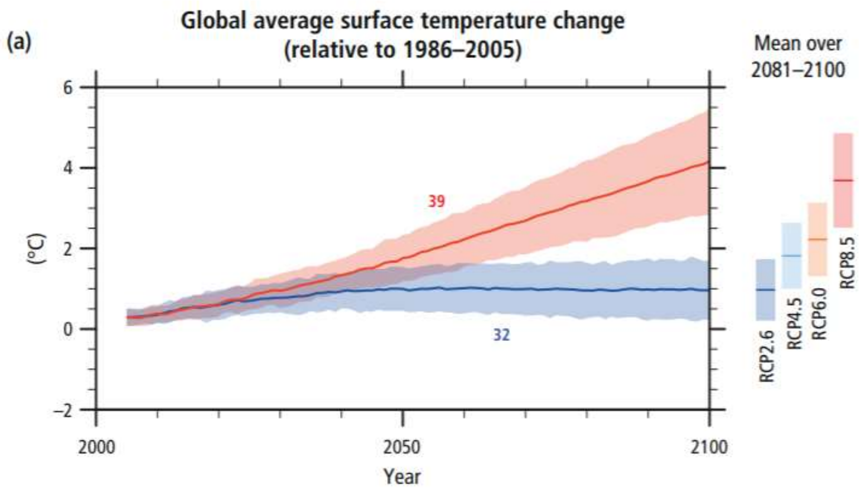
Climate scientists use **global greenhouse gas emissions** and **current warming trends** to try to **predict** how the climate will change **up until 2100**. Scientists on **The Intergovernmental Panel on Climate Change (IPCC)** have created **projections** of **temperature** and **sea level rise** based on different **scenarios**:

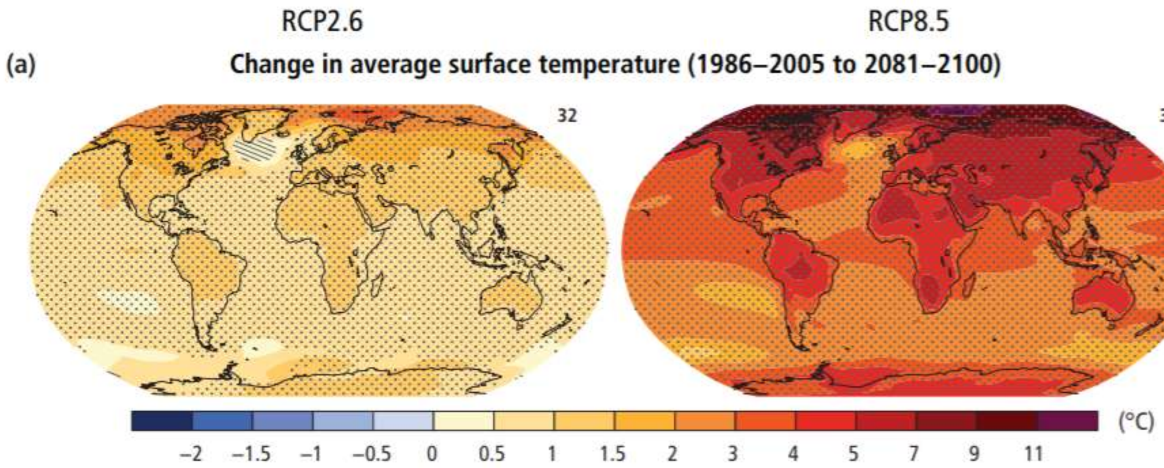
- The worst case scenario (the most warming) is known as **RCP8.5**, which is where global greenhouse gas emissions remain **very high** throughout the century.
- The best case scenario (the least warming) is known as **RCP2.6,** which is where global emissions are cut dramatically.
- RCP4.5 and RCP6.0 are **intermediate** scenarios (between very low emissions and very high emissions).

Below are the **projected** trends in **temperature change** and **sea level rise** up until 2100 made by the IPCC. All of the graphs are from the IPCC's 2014 report.

Global Temperature Change

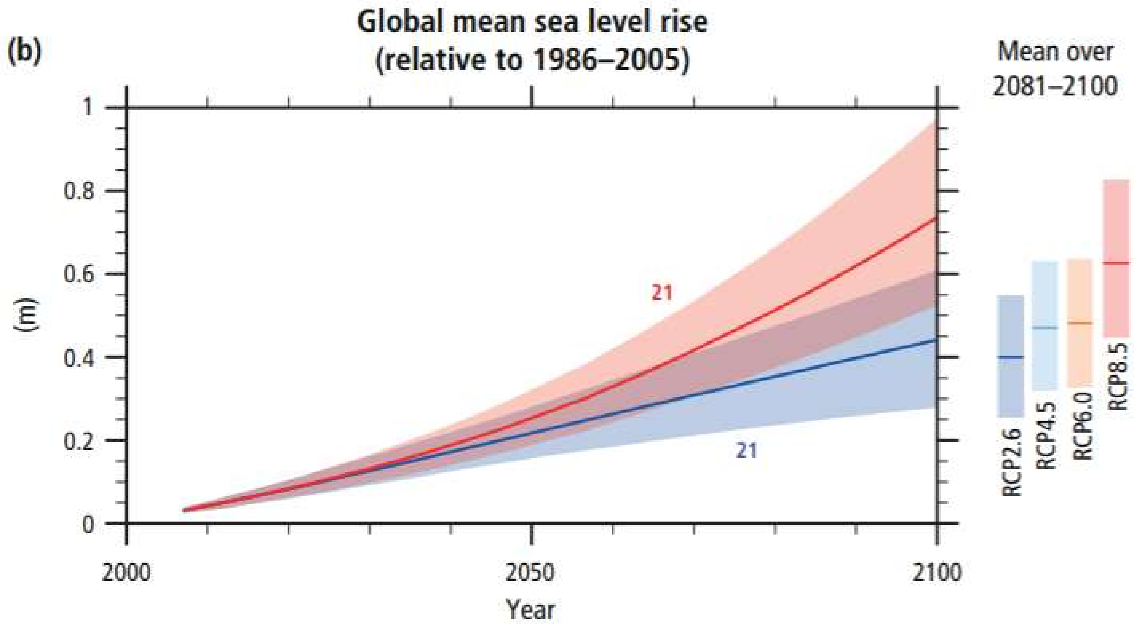
Global surface temperatures are **expected to rise by the end of the century**. The amount of warming is projected to be between **1.1°C and 6.4°C**, although the amount of warming is dependent on the **location** (there will be a lot more warming in The Arctic)





Sea Level Rise

Sea level rise is estimated to be between **30cm and 1 metre**. Sea level rise is expected to occur due to two reasons: firstly, **meltwater** from ice sheets and glaciers will mean more water is in the ocean; secondly, the sea is going to get **hotter** and the sea will **expand** and takes up more space when it warms (known as thermal expansion).



Uncertainties

Climate scientists can not predict exactly how the climate will change because there are many **physical** and **human** influences on climate change. There is so much **uncertainty** around these projections because we can't say for sure how the population and the Earth's systems **will respond to climate change in the future**.

Physical Uncertainties	Human Uncertainties
• As the climate warms, there is uncertainty about how **natural processes** may **enhance** warming. E.g. **methane** is being released by melting permafrost in the Arctic, more CO_2 from **forest fires** etc. • Some sources of water that contribute to **sea level rise** are so variable they are difficult to account for when projecting future sea level rise (e.g. water in reservoirs). • There is uncertainty about **how weather phenomena** may affect temperatures, such as the **El Niño** climate cycle. • **Cold** meltwater from glaciers and ice caps will reduce the effect of **thermal expansion**, which therefore may influence sea level rise.	• We don't know how big the **population will be** in the future, so there is uncertainty over future **energy and food demands**. • **Lifestyles** may change as more people become aware of climate change. More people may choose to **recycle** and **eat less meat**, and governments may adopt greenhouse gas reduction policies. • **Future technologies** may help to cut emissions, such as **Carbon Capture and Storage** or developing lithium-ion batteries. • There is uncertainty over how much **green energy** we will use globally. We may shift to **renewable energy** such as wind and solar power, or we may continue to be reliant on greenhouse gas-producing **fossil fuels**.