An Introduction to Climate Change

Alex Edwards MSc

An Introduction to Climate Change

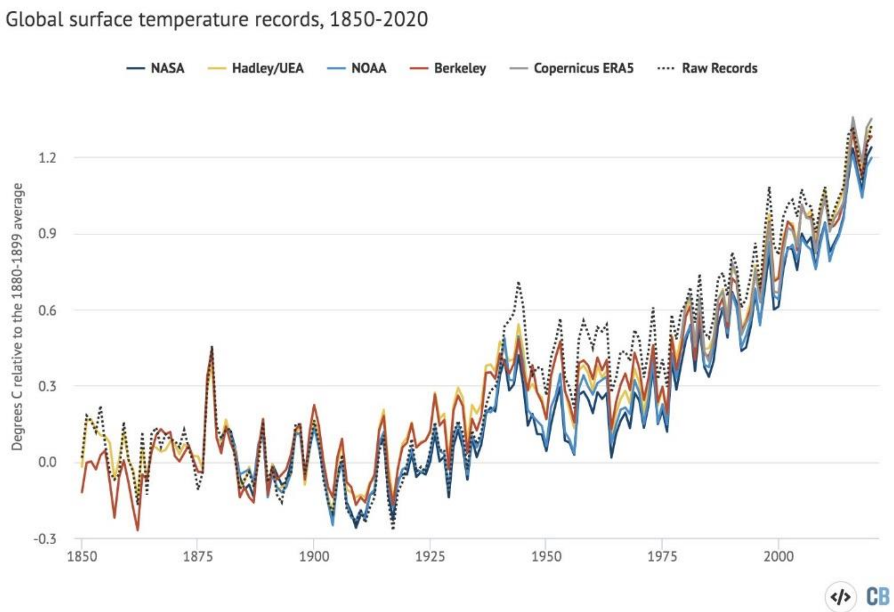
What is the climate?

By now, everyone has likely heard of climate change, but it is not always clear what the climate is or how it is different from the weather. Essentially, it all comes down to time. The weather refers to short-term atmospheric conditions for a given location, such as wind, rain, snow, fog, or sunshine – what we experience on a weekly, daily, hourly or in the UK, a minutely basis. Whilst the climate, refers to atmospheric conditions for a given location averaged over a longer time period for a given region. One way to remember it is that the climate is what you expect, such as a hot dry summer, whilst the weather is what you get, such as a thunderstorm.

Another way to think of the difference between weather and climate is to imagine them as our mood and personality. Like our mood, the weather is highly dynamic, and can change quickly over a short period of time. Whereas our personality can be viewed as our mood averaged over months or years, the climate can be seen as the weather averaged over years, decades or even centuries and millennia. So, when we talk about climate change, we are referring to changes in long-term averages of daily weather.

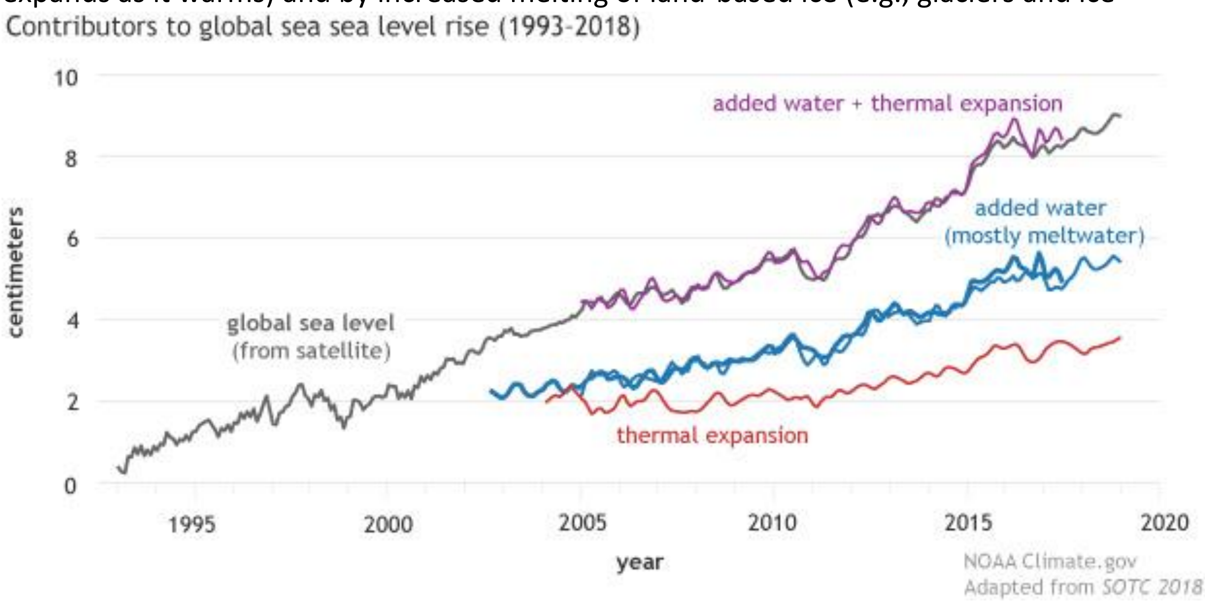
How do we know the climate is changing?

Climate change is already affecting every inhabited area of the world. The clearest sign that the climate is changing is that the Earth is getting hotter. Multiple, independent temperature datasets all show that the global mean temperature has been steadily increasing since at least the 1850's. At the time of writing, the world has warmed by approximately 1.1^{o}C. The majority of this warming has taken place in the last 40 years, with 9 of the 10 hottest years ever recorded occurring since 2010 – 2020 and 2016 are tied as the hottest ever years. It is important to note that an increase in global average temperature, does not necessarily translate to an increase in temperature everywhere on Earth. It is only when you look at the planetary scale is the true extent of warming clear. And so, despite most areas of the Earth showing considerable warming, there are pockets where temperatures have remained stable – often this is a result of local climatic factors.



But it is not just the global average temperature that matters, [temperature extremes]() are also important. It feels like every few weeks we hear that somewhere has set a new record-breaking temperature. In August this year Canada experienced a [temperature of 49.6°C](), smashing the previous record by nearly 5°C. Last year Siberia (in the Artic Circle) recorded a [temperature of 38°C](), whilst in 2019 temperature records were smashed throughout Europe. The [UK](), [Germany](), [Belgium](), [the Netherlands](), [France]() and [Luxemburg]() all saw record breaking temperatures, many [within hours of each other](). It may not be clear how these temperature extremes are linked to climate change, but scientists can perform [attribution studies]() to examine the influence of climate change on temperatures. In one such analysis, scientists found the many of the heatwaves experienced in Europe in 2019 "[would have had extremely little chance to occur without human influence on climate]()". They suggest that climate change made the heatwave 100 times more likely to occur.

The evidence does not end at changing temperatures though. Since 1880, the global [sea level has risen by approximately 22cm](), driven mainly by thermal expansion (as water expands as it warms) and by increased melting of land-based ice (e.g., glaciers and ice



sheets). As the Earth heats up, over 90% of the extra heat is absorbed by the ocean resulting in the ocean warming by approximately 0.76°C. As the ocean warms it expands, which has caused around a third of the observed sea level rise. The remainder of sea level rise is the result of melting ice sheets and glaciers. Since 1990, the ice sheets in Greenland and Antarctica have lost an astonishing 6.4 trillion tons of ice – losing an average of 475 billion a year in the 2010's. Whilst glaciers which cover 10% of the world's land surface and contain 70% of the world's freshwater have been retreating at alarming rates.

All of this makes it abundantly clear that the climate is changing, but some will argue that the climate has always changed and therefore we shouldn't worry about the climate changing now – this was an argument regularly made by the ex-president of America, Donald Trump. Over the Earths 4.5-billion-year history the climate has been constantly changing, that much is true. 66-145 million years ago CO_2 levels in the atmosphere were significantly higher, resulting in a global climate much hotter than we experience today. This period is known as the Cretaceous, the period when Tyrannosaurus rex, Spinosaurus, Triceratops and giant Sauropods such as Argentinosaurus roamed the Earth. But it wasn't just dinosaurs that thrived, birds started to diversify, amphibians and reptiles proliferated, and flowering plants spread around the world. In the seas, modern day sharks and rays became more common, and reefs grew bigger and bigger. Life could flourish back then, despite the warmer temperatures, because natural sources of greenhouse gases were in balance with natural sinks (something that absorbs more greenhouse gases than it emits), leading to a stable climate.

But when levels of greenhouse gases in the atmosphere changed rapidly, the resulting climate change was incredibly disruptive and sometimes even lead to mass extinction events - where 75% or more of all species went extinct. Everyone is probably aware of the asteroid that wiped out the dinosaurs 65 million years ago, but in total there have been five mass extinction events in Earth's history. We know what caused some of these, whilst others are still shrouded in mystery, but what they all have in common is that they are the result of large sudden changes in temperature, rising sea levels and ocean acidification – all of which are happening today because of human-caused climate change. In fact, the rate we are emitting greenhouse gases into the atmosphere now is even greater than the most destructive climate changes in the past. So yes, the climate has always changed, but we should see that as a warning – large disruptive changes to the climate can be catastrophic - and ensure we do not cause the next mass extinction event.

Is it climate change or global warming?

Both terms are commonly used in the scientific literature and by the mainstream media, but is there actually a difference between them?

Well, global warming refers specifically to the long-term trend of increasing global average temperature, whilst climate change refers to warming and all the other impacts, such as rising sea levels, ocean acidification, drought and, rainstorms etc. Other terms such as climate emergency, the climate crisis and climate breakdown are synonymous with climate change but are used to convey the destruction climate change will bring and the urgency in needing to confront it.

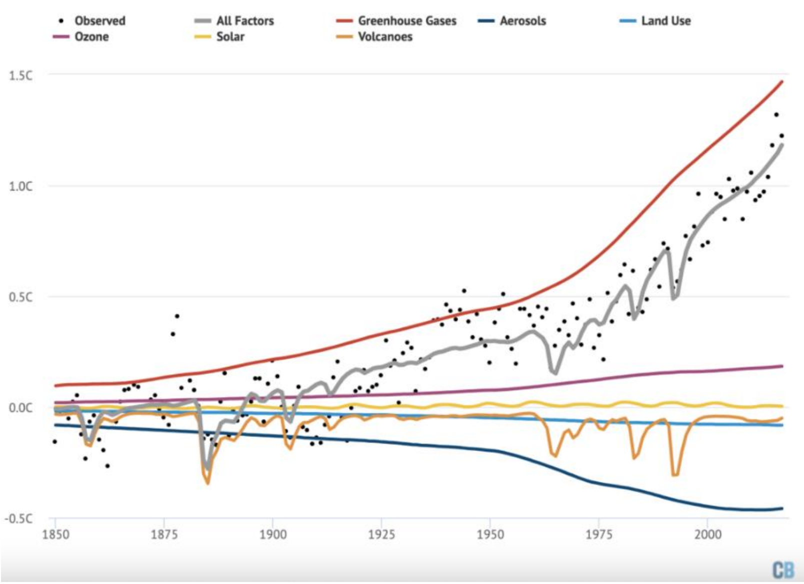
How do we know humans are causing climate change?

In their latest report, the Intergovernmental Panel on Climate Change (IPCC), stated that "it is unequivocal that human influence has warmed the atmosphere, ocean and land". And it is widely agreed by climate scientists that humans are responsible for 100% of global warming. In fact, some scientists have pointed out that humans are likely responsible for more than 100% of warming, given that natural factors such as solar activity and volcanoes has had a cooling effect over the past 50 years and thus has offset some human-caused warming – we will come back to this point later. So, what is the evidence to support these claims?

To start with, it is important to understand that fluctuations in the Earth's temperature are the result of changes in the amount of energy reaching, and remaining, in the Earth's climate – factors that influence this are known as 'radiative forcings'. Examples of these radiative forcings include greenhouse gases, aerosols (either from human activities or natural sources such as volcanic eruptions), changes in solar output and, changes in the Earth's reflexivity (also known as albedo). Some will have a cooling effect, such as aerosols which can reflect sunlight and influence the formation of clouds, whilst others will have a warming effect, most notably greenhouse gases which trap outgoing heat through a process known as the greenhouse effect.

Scientist can use climate models to try and untangle the influence of each of these radiative forcings in changing global temperature. The graph below, shows the estimated warming of several radiative forcings as well as observed temperature changes since 1850. It is clear that the combination of all these radiative forcings (shown by the grey line) closely matches the long-term changes in observed temperature. There is some year-to-year variability which is not well captured by the model, partly due to El Niño events which are not influenced by radiative forcings. The main take away from this graph is that of all the radiative forcings, greenhouse gases are the only factor that could have produced the warming experienced since 1850. We know that the increase in atmospheric greenhouse gases is a result of human activity because it almost perfectly correlates with cumulative human emissions and the timing of the increase coincides with the rise of fossil fuel use. Of all the greenhouse gases we emit, carbon dioxide (or CO_2) has by far the greatest impact on temperature increases, although this is closely followed by methane. What makes climate change predominantly a CO_2 issue though, is that CO_2 is a cumulative pollutant meaning that it lingers in the atmosphere for centuries. That means that the CO_2 emitted 200 years ago is still in the atmosphere today and will likely remain there for several hundred more years. Most CO_2 humans release comes from the burning of fossil fuels, to power our cars, planes, to heat our homes and to produce electricity. Methane on the other hand, although significantly more potent as a greenhouse gas (over 100 years it has a warming effect 30x greater than CO_2 and 83x greater over 20 years), is short lived and will only remain in the atmosphere for around a decade. Thus, cutting methane emissions is a powerful lever for reducing warming in the short-term, however unless CO_2 emissions get to zero the planet will continue to warm.

Global temperatures: Human and natural factors, 1850-2017



However, if greenhouse gases were the only factor influencing temperature, then we would expect to see up to a third more warming, but this extra warming is offset by other radiative forcings, most notably aerosols. In climate science, aerosols refer to tiny particles that float around in the air. This is in contrast to the popular image of aerosols as spray cans which released chlorofluorocarbons (CFCs) in the 1980's and 1990's which depleted the ozone layer. The vast majority of aerosols are the result of human activities including pollution from cars and factories, but aerosols can also have natural sources such as volcanic ash, dust and even sea salt. As alluded to earlier, aerosols tend to have a cooling effect on the climate by reflecting solar energy back into space or by seeding clouds which prevent sun light from reaching the surface. It can therefore seem that aerosols are a positive thing, however they also have a significantly detrimental effect on human health, resulting in large numbers of premature deaths.

It is also clear that natural radiative forcings, such as solar and volcanic activity have had an almost negligible effect on temperature changes since 1850. In fact, solar energy reaching the Earth has actually decreased slightly in the past 50 years, whilst temperatures have skyrocketed. Further supporting the evidence that solar activity is not resulting in an increase in temperature is that the upper atmosphere (the stratosphere) has been cooling over recent years, whilst the lowest level of the atmosphere (the troposphere) has been warming. If the warming was due to solar activity, we would expect the temperature of all levels of the atmosphere to increase. Whereas if it was due to greenhouse gases, then just the troposphere and surface would warm, while the stratosphere would cool, as greenhouse gases trap heat and prevent it escaping the troposphere – in line with what is being observed. Another natural factor which can influence temperature is volcanic activity, but again, in recent years volcanic activity has caused some short-term cooling. This is because volcanoes inject sulphate particles into the atmosphere that reflect sunlight back into space. However, these particles only remain aloft in the atmosphere for a few years, before drifting back down to Earth, at which point the cooling effect stops. For example, when Mt. Pinatubo in the Philippines erupted in 1991, in ejected some 15 million tons of sulphur dioxide into the stratosphere, resulting in global cooling of about 0.4^{o}C. It can therefore be said, with certainty, that the cause of the climate crisis, does not have its origin in the sun, or in volcanoes or in any other natural phenomenon, but instead lies solely on the emissions of greenhouse gases released by us.

What are the risks of climate change?

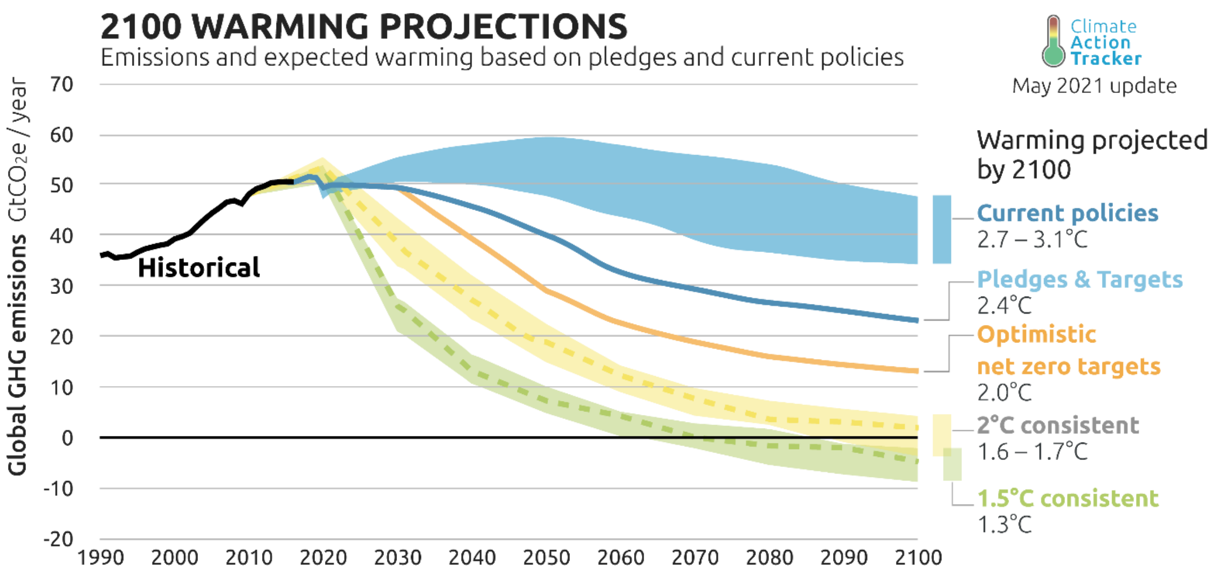
We have seen that the climate is changing and that the main driver of that change is our burning of fossil fuels. So, what does this mean for us? Firstly, although the impacts of climate change will be felt by every nation on Earth, they will not be felt equally by everyone, with some regions and countries far more at risk than others. In general though, we can expect climate change to make many areas drier and increase the risk of severe droughts. This will have knock on affects, reducing the yields of many of the world's most important crops (e.g., maize and wheat) and increasing water scarcity for many of the world's most vulnerable people. Rising temperatures is also likely to increase the area where diseases such as Malaria and Dengue fever can thrive, with droughts and flooding further increasing the disease risk. Rising sea levels are already wreaking havoc for many low lying areas and with nearly 40% of the world's population living within 100km of the coast, further rises will mean more and more people will experience flooding. This will be exacerbated by heavier rainfall in many areas, further increasing the flood risk - as warmer air can hold more moisture. Natural disasters, such as Hurricane Ida which struck the east coast of America early this year and caused widespread damage and death, will likely increase in frequency and severity. And there are some impacts we can't predict. What happens when global supply chains are disrupted by natural disasters or vital infrastructure damaged? When the sun is blocked by wildfire smoke or kids can't attend school because of floods. We have never experienced such a rapidly changing climate and so who knows what tipping points we may cross in our human-built systems. What we do know for certain though, is that the more temperatures rise by, the worse the impacts will be.

When the Paris Agreement was adopted in 2015, almost every nation on Earth committed to limit global warming to 'well below 2°C above pre-industrial levels and to pursue efforts to limit temperature increase even further to 1.5°C'. Although there is no truly safe level of global warming, these temperature objectives of 2°C and more recently 1.5°C have been identified as targets we should not cross if we want to prevent dangerous climate change and avert the suffering of millions, if not billions of people. The more recent focus on 1.5°C as the key target is because of a growing awareness of the world of difference that half a degree can make when it comes to the impacts of climate change. It could be the difference between whole island nations disappearing under rising sea levels, between ice free summers in the Arctic and, between the survival of some coral reefs and their complete decline. Carbon brief have a fantastic interactive article examining the full range of differences between 1.5°C, 2°C and beyond of warming.

One of the major arguments for limiting warming to 1.5°C is that it would substantially reduce the risk of exceeding several key tipping points – causing fundamental and irreversible changes to pieces of the Earth system. Tipping points describe a threshold where a tiny change can push a system into a completely new state. So rather than changing linearly, when a tipping point is crossed it can result in a rapid, irreversible change. One of the systems vulnerable to tipping is the Amazon rainforest, the largest forest in the world and a major carbon sink. As its name suggests, the Amazon rainforest relies on very wet conditions and the forest itself plays a critical role in regulating the local climate. When there is heavy rain, much of the water is returned to the atmosphere by evaporation, whilst some moisture is also transferred from the soil to the leaves of trees where it makes it way back into the atmosphere in a process called transpiration. Both these processes together are known as evapotranspiration, which helps maintain moisture in the air and is essential for the production of clouds and the rainfall that sustains the Amazon. In fact, it has been shown that the Amazon rainforest produces half of its own rain. As a result, a reduction in the amount of water entering the Amazon system could cause a shift to a much drier state which would no longer support a rainforest. Scientists have identified three factors that could potentially lead to the Amazon tipping into a drier state and transforming into a savannah. The first is a reduction in rainfall due to climate change, the second, a reduction in transpiration due to elevated levels of CO_2 in the atmosphere and finally deforestation (driven mainly by cattle ranching) could reduce the level of evapotranspiration and thus reduce the amount of rainfall. All these factors together make it very difficult to estimate when a tipping point may be crossed, but we certainly don't want to find out by tipping it.

Talking about limiting warming to 1.5°C is easy, but actually doing so is substantially harder. If we had acted in 1990 when the first IPCC report was published, then we would have had over 100 years to reach net zero, with a steady reduction in emissions of a few percent a year. But now, because emissions have continued to grow, the challenge is significantly harder, with emissions needing to decline by over 15% a year and reach zero within 30 years. To put that into context, in 2020 global emissions only fell by about 7%, despite national lockdowns in many countries preventing people from driving or flying and many factories shutting down production. The task ahead is monumental, it will require no less than 'far-reaching and unprecedented changes in society'. Making this decade arguably the most important decade in human history.

Governments need to do a lot more if we are to limit warming to 1.5°C, based on current policies, the world is heading for 2.7°C. When it comes to climate change, the future is not yet written. How much the Earth warms by is still very much in our control but will depend strongly on our actions over the next decade. The chances of limiting warming to 1.5°C are slim, but not impossible, but even if we fail, every 0.1°C of warming we avoid will reduce the suffering of millions of people.



I will leave you with the words of some of the most famous climate advocates and environmentalists on what they have to say on current pledges by governments.

Greta Thunberg, the famous Swedish school strike activist, said in a recent speech, "they've [world leaders] now had 30 years of blah, blah, blah and where has that led us? We can still turn this around – it is entirely possible. It will take immediate, drastic annual emission reductions. But not if things go on like today. Our leaders' intentional lack of action is a betrayal toward all present and future generations".

Sir David Attenborough, the world-famous naturalist and broadcaster and people's advocate for COP26 recently said that "the world's scientists have been clear on what's at stake for mankind if we don't act on climate change. Our political leaders now need to lead and give people confidence that all the changes needed to deliver net zero are desirable and possible for all of us".

Leonardo DiCaprio, the academy award winning actor and outspoken environmentalist, said in a speech to the UN, "No more talk, no more excuses, no more 10-year studies. This is the body that can do what is needed, all of you sitting in this very hall. The world is now watching. You will either be lauded by future generations or vilified by them".

Al Gore, the former vice president, Noble Laurette, and Oscar winner, said prior to the signing of the Paris Agreement, "solutions to the climate crisis are within reach, but in order to capture them, we must take urgent action today across every level of society".