Climate Science

Zero Carbon Analytics

Briefing · November 2023

Unpacking 2023's unprecedented heat

Key points:

- Scientists predict that 2023 will be the hottest year to date, with record-high temperatures observed on land and in the sea.
- June, July, August, September and October this year were the hottest months since records began in the mid-1800s.
- These temperature extremes are occurring against a backdrop of a planet that has already warmed to unprecedented levels. Every fraction of a degree of warming at the global level increases the odds of additional and often extreme climate impacts, such as heatwaves and severe rainfall.
- The long-term build-up of greenhouse gases in the atmosphere from burning fossil fuels is the main factor driving increases in earth's temperature.
- The speed at which the earth is warming is accelerating at unprecedented levels, and record high greenhouse gas emissions are primarily to blame.
- Other natural and human-caused factors are acting on top of a high baseline global temperature, edging us towards record-breaking heat at increasingly fast rates as the warming trajectory of the planet continues upwards. Those factors include:
    - A developing El Niño
    - Natural and human-caused variability in Atlantic sea surface temperatures
    - An unusual volcanic eruption
    - Reduced Saharan dust and particulate emissions
    - Reduced sulphur emissions from shipping fuels
    - Record low sea ice levels
    - The 11-year solar cycle
- Overshooting the Paris Agreement goal of limiting warming to 1.5°C - even temporarily - could have devastating impacts by catalysing large and often irreversible changes to climate systems.
- At current emissions rates, we may only have six years left until we blow our remaining carbon budget to keep warming below 1.5°C.
- The impacts of climate change will only worsen until we stop putting more greenhouse gases into the atmosphere than can be removed by the planet.

Temperature extremes in a warming world

Record heat in 2023

June, July, August, September and October this year were unambiguously the hottest months since records began in the mid-1800s, according to data from tens of thousands of meteorological stations across the world.[1] Scientists are now confident that 2023 will be

[1] Scientists are confident that this is the warmest decade in the last 125,000 years.

the hottest year on record to date, despite initial predictions that it could be the fourth-hottest year.

September's heat was particularly unusual, with the highest temperature anomaly – an indication of how divergent temperatures are from the long-term average – ever recorded for any month. One climate scientist described this unprecedented 0.5°C anomaly, which made September around 1.8°C hotter than pre-industrial levels, as "absolutely gobsmackingly bananas".[2] The impacts of this year's heat were felt across the world: Africa, Europe, North America, South America and Antarctica all had their hottest September on record. Alongside higher land temperatures, sea surface temperatures have been at record high levels since April this year.

The average temperature for 2023 will very likely be more than 1.5°C above pre-industrial levels. A breach of the Paris Agreement goal would require temperatures to be sustained above 1.5°C for at least 20 years, so this does not mean we have blown our chance. However, the fact that we are increasingly seeing average monthly temperatures above this goal signals that we are getting closer.[3]

Global warming fuels extremes

Temperature extremes such as those recorded this year are occurring in a planet that has already warmed to unprecedented levels – the past eight years were the warmest on record. The speed of this warming has accelerated over the last decade, reaching an unprecedented rate of more than 0.2°C over 2013-2022. Scientists attribute this to record-high greenhouse gas emissions and reduced aerosols – particles in the atmosphere that scatter or absorb the sun's radiation. Every fraction of a degree of warming at the global level increases the odds of additional, and often extreme, impacts at regional and local levels. With the increased build-up of greenhouse gases in the atmosphere, heatwaves are becoming hotter and more frequent. As emphasised by climate scientist Sarah Perkins-Kirkpatrick, "It only takes a small change in average temperature for the frequency of extremes to completely blow out, which is what we've seen in the Northern Hemisphere recently".

The global temperature is an average taken from across the world, with actual temperatures at different locations ranging from much lower to much higher, meaning the impacts of warming are unequally distributed. For example, average July temperatures in some parts of northern Canada this year were more than 7°C above the 30-year average.[4] This extreme heat, combined with unusually dry conditions, fuelled unprecedented wildfires in the region, highlighting how temporary spikes in temperature combined with longer-term elevated warming can have devastating consequences.[5] "Summer 2023's record-setting temperatures aren't just a set of numbers – they result in dire real-world consequences," said NASA Administrator Bill Nelson.

Events such as wildfires may have knock-on effects that fuel further warming: the fires in Canada this year have released record-high carbon emissions, risking the creation of a self-perpetuating cycle that speeds up warming, known as a positive feedback loop.[6]

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[2] Depending on the dataset used, the level of warming may be 1.7°C or 1.8°C.
[3] The Paris Agreement – a legally binding international treaty on climate change – set a goal to limit "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."
[4] Parts of northern Canada fall within the Arctic, which has been warming at four times the rate of the global average over the last four decades.
[5] The extent of burned area by the end of July was twice as high as the previous record for the whole of 1995.
[6] More than double the wildfire emissions of a previous record-high year.

Warmer, drier conditions as a result of climate change create the conditions for wildfires, and wildfires further fuel climate change by releasing stored carbon and reducing the carbon sink capacity of forests as they burn down, which then creates warmer and drier conditions, ultimately locking us into more warming.

Climate is complex

While the overall warming trend does not come as a surprise to scientists and matches projections by climate models, the extent to which temperature records have been broken this year - particularly the 0.5°C September anomaly - is remarkable. This is because temperature records are typically broken by margins of 0.1 or 0.2°C. To better understand this anomaly, scientists scrutinised over 150 outputs from climate models to work out the chances of a 0.5°C September anomaly. They found that the chance is very low - roughly 1 in 10,000 in any given September.

Some models may not be fully capturing certain processes that add to warming. Recent developments in policy, leading to reduced pollution for example, have occurred faster and in different places than previously anticipated. Similarly, the impacts of natural processes - which are infinitely complex - can be difficult to predict: a volcanic eruption in the South Pacific last year was unusual in that it may have had a warming effect rather than a cooling effect due to an uncharacteristically low level of sulphur dioxide.

The Earth's climate system is made up of complex dynamics and interactions among various natural and human-caused processes. Exact future temperatures are hard to predict, and will become harder as the world warms and weather becomes harder to forecast. However, we do know that rising heat will have catastrophic consequences, and we should do everything in our power to limit overall warming as soon as possible.

Interplay between long-term warming and natural variability

Air temperatures on earth have a natural degree of variability due to factors such as changes in solar radiation, ocean-atmosphere interactions and volcanic eruptions. This inherent variability means that even if there was no global warming, average global temperatures would not be identical from year to year. However, it is clear that global warming - fuelled by the long-term build-up of greenhouse gases in the atmosphere from burning fossil fuels - is driving the persistent upward trend in global average temperatures since industrial times, and that the natural variability of the climate system has had very little impact on this trend.

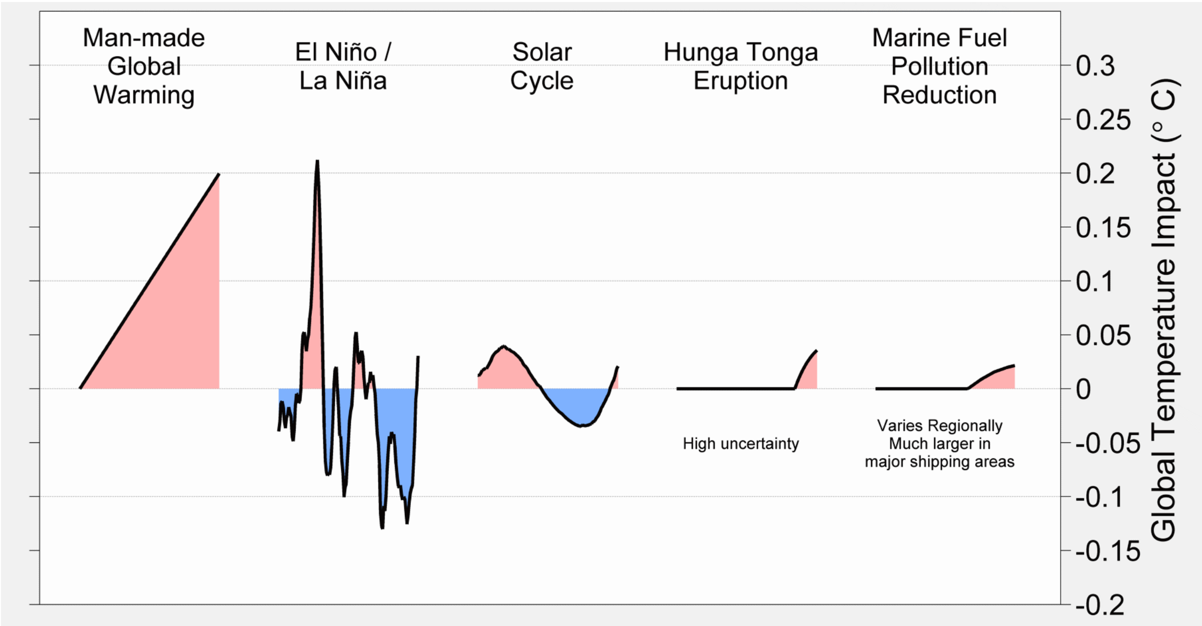
Contributors to temperature spikes

Though global warming is a gradual process that can't solely explain the sharp uptick in temperatures observed this year, a number of other factors - such as an emerging El Niño, an unusual volcanic eruption in the South Pacific, and decreased sulphur dioxide emissions from shipping - are acting on top of a high baseline global temperature, edging us towards record-breaking heat at increasingly fast rates as the warming trajectory of the planet continues upwards (Figure 1).[7] These other factors are responsible for the variability in temperatures - such as spikes in heat - witnessed at daily, monthly or yearly scales, but are not driving the persistent long-term warming trend. It just so happens that they are occurring all at once in an increasingly hot world. The exact contribution of these other

[7] Compared to the 1970-2014 period, climate models project global warming to be 40% faster in the period between 2015 and 2030.

factors to temperature spikes is highly variable and uncertain, with some playing very small roles.

Figure 1: Factors contributing to global temperature change over the last 10 years



Source: Berkeley Earth, August 2023 Temperature Update, 2023.

El Niño

El Niño is a natural climate phenomenon occurring every two to seven years whereby sea surface temperatures in the Pacific Ocean are warmer than average, causing short-term increases in global average temperatures as heat is pushed from the ocean into the atmosphere. El Niño events are often correlated with the hottest years on record. The previous hottest year on record, 2016, was during a "super El Niño event" - one of the three strongest in history. There is a growing scientific consensus that human-caused warming has, at least partly, made El Niño more variable and difficult to predict.

Some scientists have speculated that El Niño has been one of the main drivers of extreme heat this year, particularly as there was a rapid transition earlier this year from its cold counterpart La Niña, which has been in effect during the past three years.[8] Others are more cautious, pointing out that El Niño was only in its early phase at the onset of the record-breaking heat this year and that its biggest impacts are only anticipated in February to April next year. Temperatures typically respond around three months after El Niño peaks, which is only expected around the end of this year. There will likely be greater clarity on the role of El Niño in early 2024.

Warming oceans

Even before El Niño officially started this year, global average sea surface temperatures were already 0.1°C higher than the previous record, with marine heatwaves detected around the world. As the **Pacific Ocean** represents around half of the world's ocean area -

[8] The last La Niña event was a rare 'triple-dip' event lasting three years, which was associated with various impacts and natural disasters around the world.

and El Niño originates in the Pacific – what happens in the Pacific will tend to have a significant impact on global sea temperatures.

Warming has also been exceptional in the **North Atlantic Ocean**, which in June was a record 0.5°C warmer than the long-term average, with localised extreme marine heatwaves of up to 5°C higher than average recorded. Natural variability in sea surface temperatures linked to the Atlantic Multidecadal Oscillation – a cyclical pattern of warm and cool sea surface temperatures – may partly explain these warmer temperatures. Research also shows that much of the heat stored in the subtropical North Atlantic is in deeper waters, with currents redistributing this heat to other regions of the ocean – believed to be a key driver of North Atlantic warming. At the same time, lower than average wind speeds in the northeastern Atlantic mean there is less mixing of colder ocean water from lower depths, causing sea surface temperatures to rise. Low winds also resulted in fewer dust particles – which scatter solar radiation back into the atmosphere before it can warm the ocean – being blown off the **Sahara** over the ocean. Similarly, reduced **particulate pollution** in North America and Europe, driven by policies on air quality, may have had a similar effect by reflecting less radiation.

It is important to remember that these processes – whether El Niño or reduced Saharan dust – are happening on top of an already warming ocean: more than 90% of global heat caused by greenhouse gas emissions has been absorbed by the ocean.[9] "Over the long term, we're seeing more heat and warmer sea surface temperatures pretty much everywhere…[t]hat long-term trend is almost entirely attributable to human[s]", said Gavin Schmidt, the director of NASA's Goddard Institute for Space Studies. Unlike this long-term trend, changes in wind speeds or particulate pollution typically have very small impacts on longer-term temperature averages but do contribute to sudden spikes in temperature.

Low sea ice levels

Decades of warming has led to lower than average sea ice in **Antarctica** and the **Arctic**. Low sea ice levels may increase local warming, and at the same time, local warming may lower sea ice levels. Lower sea ice reinforces warming because less ice means less solar radiation reflected back into space and more radiation absorbed by the ocean, causing further warming and delaying sea ice growth. However, scientists are uncertain of the extent to which the lower sea ice influenced the warm conditions observed in Antarctica this year.

Volcanic eruption in the South Pacific

The lower sea ice and higher earth temperatures observed this year may have been influenced by the eruption of an undersea volcano in January 2022, which increased the amount of water vapour in the upper atmosphere, where it potentially acted as a powerful greenhouse gas and trapped heat. The additional warming caused by this eruption is not yet known, with some scientists speculating that its contribution is likely quite small, and others suggesting that more analysis is needed to fully understand the impacts.

Sulphur regulations

[9] As oceans continue to warm, they will take up less heat from the atmosphere and cause global average surface temperatures to rise further.

Researchers have suggested that regulations imposed on emissions of sulphur - a harmful air pollutant emitted by marine fuels - from shipping since 2020 could have also contributed to temperature spikes this year. This is because sulphur particles - which are harmful to human health - reflect radiation back into the atmosphere or block sunlight by forming 'pollution clouds', and their reduction has a warming effect. Estimates suggest that the cuts in particulate emissions from shipping regulations are equal to two additional years of human-caused greenhouse gas emissions at current rates. However, scientists caution that while a reduction in sulphur emissions may boost warming by around 0.045°C over the next few decades, it is unlikely to have any major influence on long-term global warming.

As a counterbalance to temporary spikes in warming as aerosols are cleaned up, the Intergovernmental Panel on Climate Change (IPCC) recommends reducing human-caused methane emissions. While carbon dioxide remains in the atmosphere for a long time - up to 1,000 years - before breaking down, methane has a much shorter lifespan of around 12 years.[10] This means that reductions in warming can be quickly achieved with methane emission cuts - reducing methane emissions from the energy sector alone could avoid up to 0.1°C of warming by mid-century.

Solar fluctuations

Another natural phenomenon contributing to global temperatures is fluctuations in the output of the sun as part of the 11-year solar cycle. During this cycle, the average temperature of the earth increases by around 0.05°C. The current solar cycle is heading towards its peak, with the latest evidence suggesting that the sun's activity has already reached levels not seen for 20 years. The current solar cycle is expected to peak between January and October 2024 - around the same time that the warming impacts of El Niño are expected to be greatest.

Overshooting 1.5°C of warming

The 2015 Paris Agreement aims to avoid "unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall". The point in time where we breach 1.5°C of warming is getting dangerously close. Latest estimates show that we may only have six years left of emissions at current levels before our carbon budget runs out.

In the IPCC's report on the impacts of 1.5°C of global warming, 90% of the emissions scenarios that limit warming to 1.5°C by 2100 include a period of 'temperature overshoot'. Temperature overshoot describes when global average temperatures exceed 1.5°C (or 2°C) of warming before returning to that level at some point in the future. In most of the IPCC pathways - which describe different levels of greenhouse gas emissions for reaching a certain level of warming - global average temperatures exceed the target for at least one decade and up to several before dropping back down - achieved through the deployment of carbon dioxide removal.[11]

The **magnitude** - how much the specified level of warming is exceeded - and the **duration** - how long that level of warming is exceeded - differ across scenarios. Keeping the magnitude and duration of overshoot as low as possible is critical if we are to avoid the

[10] If we were to stop all methane emissions right now, global warming caused by methane would be halved in around 20 years. Methane also has more warming power as it absorbs more energy than carbon dioxide.
[11] Many pathways limiting warming to 1.5°C rely on the deployment of carbon dioxide removal technologies, which are 'uncertain and entail clear risks'.

worst climate impacts to people and the planet. Every fraction of a degree of overshoot increases the severity, frequency and duration of climate impacts, such as heatwaves, as does whether we meet temperature targets early in the century or not. In addition, the closer we stick to 1.5°C, the better the economic outcome. Climate impacts from temperature overshoot will lead to higher mitigation costs and economic losses later in the century.[12]

Tipping points

Scientists warn that overshooting 1.5°C - even temporarily - could have devastating and irreversible impacts. Numerous 'tipping points' could be crossed with just 1.5°C of warming. These are critical thresholds at which the global climate system tips into another state, triggering feedback loops and catalysing large and often irreversible changes to the climate.

One tipping point is the drying of the Amazon rainforest, caused by deforestation, fires and less rainfall, which could transform this critical carbon sink into a savanna. This would not only impact the millions of people and animals living in the region, but would result in billions of tonnes of carbon dioxide being released into the atmosphere - further fuelling global warming - as well as less rainfall and changes to global climate patterns.

In addition to triggering tipping points, overshoot could temporarily push thousands of species beyond the range of temperatures at which they can survive. For some species, life may not fully recover after overshoot: even temporary overshoot could cause irreversible extinctions and lasting damage to tens of thousands of species, with knock-on effects for entire ecosystems. If we are to limit warming to 1.5°C with limited or no overshoot, deep, rapid and immediate reductions in emissions are essential.

Solutions

Cutting emissions

Emissions are at an all-time high and are rising, with atmospheric carbon dioxide levels higher than they have been for at least four million years. Continued warming means land and ocean carbon sinks will become increasingly less effective at slowing the accumulation of carbon dioxide in the atmosphere. If reductions in emissions are achieved now, there would still be a lag in the warming response of the earth.[13] However, pursuing strict mitigation measures to keep warming under 1.5°C with limited or no overshoot would substantially reduce climate risks over the next 20 years and allow societies and ecosystems to avoid the worst impacts of climate change. To do this, net carbon dioxide emissions would need to be reduced by 48% by 2030, according to the IPCC.

The fastest and cheapest way to deliver emissions cuts is to reduce our reliance on fossil fuels for energy and switch to renewable-powered electricity. To limit warming to 1.5°C with limited or no overshoot, the use of coal would need to be reduced by 100%, oil by 60% and gas by 70% by 2050.[14] There would need to be increased electrification of energy, with almost all electricity coming from zero-carbon or low-carbon sources. Since 2010, solar and wind power have become cost-competitive with fossil fuels globally - the

[12] While higher initial investments are needed to keep temperatures down, this is outweighed by the economic benefits later in the century.
[13] If we stopped all greenhouse gas emissions today, there's still a 42% chance that we would overshoot 1.5°C.
[14] This is assuming no carbon capture, storage and utilisation.

current average levelised cost of solar photovoltaic is almost one-third less than the cheapest fossil fuel.[15] In 2022, electricity fuel costs of USD 520 billion were saved as a result of renewable capacity added since 2010. Rapid renewables deployment - around 1,000 GW per year until 2030 - will be critical for keeping warming to 1.5°C.

Reducing methane

One promising solution for rapidly reducing global warming involves cutting emissions of methane - which has contributed around one-third of global warming since pre-industrial times. Methane concentrations in the atmosphere have been rising dangerously quickly since around 2007, and have reached record levels in recent years. Due to its short lifespan, cutting methane emissions offers the "single fastest, most effective way to slow the rate of warming right now". It is also one of the cheapest ways to reduce warming. By using cost-effective measures such as reducing leaks from pipelines, shutting down abandoned oil wells and reducing livestock numbers, human-caused methane emissions could be reduced by up to 45% by 2030, avoiding nearly 0.3°C of warming by the 2040s.[16] According to the IPCC, a reduction of 34% is needed by 2030, along with cuts to other greenhouse gas emissions, to achieve 1.5°C with limited to no overshoot without relying on carbon dioxide removal.

Agriculture, and particularly livestock farming, is the single largest source of methane emissions from human activity, and livestock emissions are expected to increase by up to 16% by 2030. Through reducing livestock numbers, improving livestock nutrition and breeding, and reducing food loss and waste, significant reductions in warming from methane can be achieved in the next few decades. According to the International Energy Agency, technology to reduce methane emissions from fossil fuel operations - which account for around 40% of methane emissions from human sources - already exists and could cut around 70% of emissions from this sector.

Carbon dioxide removal

Proposed solutions for reducing warming can be nature-based, such as planting trees which store carbon in their tissues, or growing crops, burning them for energy, and storing the released carbon. There are also technological solutions, such as machines that suck carbon dioxide from the atmosphere and store it long term, called direct air capture and storage. Collectively, these approaches are referred to as carbon dioxide removal (CDR).

There are major uncertainties with both nature-based and technological solutions: forests burn down, risking the release of stored carbon, and there is limited space for planting trees. Growing energy crops requires large areas of land, which could potentially endanger biodiversity through the conversion of natural land or threaten human food security by supplanting food crops. Machines for drawing carbon from the atmosphere are not yet fully developed and are expensive, and none of these solutions have been shown to work at the scale needed. The world's largest direct air capture plant only saves us 3 seconds of emissions per year. Atmospheric physics and the changing nature of forests as carbon sinks are also not fully understood, but current evidence suggests that CDR may not compensate for emissions on a like-to-like basis. The reduction in atmospheric carbon dioxide achieved by deploying CDR may be less than 10% of the carbon dioxide released into the atmosphere from an equal amount of emissions.

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[15] The levelised cost is the price at which electricity should be sold for the system to break even at the end of its lifetime.
[16] UNEP, Global Methane Assessment, 2021. Pg 8. https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions

Forest carbon offsets - under which companies or individuals can purchase credits for preserving a forest or planting a tree that is equal to the amount of carbon to be offset in order to achieve their net-zero pledges - have been shown to be ineffective and are marred by alleged greenwashing and dubious accounting methods.

The uncertainty around the effectiveness of these technologies offers a strong incentive for ramping up climate action in the near-term to reduce our reliance on them. However, because emission reductions have been so delayed, some amount of CDR will be necessary to meet 1.5°C, together with decarbonisation of energy and electricity, electrification, and deep emissions cuts, particularly of methane. In IPCC pathways that limit warming to 1.5°C with limited or no overshoot, CDR is only used in sectors for which no mitigation measure is available and to counterbalance historical emissions. The longer we delay emissions cuts, the more we will have to rely on unproven technologies to reduce warming and risk large-scale, irreversible impacts on society and nature.

Immediate, meaningful action now can bring benefits within our lifetime. Bold pledges and policies, stricter net-zero standards, and strengthened accountability are needed to deliver real and immediate emissions cuts.