GLOBAL FUTURE RESEARCH

Insight #6:
Playing with Fire -
Is Global Warming an Existential Threat?

Global warming is a rapidly evolving issue, with the United Nations calling for fast and decisive world-wide action to avoid more dangerous climate change.

In Insight 6 we recommended a focus on biophysical climate system indicators to assess global warming status and trends, as these can be measured scientifically. Additionally, measuring the amount of Greenhouse Gases (GHGs) being released is a critical way to determine how society is responding, as this is our principal strategy to control global warming.

In this 2024 update we report on the latest data and trends for these key indicators.

2023 smashed global warming records, the extent to which scientists are struggling to explain. There was an unexpected surge in global warming in 2023, with temperatures reaching 1.45°C above 1850-1900 levels, and staying at or above 1.5°C for every month from June 2023 to June 2024--well above model predictions. This was accompanied by a massive meltdown of Antarctic sea-ice.

Several key climate system indicators are accelerating in the wrong direction, including surface temperature, ocean temperature, sea-level rise, atmospheric carbon dioxide, and total GHG radiative forcing. In the face of these accelerating threats, efforts to reduce GHG emissions arising from human activities have, to date, only slowed the rate of increase rather than achieving the fast and deep reductions that scientists say are urgently needed.

Overshooting 1.5°C, the stretch target of the United Nations 2016 Paris Agreement, is fast becoming inevitable, and current policy settings mean we are likely to see a global warming of 3°C by 2100. Lack of political will, amongst other societal factors, is setting the world on a very turbulent path.

INDICATOR 1. Mean planet surface temperature is both increasing and accelerating. 2023 was the hottest year on record and 1.45°C above the 1850-1900 average. For the last 13 months, to June 2024, every month has been a record high with temperatures at least 1.5°C above the 1850-1900 average. This is a previously unseen run of monthly records.

INDICATOR 2. Ocean warming has been increasing since 1950 and has accelerated since 1991. Global ocean heat content to a depth of 2,000 m set a record high in 2023, and the five highest values have all occurred in the last five years.

INDICATOR 3. Global mean sea-level rise has been accelerating since 1993. The mean global sea-level has risen 103.3 mm over the satellite recorded period from 1993 to 2024, at an average annual rate of 3.3 mm/yr. The average rate of increase for the first 10 years of the record (1993-2003) was 2.13 mm/yr, while for the last 10 years of the record (2014-2024) it was 4.25 mm/yr--effectively a doubling.

INDICATOR 4. Melting of glaciers is increasing. Since 1970, the ice thickness of reference glaciers around the world has dropped by almost 30 m. In 2022-23, the glaciers experienced a record ice loss of 1.2 m water equivalent.

INDICATOR 5. The concentration of the most important GHG in the atmosphere, carbon dioxide (CO_2), is increasing and accelerating. CO_2 has been increasing in the Earth's atmosphere year-by-year since the beginning of the record in Hawaii in 1959. In June 2024 the mean CO_2 concentration was 426.91 ppm, compared to 423.68 ppm in June 2023, reflecting an annual increase of 3.23 ppm. The rate of increase has been accelerating over the measurement period.

INDICATOR 6. Total radiative forcing by key GHGs is both increasing and accelerating. The Annual Greenhouse Gas Index (AGGI), representing the combined warming influence of the most important, long-lived GHGs (CO_2, methane, nitrous oxide, and several halogenated gases) has been increasing since 1979 and by 2022, AGGI was 1.49 times the 1990 baseline. Its rate of increase has accelerated in the last decade.

INDICATOR 7. Extreme heat events are on the rise. Over the last 12 months, human-caused climate change added 26 days of extreme heat (on average, across all places in the world) that wouldn't have occurred without global warming. These events put billions of people at risk, including in densely populated areas of South Asia, East Asia, the Sahel, and South America. In the summer of 2022, an estimated 61,672 heat-related fatalities occurred across Europe. The Earth also experienced its warmest day in recent history on 22 July 2024.

INDICATOR 8. CO_2 emissions from human activities continue to rise. Preliminary estimates indicate that fossil CO_2 emissions may have increased by 1.1% in 2023 relative to 2022, bringing emissions to 36.8 Gt CO_2 (1.4% above the 2019 level). These annual emissions have increased some four times since 1960, but the rate of increase has been slowing over the past decade. However, the fast and deep cuts in emissions required for global warming to be restricted to 1.5°C or even 2°C are not yet occurring.

Climate system indicators

Indicator 1. Mean planet surface temperature

According to the World Meteorological Organisation's State of the Global Climate 2023 report (WMO, 2024), the global mean near-surface temperature in 2023 was 1.45°C above the 1850–1900 average (see Figure 1). The analysis is based on a synthesis of six global temperature datasets. 2023 was the warmest year in the 174-year instrumental record in each of the six datasets, clearly surpassing the previous warmest years (2016 at 1.29°C and 2020 at 1.27°C). The past nine years, from 2015 to 2023, were the nine warmest years on record. The 10-year average 2014–2023 global temperature anomaly was 1.20°C above the 1850–1900 average, making it the warmest 10-year period on record.

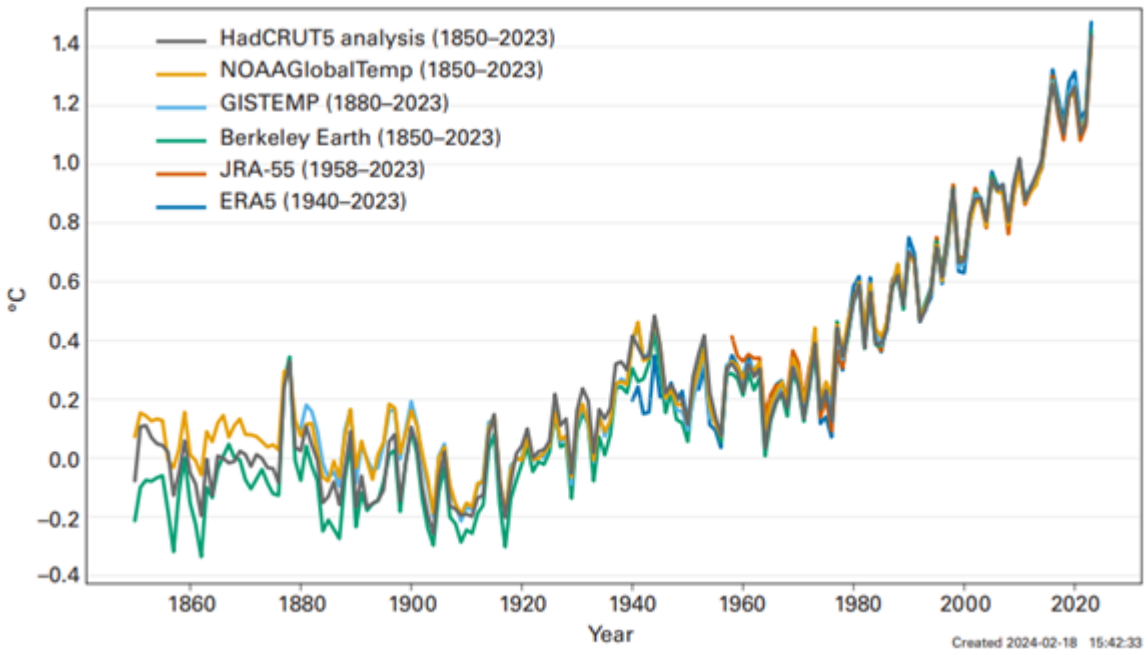

Figure 1. Annual global mean surface temperature anomalies (relative to 1850–1900). Data are from the six datasets indicated in the legend.
Source: WMO-No. 1347 © World Meteorological Organization, 2024

Globally, each month from June 2023 to June 2024 saw record warming of 1.5°C or more. This period was the longest recorded stretch of consecutive monthly records.

September 2023 was particularly noteworthy, surpassing the previous global record for September by a wide margin (0.46°C–0.54°C) in all datasets. July is typically the warmest month of the year globally, and July 2023 is now the warmest month on record.

How do we explain the 2023 global temperature anomaly?

The large 2023 global temperature anomaly was an unprecedented increase in the temperature record--a huge 0.16°C above the previous record. In 2024 the world has continued to be hot – hitting 13 months in a row at or above the 1.5°C Paris Agreement target. June 2024 was marked by several deadly heatwaves across the northern hemisphere.

There are some factors that have been considered in the context of this sudden temperature increase:

- El Niño had fully developed by September 2023, explaining some of the rise in temperature.
- Hotter than normal sea surface temperatures were recorded in 2023.
- The ongoing increase of GHG concentrations in the Earth's atmosphere would account for further warming (of only about 0.02°C).
- Decreasing atmospheric aerosols (such as smoke, dust, vehicular and industrial emissions) resulting from government programs to reduce air pollution may have acted to increase global temperature--but if so, this effect is likely to be small compared to the observed increase.
- Volcanic eruptions were determined to have negligible effect over 2022 and 2023.
- Increasing solar activity in the run-up to a predicted solar maximum would at best contribute a few hundredths of a degree C.

After taking all these factors into account, the magnitude of the temperature anomaly increase exceeds model predictions by as much as 0.2°C, according to Gavin Schmidt, Director of NASA's Goddard Institute for Space Studies (Schmidt, 2024). He said the 2023 temperature anomaly has come out of the blue, potentially taking the world into unchartered territory.

Indicator 2. Ocean warming

Global ocean heat content (OHC) to a depth of 2000 m set a record high in 2023 (Figure 2). OHC is a key climate indicator because the ocean absorbs 90% of the excess heat from the enhanced Greenhouse Effect. The indicator, tracked since 1958, shows a steady upward trend since around 1970, with the five highest values all occurring in the last five years. OHC shows a distinct acceleration after 1991, matching the increase in GHG emissions and other radiative forcings over the past few decades.

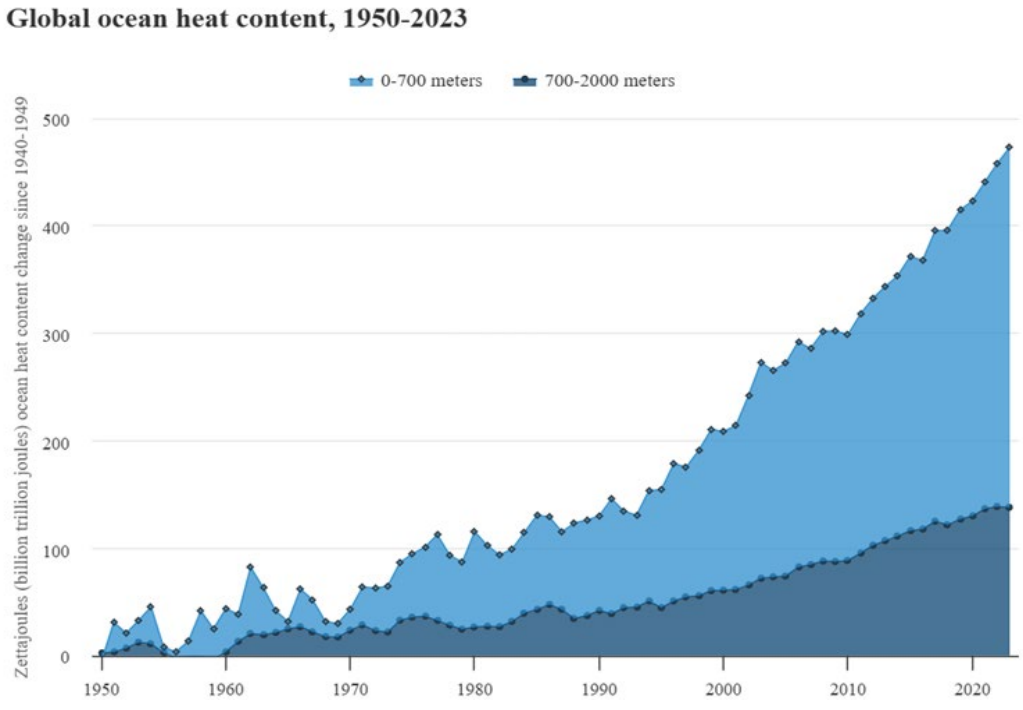

Figure 2. Annual global ocean heat content (in billion trillion joules) for the 0-700 m and 700-2,000 m layers. Data from Cheng et al. (2024). Chart by Carbon Brief.

Indicator 3. Global mean sea-level

Sea level rise results from melting ice sheets and glaciers, combined with the expansion of warming oceans. Figure 3 shows mean global sea-level rising from January 1993 to January 2024, as observed by satellites. The record high of 104.5 mm was recorded in October 2023. The rise in sea-level over the 31 years from 1993-2024 is 103.3 mm, equating to an average annual rate of increase of 3.3 mm/yr. The average rate of increase for the first 10 years of the record (1993-2003) was 2.13 mm/yr, while for the last 10 years of the record (2014-2024) it was 4.25 mm/yr--effectively a doubling. The mean acceleration rate is 0.2 mm/yr.

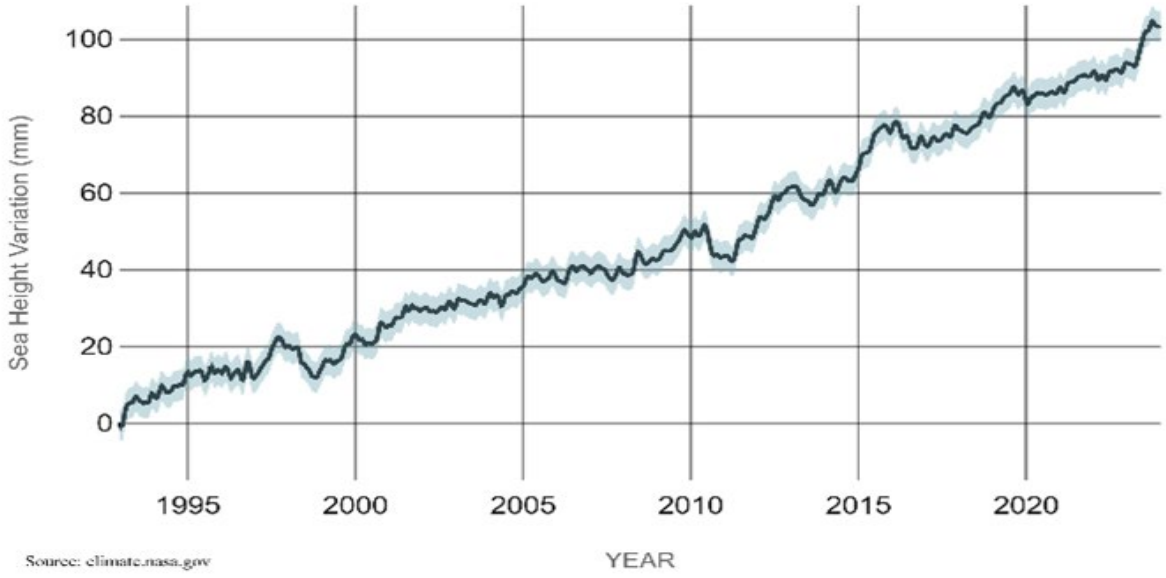

Figure 3. Satellite mean global sea level observations 1993-2024. Credit: NASA's Goddard Space Flight Center. Sourced in July 2024 from [Global Mean Sea Level | Key Indicators – NASA Sea Level Change Portal]

Indicator 4: Melting of reference glaciers

The cryosphere, comprising the frozen parts of Earth – glaciers, ice sheets, sea ice, snow and permafrost - is highly vulnerable to global warming. As there is no single indicator of cryosphere melting, we adopt glaciers as an indicator representing the cryosphere as it has a good length of record.

The indicator for the average thickness of the world's glaciers is calculated by estimating the annual ice mass balance for a set of global reference glaciers with a continuous observation record from 1949-50 to 2022-23. The state of a glacier is measured as the annual difference between mass gain from snow accumulation and mass loss from melting. Since 1970, this ice thickness indicator has **dropped almost 30 m (Figure 4).** In 2022-23, the reference glaciers experienced a record ice loss of 1.2 m water equivalent (w.e.). Of the ten years that saw the biggest reduction in mass balance, seven have been recorded since 2010. The cumulative mass change in the representative glaciers since 1949 shows an accelerating loss rate.

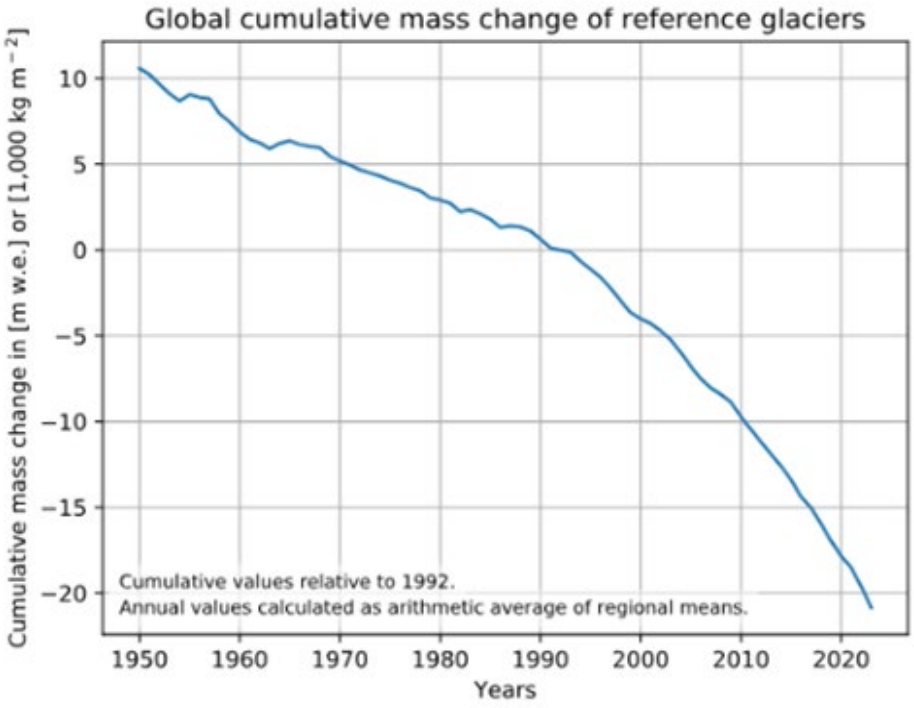

Figure 4: Cumulative mass change of reference glaciers 1949-2023. Sourced from the World Glacier Monitoring Service in July 2024, [global glacier state – world glacier monitoring service (wgms.ch)]

Cryosphere melting in response to global warming is also evidenced by Arctic sea-ice extent decline, Antarctic sea-ice extent decline, ice sheets reduction, and permafrost melting.

The maximum Arctic sea ice extent in 2023 was the 5th lowest on the 45-year satellite record, and the minimum Arctic sea ice extent was the 6th lowest on record. The downward linear trend in Arctic sea-ice extent is 3.7% per decade over the period 1979-2024.

Antarctic sea-ice extent reached an absolute record low for the period 1979-2023 in February 2023 and was at a record low for the time of year from June until early November 2023. In 2024, Antarctic sea-ice extent continues to track well below all previous years except for 2023, which remains the record low year.

Glacier melt, combined with ice sheet melt in Greenland and Antarctica, accounts for some 50% of sea level rise, which as we have seen above is accelerating.

Indicator 5. The concentration of CO2 in the atmosphere

Atmospheric carbon dioxide (CO_2) concentration is chosen as the key GHG emissions indicator as it has accounted for nearly 80% of global warming increase since 1990. Figure 5 shows CO_2 measurements at Mauna Loa Observatory, Hawaii, which has the longest continuous record from 1959-2024. The data shows CO_2 has been increasing in the Earth's atmosphere year-by-year since the beginning of the record. The monthly mean CO_2 shown in red has a sawtooth shape, reflecting seasonal changes. The running mean value is shown by the black line. In June 2024 the mean CO_2 concentration was 426.91 parts per million (ppm), compared to 423.68 ppm in June 2022, reflecting an annual increase of 3.23 ppm. The rate of increase has been accelerating over the measurement period as seen from the steepening of the concentration curve. The mean annual CO_2 concentration increase for 1959-1963 was 0.716 ppm, for 1989-1993 was 1.076 ppm, and for 2019-2023 was 2.414 ppm. The rate of increase is now 3.37 times that at the beginning of the record.

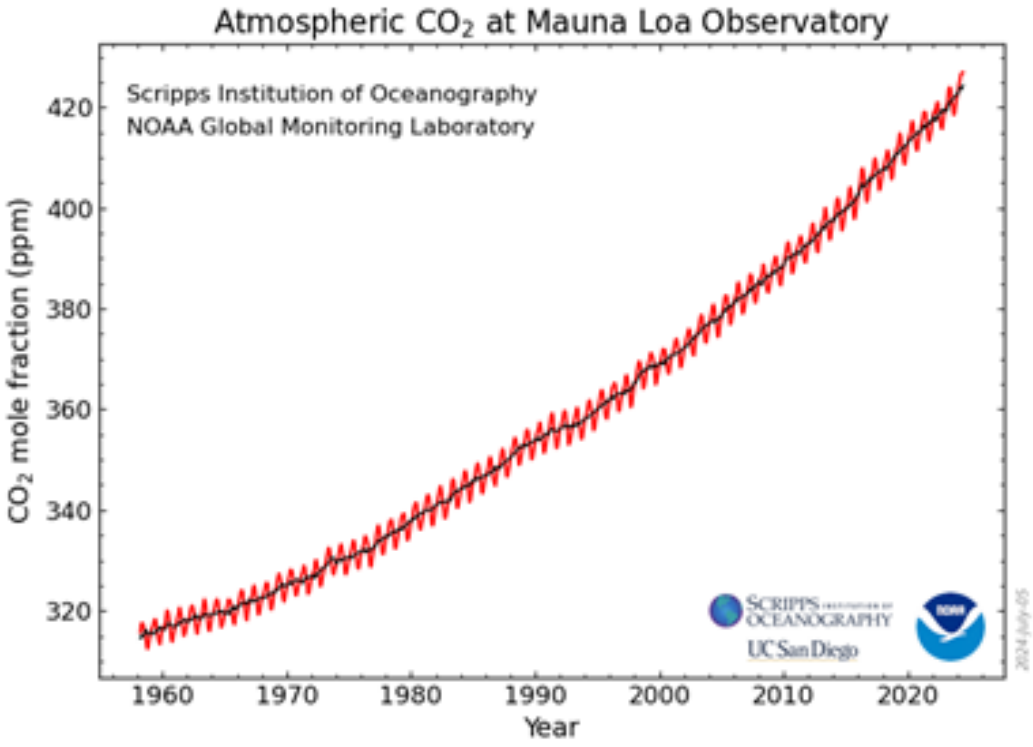

Figure 5. Atmospheric CO2 concentration measured at Mauna Loa Observatory, Hawaii, from 1959-2024.
Sourced in July 2024 from co2_data_mlo.png (800×600) (noaa.gov)

The Mauna Loa measurements are taken at an elevation of 3,400 m. The global surface average CO_2, determined by averaging sea-level sites, shows the same trends--with an April 2024 value of 423.46 ppm compared to an April 2023 value of 420.50 ppm. This represents an annual increase of 2.96 ppm.

Methane is a more potent GHG than CO_2 but is shorter lived in the atmosphere. Its concentration has risen from around 1650 ppb in 1984 to 1930.75 ppb in March 2024, rising 11.05 ppb in the last year. Methane is of special concern due to its potential for a major release from permafrost melting.

Indicator 6. Total radiative forcing by key GHGs

The Annual Greenhouse Gas Index (AGGI) is a measure of the combined warming influence of the most important, long-lived GHGs: CO_2, methane, nitrous oxide, and several halogenated gases. AGGI for the current year is compared to the AGGI in 1990, when good quality records became available. As seen in Figure 6, AGGI has increased steadily since 1990, reflecting increasing GHG concentrations in the atmosphere. In 2022 AGGI was 1.49 times the 1990 baseline. AGGI has accelerated in the last decade.

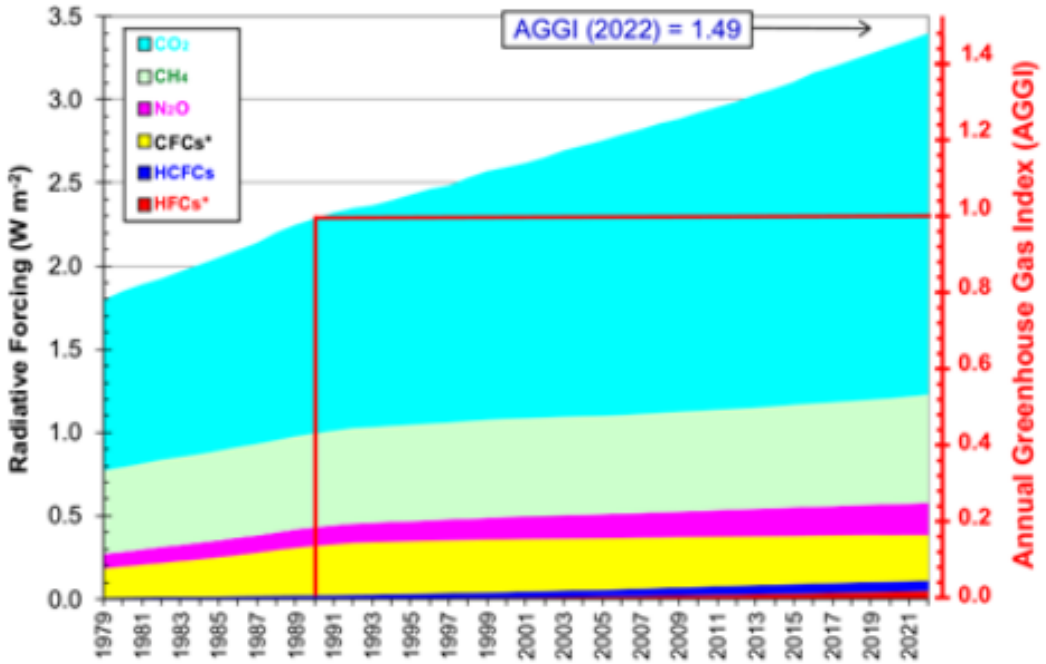

Figure 6. The global warming potential of key GHGs (AGGI) from 1979-2022.
Sourced in July 2024 from: NOAA Global Monitoring Laboratory- THE NOAA ANNUAL GREENHOUSE GAS INDEX (AGGI)

Indicator 7. Extreme heat events

One of the most impactful aspects of global warming is worsening extreme climate events. The 'new norm' is one of record-breaking land and marine heat waves, more intense rains, severe floods, landslides, more severe droughts, devastating wildfires, and stronger cyclones. The Intergovernmental Panel on Climate Change (IPCC 2021) concluded that even relatively small increases in global warming cause statistically significant changes in extremes on the global scale and for large regions (high confidence), in particular temperature extremes (very likely), the intensification of heavy precipitation (high confidence), and the worsening of droughts in some regions (high confidence).

Here we use 'extreme heat' as our indicator of climate extremes. Globally, extreme heat is the deadliest of natural hazards, with thousands of people dying from heat-related causes each year. In the summer of 2022, an estimated 61,672 heat-related fatalities occurred across Europe (Ballester et al., 2023). Record temperatures in recent weeks are suspected to have caused thousands of deaths across the Middle East, Asia and Europe. The Earth also experienced its warmest day in recent history on 22 July 2024. According to the Copernicus Climate Change Service data, the daily global average temperature reached a new record high of 17.16°C. The previous record was 17.09°C, set just one day earlier on 21 July 2024. Before that, the highest recorded temperature was 17.08°C, set on 6 July 2023.

Arrighi et al. (2024) assessed the influence of human-caused climate change on dangerous heat waves over the period May 15, 2023 to May 15, 2024. Over this period 76 extreme heat events were identified in 90 different countries across all continents, excluding Antarctica. 6.3 billion people were found to experience at least 31 days of extreme heat that was made at least two times more likely due to human-caused climate change. Over the last 12 months, human-caused climate change added an average of 26 days of extreme heat (on average, across all places in the world) than there would have been without a warmed planet. These events put billions of people at risk, including in densely populated areas of South and East Asia, the Sahel, and South America. The two countries where the average person experienced the most days with extreme heat above their local heat level were Suriname, with 182 days, and Ecuador, with 180 days. Without human-induced climate change, the average person in Suriname would have experienced 24 such days and in Ecuador, 10 such days.

Extreme weather and climate events, including major floods, tropical cyclones, extreme heat and drought, and wildfires, had major impacts on all inhabited continents in 2023-24. One of many examples was Canada's wildfire season which exceeded anything previously recorded. The total area burned in 2023 was more than six times the 10-year average (2013–2022). The fires also led to severe smoke pollution, affecting the heavily populated areas of eastern Canada and the north-eastern United States. Another extreme climate example is the 5th mass coral bleaching of the Great Barrier Reef in 8 years, which occurred during the 2023−24 summer. The extent of the heat stress, as shown by aerial coral surveys, indicate this is one of the most extensive bleaching events the Reef has experienced in nearly 40 years of monitoring.

Societal response

Indicator 8. CO_2 emissions

Measuring the concentration of CO_2 in the atmosphere is one biophysical climate system indicator that assesses our global warming status, but measuring GHG emissions is the principal way of determining how humanity is responding to climate change. The best data available for 2023 is on fossil CO_2 emissions, and preliminary estimates suggest these will increase by 1.1 % relative to 2022, bringing annual emissions to 36.8 Gt CO_2. This figure is 1.4 % above the 2019 level (Figure 7).

These annual emissions have increased some four times since 1960 but are showing signs of slowing down and even starting to plateau. However, fast and deep cuts in emissions are not occurring as required for global warming to be restricted to 1.5°C or even 2°C. Emissions from coal, oil, and gas in 2023 are expected to increase above their 2022 levels by 1.1 %, 1.5 %, and 0.5 %, respectively. Hence calls to exit coal are not yet identifiable in the emissions data. Fossil CO_2 emissions in 2023 are expected to increase by 8.2 % in India, 4.0 % in China and −0.4 % for the rest of the world.

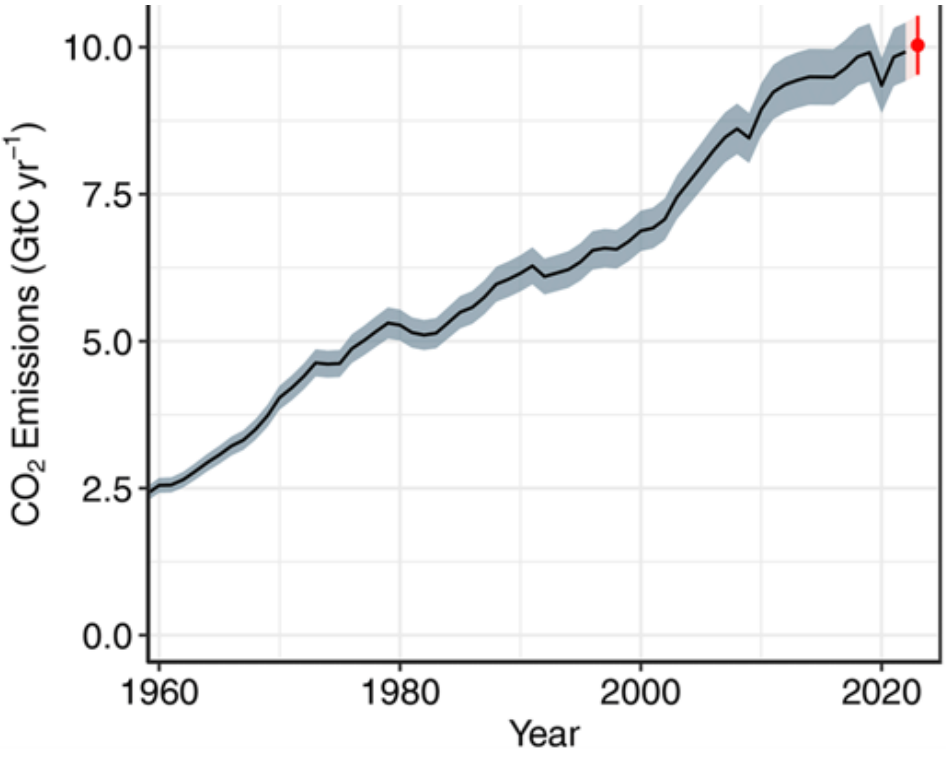

Figure 7. Global fossil CO2 emissions with projection and uncertainty in red for 2023.

Sourced in July 2024 from ESSD- Global Carbon Budget 2023 (copernicus.org)

When the major GHGs (CO2, methane and nitrous oxide) are combined into CO2-equivalents, emissions in 2022 were 53.85 billion tons (Bt)—up 0.74% from 53.45 Bt in 2021 (Jones et al. 2024). Over the 10-year period 2012-2022, the annual growth rate was 0.41%, which compares to 3% over the period 1952-2022. This demonstrates a significant slow-down in global GHG emissions over the past 10 years, although total emissions are still increasing.

This Emissions Gap Report's annual assessment (UNEP 2023) of the gap between the pledged GHG emissions reductions and the reductions required to align with the long-term temperature goal of the Paris Agreement, finds that the failure to stringently reduce emissions in high-income and high-emitting countries--which bear the greatest responsibility for past emissions--and to limit emissions growth in low- and middle-income countries--which account for the majority of current emissions--now requires urgent action by all countries. According to the Report, if current policies are continued, global warming is estimated (66% chance) to be limited to 3°C (range: 1.9–3.8°C) throughout this century. Delivering on all unconditional and conditional pledges by 2030 lowers this estimate to 2.5°C (range 1.9-3.6°C). In the most optimistic scenario where all conditional and net-zero pledges are assumed to be fully achieved (including those made as part of long-term low-emissions development strategies) global warming is projected to be limited to 2°C (range: 1.8–2.5°C) with 66% chance over the course of the century. In the most optimistic scenario considered in the Report, the chance of limiting global warming to 1.5°C is only 14%, and the various scenarios leave open a large possibility that global warming exceeds 2°C or even 3°C.

According to New Insights in Climate Science (2023/2024), overshooting 1.5°C is fast becoming inevitable. Governments and companies worldwide still plan to extract vastly more fossil fuels than would be consistent with limiting global warming to 1.5°C, and many also plan to expand their fossil fuel infrastructure. This report notes that the challenges of a global fossil fuel phase-out are complicated by:

- Geopolitical considerations related to energy security.
- Energy poverty, especially in lower-income countries, and insufficient international support to diversify or leapfrog to clean energy systems and alternative development pathways.
- Heavy dependence on fossil fuel revenues in many countries.
- Fossil fuel interests that continue to undermine, delay and block climate action through lobbying, greenwashing and disinformation campaigns.

Political will is also weak in at least one respect. Research by Wappenhans *et al.* (2024) found that extreme weather events do not increase political attention towards environmental issues and hence the consequences of climate change, except in Green parties.

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