United in Science 2021

A multi-organization high-level compilation of the latest
climate science information

WORLD METEOROLOGICAL ORGANIZATION

UN environment programme

GLOBAL CARBON project

ipcc INTERGOVERNMENTAL PANEL ON climate change

World Health Organization

Met Office

This report has been compiled by the World Meteorological Organization (WMO) on behalf of the United Nations Secretary-General to bring together the latest climate science related updates from a group of key global partner organizations: WMO, Global Carbon Project (GCP), Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme (UNEP), World Health Organization (WHO), the Met Office (United Kingdom, UK) and the jointly sponsored WMO/Intergovernmental Oceanographic Commission (IOC) of UNESCO/International Science Council (ISC) and World Climate Research Programme (WCRP). The content of each chapter is attributable to each respective entity.

The report is available electronically at: public.wmo.int/en/resources/united_in_science

Cover Illustration: Flooding after heavy rainfall in Koblenz, Deutsches Eck, a headland where the river Mosel joins the Rhine river. Adobe stock/EKH-Pictures.

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Foreword by Antonio Guterres, Secretary-General of the United Nations

This is a critical year for climate action. This report by the United Nations and global scientific partner organizations provides a holistic assessment of the most recent climate science. The result is an alarming appraisal of just how far off course we are.

We are still significantly off-schedule to meet the goals of the Paris Agreement. This year has seen fossil fuel emissions bounce back, greenhouse gas concentrations continuing to rise and severe human-enhanced weather events that have affected health, lives and livelihoods on every continent. Unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5°C will be impossible, with catastrophic consequences for people and the planet on which we depend.

This report is clear. Time is running out. For the 2021 United Nations Climate Change Conference in Glasgow, known as COP26, to be a turning point, we need all countries to commit to net zero emissions by 2050, backed up by concrete long-term strategies, and enhanced Nationally Determined Contributions (NDCs) which collectively cut global emissions by 45 per cent by 2030, compared to 2010 levels.

We need a breakthrough on protecting people and their livelihoods, with at least half of all public climate finance committed to building resilience and helping people adapt. And we need much greater solidarity, including full delivery of the long-standing climate finance pledge to help developing countries take climate action. There is no alternative if we are to achieve a safer, more sustainable and prosperous future for all.

A. Guterres, Secretary-General UN

Foreword by Prof. Petteri Taalas, Secretary-General of the World Meteorological Organization

Throughout the pandemic we have heard that we must “build back better” to set humanity on a more sustainable path, and to avoid the worst impacts of climate change on society and economies. This report shows that so far in 2021, we are not going in the right direction.

Greenhouse gas concentrations – which are already at their highest levels in three million years – have continued to rise, reaching new record highs this year. Fossil fuel emissions in many sectors are back at the same or at even higher levels than before the pandemic. Global temperatures in 2017–2021 are among the warmest of any equivalent period since meteorological measurements, with warming evident in many climate indicators such as sea ice, glacier melt and sea-level rise.

United in Science 2021 delivers on its mission, to present the very latest scientific data and findings related to climate change, to inform policy and decision-makers. This work depends on a global network of scientists and institutions, and on the critical underpinning observation, modelling and research infrastructure, which we must be supported to meet the demands of today’s challenges.

I would like to thank the many expert teams involved in creating this report – most notably from Global Carbon Project, the Intergovernmental Panel on Climate Change, World Health Organization, UN Environment, the World Climate Research Programme, and the Met Office (UK) – for their collaboration, uniting the climate science community to deliver the latest essential information, in these unprecedented times.

Prof. P. Taalas, Secretary-General WMO

Key Points

Greenhouse Gas Concentrations in the Atmosphere – WMO GAW

- Concentrations of the major greenhouse gases – CO_2, CH_4, and N_2O – continued to increase in 2020 and the first half of 2021.
- Overall emissions reductions in 2020 likely reduced the annual increase of the atmospheric concentrations of long-lived greenhouse gases, but this effect was too small to be distinguished from natural variability.
- Reducing atmospheric methane (CH_4) in the short term could support the achievement of the Paris Agreement. This does not reduce the need for strong, rapid and sustained reductions in CO_2 and other greenhouse gases.

RECENT CHANGES IN THE CLIMATE SYSTEM ARE **UNPRECEDENTED OVER 100s TO MANY 1000s OF YEARS**

CO2 EMISSIONS HAVE LARGELY **BOUNCED BACK** TO PRE-PANDEMIC LEVELS

GREENHOUSE GAS CONCENTRATIONS CONTINUE TO RISE TO **NEW RECORD HIGHS**

EXTREME HEAT, DROUGHTS, HEAVY RAIN AND FLOODS ARE **MORE LIKELY BECAUSE OF CLIMATE CHANGE**

COVID-19 EXACERBATES HEALTH HAZARDS LINKED TO POOR AIR QUALITY, WILDFIRES AND HEATWAVES

SEA-LEVEL RISE HAS **ACCELERATED**, THREATENING LIVES & LIVELIHOODS. IT WILL CONTINUE **FOR CENTURIES**

THERE IS A 40% CHANCE THAT ONE YEAR UP TO 2025 WILL BE **1.5 °C WARMER** THAN PRE-INDUSTRIAL TIMES

NET ZERO EMISSIONS COMMITMENTS NEED TO BE MORE AMBITIOUS AND **REFLECTED IN POLICY**

Global GHG Emissions and Budgets – GCP

- Fossil CO_2 emissions – coal, oil, gas and cement – peaked at 36.6 $GtCO_2$ in 2019, followed by an extraordinary drop of 1.98 $GtCO_2$ (5.6%) in 2020 due to the COVID-19 pandemic.
- The drop in CO_2 emissions is temporary, and based on preliminary estimates, from January–July 2021 global emissions in the power and industry sectors were already at the same level or higher than in the same period in 2019. Emissions from road transport remained about 5% lower.
- Recent emissions trends of N_2O, the third most important greenhouse gas after CO_2 and CH_4, exceed the most greenhouse gases intense socioeconomic pathways used to explore future climate change.

Global Climate in 2017–2021 – WMO

- The global average mean surface temperature for the period from 2017–2021 is among the warmest on record, estimated at 1.06 °C to 1.26 °C above pre-industrial (1850–1900) levels.
- In every year from 2017 to 2021, the Arctic average summer minimum and average winter maximum sea-ice extent were below the 1981–2010 long term average. In September 2020, the Arctic sea-ice extent reached its second lowest minimum on record.
- 2021 recorded devastating extreme weather and climate events – a signature of human-caused climate change has been identified in the extraordinary North American extreme heat and west European floods.

Key Points

Highlights of AR6: The Physical Science Basis – IPCC

- It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.
- The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.
- Human-induced climate change is already increasing the frequency and intensity of many weather and climate extremes in every region across the globe.

Heatwaves, Wildfires, and Air Pollution: Compounding and Cascading Climate Hazards to Health – WHO/WMO

- Rising temperatures are linked to increased heat-related mortality and work impairment, with an excess of 103 billion potential work hours lost globally in 2019 compared with those lost in 2000.
- COVID-19 infections and climate hazards such as heatwaves, wildfires and poor air quality combine to threaten human health worldwide, putting vulnerable populations at particular risk.
- COVID-19 recovery efforts should be aligned with national climate change and air quality strategies to reduce risks from compounding and cascading climate hazards, and gain health co-benefits.

Sea-level Rise and Coastal Impacts – WCRP (WMO/IOC/ISC)

- Global mean sea levels rose 20 cm from 1900 to 2018 and at an accelerated rate of 3.7+0.5 mm/yr from 2006 to 2018.
- Even if emissions are reduced to limit warming to well below 2 °C, global mean sea level would likely rise 0.3–0.6 m by 2100 and could rise by 0.3–3.1 m by 2300 (relative to 1995-2014).
- If greenhouse emission continue to rise unabated global mean sea level will likely rise 0.6–1.0 by 2100 (relative to 1995-2014) and, with less confidence, range from 1.7–6.8 m (perhaps more) by 2300 with further large rises continuing beyond.
- Even with climate stabilization, adaptation to this residual rise will be essential – adaptation strategies are needed where they do not exist – especially in low-lying coasts, small islands, deltas and coastal cities.

Global Climate in 2021–2025 – WMO Global Annual to Decadal Climate Update – Met Office/WMO/WCRP

- Annual global mean near-surface temperature is likely to be at least 1 °C warmer than pre-industrial levels (defined as the 1850–1900 average) in each of the coming five years and is very likely to be within the range 0.9 °C to 1.8 °C.
- There is a 40% chance that average global temperature in one of the next five years will be at least 1.5 °C warmer than pre-industrial levels but it is very unlikely (~10%) that the 5-year mean temperature for 2021–2025 will be 1.5 °C warmer than pre-industrial levels.
- Over 2021–2025, high latitude regions and the Sahel are likely to be wetter than the recent past.

Emissions Gap – UNEP

- Five years after the adoption of the Paris Agreement, the emissions gap is as large as ever: global emissions need to be 15 $GtCO_2e$ lower than current unconditional Nationally Determined Contributions (NDCs) imply for a 2 °C goal, and 32 $GtCO_2e$ lower for the 1.5 °C goal.
- The COVID-19 crisis offers only a short-term reduction in global emissions. It will not significantly reduce emissions by 2030 unless countries pursue an economic recovery that incorporates strong decarbonization.
- The increasing number of countries committing to net-zero emission goals is encouraging, with about 63% of global emissions now covered by such goals. However, to remain feasible and credible, these goals urgently need to be reflected in near-term policy and in significantly more ambitious NDCs for the period to 2030.

Greenhouse Gas Concentrations in the Atmosphere – WMO Global Atmosphere Watch

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Levels of Greenhouse Gases in the Atmosphere

Levels of atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) continue to rise. Preliminary analysis of the data – from a subset of the WMO Global Atmosphere Watch (GAW) greenhouse gas (GHG) observational network – demonstrated that CO_2 concentrations[1] in the Northern Hemisphere exceeded 410 parts per million (ppm) for most of 2020 and exceeded 415 ppm in the first half of 2021.

A full analysis of the three main GHGs (Figure 1) shows the globally averaged atmospheric concentrations of CO_2 at 410.5 ± 0.2 ppm, CH_4 at 1877 ± 2 parts per billion (ppb) and N_2O at 332.0 ± 0.1 ppb for 2019 (respectively 148%, 260% and 123% of pre-industrial levels in 1750). The annual increases of CO_2 and CH_4 were larger in 2019 than the 10-year averaged rate of increase, while the N_2O annual increase was slightly less than the 10-year average growth rate (WMO, 2020).

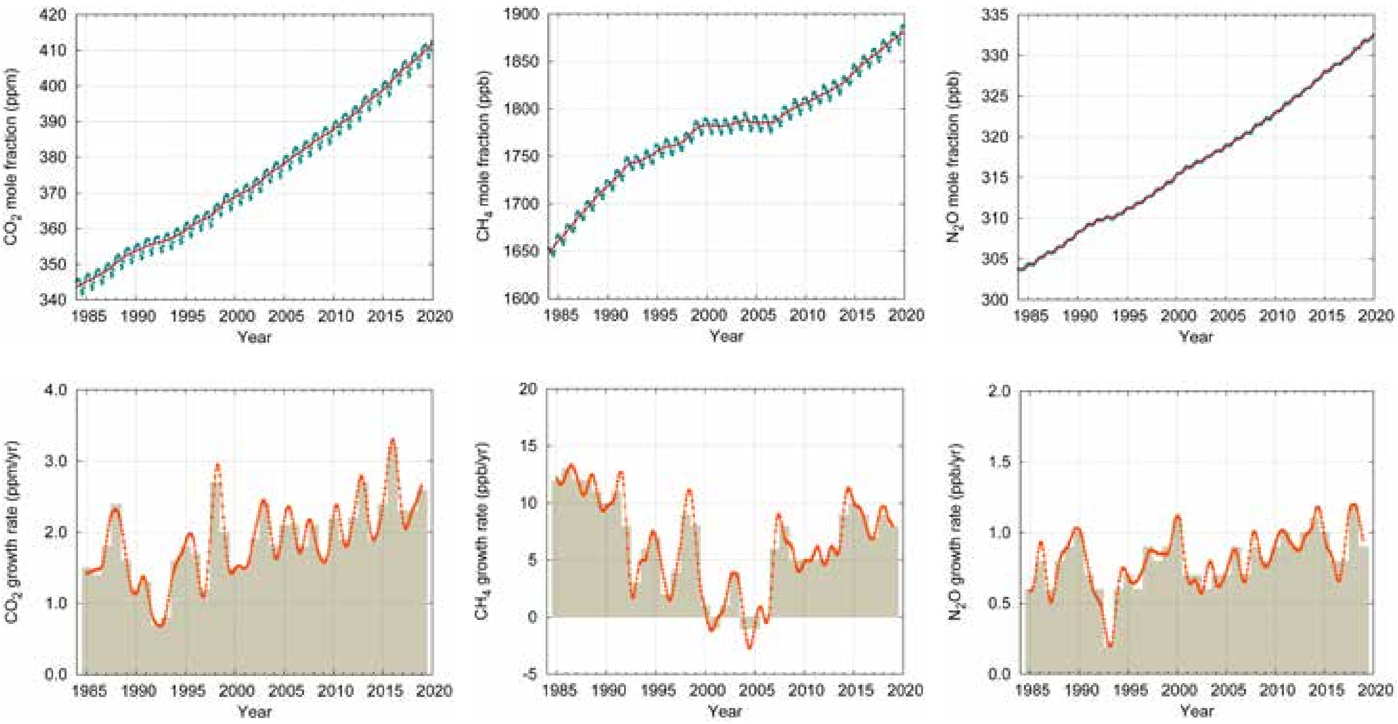

Figure 1. (upper row) Globally averaged CO_2, CH_4 and N_2O mole fraction in ppm (CO_2) and ppb (CH_4; N_2O, respectively) and its growth rates (bottom row) from 1984 to 2019. Increases in successive annual means are shown as the shaded columns in the bottom row. The red line in the upper row is the monthly mean with the seasonal variation removed; the blue dots and line depict the monthly averages

Final global average concentration data figures for 2020 will not be available until the second half of 2021, but data from all global locations, including flagship observatories, indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2020 and 2021 (Figures 2 and 3). In July 2021, CO_2 concentration at Mauna Loa (Hawaii, US) and Cape Grim (Tasmania, Australia) reached 416.96 ppm and 412.1 ppm, respectively, in comparison with 414.62 ppm, and 410.03 ppm in July 2020.

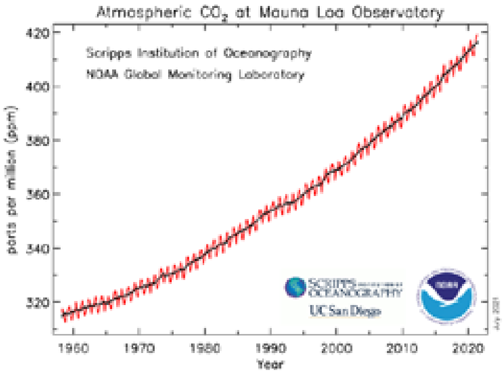

Figure 2. Monthly mean CO_2 mole fraction in ppm at Mauna Loa observatory from March 1958 to July 2021. The dashed red line represents the monthly mean values, centred on the middle of each month. The black line represents the same, but here the average seasonal cycle has been removed by a statistical treatment. Source: www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html

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[1] In this section, the physical quantity related to the amount of gases in the atmosphere (dry mole fraction) is referred to as "concentration"

Greenhouse Gas Concentrations in the Atmosphere – WMO Global Atmosphere Watch

Concentration variability and COVID-19

The Global Carbon Project (Friedlingstein et al., 2020) estimated that total emissions from 2010–2019 were partitioned into the atmosphere (44%), ocean (23%) and land (29%) with an unattributed budget imbalance (4%). While the increase of GHG concentrations in the atmosphere is driven by human emissions, the interannual changes in the atmospheric CO_2 increase rates are modulated by the variability of the sinks, and especially of the land-based biosphere. The CO_2 growth rate was between 2 ppm and 3 ppm per year within the last 10 years, with the highest increase rate of 3.2 ppm observed in 2016, during the strong El Niño (WMO, 2016). El Niño typically reduces the uptake of CO_2 from the atmosphere by vegetation, due to the increased extent of droughts over land surfaces (Betts et al., 2016).

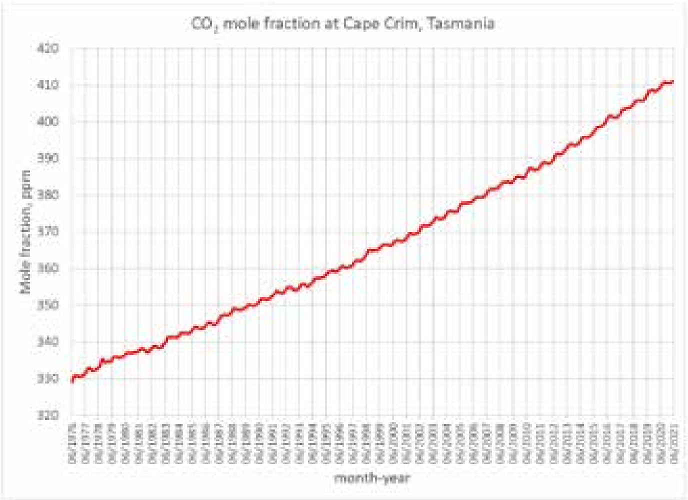

Figure 3. Monthly mean CO_2 mole fraction in ppm from May 1976 to July 2021 at Cape Grim observatory (https://www.csiro.au/greenhouse-gases/)

The decline of CO_2 emissions due to the COVID-19 crisis (-5.6%, see section “Global Emissions and Budgets – GCP”) would result in a final change of the annual growth rate of less than 0.2 ppm – well within the 1 ppm – driven by the uptake of the biosphere. This difference can be detected by the GAW network, which has a precision goal that is better than 0.1 ppm, but its detection will require longer than one year of measurements.

The WMO Integrated Global Greenhouse Gas Information System IG^{3}IS (www.ig3is.wmo.int) uses atmospheric observation and analysis tools to improve knowledge of greenhouse gas sources and sinks at national and smaller scales. To achieve its objectives, WMO IG^{3}IS is developing good-practice guidelines for producing observation-based emissions estimates for nations, as well as guidelines for estimating emissions from cities and states, and works toward broadening the use of this methodology.

Methane monitoring in support of the temperature target of the Paris Agreement

Methane accounts for about 16% of radiative forcing by long-lived greenhouse gases, making CH_4 the second most important anthropogenic GHG. Approximately 40% of methane is emitted into the atmosphere by natural sources, for example, wetlands and termites, and about 60% comes from anthropogenic sources such as ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning (Saunois et al., 2020). CH_4 emissions also indirectly affect human health and agricultural productivity through the production of tropospheric ozone (UNEP, 2021). To limit global warming, strong, rapid, and sustained reductions in CO_2, CH_4, and other greenhouse gases are necessary (IPCC, 2021).

The global CH_4 increase of 8 ppb in 2019 (WMO, 2020) continues the trend of the past decade, which experienced increases of 5–10 ppb per year (ppb/yr). Preliminary analysis from the US National Oceanic and Atmospheric Administration (NOAA) network demonstrates an increase of CH_4 concentration in 2020 of 15 ppb, which is the largest increase within the 37-year (from 1984 to 2020) record (https://gml.noaa.gov/ccgg/trends_CH_4/).

Observations of CH_4 stable isotopes are used to identify sources of atmospheric CH_4 (Nisbet et al., 2016). The observed trend in ^{13}C-CH_4 is explained by a combined increase in microbial (both natural and anthropogenic) and fossil emissions (WMO, 2020).

Addressing CH_4 emissions starts with finding, identifying and quantifying emissions (Nisbet et al., 2020). Satellite data play an important role in locating previously unknown large CH_4 emission sources (hotspots), for example, from gas and oil production sites. The satellite TROPOspheric Monitoring Instrument (TROPOMI) provides CH_4 column concentrations with high sensitivity at the Earth's surface, a good spatiotemporal coverage and sufficient accuracy to facilitate inverse modelling of sources and sinks. Data from TROPOMI were used to identify emission hotspots (Figure 4) and can guide action to address methane super-emitters.

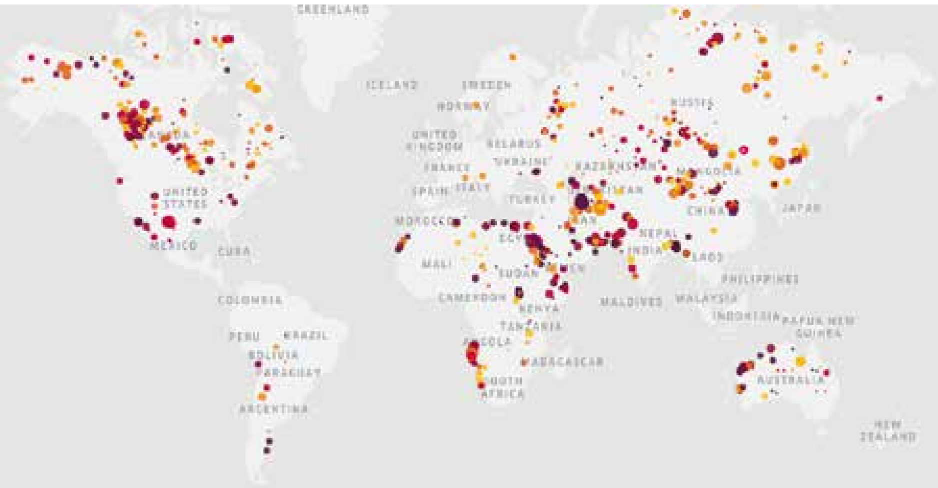

Figure 4. This image shows a sample of abnormal methane concentrations over 2019 as measured by Sentinel-5P. The size and colour of the circles indicate the size and intensity of the plume detected. The redder the colour, the higher the concentration of the methane plume. This image contains modified Copernicus Sentinel data (2019), processed by Kayrros.

Substantial methodological development is still needed to improve satellite-derived emission estimates, for which accurate measurements on the ground are indispensable. However, with the current capabilities, an important new contribution to regional emission monitoring can already be made. The combination of Sentinel-5P and Sentinel2 Methane measurements show promising results in deriving emission rates (see Figure 5).

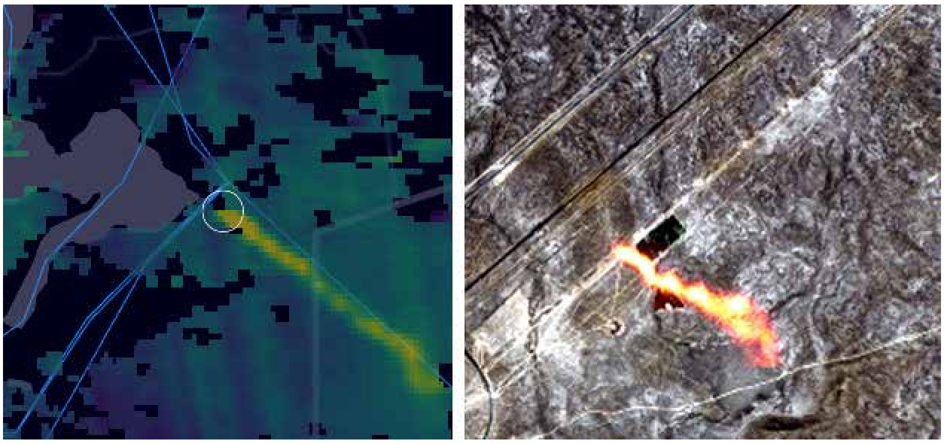

Figure 5: Methane emission hotspots over a gas pipeline in Kazakhstan detected by Sentinel-5P (left) and Sentinel2 (right) missions. This image contains modified Copernicus Sentinel data (2019), processed by Kayrros

Several studies have pointed to the short-term climate benefits and cost-effectiveness of mitigating CH_4 emissions, which are well described in the UNEP methane assessment of 2021. There is a strong call to upscale action on CH_4 emissions and there are indicative plans for an International Decade for Methane Management to be proposed at the 76th Session of the United Nations General Assembly.

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Global GHG Emissions and Budgets – Global Carbon Project (GCP)

Global CO_2 emissions from the combustion of fossil fuels and land use change in 2019 reached a new high of 43 Gigatonnes of CO_2 (Gt, billion metric tonnes), 56% above the level when international climate negotiations started early in the 1990s. Fossil CO_2 emissions (coal, oil, gas and cement), which account for about 85% of all CO_2 emissions (2010–2019), peaked at 36.6 $GtCO_2$ in 2019, followed by an extraordinary drop of 1.9 $GtCO_2$ (5.6%) in 2020 (updated from Friedlingstein et al., 2020, Figure 1). The drop in emissions was mainly due to the slowdown of the global economy and lower energy demands during the COVID-19 pandemic, especially during the first wave of confinements. The transport sector, particularly road transport, contributed the most to the decline. Although aviation dropped by 75% at the peak of the lockdown in spring 2020, its contribution was smaller given that the sector only accounts for about 2.8% of the total mean annual global emissions (Le Quéré et al., 2020).

The emissions drop in 2020 was almost four times the size of the one during the Global Financial Crisis in 2008 (1.5%, compared to the previous year), and was the largest annual drop ever recorded in absolute values (1.9 Gt CO_2, Figure 2). Although there is uncertainty about the global post-pandemic recovery, the drop is temporary and initial estimates for 2021 show a strong recovery in emissions with a possible return to pre-COVID levels within a year or two (Figure 3).

Based on preliminary estimates, global emissions in the power and industry sectors were already at the same level or higher in January-July 2021 than in the same period in 2019, before the pandemic, while emissions from road transport remained about 5% lower. Excluding aviation and sea transport, global emissions were at about the same levels as in 2019, averaged across those 7 months.

Despite the expected high growth rates in 2021, the medium-term outlook is for slower emissions growth than seen earlier in this century. In fact, slowing growth rates already began before the pandemic, with an average of 1% per year during the last decade, down from 3% in the previous decade (2000–2009). The emissions growth in 2019, just before the pandemic, was near zero. There is no certainty as to when peak CO_2 emission will be reached, given that 150 countries had increasing fossil CO_2 emissions during the five years prior to the pandemic, but progress is occurring, with 64 countries recording declining emissions (Le Quéré et al., 2021).

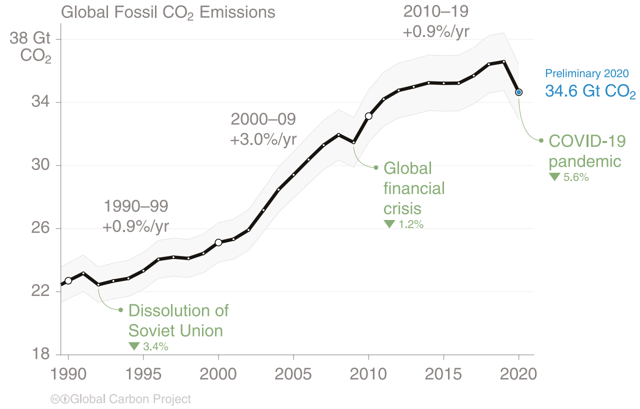

Figure 1. Global fossil CO_2 emissions which include coal, oil, gas and cement production. Data updated from Friedlingstein et al. (2020)

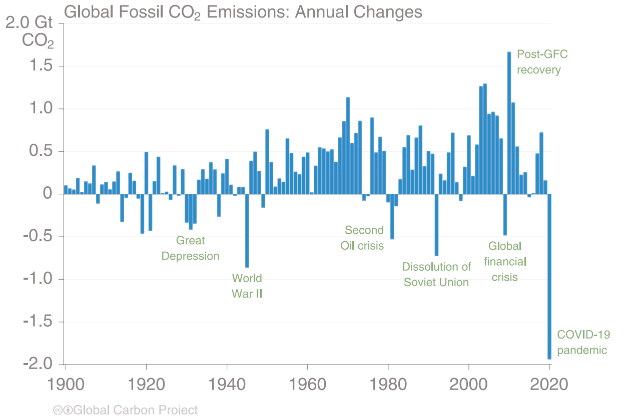

Figure 2. Annual changes in global fossil CO_2 emissions. Data updated from Friedlingstein et al. (2020)

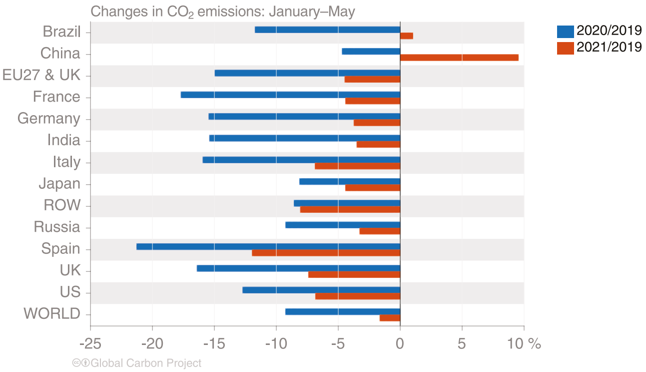

Figure 3. Changes in fossil fuel CO_2 emissions for the world and a selected group of countries for January-May in 2020 and 2021 compared with the same period in 2019 (Carbon Monitor).

Additional 6.6 ± 2.5 Gt CO_2 were added to the atmosphere in 2019 from the net impact of land-use change – that is, deforestation, degradation, reforestation. These emissions are above the average from the past decade (2010–2019) of 5.8 Gt CO_2 due to large land-clearing fires in the Amazon and Indonesia (Friedlingstein et al., 2020). For the first time in the global carbon budget, we provide estimates for the contributing gross fluxes that make up net land-use change emissions and show that gross emissions, such as land clearing, shifting cultivation and peat draining, are about 2–3 times larger (16 ± 2.6 Gt CO_2) than the net flux (average for 2010–2019). However, the trends for land use emissions in the last decade are inconsistent between estimates because of divergent estimates of forest loss areas. These emissions are only partially offset by anthropogenic sinks such as reforestation and vegetation regrowth after crop abandonment.

The land and oceans sinks removed almost half of all anthropogenic CO_2 emissions, with oceans sinks remaining close to the decadal average (2000–2009) in 2019 and 2020. Land sinks were slightly below their average, reflecting several climate anomalies such as wildfires in Australia and elsewhere.

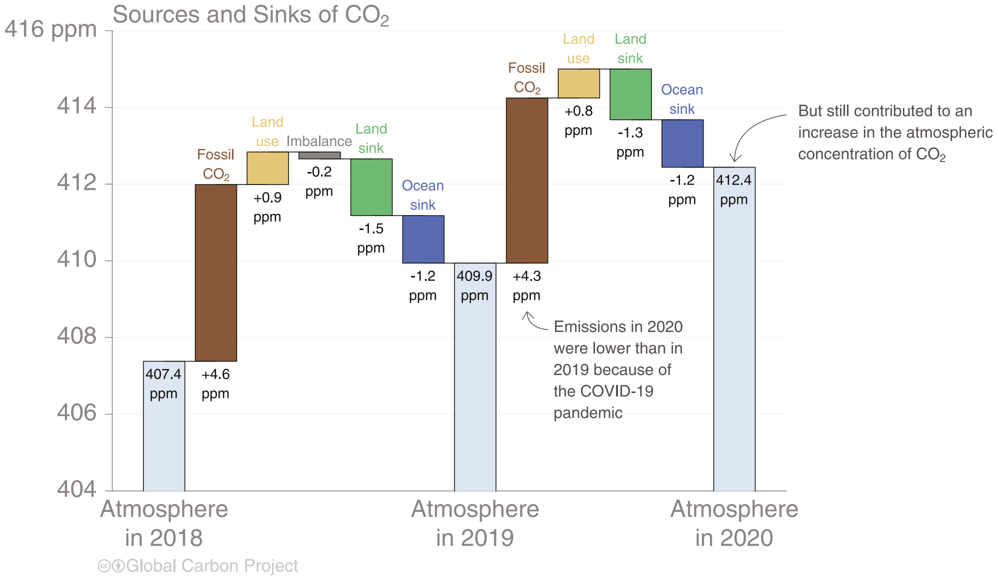

Figure 4. Attribution of changes in atmospheric CO_2 concentrations (parts per million, ppm) to main sources of fossil fuels and cement production. Data from Friedlingstein et al. (2020). Note that atmospheric concentrations are estimated from the NOAA/ESRL network and therefore are not exactly the same as the ones based on the WMO global network; this choice is determined by data availability at the time of submission of the Global Carbon Budget for publication.

The importance of nitrous oxide (N_2O) emissions

Nitrous oxide (N_2O) is the third most important greenhouse gas contributing to human induced warming, after CO_2 and methane (CH_4). Its third place often results in its receiving less attention, although N_2O is 298 times more effective at trapping heat per unit mass than CO_2 (on a 100-y time scale). Once emitted, N_2O remains in the atmosphere for 116 ± 9 years, a shorter lifetime than CO_2 but much longer than CH_4.

Anthropogenic emissions of N_2O have been growing for over 100 years, with a 30% increase in the past three decades. Agriculture, owing to the use of nitrogen fertilizers and manure, contributes 70% of all anthropogenic N_2O emissions (Tian et al., 2020). Excess nitrogen in the environment has led to a four-fold increase in global riverine N_2O emissions in the period from 1900 to 2016 with emissions peaking over the past decade (Yao et al., 2020).

The recently published Global N_2O Budget (Figure 5) estimated all anthropogenic and natural sources and sinks that determine the accumulation of atmospheric N_2O.

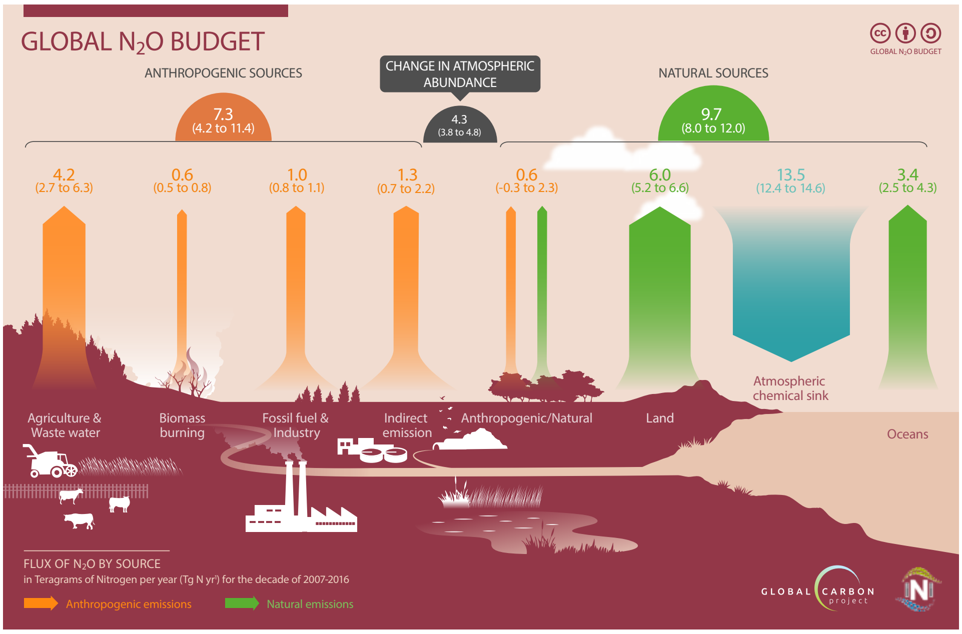

Figure 5. Mean global N_2O budget for all major anthropogenic and natural sources and sinks for the decade 2007–2016 (redrawn from Tian et al., 2020).

Recent trends in N_2O emissions exceed the illustrative socioeconomic pathways used by the global climate community, and show a rapidly departing trajectory from scenarios that are consistent with the Paris Agreement targets (Figure 6). Despite this growth, some regions (for example, Europe) have stable emissions, often resulting from reductions in industrial emissions (through emission abatement technologies) and increased nitrogen use efficiency in agriculture (Thompson et al., 2019). These technological and efficiency improvements are important also in offsetting a growth in N_2O emissions from increases in, for example, agricultural activity in some regions, such as North America.

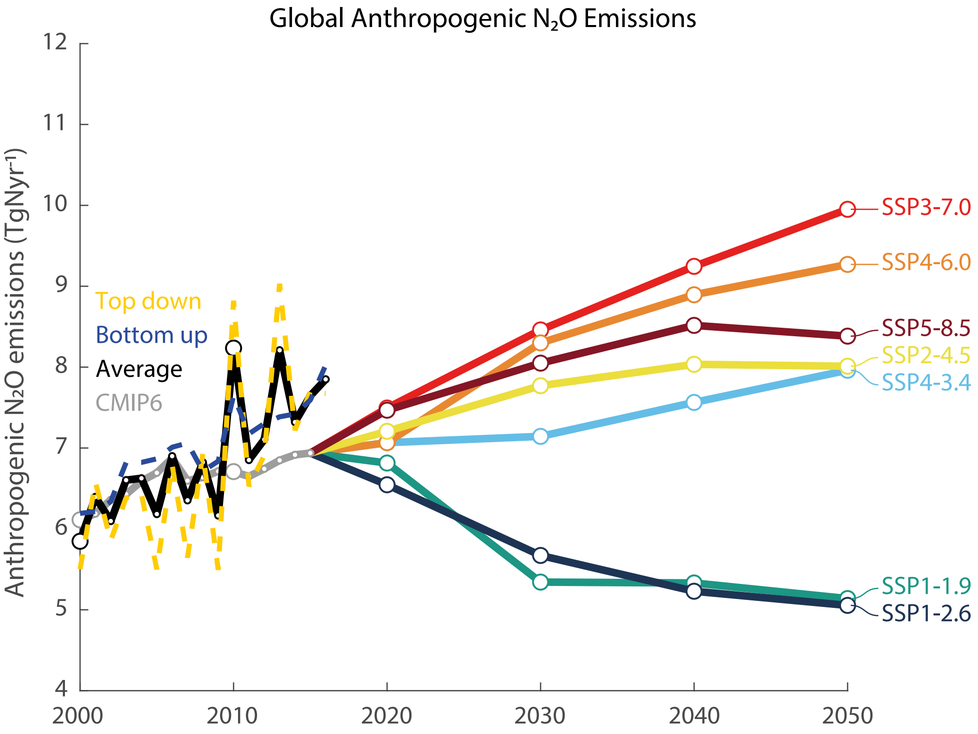

Figure 6. Historical and projected global N_2O emissions used in the marker socioeconomic pathway scenarios used in the IPCC AR6 (Tian et al., 2020).

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Global Climate in 2017–2021 – WMO

This section provides a summary on the state of change of two important climate indicators (Trewin et al., 2021) – temperature and sea ice – in the five-year period from 2017–2021. The global average mean surface temperature for 2017–2021 (2021 data are based on averages for January to May or June, depending on the data set) is among the warmest of any equivalent period on record (Figure 1). It is estimated to be 1.06 °C to 1.26 °C above pre-industrial (1850–1900) levels, depending on the data set used.

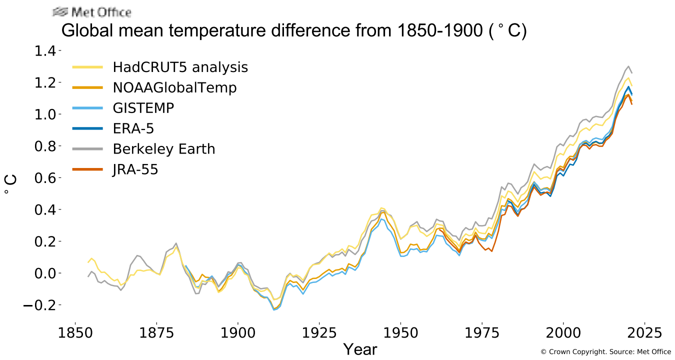

Figure 1. Five-year running average of global temperature anomalies (relative to pre-industrial) from 1854 to 2021 for six data sets: HadCRUT.5.0.1.0, NOAA GlobalTemp v5, GISTEMP v4, Berkeley Earth, ERA5, and JRA-55. Data for 2020 to June 2021 for HadCRUT5 and July for NOAAGlobalTemp, GISTEMP, Berkeley Earth, ERA5 and JRA-55.

The 2017–2021 average global temperature dropped slightly from the record high for 2016–2020. This is mainly due to the El Niño conditions in 2016 which boosted global temperatures (WMO, 2016) and the La Niña conditions in early 2021 that contributed to a slight drop of the global annual temperatures. The 2017–2021 five-year average temperature is likely to be the highest on record for large areas of North Africa, the Middle East, Eastern Asia, eastern parts of the US, parts of Central America, and areas of South America. Only a few land areas were close to or slightly cooler than the 1981–2010 average, most notably an area of North America (Figure 2).

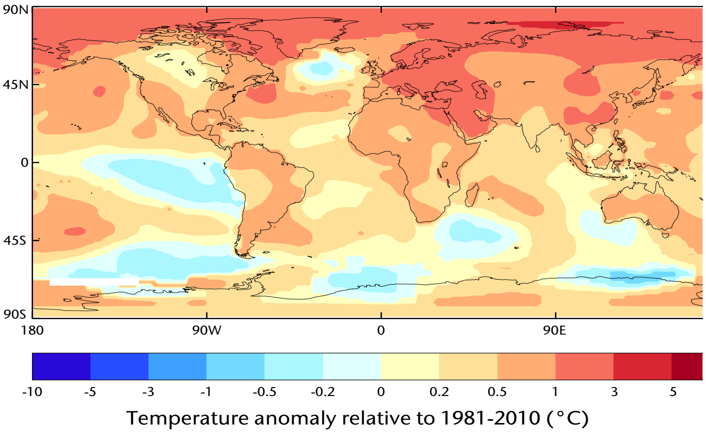

Figure 2. 2017-2021 five-year average temperature anomalies relative to the 1981-2010 average. Data is from NASA GISTEMP v4. Date updated to July 2021

Sea ice

Arctic sea ice has seen a long-term decline every month since the beginning of the satellite era (1979–present), with the largest relative losses in late summer, around the time of the annual minimum in September (Figure 3), albeit with regional variations. For the 2016–2020 period, the average arctic sea-ice extent in September was 28% below the 1981–2010 average while the average March maximum was around 6% below the 1981–2010 average.

In every year from 2017 to 2021, the Arctic average summer minimum and average winter maximum sea-ice extent were below the 1981–2010 long term average. In September 2020, the Arctic sea-ice extent reached its second lowest minimum on record.

There has also been a marked decline in the fraction of older, usually thicker, ice. At the time of the March maximum, the fraction of ice older than one year has declined from around 60% in 1985 to around 27% in 2021.[1] The fraction of ice older than four years has declined from 30% in 1985 to less than 5% in 2021.

Antarctic sea-ice extent increased slowly from the start of the satellite era to around 2015. However, in the three years following 2015, ice extent dropped rapidly (Figure 3). The drop was associated with ocean warming, combined with incursions of warm air during the spring and an unusual weakening of the mid-latitude westerly winds.[2] Since then, ice extent has returned close to the long-term average.

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[1] http://nsidc.org/arcticseaicenews/2021/05/

[2] https://www.nature.com/articles/s41561-021-00768-3

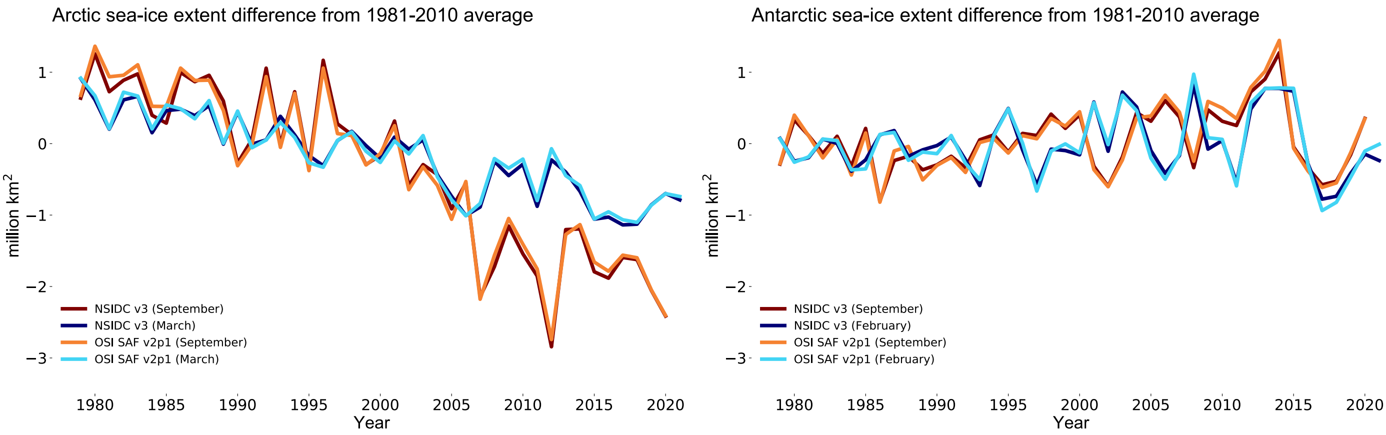

Figure 3. For 1979–2021: (left) monthly September and March Arctic sea-ice extent anomalies relative to the 1981–2010 average; (right) monthly February and September Antarctic sea-ice extent anomalies relative to the 1981–2010 average (Sources: US National Snow and Ice Data Center (NSIDC) and EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF))

An exceptional and dangerous heatwave devastated the US northwest and Western Canada in June /July

The all-time Canadian heat record was broken when Lytton, British Columbia, recorded a high of 49.6 °C on 29 June 2021. Using published peer-reviewed methods (van Oldenborgh et al., 2021), the World Weather Attribution (WWA) initiative investigated the role of human-induced climate change in the likelihood and intensity of this extreme heatwave. The occurrence of a heatwave with the high maximum daily temperatures observed in the area 45–52 ºN, 119–123 ºW, was virtually impossible without human-caused climate change (World Weather Attribution; Philip et al., 2021). The temperatures were so extreme that they were far beyond the range of historically observed temperatures. This makes it hard to quantify with confidence how rare the event was. In the most realistic statistical analysis, the event is estimated to be a 1 in 1000 year event in today's climate. An event such as the Pacific Northwest 2021 heatwave is still rare or extremely rare in today's climate, yet would be virtually impossible without human-caused climate change. As warming continues, it will become a lot less rare (Philip et al., 2021).human-caused climate change. As warming continues, it will become a lot less rare (Philip et al., 2021).

Severe Flooding Event in Germany and neighbouring countries

Very pronounced heavy rainfall occurred in Germany and neighbouring countries in connection with the low-pressure system "Bernd", especially in the period from 12–15 July 2021. This led to severe flooding, particularly in North Rhine-Westphalia and Rhineland-Palatinate. The flooding resulted in a high number of fatalities (186 deaths and 26 missing) and considerable infrastructure damage – estimated around € 5 billion (US$ 5.9 billion) by insurers. The flooding was triggered by long-lasting heavy precipitation that fell on already saturated ground and, in many parts, rocky underground. Wide areas experienced 100 litre (l) /m^2 within 12 to 72 hours, some areas even 150 l/m^2 within 12 to 24 hours (Figure 4). In the current climate, for a given location within the larger area north of the Alps to the Netherlands on average it is expected one such event every 400 years (Kreienkamp et al., 2021).

The World Weather Attribution (WWA) initiative analyzed how human-induced climate change affected maximum 1-day and 2-day rainfall events in the summer season (April–September) in two small regions where recent flooding has been most severe (Ahr-Erft region, Germany; and the Meuse, Belgium) as well as anywhere over a larger region including Germany, Belgium and the Netherlands (Kreienkamp et al., 2021).

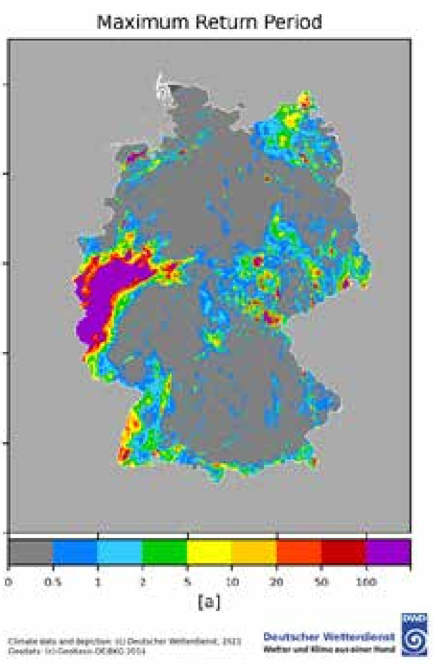

Figure 4. Maximum return period (years) of rainfall with durations between 1 and 72 hours from 12.07.2021 05:50 UTC to 19.07.21 05:50 UTC based on an hourly precipitation sum from the Deutscher Wetterdienst (DWD, Germany's National Meteorological Service) radar network adjusted to rain gauge observations.

All available evidence taken into consideration, including physical understanding, meteorological observations as well as different regional climate models, give high confidence that human-induced climate change has increased the likelihood and intensity of such an event to occur and these changes will continue in a rapidly warming climate (Kreienkamp et al., 2021). Under future climate change, such events will occur more frequently.

Weather, climate and water in 50-year disaster data

The recent *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes* (WMO-No. 1267) shows that of the 22 326 disasters recorded worldwide from 1970 to 2019 over 11 000 were attributed to weather, climate and water-related hazards. Those disasters resulted in 2.06 million deaths and US$ 3.64 trillion in losses. Some 44% of the disasters were associated with floods (riverine floods 24%, general floods 14%) and 17% with tropical cyclones (Figure 5). Tropical cyclones and droughts were the most prevalent hazards with respect to human losses, accounting for 38% and 34% of disaster related deaths respectively. In terms of economic losses, 38% were associated with tropical cyclones, while different types of floods account for 31%, riverine floods (20%), general floods (8%) and flash floods (3%) (WMO, 2021).

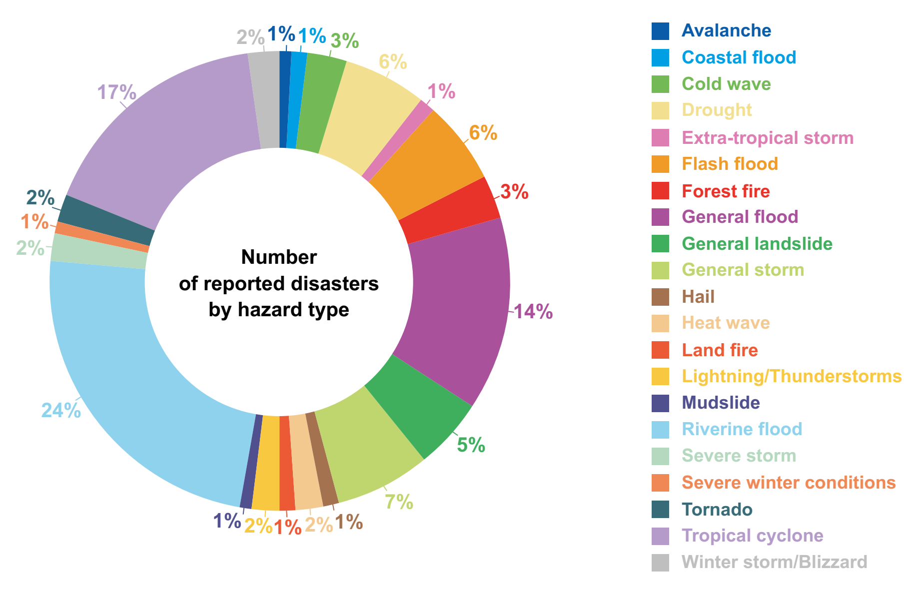

Figure 5. Distribution of number of disasters globally covering the period 1970–2019 (WMO, 2021)

Although the number of recorded disasters rose by a factor of five over the period the number of deaths decreased almost three-fold. This is due, in part, to better multi-hazard early warning systems, which are improving prevention, preparedness and response.

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Highlights of IPCC Climate Change 2021, The Physical Science Basis for the current state of climate

It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.

Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Their concentrations have continued to increase in the atmosphere. Land and ocean have taken up a near-constant proportion (globally about 56% per year) of CO_2 emissions from human activities over the past six decades, with regional differences.

Human-caused radiative forcing of 2.72 [1.96–3.48] W m^{-2} in 2019 relative to 1750 has warmed the climate system. This warming is mainly due to increased GHG concentrations, partly reduced by cooling due to increased aerosol concentrations. The radiative forcing has increased by 0.43 W m^{-2} (19%) relative to the previous IPCC report (AR5, published in 2013), of which 0.34 W m^{-2} is due to the increase in GHG concentrations since 2011. The remainder is due to improved scientific understanding and changes in the assessment of aerosol forcing, which include decreases in concentration and improvement in its calculation.

Each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature in the first two decades of the twenty-first century (2001–2020) was 0.99 [0.84–1.10] °C higher than 1850–1900. Global surface temperature was 1.09 [0.95–1.20] °C higher in 2011–2020 than 1850–1900, with larger increases over land (1.59 [1.34–1.83] °C) than over the ocean (0.88 [0.68–1.01] °C).

For the period when attribution studies are available, the observed warming from 1850–1900 to 2010–2019 is 1.06 [0.88–1.21] °C, and the best estimate of total human-caused warming is 1.07 °C, with a likely range of 0.8–1.3 °C. It is likely that well-mixed GHGs contributed a warming of 1.0–2.0 °C, other human drivers (principally aerosols) contributed a cooling of 0.0–0.8 °C, natural drivers changed global surface temperature by -0.1–0.1 °C, and internal variability changed it by -0.2–0.2 °C (Figure 1).

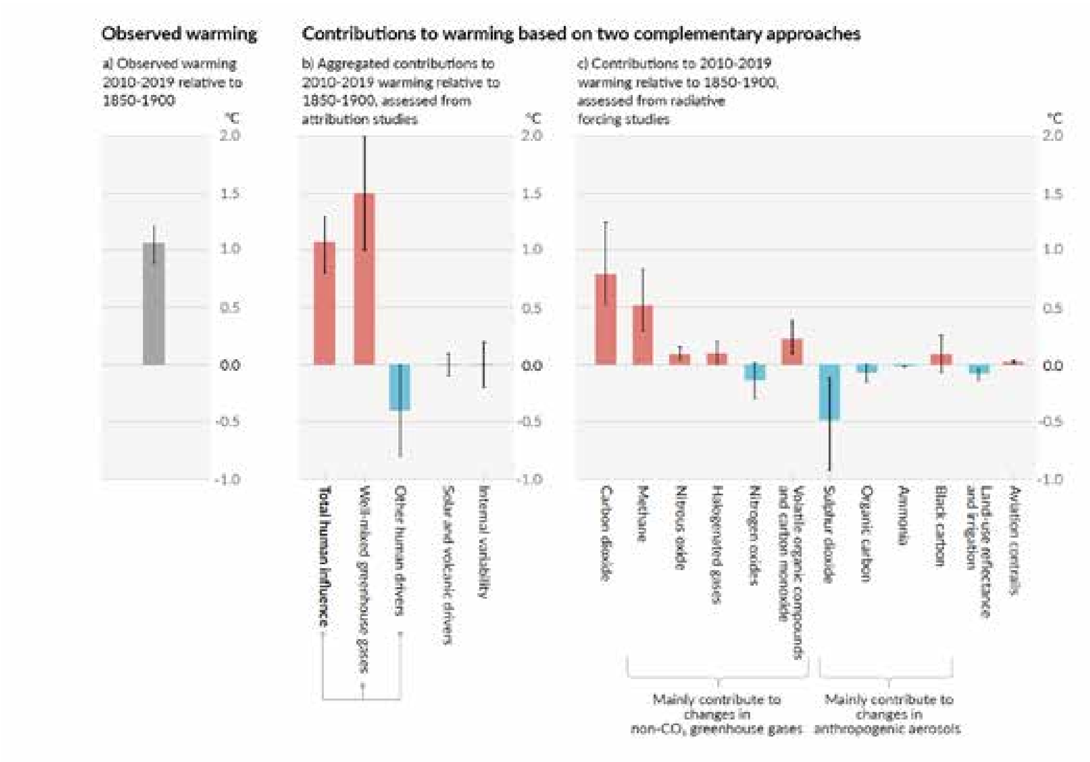

Figure 1. Taken from IPCC AR6 WG1 Figure SPM.2: Assessed contributions to observed warming in 2010–2019 relative to 1850–1900. Panel a): Observed global warming (increase in global surface temperature) and its very likely range Panel b): Evidence from attribution studies, which synthesize information from climate models and observations. The panel shows temperature change attributed to total human influence, changes in well-mixed greenhouse gas concentrations, other human drivers due to aerosols, ozone and land-use change (land-use reflectance), solar and volcanic drivers, and internal climate variability. Whiskers show likely ranges {3.3.1}. Panel c): Evidence from the assessment of radiative forcing and climate sensitivity. The panel shows temperature changes from individual components of human influence, including emissions of greenhouse gases, aerosols and their precursors; land-use changes (land-use reflectance and irrigation); and aviation contrails. Whiskers show very likely ranges. Estimates account for both direct emissions into the atmosphere and their effect, if any, on other climate drivers. For aerosols, both direct (through radiation) and indirect (through interactions with clouds) effects are considered.{6.4.2, 7.3}

Details of observed changes in other parts of the climate system, such as the land, oceans, cryosphere and biosphere, and their attribution to human influence, can be found in the Summary for Policy Makers and the Technical Summary (IPCC, 2021).

The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.

In 2019, atmospheric CO_2 concentrations were higher than at any time in at least 2 million years and concentrations of CH_4 and N_2O were higher than at any time in at least 800 000 years.

Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (Figure 2). Temperatures during the most recent decade (2011–2020) exceed those of the most recent multi-century warm period, around 6500 years ago [0.2–1 °C relative to 1850–1900]. Prior to that, the next most recent warm period was about 125 000 years ago when the multi-century temperature [0.5 °C–1.5 °C relative to 1850–1900] overlaps the observations of the most recent decade.

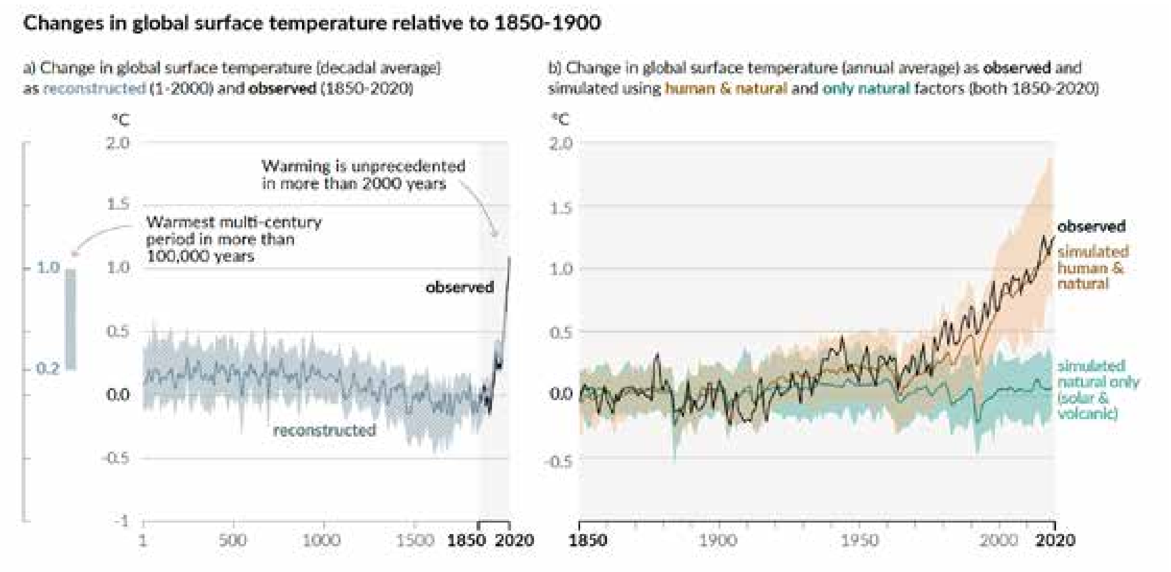

Figure 2. Taken from IPCC AR6 WG1 SPM.1: History of global temperature change and causes of recent warming. Panel a): Changes in global surface temperature reconstructed from paleoclimate archives (solid grey line, 1–2000) and from direct observations (solid black line, 1850–2020), both relative to 1850–1900 and decadally averaged. The vertical bar on the left shows the estimated temperature (very likely range) during the warmest multi-century period in at least the last 100 000 years, which occurred around 6 500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125 000 years ago, is the next most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) orbital variations. The grey shading with white diagonal lines shows the very likely ranges for the temperature reconstructions. Panel b): Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to CMIP6 climate model simulations

In 2011–2020, late summer Arctic sea-ice area was smaller than at any time in at least the past 1000 years). The global nature of glacier retreat, with almost all of the world’s glaciers retreating synchronously, since the 1950s is unprecedented in at least the last 2000 years.

Global mean sea level has risen faster since 1900 than over any preceding century in at least the last 3000 years. The global ocean has warmed faster over the past century than since the end of the last deglacial transition (around 11 000 years ago).

Highlights of IPCC Climate Change 2021, The Physical Science Basis for the current state of climate

Human-induced climate change is already affecting many weather and climate extremes in every region around the globe. Evidence of observed changes in extremes – such as heatwaves, heavy precipitation, droughts, and tropical cyclones – and, in particular, their attribution to human influence has strengthened since the publication of the previous IPCC report (AR5) in 2013.

It is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver of these changes. Some recent hot extremes observed over the past decade would have been extremely unlikely to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s, and human influence has very likely contributed to most of them since at least 2006.

The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis, and human-induced climate change is likely the main driver. Human-induced climate change has contributed to increases in agricultural and ecological droughts in some regions due to increased land evapotranspiration.

Decreases in global land monsoon precipitation from the 1950s to the 1980s are partly attributed to human-caused Northern Hemisphere aerosol emissions but increases since then have resulted from rising GHG concentrations and decadal to multi-decadal internal variability. Over South Asia, East Asia and West Africa increases in monsoon precipitation due to warming from GHG emissions were counteracted by decreases in monsoon precipitation due to cooling from human-caused aerosol emissions over the twentieth century. Increases in West African monsoon precipitation since the 1980s are partly due to the growing influence of GHGs and reductions in the cooling effect of human-caused aerosol emissions over Europe and North America.

It is likely that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone. There is low confidence in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones but data limitations inhibit clear detection of past trends on the global scale.

Human influence has likely increased the chance of compound extreme events since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale; fire weather in some regions of all inhabited continents; and compound flooding in some locations.

Highlights of IPCC Climate Change 2021, The Physical Science Basis for the current state of climate

In addition to this state of knowledge regarding observed climate change, and its attribution, these are the headline statements from the report:

- Improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing gives a best estimate of equilibrium climate sensitivity of 3 °C with a narrower range compared to AR5.
- Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5 °C and 2 °C will be exceeded during the twenty-first century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades.
- Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic se ice, snow cover and permafrost.
- Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.Under scenarios with increasing CO_2 emissions, the ocean and land carbon sinks are projected to be less effective at slowing the accumulation of CO_2 in the atmosphere.
- Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.
- Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.
- With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2 °C compared to 1.5 °C global warming and even more widespread and/or pronounced for higher warming levels.
- Low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed very likely range of future warming cannot be ruled out and are part of risk assessment.
- From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in CH_4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.
- Scenarios with very low or low GHG emissions lead within years to discernible effects on greenhouse gas and aerosol concentrations and on air quality relative to high and very high GHG emissions scenarios. Under these contrasting scenarios, discernible differences in trends of global surface temperature would begin to emerge from natural variability within around 20 years, and over longer time periods for many other climatic impact-drivers.

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Heatwaves, Wildfires and Air Pollution: Compounding and Cascading Climate Hazards to Health during the COVID-19 Pandemic – WHO/WMO

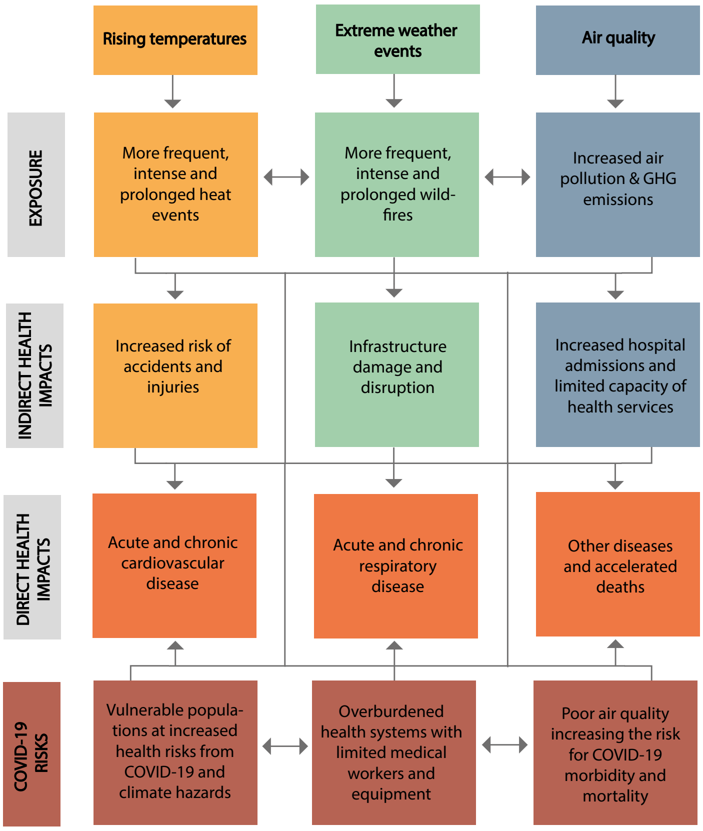
The severe short- and long-term impacts of COVID-19 are an additional burden for communities worldwide already dealing with the existing climate threats to health. Individuals infected with COVID-19 and exposed to climate hazards such as heat, wildfires or air pollution are at risk of experiencing more severe health outcomes compared to the risks from individual hazards. In addition, each individual climate hazard and COVID-19 impact can undermine and complicate public health responses to other climate hazards and COVID-19 impacts, compounding the stresses on health care quality and capacity. Heat and wildfire exposure combined with COVID-19 dynamics may lead to significant increases in hospital admissions whilst reducing health care services and infrastructural capacities – medical equipment is limited, medical staff may be affected and health care facilities may be impaired (Figure 1). Climate hazards and COVID-19 impacts could also interact to make specific and routine interventions less effective, more challenging or more risky.

Heat impacts: Mechanisms and vulnerabilities

Heat can affect human health in several ways. Direct impacts include increased morbidity and mortality due to heat stress, heatstroke and exacerbations of cardiovascular, respiratory and cerebrovascular diseases (Figure 2). Heat can also impair human behaviour (e.g., physical and mental activities), health service delivery, air quality and critical infrastructure, leading to indirect health effects. Some population groups are particularly vulnerable: people over the age of 65, infants and children, individuals with disabilities or pre-existing medical conditions, outdoor workers and people with low socioeconomic status. In urban areas, the dense concentrations of structures and the beehive of human activities can produce higher temperatures – the urban heat island effect – which may, for example, alter and deprive people of sleep at night.

Heat and health threats in recent years

Rising temperatures and more frequent, longer and persistent heatwaves in recent years are affecting human health, increasing heat-related mortality and impairment of capacity to work. Global heat-related mortality in people older than 65 years increased by 53.7% from 2000–2004 to 2014–2018, reaching 296 000 deaths in 2018, with the majority occurring in Japan, eastern China, northern India and central Europe. 37% of heat-related deaths can be attributed to human-induced warming, according to a global analysis including



Rising temperatures

Extreme weather events

Air quality

EXPOSURE

More frequent, intense and prolonged heat events

More frequent, intense and prolonged wild-fires

Increased air pollution & GHG emissions

INDIRECT HEALTH IMPACTS

Increased risk of accidents and injuries

Infrastructure damage and disruption

Increased hospital admissions and limited capacity of health services

DIRECT HEALTH IMPACTS

Acute and chronic cardiovascular disease

Acute and chronic respiratory disease

Other diseases and accelerated deaths

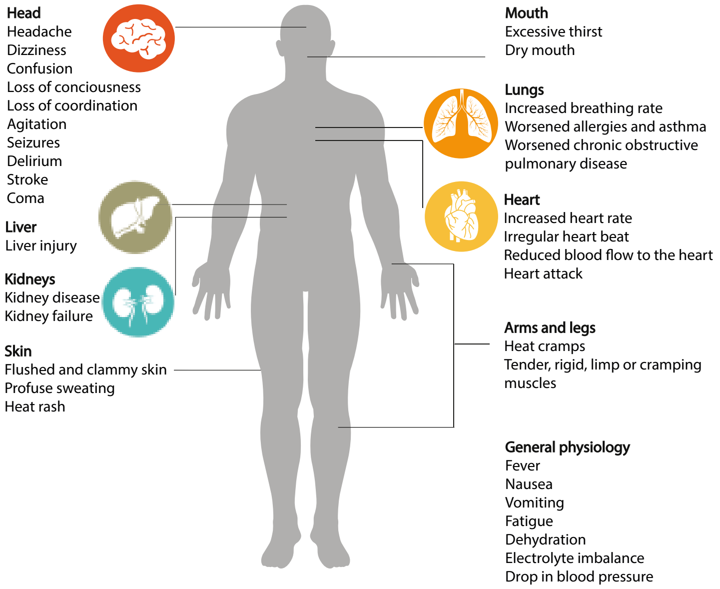
COVID-19 RISKS

Vulnerable populations at increased health risks from COVID-19 and climate hazards

Overburdened health systems with limited medical workers and equipment

Poor air quality increasing the risk for COVID-19 morbidity and mortality

Figure 1. Direct and indirect health impacts of climate hazards and COVID-19 risks representing compounding and cascading factors.



Head
Headache
Dizziness
Confusion
Loss of conciousness
Loss of coordination
Agitation
Seizures
Delirium
Stroke
Coma

Liver
Liver injury

Kidneys
Kidney disease
Kidney failure

Skin
Flushed and clammy skin
Profuse sweating
Heat rash

Mouth
Excessive thirst
Dry mouth

Lungs
Increased breathing rate
Worsened allergies and asthma
Worsened chronic obstructive pulmonary disease

Heart
Increased heart rate
Irregular heart beat
Reduced blood flow to the heart
Heart attack

Arms and legs
Heat cramps
Tender, rigid, limp or cramping muscles

General physiology
Fever
Nausea
Vomiting
Fatigue
Dehydration
Electrolyte imbalance
Drop in blood pressure

Figure 2. Symptoms of heat exposure affecting different organ systems. Adapted from Dahl et al., 2019.

data from 43 countries between 1991–2018 (Vicedo-Cabrera et al., 2021). In addition, rising temperatures were responsible for an excess of 103 billion potential work hours lost globally in 2019 compared with those lost in 2000 (Watts et al., 2020).

Combined risks of COVID-19 and heat

Susceptibility to COVID-19 overlaps significantly with susceptibility to heat, exacerbating the risks of compounding and cascading negative effects on health for vulnerable populations. Higher COVID-19 mortality rates were found among the elderly and individuals with underlying chronic conditions. Prevalent co-morbidities associated with increased COVID-19 severity include respiratory and cardiovascular diseases, hypertension, diabetes, chronic obstructive pulmonary disease, malignancy and chronic kidney disease, which are also risk factors for heat-related complications (Emami et al., 2020).

Wildfire smoke impacts: Mechanisms and vulnerabilities

Rising global temperatures and heatwaves increase the likelihood of wildfires, which in turn drive further global warming by increasing CO_2 emissions. Wildfire smoke contains a complex mixture of particles and significantly reduces air quality. Wildfire smoke can compromise air quality, which can irritate the lungs, cause inflammation, affect the immune system and increase the risk of lung infections. Fine particulate matter ($PM_{2.5}$), specifically, can penetrate deep into the lungs, where they pose a particular risk to human health. Vulnerable population groups include the elderly, socioeconomically disadvantaged individuals, people with co-morbidities and outdoor workers – all of whom are also vulnerable to heat and COVID-19. The specific health impacts of wildfire smoke still need to be better understood, given that the chemical composition might differ from air pollutants from other sources, potentially affecting health in different ways.

Wildfire, air pollution and health threats in recent years

In 114 countries, there was an increase in the number of days people were exposed to very high or extremely high risk of danger from fire in 2016–2019 compared with 2001–2004, translating into an increase in population exposure to wildfires in 128 countries (Figure 3, Watts et al., 2020). The increased occurrence of wildfires leads to peaks in air pollution concentrations that represent not only a risk factor for respiratory diseases but also a significant factor associated to all-cause and cardiovascular mortality (Karanasiou et al., 2021).

Combined risks of COVID-19, wildfires and air pollution in recent years

Long-term exposure to air pollution is linked to chronic diseases such as asthma, chronic obstructive pulmonary disease, lung cancer, heart diseases, effects on the nervous system and diabetes. Cardiovascular and respiratory diseases, diabetes, hypertension and cancer have been suggested to be associated with adverse prognosis in SARS-CoV-2 infected people (Wu et al., 2020). A significant fraction of COVID-19 infections lead to adverse long-term conditions affecting the heart, lungs and other organ systems, which could be worsened by air pollution exposure (Brunekreef et al., 2021). While quantification is difficult, emerging evidence suggests that the compound effects of air pollution and COVID-19 may lead to increased COVID-19 mortality. In the US, an increase of $1\ \mu g/m^3$ in the long-term $PM_{2.5}$ was associated with a statistically significant 11% increase in the COVID-19 mortality rate (Wu et al., 2020). In addition, long-term exposure to particulate matter was estimated to contribute to approximately 15% of COVID-19 mortality worldwide (Pozzer et al., 2020).

Heatwaves, Wildfires and Air Pollution: Compounding and Cascading Climate Hazards to Health during the COVID-19 Pandemic – WHO/WMO

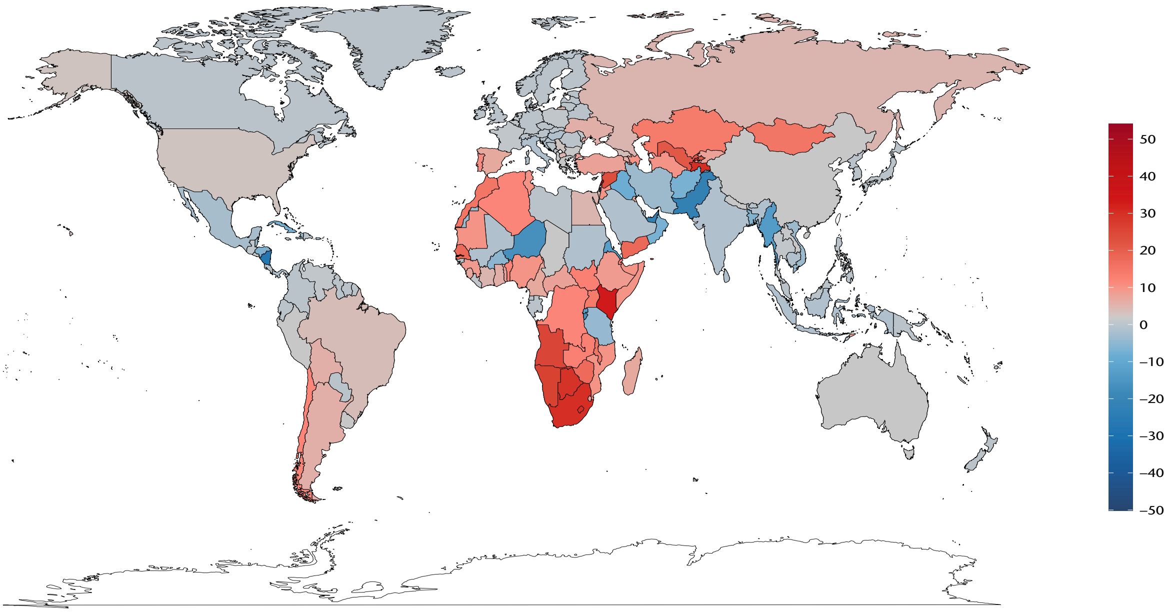


Figure 3. Change in the average number of days per year each person was exposed to very high or extremely high wildfire risk in 2016–2019 compared to 2001–2004. Adapted from Watts et al. 2020.

Strategic response to future increases in climate hazards and health impacts

Efforts to protect and rebuild local communities from public health, economic and societal consequences of COVID-19 will need to be sustained and aligned with national climate change strategies. This is not currently happening. Since the start of the pandemic, close to half of stimulus spending by G20 countries on energy-producing and consumer activities has gone to coal, oil and gas. In the absence of effective mitigation and adaptation, population exposure to compounding and cascading effects of climate hazards will continue to grow as scientists expect extreme temperature and wildfire events to occur with increased frequency, duration and magnitude in coming years due to climate change. Besides addressing impacts of individual climate hazards, public health researchers and decision-makers need to analyze and integrate health risks of compounding climate impacts into health adaptation plans and projections, target actions to protect vulnerable population groups, and promote COVID-19 recovery investments that both protect human health and reduce environmental and climate impacts (WHO, 2020).

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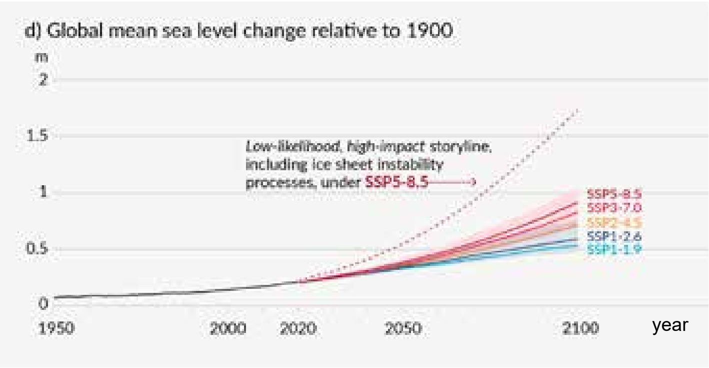
Sea Level and Coastal Impacts – WCRP (WMO/IOC/ISC)

Global mean sea levels rose 20 cm from 1900 to 2018 at an accelerating rate of 3.7 ± 0.5 mm/yr from 2006 to 2018 (IPCC, 2021). This is due to human-induced global warming which is causing thermal expansion of ocean water and melting land-based ice. The rate of ice sheet loss in Greenland and Antarctica increased by a factor of four between 1992-1999 and 2010-2019, so that ice sheet and glacier mass loss were the dominant contributors to sea level rise from 2006 to 2018. The IPCC Sixth Assessment Report (IPCC, 2021) projects that if greenhouse gas emissions continue to rise unabated (i.e., a SSP1-8.5 8.5 emission pathway), global mean sea level will likely rise 0.6–1.0 metres by 2100 (relative to 1995–2014) and, with less confidence, range from 1.7–6.8 m (perhaps more) by 2300 (Figure 1), with continued large changes beyond. The large increases in sea level by 2300 would be mostly attributable to significant inputs from the melting of the large ice sheets of Antarctica and Greenland. A substantial reduction in future greenhouse gas emissions would substantially reduce global sea-level rise. If emissions are reduced to meet the Paris Agreement goal of limiting global warming to “well below 2 °C” (i.e., an SSP1-2.6 emissions pathway), global mean sea level would still likely rise 0.3–0.6 m by 2100 (relative to 1995–2014) and with less confidence range from 0.3–3.1 m by 2300. This is a lower rise; but since the future emissions pathway is unknown at this point, and the ice sheet response to a given temperature rise is also highly uncertain, future sea-level rise might be substantially higher (IPCC, 2021).



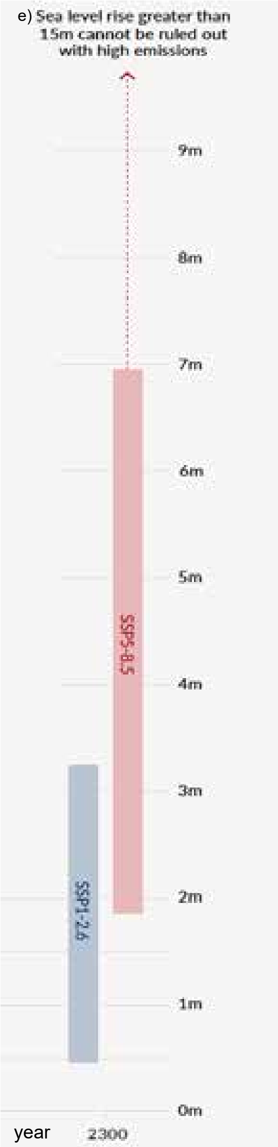


Figure 1. Panels d) and e) from Figure SPM.8 in IPCC AR6 Working Group 1 Summary for Policy Makers (IPCC, 2021). Panel d) Global mean sea level change in meters relative to 1900. The historical changes are observed (from tide gauges before 1992 and altimeters afterwards), and the future changes are assessed consistently with observational constraints based on emulation of CMIP, ice sheet, and glacier models. Likely ranges are shown for SSP1-2.6 and SSP3-7.0. Only likely ranges are assessed for sea level changes due to difficulties in estimating the distribution of deeply uncertain processes. The dashed curve indicates the potential impact of these deeply uncertain processes. It shows the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice sheet processes that cannot be ruled out; because of low confidence in projections of these processes, this curve does not constitute part of a likely range. Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated and observed changes relative to 1995–2014. Projected sea-level rise 1900 to 2100 for a range of emission scenarios. Panel e): Global mean sea level change at 2300 in meters relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice sheet processes that cannot be ruled out.

Sea-level rise threatens the world’s coastal areas through a range of biophysical impacts and changes (Oppenheimer et al., 2019) which include:

- permanent submergence of land by rising mean sea levels and high tides
- more frequent and deeper coastal flooding
- enhanced coastal erosion
- degradation, change and loss of coastal ecosystems
- salinization of soils and of ground and surface water
- impeded drainage and waterlogging.

These biophysical impacts will in turn have socioeconomic impacts on coastal residents and their livelihoods, such as direct damage to buildings and infrastructure and disruption of economic activities. In 2020, an estimated 267 million people (or about 4% of the world's population) were living within 2 m above sea level (Hooijer and Vernimmen, 2021). This number is growing due to both sea-level rise and demographic trends. It has long been recognized that small islands, deltas and coastal cities are especially threatened due to their high exposure and/or vulnerability.

When considering the impacts of sea-level rise, it is important to note that most of these occur because of increases in extreme sea-level events produced by combinations of tides, storm surges and waves that rise with mean sea level. Further impacts are due to local relative sea-level change rather than global mean sea-level rise because of both regional and local climatic – oceanic circulation changes, local hydrology, gravitational changes linked to ice melting, etc – and non-climatic components – land uplift/ subsidence – which also contribute to local sea levels (Figure 2). Hence, global changes need to be downscaled when evaluating future impacts and adaptation needs. In coastal areas where land is rising significantly today, for example, Alaska and northern Scandinavia, relative sea-level rise is reduced or may even be falling. In contrast, human-induced land subsidence in densely populated sedimentary coastal plains due to groundwater withdrawal and related processes is causing local substantial relative sea-level rise – for example, sometimes exceeding 1 cm/yr and up to 10 cm/yr in Jakarta. Due to the concentration of people in subsiding coastal areas, such subsidence is of global significance (Nicholls et al., 2021). The Asian coast is particularly prone to this process reflecting its geological heritage (often comprising deltas and alluvial plains) and associated high and growing urban populations (e.g., Jakarta, Bangkok, Shanghai).

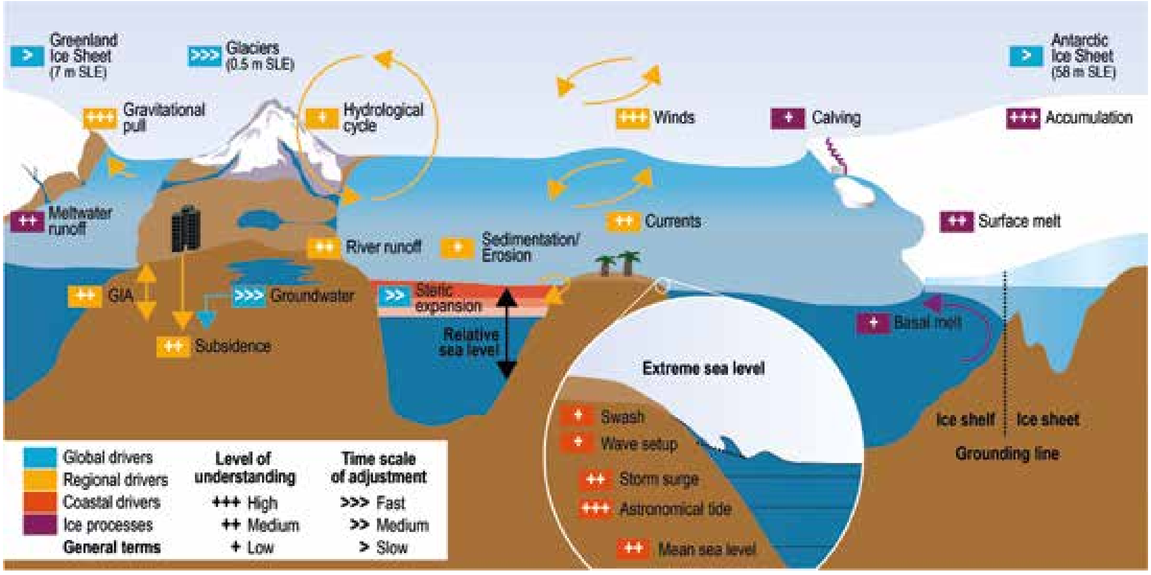


Figure 2. Scheme of the climate and non-climate driven processes that can influence global, regional (green colours), relative and extreme sea-level events (red colours) along coasts. Major ice processes are shown in purple and general terms in black. SLE stands for Sea Level Equivalent and reflects the increase in GMSL if the mentioned ice mass is melted completely and added to the ocean. [reproduction of Figure 4.4 in Oppenheimer et al., 2019] (GMSL – Global Mean Sea Level; GIA – Glacial Isostatic Adjustment.)

Adaptation to sea-level rise can be conducted using a range of contrasting methods, (Oppenheimer et al., 2019) including:

- Protection which reduces the likelihood of coastal impacts and can be implemented with (i) hard engineered structures such as dikes, seawalls, breakwaters and surge barriers, and (ii) sediment-based (or soft) protection such as beach and shore nourishment and dunes. It is also important to note that protection always leaves a residual risk—due to extreme events that exceed protection standards – and hence flood damage cannot necessarily be completely prevented.
- Advance creates new land by building seaward and upward or raises existing floodprone land. It can be achieved through land reclamation above sea levels and polderization, the gain of new low land enclosed by dikes. Advance is widely practiced around coastal cities where land is scarce and valuable and needs to take full account of sea-level rise in the future.

- Accommodation involves floodproofing and elevating buildings and infrastructure and is supported by early warning systems for floods. It does not entirely prevent coastal impacts but reduces the vulnerability of coastal residents, infrastructure, and associated activities.
- Planned or managed retreat reduces exposure to coastal impacts by moving people, infrastructure and human activities out of the exposed area – or by avoiding development of the coastal floodplain in the first place.
- Forced migration due to sea-level rise and/or extreme events may also occur.

Ecosystem-based or nature-based adaptation is of growing interest as these solutions recognizes the natural protection provided by coastal ecosystems, an advantage that was often ignored in the past. Coral and oyster reefs, mangroves, marshes and seagrass meadows act as protective buffers that attenuate extreme water levels (surges, waves), reduce rates of erosion and can raise elevation or create new land by trapping sediments and building up organic matter and detritus.

Effective use of these physical adaptation responses requires planning and institutional arrangements. Such plans might define standards for dike heights, building codes and/or setbacks for the flood plain, incentives for risk management, and disaster preparedness and early warning systems. Given the high uncertainties about future sea levels, adaptation pathways are being increasingly explored in coastal areas as an effective way of making adaptation decisions today (Haasnoot et al., 2019). However, these natural systems are poorly understood compared to engineered approaches so further research, development and learning is required to support wider and more confident application and promulgation for the future.

The challenge posed by climate-induced sea-level rise is massive and deeply uncertain, especially beyond 2100. To meet this challenge, the World Climate Research Programme (WCRP), which is jointly sponsored by WMO, the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the International Science Council (ISC), leads an integrated sea level research agenda reaching from the global down to the regional and coastal scales.

Strong mitigation efforts are needed now to avoid the multiple metres of sea-level rise over the next centuries that threatens all the coastal regions of the world. But even with such efforts, sea levels will continue to slowly rise for decades and centuries to come. Thus, coastal adaptation is essential in any future, but it will be easier and more likely to be successful when combined with stringent mitigation. There is a need to start exploring long-term adaptive strategies now if they are not already initiated. Such efforts should be linked to wider coastal management and development objectives. Small islands, deltas and coastal cities are key targets for such action. In addition, the establishment of coastal early warning systems, especially multi-hazard ones, is crucial, considering the multiple sources of coastal flooding in addition to sea-level rise. The WMO Coastal Inundation Forecasting Initiative (CIFI), which establishes early warning systems to enable vulnerable communities to respond and act fast when hazards threaten, is one of many UN activities aimed at coastal adaptation.

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Global Climate in 2021–2025 – WMO Global Annual to Decadal Climate Update

Climate Predictions for 2021–2025

The WMO Lead Centre for Annual to Decadal Climate Prediction produces a summary of predictions for the coming five years (Hermanson et al., 2021). These predictions are the best estimate of the near-term climate as they are based on the world's leading decadal prediction systems from WMO designated Global Producing Centres and non-designated contributing centres. They include multiple realizations (100 in total) with both observed initial conditions, of the type used in seasonal prediction, and boundary forcing, of the type used to drive long-term climate projections. The predictions do not include the small effects of changes in emissions – such as those due to the COVID-19 lockdowns – and they assume that no major volcanic eruptions occur in the period covered.

Predicted temperature patterns for 2021–2025 show a high probability for temperatures above the 1981–2010 average almost everywhere, with enhanced warming at high northern latitudes and over land compared to the ocean (Figure 1). The Arctic (north of 60 °N) anomaly is more than twice as large as the global mean anomaly.

Figure 2 shows the predicted annual mean global near surface temperature for the five-year period 2021–2025 relative to 1981–2010. The global mean near surface temperature is predicted to be between 0.9 °C and 1.8 °C above pre-industrial conditions (taken as the average over the period 1850 to 1900). The chance of at least one year exceeding 1.5 °C above pre-industrial levels is 40%, with a small chance (10%) of the five-year mean exceeding this level. It is important to note, that this is not the same as surpassing the Paris Agreement 1.5 °C level, which refers to the climatological condition over a long-term average. Instead this metric shows the increasing likelihood of a temporary exceedance of the 1.5 °C temperature level as the climate warms, which is likely to occur as Earth's climate draws closer to the Paris level. Confidence in forecasts of global mean temperature is high. Skill scores are shown in the right panels of Figure 2. Although the global coronavirus pandemic caused changes in emissions of greenhouse gases – and aerosols were not included in the forecast models – the impact of these changes on greenhouse gas levels is small (WMO, 2021).

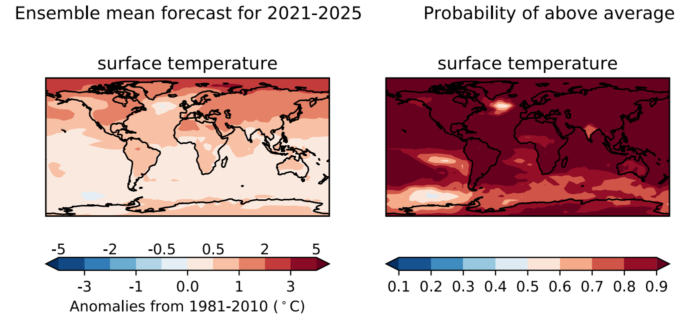

Figure 1. Predictions for 2021–2025 near surface temperature anomalies relative to 1981–2010. Ensemble mean (left) and probability of above average (right). As this is a two-category forecast, the probability for below average is one minus the probability shown on the right (WMO, 2021; Hermanson et al., 2021)

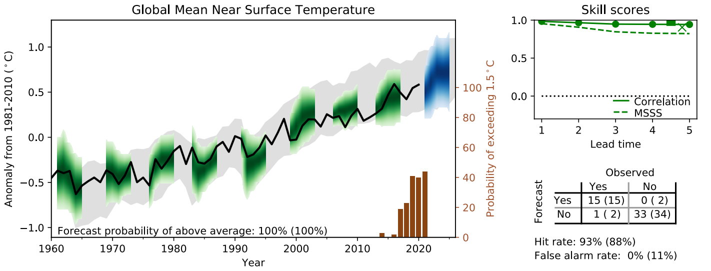

Figure 2. Multi-annual predictions of annual global mean near surface temperature relative to 1981–2010. Annual mean observations in black, forecast in blue, hindcasts in green and uninitialized simulations in grey. The shading indicates the 90% confidence range. The probability for above average in the five-year mean of the forecast is given at the bottom the main panel (in brackets the probability for above average in the first year). The inset in the main panel, referring to the right axis, is the probability of global temperature exceeding 1.5 °C above pre-industrial levels for at least one year during the five years starting in the indicated year (Smith et al. 2018). Observed temperatures are an average of three observational data sets (Hansen et al., 2010, updated; Karl et al., 2015, updated; Morice et al., 2021, updated), they are near surface (1.5 m) over land and surface temperatures over the ocean. Model temperatures are near surface throughout (WMO, 2021; Hermanson et al., 2021). Correlation and Mean Squared Skill Score (MSSS) for annual means in the forecast are shown in the upper right panel. A contingency table for the probabilistic skill is shown in the lower right.

Precipitation forecasts for 2021–2025 (Figure 3) suggest wetter than average conditions are likely to occur at high latitudes in both hemispheres and across the Sahel. The pattern of increased precipitation in the tropics and midlatitudes and reduced precipitation in the subtropics compared to the 1981-2010 reference period is consistent with an increased hydrological cycle that is expected as the climate warms. There is moderate but significant correlation skill over the Sahel, Greenland and across northern Europe and Eurasia (Hermanson et al, 2021), giving medium confidence in the forecast for an increased chance of precipitation in these regions.

This work is done in collaboration with the World Climate Research Program (WCRP) and supports the development of climate services. These forecasts are used by several National Meteorological and Hydrological Services and in research projects worldwide.

They will soon be used by WMO Regional Climate Centres to provide advance warnings to minimize the impact of climate hazards.

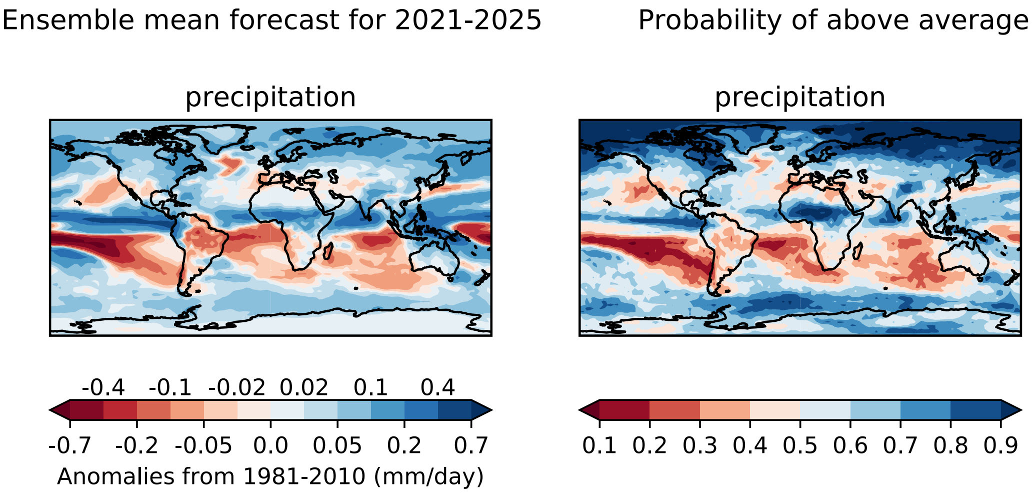

Figure 3. Predictions for 2021–2025 precipitation anomalies relative to 1981–2010. Ensemble mean (left) and probability of above average (right). As this is a two-category forecast, the probability for below average is one minus the probability shown in the right column (WMO, 2021; Hermanson et al., 2021)

Based on paleoclimate and historical evidence, it is likely that at least one large explosive volcanic eruption would occur during the twenty-first century. Such an eruption would reduce global surface temperature and precipitation, especially over land, for one to three years, alter the global monsoon circulation, modify extreme precipitation and change many CIDs (medium confidence). If such an eruption occurs, this would therefore temporarily and partially mask human-caused climate change (IPCC, WG1, 2021)

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Five years after the adoption of the Paris Agreement, the emissions gap is as large as ever

The emissions gap has not been narrowed and is, as yet, unaffected by COVID-19 (Figure 1). By 2030, annual emissions need to be 15 $GtCO_2e$ (range: 12–19 $GtCO_2e$) lower than current unconditional National Determined Contributions (NDCs) imply for a 2 °C goal, and 32 $GtCO_2e$ (range: 29–36 $GtCO_2e$) lower for the 1.5 °C goal. Full implementation of both unconditional and conditional NDCs would reduce each of these gaps by around 3 $GtCO_2e$. Collectively, current policies fall 3 $GtCO_2e$ short of meeting the level associated with full implementation of the unconditional NDCs.

The emissions gap for 2030 is defined as the difference between global total GHG emissions from least-cost scenarios that keep global warming to 2 °C, 1.8 °C or 1.5 °C with varying levels of likelihood and the estimated global total GHG emissions resulting from a full implementation of the NDCs.

As of mid-November 2020, when the latest Emissions Gap Report was published, none of the major emitters had submitted new or updated NDCs with stronger targets for 2030 and NDC target updates from 2019 were projected to reduce total emissions by less than 1% by 2030.

NDCs as at mid-November 2020 remained blatantly inadequate to achieve the climate goals of the Paris Agreement and would lead to a temperature increase of at least 3 °C by the end of the century. Countries must collectively increase their NDC ambitions threefold to get on track to a 2 °C goal and more than fivefold to get on track to the 1.5 °C goal.

Preliminary estimates of the impact of NDC target updates during the first six months of 2021, including by the US, the EU27 and the United Kingdom, and the announcements of Canada, China and Japan, indicate that emissions projections under the unconditional NDC scenario could be reduced by 12%–15% compared with the projection in the 2020 edition of the Emissions Gap Report. However, this is still far from sufficient to bridge the emissions gap in 2030. The 2021 edition of the Emissions Gap Report will provide a full assessment of the emissions and warming implications of the updated NDC targets.

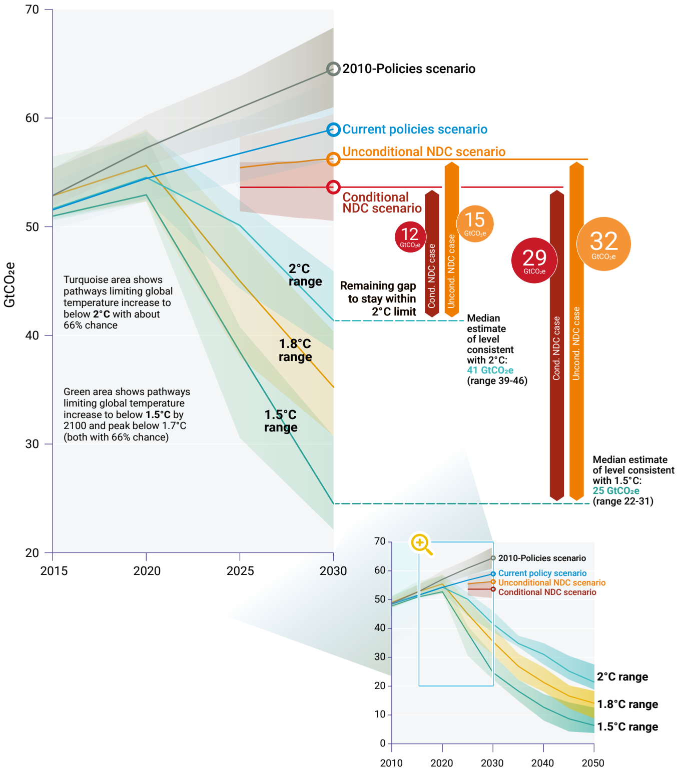

Figure 1. Global GHG emissions under different scenarios and the emissions gap in 2030 (median and 10th to 90th percentile range; based on the pre-COVID-19 current policies scenario), UNEP Emissions Gap report 2020

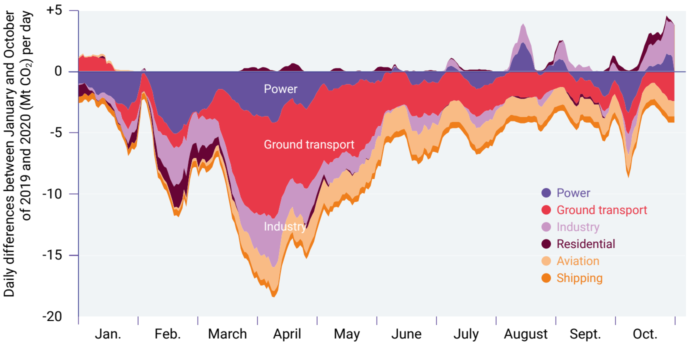

Figure 2. Reduction in emissions in 2020 relative to 2019 levels due to COVID-19 lockdowns, (UNEP Emissions Gap Report 2020)

The COVID-19 crisis likely only offers a short-term reduction in global emissions

COVID-19 containment measures significantly reduced global GHG emissions in 2020 (Figure 2). CO_2 emissions decreased by about 7% compared with 2019 emission levels, with a smaller drop in GHG emissions, as non-CO_2 is less affected (Emissions Gap Report, 2020). However, unless the containment measures are followed by economic rescue and recovery measures that support a low-carbon transition, this dip in global GHG emissions is estimated to result in no more than a 0.01 °C reduction of global warming by 2050, which by then is expected to have exceeded 1.5 °C (Forster et al., 2020).

Explorative projections based on available studies indicate that global GHG emissions are only significantly reduced by 2030 if COVID-19 economic recovery is used as an opening to pursue strong decarbonization (Figure 3, IEA sustainable recovery scenario). This could result in global GHG emissions of 44 $GtCO_2e$ by 2030, a reduction of 15 $GtCO_2e$ (just over 25%) by 2030 compared with the pre-COVID-19/current policies scenario, and considerably below global emissions in 2015.

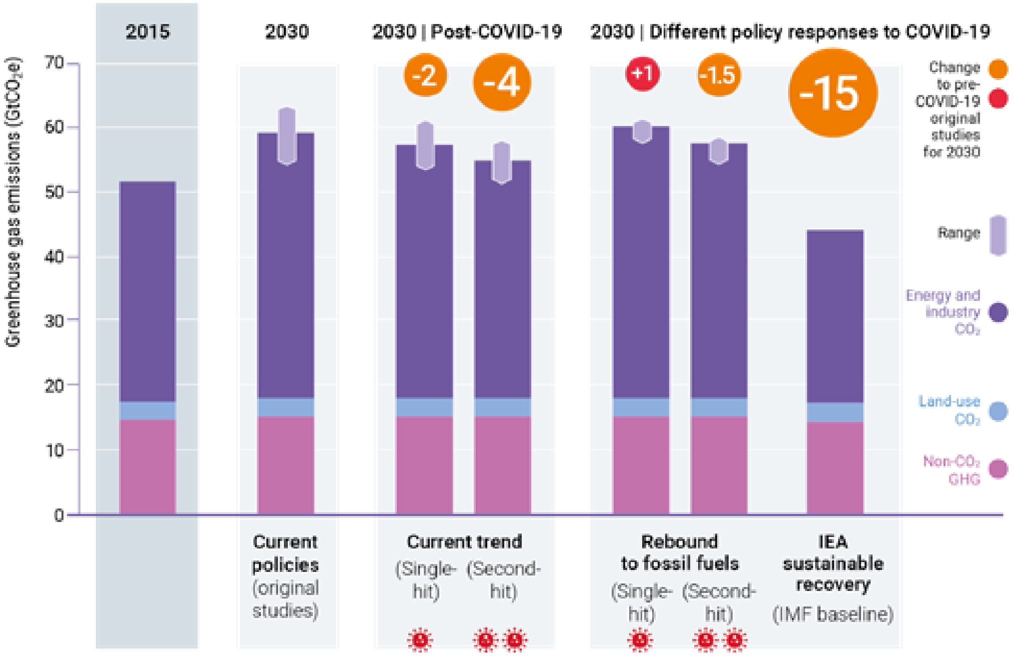

Figure 3. Global total GHG emissions by 2030 under a current policies scenario based on pre-COVID-19 studies and various "what if" scenarios using explorative calculations (post-COVID-19) (median and 10th to 90th percentile range), UNEP Emissions Gap Report 2020

So far, fiscal rescue and recovery measures have not accelerated a low-carbon transition

COVID-19-related fiscal spending by governments is of unprecedented scale, amounting to roughly US$ 12 trillion globally as at October 2020, or 12% of global gross domestic product (GDP) in 2020.

So far, the COVID-19 fiscal spending of G20 members has primarily supported the global status quo of high-carbon economic production or had neutral effects on GHG emissions (Figure 4). All G20 members have implemented several immediate rescue measures in response to the COVID-19 pandemic. These are mostly assessed neutral in terms of GHG emissions impact (for example, health-care-related spending) or supporting high-carbon industries without conditions for a low-carbon transition attached. As at November 2020, only around a quarter of G20 members had dedicated shares of their packages (accounting for up to 3% of GDP) explicitly to low-carbon measures. Most G20 members have brought forward measures and packages supporting a high-carbon status quo of their economies or are even fostering new high-carbon investments. Policies with positive impacts on reducing GHG emissions have been slightly more prevalent in fiscal recovery measures than rescue measures. This is noteworthy, as the next stages of COVID-19 fiscal interventions are likely to shift a greater proportion of capital towards recovery measures, indicating that there is potential for increased implementation of low-carbon measures.

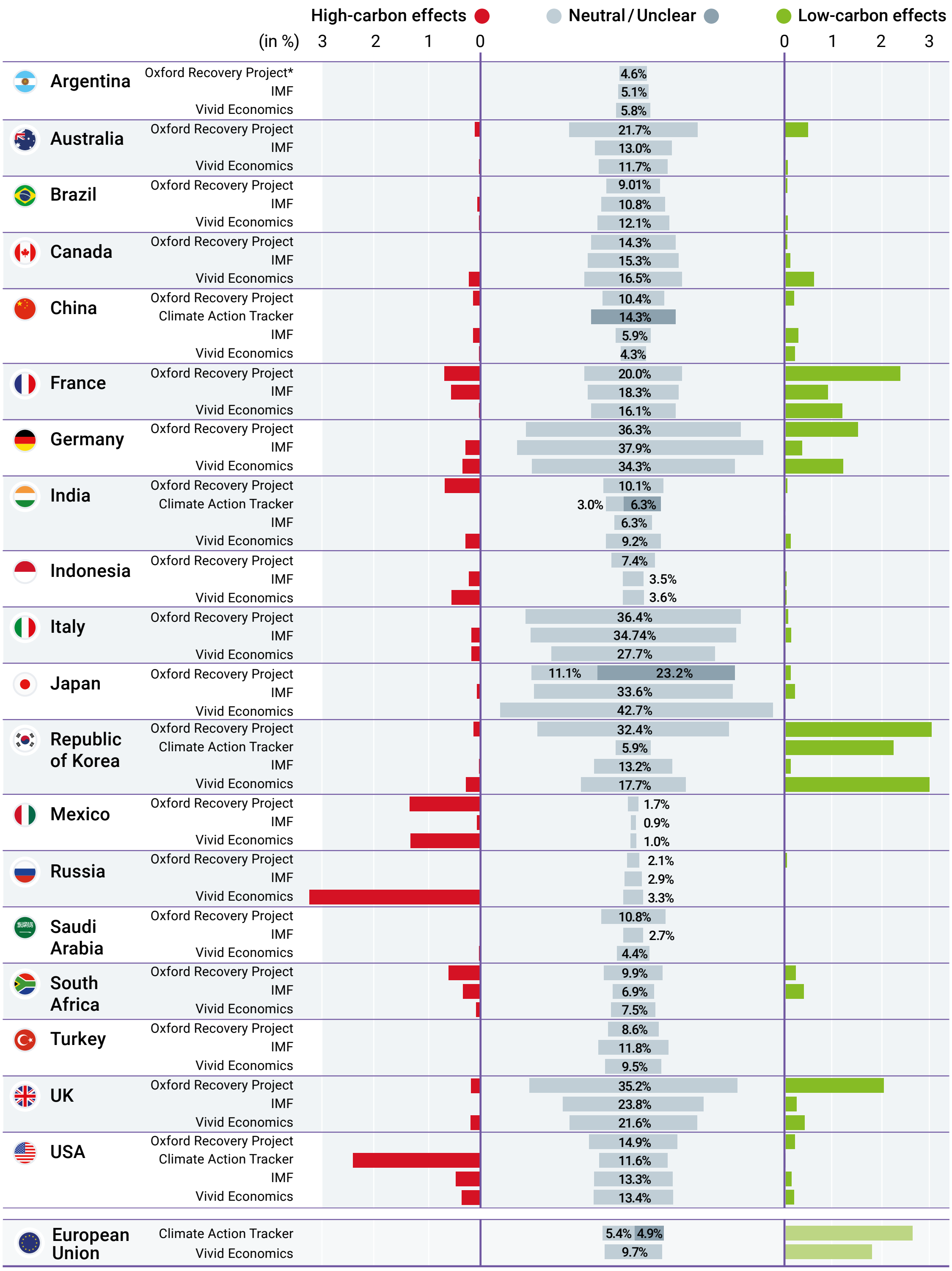

Figure 4. Non-exhaustive overview of total fiscal rescue and recovery measures of G20 members with high-carbon, neutral and low-carbon effects as a share of 2019 GDP (UNEP Emissions Gap Report 2020)

It is still in the hands of policymakers whether global economic rescue and recovery responses to the COVID-19 pandemic will lead to decreased or increased global GHG emissions in the longer term.

Net-zero emissions goals are encouraging but must be translated into strong near-term policies and reflected in the NDCs

One of the most significant and encouraging climate policy developments of 2020 is the growing number of countries that committed to achieving net-zero emissions by around mid-century. These commitments are broadly consistent with the Paris Agreement temperature goal, provided they are achieved globally.

At the time of completing the Emissions Gap Report 2020, 126 countries covering 51% of global GHG emissions had net-zero goals that were either formally adopted, announced or under consideration. With the adoption of a net-zero GHG target by 2050 by the United States of America, this share increased to around 63%.

Although the recent announcements of net-zero emissions goals are very encouraging, they highlight the vast discrepancy between the ambitiousness of these goals and the inadequate level of ambition in the NDCs for 2030.

To make significant progress towards achieving the long-term temperature goal of the Paris Agreement by 2030, two steps are urgently required. First, more countries need to develop long-term strategies that are consistent with the Paris Agreement, and second, the net-zero commitments need to be translated into strong near-term policies and action, and reflected in the NDCs for 2030. How countries choose to design and implement COVID-19 recovery packages is likely to be crucial in this context.

References

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