

Indicators of Global Climate Change 2024:

Annual update of key indicators of the state of the climate system and human influence

Introduction

Since 2023, the Indicators of Global Climate Change (IGCC) initiative, published in the journal [*Earth System Science Data*](#), has provided annual updates of key global climate indicators reported by the Intergovernmental Panel on Climate Change (IPCC).

IGCC differs from other annual publications by estimating the human contribution to long-term global warming and by being grounded in methods assessed by the IPCC Sixth Assessment Report (AR6)—employing the same IPCC methods with updated datasets. This ensures that IGCC published numbers are traceable back to the latest IPCC assessment (see Table 1 below and Table 11 of the ESSD publication). IGCC follows the same assessment process chain as employed in AR6 to estimate the human contribution to global warming from the the observed trends in atmospheric concentrations and surface temperatures.

In doing so, IGCC provides vital timely scientific information in the gaps between IPCC assessment reports, on policy-relevant global climate indicators such as greenhouse gas emissions, human-caused warming, and the remaining global carbon budget. This year's edition includes two additional indicators, global land precipitation and global mean sea level rise.

IGCC 2024 was produced by an international team of 61 scientists, including IPCC Lead Authors, Contributing Authors, and Chapter Scientists, from 54 institutions across 17 countries.

The importance of observations

The production of these annual updates relies fundamentally on the availability, continuity, and integrity of continued systematic climate observations. Drawing from a wide array of global monitoring systems—including emissions inventories, atmospheric concentration measurements, satellite observations, and in situ data—this work synthesizes multiple lines of evidence to generate robust, policy-relevant indicators of climate change and human influence.

These observations, coordinated through the considerable efforts of GCOS, WMO, WRCP, GCOS, GOOS, ECWMF, ESA, NOAA and NASA as well as national meteorological services and research institutions worldwide, underpin the scientific rigor and transparency of the IGCC framework.

Without them, IGCC's updates would be based solely on simulations and lack observational anchoring. IGCC therefore acknowledges all of these efforts, noting that their sustained provision and the international collaboration they represent are essential to ensuring that decision-makers are equipped with timely, consistent, and actionable climate information in the gaps between IPCC assessment reports.

We also acknowledge efforts dedicated to coordinating and advancing systematic observations and safeguarding the future availability of the data that IGCC and many others rely upon to further understanding of the state of the climate system and how it is changing, including SOFF and EW4ALL.

Observations and datasets used to produce IGCC indicators include:



GHG Emissions GCB, PRIMAP, CEDS, EDGAR GFED, Grassi NGHGI, CIP

- 🌐 GHG Concentrations *NOAA GML, AGAGE*
- 🌐 Short-Lived Climate Forcers *CEDS, CAMS, GFED*
- 🌐 Natural Forcing *GloSSAC, OMPS LP*
- 🌐 Earth Energy Imbalance *including IAP, EN4, JNA, NCEI*
- 🌐 Surface Temperature *HadCRUT5, NOAA GlobalTemp, Kadow, Berkeley Earth, China-MST*
- 🌐 Sea Level *AR6 GMSLR time series (tide gauge and satellite altimetry -AVISO/CNES, CSIRO, NASA/GSFC, NOAA, SL_cci/ESA and University of Colorado)*
- 🌐 Global Land Precipitation *GPCC, CRU TS, GPCP, GHCN*
- 🌐 Land Average Maximum Temperatures *HadEX3, Berkeley Earth, ERA5*

Headlines from IGCC 2024

- Human activities have resulted in the equivalent of around 53 billion tonnes of carbon dioxide (GtCO₂) being released into the atmosphere on average each year over the last decade. Atmospheric concentrations of all three major greenhouse gases have increased.
- Between 2015 and 2024, the temperature was 1.24°C higher than in pre-industrial times. Of this, 1.22°C was caused by human activities. Allowing for small uncertainties, this means essentially all of the global warming was human-induced.
- Human-caused warming has meanwhile increased at a rate of around 0.27°C per decade (2015-2024).
- Surplus heat accumulating in the Earth's system at an accelerating rate is driving changes in every component of the climate system, including sea level rise.
- Between 2019 and 2024, global mean sea level increased by around 26 mm, more than doubling the long-term rate of 1.8 mm per year seen since the turn of the twentieth century.
- The central estimate of the remaining carbon budget for 1.5°C is 130 billion tonnes of carbon dioxide (CO₂) (from the beginning of 2025). This would be exhausted in a little more than three years at current levels of CO₂ emissions.

Other key findings

- The most recent decade (2015-2024) was 0.31°C warmer than the previous decade (2005-2014). These changes, although amplified somewhat by the exceptionally warm years in 2023 and 2024, are broadly consistent with warming rates over the last few decades.
- Emissions of non-methane short-lived climate forcers (SLCFs) have decreased relative to 2019, except for nitrogen oxide (NO_x), partly driven by increased emissions from biomass burning.
- Emissions of cooling aerosols continue to decline as a result of tackling air pollution, unmasking more of the warming effect of greenhouse gases.
- Total anthropogenic effective radiative forcing (ERF) has increased due to increased GHG concentrations resulting from rising emissions combined with decreases in emissions of aerosols.
- The rate of global heating has about doubled from the levels seen in the 1970s and 1980s.
- The rapid warming over the last few decades has resulted in record extreme temperatures over land, with average maximum temperatures reaching 1.9°C over the decade 2015-2024 and rising at a substantially faster rate than global mean surface temperature.

Full reference

Forster, P. M., Smith, C., Walsh, T., Lamb, W. F., Lamboll, R., Cassou, C., Hauser, M., Hausfather, Z., Lee, J.-Y., Palmer, M. D., von Schuckmann, K., Slangen, A. B. A., Szopa, S., Trewin, B., Yun, J., Gillett, N. P., Jenkins, S., Matthews, H. D., Raghavan, K., Ribes, A., Rogelj, J., Rosen, D., Zhang, X., Allen, M., Aleluia Reis, L., Andrew, R. M., Betts, R. A., Borger, A., Broersma, J. A., Burgess, S. N., Cheng, L., Friedlingstein, P., Domingues, C. M., Gambarini, M., Gasser, T., Gütschow, J., Ishii, M., Kadow, C., Kennedy, J., Killick, R. E., Krummel, P. B., Liné, A., Monselesan, D. P., Morice, C., Mühle, J., Naik, V., Peters, G. P., Pirani, A., Pongratz, J., Minx, J. C., Rigby, M., Rohde, R., Savita, A., Seneviratne, S. I., Thorne, P., Wells, C., Western, L. M., van der Werf, G. R., Wijffels, S. E., Masson-Delmotte, V., and Zhai, P.: Indicators of Global Climate Change 2024: annual update of key indicators of the state of the climate system and human influence, *Earth Syst. Sci. Data*, 17, 2641–2680, <https://doi.org/10.5194/essd-17-2641-2025>, 2025

Changes to key indicators since publication of the IPCC AR6 WGI report



Key Indicators of Global Climate Change: Since IPCC Sixth Assessment Report

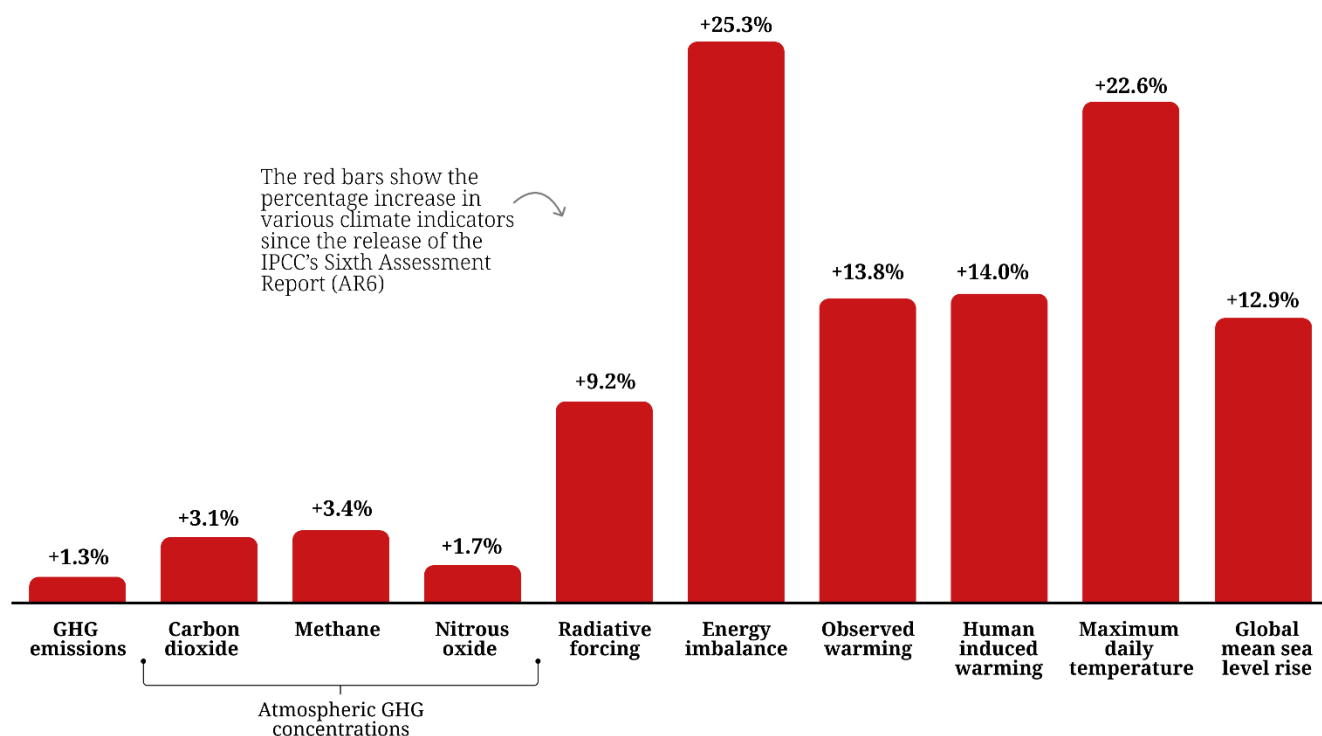
	IPCC 6th assessment	→	2024	Change %
Greenhouse gas emissions	52.9	↗	53.6 GtCO ₂ e/year	+1.3%
CO ₂ concentration	410.1	↗	422.8 ppm	+3.1%
CH ₄ concentration	1 866.3	↗	1 929.7 ppb	+3.4%
N ₂ O concentration	332.1	↗	337.9 ppb	+1.7%
Effective radiative forcing	2.72	↗	2.97 W/m ²	+9.2%
Earth's energy imbalance	0.79	↗	0.99 W/m ²	+25.3%
Global mean surface temperature change	1.09°	↗	1.24° °C	+13.8%
Human-induced warming (decade)	1.07°	↗	1.22° °C	+14.0%
Land average max temp change	1.55°	↗	1.9° °C	+22.6%
Remaining carbon budget (± 1.5°C, 50% probability)	500	↘	130 GtCO ₂	-74.0%
Sea level rise (GMSLR)	201.9	↗	228 mm	+12.9%

Percentage changes to key indicators since publication of the IPCC AR6 WGI report

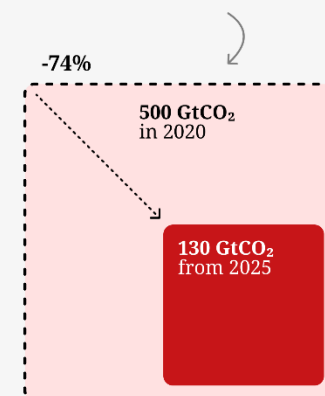


Key Indicators of Global Climate Change:

Percentage change since IPCC Sixth Assessment Report



The large pink square represents the 2020 remaining carbon budget for $\uparrow 1.5^{\circ}\text{C}$, while the smaller red square shows how much is left now



Remaining carbon budget for $\uparrow 1.5^{\circ}\text{C}$ (50% likelihood)

Table 1: Summary of headline results and methodological updates from IGCC 2024

Climate indicator	AR6 2021 assessment	This 2024 assessment	Explanation of changes	Methodological updates since AR6
GHG emissions AR6 WGIII Chap. 2: Dhakal et al. (2022); see also Minx et al. (2021)	2010–2019 average: 55.9±6 Gt CO ₂ e	2010–2019 average: 52.9±5.4 Gt CO ₂ e 2014–2023 average: 53.6±5.2 Gt CO ₂ e	Average emissions in the past decade grew at a slower rate than in the previous decade. The change from AR6 is due to a systematic downward revision in CO ₂ -LULUCF and CH ₄ estimates. Real-world emissions have slightly increased.	CO ₂ -LULUCF emissions revised down. CO ₂ GCB fossil fuel and industry emissions used instead of EDGAR. PRIMAP-hist TP used in place of EDGAR for CH ₄ and N ₂ O emissions and atmospheric measurements taken for F-gas emissions. These changes reduce estimates by around 3 Gt CO ₂ e (Sect. 2).
GHG concentrations AR6 WGI Chap. 2: Gulev et al. (2021)	2019: CO ₂ , 410.1 [±0.36] ppm CH ₄ , 1866.3 [±3.2] ppb N ₂ O, 332.1 [±0.7] ppb	2024: CO ₂ , 422.8 [±0.4] ppm CH ₄ , 1929.7 [±3.3] ppb N ₂ O, 337.9 [±0.4] ppb	Increases caused by continued GHG anthropogenic emissions	Updates based on NOAA data and AGAGE (Sect. 3)
Effective radiative forcing change since 1750 AR6 WGI Chap. 7: Forster et al. (2021)	2019: 2.72 [1.96 to 3.48] W m ⁻²	2024: 2.97 [2.05 to 3.77] W m ⁻²	Trend since 2019 is caused by increases in GHG concentrations and reductions in aerosol precursors.	Follows AR6 with minor update to aerosol precursor treatment and emissions dataset that revises 2019 ERF estimate relative to 1750 downwards (more negative) by 0.09 W m ⁻² . Added this year is a new method to estimate the ERF from land-use surface reflection and irrigation to avoid scaling with cumulative emissions. This does not materially affect the ERF (Sect. 5).

Climate indicator	AR6 2021 assessment	This 2024 assessment	Explanation of changes	Methodological updates since AR6
Earth's energy imbalance AR6 WGI Chap. 7: Forster et al. (2021)	2006–2018 average: 0.79 [0.52 to 1.06] W m ⁻²	2012–2024 average: 0.99 [0.70 to 1.28] W m ⁻²	A 25 % increase in energy imbalance estimated based on increased rate of ocean heating.	Ocean heat content time series extended from 2018 to 2024 using all five of the AR6 datasets. Other heat inventory terms updated following von Schuckmann et al. (2023). Ocean heat content uncertainty is used as a proxy for total uncertainty. Further details in Sect. 6.
Global mean surface temperature change since 1850–1900 AR6 WGI Chap. 2: Gulev et al. (2021)	2011–2020 average: 1.09 [0.95 to 1.20] °C	2015–2024 average: 1.24 [1.11 to 1.35] °C	An increase of 0.15 °C within 4 years, indicating a high decadal rate of change which may in part be internal variability.	Methods match four datasets used in AR6. Individual datasets have updated historical data, but these changes are not materially affecting results (Sect. 7).
Human-induced global warming since pre-industrial levels AR6 WGI Chap. 3: Eyring et al. (2021) SR1.5 Chap. 1	2010–2019 decade average: 1.07 [0.8 to 1.3] °C 2017 single year: 1.0 [0.8 to 1.2] °C	2015–2024 decade average: 1.22 [1.0 to 1.5] °C 2024 single year: 1.36 [1.1 to 1.7] °C	An increase of 0.15 °C within 5 years, indicating a high decadal rate of change (broadly consistent with warming projections). The decadal warming rate increased slightly between 2019 and 2024. One of the three AR6 methods is diverging.	The three methods for the basis of the AR6 assessment are retained, but each has new input data (Sect. 8).

Climate indicator	AR6 2021 assessment	This 2024 assessment	Explanation of changes	Methodological updates since AR6
Remaining carbon budget for 50 % likelihood of limiting global warming to 1.5 °C AR6 WGI Chap. 5: Canadell et al. (2021)	From the start of 2020: 500 Gt CO ₂	From the start of 2025: 130 Gt CO ₂	The 1.5 °C budget is becoming very small. The RCB can exhaust before the 1.5 °C threshold is reached due to having to allow for future non-CO ₂ warming.	Emulator and scenario change has reduced budget since 2020 by 100 Gt CO ₂ (Sect. 9).
Land average maximum temperature change compared to pre-industrial times. AR6 WGI Chap. 11: Seneviratne et al. (2021)	2009–2018 average: 1.55 °C	2015–2024 average: 1.90 °C	Rising at a substantially faster rate compared to global mean surface temperature	HadEX3 data used in AR6 replaced with ERA reanalysis data employed in this report, which is more updatable going forward. Adds 0.01 °C to estimate (Sect. 10)
Global land precipitation compared to pre-industrial times (Douville et al., 2021)	Likely increased since the middle of the 20th century with a faster increase since the 1980s with large	Large interannual variability associated with El Niño dominates the record in recent years, making	2023 exhibited a negative anomaly relative to pre-industrial times due to El Niño conditions	The four datasets used in AR6 have been extended (Sect. 11)

Climate indicator	AR6 2021 assessment	This 2024 assessment	Explanation of changes	Methodological updates since AR6
	interannual variability	long-term trend less clear		
Global mean sea-level rise since 1901 (Gulev et al., 2021; Fox-Kemper et al., 2021)	1901 to 2018 change 201.9 [150.3 to 253.5] mm at a rate of 1.73 [1.28 to 2.17] mm yr ⁻¹	1901 to 2024 change 228.0 [176.4 to 279.6] mm at a rate of 1.85 [1.43 to 2.27] mm yr ⁻¹	Sea-level rise continues to accelerate.	AR6 data extended with three of the six datasets from AR6, using latest satellite data (Sect. 12).