Comment

Supplementary information to:

Approaching 1.5 °C: how will we know we've reached this crucial warming mark?

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Approaching 1.5°C: How will we know we've reached this crucial warming mark? Supplementary information

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Here we assess various indicators used for quantifying the current level of global mean temperature change, and compare their indications of global temperature change over recent decades (Figure S.1) and of the current level of global warming (Table S.1). We also compare the year of exceeding past global warming levels of 0.5°C, 1.0°C and 1.2°C for each indicator (Table S.1). We use a combined observational dataset following IPCC methods (Forster et al., 2023) and process the indicators from this. We follow the Intergovernmental Panel on Climate Change (IPCC) convention of using the mean from 1850-1900 as representative of "pre-industrial", so anomalies are defined relative to 1850-1900. For each indicator, we explain potential difficulties that could arise from its use to assess when global warming reaches 1.5°C relative to pre-industrial, and explain the rationale for our proposed indicator, the Current Global Warming Level.

Proposed criteria for an appropriate indicator for identifying when global warming reaches 1.5°C.

We propose that the indicator should meet 2 requirements:

1. Immediacy of identification of passing particular levels of global warming, such as 1.5°C, to avoid unnecessary delays in responding to the exceedance.
2. Consistency with methods and definitions of related quantities in the IPCC 6th Assessment Report (AR6), which represents the authoritative source of climate science information accepted by governments worldwide.

A key quantity of interest is the projected year of exceedance for 1.5°C global warming. In AR6, future Global Warming Levels are defined using 20-year means of projected temperature anomalies, and the crossing time or "exceedance year" for a GWL is defined as the mid-point of the 20-year period (Gulev at al., 2021). We suggest that the indicator for the current level of global warming should be consistent with this definition, otherwise the apparent time of reaching 1.5°C could differ from the time previously projected by the IPCC merely because of differences in the definition. We anticipate that this could potentially be misinterpreted as indicting that global warming had reached 1.5°C either earlier or later than projected, which could either undermine confidence in projections or misinform discussions on action to address climate change.

The IPCC also assesses impacts of climate change in relation to baselines of observed global temperature, typically averaged over 20 or 30 years. We anticipate that once 1.5°C global warming has been exceeded, an observed baseline at that level will be established for assessing the impacts of any further

ongoing climate change. The indicator used for the current level of global warming should also allow consistency with such a future definition of 1.5°C warming in observations.

Indicators of current warming using time-means from observations

The IPCC AR6 Working Group 1 report Summary for Policymakers (IPCC, 2021) gave its headline figure of observed global mean temperature rise in terms of means over the preceding 10 and 20-year periods. These IPCC 20-year and 10-year warming metrics are now being monitored and updated on an annual basis: by applying IPCC AR6 methods to more recent data (Forster et al., 2023), the global mean temperature anomaly for 2003-2022 has been assessed as 1.03 [0.87 – 1.13] °C and the anomaly for 2013 – 2022 is 1.15 [0.95 to 1.20] °C (Table S.1).

These indicators would not meet our first requirement for a suitable indicator as there would be a delay in identifying the exceedance of a global warming level. The reporting of observed warming at the end of a 20-year period would mean the reaching of 1.5°C warming would not be known until a decade after the exceedance year, which would have been defined retrospectively (Figure S.1(a)). Even if a 10-year mean is used, which has been shown to be reasonably representative of longer-term means centred around it (Trewin, 2022), using this would still leave a 5-year delay (Figure S.1(a)).

Instantaneous indicators of current warming

The Copernicus Climate Change Service provides a monitoring product[1] which defines "current global warming" as the end-point of a linear trend fitted to the final 30 years of the observed global mean temperature anomaly. This gives the current global warming as 1.24°C for September 2023, based on the ERA5 reanalysis, which uses observations combined with a model to reconstruct historical climate. Applying the same method to observations up to 2022 gives 1.23°C (Table S.1).

A widely-used approach is to use a statistical smoothing (such as LOESS) to instantaneously calculate current warming, allowing for the non-linear nature of change but also removing internal variability over short periods. Applying LOESS smoothing to observational data over the last century (from 1923 to 2022) suggests current warming of 1.08 to 1.34°C, depending on parameter choices (Table S.1).

Another instantaneous indicator of current level of global warming is provided by a calculation of the warming attributable to human causes using observed changes in the concentrations of greenhouse gases and aerosols along with calculations of the radiative forcing due to these changes and estimates of the climate sensitivity (the response of temperature to a given radiative forcing) (Haustein et al., 2017). For 2022, the human-induced warming has been assessed as 1.26 [1.0 to 1.6]°C (Forster et al., 2023; Table S.1).

[1] Global temperature trend monitor (copernicus.eu)

Timeseries of these instantaneous indicators are shown in Figure S.1(b).

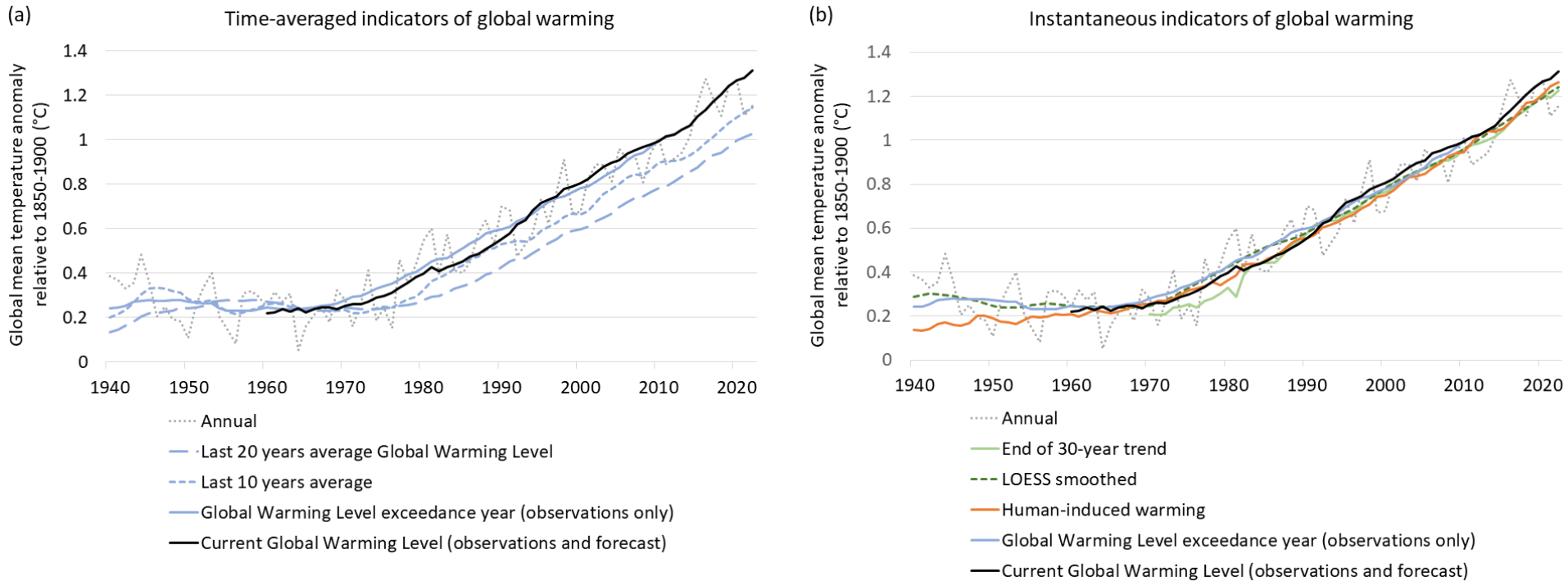

Figure S.1*. Timeseries of indicators for defining current level of global mean temperature change. (a) Time-mean indicators. (b) Instantaneous indicators. See Table S.1 for description of indicators.*

Table S.1. *The level of change in 2022 for the global mean temperature anomaly with various metrics, and the human-induced warming, and the years when anomalies of 0.5°C, 1.0°C and 1.2°C relative to 1850-1900 are identified as having been passed. Blue rows show metrics with a delay in identifying warming level exceedance, green rows show existing instantaneous metrics, and yellow rows show variants of our proposed Current Global Warming Level (CGWL) metric with the exceedance year defined as the middle of the 20-year period, with different assumptions or methods. n/a: calculation not available*

Indicator	Description	Exceedance year for 0.5°C global warming	Exceedance year for 1.0°C global warming	Exceedance year for 1.2°C global warming	Currently-identified level of change (°C)
Last 20 years average Global Warming Level	Average of last 20 years using observed surface temperature timeseries based on IPCC methods (Forster et al, 2023). The "exceedance year" is 10 years in the past, so can only be defined retrospectively.	1985 (but not known until 1995)	2011 (but not known until 2021)	Not yet known from observations alone	1.03 [0.87 – 1.13]
Last 10 years average	Average of last 10 years using observed surface temperature timeseries based on IPCC methods (Forster et al, 2023).	1983 (but not known until 1988)	2012 (but not known until 2017)	Not yet known from observations alone	1.15 [1.00 – 1.25]
End of 30-year trend (reanalysis)	End of 30-year linear trend based on the surface temperature timeseries from reanalysis, as published by the Copernicus Climate Change Service. Warming value applies to September 2023. Indicative uncertainties are based on the average of last 20 years of observations (see above).	N/A	2016	2021	1.24 [1.07 – 1.33]
End of 30-year trend (observed)	End of 30-year linear trend using observed surface temperature timeseries based on IPCC methods (Forster et al, 2023). Warming value applies to the most recent year. Indicative uncertainties are based on the average of last 20 years of observations (see above).	1988	2013	2022	1.23 [1.07 – 1.33]

LOESS-smoothed (observed)	Locally Estimated Scatterplot Smoothing (LOESS) applied to using observed surface temperature timeseries based on IPCC methods (Forster et al, 2023). Warming value applies to the most recent year. Indicative uncertainties are based on the average of last 20 years of observations (see above).	1984	2012	2021	1.24 [1.08 – 1.34]
Human-induced Warming	An estimate of the surface temperature rise attributable to forcing of the climate system by human activities from (Forster et al, 2023). Warming value applies to the most recent year.	1982	2012	2020	1.26 [1.0 – 1.6]
Current Global Warming Level (observations + WMO forecast)	20-year mean from last 10 years observations and next 10 years from forecast initialised with recent data (Hermanson et al, 2022). RCP4.5 concentrations scenario. Centred on most recent year.	1988	2011	2018	1.31 [1.19 – 1.43]
Current Global Warming Level (observations + UKCP projection, RCP4.5)	20-year mean from last 10 years observations and next 10 years from UKCP projections (Lowe et al, 2018). RCP4.5 emissions scenario. Centred on most recent year.	n/a	2014	2020	1.25 [1.15 – 1.35]
Current Global Warming Level (observations + UKCP projection, RCP6.0)	20-year mean from last 10 years observations and next 10 years from UKCP projections (Lowe et al, 2018). RCP6.0 emissions scenario. Centred on most recent year.	n/a	n/a	n/a	1.24 [1.14 – 1.34]
Current Global Warming Level (observations + UKCP projection, RCP2.6)	20-year mean from last 10 years observations and next 10 years from UKCP projection Lowe et al, 2018). RCP2.6 emissions scenario. Centred on most recent year.	n/a	n/a	n/a	1.23 [1.13 – 1.33]

Inconsistency with IPCC definition of future Global Warming Levels

While the above instantaneous indicators would allow the exceedance of 1.5°C global warming to be identified rapidly, they are inconsistent with the IPCC definition of future Global Warming Levels defined as 20-year averages. Moreover, impacts assessments do not use baselines defined with end-points of linear or statistically-smoothed trends. Furthermore, impacts assessments use baselines defined in terms of actual temperatures, not a calculation of the human contribution to warming, since it is the actual climatic conditions that exert the impact. Hence we argue that none of the above instantaneous indicators are consistent with established practice for defining 1.5°C global warming in the future or with how it will be defined for impacts assessment once it is in the past, and hence do not meet our second requirement for a suitable indicator.

The Current Global Warming Level metric

We propose an alternative indicator, the Current Global Warming Level (CGWL), calculated as a 20-year average centred at the end of the most recent calendar year for which complete observations are available across the year, using the average of the previous 10 years from observations combined with the next 10 years from future projections or forecasts. This meets the requirement both for rapid identification and consistency with established IPCC practice.

Figure S.1 shows timeseries of the CGWL derived from observations combined with the initialised 10-year forecast from the World Meteorological Organisation (WMO) which follows the methods described in Hermanson et al (2022), for which initial conditions in 2022 are consistent with observations. This is driven with concentrations from the RCP4.5 scenario. Table S.1 compares the CGWL and its exceedance years for past warming levels with those from other indicators. The uncertainty range is quantified with the 5th and 95th percentiles from the ensemble.

Table S.1 also shows results from alternative calculations of the CGWL using future projections from the UK Climate Projections (UKCP) global probabilistic projections (Lowe et al, 2019). The central estimates use the ensemble member with a 10-year mean matching the 50th percentile of the distribution as the central estimate, and uncertainty ranges are from ensemble members with 10-year means matching the 5th and 9th percentiles. We use three emissions scenarios: RCP2.6, RCP4.5 and RCP6.0, representing future emissions scenarios judged as being within the plausible ranges for currently-implemented global policies (RCP4.5 and RCP6.0) and a lower emissions scenario representing rapid mitigation action (RCP2.6). Scenarios with emissions lower than RCP2.6 are not available with UKCP.

In the figure “Current Global Warming Levels” in the main paper, the illustrative projected future 10-year trend (dashed orange line at top right) is a linear approximation of the projection with the UKCP ensemble member with a 10-year mean at the 50th percentile of the global probabilistic projection using the RCP4.5 emissions scenario.

Central estimates and uncertainties for groups of indicators

The central estimate of the most recent values of the instantaneous indicators is the mean of the 4 values in the right column of the green rows in Table S.1, ie: 1.24°C.

The central estimate of the Current Global Warming Level for 2022 is the mean of that calculated using the WMO forecast forced with the RCP4.5 concentration scenario (Table S.1, top yellow row, right column) and the three values using the UKCP projections with the RCP4.5, RCP6.0 and RCP2.6 emissions scenarios (Table S.1, second, third and fourth yellow rows, right column), ie: 1.26°C

Uncertainty estimates for the 20-year and 10-year observation-based metrics (blue rows) are from Forster et al (2022) and have also been applied to the two metrics using the end of the 30-year trend and the metric using LOESS smoothing (top 3 green rows) in order to provide an indicative estimate of uncertainty. The uncertainty in human-induced warming (4th green row) is from a separate calculation, also from Forster et al (2022).

Additional information and updates

Further information on the Current Global Warming Level and other metrics, including routine updates, can be found on the Indicators of Global Warming page on Met Office Climate Dashboard: climate.metoffice.cloud/current_warming.html

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