Interpretations of the Paris climate target

To the Editor — In the 2015 UNFCCC Paris Agreement, article 2 expresses the target of "Holding the increase in global temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C … recognizing that this would significantly reduce the risks and impacts of climate change"[1]. Different interpretations of the precise meaning of the phrases 'increase in global temperature'[2] and 'pre-industrial'[3] could have large effects on mitigation requirements and corresponding social, policy and political responses. Here we suggest that levels of current global mean surface warming since pre-industrial times that are higher than those derived by Millar et al. could have been calculated using alternative, but equally valid, assumptions as the ones made by those authors.

In the work by Millar and colleagues[4], an observational dataset (HadCRUT4)[5] was used to estimate current levels of anthropogenic warming above 1861–1880 (0.93 °C as of 2015) and thereby determine the amount of warming remaining before the 1.5 °C target is reached. HadCRUT4, in common with most datasets, calculates global mean surface temperature (GMST) as a blend of surface air temperature (SAT) measurements over land and sea surface temperatures (SSTs) over the ocean. It only has partial global coverage, limited to where the observations exist. As such, data from the Arctic, which has been found to be warming much faster than the global mean, are not included. By choosing to use this observational dataset Millar and co-workers have implicitly assumed a definition of GMST that is restricted to observational coverage, measured as a blend of SATs and SSTs. In addition, they assume that 1861–1880 is representative of pre-industrial conditions as used in the UNFCCC Structured Expert Dialogue (SED)[6]. However, this approach has potential shortcomings. For example, when model simulations are processed in a similar way to the observations, they show less warming with the SED method, compared to an alternative approach where complete global coverage of SAT is assumed. It therefore seems likely that the SED approach underestimates the warming that has actually occurred in global air temperatures[7]. In addition, changes in GMST could have been calculated from a different baseline. As industrialization was already under way by the late nineteenth century, an earlier period could be more appropriate for a pre-industrial baseline.

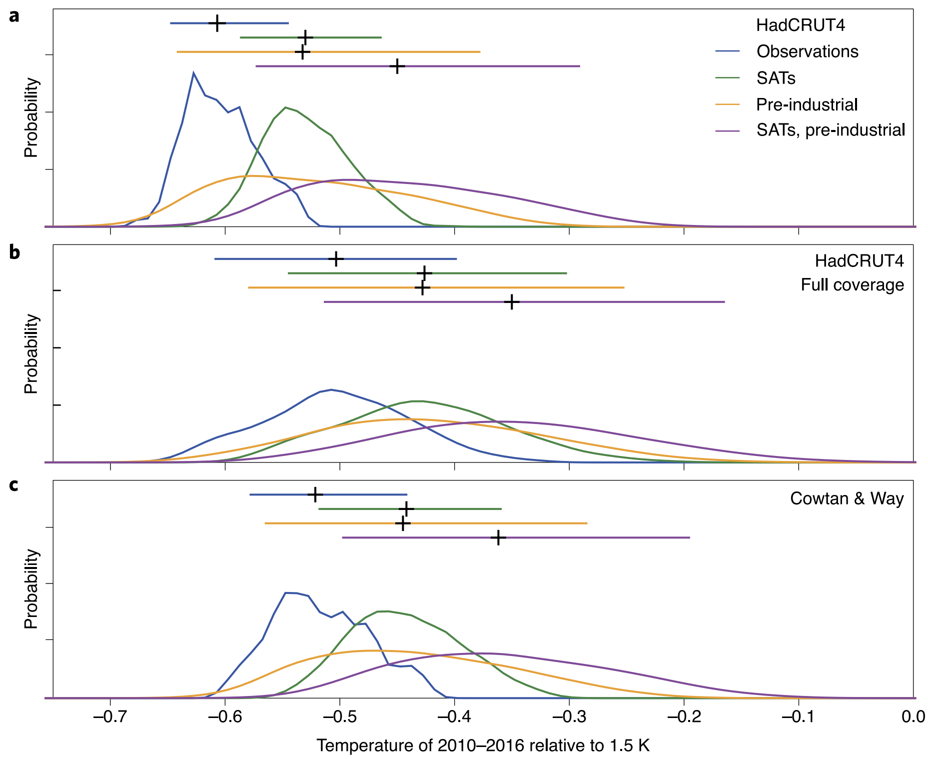

Fig. 1 | Present global temperatures relative to 1.5 °C above pre-industrial temperatures. Kernel density estimates and 5–95% range of the observed warming: HadCRUT4[5] (**a**, a dataset with partial coverage); HadCRUT4 scaled to full global coverage using a ratio calculated in model simulations (**b**); and Cowtan and Way[8] (**c**, a dataset that has been in-filled using kriging). Panels show observed GMST warming since 1850–1900 with published uncertainty (blue), GMST warming estimated as SATs over whole globe (green), observed GMST with anomalies from for a true pre-industrial baseline (orange), and SATs with pre-industrial baseline (purple). All conversion factors are calculated using model CMIP5 simulations with RCP2.6 projections.

The sensitivity of observed warming in 2010–2016 to these choices is highlighted in Fig. 1, which estimates the effect of calculating: (1) warming for total global coverage rather than for the coverage for which observations are available; (2) warming using SATs over the entire globe instead of the observational blend of SSTs and SATs; (3) warming from a pre-industrial, instead of a late-nineteenth-century baseline. The effect of observational coverage is estimated in two ways. First, we compare HadCRUT4 to a dataset that uses identical temperature information but fills in missing data with a kriging statistical technique[8]; alternatively, we calculate a correction factor from CMIP5 model simulations to convert spatially incomplete temperatures to full global coverage. A factor to convert the observed blend of SSTs and SATs to a fully SAT product is also calculated from the range of CMIP5 model simulations[7]. Finally, we estimate additional warming associated with placing the pre-industrial baseline further back in time, using model simulations of the period 1400–1800[3]; an observational-based estimate[9] gives a similar result.

We conclude that alternative assumptions that are equally valid as those made in Millar and colleagues' paper lead to estimated higher levels of present-day GMST warming compared to pre-industrial conditions. Each of the factors considered above adds approximately 0.1 °C of warming to the estimate in ref. [5] (Fig. 1). Millar et al. show (ref. [4], Tables 1, 2) that an additional 0.3 °C warming to date would halve the remaining carbon budget, which highlights the high

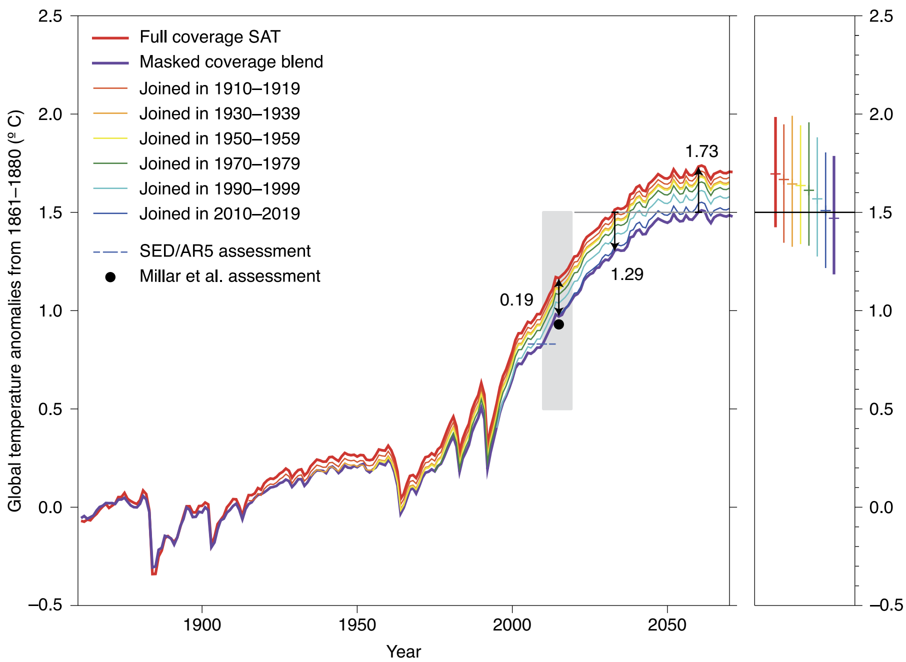

Fig. 2 | Global temperature for CMIP5 model simulations with RCP2.6 projections. Multi-model ensemble mean temperature for SATs for complete global coverage (red) and for a blend of SATs and SSTs with masked coverage, mimicking HadCRUT4[5] (purple), where future projections are masked with the mean HadCRUT4 coverage from 2000 to 2009. To mimic the use of observed temperature for the past and projected model temperatures for the future, different coloured lines show results when the two are joined together in different periods. The shaded grey box in the main panel shows where Millar and colleagues[4] tied the past observations to future projections: the double headed arrow within and accompanying value indicate difference between red and purple lines in 2015; and the black dot shows their estimated anthropogenic warming (0.93 °C, Millar et al.[4]). The blue dashed line shows the assessed level of warming reported in the SED[6]. Additional arrows indicate GMST for the HadCRUT4 approach when the models (SAT, full coverage) passes 1.5 °C and vice versa. The $p > 0.66$ GMST model range from 2050 to 2060 is shown in the right panel.

sensitivity of carbon budgets to definitions of GMST.

Millar et al. then used climate models (using full coverage of SAT) to calculate the remaining budget of carbon emissions consistent with keeping GMST within 1.5 °C above pre-industrial levels, using their observed estimate of current warming. Projections have been tied to more recent observations instead of using model simulations to assess past warming, as in earlier studies[3,10], because it reduces the impact of uncertainty in past radiative forcing for future projections. Negotiators at the time when the Paris Agreement text was finalized[6] were aware of this approach; however, it mixes different definitions of GMST. These inconsistencies may not have been explicitly discussed and have only been fully investigated subsequently[7]. We explore the implications of this approach in Fig. 2 using model simulations with strong mitigation (RCP2.6). The simulations display a difference of approximately 0.25 °C by 2050–2060 between the typically model-derived GMST values (SATs for complete coverage) and a GMST calculated to mimic observations (blended SATs and SSTs with partial coverage). In addition, if one definition is used for past GMST warming and a different one for projected GMST warming — as in Millar et al. and the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5)[10] — then the final results will be dependent on the period when the two are joined. For example, the choice of the year 2015 in Millar et al. leads to final temperatures close to the blended partial coverage definition, because in this case most of the warming has occurred in the past. Mixing different definitions of GMST could also lead to misleading findings about the carbon budget remaining. In Fig. 1 in Millar and co-workers' paper, results from model simulations (SATs, full global coverage) are used to calculate the warming for a given level of cumulative carbon emissions and then the current observed warming (blended, partial coverage — shown by the black cross) combined with actual emissions is used to realign the graph to calculate the remaining carbon budget. This is in effect a correction of the modelled estimate based on the observations. However, approximately 0.2 °C of the difference between the two approaches can be explained by the different definitions of GMST (Fig. 2).

Crucially, in order for the temperature targets in the Paris Agreement to be as meaningful as possible, the amount of mitigation required to cap GMST needs to be linked to the impacts expected at that level of warming. It is here that ambiguity surrounding the definition of GMST is most problematic. For example, the impacts of 1.5 °C global warming on Australia were calculated with a GMST estimate based on SATs with complete coverage[11], contrary to Millar and colleagues' assumptions, and other impact studies also used different definitions[12].

We therefore recommend that a clear definition of GMST change is agreed, so that mitigation actions required to limit climate change impacts are assessed using self-consistent information. This would prevent apparently contradictory results due to differing interpretations. ❐

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