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DISCUSSION PAPER

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Discussion on "A combined estimate of global temperature"

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Abstract

While the real-world has warmed in one unique way, the available data, which is spatio-temporally incomplete and contains biases of unknown nature and timing, means this quantity can only ever be estimated. Craigmile and Guttorp (2022) propose an approach that optimally combines the range of existing products to gain a refined estimate. Implicit in this or, indeed, any similar approach, are assumptions about the available estimates representing both an unbiased and representative draw from the population of potential plausible estimates that could have been created. There are well-founded reasons to doubt that this is the case. An alternative approach, used in the IPCC report, is to employ much simpler approaches which, in particular, hedge against underestimation of the true uncertainty in the evolution of global surface temperatures, and thus serve to future-proof current estimates against subsequent dataset innovations arising from future improvements in our understanding.

KEYWORDS

homogeneity, interpolation, temperatures, uncertainty

1 | THE POLICY CONTEXT

The question of what is the true global surface temperature change since pre-industrial is of increased policy importance since the UNFCCC Paris Agreement in 2015, which agreed to keep temperatures below 2°C and strive to keep them below 1.5°C above pre-industrial levels (UNFCCC, 2015). This, for the first time, places global climate mitigation targets in the explicit context of geophysical system changes, as indicated by global surface temperatures. Irrespective of broader discussions of societal and practical relevance of the global surface temperature metric, it therefore has very direct policy relevance. Mitigation targets and adaptation needs entail policy decisions which carry trillions of dollars in value and have major implications for lives and livelihoods. Many of these are now explicitly or implicitly framed in the context of global surface temperature changes.

2 | DATASETS OF GLOBAL SURFACE TEMPERATURE CHANGE

Available observations to inform the estimation of global surface temperature changes are sparse and oftentimes discontinuous, with some regions consistently under-sampled or, worse still, completely unsampled (Freeman et al., 2017; Rennie et al., 2014). Coverage of available observations has varied considerably over time with early records being much more sparse (Noone et al., 2021). They also suffer from time-varying biases arising from changes in instrumentation, siting and observational practices which must be adjusted for prior to use in long-term climate applications (Aguilar et al., 2003; Conrad & Pollak, 1950; Kennedy, 2014; Menne & Williams, 2009; Trewin, 2010; Venema et al., 2020). Metadata, which

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may help to disentangle physically what biases exist and why, are more often than not either entirely absent or grossly incomplete. Therefore, the timing and potential nature of breaks in the series is frequently unknown. The creation of a climate data record thus is inherently statistical in nature and is ill-posed in that the data is sparse and the biases are a priori unknown both in terms of their location in the series and their nature.

Research groups take these data, which are managed in international repositories, and make data selections, perform assessments of homogeneity of land and marine holdings, merge these to create globally complete estimates, and then perform post-processing to account to the extent possible and practicable for data sparse regions and epochs to create datasets. Numerous groups have created and then continuously revised and updated their estimates of global surface temperature changes (see Section 2.3.1.1 in Gulev et al., 2021 for a summary). Over time, as more has been learnt about the data, and with the advent of new computational approaches and capabilities, the products have taken account of an increased range of data issues and, through use of interpolation schemes, become more globally complete. The range of datasets resulting provides some estimate of the structural uncertainty in global surface temperatures. In addition, products increasingly also quantify parametric uncertainty estimates resulting from varying uncertain choices and assumptions within their given method. Oftentimes these are expressed via ensembles of "equi-probable" solutions.

3 | THE DESIRE FOR A BEST ESTIMATE

There is a natural and entirely understandable desire to extract a best estimate from the family of available estimates. A better constrained and less biased estimate would clearly have enormous practical and policy benefits. Given that the estimates each purport to estimate the same geophysical quantity and that, in the real-world, that quantity must have evolved in one unique way, it is natural to ask whether a better estimate can be accrued via some appropriate means of weighted combination as proposed by Craigmile and Guttorp (2022). The question is whether this is warranted, and this fundamentally rests upon the validity or otherwise of assumptions around whether the sample of available estimates represents a truly unbiased and representative draw.

4 | ARE AVAILABLE ESTIMATES A REPRESENTATIVE AND UNBIASED DRAW FROM THE PARENT DISTRIBUTION OF PLAUSIBLE ESTIMATES?

If we trained up sufficient individuals and funded them to work quasi-independently on the problem we could, in principle, produce hundreds or thousands of estimates of global surface temperature changes, all taking different approaches to data selection, data adjustments and data post-processing to create global estimates. An implicit and central assumption not just in Craigmile and Guttorp (2022), but in any similar approach which takes some form of weighted average from the still small, but growing, number of available estimates is that they represent both a representative and an unbiased draw from this larger population of plausible estimates that could in principle exist. Here, representative means that they reasonably span the entire range of such plausible estimates, and unbiased means that the draw is not preferentially from any portion of this hypothetical parent distribution. Of course, this parent distribution is just that—hypothetical. We do not know what the true distribution is and if we did we would, of course, use that and this entire discussion would be moot. In truth, given the nature of available data and metadata, this true distribution is unknowable. There are, however, some things we do know that suggest a considerable degree of caution is warranted.

First, we know that there exists a substantial degree of scientific cross-dressing between the available estimates, such that the true methodological degrees of freedom is smaller than that implied from simply counting the number of available estimates (Table 2.3 and associated discussion in Gulev et al., 2021). In several cases the sole difference between products arises in their post-processing to create interpolated products, for example, NASA GISTEMP and NOAA GlobTemp products are identical in their selection and homogenization of land and marine data. In other cases, such as HadCRUT and NOAA GlobTemp, the methods are substantively independent in all aspects. Given that the available estimates are fundamentally drawn from just three gridded and homogenized estimates of sea surface temperature changes (HadSST [Kennedy et al., 2019], ERSST [Huang et al., 2017], and COBE-SST [Hirahara et al., 2014]) and three gridded and homogenized estimates of land surface temperatures (GHCNM [Menne et al., 2018], CRUTEM [Osborn et al., 2021], and Berkeley Earth [Rohde et al., 2013]) which have then been variously combined and post-processed, the likelihood that the available estimates constitute a truly unbiased draw is very low. The estimates must preferentially draw from regions of the distribution arising from the areas populated by these underlying land and marine products.

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Second, we know that the estimates may not have addressed all data biases. At the time of the IPCC fifth assessment report residual issues relating to marine data biases and accounting for habitually data sparse regions were highlighted (Hartmann et al., 2013). In addressing these two issues, the new estimates assessed in the next IPCC report, on a like-by-like metric raised the estimates by 0.08°C or about 10% of the long-term change that was estimated at the time of the prior assessment (Gulev et al., 2021). It would be unduly naïve to believe that all actual (rather than presently known) biases have been identified and accounted for. Just like we now believe prior assessments to have been biased it cannot be guaranteed that the present generation of estimates will not prove unbiased with future insights. Furthermore, some of the available estimates, such as that arising from JMA, have yet to incorporate all the new understanding and thus are known to represent potentially biased estimates. It is prudent to consider current estimates to constitute a snap-shot based upon current knowledge that may be subject to revisions, which may prove to be non-negligible in nature, in future.

Third, while in the real-world we cannot ascertain the performance of different aspects of the dataset creation algorithms, we can use benchmarking assessments against synthetic cases where the real answer is known to make some inferences. Such benchmarking assessments are most mature for meteorological land station homogenization. Here, they find that the best performing algorithms tend to shift the data towards the truth but, on a network wide basis, not far enough (Venema et al., 2012; Williams et al., 2012). The employed approaches struggle most when data are sparse and when breaks are frequent and small in magnitude. Such benchmarking studies highlight the potential for common residual biases even across ostensibly independent approaches to homogenization (Venema et al., 2012).

Finally, the parametric uncertainty estimates, because they account for different sources of uncertainty, often in distinct ways, lack direct comparability. As discussed in Hartmann et al. (2013) even if nominally the same sources of uncertainty are considered, the means by which they are quantified generally differ and estimates could be over- or under-dispersive. Combination or exploitation of these uncertainty estimates to inform a combined-estimation is thus even more challenging a proposition than that of the best estimates. It cannot be assumed that the estimates are either equivalent or comprehensive in nature. In particular, across many climate datasets more constrained estimates can often indicate either omitted uncertainty terms or under-dispersive estimation rather than truly better constrained estimates (Hartmann et al., 2013).

Taken together, these lines of evidence cast considerable doubt upon assumptions around the available estimates constituting an unbiased and representative draw from the population of plausible estimates. This should not be over-interpreted. The ambiguity is in the precise details of the warming and not the fact that the globe has indeed warmed. To call into question the fact that the globe has warmed since the late 19th century would require artifacts and uncertainties many orders of magnitude greater than those already accounted for and quantified. Furthermore, quantified changes in a broad range of other essential climate variables (Bojinski et al., 2014), which are all consistent with a warming planet, would need to be explained.

5 | THE ALTERNATIVE CASE FOR A CONSERVATIVE AND EASY TO UNDERSTAND ESTIMATE

Given the policy relevance of the global surface temperature metric and questions around whether available estimates represent a truly unbiased and representative sample, Gulev et al. (2021) take a different approach. An initial filtering is undertaken to rule out those estimates using land and sea surface temperature estimates that are known to be deprecated and contain residual (known) biases. Next, the best estimate is taken as the simple average of remaining estimates which minimizes, but of course cannot remove, the risk of weighting towards any estimates that are commonly systematically biased. Finally, to minimize the chances of the true value falling outside the quoted range the maximum and minimum of available parametric uncertainty ranges are taken to provide conservative bounds on the estimated uncertainty of the assessed change. This approach is both simple for users of the IPCC report to understand but, also, crucially minimizes the chance that the true unknown, and unknowable, real-world global surface temperature change falls outside the assessed *very likely* range (where *very likely* has a very specific meaning and represents a 5%–95% range). In turn this ensures that the full potential range of values for change in global surface temperatures to date are pulled through to subsequent assessments around key questions such as when certain global warming levels might be reached (Lee et al., 2021), the quantification of remaining carbon budgets (Canadell et al., 2021), or estimates of equilibrium climate sensitivity (Forster et al., 2021).

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