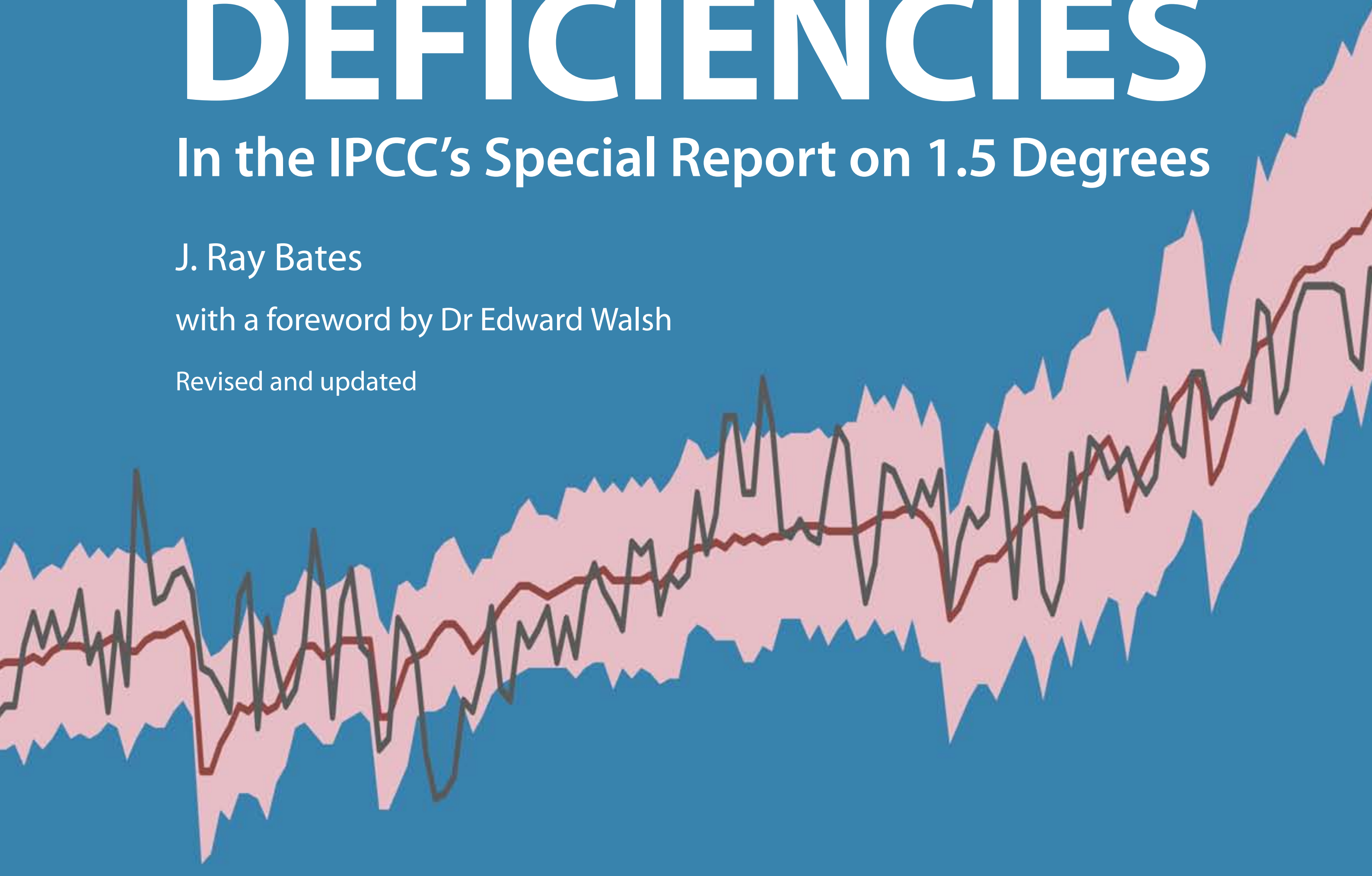
DEFICIENCIES

In the IPCC's Special Report on 1.5 Degrees

J. Ray Bates

with a foreword by Dr Edward Walsh

Revised and updated



The Global Warming Policy Foundation

GWPF Briefing 36

DEFICIENCIES

In the IPCC's Special Report on 1.5 Degrees

J. Ray Bates

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Foreword

By Dr Edward Walsh

This paper presents an evidence-based critique of some central aspects of the recent Special Report on a Global Warming of 1.5°C (SR1.5) issued by the Intergovernmental Panel on Climate Change (IPCC). The author, Professor Ray Bates, is an eminent scientist with a lifetime of international experience in weather and climate research; at MIT, as a senior scientist at NASA and as professor of meteorology at the Niels Bohr Institute, Copenhagen, and at University College Dublin. His independent scrutiny points to a lack of scientific rigour and balance in key aspects of the SR1.5 report. Specifically, he presents compelling evidence that the SR1.5 report is deficient in three regards:

- It departs from the IPCC (2013) Fifth Assessment in the direction of an increased sense of planetary emergency without giving rigorous scientific reasons for doing so.
- Crucial research evidence, accumulated since the IPCC Fifth Assessment (2013), significantly reduces the prospect of a looming emergency. This evidence has not been taken into account; nor is it even referred to in the SR1.5 report.
- The disturbing revelation of the widespread practice of 'tuning' global climate models to achieve desired results, disclosed since the Fifth Assessment, has not been referred to either.

The importance of adherence to the highest scientific standards on the part of the IPCC in its periodic reports can hardly be overemphasised. Governments rely on the scientific objectivity of these reports to make crucial decisions related to the economies of their countries and the wellbeing of their people. Policymakers should carefully reflect on the significant deficiencies identified in the report before considering implementing its recommendations.

The Global Warming Policy Foundation is to be commended for publishing this important paper. It deserves a wide audience.

Dr. Edward Walsh is Founding President of the University of Limerick and has served as chairman of both Ireland's National Council for Science Technology and Innovation and of Ireland's National Allocation Advisory Group (Carbon Trading).

About the author

Professor J. Ray Bates is Adjunct Professor of Meteorology in the Meteorology and Climate Centre at University College Dublin. He was formerly Professor of Meteorology at the Niels Bohr Institute, University of Copenhagen, and a Senior Scientist at NASA's Goddard Space Flight Centre. In his early career he was Head of Research at the Irish Meteorological Service. He obtained a bachelor's degree in physics at University College Dublin and a PhD in meteorology at MIT. His PhD supervisor at MIT was Jule G. Charney, chairman of the committee that wrote the 1979 'Charney Report' on the effects of carbon dioxide on climate. Professor Bates has been the recipient of a number of awards for his scientific work, including the 2009 Vilhelm Bjerknes Medal of the European Geosciences Union. He is a former President of the Irish Meteorological Society. He has served as an Expert Reviewer of the IPCC's Third and Fifth Assessment Reports. He is a member of the Royal Irish Academy and the Academia Europaea and a Fellow of the American Meteorological Society and the Royal Meteorological Society.

Note to revised version

This is a revised version of the original document of the same name published by the Global Warming Policy Foundation on 20 December 2018. It contains some clarifications that arose in the context of discussions with colleagues. The main conclusions are unchanged.

1 Introduction

The recent special report of the Intergovernmental Panel on Climate Change, known as SR1.5,[1] goes far beyond all its previous publications in raising the level of alarm about climate change and in calling for drastic action to combat it. The report adopts the standpoint that the essential aspects of climate science are settled and then conflates what it sees as a necessary policy response with ethical issues of sustainable development, poverty eradication and reducing inequalities.

The report calls for radical changes in the world's economy to achieve zero carbon emissions by mid-century. Given the extremely costly and highly disruptive changes this course of action would entail, the rigour of the underlying scientific case should be beyond question. Here, some central aspects of SR1.5 are examined to see whether the report exhibits a level of scientific rigour commensurate with the scale of its prescribed course of action. The conclusion, based on the evidence, is that it does not.

2 Departure from the IPCC's Fifth Assessment Report

The IPCC's assessment reports have each been presented in three parts, representing Working Group I (The Physical Science Basis), Working Group II (Impacts and Adaptation) and Working Group III (Mitigation of Climate Change). For SR1.5, these three working groups were merged to produce a generalized report, with a consequent lack of focus on a purely scientific analysis.

The central attribution statement of Working Group I in the Fifth Assessment Report[2] (hereafter WGI AR5) was as follows:

> It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period.

This statement arises primarily from a detection and attribution analysis applied to global climate model (GCM) simulations.[3] It does not attribute the substantial early 20th century warming (1910–1945) to anthropogenic effects. Regarding this early warming, the report concluded (Section 10.3.1.1.3, p. 887):

> It remains difficult to quantify the contribution to this warming from internal variability, natural forcing and anthropogenic forcing, due to forcing and response uncertainties and incomplete observational coverage.

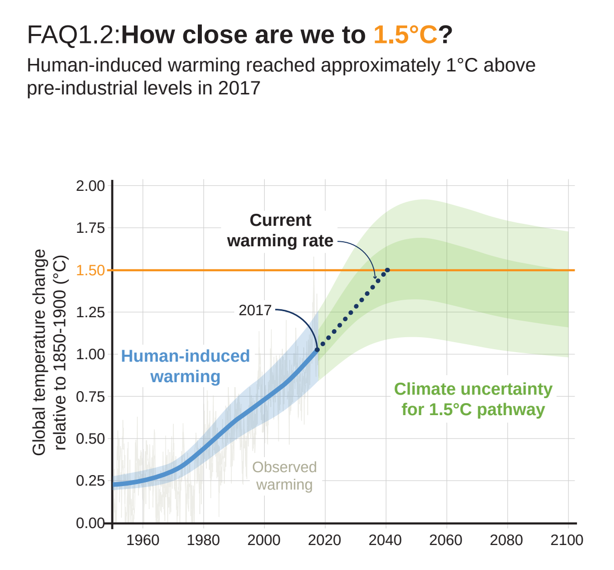
In contrast to this caution, SR1.5 portrays essentially all the global warming observed since the late 19th century[4] as being human-induced (see Figure 1).[5] This major departure from the Fifth Assessment is presented without any rigorous justification.

3 Lines of evidence

A phrase much used by the IPCC is 'lines of evidence'. Implicit in this phrase is the realistic acknowledgement that there is much in climate science that is not known with certainty and which perhaps never can be. Something that is known with certainty is that the concentrations of carbon dioxide and other trace gases that trap heat radiation at infrared wavelengths in the atmosphere are increasing as a result of human activities. Balancing this, it is

FAQ

FAQ 1.2 (continued)



FAQ 1.2, Figure 1 | Human-induced warming reached approximately 1°C above pre-industrial levels in 2017. At the present rate, global temperatures would reach 1.5°C around 2040. Stylized 1.5°C pathway shown here involves emission reductions beginning immediately, and CO_2 emissions reaching zero by 2055.

Figure 1: SR1.5 portrayed essentially all global warming above pre-industrial levels as man-made.

Reproduced from SR1.5, Chapter 1, FAQ 1.2, Figure 1, p. 82. The original caption reads 'Human-induced warming reached approximately 1°C above pre-industrial levels in 2017.'

also known that the dominant greenhouse gas (GHG) in the atmosphere is naturally occurring water vapour, which is far more abundant than the trace gases. When air rises and cools, the water vapour it contains condenses into clouds, which affect the greenhouse properties of the atmosphere in major ways. Quantifying cloud radiative effects with precision, however, is beyond the capability of present day climate science. For as long as this remains the case, modelling the climate system's response to increasing GHG emissions will remain an area of uncertainty.

4 SR1.5's main lines of evidence for anthropogenic warming

In its Summary for Policymakers (SPM), the SR1.5 report presents a plot of observed and modelled global mean surface temperature[6] (GMST) for the years 1960–2017 (Figure 2). The solid orange line shows the modelled central estimate of anthropogenic global warming up to 2017. The stated modelling method is a multiple regression, in which the dependent variable is the observed GMST and the independent variables are the estimated global responses to total anthropogenic forcing and to natural (combined volcanic and solar) forcing, these responses being calculated using a simple globally-averaged impulse-response model. The central estimate portrays anthropogenic global warming as markedly accelerating, the rate of warming increasing from about 0.04°C/decade at the beginning of the period

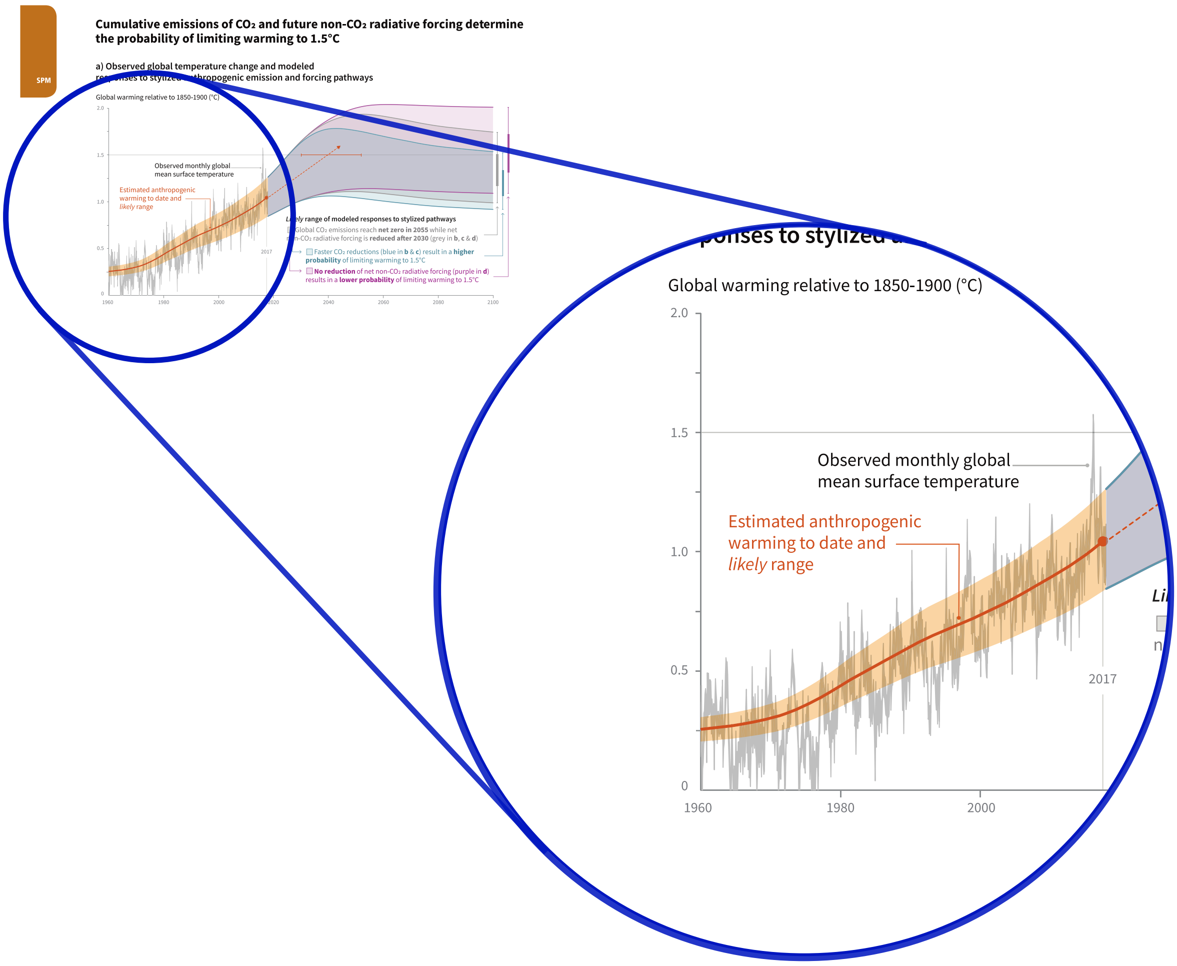


Figure 2: How SR1.5 portrayed observed and modelled temperatures since 1960.
Observed monthly GMST, grey line up to 2017 (from the HadCRUT4, GISTEMP, Cowtan & Way, and NOAA datasets) and model-estimated anthropogenic global warming (solid orange line up to 2017, with orange shading indicating assessed *likely* range). Source: SR1.5, Figure SPM.1.

to about 0.22°C/decade at the end. The agreement shown in the figure between the observations (with interannual variations smoothed out) and the modelled central estimate of the anthropogenic warming is close, suggesting that strong confidence can be placed in both the indicated acceleration of the warming and its modelled anthropogenic origin.

In its Chapter 1, the SR1.5 report provides further evidence suggesting the recent warming is anthropogenic. It does this by including results of GCM simulations along with the results of the simple model, in this case for the years 1850–2017 (Figure 3). The GCM results again show good agreement with the observed warming in recent decades.

However, the picture of global warming for the longer period 1850–2017 shown in Figure 3 is much more complex than the picture for the recent period 1960–2017 shown in Figure 2. The longer-term observational picture is no longer a simple one of accelerating warming. The observational data presented in Figure 3 show that prior to 1960, global cooling took place over the 25-year period 1945–1970. Prior to that, between 1910 and 1945, there was another period of significant global warming. This early 20th-century warming occurred before anthropogenic GHGs exerted a major influence. Prior to that again, there was another multi-decadal period of cooling. Figure 3 clearly indicates the existence of substantial natural variability of GMST that is independent of GHGs.

Furthermore, the modelled temperatures – simple model or GCM – do not agree well with the observational data over the longer period. This lack of agreement is particularly evident during the early 20th century warming period. This was clearly a factor (in the GCM context) influencing IPCC AR5 not to attribute the early 20th century warming to anthropogenic causes (Section 2 above). In contrast, despite a similar lack of agreement between the simple model output and the observational data during this period, SR1.5 concludes that this early warming was very largely anthropogenic.

Questions arise as to why the human-induced warming given by the simple model agrees so well with the observed GMST during the period 1960–2017, giving an even better fit than the GCM-based results, and as to why these quantities disagree so markedly during the early 20th century warming period. All quantities in the simple model represent global averages and all its input data are global averages; thus the simple model allows for no effects of spatial variation. It therefore allows no scope for preventing erroneous attribution to globally-averaged forcing of any global warming fluctuation that might in reality result from a spatially varying temperature pattern, whereas GCMs – despite their limitations – would allow scope for this. The simple model is also constrained by the fact that its explanatory variables are modelled responses to anthropogenic forcing and to natural forcing. The sum of natural solar and volcanic forcings had very little trend over the 1960–2017 period.[7] Internal variability was not treated as an explanatory variable in deriving the central estimate of the human-induced warming (though it was used in estimating its likely range). These factors appear likely to influence the recent degree of fit between model output and observations and to be relevant in any attempt to explain the difference in this regard between the recent and the early 20th century period.

In what follows, the rigour of the SR1.5 report will be examined further in relation to some of the matters discussed above. Evidence regarding global data will be considered in Section 5, while evidence regarding GCM modelling will be considered in Section 6.

5 Related lines of evidence: observational

Atmospheric temperature evolution observed by satellite

The marked acceleration in the rate of surface warming in recent years, as suggested by Figures 1–3, is not apparent in satellite-based measurements of lower tropospheric temperatures (some kilometres above the ground), an example of which is shown in Figure 4.

In fact, the satellite temperatures, though showing a warming trend of 0.13°C /decade over the full observational period 1979–2018, show very little warming since the year 2000. Scafetta et al. have performed a statistical analysis in which the prominent El Niño signal in the satellite temperatures in the period 2000-2016 is removed from the record,[12] and found that the remaining warming trend in this period is only of the order of 0.04°C /decade.[13]

The SR1.5 report does not discuss satellite-observed temperature trends and does not address the problem of why they differ so markedly from the GMSTs. This is a serious defect, since there are strong reasons to believe that satellite temperatures are more reliable indicators of the true rate of global warming than the GMST; the satellite temperature measurements have near-global coverage while surface temperature measurements are sparse and irregularly distributed.

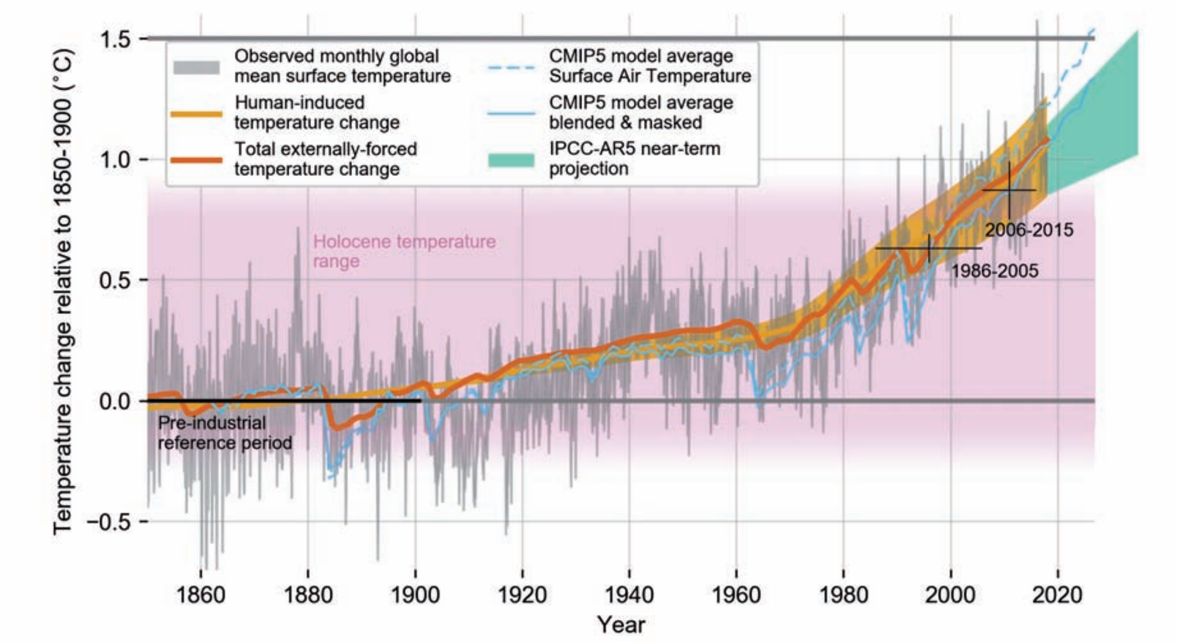


Figure 3: How SR1.5 portrayed the observed and modelled temperatures since 1850.

Evolution of GMST over the period of instrumental observations. Grey shaded line shows observed monthly mean GMST in the HadCRUT4, NOAAGlobalTemp, GISTEMP and Cowtan-Way datasets, expressed as departures from 1850–1900. Modelled human-induced (yellow) and total (human- and naturally-forced, orange) contributions to these GMST changes are shown, calculated following Otto et al.[8] and Haustein et al.[9] Thin blue lines show the modelled GMST (dashed) and blended surface air and sea surface temperature accounting for observational coverage (solid) from the CMIP5 historical ensemble average extended with RCP8.5 forcing. Light green plume shows the AR5 prediction for average GMST over 2016–2035. Note that the yellow curve in this figure corresponds to the orange curve in Figure 2. Source: SR1.5, Figure 1.2.

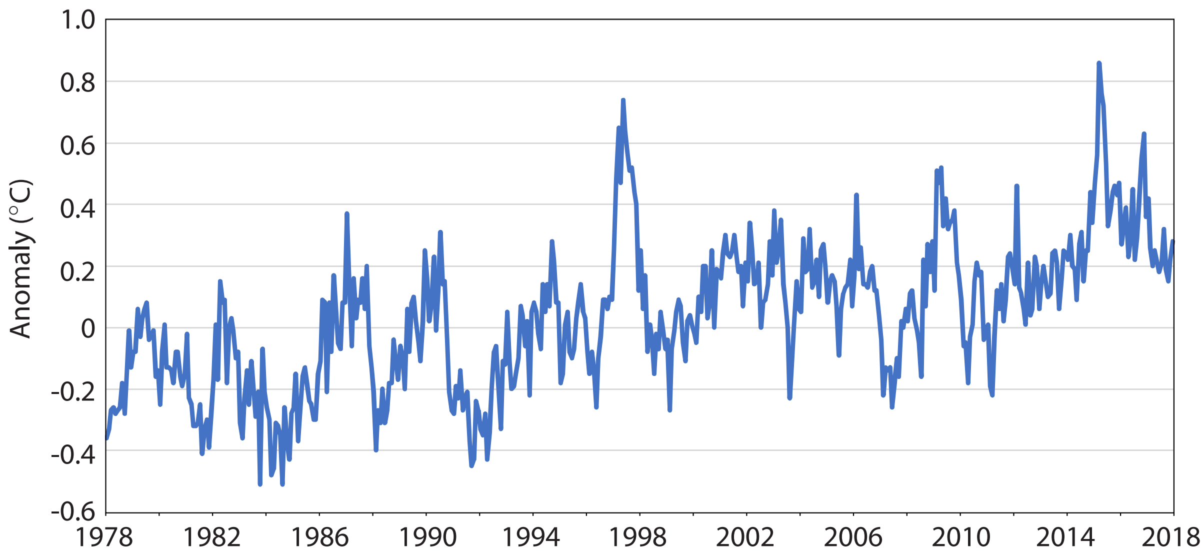


Figure 4: UAH[10] version 6.0 satellite-based global mean lower tropospheric temperature anomalies.

From January 1979 through November 2018. The linear trend is +0.13°C /decade. Source: Roy Spencer.[11]

Apart from the issue of coverage, satellite temperatures have the added advantage of not being influenced by urban heat island and land use change effects in the way the GMST is. Urbanization is currently leading to rapid temperature change in many cities around the world relative to the surrounding rural areas. Recent research comparing urban and rural temperature trends on different continents has provided evidence that urban heat island effects have previously been underestimated and that the relative warmth of the mid-20th century warm period at rural observing stations was comparable to the recent warm period.[14] This result is consistent with recent independent findings for the global sea surface temperature – see next section.

Observations of ocean warming

The temperature graphs in Figures 1–3 have not separated the GMST into its land and sea components. An example of a plot where these components are separated is shown in Figure 5. Examining the period 1900–1980 (no comment will be made here on the data-sparse period 1850–1900), it is seen that the land and sea-surface temperatures (SSTs) rose and fell at the same rate over multi-decadal periods. From 1980 onward, a strong divergence appears, with the land temperatures rising much faster than the SSTs. Taken without reference to the urban heat island and land use change effects mentioned above, the land temperatures in this period appear to exhibit a GHG-induced signal that has risen well above the bounds of natural variability.

It is not possible to make such an assertion with the same degree of confidence in respect of the sea-surface temperatures. A simple calculation using raw sea-surface temperature data[15] shows that the average SST for the period 2000–2014 (before the onset of the recent El Niño) was only 0.36°C warmer than the average for the period 1936–1950. In the light of the full 1850–2018 graph, it can be seen that this small degree of SST warming, though consistent with GHG-induced warming with low climate sensitivity, does not unambiguously exceed the bounds of natural variability.

Recently, results of an extensive ocean data study carried out at the European Centre for Medium Range Weather Forecasts (ECMWF) have been published.[17,18] The study involved rescuing over two million station-days of surface data and importing them into the most up-to-date data-assimilation system. The results for the upper ocean heat content (OHC; top 300 m) for the period 1900–2010 are shown in Figure 6. This figure shows that the OHC (0–300 m) reached values during the period 1935–1955 that exceed any reached during the period 2000–2010. These results clearly suggest the possibility that the natural variability of OHC (0–300 m), and hence of the closely related global SST, is greater than had previously been estimated.

These results were not referred to in the SR1.5 report, although the important Laloyaux et al. paper was accepted for publication well before the deadline for inclusion.

6 Related lines of evidence: GCM modelling

Model tuning (setting of parameters)

It was pointed out in Section 2 that the AR5 attribution statement for the post-1950 warming is primarily GCM-based, and in Section 4 that SR1.5 also used GCM results to provide supplementary evidence that the warming of recent decades is human-induced. However, some

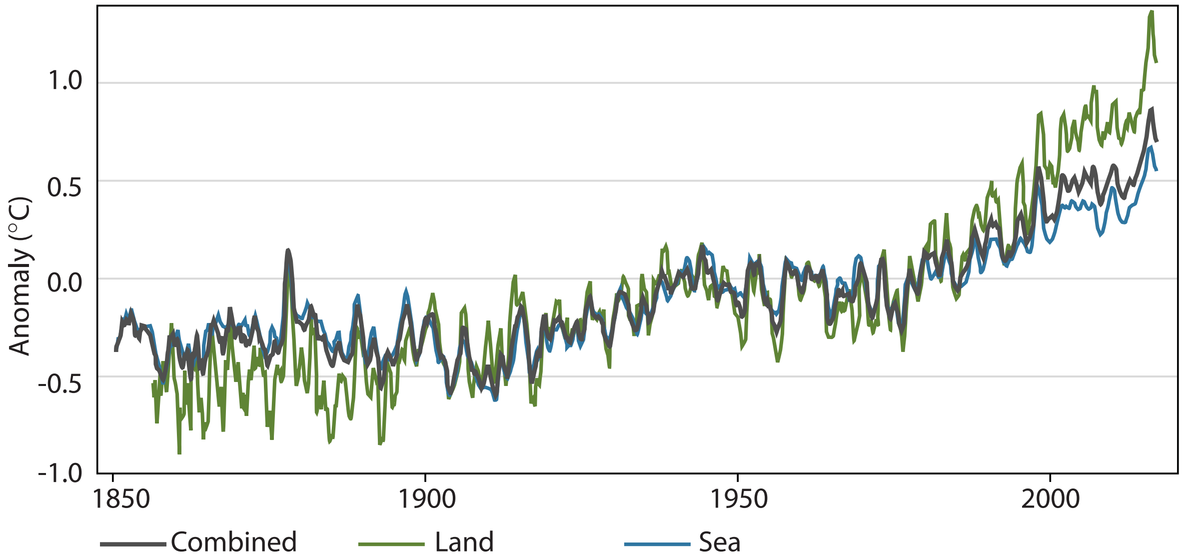


Figure 5: Land, sea and combined temperature measurements.
Global 12-month running mean temperature anomalies relative to the 1961-1990 mean. Black: land and sea temperature (HadCRUT4). Green: land surface air temperature (CRUTEM4). Blue: SST (HadSST3). Redrawn from Osborn *et al.*[16]

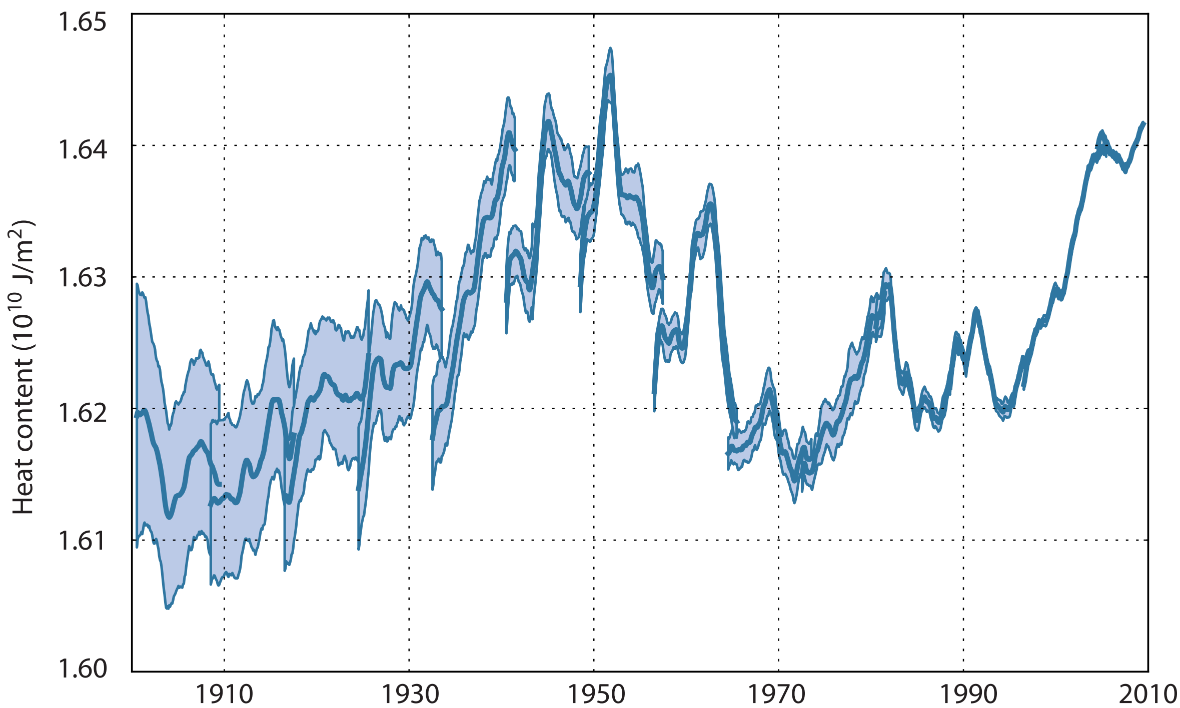


Figure 6: Global average ocean heat content for the upper 300 m.
From the ECMWF CERA-20C reanalysis ensemble, and redrawn from Laloyaux *et al.* Figure 10.

very important papers published since the Fifth Assessment Report give reasons to exercise great caution in using GCM results to attribute warming to human causes. Examples are

- 'Climate scientists open up their black boxes to scrutiny', by Voosen[19]
- 'The art and science of climate model tuning', by Hourdin *et al.*[20]
- 'Uncertainty in model climate sensitivity traced to representations of cumulus precipitation microphysics', by Zhao *et al.*[21]

These papers, none of which was referred to in SR1.5, point out that relatively small changes to the parameter settings in the representations of subgrid-scale physical processes in GCMs can lead to large changes in the models' rate of warming in response to increasing GHGs. The Voosen paper reports an example in which modifying a poorly-determined parameter controlling how fast fresh air mixes into clouds changed the climate sensitivity – the equilibrium warming resulting from a doubling of carbon dioxide levels – of the model in question from 3.5°C to 7°C. The Hourdin *et al.* paper makes it clear that what modellers do in practice is to tune their GCMs empirically so that they reproduce the observed 20th century warming, while giving a value of equilibrium climate sensitivity that lies in 'an anticipated acceptable range'. The Zhao et al. paper shows that by tuning the convective precipitation parameterisation in their GCM they could change its climate sensitivity by a factor of almost two, without any clear observational constraint that they could find favouring one version of the model over the others.

Tunings that have enabled models to successfully reproduce the late 20th century warming have not enabled them to reproduce either the marked early 20th century warming or the recent slow rate of tropospheric warming. Examples of model deficiency in the former case are shown in Figure 3 (for GMST) and Figure 7 (for SST), and in the latter case in Figure 8.

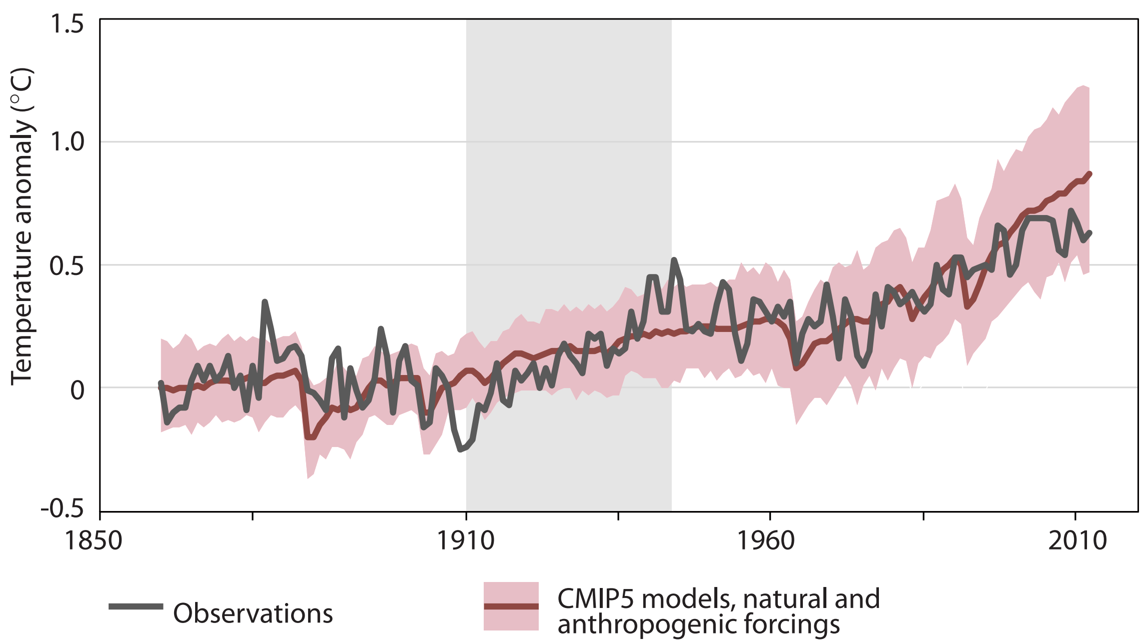


Figure 7: SSTs: modelled and observed.

The modelled warming rate differs by a factor of about four from the observed rate in the period 1910–1945 (shaded grey). Adapted from figure in the Fifth Assessment Report.[22]

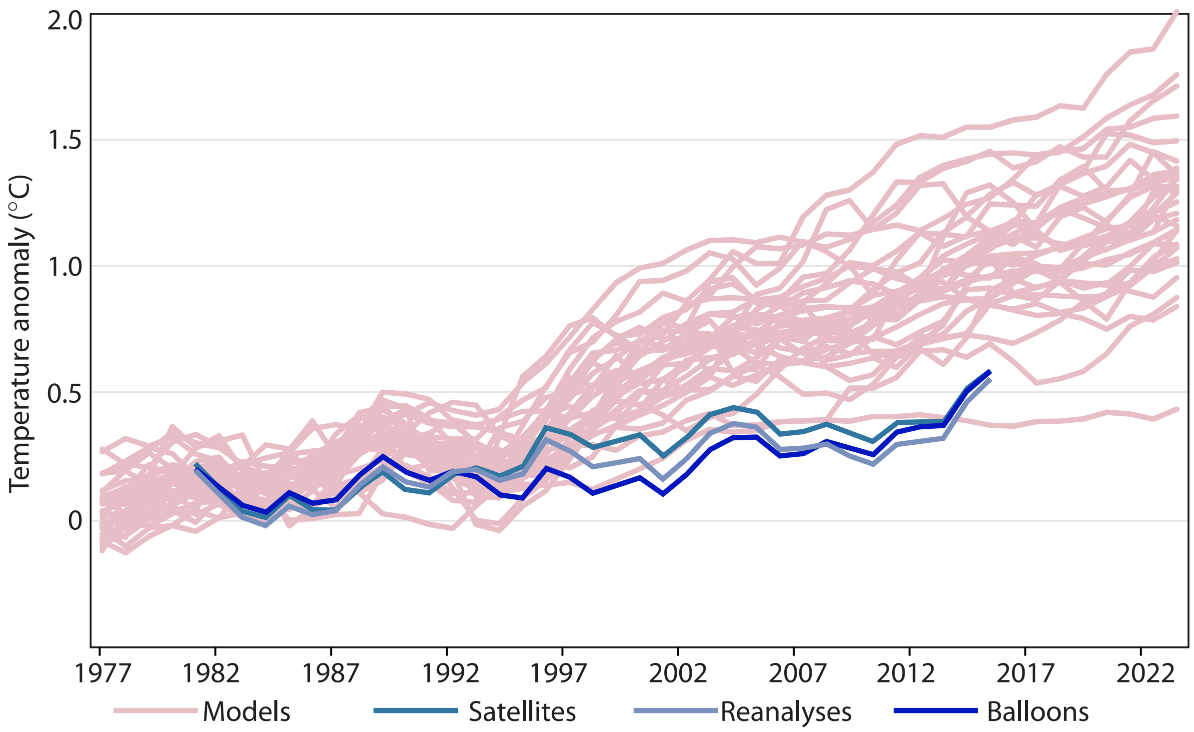


Figure 8: Tropical mid-tropospheric temperatures, models vs. observations.
Models in pink, against various observational datasets in shades of blue. Five-year averages 1979–2016. Trend lines cross zero at 1979 for all series. Adapted from Figure 2 of Dr. John Christy's testimony to the U.S. House of Representatives Committee on Science, Space and Technology, 29 March 2017.[23]

The Hourdin *et al.* paper referred to above was the result of a World Meteorological Organization workshop on model tuning. Its fourteen authors represent a broad international spectrum of climate modellers. The paper points out that the tuning strategy used in the models whose climate projections were used in the Fifth Assessment (and again in SR1.5) was not part of the IPCC's required documentation. The authors explicitly refer to this as a 'lack of transparency'.

Clearly, any agreement (as indicated for recent decades in Figure 3) between the warming observed over a given period and the GHG-driven warming from GCMs that have been tuned to agree with the observations for that period does not constitute evidence that the observed warming is GHG-driven.

Some recent independent estimates of climate sensitivity

As mentioned above, equilibrium climate sensitivity (ECS) is the eventual warming that would take place if the carbon dioxide content of the atmosphere were hypothetically doubled and then held fixed. ECS is the most important metric in climate science. It is an indicator of how much warming would take place for any actual increase in CO_2.

The true value of ECS is unknown. IPCC AR5 states that its value is likely to lie in the range of 1.5–4.5°C, with no best estimate being possible because of a 'lack of agreement on values across assessed lines of evidence'.[24] The 1.5–4.5°C estimated range, based mainly on results from GCMs, is unchanged from that given in the IPCC's First Assessment Report in 1990. In view of our current knowledge regarding empirical tuning of climate models to achieve desired results, it is clear that estimates of ECS from these models should not be taken as representing an outcome of basic physics.

An independent method of estimating ECS is to use a simple global energy balance model in conjunction with observations of the global mean values of radiative forcing, ocean heat uptake and temperature change over a base period and a final period. A recent example of this method cited in the SR1.5 report is the study by Lewis and Curry.[25] They found an ECS value of 1.5°C with an estimated uncertainty range of (1.05–2.45)°C . However, although SR1.5 referred to the study, it did not judge the result to be of sufficient weight to revise the lower bound of the IPCC AR5 estimated range, because it represented only 'a single line of evidence'.

A separate line of evidence indicating that the value of ECS lies below the lower bound of the IPCC AR5 estimated range comes from studies that use recent satellite observations of the Earth's tropical radiative response coefficient (change in outgoing top-of-atmosphere radiation in response to a unit change in surface temperature) in conjunction with two-zone (tropical/extratropical) energy balance models. Examples are found in the papers by Lindzen and Choi[26] and Bates;[27] the Bates paper uses observational estimates of the tropical longwave radiative response coefficient from both the Lindzen and Choi and the more recent Mauritsen and Stevens paper.[28] The results of the Lindzen–Choi and Bates studies suggest a value for ECS of around 1°C or even below. The SR1.5 report did not refer to any of these studies.

There are good reasons, however, why these studies should have been accepted as providing a valid line of evidence. In the first place, the deficiencies they highlight in the GCMs' representation of the Earth's tropical longwave radiative response coefficient are very marked; see Figure 9.

This figure shows clearly how seriously the GCMs underestimate the Earth's longwave radiative response to surface temperature variations in the tropics. The two-zone models indicate that such an underestimation leads to substantial overestimation of ECS.

In the second place, the low climate sensitivity indicated by the two-zone energy balance models is consistent with the recent observational findings that current global temperatures (GMST and SST) are little warmer than they were around the middle of the last century.

7 Conclusions

The SR1.5 report represents a very significant departure from previous IPCC reports in the direction of increased alarm regarding global warming, particularly as compared with the Fifth Assessment. No rigorous justification for this departure has been provided.

In reality, since the Fifth Assessment considerable evidence has accumulated suggesting that global warming is more of a long-term threat than a planetary emergency. This evidence consists mainly of observational results suggesting lower climate sensitivity (i.e. less warming in response to any given increase in greenhouse gas concentrations) and results indicating a greater contribution from natural variability to explaining observed global temperature trends. The IPCC has not passed on this evidence to policymakers in its SR1.5 report.

The report has also not passed on to policymakers some very important information published by climate modellers since the last IPCC assessment report regarding the empirical tuning of global climate models to achieve desired results. The failure of previous IPCC reports to document the models' tuning procedures has been described by these modellers

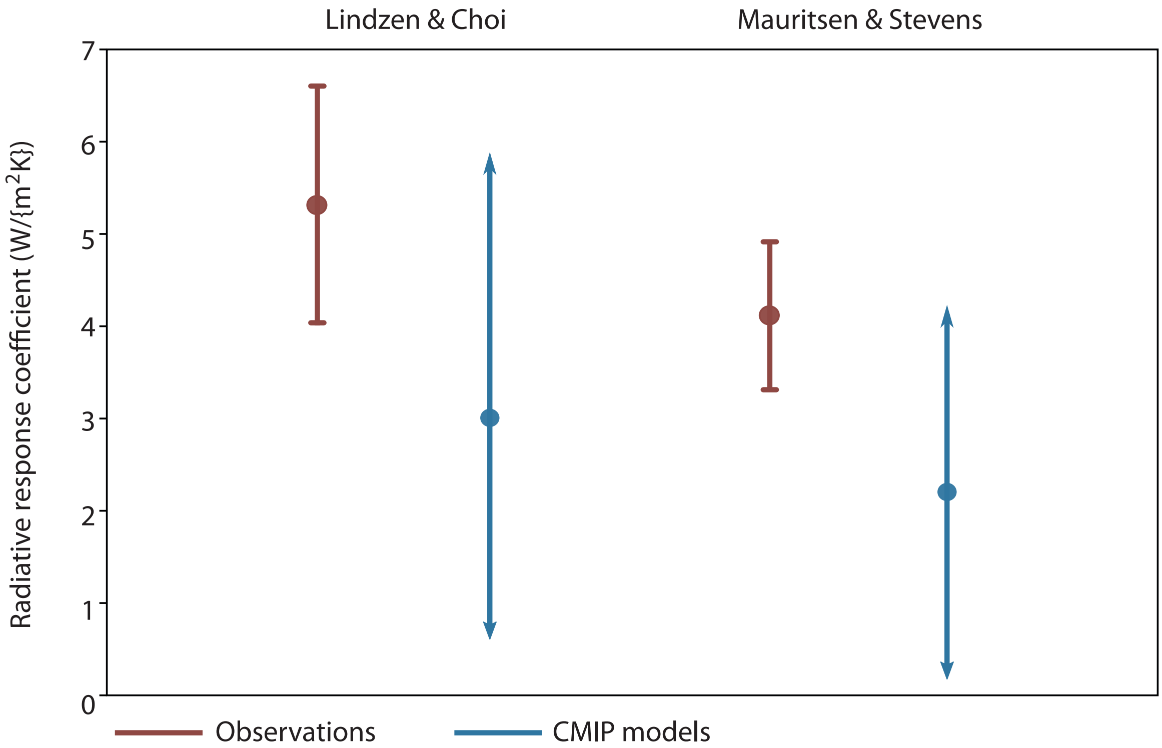


Figure 9: Longwave radiative response coefficient in the tropics.
The figure compares the uncertainty ranges for observed (satellites) and modelled radiative response coefficient from Lindzen and Choi (2011) and Mauritsen and Stevens (2015). The uncertainty intervals are marked by either arrows (showing outer limits) or bars (showing one standard error). The magnitudes shown correspond to values given in Table 1 of Bates (2016). Reproduced from Figure 2 of Park and Choi (2017).[29]

as a 'lack of transparency'. The projections of future warming published by the IPCC are completely dependent on the reliability of these models.

In view of these deficiencies, the SR1.5 report does not merit being regarded by policymakers as a scientifically rigorous document. There is much recent scientific evidence, not referred to in the report, to support a more considered mitigation strategy than the extreme measures proposed in the report.

Meanwhile, the worthy goals discussed in the report, such as sustainable development, poverty eradication and reducing inequalities, should be pursued on their own merits and not made dependent on unsettled climate science.

Notes

1. IPCC. *Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* World Meteorological Organization, Geneva, Switzerland, 2018. https://www.ipcc.ch/sr15/.

2. Stocker TF *et al.* (eds) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 2013. The sentence quoted comes from the Summary for Policymakers, p. 17

3. Results presented in WGI AR5 Figure 10.4 and shown schematically in Figure 10.5.

4. Specifically, in relation to the average of the base period 1850–1900, referred to as 'pre-industrial'.

5. The qualifier 'essentially all' is quantified in the 'Results and discussion' section of a paper by Haustein *et al.* (2017). That paper is the source of the human-induced warming estimated using a simple globally-averaged model and shown in Figures 1, 2 and 3. Haustein, K. *et al.* A real-time Global Warming Index. *Scientific Reports* 2017; 7(1): 15417.

6. Estimated global average of near-surface air temperatures over land and sea-ice, and sea surface temperatures over ice-free ocean regions.

7. Haustein *et al.*, Figure 1.

8. Otto, FEL *et al.*, Embracing uncertainty in climate change policy. *Nature Climate Change* 2015; 5: 917–920.

9. Haustein *et al.* op. cit.

10. University of Alabama in Huntsville.

11. http://www.drroyspencer.com/

12. Scafetta N, Mirandola A and Bianchini A. 'Natural climate variability, part 2: Interpretation of the post 2000 temperature standstill'. *International Journal of Heat and Technology* 2017; 35(Special issue 1): S18–S26.

13. See their Table 2.

14. Soon W, Connolly R and Connolly M. 'Re-evaluating the role of solar variability on Northern Hemisphere temperature trends since the 19th century'. *Earth-Science Reviews* 2015; 150: 409–452. https://www.infona.pl/resource/bwmeta1.element.elsevier-897b3366-77be-34b6-accc-74d1d251db71

15. For HadSST3 (available at the KNMI Climate Explorer website; https://climexp.knmi.nl/start.cgi).

16. Osborn TJ, Jones PD and Joshi M. 'Recent United Kingdom and global temperature variations'. *Weather* 2017: 72(11): 323–329.

17. Buizza R. 'ERA-CLIM2 outcomes boost NWP and climate work'. ECMWF Newsletter No. 155, Spring 2018, pp. 6–7.

18. Laloyaux P., *et al.* 'CERA-20C: A coupled reanalysis of the twentieth century'. *Journal of Advances in Modeling Earth Systems* 2018; 10: 1172–1195.

19. Voosen P. 'Climate scientists open up their black boxes to scrutiny'. *Science* 2016; 354: 401–402.

20. Hourdin F *et al.* 'The art and science of climate model tuning'. *Bulletin of the American Meteorological Society* 2017; 98: 589–602.

21. Zhao, M. *et al.* Uncertainty in model climate sensitivity traced to representations of cumulus precipitation microphysics. *Journal of Climate* 2016; 29, 543-560

22. IPCC Fifth Assessment (2013), Working Group 1 report, Fig. 10.21.

23. Christy's testimony was republished in *Climate Science: Assumptions, policy implications, and the scientific method*. Report No. 24, Global Warming Policy Foundation, 2017.

24. AR5 WG1 SPM, p. 16.

25. Lewis N and Curry J. 'The impact of recent forcing and ocean heat uptake data on estimates of climate sensitivity'. *Journal of Climate* 2018; 31: 6051–6071.

26. Lindzen RS and Choi Y. 'On the observational determination of climate sensitivity and its implications'. *Asia-Pacific Journal of Atmospheric Science* 2011; 47: 377–390.
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About the Global Warming Policy Foundation

The Global Warming Policy Foundation is an all-party and non-party think tank and a registered educational charity which, while openminded on the contested science of global warming, is deeply concerned about the costs and other implications of many of the policies currently being advocated.

Our main focus is to analyse global warming policies and their economic and other implications. Our aim is to provide the most robust and reliable economic analysis and advice. Above all we seek to inform the media, politicians and the public, in a newsworthy way, on the subject in general and on the misinformation to which they are all too frequently being subjected at the present time.

The key to the success of the GWPF is the trust and credibility that we have earned in the eyes of a growing number of policy makers, journalists and the interested public. The GWPF is funded overwhelmingly by voluntary donations from a number of private individuals and charitable trusts. In order to make clear its complete independence, it does not accept gifts from either energy companies or anyone with a significant interest in an energy company.

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2	Philipp Mueller	The Greening of the Sahel
3	William Happer	The Truth about Greenhouse Gases
4	Gordon Hughes	The Impact of Wind Power on Household Energy Bills
5	Matt Ridley	The Perils of Confirmation Bias
6	Philipp Mueller	The Abundance of Fossil Fuels
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