THE FROZEN CLIMATE VIEWS OF THE IPCC

An analysis of AR6

EDITED BY MARCEL CROK, ANDY MAY

clintel.org

Colophon

Clintel Foundation
Zekeringstraat 41C
1014 BV, Amsterdam
The Netherlands
https://clintel.org
Send feedback to office@clintel.org

ISBN: ????? (ebook)
ISBN: ????? (paperback)

Edited by Marcel Crok and Andy May
Text design and composition by Maarten Bosch (Little Shop of Graphics)

Contributing authors:
Dr. Javier Vinós (molecular biologist, writer, Spain)
Dr. Ross McKitrick (Professor of Economics, University of Guelph, Canada)
Dr. Nicola Scafetta (Professor of Atmospheric Physics, University of Naples Federico II, Italy)
Kip Hansen (science research journalist, USA)
Dr. Fritz Vahrenholt (Professor, University of Hamburg, Germany)
Dr. Ole Humlum (Professor, University of Oslo, emeritus, Norway)
Marcel Crok (Director, Clintel, The Netherlands)
Andy May (Science writer and retired petrophysicist, USA).

Special discounts for bulk sales are available. Please contact office@clintel.org.

Publisher: Andy May Petrophysicist LLC, The Woodlands, Texas, USA

Contents

Summary 1
Erasing climate history 4
New hockey stick 4
Global temperature 6
Snow cover 8
Sea Level Rise 9
The Sun's Role in Climate Change 10
Climate Sensitivity to CO_2 11
Are climate models unreliable? 12
The Climate Change Scenarios 13
Hiding good news on extremes 13
Disaster losses 14
Climate-related deaths 15
Our summary 16

A Observations 18

1 No confidence that the present is warmer than the Middle Holocene 20
Proxy-Based Temperature Reconstructions 22
The Holocene Temperature Conundrum 24
Glacier Advances 25
Treelines 26
Instrumental Temperature Changes Uncertainty 27

2 The Resurrection of the Hockey Stick 30
Are humans 100% responsible for Modern Warming? 33
University of Bern and the Hockey Stick 35
How the Medieval Warm Period disappeared from AR6 35
How robust is the new hockey stick? 37
Conclusion 39

3 Measuring Global Surface Temperatures 40
How significant is the global warming since the 19th century? 45
Ocean temperatures 47
GSAT, the Global Surface Air Temperature 50
Discussion and Conclusions 52

4 Controversial Snow Trends 54
Snow Cover Extent in AR6 56
Discrepancy with other studies 58
Statistical issues in Mudryk et al. 2020 60
Comparison with climate models 62
Discussion 63

5 Accelerated Sea Level Rise: not so fast 64
Relative sea level 70
Absolute sea level rise 72

B Causes of Climate Change 74

6 Why does the IPCC downplay the Sun? 76

Numerous case studies support solar participation in the climate equation 78
The Past as a Plausibility Check 82
Sun influences rain 85
IPCC's AR6 downplays the Sun 85
The UV Amplifier 86
The Cosmic Ray Amplifier 87
Climate models cannot capture the sun 88
IPCC has progressively downgraded the sun 89
Conclusions 90

7 Misty Climate Sensitivity 92

A Sensitive Matter 95
The importance of high climate sensitivity 96
Spectacular new likely range 96
The Sherwood paper 97
Different lines of evidence 98
Historical estimates 99
The pattern effect 101
A clear error by the IPCC 103

8 AR6: More confidence that models are unreliable 106

Is Warming Amplified Higher in the Atmosphere? 109
Is the Stratosphere still Cooling? 110
AR6/CMIP6 Models are too Warm Globally 112
Conclusions 113

C Climate Change Scenarios 114

9 Extreme scenarios 116

Baseline Scenario 119
How Plausible are the Extreme Scenarios? 121
Scenario Reality Check 123
Most realistic scenario 126

10 A miraculous sea level jump in 2020 128

AR6 Sea Level Projection Tool 131
Reflections 135

D Human Impacts 136

11 Hiding the good news on hurricanes and floods 138

Pielke Jr.'s Assessment 140
Damage Trends 142
Tropical cyclones 142
Drought 145
Extreme hot days and heatwaves 145
AR6 WG1 Summary for Policy Makers 146
Floods 147
WG1 Report 148
WG2 report 148
Conclusions 149

12 Extreme views on disasters 150

Normalisation of damage 152
Landfalling hurricanes 154
Earlier IPCC reports 155
Global weather losses 156
Working Group 2 report 156
AR6, Pielke Jr., and Normalisation 158
AR6 misrepresents Mechler and Bouwer 158
Conclusions 160

13 Say goodbye to climate hell, welcome climate heaven 162

Bjorn Lomborg 164
Climate heaven 165
EM-DAT database 166

Epilogue 169

Summary

BY MARCEL CROK AND ANDY MAY

If we must summarize the IPCC-reports in one paragraph, it might sound like this: Climate change is happening at an increasingly rapid pace. Current warming is unprecedented in at least 125,000 years and the current CO_2 concentration is unprecedented in at least two million years. CO_2 and other greenhouse gases have caused all or most of the warming since 1850. As a result, some changes, like sea level rise, are already irreversible for centuries to come. Climate change is already making the weather more extreme. Around half of the global population is very vulnerable to climate change. Only urgent climate action, i.e., reducing CO_2, methane, and other greenhouse gases, can secure a liveable future for all. Luckily, renewable energy has become much cheaper in the past decade, so we can do it.

Some sentences here are paraphrased, but others are literally from IPCC text. An even shorter summary would be this: the current warming is unprecedented, is caused by us, it is very dangerous, and we should stop it by reducing our CO_2 emissions, preferably by enhancing the production of renewable energy.

From the IPCC website:

> Created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies. IPCC reports are also a key input into international climate change negotiations. The IPCC is an organization of governments that are members of the United Nations or WMO. The IPCC currently has 195 members. Thousands of people from all over the world contribute to the work of the IPCC.

The role of the IPCC is laid down in its procedures.[1] Here is the most relevant one (our bold):

> The role of the IPCC is to assess on **a comprehensive, objective, open and transparent basis** the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies.

The IPCC can also be seen as a "knowledge monopoly" and as such it suffers from the same dangers as any other monopoly. The well-known Dutch (climate) economist Richard Tol, who contributed to several IPCC reports, but was not invited to work on AR6, after he criticized and left the author team of the AR5 Working Group 2 (WG2) *Summary for Policy Makers* report in 2013.[2] He wondered how you could regulate such a knowledge monopoly.[3] In his abstract, Tol described the IPCC process in the following way:

> The Intergovernmental Panel on Climate Change has a monopoly on the provision of climate policy advice at the international level and a strong market position in national policy advice. This may have been the intention of the founders of the IPCC. I argue that the IPCC has a natural monopoly, as a new entrant would have to invest time and effort over a longer period to perhaps match the reputation, trust, goodwill, and network of the IPCC. The IPCC is a not-for-profit organization, and it is run by nominal volunteers. It therefore cannot engage in the price-gouging that is typical of monopolies. However, the IPCC has certainly taken up tasks outside its mandate. The IPCC has been accused of haughtiness. Innovation is slow. Quality may have declined. And the IPCC may have used its power to hinder competitors. [These] are all things that monopolies tend to do, against the public interest. The IPCC would perform better if it were regulated by an independent body which audits the IPCC procedures and assesses its performance; if outside organizations would be allowed to bid for the production of reports

1 https://www.ipcc.ch/site/assets/uploads/2018/09/ipcc-principles.pdf

2 https://www.bbc.com/news/science-environment-26655779

3 Tol, Richard S J (2011) *Regulating knowledge monopolies: The case of the IPCC.* Climatic Change, 108 (4). pp. 827-839. ISSN 0165-0009

and the provision of services under the IPCC brand; and if policy makers would encourage potential competitors to the IPCC.

This was written by Tol in 2011, a year after the InterAcademy Council (IAC) investigated the IPCC process, after errors in the IPCC AR4 report received a lot of attention in the media.[4] The most striking error was the claim in the AR4 WG2 report that Himalayan glaciers would be completely gone in 2035, a claim the IPCC later admitted was unfounded.[5]

The IAC made several recommendations. In our (i.e., Clintel's) view a key IPCC problem is group-think. The IPCC tends to invite only those scientists that strongly agree with claims in earlier IPCC reports, i.e., that current warming is unprecedented, caused by greenhouse gases, and is danger-ous. Then they write the same conclusion in the next report. Big surprise.

The IAC review was quite clear about dealing with a range of views (page 17-18, our bold):

> **Handling the full range of views**
> An assessment is intended to arrive at a judgment of a topic, such as the best estimate of changes in average global surface temperature over a specified time frame and its impacts on the water cycle. Although all reasonable points of view should be considered, they need not be given equal weight or even described fully in an assessment report. Which alternative viewpoints warrant mention is a matter of professional judgment. Therefore, Coordinating Lead Authors and Lead Authors have considerable influence over which viewpoints will be discussed in the process. **Having author teams with diverse viewpoints is the first step toward ensuring that a full range of thoughtful views are considered.**
> **Equally important is combating confirmation bias—the tendency of authors to place too much weight on their own views relative to other views** (Jonas et al., 2001). As pointed out to the Committee by a presenter and some questionnaire respondents, alternative views are not always cited in a chapter if the Lead Authors do not agree with them. Getting the balance right is an ongoing struggle. However, concrete steps could also be taken. For example, **chap-ters could include references to all papers that were considered by the authoring team and describe the authors' rationale for arriving at their conclusions.**

In this book we will show that not only did the IPCC not follow this recommendation, it did the opposite. It went to great lengths to exclude "diverse viewpoints" to draw its often alarmist con-clusions. We will show that one well-known scientist, Roger Pielke Jr., whose work is relevant for many chapters, is treated by the IPCC as a 'Voldemort', the Harry Potter villain 'whose name shall not be named'.[6] Indeed, as we document in several chapters of this book, the IPCC avoids men-tioning his work, so they can draw opposite conclusions. Pielke told us that a U.S. IPCC contributor literally told him that "he would never be involved in IPCC".

Other well-known sceptical scientists, like Richard Lindzen, John Christy, and Roger Pielke Sr (yes, the father of Jr) have contributed or tried to contribute to earlier WG1 reports but were disap-pointed about the process and decided not to spend their energy on it anymore. A pity, because if the IPCC author teams would recruit scientists with diverse viewpoints, a lot of the shortcomings that we document in this book could have been prevented. The conclusions of the IPCC reports would be radically different though, and far less apocalyptic.

This book is written by scientists and experts who were not directly involved in the writing of the IPCC reports (although some have been "expert reviewer" of one or more IPCC reports) and who are experienced with the underlying climate science literature. We investigated if the IPCC fol-lowed their own principles. Are the reports and its claims really based on a comprehensive review

4 https://archive.ipcc.ch/organization/organization_review.shtml
5 https://www.theguardian.com/environment/2010/jan/20/ipcc-himalayan-glaciers-mistake
6 This is going on for a long time. Here an example by Andrew Revkin in 2012: The Superstorm and Humanity's Disaster Blind Spot - The New York Times (nytimes.com)

of the literature? Are the conclusions unbiased, objective and the methods of reaching them transparent? The short answer to these questions is a very clear "no".

The book is divided into four parts. Part 1 deals with observations, starting at the end of the last ice age (the start of the Holocene) all the way to the current modern warming period. Part 2 looks at causes of climate change, including the role of the sun and the effect of additional greenhouse gases. Part 3 examines the scenarios used by the IPCC especially the most extreme one, the so-called RCP8.5 or SSP5-8.5 scenario. In part 4 we delve into the impacts of climate change, mainly on humans. Parts 1 to 3 of the book discuss the Working Group 1 report (WG1) of AR6 while part 4 deals with the Working Group 2 report (WG2).

Erasing climate history

In AR6, the IPCC makes the remarkable claim that "global surface temperatures are more likely than not unprecedented in the past 125,000 years." This claim erases the so-called Holocene Thermal Maximum, sometimes called the Holocene Climatic Optimum, terms that are avoided by the IPCC. The IPCC flattens our climate history thereby making the current warming look "unprecedented" and therefore "unique". But is this realistic?

The Holocene Thermal Maximum is well documented in the literature and can be considered a period that extended from c. 9800-5700 before present (BP[7]) when temperatures varied considerably in many parts of the globe and maximal Holocene temperatures were reached in many areas, but often at different times. As the Spanish scientist Javier Vinós, author of the recent book *Climate of the Past*[8], notes in Chapter 1:

> Multi-proxy reconstructions are useful, but biases and unavoidable limitations of the technique result in their inability to answer the IPCC question: Was the last decade the warmest the planet has been during the Holocene?

As Vinós explains a multi-proxy reconstruction is very dependent on researcher's choices, starting with the proxies included and excluded, whether land and marine proxies are representative of temperatures in the area, and what their respective weight should be in the mix. Attempting to measure the average temperature of the planet with a few hundred low-precision uncalibrated proxy thermometers that provide a reading once a decade to once a century or two at best is a laughable task. Comparing the resulting global average with our daily modern measurements, including satellites and thousands of high-precision calibrated thermometers distributed all over the world, including all the oceans, and then declaring we can trust that it is *more likely than not* that the past decade is warmer than any century during the past 12,000 years is an untenable claim.[9]

New hockey stick

A big surprise in the AR6 Working Group 1 report was the publication of a new hockey stick graph. The first pronounced hockey stick graph was published by Michael Mann in 1998 and 1999[10] and it was heavily promoted in the 3rd IPCC (TAR) report in 2001.

---

7 B.P. (Before the Present) is the number of years before the present. Because the present changes every year, archaeologists, by convention, use A.D. 1950 as their reference.

8 Vinós, J. (2022). Climate of the Past, Present and Future, A Scientific Debate. 2nd ed. Critical Science Press

9 Chapter 1: No confidence that the present is warmer than the Middle Holocene

10 Mann, M. E., Bradley, R. S., and Hughes, M. K., 1999, Northern Hemisphere Temperatures during the past Millennium: Inferences, Uncertainties, and Limitations: Geophysical Research Letters, v. 26, no. 6, p. 759-762.

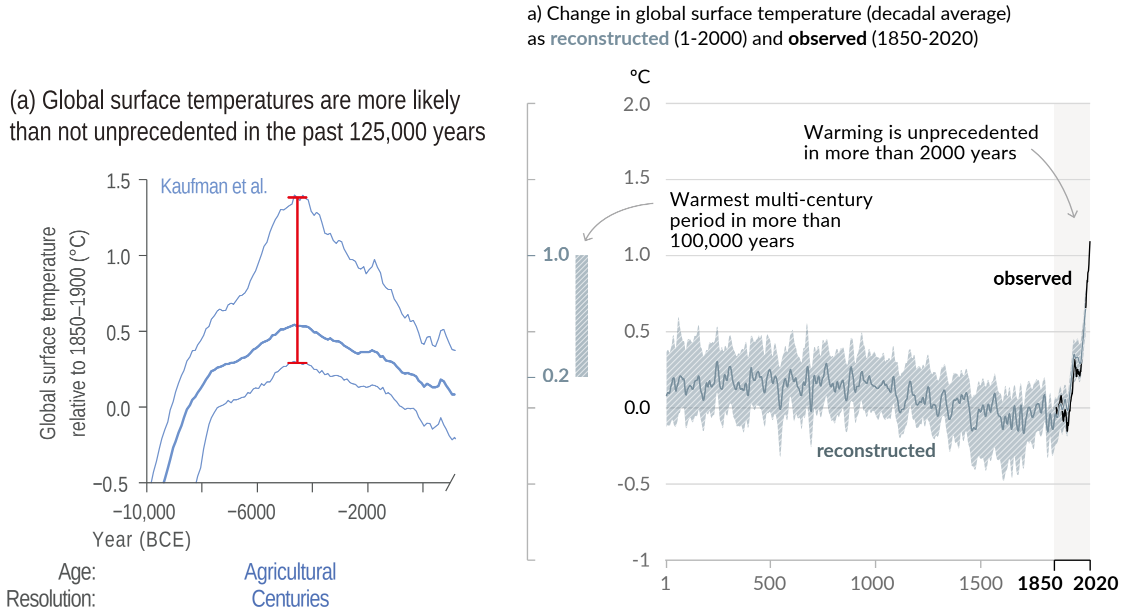


Figure 1: The new AR6 hockey stick is shown on the right. On the left is part of AR6 WG1 figure 2.11a. It shows a temperature reconstruction by Kaufman et al. (2020) with the uncertainty noted with a red bar at the peak of the Holocene Thermal Maximum. The uncertainty is as large or larger than the total modern warming.

Hockey stick graphs are used by the IPCC to claim that the current warming is unprecedented in the last 1000 or 2000 years. Both the current (AR6) hockey stick, and the first one by Mann et al. in 1998 attempt to erase the historically well-documented Medieval Warm Period and Little Ice Age. They are trying to send the message that these were only regional phenomena, with little consequence globally.

The earlier hockey stick was heavily criticized for major deficiencies in paleoclimatic proxies, and the statistical methods used to construct it (Soon et al. 2003[11], McIntyre and McKitrick, 2003[12], 2005[13]; McShane and Wyner, 2011a, b[14]; Montford, 2010[15]).

According to Stephen McIntyre, the problem with all these reconstructions is more or less the same. Authors select proxies from thousands of available proxy series in international databases. Most proxies show anything at all raising doubt about their validity as a temperature proxy in the first place. Authors then select their proxies, apply one or more statistical methods to them to end up with their hockey stick. The latest incarnation of the hockey stick is examined in more detail in Chapter 2.[16]

In summary, we find the claims by the IPCC, that current warming is unprecedented in the last 2000 or even the last 125,000 years, very unconvincing to say the least. There is good evidence that both in the last 2000 years as well during the Holocene Thermal Maximum, temperatures were similar or higher than during the current warming period. In this case, the IPCC seems to act like George Orwell's ministry of truth, by rewriting earth's climate history. Moreover, the IPCC failed to discuss these issues in a comprehensive and transparent way. Their bias is revealed in their choice of what studies they include in the report and what studies they ignore.

11 Soon, Willie, and Sallie Baliunas. "Proxy Climatic and Environmental Changes of the Past 1000 Years." *Climate Research*, vol. 23, no. 2, 2003, pp. 89–110. *JSTOR*, http://www.jstor.org/stable/24868339. Accessed 3 Apr. 2023.

12 McIntyre, S., and McKitrick, R., 2003, Corrections to the Mann et al. (1988) proxy data base and northern hemispheric average temperature series: Energy & Environment, v. 14, no. 6, p. 751-771.

13 McIntyre, Stephen and Ross McKitrick (2005a) "The M&M Critique of the MBH98 Northern Hemisphere Climate Index: Update and Implications." Energy and Environment 16(1) pp. 69-100; (2005b) "Hockey Sticks, Principal Components and Spurious Significance" Geophysical Research Letters Vol. 32, No. 3, L03710 10.1029/2004GL021750 12 February 2005.

14 McShane, B. B., and Wyner, A. J., 2011a, Rejoinder: The Annals of Applied Statistics, v. 5, no. 1, p. 99-123. -, 2011b, A statistical analysis of multiple temperature proxies: Are reconstructions of surface temperatures over the last 1000 years reliable?: The Annals of Applied Statistics, v. 5, no. 1, p. 5-44.

15 Montford, A. W., 2010, The Hockey Stick Illusion, London, Stacey International, 482 p.

16 Chapter 2: The Resurrection of the Hockey Stick

Global temperature

The Global Mean Surface Temperature (GMST) has become the iconic parameter in the climate change debate. It is the measurement of choice when deciding international climate policy, as in are we to exceed either the 1.5°C or 2°C target. Even though these targets are arbitrary and political[17] rather than scientific. Unscientific as they are, these targets dominate the scientific discourse about climate change. But is that deserved? How reliable are these temperature measurements and are there 'better' alternatives?

Before Andy May delves into detailed discussions[18] about the many different temperature datasets and their uncertainties, he first puts the rise in global average temperature of one degree Celsius since 1850 into perspective.

Each year the globe experiences temperature swings that are much larger than the one degree rise in the annual average temperature seen in the past 170 years. The global average temperature of Earth varies over three degrees every year, it is just over 12 degrees in January and just under 16 degrees in July as shown in figure 2 from Phil Jones and colleagues at the UK Met Office. The Northern Hemisphere average temperature has a larger swing from eight degrees in January to over 21 degrees in July, a remarkable change of 13°C in only six months.

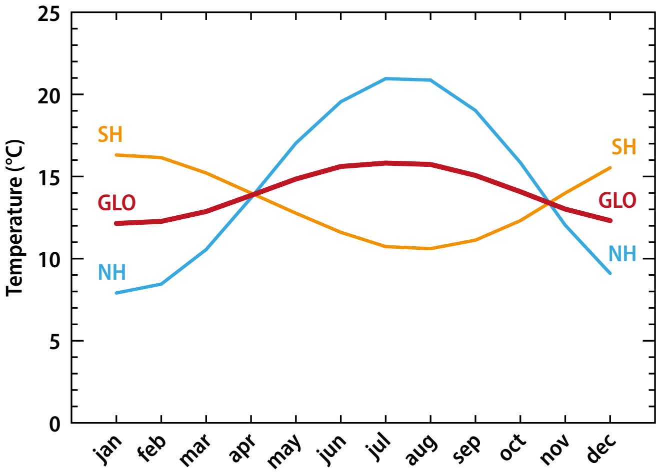


Figure 2: Average global surface temperatures from 1961-1990 for the globe (GLO), Northern Hemisphere (NH) and Southern Hemisphere (SH) by month. After: (Jones, New, Parker, Martin, & Rigor, 1999).[19]

The IPCC appears to agree that GMST is a poor measure of climate change and provides a plot of the change in ocean heat content in AR6 on page 350, it is shown below as Figure 3. The steep upward slope appears alarming as it moves from 0 to 500 zettajoules. Even the unit "zettajoules" sounds scary. But how many zettajoules of energy do the global oceans contain? A staggering 1,514,000! So, an increase of 500 zettajoules is a change of 0.03% in the global energy content, hardly an alarming change. The IPCC avoided giving this important background information.

The steep slopes are an artifact of the scales chosen and the starting point. Figure 4 is more meaningful and is roughly the same body of water as shown in the right graph in figure 3. The only difference is figure 3 is to the surface and figure 4 is from 100 meters depth to 2000 meters.

17 https://rogerpielkejr.substack.com/p/the-two-degree-temperature-target

18 Chapter 3: Measuring global surface temperature

19 Jones, P. D., New, M., Parker, D. E., Martin, S., & Rigor, I. G. (1999). Surface Air Temperature and its Changes over the Past 150 years. Reviews of Geophysics, 37(2), 173-199. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.546.7420&rep=rep1&type=pdf

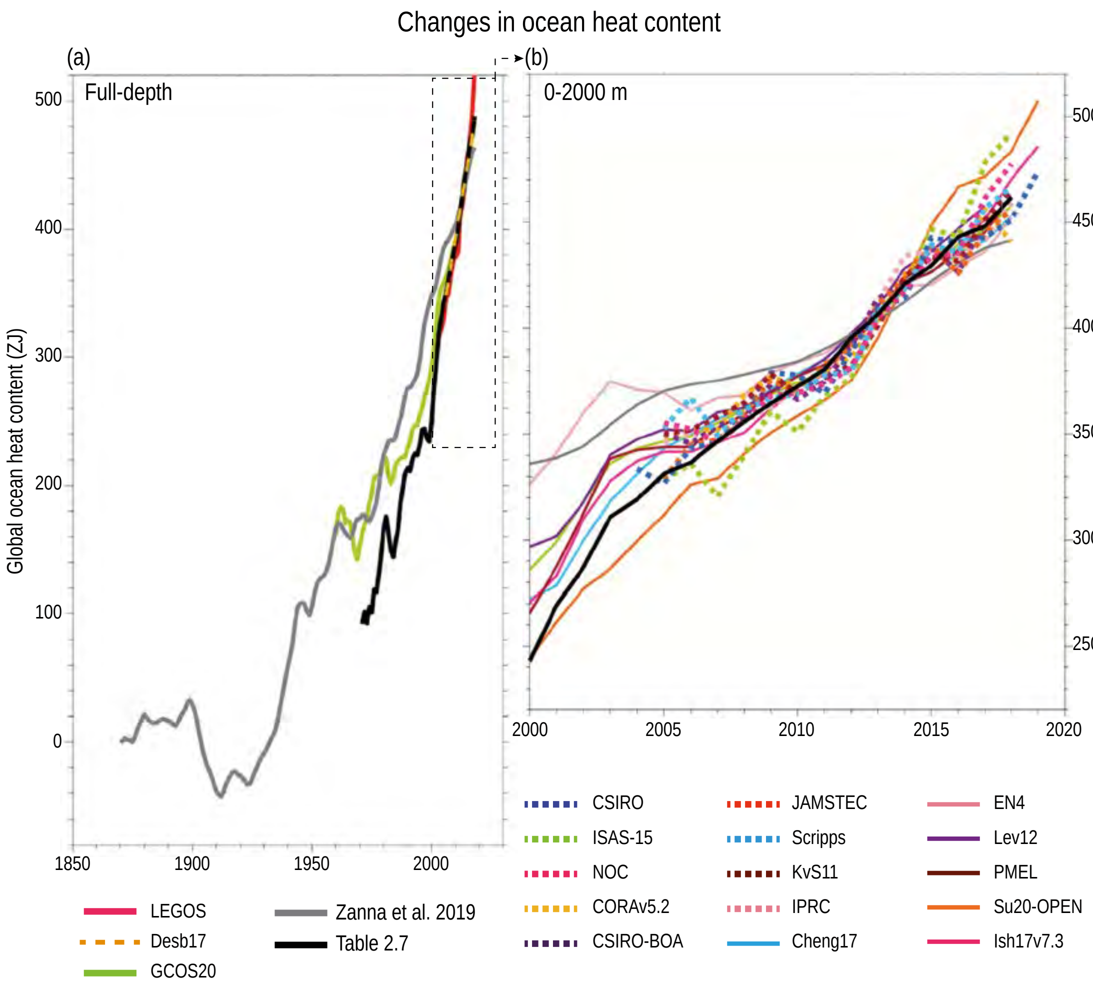


Figure 3: Changes in ocean heat content from AR6, Chapter 2, page 350.

In figure 4 we see a rate of increase of about 0.4°C/century. This is less than half that reported for the surface over the past century or so. Reporting the change in ocean temperature is a more relevant and understandable way to show recent changes in the climate system, as Roger Pielke Sr. wrote in 2003.[20] When interested in global warming or cooling one should look at the ocean heat content.

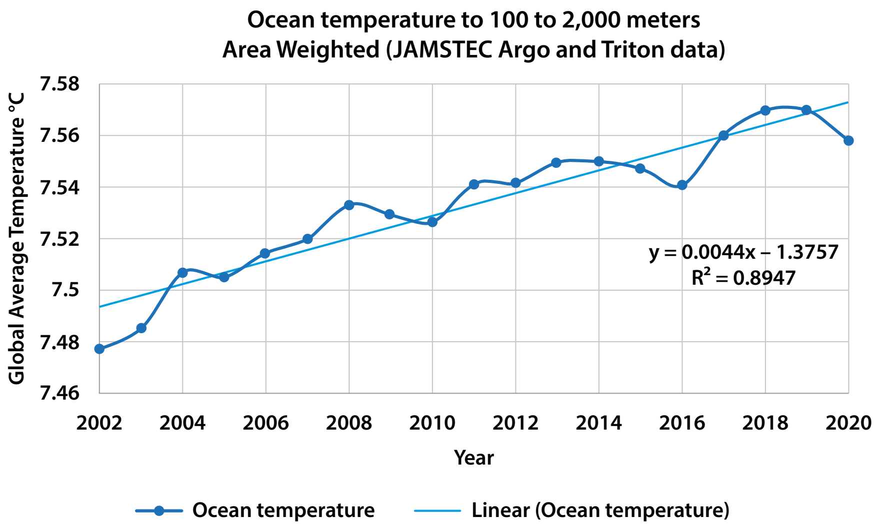


Figure 4: Average temperature for the world ocean from 100 to 2,000 meters. Data from JAMSTEC.

20 Pielke Sr., r. (2003, March). Heat Storage within the earth System. BAMS, 84(3), 331-335. Retrieved from https://journals.ametsoc.org/view/journals/bams/84/3/bams-84-3-331.xml

May concludes by answering questions he posed at the beginning of his chapter. Are the estimates of global temperature change since 1850 accurate and comprehensive enough to tell us how quickly Earth's entire surface, including the oceans, are warming? *No.* Is the global mean surface temperature a key indicator of climate change? *No*, the measurements used simply reflect local weather and environmental conditions and are affected by the chaotic conditions at the surface. Further, the total change recorded over the past century is too small relative to the basic temperature measurement accuracy and natural climate variability.

Snow cover

In 2000, Dr David Viner, a senior research scientist at the climatic research unit (CRU) of the University of East Anglia, said that within a few years winter snowfall in the UK would become "a very rare and exciting event". "Children just aren't going to know what snow is," he said.[21]

It's now 2023 and his prediction didn't come through. It's tempting to think that global warming will mean less snow. On the other hand, warming could mean more evaporation and more precipitation, including in the form of snow. There is no necessary relationship between global average temperature and snowfall.

The IPCC decided to show a snow trend graph only for the month of April (figure 5):

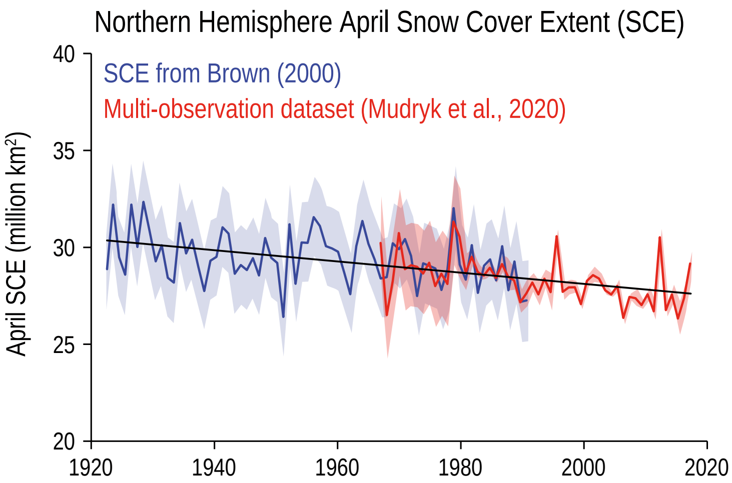


Figure 5: April snow cover extent (SCE) for the Northern Hemisphere. From: AR6, chapter 2.

The IPCC introduced a brand-new dataset that wasn't even published yet at the time of the Second Order Draft, the last version that is seen by reviewers. Not surprisingly, the scientist behind this new dataset, Lawrence Mudryk, was also a contributing author of the chapter in the IPCC report. This new dataset is a so-called hybrid dataset, it consists of seven different datasets. Some of these datasets use measurements, others use models or a combination of models and measurements. We tried unsuccessfully to download the different datasets behind this new dataset.[22]

With the new dataset the IPCC now made the claim that snow cover extent is in decline in all months of the year. This is remarkable, because until now, the well-known Rutgers Global Snow Map dataset showed increasing snow cover extent during the Fall and Winter.

The IPCC mentions a relevant paper by Connolly et al. but failed to mention its key conclusion, namely that climate models are unable to simulate the increasing trend in snow cover in the Fall and Winter:[23]

21 https://web.archive.org/web/20130422045937/http://www.independent.co.uk/environment/snowfalls-are-now-just-a-thing-of-the-past-724017.html

22 Chapter 4: Controversial Snow Trends, by the Clintel Team.

23 Connolly, et al., 2019, Northern Hemisphere Snow-Cover Trends (1967-2018): A Comparison between Climate Models and Observations, Geosciences, 9, 135, doi:10.3390/geosciences9030135

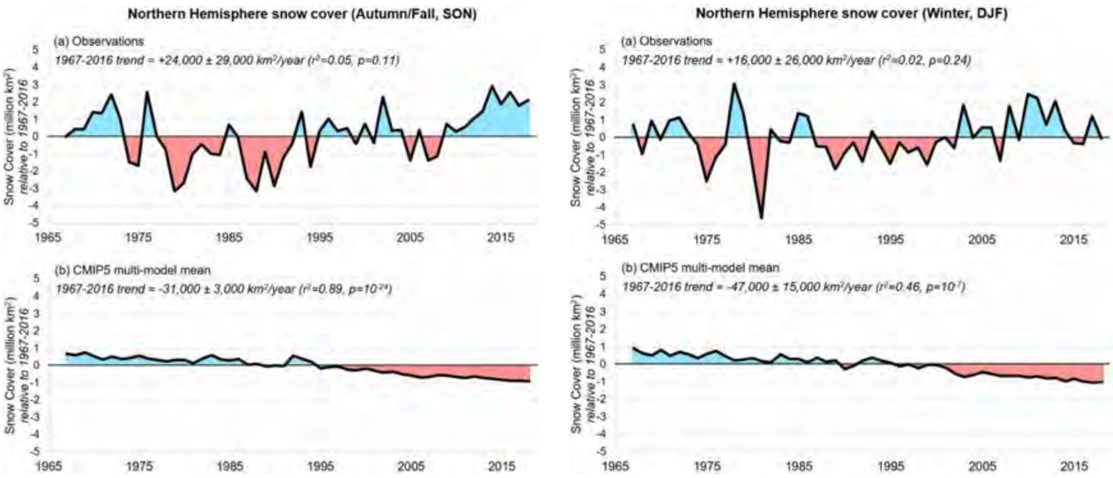


Figure 6: Northern Hemisphere snow cover in Autumn/Fall and winter. Top panel: observations based on the Rutgers Snow Lab data. Bottom panel: based on CMIP5 simulations. Source of the figure: Connolly et al. (2019).

The IPCC introduced a brand-new dataset far too late in the process. Reviewers were unable to check the validity of this radically new dataset.

The trends in Northern Hemisphere snow cover extent are just one of many examples of biased reporting in the IPCC AR6 report. The outcome of the assessment is largely decided when report authors are nominated. In this case, the lead author of a key paper, Lawrence Mudryk, was nominated as contributing IPCC author and most likely influenced the direction of the IPCC literature review in his own favour.

Sea Level Rise

The IPCC's Sixth Assessment Report (AR6) claims that sea level rise is accelerating. However, the evidence for this is rather thin.

As Kip Hansen points out[24], the best available evidence for long-term sea level changes comes from tide gauge records. These records typically show remarkably linear behaviour for more than a century. The IPCC likes to use satellite sea level measurements combined with a blend of tide gauge records to show that sea level rise is accelerating. The IPCC ignores the fact that the rise in sea level shows multidecadal variability, probably related to the Atlantic Multidecadal Oscillation. A paper the IPCC itself frequently cited has this figure:

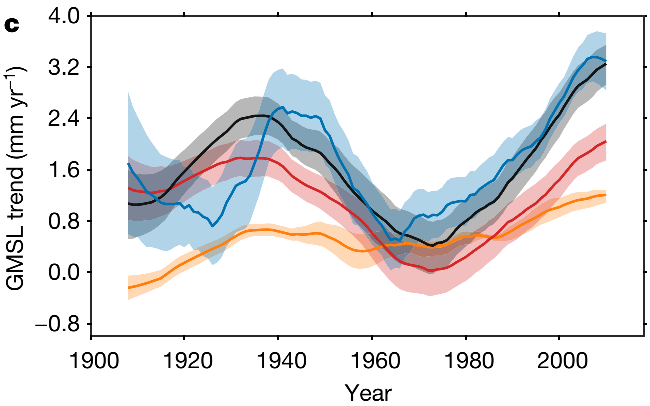


Figure 7: Sea level trend based on a so-called sea level budget method model as used in Frederikse et al 2020.[25] The thick blue line is the observed trend and black is the sum of different model components. Orange and red are two important components, they are thermosteric (thermal expansion) change and barystatic (the change in seawater mass) respectively.

---

24 Chapter 5: Accelerated Sea Level Rise: not so fast

25 Frederikse, T., Landerer, F. C., Caron, L., Adhikari, S., Parkes, D., & Humphrey, V. (2020). The causes of sea-level rise since 1900. Nature, 584, 393-397. Retrieved from https://www.nature.com/articles/s41586-020-2591-3

So, it is likely that the IPCC conflates their recent 'acceleration' of the sea level with this multidecadal variability. This should become clear in the next 10 to 20 years. Right now, it is very preliminary to claim there is an acceleration of the sea level rise.

In Chapter 10[26], Ole Humlum uses the IPCC sea level projection tool,[27] which the public can use to 'make' different sea level scenarios for tide gauge stations around the world, to project sea level for four Scandinavian capitals and shows us the surprising results. It seems that the IPCC projections contrast sharply with observations. Below, in figure 8, we compare the IPCC projections and observations for Stockholm, Sweden.

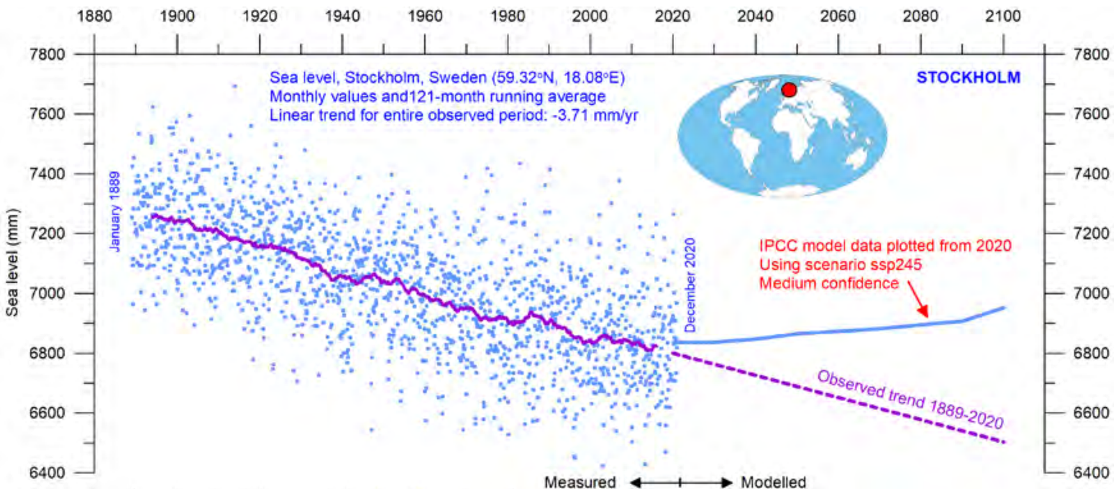


Figure 8: The IPCC projected sea level change versus observations for Stockholm, Sweden.

Only time will tell if the IPCC sea level projections are correct, but they do contrast strongly when compared to recent observations. Humlum observes:

> It is … extremely surprising that the modelled effect of this [change] should first appear in 2020 as a rather marked step change in the relative sea level. Had the modellers instead modelled their sea level data from an earlier date, e.g., 1950, which would have been entirely possible, the conflict between measured and modelled data would immediately have become apparent. Usually, model improvements would then have been initiated as the next scientific step. It is highly disappointing that such a simple quality- or sanity check was apparently never requested or performed by the IPCC.

It seems that this tool was not produced to test the validity of a scientific idea. It was instead an attempt to alarm the user.

The Sun's Role in Climate Change

We start Part 2 on the causes of climate change with Nicola Scafetta's and Fritz Vahrenholt's chapter on the Sun.[28] They point out that the Medieval Warm Period (MWP) and the Little Ice Age (LIA) are historically well documented climatic anomalies in the peer-reviewed literature from around the world. Historical records of sunspots, auroras, and solar proxies, also document significant changes in solar activity. The climate changes and the solar activity changes correlate well.[29] Temperatures were relatively warmer during the MWP and solar activity was higher, temperatures were lower during the LIA and solar activity was lower. Common sense suggests there is probably some connection between the two.

26 Chapter 10: A miraculous sea level jump in 2020

27 https://sealevel.nasa.gov/data_tools/17

28 Chapter 6: Why does the IPCC downplay the Sun?

29 Connolly et al., R. (2021). How much has the Sun influenced Northern Hemisphere temperature trends? Research in Astronomy and Astrophysics, 21(6). Retrieved from https://iopscience.iop.org/article/10.1088/1674-4527/21/6/131?fbclid=IwAR0U-5WARVnuGVjj2qeiiBYgGo0llxXb9NNzUbeqqN-th2Zp1YU8rLOZkrMM

As Scafetta and Vahrenholt point out, these two well documented periods provide an excellent scientific blind test of the solar-climate connection. They list many peer-reviewed studies that show the close connection between climate changes and solar activity. They correlate well in Spain, Portugal, Slovakia, China, Bhutan, and the Canadian Rocky Mountains. During the Wolf, Spörer, and Maunder solar minima, the intermediate water layers of the North Atlantic cooled by 2-3°C, while the surface water in the tropical North Atlantic off Mauritania cooled by 1°C. On Sakhalin, Russia's largest island, the lowest temperatures were recorded during the Maunder Solar Minimum. In Tasmania, Australia, proxies show cold periods during the Spörer and Maunder Solar Minima. Even in Antarctica, climate proxies correlate with repeated drops in solar activity.

Similar evidence shows that the Medieval Warm Period, which coincides with a solar maximum, was unusually warm around the world. Further, historical records and climate proxies show that solar minima and maxima correlate with precipitation around the world, including in the USA, Tibet, South America, India, China, Egypt, and elsewhere.

The first page of Chapter 6 contains a quote from a review paper by Connolly et al. (including Scafetta) that was published after the IPCC deadline but came to a different conclusion about the potential role of the sun in the warming period since 1850. The paper discusses the current uncertainties regarding both solar and climate data, and concludes that the data on past solar activity and climate changes:

> "suggest everything from no role for the Sun in recent decades (implying that recent global warming is mostly human-caused) to most of the recent global warming being due to changes in solar activity (that is, that recent global warming is mostly natural)".[30]

Thus, it appears that the conclusions presented in IPCC AR6 are consistent only with a portion of the published scientific literature, the portion that minimizes the role of the sun so as to maximize the anthropogenic component.

The exact mechanisms for the climate/solar correlation are unclear and the chapter lists and discusses several possible mechanisms. However, the correlation exists and for the IPCC to ignore it, and claim that modern climate change is 100% anthropogenic, simply because the solar connection cannot be explained is unacceptable.

Climate Sensitivity to CO_2

One of the most important conclusions of the 6th Assessment Report of the Intergovernmental Panel on Climate Change was to reduce the uncertainty in estimates of climate sensitivity to doubling the amount of carbon dioxide in the atmosphere. Since the Charney Report 1979[31], the *likely* range (66% chance) of climate sensitivity has been between 1.5°C and 4.5°C. This range has remained stubbornly wide, until the IPCC AR6 narrowed the *likely* range to be between 2.5°C and 4.0°C.

Andy May discusses the AR6 estimate of climate sensitivity to CO_2 in Chapter 7.[32] He explains that AR6 relied heavily on Sherwood et al. (2020), an important paper (Chapter 7 mentions the Sherwood paper 43 times) that was written by the who's who of the climate sensitivity community.[33] In earlier IPCC reports estimates for climate sensitivity relied heavily on climate model calculations, but the 'good news' is that the Sherwood et al paper, which was the basis for the narrowing of the likely range to 2.5°C and 4.0°C, did not.

30 Connolly et al., R. (2021). How much has the Sun influenced Northern Hemisphere temperature trends? Research in Astronomy and Astrophysics, 21(6). Retrieved from https://iopscience.iop.org/article/10.1088/1674-4527/21/6/131?fbclid=IwAR0U-5WARVnuGVjj2qeiiBYgGo0llxXb9NNzUbeqqN-th2Zp1YU8rLOZkrMM

31 Charney, J., Arakawa, A., Baker, D., Bolin, B., Dickinson, R., Goody, R., . . . Wunsch, C. (1979). *Carbon Dioxide and Climate: A Scientific Assessment.* National Research Council. Washington DC: National Academies Press. doi:https://doi.org/10.17226/12181

32 Chapter 7: Misty climate sensitivity

33 Sherwood, S. C., Webb, M. J., Annan, J. D., Armour, K. C., J., P. M., Hargreaves, C., . . . Knutti, R. (2020, July 22). An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence. Reviews of Geophysics, 58. doi:https://doi.org/10.1029/2019RG000678

The 'bad news' is that when independent scientist Nic Lewis redid the analysis of Sherwood et al (after the deadline of AR6) he discovered flaws in the statistics and shortcomings in the input data.[34] Lewis remedied these shortcomings and also revised key input data, almost entirely to reflect more recent evidence. The results of Lewis' analysis determined a *likely* range of 1.75 to 2.7°C for climate sensitivity. The central estimate from Lewis' analysis is 2.16°C, which is well below the IPCC AR6 *likely* range. This large reduction relative to Sherwood et al. shows how sensitive climate sensitivity estimates are to input assumptions. Lewis' analysis implies that climate sensitivity is more likely to be below 2°C than it is to be above 2.5°C.

The lower estimates of climate sensitivity determined by Nic Lewis have profound implications for climate models and projections of warming for the 21st century. Climate models used in the IPCC AR6 had values of climate sensitivity ranging from 1.8°C to 5.6°C. The IPCC AR6 judged that some of the climate models had values of climate sensitivity that were too high. Hence the AR6 selected only the climate models with reasonable values of climate sensitivity to be used in projections of 21st century climate change. Lewis' analysis indicates that a majority of climate models used in the IPCC AR6 have values higher than the *likely* range.

May discusses more evidence that the IPCC climate sensitivity is too high and speculates that the estimate is too high due to incorrect IPCC assumptions about cloud cover. The IPCC admits that a "multitude of studies" imply that the AR6 ECS is too high but ignores the "multitude of studies" without explaining why. Or rather their explanation is the IPCC is correct and everyone else is wrong.

Are climate models unreliable?

Ross McKitrick shows that the IPCC climate models compute global and tropical tropospheric air temperatures too high relative to observations.[35] This error appears in the model results from every model at a statistically significant level and invalidates the climate models. Since climate model projections are used to compute the future impact of climate change, this result invalidates the future projections as well.

Surprisingly, McKitrick found that if the impact of anthropogenic greenhouse gas emissions are removed from the climate models, the results match observations in the tropical troposphere much more closely. McKitrick also found that the AR6 model results, which are higher than the previous (AR5) results, universally overestimate *global* average temperature as shown in figure 9 below for the lower troposphere. The red dots and error ranges (95% confidence intervals) are the model results for 38 models and the blue dots and error ranges are observations from three data sources.

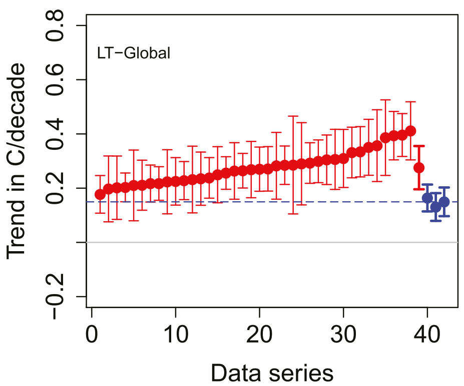


Figure 9: Model results in red, and observations in blue, with 95% confidence intervals indicated. The red dot and bar most right is the average of all the models. The Y axis is the warming trend in °C/decade for 1979-2014 for Earth's global lower troposphere.

34 climate sensitivity evidence. Climate Dynamics. Retrieved from https://link.springer.com/article/10.1007/s00382-022-06468-x?mc_cid=6760f55b0f&mc_eid=133f53df

35 Chapter 8: AR6: More confidence that models are unreliable

As McKitrick tells us in the conclusions of Chapter 8:

> If the discrepancies in the troposphere were evenly split across models between excess warming and cooling, we could chalk it up to noise and uncertainty. But that is not the case: it's all excess warming. The AR5/CMIP5 models warmed too much over the sea surface and too much in the tropical troposphere. Now the AR6/CMIP6 models warm too much throughout the global lower- and mid-troposphere. That's bias, not uncertainty, and until the modeling community finds a way to fix it, the economics and policy making communities are justified in assuming future warming projections are overstated, potentially by a great deal depending on the model.

The Climate Change Scenarios

Marcel Crok takes a close look at the CO_2 human emissions scenarios used by the IPCC to predict future temperatures and climate.[36] He finds that the IPCC admission that the higher emissions scenarios, SSP5-8.5 and SSP3-7.0 are unlikely is deeply buried in the report, and unlikely to be read by the policy makers. In addition, he finds that significant and important sections still emphasize these too-high unlikely scenarios, potentially invalidating those sections of the report.

This has serious implications from a policy standpoint. Figure 10 compares the various emissions scenarios and the resulting projected temperatures.

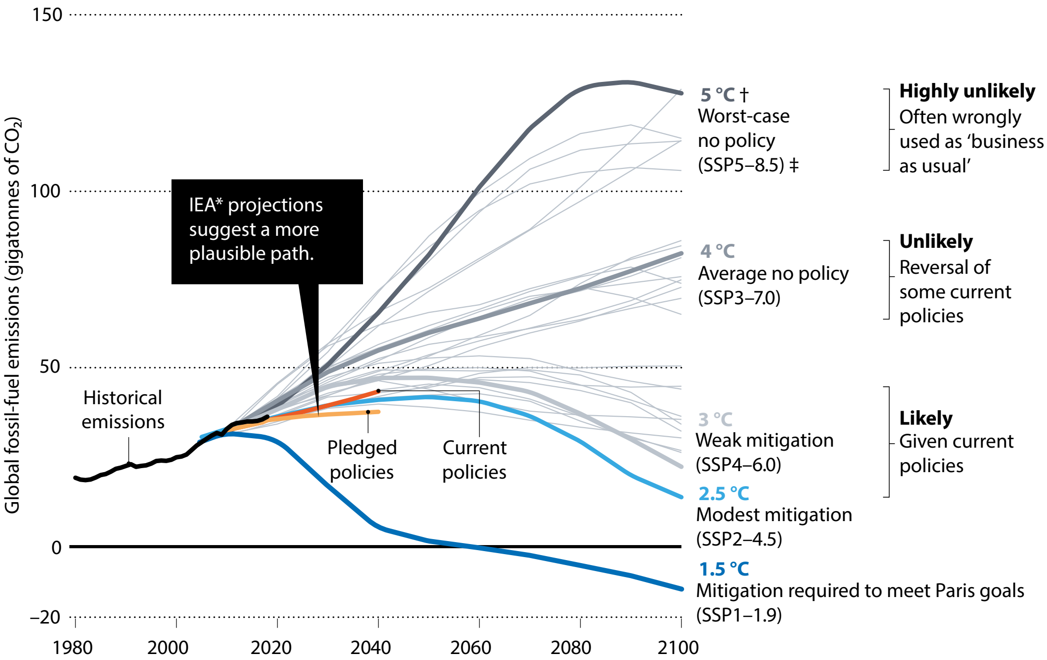


Figure 10: Various emissions scenarios projected into the future. This plot is from an article by Hausfather and Peters in *Nature* in 2020. The assessments of likelihood on the right are from Hausfather and Peters.

Figure 10 makes it clear that the extreme IPCC emissions scenarios are unlikely and should be considered unrealistic, academic extremes. Crok reports that 42% of the AR6 mentions of scenarios are of the most unlikely SSP5-8.5 scenario. Given that numerous authors have called this scenario "highly unlikely," this causes AR6 to lose credibility.

Hiding good news on extremes

The final part of the report is on the human impacts due to climate change. It starts with a chapter by Marcel Crok on hiding the good news.[37] He points out that AR6 claims that climate is becoming more extreme with time, but the data suggests this is not the case in most categories of climate (or

36 Chapter 9: Extreme scenarios

37 Chapter 11: Hiding the good news on hurricanes and floods.

more accurately “weather”) events. For example, deep inside the report the IPCC acknowledges that there is no trend in tropical cyclones and floods. Such extreme events cause about 90% of the global disaster losses, so it should be regarded as ‘good news’ that they show no increasing trend.

The longest available time series about landfall hurricanes is from the US. Although the graph below has been published in a peer reviewed paper it is not shown in any of the IPCC reports:

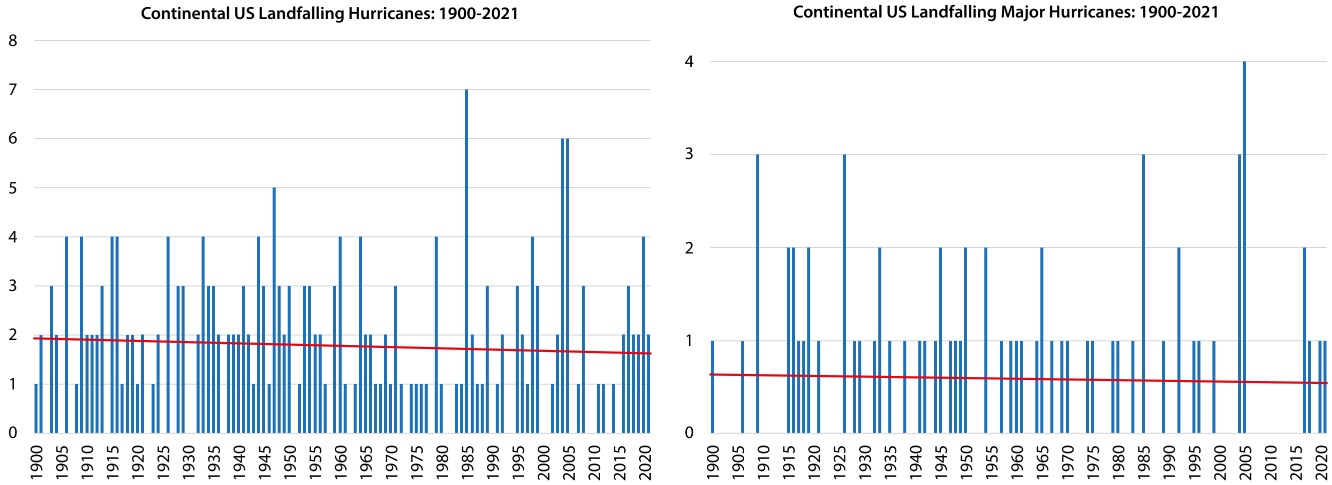


Figure 11: Number of US landfalling hurricanes and major hurricanes between 1900 and 2021. Updated graph from Klotzbach 2018.[38]

Global cyclones and U.S. hurricanes are decreasing in frequency and strength in recent decades, not increasing. On (hydrological and meteorological) droughts, deep in AR6 WG1 (pages 1578-1579) Crok finds that the authors have low confidence that human activities have contributed to those droughts at a regional scale. They do conclude that heat waves have increased globally since 1950, but the warmest years in the U.S. were in the 1930s, so this may be a result of the time period chosen.

Crok points out some serious contradictions between various parts of AR6 on this subject, especially between the WG1 and WG2 reports. The full WG1 report states that the IPCC has low confidence that humans have contributed to flooding, yet the *Summary for Policy Makers* (SPM) says the opposite, they believe that human influence has increased “compound” flooding (WG1 SPM A.3.5).

Crok concludes that the full AR6 WG1 report, except for the SPM, did a reasonably good job reporting on trends in extreme weather, however all the good news is buried and only the bad news is brought forward to the *Summary for Policy Makers*. In WG2 things really get worse, the IPCC even contradicts many of its own claims in the WG1 report.

Disaster losses

In the next chapter (Chapter 12[39]) Crok continues discussing weather disasters and the possible attribution, if any, to human activities or emissions. In Chapter 12 he focusses on comparing the results of past disasters to today.

During the past century, the global population has increased from 2 to 8 billion people and people today are much more affluent than they were 100 years ago. Buildings, roads, and other infrastructure destroyed by extreme weather are much more valuable and numerous than in the past. Thus, comparing the dollar-to-dollar nominal cost of destruction today to in the past is invalid. Present costs must be adjusted for inflation, population growth, economic growth, and affluence. The adjustment is called normalization.

38 Klotzbach, Philip J., et al. „Continental US hurricane landfall frequency and associated damage: Observations and future risks.“ Bulletin of the American Meteorological Society 99.7 (2018): 1359-1376

39 Chapter 12: Extreme views on disasters

Crok examines the peer-reviewed literature on normalization of disaster costs from their beginning in a landmark paper by Roger Pielke Jr. in 1998.[40] Since this paper was written, more than 50 normalization studies have been published, and the technique has become established and routine. All 54 papers, except one, conclude that the costs associated with the extreme weather events they studied could *not* be attributed to human activities. Guess which one of the 54 studies is cited in AR6?

The earlier AR5 report acknowledges Pielke Jr.'s conclusions and restates them as follows:

> The 2014 IPCC assessment reinforced the conclusions of the IPCC (2012) special report on extreme events, providing even stronger evidence: 'There is medium evidence and high agreement that long-term trends in normalised losses have not been attributed to natural or anthropogenic climate change' and 'Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters (high confidence)' (IPCC, 2014).

So, the earlier reports acknowledged that normalization of costs is needed and the increase in nominal costs was largely caused by increased exposure of people and assets. Crok concludes:

> with respect to the literature on disaster losses, the latest AR6 WG2 report was neither comprehensive, open and transparent (it ignored most of the published literature on the topic), nor objective (it cherry picked the few studies that claimed an increase of losses due to greenhouse gases while the majority of the published studies show the opposite, no increasing trend after normalisation of the data). This is very poor performance by the IPCC.

In this chapter it becomes clear that Roger Pielke Jr is a real 'Voldemort' for the IPCC. They do everything to ignore his work even though it is highly relevant. So, apart from his important review article about disaster losses, the IPCC also ignored another of his papers that shows an important graph of normalized global weather disaster losses as a percent of global GDP (figure 12, below):

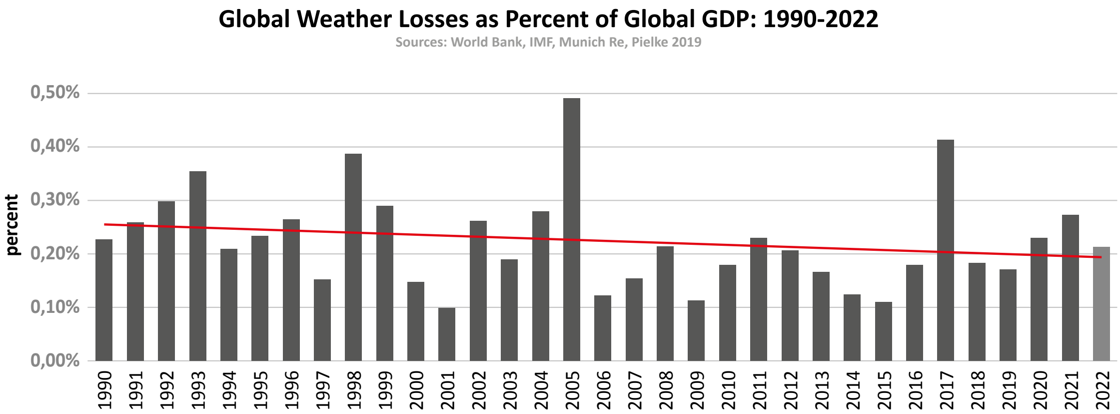


Figure 12: Normalised global disaster losses as a percentage of global GDP. Source: Updated from Pielke (2019), from Pielke's website here.[41]

Climate-related deaths

In Chapter 13[42], Crok examines UN Secretary-General Antonio Guterres statement that "we are on a highway to climate hell with our foot on the accelerator". He made this claim during his speech to delegates of the COP27 conference in Egypt. Is there any truth in the statement?

40 Pielke Jr. & Landsea, (1998). Normalized hurricane damages in the United States: 1925–95, Weather and Forecasting, 13(3).

41 Pielke, R. (2019). Tracking progress on the economic costs of disasters under the indicators of the sustainable development goals. Environmental Hazards, 18(1), 1–6. https://doi.org/10.1080/ 17477891.2018.1540343

42 Chapter 13: Say goodbye to climate hell, welcome climate heaven

It seems there isn't. Crok explains that Bjorn Lomborg has shown that climate (strictly speaking "weather") related deaths have plummeted in the past 100 years from nearly half-a-million per decade in 1920 to a few thousand per decade today.[43] An astounding 96% decrease.

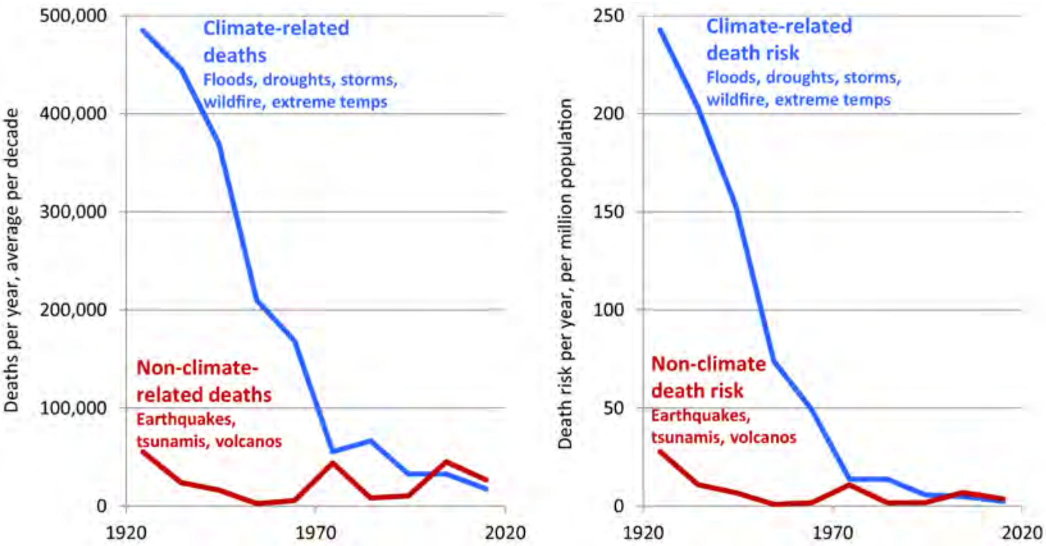


Figure 13: Climate and non-climate-related deaths and death risks from disasters 1920–2018, averaged over decades. Data comes from EM-DAT (2019), using floods, droughts, storms, wildfire, and extreme temperatures for climate-related deaths, and earthquakes, tsunamis, and volcanos for non-climate-related deaths. Source: Lomborg (2020).

Yet, this good news is not to be found in AR6, nor is there any mention of Lomborg's 2020 paper. Although most peer-reviewed papers cannot attribute any extreme weather events to human activities, the AR6 *Summary for Policy Makers* states:

> Increasingly since AR5, these observed impacts have been attributed to human-induced climate change particularly through increased frequency and severity of extreme events. These include increased heat-related human mortality (medium confidence) … [AR6 WG2 SPM B.1.1]

This is the opposite of the conclusions reached by most researchers and previous IPCC reports. It is also opposite of what is written on page 2435 of the AR6 WG2 report, where we see:

> Formetta and Feyen (2019)[44] demonstrate declining global all-cause mortality and economic loss due to extreme weather events over the past four decades, with the greatest reductions in low-income countries, and with reductions correlated with wealth. (AR6 WG2 p 2435)

The deterioration in the quality of IPCC reports, with time, is evident to anyone who has read all of them. The first report (FAR) in 1990 was a reasonably fair assessment of climate science at the time, but the subsequent reports have become more biased with each passing year. No honest assessment of AR6 would conclude it is fair and unbiased, quite the opposite. The problems seem to be worse in Working Group 2 than in the Working Group 1 report.

Our summary

We started this summary with how you could summarize the IPCC view on climate change. In this book we have shown that many of the important claims of the IPCC – i.e., that current warming is unprecedented, that it is 100% caused by humans, that it is dangerous – are all questionable.

Based on the same available evidence we would phrase a summary in the following way:

---

43 Bjorn Lomborg, (2020), Welfare in the 21st century: Increasing development, reducing inequality, the impact of climate change, and the cost of climate policies, Technological Forecasting and Social Change, Volume 156, 119981, iSSN 0040-1625, https://doi.org/10.1016/j.techfore.2020.119981.

44 Giuseppe formetta, luc feyen, empirical evidence of declining global vulnerability to climate-related hazards, Global environmental change, Volume 57, 2019, 101920, iSSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2019.05.004.

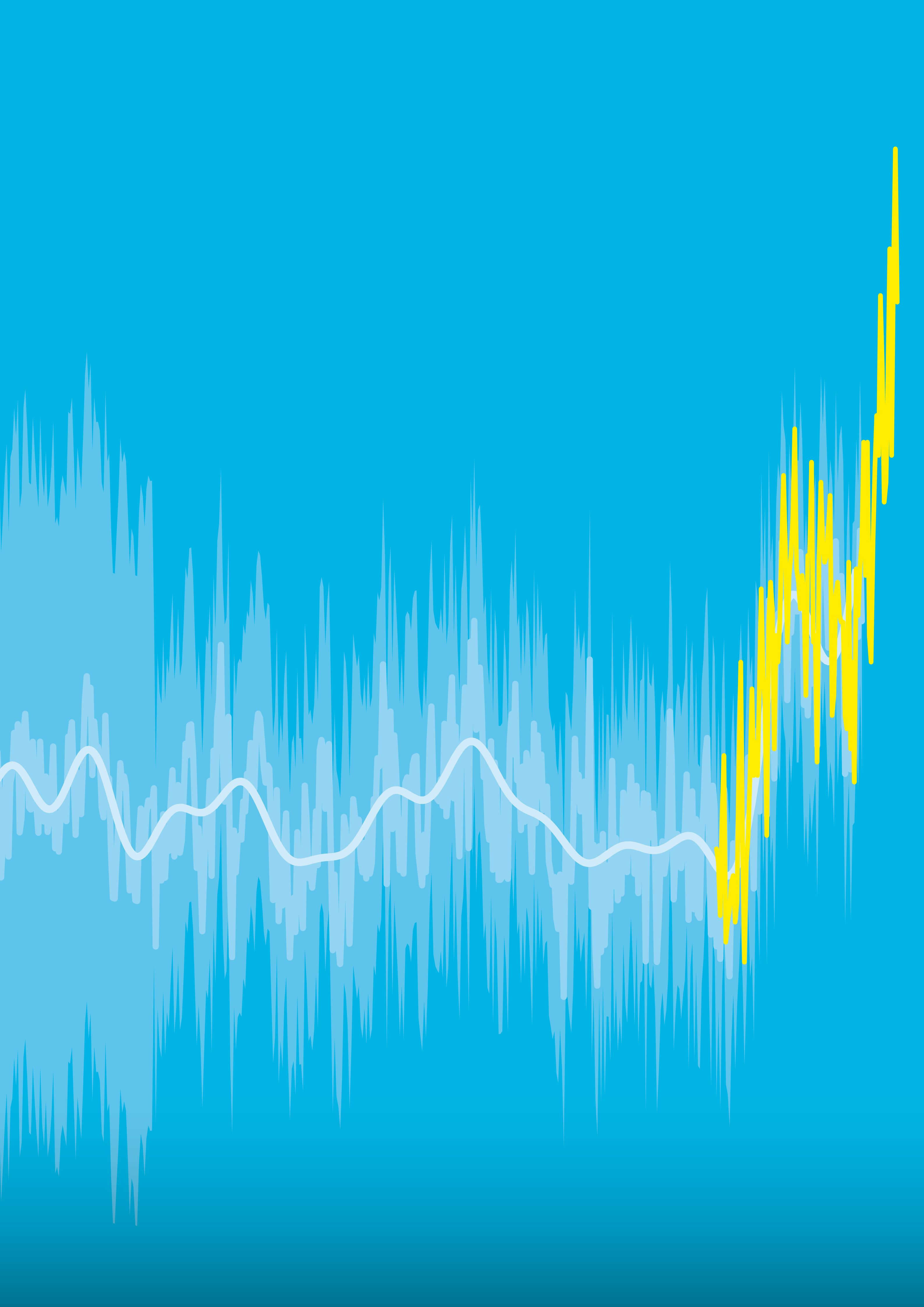
Warming in the Holocene likely peaked during the Holocene Thermal Maximum (9800-5700 years before present) after which a slow cooling began, that follows the Milankovitch cycles. The cooling climaxed in the Little Ice Age, which was probably the coldest period of the Holocene. Greenhouse gases have likely contributed to the moderate modern warming since 1850. It is impossible (and also unimportant) to state what percentage of the warming is due to greenhouse gases. Sea level started rising in the 19th century and there is no acceleration visible after 1950, the period in which the climate is supposedly dominated by greenhouse gases.

Moreover, most types of extreme weather have not become more frequent or more intense. This is especially true for tropical cyclones and floods, events that cause the most damage globally. Disaster losses, if normalized for economic development, show a slight decrease since the 1990s. Climate-related deaths show more than a 95% drop since the 1920s. This reflects increasing wealth and availability of technologies that better prepare humanity for disasters. In short, a prosperous humanity is largely prepared for climate change and can easily cope with it.

Marcel Crok and Andy May
April 2023

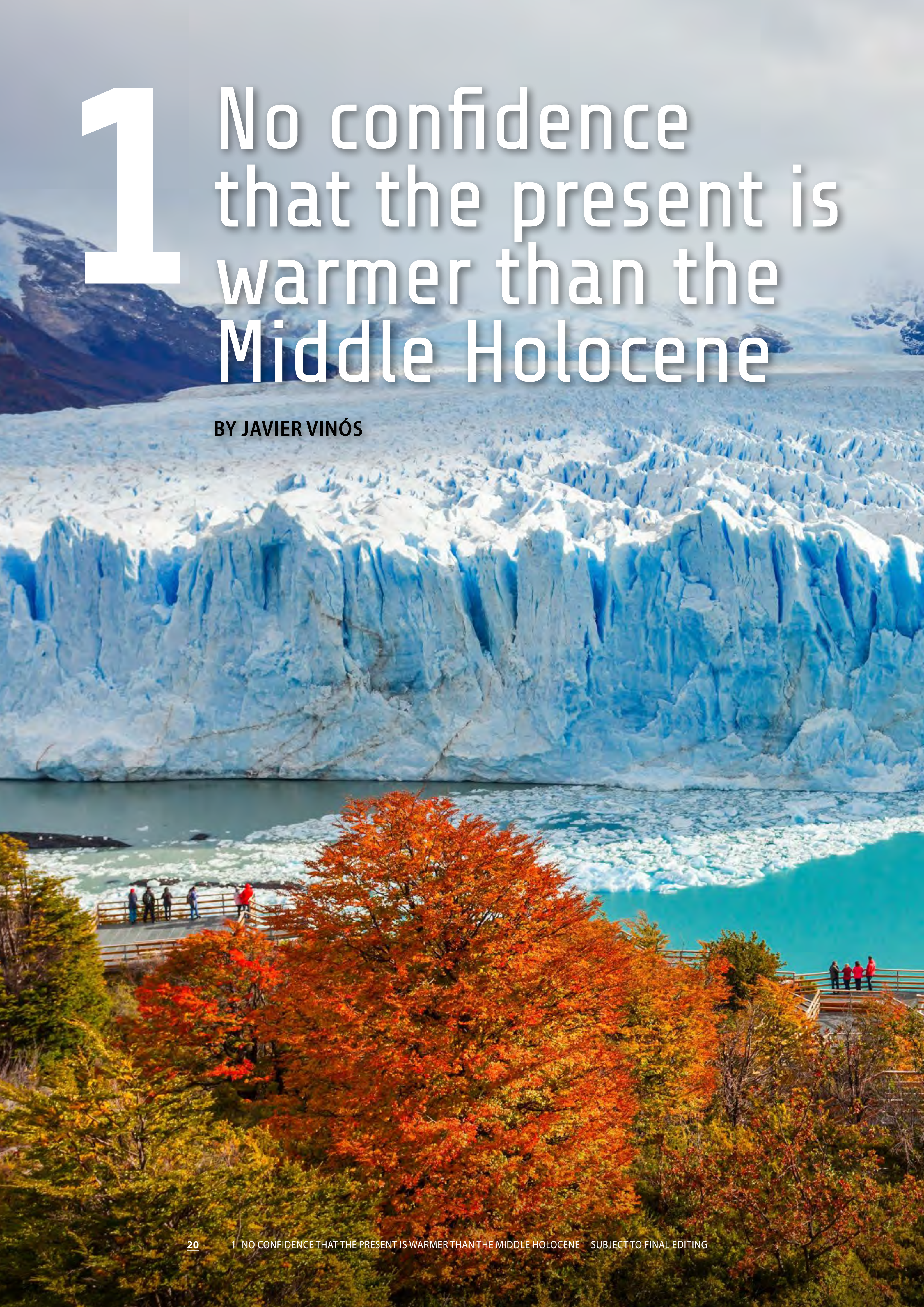
A

Observations



1 No confidence that the present is warmer than the Middle Holocene

BY JAVIER VINÓS



The new IPCC report came with the remarkable claim that it is now warmer than in the past 125000 years. This would mean it is now warmer than during the Mid Holocene, a period that was also relatively warm. Javier Vinós investigates the evidence for this and shows that glaciers and treelines contradict this evidence. It is more likely that the Holocene Thermal Maximum was warmer than it is now.

Several of the IPCC's Assessment Reports have been preceded by controversial new past temperature reconstructions. The latest IPCC report, AR6 (WG1), includes the surprising new position that present "global surface temperatures are *more likely than not* unprecedented in the past 125,000 years" (IPCC AR6, Gulev et al. 2021; Fig. 1[1]), and that "it is therefore *more likely than not* that no multi-centennial interval during the post-glacial period was warmer globally than the most recent decade" (IPCC AR6, Gulev et al. 2021; 2.3.1.1.2). It is expected that such an extraordinary claim, that breaks the tradition of considering the Holocene Thermal Maximum (HTM, previously known as the Holocene Climatic Optimum, or Altithermal) the warmest period of the Holocene, must be based on extraordinary evidence. However, it is based on the work of a group of authors (Kaufman et al. 2020) that have performed a new multi-proxy reconstruction.

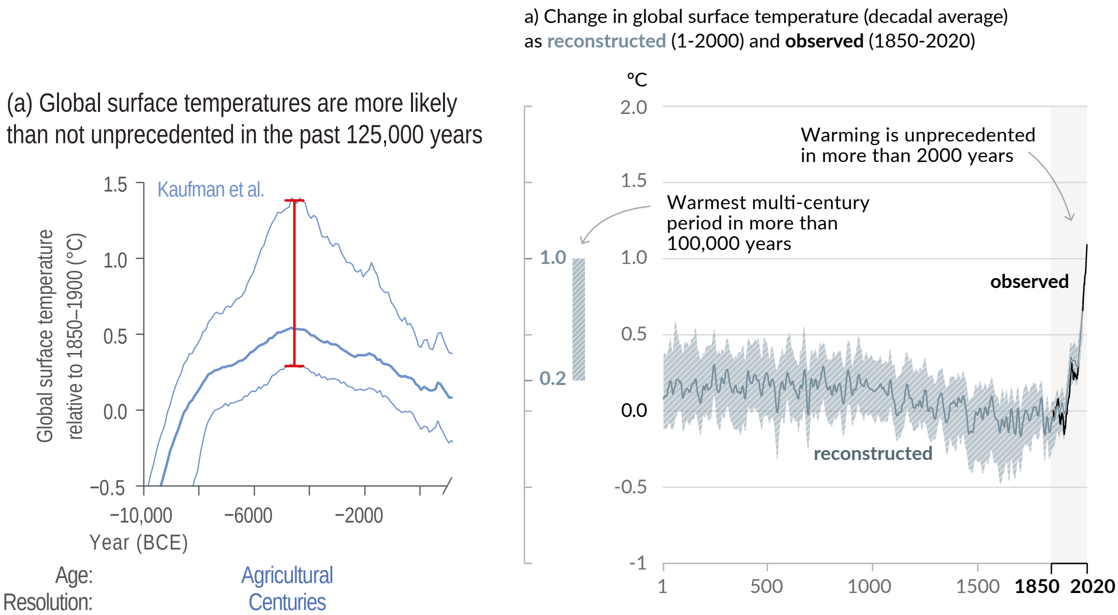


Figure 1: Evidence for the IPCC AR6 claim that present temperature is unprecedented in 125,000 years. Left, part of AR6 WG1 figure 2.11a based on Kaufman et al. 2020 with the uncertainty at the mid-Holocene highlighted with a red bar (added). Right, part of AR6 figure SPM.1 at the same temperature scale showing that present temperature is included in mid-Holocene uncertainty. The claim is based on a statistically weak medium confidence range (grey vertical bar at right figure) from a single multi-proxy reconstruction.

Proxy-Based Temperature Reconstructions

Trying to gauge past global temperatures from proxy reconstructions is a task so full of uncertainties and potential problems that most authors will not attempt it. Proxies do not record temperatures but physical, chemical, or biological processes that are affected by temperature. When con-

1 Gulev SK, Thorne PW, Ahn J et al (2021) Changing State of the Climate System. In Masson-Delmotte V, Zhai P, Pirani SL et al (eds) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

verting a proxy into temperature there are many things that can go wrong, and the researcher won't know it. The proxy concentrates into a small interval (e.g., a few cm in a speleothem), non-uniformly, what has happened to the proxy at a single location over thousands of years. There are uncertainties in the dating of that interval, uncertainties about how other environmental changes have affected the proxy over that long time (e.g., how precipitation changes affect tree-ring width), uncertainties about a possible proxy non-linear response to temperature changes, the proxy might respond to temperature changes at some times and not others (e.g., growing season for plants). These are only some of the known unknowns, there are unknown unknowns affecting proxies.

Even if the researcher does his best there is a great uncertainty in the conversion of the changes the proxy has recorded at a specific location into a set of temperatures. Averaging several dozens or a few hundreds of such proxy-derived temperature records from different locations into a multi-proxy reconstruction adds new uncertainties. Some proxies record huge local changes that might seriously bias the average. For example, the change in the position of the Inter-Tropical Convergence Zone that took place in the Middle Holocene due to changes in insolation, resulted in an estimated change of 5°C over the course of a century in a proxy from the West African coast (core 658C; de Menocal et al. 2000[2]). This is a known case of an extreme local effect, but any multi-proxy average is bound to include such "locally biased proxies" that unknowingly bias the average at different times.

A multi-proxy reconstruction thus depends greatly on researcher choices. One outstanding example is the Holocene temperature reconstruction by Marcott et al. 2013[3]. In his doctoral dissertation (Marcott 2011[4]), Shaun Marcott reconstructed Holocene temperature changes using 73 proxies. His reconstruction displayed a weak uptick of +0.2°C after 1750, as his dissertation figure 4.3a shows (our Fig. 2a). However, when his reconstruction was published in *Science* just ahead of AR5 (Marcott et al. 2013), the reconstruction displayed a huge uptick of +0.8°C in the last 250 years, as can be appreciated in their figure 1c (our Fig. 2b). The difference was the result of decisions taken by Marcott et al. on how to perform the reconstruction from the same proxies. The press release by the National Science Foundation that funded the study highlighted the magnitude of the final warming resulting in the news media transmitting a misleading message to the public (Fig. 2c).

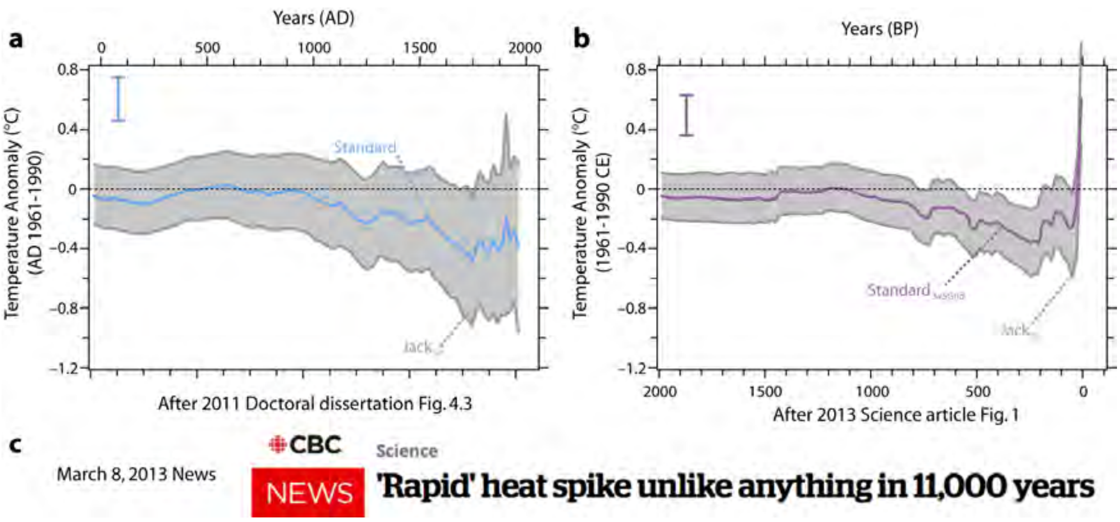


Figure 2: Researchers' decisions can greatly affect multi-proxy reconstructions. a) The final 2000 years of a multi-proxy Holocene global temperature reconstruction, after Marcott 2011 doctoral dissertation figure 4.3a. b) The final 2000 years of a reconstruction with the same proxies, after Marcott et al. 2013 figure 1c. c) An example of the media reaction to the press release ahead of Marcott et al. 2013 publication.

2 de Menocal P, Ortiz J, Guilderson T and Sarnthein M (2000) Coherent high-and low-latitude climate variability during the Holocene warm period. Science 288 (5474) 2198-2202

3 Marcott SA, Shakun JD, Clark PU and Mix AC (2013) A reconstruction of regional and global temperature for the past 11,300 years. Science 339 (6124) 1198-1201

4 Marcott SA (2011) Late Pleistocene and Holocene glacier and climate change. Dissertation, Oregon State University. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/3484zm26f Accessed 11 Oct 2021

Multi-proxy reconstructions are useful, but biases and unavoidable limitations of the technique result in their inability to answer the IPCC question: Was the last decade the warmest the planet has been during the Holocene? The final result of a multi-proxy reconstruction is very dependent on multiple researcher's choices, starting with the proxies included and excluded, whether land and marine proxies are representative, and what their respective weight should be in the mix. Proxies have big intrinsic uncertainties many of which cannot be properly estimated. On top of that, global coverage is very low.

Attempting to measure the average temperature of the planet with a few hundred low-precision uncalibrated thermometers that provide a reading once a decade at best would be a laughable task, and proxies are not even thermometers. Comparing the resulting global average with our modern measurements, including satellites and thousands of high-precision calibrated thermometers distributed all over the world, including all the oceans, and then declaring we can trust that it is *more likely than not* that the past decade is warmer than any century during the past 12,000 years is an untenable claim.

The Holocene Temperature Conundrum

The Holocene Thermal Maximum (HTM) can be considered a period that extended from c. 9800-5700 BP when temperatures varied considerably in many parts of the globe and maximal Holocene temperatures were reached in many areas, but often at different times. For example, in the Baltic Sea region the highest temperatures occurred c. 6500 BP and are estimated at 1.5–2.5°C above present-day values in the north-west area and 1.0–1.5 °C in the north-east (Borzenkova et al. 2015[5]). The HTM was certainly not a time of uniformly warm temperatures and trying to determine if at a certain time there was a global average, higher than the global average of the past decade has little scientific value, but apparently great political value. Regionally, most parts of the globe were warmer sometime during the HTM than now. Determining the global average temperature at any time in the HTM is not possible, we can only roughly determine the temperature, relative to today, in special locations with crude proxies.

At the core of the problem is that climate models do a poor job of reproducing a warmer past during the Holocene, given that CO_2 levels were much lower. This is known as the Holocene temperature conundrum (Liu et al. 2014[6]). Samantha Bova and colleagues tried to explain it was because of a more marked seasonality during the HTM that multi-proxy reconstructions fail to capture (Bova et al. 2020[7]). However non-biogenic mean annual-temperature reconstructions also underscore the conundrum (Affolter et al. 2019[8]) and point instead to strong latitudinal temperature gradients that models are unable to reproduce.

Another significant problem is that the oceans, which respond more slowly to temperature changes, appear to have cooled significantly since the HTM. The fossil coral Sr/Ca record at the Great Barrier Reef, Australia, shows that the mean SST (sea surface temperature) c. 5350 BP was 1.2°C warmer than the mean SST for the early 1990s (Gagan et al. 1998[9]). At the Indo-Pacific Warm Pool, the warmest ocean region in the world, Stott et al. (2004[10]) find that SST has decreased by c. 0.5°C in the last 10,000 years, a finding confirmed by Rosenthal et al. (2013[11]), who show a

5 Borzenkova I, Zorita E, Borisova O, et al (2015) Climate change during the Holocene (past 12,000 years). In The BACC II Author Team (eds) Second assessment of climate change for the Baltic Sea basin 25-49. Springer Cham.

6 Liu Z, Zhu J, Rosenthal Y et al (2014) The Holocene temperature conundrum. Proceedings of the National Academy of Sciences 111 (34) E3501-E3505

7 Bova S, Rosenthal Y, Liu Z et al (2021) Seasonal origin of the thermal maxima at the Holocene and the last interglacial. Nature 589 (7843) 548-553

8 Affolter S, Häuselmann A, Fleitmann D, et al (2019) Central Europe temperature constrained by speleothem fluid inclusion water isotopes over the past 14,000 years. Science advances 5 (6) eaav3809

9 Gagan MK, Ayliffe LK, Hopley D et al (1998) Temperature and surface-ocean water balance of the mid-Holocene tropical western Pacific. Science 279 (5353) 1014-1018

10 Stott L, Cannariato K, Thunell R et al (2004) Decline of surface temperature and salinity in the western tropical Pacific Ocean in the Holocene epoch. Nature 431 (7004) 56-59

11 Rosenthal Y, Linsley BK and Oppo DW (2013) Pacific Ocean heat content during the past 10,000 years. Science 342 (6158) 617-621

decrease of 1.5-2°C for intermediate waters. The tropics display a very reduced climate change compared to the rest of the globe, and if the tropical oceans were warmer at the HTM it would be difficult to claim that the Earth is warmer globally now.

Glacier Advances

To solve the problem of comparing HTM and present temperatures we should avoid uncertain proxy blends and try to find indicators less prone to artifacts, even if they will not give us a quantitative response. One of these indicators is glacier changes. We know that on average glaciers were at their most reduced state for the past 100,000 years during the HTM and at their most expanded state for the past 7,000 years during the LIA. In most regions of the mid-high latitudes of the NH (Northern Hemisphere), glaciers were smaller than now between 8000-4000 BP (Solomina et al. 2015[12]).

In their outstanding work, Solomina et al. divided 189 glacier timelines into 17 regions: 12 from the NH, 1 from low latitudes, and 4 from the SH. Then they studied the major glacier advances at each region for each of the 118 centuries of the Holocene. Figure 3a shows how many of those regions were experiencing advances at each century. It is very interesting that their result essentially reads as a negative print of a global temperature anomaly change reconstruction, despite being completely independent.

For comparison a reconstruction using the same 73 proxies of Marcott et al. (2013) is made, so a new selection bias is not introduced, but with their originally published dates, and averaging them after expressing them as differences to their individual means to convert them into anomalies. This reconstruction (Fig. 3b, inverted) ends in 1910 due to lack of sufficient proxies afterward, so it does not include 20th century warming. The temperature anomaly is expressed as a Z-score, or distance to the mean Holocene temperature anomaly (upper horizontal straight dashed line in Fig. 3b), to avoid making inferences about actual Holocene temperatures that we cannot possibly know.

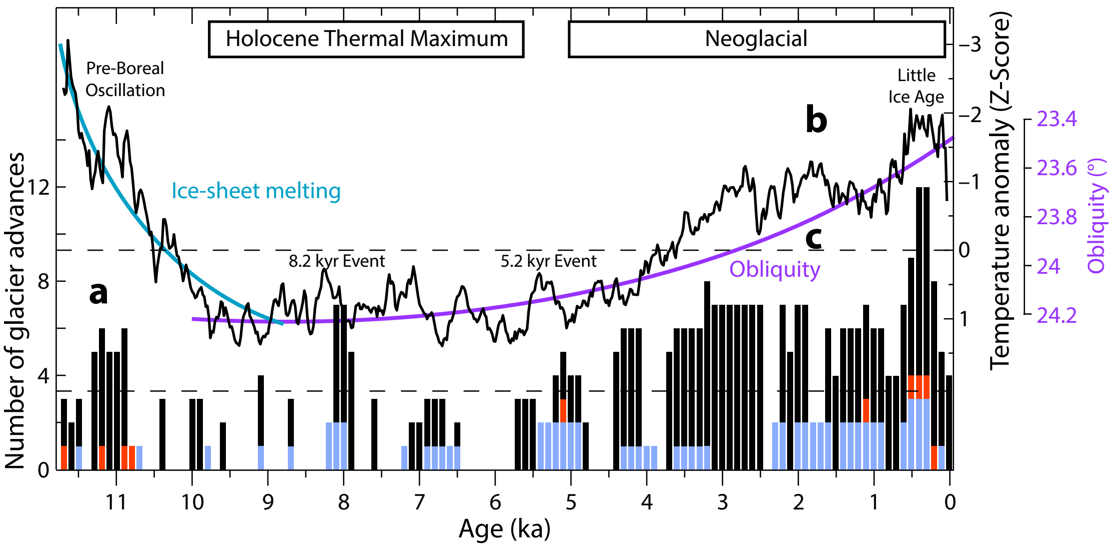


Figure 3: Glacial advances versus temperature (inverted) during the Holocene. a) Number of regions displaying glacier advances at each Holocene century. Black, NH 17 regions; orange, low latitudes single region; ice blue, SH 4 regions. Bottom dashed line, Holocene glacial position average. b) Inverted temperature reconstruction from the same 73 proxies used by Marcott et al. 2013. The reconstruction ends in 1910 and does not include modern warming. Temperature anomaly changes are expressed as Z-score (distance to the mean). Some well-known cooling periods or events are indicated by their accepted names. The period affected by the melting of the extra-Arctic ice sheets is indicated in aquamarine. c) Inverted changes in obliquity. Vinós, 2022, page 55.[13]

12 Solomina ON, Bradley RS, Hodgson DA et al (2015) Holocene glacier fluctuations. Quaternary Science Reviews 111 9-34

13 Vinós, J. (2022). Climate of the Past, Present and Future, A Scientific Debate. 2nd ed. Critical Science Press.

A comparison of centurial glacier advances to this multi-proxy reconstruction shows that both share a very similar general pattern. From the start of the HTM both follow the obliquity curve (Fig. 3c; Bosmans et al. 2015[14]), the main Milankovitch parameter for interglacials, as it is the only one that alters the insolation distribution between low and high latitudes. Not only that, but major Holocene cooling events show clear correspondence, like the Pre-Boreal Oscillation, the 8.2 kyr event, the 5.2 kyr event that initiated the Neoglaciation, or the LIA; they all coincide with increases in glacier advances. Less conspicuous are warming periods like the Roman or Medieval Warm Periods, that can also be detected in both records (Solomina et al. 2015). The 20th century has 4 glacier-advancing regions in the NH in Figure 3. This is the right-most bar in Figure 3, and it is slightly above the Holocene average of 3.35 (Fig. 3, bottom dashed line).

Centurial glacier advances appear to reconstruct the general temperature evolution during the Holocene, lending strong support to the Holocene temperature conundrum. Temperature changes during the Holocene do not appear to follow CO_2 changes. This is strongly supported by implied large perturbations in ocean heat content and Earth's energy budget at odds with the very small radiative forcing anomalies throughout the Holocene (Rosenthal et al. 2017[15]).

AR6 recognizes that most NH glaciers are larger now than at the HTM (IPCC AR6, Gulev et al. 2021; section 2.3.2.3) but points towards the relatively long adjustment time of glaciers. That is true for large slow continental glaciers, however 80% of world glaciers are very small (with area ≤1 km^2; Li et al. 2019[16]) and glaciers respond to mean annual temperature and precipitation at their surface, not to global warming. The glaciers that have reduced the most since 1980 are tropical glaciers, where warming is less intense. In the mid-high latitudes, where warming has been more intense (Li et al. 2019), the glacial retreat is less.

The great worldwide glacier retreat started around 1850. By 1950, before the fast increase in anthropogenic CO_2 started, 169 glaciers from different parts of the world had already reduced their length by 70% of the year 2000 total (Oerlemans 2005[17]). Glaciers are reducing due to a combination of factors that includes anthropogenic black carbon and debris accumulation, not just temperature increases. Since the extra-tropical NH has warmed the most due to modern global warming, the presence of multiple glaciers and small permanent ice patches (Koch et al. 2014[18]) in the NH that did not exist during the HTM is a strong argument that the HTM was warmer than the present.

Treelines

Another independent means of assessing whether the HTM was warmer than the present is through biology. Trees grow on the slope of mountains up to a certain altitude—the treeline—above which they are unable to survive. Temperature is the primary control on treeline formation and maintenance (Körner 2007[19]) and consequently the treeline has been moving higher over the past century at over half the locations studied, while receding at only 1% (Harsch et al., 2009[20]). The advances have taken place mainly in the extra-tropical NH, where more warming has been experienced, and particularly in locations where winter warming has been stronger. This aspect is also important as it indicates that winter tree survival might be a limiting factor for treeline altitude, and not only growth-season mean temperature.

14 Bosmans JH, Hilgen FJ, Tuenter E and Lourens LJ (2015) Obliquity forcing of low-latitude climate. Climate of the Past 11 (10) 1335-1346

15 Rosenthal Y, Kalansky J, Morley A and Linsley B (2017) A paleo-perspective on ocean heat content: Lessons from the Holocene and Common Era. Quaternary Science Reviews 155 1-12

16 Li YJ, Ding YJ, Shangguan DH and Wang RJ (2019) Regional differences in global glacier retreat from 1980 to 2015. Advances in Climate Change Research 10 (4) 203-213

17 Oerlemans J (2005) Extracting a climate signal from 169 glacier records. Science 308 (5722) 675-677

18 Koch J, Clague JJ and Osborn G (2014) Alpine glaciers and permanent ice and snow patches in western Canada approach their smallest sizes since the mid-Holocene, consistent with global trends. The Holocene 24 (12) 1639-1648

19 Körner C (2007) The use of 'altitude' in ecological research. Trends in ecology & evolution 22 (11) 569-574

20 Harsch MA, Hulme PE, McGlone MS and Duncan RP (2009) Are treelines advancing? A global meta-analysis of treeline response to climate warming. Ecology letters 12 (10) 1040-1049

There are a plethora of studies all over the NH showing that the treeline was much higher than present during the HTM. In the Italian Alps, it was 400 m higher than today from 8.4 and 4 ka (Badino et al. 2018[21]), and 150-200 m higher between 9 and 2.5 ka in the Swiss Central Alps (Tinner & Theurillat 2003; Fig. 4[22]). In the Pyrenees it was 400 m higher than the current treeline (Cunill et al. 2012[23]). In the Swedish Scandes 600-700 m higher between 9.5-6.5 ka (Kullman 2017[24]). In the British Columbia it was 235 m higher from 10.6 to 7.5 ka (Pisaric et al. 2003[25]). In New Zealand's South Island, where mean annual temperatures were at least 1.5°C warmer than present in the Early Holocene, treelines were lower however, suggesting shorter and cooler summers (McGlone et al. 2011[26]).

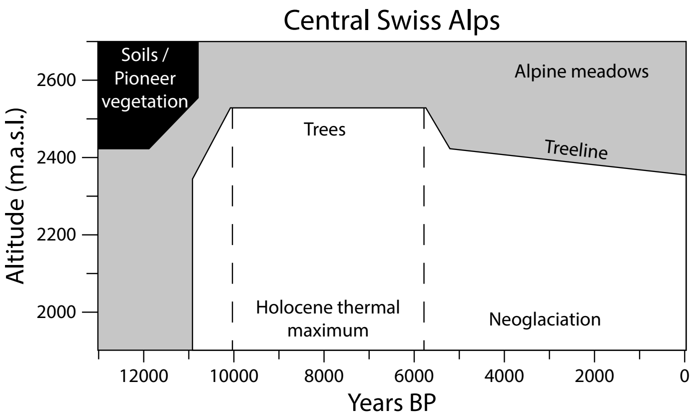


Figure 4: Fluctuations of the treeline in the Swiss Central Alps during the Holocene. The limits of the vegetational zones are placed between the sites according to the presence of the respective vegetation type as inferred by macrofossil analysis. Altitude in meters above sea-level. After Tinner & Theurillat 2003. Current treeline in the Swiss Central Alps is 150-200 m below Holocene Thermal Maximum treeline limit.

Randin et al. (2013)[27] showed that half of the 18 deciduous tree species they studied in Europe filled their thermal niche both at high latitude and high altitude, while 7 reached their latitudinal thermal limit, but not their elevational limit, where competition for space is stronger. The NH is the region that has experienced the strongest recent climate warming. Since so many NH species are at their thermal equilibrium, and yet at a great distance from their HTM limits, it is obvious that the planet cannot be warmer now, irrespective of conclusions reached via proxy reconstructions, temperature database kriging, and data homogenizing.

Instrumental Temperature Changes Uncertainty

We do not know the HTM global average temperature, with enough confidence. Also, we cannot have much confidence in present global average temperature measurements. The continuous adjustments made to current global temperature datasets demonstrate how immature that data is.

This immaturity underscores a more worrisome problem. Figure 5 is an overlay of two GISS global temperature graphs, one from 2001 and the other from 2015. With the adjustments, the year 2000 became 0.4°C warmer with respect to 1880 than previously. Ole Humlum has been tracking these

21 Badino F, Ravazzi C, Valle F et al (2018) 8800 years of high-altitude vegetation and climate history at the Rutor Glacier forefield, Italian Alps. Evidence of middle Holocene timberline rise and glacier contraction. Quaternary Science Reviews 185 41-68

22 Tinner W and Theurillat JP (2003) Uppermost limit, extent, and fluctuations of the timberline and treeline ecocline in the Swiss Central Alps during the past 11,500 years. Arctic, Antarctic, and Alpine Research 35 (2) 158-169

23 Cunill R, Soriano JM, Bal MC et al (2012) Holocene treeline changes on the south slope of the Pyrenees: a pedoanthracological analysis. Vegetation history and archaeobotany 21 (4) 373-384

24 Kullman L (2017) Further details on holocene treeline, glacier/ice patch and climate history in Swedish Lapland. International Journal of Research in Geography 3 (4) 61-69

25 Pisaric MF, Holt C, Szeicz JM et al (2003) Holocene treeline dynamics in the mountains of northeastern British Columbia Canada inferred from fossil pollen and stomata. The Holocene 13 (2) 161-173

26 McGlone MS, Hall GM and Wilmshurst JM (2011) Seasonality in the early Holocene: Extending fossil-based estimates with a forest ecosystem process model. The Holocene 21 (4) 517-526

27 Randin CF, Paulsen J, Vitasse Y et al (2013) Do the elevational limits of deciduous tree species match their thermal latitudinal limits?. Global Ecology and Biogeography 22 (8) 913-923

changes to GISS since 2008 (Climate4you 2021). At the very least these changes demonstrate that the confidence intervals of modern instrumental measurements mean very little and are only valid until the next major adjustment, therefore we do not really know how much the world has warmed since pre-industrial times with sufficient certainty.

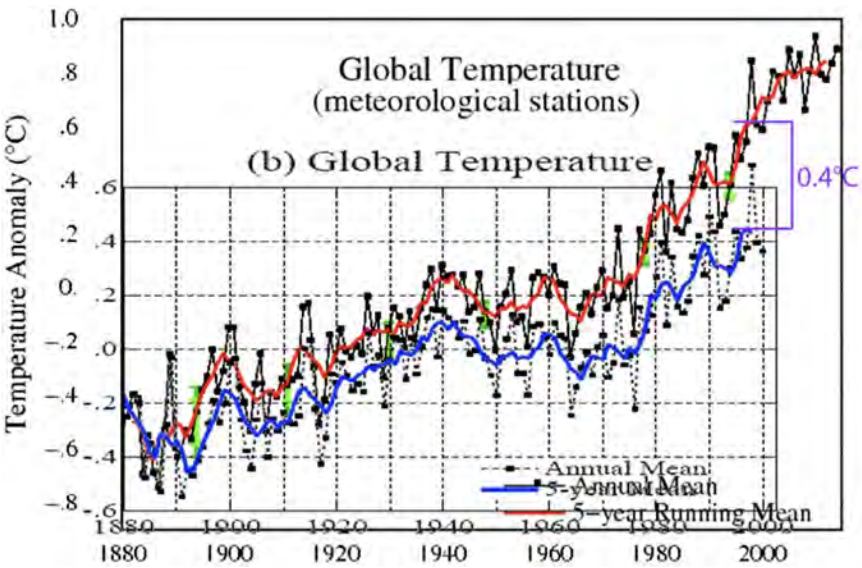
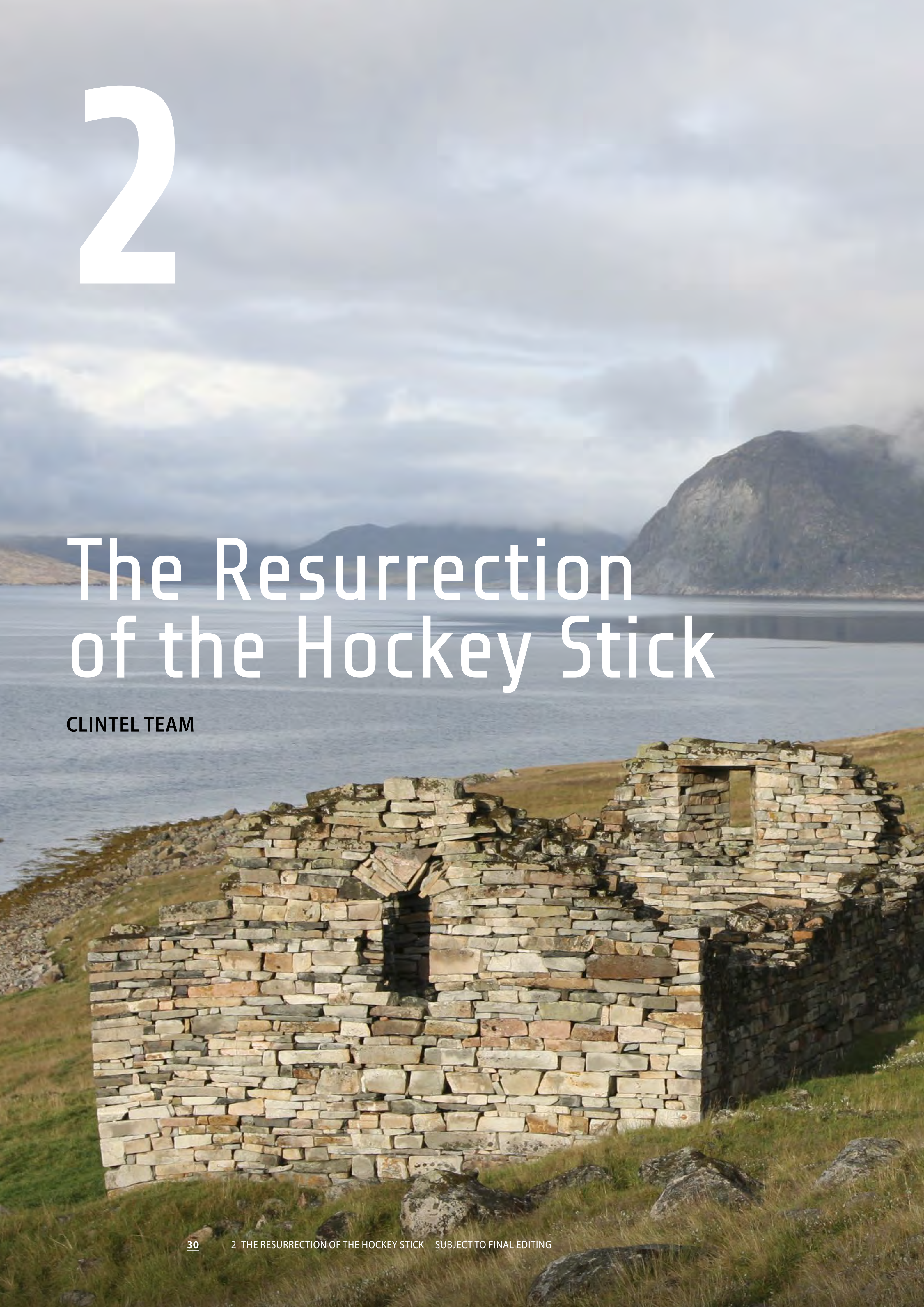


Figure 5: Overlay of GISS global temperature graphs from 2001 and 2015. Changes introduced in the dataset resulted in a 0.4°C increase in the 5-yr running mean from 1880 to 2000 between the 2001 data (blue curve) and the 2015 data (red curve).

In conclusion, there is too much uncertainty in proxy reconstructions and instrumental temperature datasets to sustain with any degree of confidence that the present is warmer than the Holocene Thermal Maximum, and independent evidence from glacier and treeline changes supports the opposite assessment.



2

The Resurrection of the Hockey Stick

CLINTEL TEAM

A big surprise in the new IPCC report is the publication of a brand new hockey stick. The IPCC once again has to cherry pick and massage proxy data in order to fabricate it. Studies that show larger natural climate variations are ignored.

One of the big surprises of the IPCC's AR6 report was the comeback of the so-called "hockey stick". This term refers to the northern hemispheric and global temperature development of the past 1000-2000 years. More than two decades ago, Mann et al. (1999)[1] published a reconstruction in which the temperatures of the pre-industrial period 1000-1850 AD appear rather flat and uneventful (the "shaft" of the ice hockey stick), followed by a fast and allegedly unprecedented warming since 1850 (the "blade"). The hockey stick became world famous because it was featured prominently in the *Summary for Policymakers* (SPM) in the IPCC's 3rd Assessment report, TAR (Fig. 1). Subsequently, the work of Mann et al. (1999) was heavily criticized for major deficiencies in paleoclimatic proxies and statistical processing (McIntyre and McKitrick, 2003[2], 2005[3]; McShane and Wyner, 2011a, b[4]; Montford, 2010[5]).

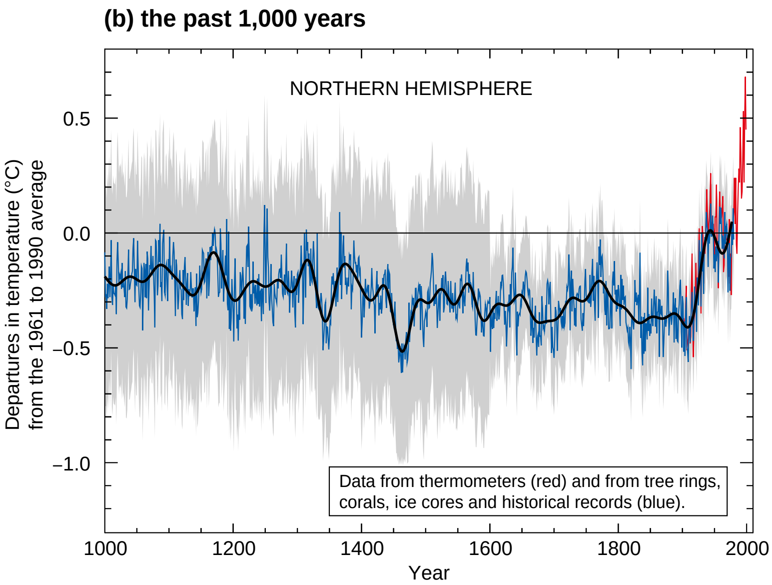


Figure 1: The original hockey stick by Mann et al. (1999) as illustrated in the Summary for Policymakers in the 3rd IPCC climate assessment report in 2001.

Interestingly, it was the group led by Michael E. Mann itself that partly corrected the hockey stick nearly a decade later (Mann et al., 2008).[6] In this new version the Medieval Warm Period (MWP, 800-1200 AD) was warmer than in the version of Mann et al. (1999). Two years later, Ljungqvist

1 Mann, M. E., Bradley, R. S., and Hughes, M. K., 1999, Northern Hemisphere Temperatures during the past Millennium: Inferences, Uncertainties, and Limitations: Geophysical Research Letters, v. 26, no. 6, p. 759-762.

2 McIntyre, S., and McKitrick, R., 2003, Corrections to the Mann et al. (1988) proxy data base and northern hemispheric average temperature series: Energy & Environment, v. 14, no. 6, p. 751-771.

3 McIntyre, Stephen and Ross McKitrick (2005a) "The M&M Critique of the MBH98 Northern Hemisphere Climate Index: Update and Implications." Energy and Environment 16(1) pp. 69-100; (2005b) "Hockey Sticks, Principal Components and Spurious Significance" Geophysical Research Letters Vol. 32, No. 3, L03710 10.1029/2004GL021750 12 February 2005.

4 McShane, B. B., and Wyner, A. J., 2011a, Rejoinder: The Annals of Applied Statistics, v. 5, no. 1, p. 99-123. -, 2011b, A statistical analysis of multiple temperature proxies: Are reconstructions of surface temperatures over the last 1000 years reliable?: The Annals of Applied Statistics, v. 5, no. 1, p. 5-44.

5 Montford, A. W., 2010, The Hockey Stick Illusion, London, Stacey International, 482 p.

6 Mann, M. E., Zhang, Z., Hughes, M. K., Bradley, R. S., Miller, S. K., Rutherford, S., and Ni, F., 2008, Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia: PNAS, v. 105, no. 36, p. 13252-13257.

(2010)[7] published another reconstruction in which the Little Ice Age (LIA, 1400-1850 AD) was colder than in the papers of the Mann group. This further increased the temperature difference between MWP and LIA, essentially eliminating the hockey stick shape by significantly deforming the "shaft". Another few years later, the PAGES 2k Consortium (2013)[8] published a reconstruction in which parts of the first millennium were occasionally as warm as present-day (Fig. 2).

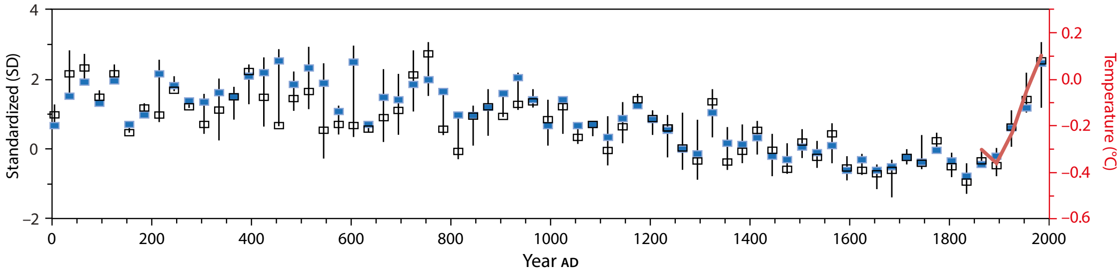


Figure 2: Global temperature reconstruction by PAGES 2k Consortium (2013)

The documented systematic pre-industrial warming and cooling presented a major challenge for the climate modellers because their simulations do not contain any powerful natural forcings that could produce such natural temperature changes. Hence, the climate models were not able to reproduce the real-world, reconstructed climate evolution.[9] This was a problem because the same, apparently deficient models are used for future temperature projections that form the basis for far-reaching political decisions and the costly transformation of global energy systems. Something was clearly wrong.

Are humans 100% responsible for Modern Warming?

The discrepancy could be resolved by two possible solutions. In the first case, climate modelers could have added stronger natural forcings to their simulations, in order to replicate the documented pre-industrial climate change. However, this would mean that the warming effect of greenhouse gases likely would be reduced. That is because the temperature rise of the past 170 years would have to be shared with anthropogenic and natural causes. However, this was complicated, because in its special report on the 1.5°C target the IPCC had claimed in 2018 that 100% (!) of the observed modern warming was anthropogenic (IPCC, 2018).[10] Natural climate factors play no significant role, says the IPCC nowadays. This was a major shift for the IPCC because only five years earlier in its AR5 report, the organization still found it reasonable that "more than half" of the observed warming was man-made, leaving theoretically up to 49% to natural causes (IPCC, 2013). As natural contributions to modern warming have been essentially excluded, the IPCC opted for

7 Ljungqvist, F. C., 2010, A new reconstruction of temperature variability in the extra-tropical northern hemisphere during the last two millennia: Geografiska Annaler: Series A, v. 92, no. 3, p. 339-351.

8 PAGES 2k Consortium, 2013, Continental-scale temperature variability during the past two millennia: Nature Geosci, v. 6, no. 5, p. 339-346.

9 Büntgen, U., Krusic, P. J., Verstege, A., Sangüesa-Barreda, G., Wagner, S., Camarero, J. J., Ljungqvist, F. C., Zorita, E., Oppenheimer, C., Konter, O., Tegel, W., Gärtner, H., Cherubini, P., Reinig, F., Esper, J. (2017): New Tree-Ring Evidence from the Pyrenees Reveals Western Mediterranean Climate Variability since Medieval Times: Journal of Climate 30 (14), 5295-5318.
Wilson, R., Anchukaitis, K., Briffa, K. R., Büntgen, U., Cook, E., D'Arrigo, R., Davi, N., Esper, J., Frank, D., Gunnarson, B., Hegerl, G., Helama, S., Klesse, S., Krusic, P. J., Linderholm, H. W., Myglan, V., Osborn, T. J., Rydval, M., Schneider, L., Schurer, A., Wiles, G., Zhang, P., Zorita, E. (2016): Last millennium northern hemisphere summer temperatures from tree rings: Part I: The long term context: Quaternary Science Reviews 134, 1-18.
Luterbacher, J., Werner, J. P., Smerdon, J. E., Fernández-Donado, L., González-Rouco, F. J., Barriopedro, D., Ljungqvist, F. C., Büntgen, U., Zorita, E., Wagner, S., Esper, J., McCarroll, D., Toreti, A., Frank, D., Jungclaus, J. H., Barriendos, M., Bertolin, C., Bothe, O., Brázdil, R., Camuffo, D., Dobrovolný, P., Gagen, M., García-Bustamante, E., Ge, Q., Gómez-Navarro, J. J., Guiot, J., Hao, Z., Hegerl, G. C., Holmgren, K., Klimenko, V. V., Martín-Chivelet, J., Pfister, C., Roberts, N., Schindler, A., Schurer, A., Solomina, O., Gunten, L. v., Wahl, E., Wanner, H., Wetter, O., Xoplaki, E., Yuan, N., Zanchettin, D., Zhang, H., Zerefos, C. (2016): European summer temperatures since Roman times: Environmental Research Letters 11 (2), 024001.
Fernández-Donado, L., González-Rouco, J. F., Raible, C. C., Ammann, C. M., Barriopedro, D., García-Bustamante, E., Jungclaus, J. H., Lorenz, S. J., Luterbacher, J., Phipps, S. J., Servonnat, J., Swingedouw, D., Tett, S. F. B., Wagner, S., Yiou, P., Zorita, E. (2013): Large-scale temperature response to external forcing in simulations and reconstructions of the last millennium: Clim. Past 9 (1), 393-421.

10 IPCC, 2018, Special Report on global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways: http://www.ipcc.ch/report/sr15/.

the second option to solve the dilemma of the model vs. reality mismatch. Flattened pre-industrial temperatures would provide a much better fit with the modelling results.

The PAGES 2k group is specialised in climate reconstructions and back in 2013 was comprised of the majority of all active paleoclimatologists. In 2019, PAGES 2k published a new version of the temperature development of the past 2000 years (PAGES 2k Consortium, 2019)[11]. Surprisingly, it differed greatly from the predecessor version. Even though the database had only mildly changed, the pre-industrial part was now suddenly nearly flat again. The hockey stick was reborn, and the modelling discrepancy conveniently solved. At least it seemed so.

The IPCC must have been delighted to get rid of this problem. The new hockey stick was immediately incorporated into the AR6 report (IPCC, 2021). Oddly, it was included in the first order draft (FOD) of AR6 in May 2019, even though the paper by the PAGES 2k Consortium (2019) was published in July 2019 (Fig. 3). Reference in the FOD was made to "PAGES 2k Consortium, in revision". Clearly, some of the IPCC authors were already aware of the manuscript prior to publication and used it in the IPCC report, even though it had not fully passed the journal review.

Among the lead authors of AR6 chapter 2 is Darrell S. Kaufman who is a co-author of the new hockey stick in the PAGES 2k Consortium (2019). This is probably not a coincidence.

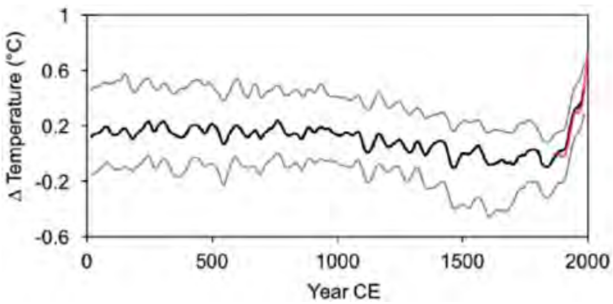


Figure 3: Global temperature development (the new hockey stick) as illustrated in the first order draft of chapter 2, working group 1, AR6, page 2-155. Reference is made to "PAGES 2k Consortium, in revision". Graph only shows palaeoclimatologiocally reconstructed, not instrumentally measured data.

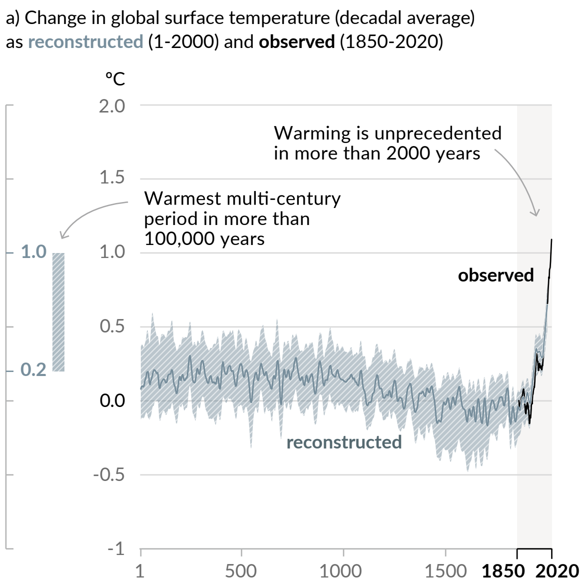


Figure 4: Global temperature development of the past 2000 years as illustrated in the final version of the Summary for Policymakers (SPM) of AR6, WG1, page SPM-7. Graph mixes reconstructed and instrumentally measured data and is based on PAGES 2k Consortium (2019).

11 PAGES 2k Consortium, 2019, Consistent multidecadal variability in global temperature reconstructions and simulations over the Common Era: Nature Geoscience, v. 12, no. 8, p. 643-649.

University of Bern and the Hockey Stick

Another interesting role in the hockey stick saga may have been played by the climate researcher and manager Thomas Stocker of the University of Bern. Stocker has contributed to IPCC reports since 1998, and in 2015 he even ran for the IPCC's chairmanship, but was defeated by South Korean Hoesung Lee. Stocker appears to have never been far from the hockey stick, both the original one and the new one. Notably, Stocker co-authored the *Summary for Policymakers* of the IPCC's 3rd report in 2001, in which the Hockey Stick played a central role. Twenty years later, the resurrected hockey stick comes from PAGES 2k (Fig. 4), a group that is headquartered at the University of Bern, where Stocker chairs the climate and environmental physics department.

It cannot be ruled out that the new hockey stick was particularly commissioned for the 6th IPCC report. Five of the 19 authors of the new field hockey stick curve are from Bern (PAGES 2k Consortium, 2019).

Evidence suggests that a significant part of the original PAGES 2k researchers could not technically support the new hockey stick and seem to have left the group in dispute. Meanwhile, the dropouts published a competing temperature curve with significant pre-industrial temperature variability (Büntgen et al., 2020)[12] (EA and EA+ in Fig. 5). On the basis of thoroughly verified tree rings, the specialists were able to prove that summer temperatures had already reached today's levels several times in the pre-industrial past. However, the work of Ulf Büntgen and colleagues was not included in the IPCC report, although it was published well before the editorial deadline.

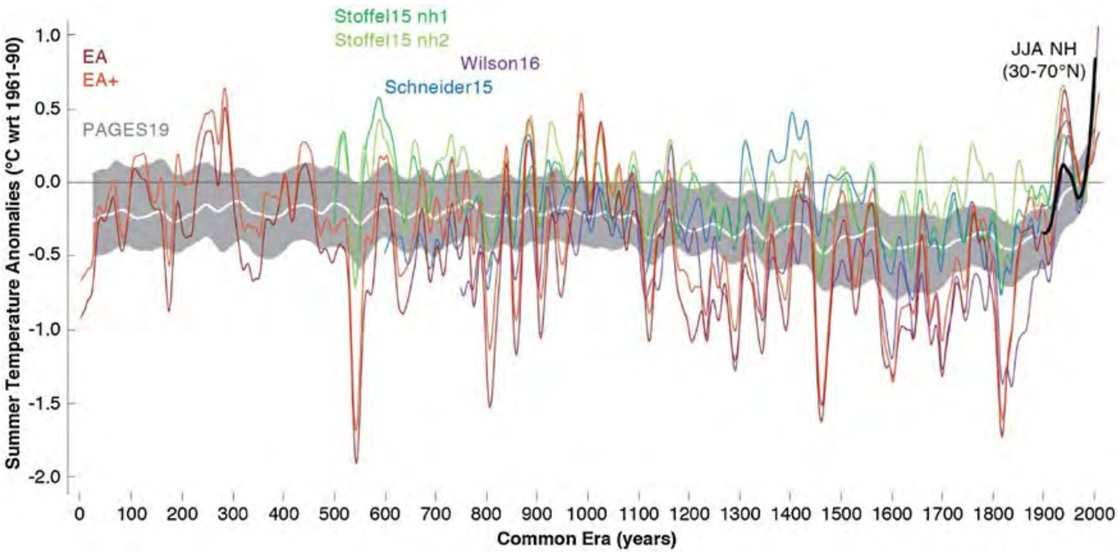


Figure 5: Temperature reconstruction for the extra-tropical northern hemisphere of the past 2000 years by Büntgen et al. (2020). The curves EA and EA+ in dark red and orange are from the Büntgen group, the other curves in green, blue and purple from other authors. The white line encased in grey is the new hockey stick by PAGES2k 2019 for comparison.

How the Medieval Warm Period disappeared from AR6

The arbitrariness of the IPCC also becomes clear in another example. The IPCC explicitly listed the Medieval Climate Anomaly and the Little Ice Age in a summary table in chapter 1 of the first order draft of the AR6 report. (Fig. 6).

12 Büntgen, U., Arseneault, D., Boucher, É., Churakova, O. V., Gennaretti, F., Crivellaro, A., Hughes, M. K., Kirdyanov, A. V., Klippel, L., Krusic, P. J., Linderholm, H. W., Ljungqvist, F. C., Ludescher, J., McCormick, M., Myglan, V. S., Nicolussi, K., Piermattei, A., Oppenheimer, C., Reinig, F., Sigl, M., Vaganov, E. A., and Esper, J., 2020, Prominent role of volcanism in Common Era climate variability and human history: Dendrochronologia, v. 64, p. 125757.

First Order Draft | Chapter 1 | IPCC AR6 WGI

Period	Age/year*	Significance of climate state
Little Ice Age (LIA)	1450–1850 CE (defined by AR5)	Series of globally heterogeneous cold periods lasting decades to centuries and including some of the lowest temperatures of the post-glacial period.
Medieval Climate anomaly (MCA)	950–1250 CE (defined by AR5)	Loosely defined interval of relative warmth, especially prevalent in the circum North Atlantic region that preceded the LIA.
Last Millennium	850–1850 CE (PMIP) or 1000-1999 CE	PMIP interval for transient climate model experiments. Encompasses the MCA and LIA, with demonstrable effects of volcanic and solar forcing.

Figure 6: Explanations of Medieval Climate Anomaly and Little Ice Age in the first order draft of AR6, WG1 (chapter 1, page 1-71)

In the second order draft (SOD), the neutral term "Medieval Climate Anomaly" was even highgraded to the more classical "Medieval Warm Period", MWP (Fig. 7). The FOD claim that the MWP was a local circum—Atlantic phenomenon was dropped in the SOD, as a response to reviewer criticism. The description was now much improved compared to the FOD. The version in SOD was the last one that reviewers have seen and could comment on.

Medieval Warm Period (MWP)	950–1250 CE	Series of globally heterogeneous relatively warm periods lasting decades to centuries. Also known as, Medieval Climate Anomaly.	
Little Ice Age (LIA)	1450–1850 CE	Series of globally heterogeneous relatively cold periods lasting decades to centuries and including some of the lowest temperatures of the post-glacial period. Coldest decades generally coincide with more frequent volcanic activity and low total solar irradiance.	

Figure 7: Explanations of Medieval Warm Period and Little Ice Age in the second order draft of AR6, WG1 (chapter 2, page 2-10)

What followed was a big surprise. In the finally published version of the table all reference to the Medieval warming and Little Ice Age cooling was silently removed (Fig. 8). Instead the collective term "the last millennium" was introduced which downplays the significance of pre-industrial climate change. Three small asterisks explain to the reader equipped with reading glasses that one does not want to use, that the terms "Medieval Warm Period" and "Little Ice Age" were removed from the report because they are allegedly too poorly defined and too regionally variable. Once the manuscript moved beyond the review stage, the IPCC has apparently gone into full reverse gear. This is how the IPCC rewrites climate history behind closed doors, ignoring reviewers' comments. And hardly anyone in the public notices.

Last millennium***	850-1850 CE	Climate variability during this period is better documented on annual to centennial scales than during previous reference periods. Climate changes were driven by solar, volcanic, land cover, and anthropogenic forcings, including strong increases in greenhouse gasses since 1750. *PMIP4 past1000,* 850–1849 CE (Jungclaus et al., 2017)	2.3.1.1.2 2.3.2.3 8.3.1.6 8.5.2.1 Box 11.3

*** The terms "Little Ice Age" and "Medieval Warm Period" (or "Medieval Climate Anomaly") are not used extensively in this report because the timing of these episodes is not well defined and varies regionally. Since AR5, new proxy records have improved climate reconstructions at decadal scale across the last millennium. Therefore, the dates of events within these two roughly defined periods are stated explicitly when possible.

Figure 8: Explanations of the "Last Millennium" in the final version of AR6, WG1 (chapter 2, pages 2-10 and 2-11)

The term "medieval" indeed no longer appears in chapter 2, in contrast to the FOD and SOD. Exceptions are the triple asterisk explanation and the titles of three recent MWP papers that are cited in the chapter (Lüning et al., 2019a; Lüning et al., 2018; Lüning et al., 2019b) (Fig. 9):

Lüning, S., M. Ga, I.B. Danladi, T.A. Adagunodo, and F. Vahrenholt, 2018a: Hydroclimate in Africa during the Medieval Climate Anomaly. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **495**, 309–322, doi:10.1016/j.palaeo.2018.01.025.

Lüning, S., M. Ga, I.B. Danladi, T.A. Adagunodo, and F. Vahrenholt, 2018b: Hydroclimate in Africa during the Medieval Climate Anomaly. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **495**, 309–322, doi:10.1016/j.palaeo.2018.01.025.

Lüning, S., M. Gałka, F.P. Bamonte, F.G. Rodríguez, and F. Vahrenholt, 2019a: The Medieval Climate Anomaly in South America. *Quaternary International*, **508**, 70–87, doi:10.1016/j.quaint.2018.10.041.

Lüning, S., L. Schulte, S. Garcés-Pastor, I.B. Danladi, and M. Gałka, 2019b: The Medieval Climate Anomaly in the Mediterranean Region. *Paleoceanography and Paleoclimatology*, **34(10)**, 1625–1649, doi:10.1029/2019pa003734.

Figure 9: The final version of chapter 2 cites four recent papers on the Medieval Climate Anomaly. Source: AR6, WG1, chapter 2, page 2-140.

How robust is the new hockey stick?

Like its predecessor, the new hockey stick by PAGES 2k 2019 is based on a large variety of proxy types and includes a large number of poorly documented tree ring data. In many cases, the tree rings' temperature sensitivity is uncertain. For example, both PAGES 2k Consortium (2013) and PAGES 2k Consortium (2019) used tree ring series from the French Maritime Alps, even though tree ring specialists had previously cautioned that they are too complex to be used as overall temperature proxies (Büntgen et al. 2012[13]; Seim et al., 2012[14]).

In contrast, Büntgen et al. (2020) were more selective, relied on one type of proxy (in this case tree rings) and validated every tree ring data set individually. Their temperature composite for the extra-tropical northern hemisphere differs greatly from the studies that use bulk tree ring input.

In some cases, PAGES 2k composites have erroneously included proxies that later turned out to reflect hydroclimate and not temperature. In other cases, outlier studies have been selected in which the proxies exhibit an anomalous evolution that cannot be reproduced in neighbouring sites (e.g. MWP data from Pyrenees and Alboran Sea in PA13) (Lüning et al., 2019b[15]). Outliers can have several reasons, e.g. a different local development, invalid or unstable temperature proxies, or sample contamination.

Steve McIntyre has studied the PAGES 2k proxy data base in great detail and summarized his criticism in a series of blog posts on his website Climate Audit (McIntyre, 2021).[16] For example, the PAGES 2k Consortium (2019) integrated a tree ring chronology from northern Pakistan near Gilgit ("Asia_207") which shows an extreme closing uptick (Fig. 10). Incorporation of data series like this strongly promote the hockey stick geometry of the resulting temperature composite.

13 Büntgen, U., Frank, D., Neuenschwander, T., and Esper, J., 2012, Fading temperature sensitivity of Alpine tree growth at its Mediterranean margin and associated effects on large-scale climate reconstructions: Climatic Change, v. 114, no. 3, p. 651-666.

14 Seim, A., Büntgen, U., Fonti, P., Haska, H., Herzig, F., Tegel, W., Trouet, V., and Treydte, K., 2012, Climate sensitivity of a millennium-long pine chronology from Albania: Climate Research, v. 51, no. 3, p. 217-228.

15 Lüning, S., Schulte, L., Garcés-Pastor, S., Danladi, I. B., and Gałka, M., 2019b, The Medieval Climate Anomaly in the Mediterranean Region: Paleoceanography and Paleoclimatology, v. 34, no. 10, p. 1625-1649.

16 McIntyre, S., 2021,
https://climateaudit.org/2021/11/02/the-decline-and-the-stick/
https://climateaudit.org/2021/09/15/pages-2019-0-30n-proxies/
https://climateaudit.org/2021/09/02/pages19-0-30s/
https://climateaudit.org/2021/08/26/pages2019-30-60s/
https://climateaudit.org/2021/08/15/pages19-asian-tree-ring-chronologies/
https://climateaudit.org/2021/08/11/the-ipcc-ar6-hockeystick/.

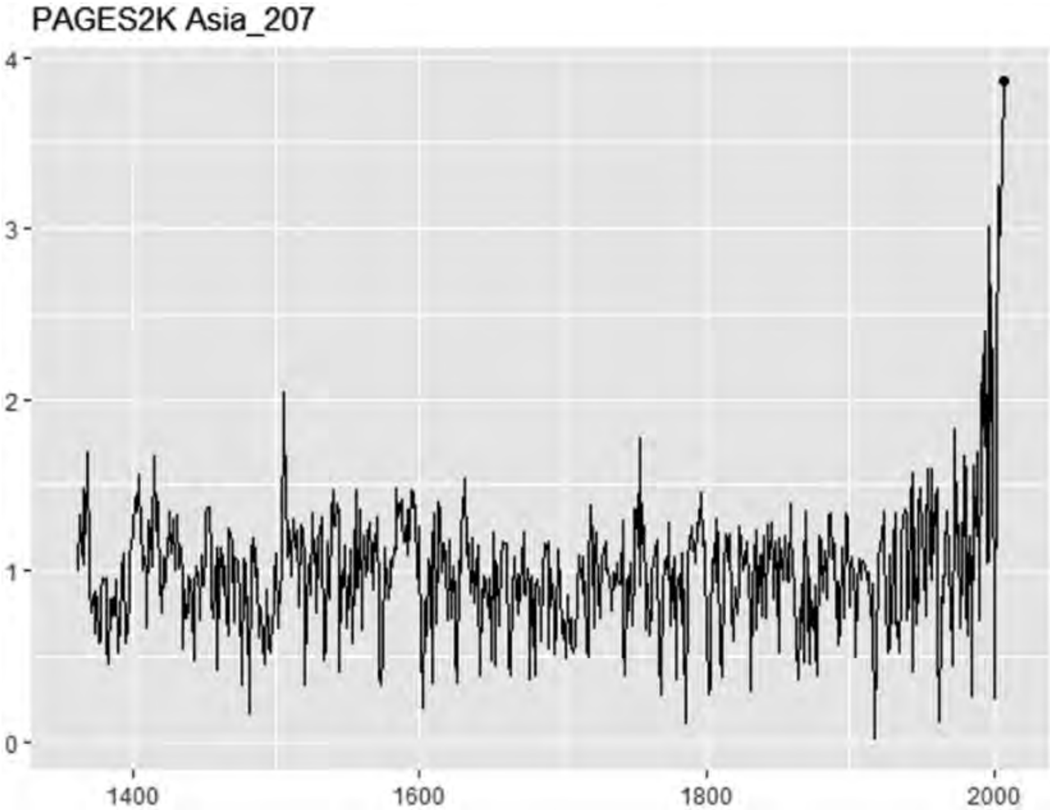


Figure 10: Hockey-stick-like tree ring chronology "Asia_207" as used by PAGES 2k Consortium (2019). Figure from McIntyre (2021).

McIntyre analysed the original tree ring data and found that the steep uptick in the Asia_207 chronology is the result of questionable data processing. When calculating the site chronology using the rcs function from Andy Bunn's dplR package, the uptick surprisingly disappears. In fact, the series declines over the 20th century (Fig. 11).

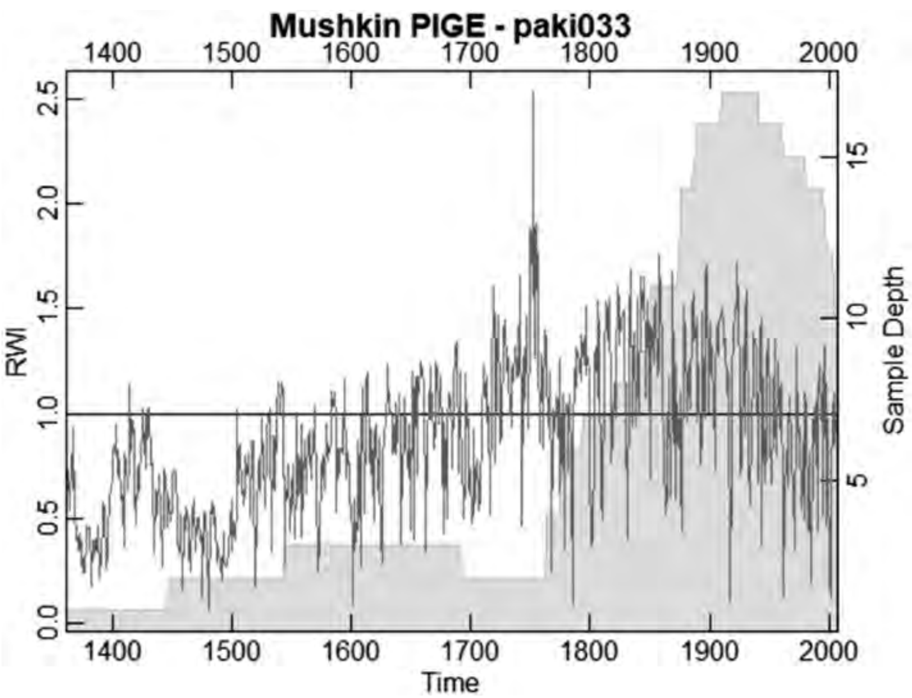


Figure 11: Tree ring chronology "Asia_207" calculated using the dplR function. Figure from McIntyre (2021).

An almost identical chronology to Figure 11 is also achieved by fitting a single Hugershoff curve to allow for growth prior to chronology calculation (Fig. 12).

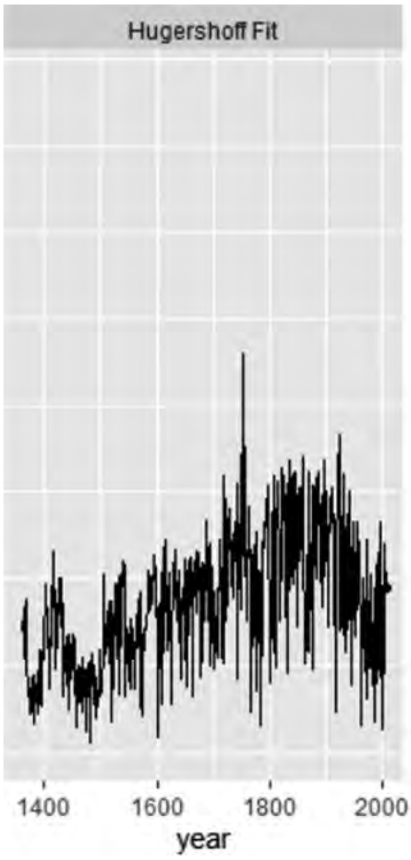
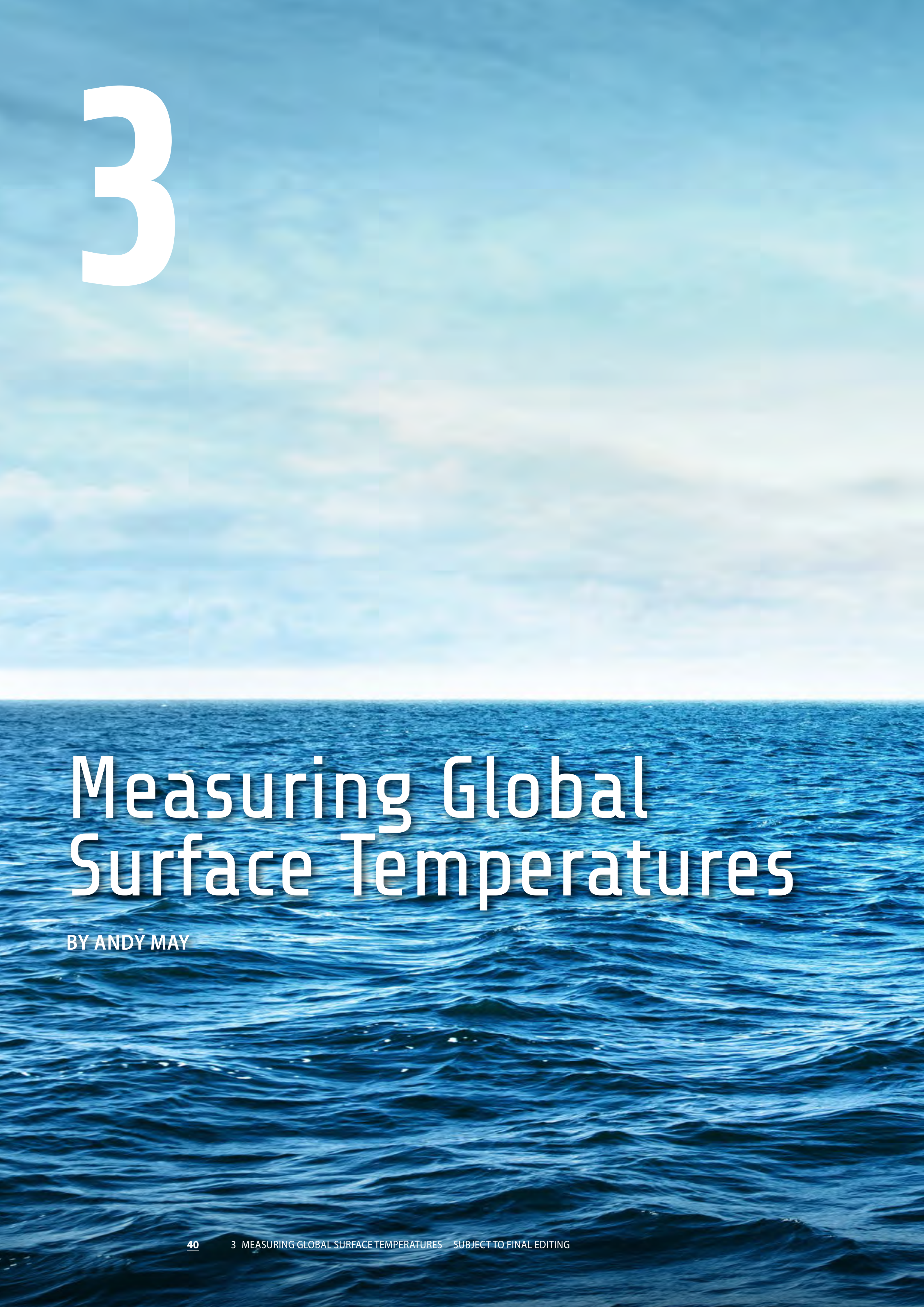


Figure 12: Tree ring chronology "Asia_207" calculated by fitting a single Hugershoff curve. Figure from McIntyre (2021).

Conclusion

The resurrected hockey stick of AR6 shows how vulnerable the IPCC process is to scientific bias. Cherry picking, misuse of the peer review process, lack of transparency, and likely political interference have led to a gross misrepresentation of the pre-industrial temperature evolution. Neutrality, scientific robustness and reliability of the IPCC and the organization's quality assurance process has to be questioned.



3

Measuring Global Surface Temperatures

BY ANDY MAY

The Global Mean Surface Temperature has become the iconic parameter/indicator in the climate change debate. Political climate targets – like the Paris targets of 2 and 1.5 degree Celsius – are determined by it. Is this deserved, how reliable are these temperature measurements and are there 'better' alternatives? Andy May takes a deep dive into the temperature records.

Chapter 2 of the sixth IPCC assessment report on climate change (AR6) asserts that "Global Mean Surface Temperature (GMST) is a key indicator of the changing state of the climate system."[1] While surface temperature helps define a climate state globally, it also helps define local and regional climates that are arguably more relevant to the people in those areas. Historically, climate is a term used to describe the long-term weather trend for a specific region. One might say, for example, that northern Europe, is wetter and warmer now than previously. In recent decades, though, we have begun to talk about a "global" climate.

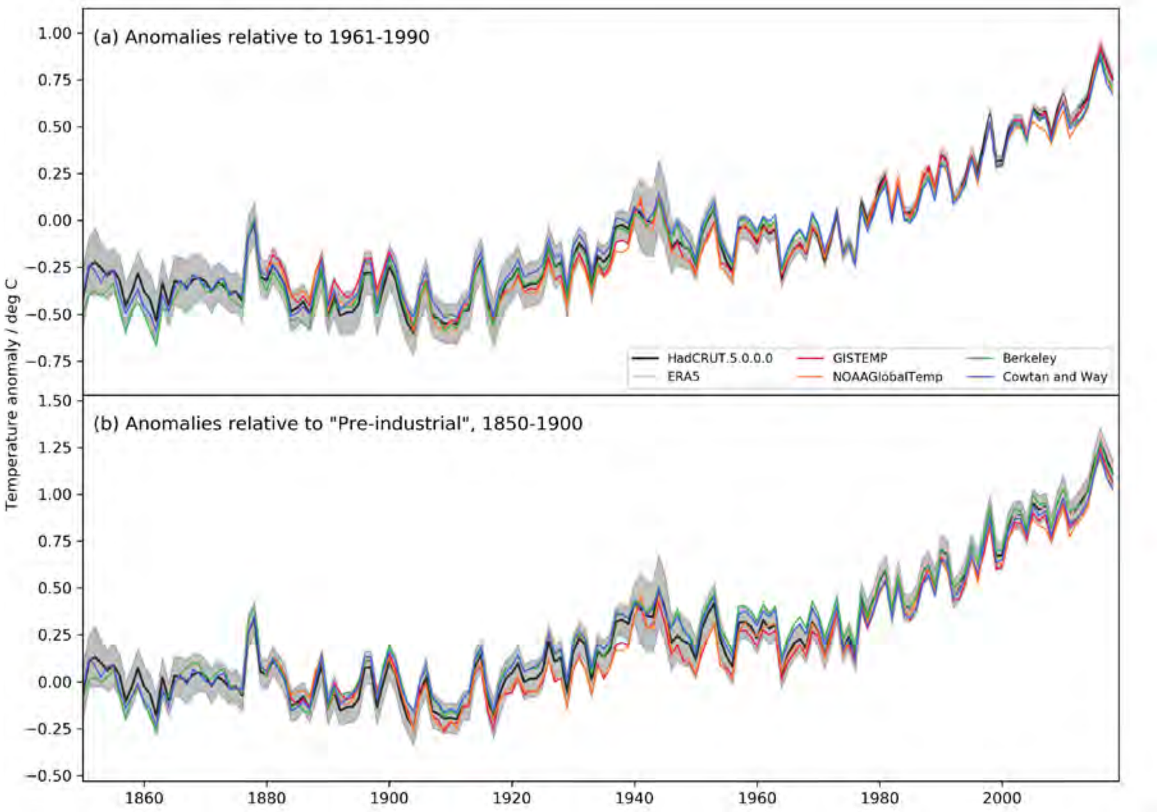


Figure 1: Various global surface temperature anomaly estimates, including HadCRUT5. The top is referenced to 1961-1990 and the bottom to the "pre-industrial period," also called the Little Ice Age. These estimates suggest about one degree of warming since 1900. Plot is from the Met Office Hadley Center web page.[2]

GMST is one indicator of climate change, whether global or local. But climate change is a long-term thing, and it has varied a lot over time. Figure 1 shows six estimates of GMST, and the estimates vary little from 1960 to the present day. The measured temperatures have been converted to "anomalies" by subtracting them from a chosen reference period. The top graph subtracts the local average from 1960-1990 from each temperature, the bottom uses an assumed "pre-industrial" or Little Ice Age

1 AR6, p. 294

2 Met Office Hadley Centre observations datasets

temperature. This is done to make the temperatures comparable and averageable; it is an attempt to make an intrinsically intensive local temperature measurement into an approximation of an extensive property. The actual measured global average surface temperature is not very meaningful, different parts of the Earth have different trends and elevations, some are warming, some are cooling, and all at different rates. As Figure 1 shows, the rate of global surface temperature change today, around one degree per century, is small relative to local temperature swings. In July, the global average surface temperature might be changing a few hundredths of a degree per annum, but the average low temperature in July at Vostok Station, Antarctica is –70°C and in Doha, Qatar the average high is 41°C. What does an average of –70 and 41 tell us about July climate change? Not much.

Figure 1 tries to suggest our estimates of global warming are accurate since all the lines are close together, but they share the same raw data and use very similar methods to correct and "homogenize" the data. While it is possible to calculate a reasonable GMST anomaly today, with thousands of ocean weather buoys[3] and ARGO floats,[4] as well as many thousands of land-based weather stations,[5] we've only had sufficient data to do so somewhat accurately for the past twenty to forty years or so.[6] While it is true that surface temperature is an indicator of climate change, are the estimates of global temperature change in Figure 1 accurate and comprehensive enough to tell us, with any precision, how quickly Earth's entire surface, including the oceans, are warming? Is the two meters of atmosphere, just above the solid or liquid surface, a *key* indicator of change in the entire climate system? We will examine just how *key* this measurement is.

The IPCC likes to frame the issue of climate change in terms of surface temperature change per volume of CO_2 and other greenhouse gas emissions. Implicit in this framing of the issues is the assumption that natural variability is insignificant. If all, or nearly all, of global warming is due to greenhouse gases and other human activities, then climate sensitivity is easily calculated. But the accuracy of the calculation is dependent upon the accuracy of the warming estimate. It also assumes that measuring surface temperature accurately reflects changes in the entire climate system. Here we examine the assumptions that the global surface temperature record is accurate and that the record reflects changes to the whole climate system.

The global average temperature of Earth varies over three degrees[7] every year, it is just over 12 degrees in January and just under 16 degrees in July as shown in Figure 2. The Northern Hemi-

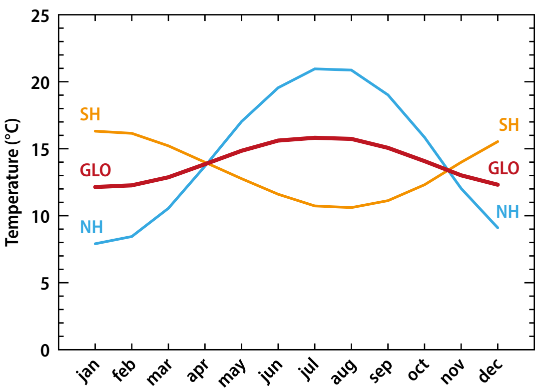


Figure 2: Average global surface temperatures from 1961-1990 for the globe (GLO), Northern Hemisphere (NH) and Southern Hemisphere (SH) by month. Source: (Jones, New, Parker, Martin, & Rigor, 1999)

3 National Data Buoy Center (noaa.gov)

4 Argo (ucsd.edu)

5 The U.S. National Temperature Index, is it based on data? Or corrections? | Andy May Petrophysicist

6 May, A. (2020e, November 27). *Ocean Temperature Update*. Retrieved from andymaypetrophysicist.com: https://andymaypetrophysicist.com/2020/11/27/ocean-temperature-update/, Kennedy, J. J., Rayner, N. A., Smith, R. O., Parker, D. E., & Saunby, M. (2011). Reassessing biases and other uncertainties in sea surface temperature observations measured in situ since 1850; 1. Measurement and sampling uncertainties. *Journal of Geophysical Research, 116*. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010JD015218, Hosada, S., Ohira, T., Sato, K., & Suga, T. (2010). Improved description of global mixed-layer depth using Argo profiling floats. *Journal of Oceanography, 66*, 773-787. doi:10.1007/s10872-010-0063-3

7 Jones, P. D., New, M., Parker, D. E., Martin, S., & Rigor, I. G. (1999). Surface Air Temperature and its Changes over the Past 150 years. *Reviews of Geophysics, 37*(2), 173-199. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.546.7420&rep=rep1&type=pdf

sphere has a larger swing from eight degrees in January to over 21 degrees in July, a remarkable change of 13°C in only six months. Compare this monthly change in global temperatures to the HadCRUT4 global change of one degree since 1850 shown in Figure 3 or the HadCRUT5 change of over 1°C since 1850 in Figures 1 and 4.

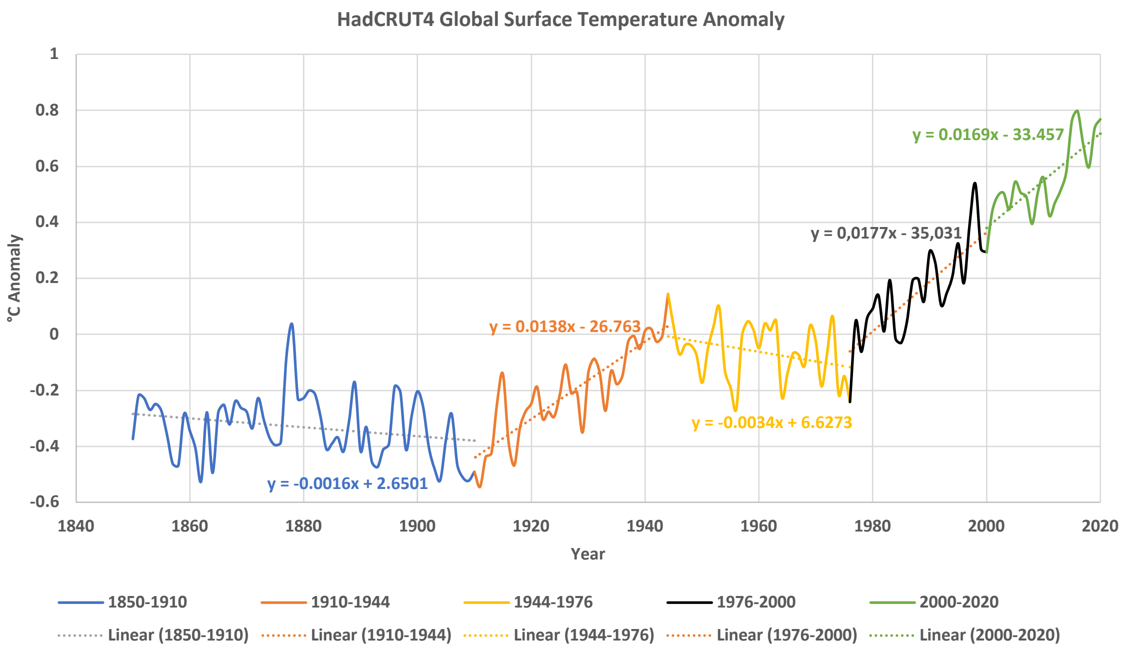


Figure 3: HadCRUT4 temperature record since 1850.

Figure 4 breaks down the HadCRUT5 temperature record into the same segments as Figure 3. Comparing Figure 2 to Figures 3 and 4 leads us the conclusion that the impact of the warming of the past 170 years is not very significant. Everyone experiences a larger global or hemispheric change every year from July to January.

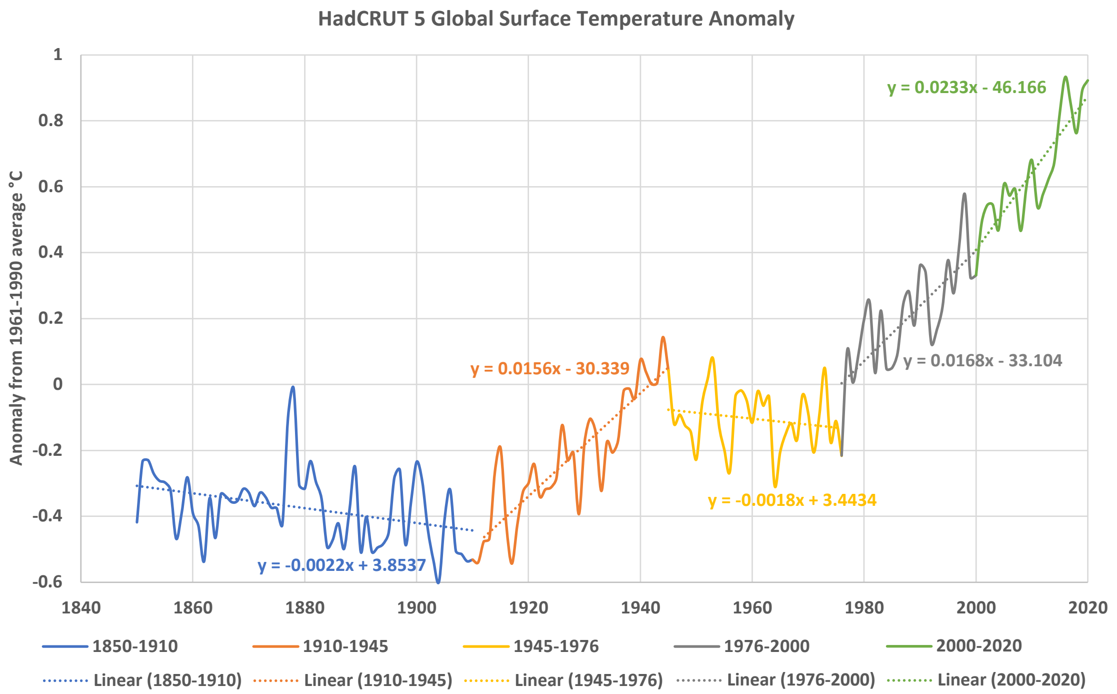


Figure 4: The HadCRUT5 temperature record.

How significant is the global warming since the 19th century?

Comparing Figure 3 to Figure 4, we can see that the newly released HadCRUT5[8] dataset shows 0.2°C more warming than its predecessor, HadCRUT4[9] over the past 170 years. Table 1 breaks the 170-year period into warming and cooling periods and computes the difference for each period.

Table 1: HadCRUT 4 and 5 warming rates.

WARMING RATES (PER DECADE)			
PERIOD	HadCRUT 4	HadCRUT 5	
	°C/decade	°C/decade	Diff
1850 - 1910	0.016	–0.022	–0.006
1910 - 1945	0.137	0.156	0.019
1945 - 1976	–0.034	–0.018	0.016
1976 - 2000	0.177	0.168	–0.009
2000 - 2020	0.169	0.233	0.064

The cooling from 1850 to 1910 increased 37%, the warming from 1910 to 1976 increased, and the warming from 1976 to 2000 has decreased a little, but the warming from 2000 to 2020 has increased 38%! Considering this is the period with the best data, this is surprising. With swings such as these from one version of the HadCRUT record to another, just how accurate can their estimates of global surface warming be?

The most significant difference between the datasets is that HadCRUT4 is not infilled, that is if a grid cell has insufficient data, it is not included in the average. The HadCRUT5 dataset is infilled via interpolation and extrapolation. In the critical period from 2000 to 2020 the HadCRUT5 dataset has 99% to 100% of its cells filled and the HadCRUT4 dataset has 85% filled.[10] It seems unlikely that interpolating or extrapolating the existing data into 14-15% of the HadCRUT5 cells could cause a 38% change in the surface warming rate.

Another difference between HadCRUT4 and HadCRUT5 is that HadCRUT5 uses a new SST (sea surface temperature) dataset, HadSST4. HadSST4 has a much higher warming trend from 2000 to 2012 than HadSST3, and the estimated uncertainty in the estimate is high, relative to earlier periods.[11] This is odd, considering that the newer data is better than the older data. Kennedy, et al. note that the warming rates, from 2000 to 2012, of HadSST4, COBE-SST-2, and ERSSTv4 are very similar, but the raw unadjusted data for the period has a warming rate *near zero*. A map of the difference between HadSST4 and the raw unadjusted data for 1995-2018 is large, but still smaller than the applied adjustments to the raw data.[12] HadSST4 is not only warmer from 2000 to 2012 than HadSST3, it is also warmer than all the other SST datasets studied by Kennedy, et al. in their 2019 paper.

When compared to the UAH v6.0[13] global satellite temperature dataset, HadCRUT5 is very anomalous, as shown in Figure 5. The UAH dataset is not a surface temperature dataset, instead it is a global average temperature of the lower troposphere, and completely independent of the surface

8 Morice, C. P., Kennedy, J., Rayner, N., Winn, J., Hogan, E., Killick, R., . . . Simpson, I. (2021, Feb. 16). An updated assessment of near-surface temperature change from 1850: the HadCRUT5 dataset. *Journal of Geophysical Research (Atmospheres), 126*(3). Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019JD032361

9 Morice, Kennedy, Rayner, & Jones. (2012, April). Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 dataset. *J Geophysical Research: Atmospheres, 117*(D8). Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JD017187

10 Temperature data (HadCRUT, CRUTEM,, HadCRUT5, CRUTEM5) Climatic Research Unit global temperature (uea.ac.uk)

11 Kennedy, J., Rayner, N., Atkinson, C., & Killick, R. (2019). An ensemble data set of sea-surface temperature change from 1850: the Met Office Hadley Centre HadSST4 dataset. *JGR Atmospheres, 124*(14), 7719-7763. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JD029867, see figure 16.

12 Kennedy, J., Rayner, N., Atkinson, C., & Killick, R. (2019). An ensemble data set of sea-surface temperature change from 1850: the Met Office Hadley Centre HadSST4 dataset. *JGR Atmospheres, 124*(14), 7719-7763. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JD029867, see Figure 12 and the text.

13 Spencer, R., Christy, J., & Braswell, W. (2017). UAH Version 6 global satellite temperature products: Methodology and results. *Asia-Pacific J Atmos Sci, 53*, 121-130. Retrieved from https://link.springer.com/article/10.1007/s13143-017-0010-y

datasets plotted in Figure 1, which all share the same raw data. The satellite signal that is used to build the UAH lower troposphere average temperature is centered on about 600 hPa (same as millibars) or an altitude of about 4.5 km. Nearly all the signal used is captured from between 900 to 300 hPa (roughly 1 km to 9 km altitude).

All climate models[14] and logic suggest that, if greenhouse gases are causing our current surface warming, the temperature should be increasing in the lower to middle troposphere faster than at the surface. This is because the increased surface warming should cause more evaporation and the water vapor will condense between 2 and 12 km releasing latent heat that warms the surrounding air. In the tropics the extra warming extends much higher, up to 18 km in some extreme cases.

Since both theory and the models predict a higher warming rate in the lower and middle troposphere than we see at the surface, Figure 5 is surprising. It shows that the HadCRUT5 infilled land and ocean surface dataset is warming 36% faster than either the lower troposphere (per UAH v6.0) or the sea surface. The HadCRUT5 land and ocean surface temperature is constructed from the CRUTEM5 land data and the HadSST4 data. The same SST (Sea Surface Temperature) data that is plotted in Figure 5 and discussed above. The lower troposphere is warming at the same rate, to two decimals, as the world ocean surface HadSST4 data. UAH v6.0 shows a slower warming rate than the other lower troposphere satellite temperature datasets analyzed in AR6, but UAH 6.0 matches observations much better than the other satellite datasets.[15] The HadCRUT5 surface warming trend is also higher than the average shown in AR6.[16]

The lack of much tropospheric excess warming, over surface warming, suggests that changes in greenhouse gases are likely not a significant factor in current warming.[17] Further, since Earth's surface is 71% water and only 29% land, it seems unlikely that the land can be warming fast enough to increase the total surface temperature warming rate 36%. The UAH warming trend for global land, since 1979, is 50% larger than for the oceans, but land is only 29% of the surface,

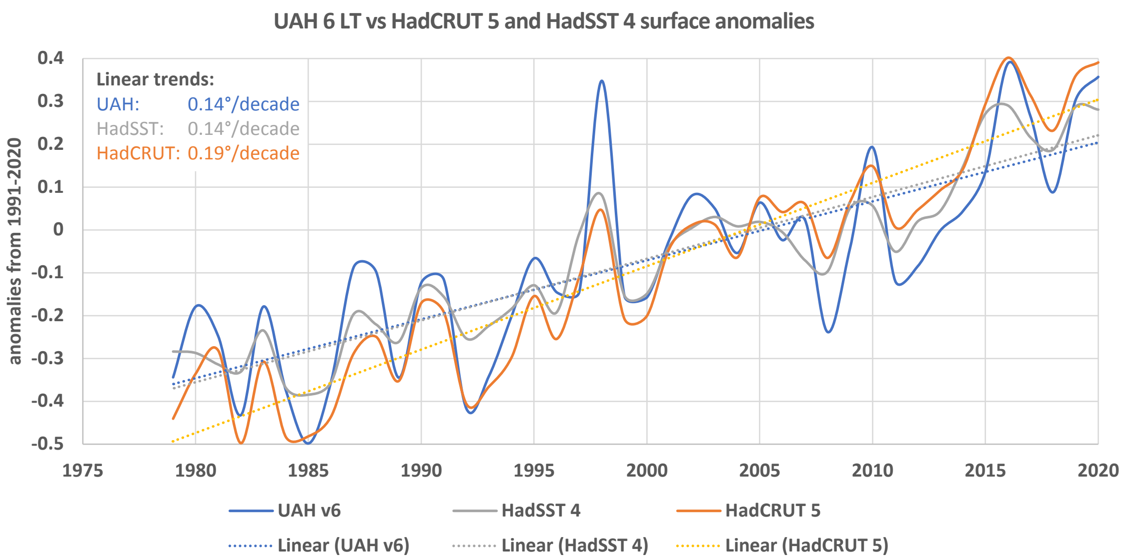


Figure 5: UAH lower troposphere temperatures compared to the Hadley SST v4 and the Hadley land plus SST surface temperatures. The plot spans 1979 (the first year of UAH data) to 2020.

14 The AR4, AR5, and AR6 climate models unanimously predict that the lower to middle troposphere will warm faster than the surface in response to greenhouse gas forcing. Natural (non-greenhouse gas forcing) also predicts some increase in warming rate, but much smaller than modeled. The observed difference is about 15-20% in the tropics and the modeled difference, with greenhouse gases, is over 30%. McKitrick, R., & Christy, J. (2018, July 6). A Test of the Tropical 200- to 300-hPa Warming Rate in Climate Models, Earth and Space Science. *Earth and Space Science, 5*(9), 529-536. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018EA000401 and Blunden, J., & Arndt, D. S. (2020). *State of the Climate in 2019.* BAMS. Retrieved from https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/

15 Christy, J. R., Spencer, R. W., Braswell, W. D., & Junod, R. (2018). Examination of space-based bulk atmospheric temperatures used in climate research. *International Journal of Remote Sensing*, 3580-3607. doi:10.1080/01431161.2018.1444293, see Figure 6

16 AR6 Table 2.5 shows an average trend warming of 0.70°C over the comparable 1980-2019 period, which compares with 0.75°C for HadCRUT5,

17 https://andymaypetrophysicist.com/2022/03/13/comparing-ar5-to-ar6/

so 29% of 50% is only 15%. The data in Figure 5 suggest that there are problems with the land-based temperature data or the processing of it.

Ocean temperatures

The ocean mixed layer is a turbulent layer just below the ocean surface. Turbulence, due to the wind and weather in the atmosphere just above the ocean surface, keeps it well mixed and thus it has a nearly constant vertical temperature throughout. The thickness of the layer varies by location, but the global average thickness is roughly 72 meters according to data gathered and mapped by JAMSTEC.[18] Shigeki Hosada and his colleagues use Argo float data and ocean buoys to grid and map the mixed layer temperature across much of the world ocean.

The mixed layer is in constant communication with the surface, with a maximum delay of a few days to a few weeks. Because the mixed layer has over 27 times the heat capacity of the entire atmosphere, it moderates the speed of temperature changes in the overlying atmosphere.

Heat capacity tells us how much energy it takes to raise the temperature of a body one degree, thus if the atmospheric temperature increased 27 degrees, and all that thermal energy ("heat") were transferred quickly to the mixed layer, the temperature would only increase one degree. The mixed layer and the atmosphere are always trying to come to equilibrium, but the enormous heat capacity of the mixed layer means that its temperature fluctuates less rapidly than the more chaotic and active atmosphere. Atmospheric temperatures reflect the day-to-day weather, mixed layer temperatures reflect month-to-month and year-to-year climatic changes. Figure 6 is a plot of JAMSTEC global mixed layer temperatures, from 2002 to 2020.

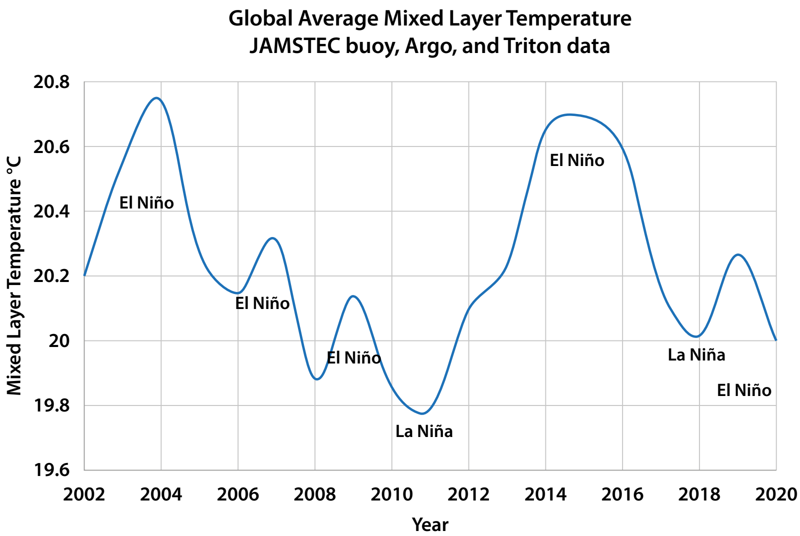


Figure 6: JAMSTEC area-weighted global average one-degree grid mixed layer temperatures. Only populated grid cells are averaged. Yearly averages are plotted. Some recent ENSO events are labeled in the graph.

We only have good mixed layer data for the past 19 years, some would say only since 2004 or 2005, but either way the data reflects recent ENSO (La Niña and El Niño) events and trends slightly downward with time so far. The plot is of actual temperature measurements, *not* anomalies from the mean. Various sea surface and mixed layer temperature measurement datasets have different trends, some up, and some down. When the measurements are converted to anomalies from a mean and "corrected" the trend is always slightly upward, this brings the conversion and corrections into question.[19]

18 The Japanese Agency for Marine-Earth Science and Technology (Hosada, Ohira, Sato, & Suga, 2010). Access to the JAMSTEC gridded data has been suspended, but more information is available here and here.

19 For a full discussion of mixed layer and sea surface measurements versus anomaly problems see these essays: (May, Ocean Temperatures, what do we really know?, 2020f), (May, Sea-Surface Temperatures: Hadley Centre v. NOAA, 2020g), (May, The Ocean Mixed Layer, SST, and Climate Change, 2020h), and (May, Ocean Temperature Update, 2020e)

While the mixed layer trends reflect climatic trends on a monthly or yearly scale, the deeper ocean looks even longer-term. Figure 7 shows the JAMSTEC grid temperatures for 100 to 2,000 meters below the ocean surface. The mixed layer rarely reaches as deep as 100 meters, so the temperatures shown in Figure 7 are partially insulated from the surface. In both Figure 6 and Figure 7 only populated cells are averaged, neither grid has values in all cells for every year. The values averaged for both graphs are area weighted since the grid cells in the higher latitudes are smaller than those at the equator.

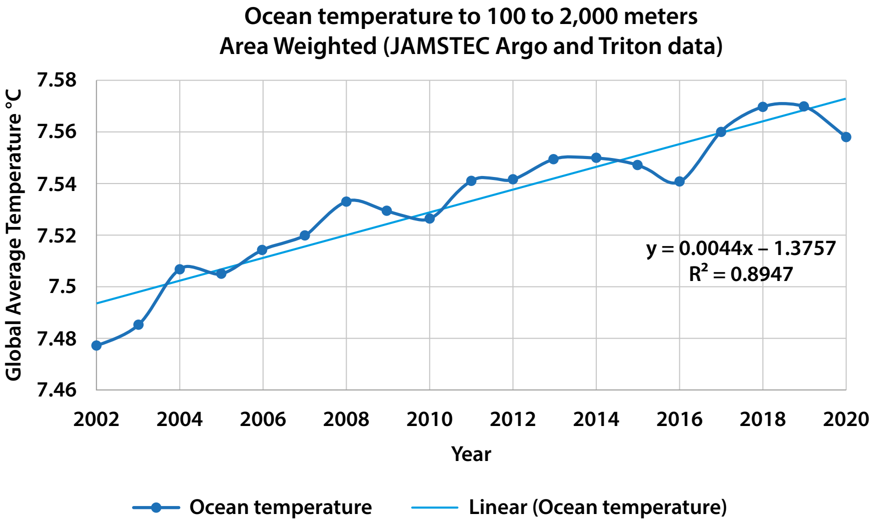


Figure 7: Average temperature for the world ocean from 100 to 2,000 meters. Data from JAMSTEC.

While recent atmospheric temperatures are reflected in Figure 6, with a delay of less than a month, they are reflected on a much longer time frame in Figure 7, perhaps centuries. In Figure 7 we see a rate of increase of about 0.4°C/century. This is less than half that reported for the surface over the past century or so. The ENSO features seen in Figure 6 are absent from Figure 7. With no ENSO related features, Figure 7 is remarkably linear, with an R^2 of 0.9. There is no sign of acceleration. Simply averaging the ocean temperatures from 100 meters to 2,000 meters is very crude, but it does make the point that a lot of historical temperature data probably exists in the deeper ocean water.

An earlier study of available ocean heat content by Roger Pielke Sr., in 2003,[20] shows no significant trend in heat storage in the upper three kilometers of the world ocean from 1958 to 1993. Pielke Sr. writes in the same paper, "Since the surface temperature is a two-dimensional global field, while heat content involves volume integrals, ... the utilization of surface temperature as a monitor of the earth system climate change is not particularly useful in evaluating the heat storage changes to the earth system." This emphasizes our point that surface temperature is not very useful as a measure of climate change.

Compare Figure 7 and Roger Pielke Sr.'s study to the IPCC AR6 Chapter 2 plot of ocean heat content shown in Figure 8. When reading the plot consider that the world ocean contains about 1,514,000 zettajoules of heat using an average ocean temperature of eight degrees C (see Figure 7). The increases shown in Figure 8 are very tiny.

Patrick Frank[21] reported that the warming from 1880 to 2000, as estimated by NOAA, is statistically indistinguishable from zero. Frank uses an estimate of the uncertainty in each land-based temperature reading of ± 0.35°C around the globe in his calculations. This estimate is derived from an error analysis study of MMTS (Minimum-Maximum Temperature System) weather stations by

20 Pielke Sr., R. (2003, March). Heat Storage within the Earth System. *BAMS, 84*(3), 331-335. Retrieved from https://journals.ametsoc.org/view/journals/bams/84/3/bams-84-3-331.xml

21 Frank, P. (2010). Uncertainty in the Global Average Surface Air Temperature Index: A Representative Lower Limit. *Energy and Environment, 21*(8), 968-989. Retrieved from https://meteo.lcd.lu/globalwarming/Frank/uncertainty_in%20global_average_temperature_2010.pdf

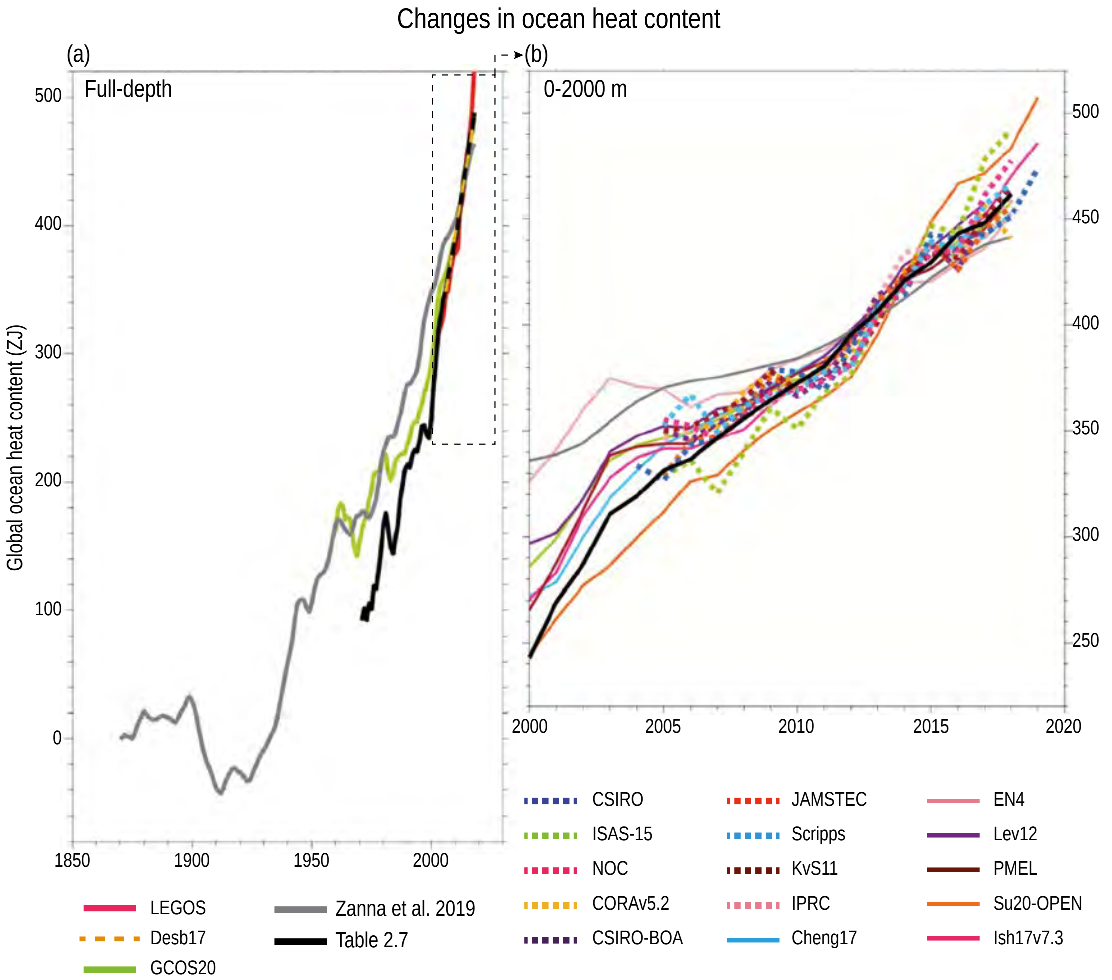


Figure 8: Changes in ocean heat content from AR6, Chapter 2, page 350. The graphs are in zettajoules change since ~1900, a relatively meaningless number given the huge heat capacity of seawater. The steep slopes are an artifact of the scales chosen. Figure 7 is more meaningful and is about the same body of water as in Figure 8, the only difference is Figure 8 is to the surface and Figure 7 is from 100 meters depth to 2000 meters.

Lin and Hubbard.[22] This error is not necessarily random. Even if the error is random, no extensive overall survey of station sensor variance has been published, and the precise accuracy of our global temperature record is unknown. Yet, we must consider the estimated warming of 0.87°C from 1875 to 2005 considering possible errors, and when we do, we see just how small the possible warming might be. Frank estimates that the total possible land-measured temperature error over this entire period is likely more than ± 0.46°C. There is also considerable uncertainty in ocean surface temperatures[23] so Frank concludes that the lower limit of uncertainty globally can credibly be set at ± 0.46°C. The various ocean SST datasets do not agree very well. Kennedy, et al. report that:

> *"The estimated uncertainties in the global and hemispheric averages are for the most part larger in HadSST4 than HadSST3 prior to around 1970." (Kennedy J. , Rayner, Atkinson, & Killick, 2019).*

It is very hard to interpret the various estimates of uncertainty in the large number of published hemispheric and global temperature records. This is particularly true of the more recent records, such as HadCRUT5 and HadSST4, where uncertainty is apparently increasing, as researchers uncover more problems in the raw data.

22 Lin, X., & Hubbard, K. (2004). Sensor and Electronic Biases/Errors in Air Temperature Measurements in Common Weather Station Networks. *J. Atmos. Ocean. Tech.*
Retrieved from https://journals.ametsoc.org/view/journals/atot/21/7/1520-0426_2004_021_1025_saeeia_2_0_co_2.xml

23 Kennedy, J. J., Rayner, N. A., Smith, R. O., Parker, D. E., & Saunby, M. (2011). Reassessing biases and other uncertainties in sea surface temperature observations measured in situ since 1850; 1. Measurement and sampling uncertainties. *Journal of Geophysical Research, 116*. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010JD015218 and Kennedy, J. J., Rayner, N. A., Smith, R. O., Parker, D. E., & Saunby, M. (2011b). Reassessing biases and other uncertainties in sea surface temperature observations measured in situ since 1850: 2. Biases and homogenization. *J. Geophys. Res., 116*. doi:10.1029/2010JD015220

GSAT, the Global Surface Air Temperature

Chapter 2 in AR6 has an extensive discussion of a new global average surface air temperature called "GSAT." GSAT stands for Global Surface Air Temperature and is different from GMST, or the global mean surface temperature. GSAT is the average air temperature over the ocean surface combined with the land-based surface air temperatures (LSAT), both sets of temperatures are meant to be from a two-meter altitude. GMST uses the same LSAT dataset but combines them with sea surface temperatures. SSTs are optimally at a 20 cm water depth.[24]

In his comments on the second order draft of AR6, Jim O'Brien commented that GSAT is probably artificially inflated by the Urban Heat Island (UHI) effect near coastal cities. The UHI is not addressed directly by either NOAA or the Met Office Hadley Centre in their respective estimates of global average surface temperature. Instead, they smooth through the excess warming in cities with a "homogenization" algorithm. This algorithm can smear warmer urban temperatures over large areas (Scafetta, 2021). The homogenization technique generally used, is best explained by Matthew Menne and Claude Williams in a 2009 *Journal of Climate* paper (Menne & Williams, 2009a). The basic technique described by Menne and Williams, has been updated several times, as described by several authors, but is still used for all the datasets in AR6.[25]

AR6 reports that GSAT is based upon nighttime marine air temperatures (NMAT) and weather reanalysis datasets. Weather reanalysis uses meteorological computer models to compute worldwide maps of meteorological conditions after the fact. The calculations are constrained by surface measurements, satellite measurements, and weather balloon data. The IPCC are interested in measuring this value because their climate models compute the global average surface air temperature at two meters, and they want to compare their model calculations to a comparable observed value.

GSAT and GMST are physically different, especially over sea ice. John Christy and colleagues examined the existing data and determined that GSAT and GMST are different measurements and there is no valid way to compute one from the other.[26] An interesting result of Christy, et al.'s study was that the difference between the air temperatures above the sea surface and the SST (as measured at about one-meter depth) is declining (going from positive to negative) from 1979 to 2000. That is, the lower-mid tropospheric air temperature of the tropical air over the sea surface cooled slightly over the period, and the SST warmed, this difference is statistically significant, but not constant. Further the NMAT, from buoys, were intermediate between the SST and the lower-mid tropospheric marine air temperature trends.

Christy and other researchers have tried to compare GSAT and GMST, but the results are confusing. Sometimes they found that GSAT warms faster than GMST and sometimes the reverse. They seem to differ, in warming rate, by less than 10%, but it can be in either direction. In other words, which one is warming faster globally, is unknown (AR6, p 192). Unable to model the difference between the two led the IPCC to throw up their hands and decided the warming rates would be "assessed to be identical."[27] This is despite the evidence presented by Christy and his colleagues that marine air temperatures (MAT) and SSTs can have different multidecadal trends and patterns of variability (AR6, p 318). Comparing the AR6 Technical Summary to the Chapter 2 text, suggests that there is a conflict within the AR6 team over the issue. AR6 Chapter 2 emphasizes the

---

24 Kennedy, J., Rayner, N., Atkinson, C., & Killick, R. (2019). An ensemble data set of sea-surface temperature change from 1850: the Met Office Hadley Centre HadSST4 dataset. *JGR Atmospheres, 124*(14), 7719-7763. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JD029867

25 Morice, C. P., Kennedy, J., Rayner, N., Winn, J., Hogan, E., Killick, R., . . . Simpson, I. (2021, Feb. 16). An updated assessment of near-surface temperature change from 1850: the HadCRUT5 dataset. *Journal of Geophysical Research (Atmospheres), 126*(3). Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019JD032361, for HadCRUT5 and Menne, m., Williams, C., & Gleason, B. (2018). The Global Historical Climatology Network Monthly Temperature Dataset, Version 4. *J of Climate, 31*(24). Retrieved from https://journals.ametsoc.org/view/journals/clim/31/24/jcli-d-18-0094.1.xml for GHCN version 4

26 Christy, J., Parker, D., Brown, S., Macadam, I., Stendel, M., & Norris, W. (2001, January). Differential Trends in Tropical Sea Surface and Atmospheric Temperatures since 1979. *Geophysical Research Letters, 28*(1), 183-186. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2000GL011167

27 AR6, p 59

differences between the two measures and how important the differences are, and the Technical Summary "assesses" that they have the same long-term trend, and the two measures of temperature changes can be used interchangeably. This is a point of controversy; it is very unlikely GSAT and GMST trends are truly interchangeable.

GMST is grounded in observations, but there are no GSAT datasets as such, and none is expected for decades.[28] Thus, NMAT datasets and weather reanalysis models are used to construct current estimates of GSAT. Nighttime marine temperatures are used to estimate the difference between GSAT and SST because the daytime heating of ship superstructures and instruments creates a bias, and spurious trends in GSAT measurements.[29]

According to AR6, the importance of the difference in GSAT and GMST warming rates was raised in SR1.5,[30] but that assessment report still used GMST for their observation-based work. The AR6 second order draft[31] indicated that they had agreed to switch to GSAT as the primary metric of surface temperature changes, but this was removed from the near final draft we are discussing here. In the final draft, GSAT and GMST trends are treated as if they are interchangeable.

All CMIP simulations imply that GSAT increases faster than GMST, which is the reverse of what is seen in most observations.[32] A simple model was considered during the drafting of AR6 that applied a 4% global change in the SST warming rate. No data or observations were used, they just increased the GMST warming rate by 4% and called the result GSAT (SOD, page 2-35). Thankfully, this arbitrary model was abandoned in the final draft.

One of the datasets they examined while looking for evidence, was the HadNMAT2 dataset.[33] The dataset provided no evidence of a systematic difference between nighttime marine air temperatures (NMAT) and SSTs from 1920 to 1990, but SST warmed faster than NMAT during the 1990s. In contrast, Robert Junod and John Christy found that UAHNMATv1 warming trends were faster than SST trends from 1900 to 2010.[34] UAHNMATv1 also shows that the relative warming trends vary by region, as well as by timeframe. The interested reader may want to look at Figures 11 and 12 in Junod and Christy's *International Journal of Climatology* article to see the lack of coherence in the difference between the SST warming rate and the GSAT warming rate. AR6 points out that Nighttime Marine Atmospheric Temperature measurements are used to correct SSTs, so after this process is completed, using them to detect a difference between GSAT and GMST is partially circular.[35]

The complexity of the relationship in the real world and the uniformity of the climate model results suggests that the models are oversimplifying a complicated problem. Or, perhaps, the data simply aren't accurate enough to resolve the two temperature trends. Either way, simply assuming trends in the two temperatures are the same—as they did in the final version of AR6—was the only sensible option the IPCC had. But, given observed differences between the two values have an uncertainty of ± 10%, and it varies from GSAT > GMST to GSAT < GMST, a huge uncertainty between the modeled surface temperature and observations is introduced. Further, oceans cover 71% of Earth's surface.

Global average temperatures, in general, have little meaning unless there is a forcing agent that acts globally. CO_2 disperses rapidly, so if it is the dominant factor in global warming, we might ex-

---

28 AR6, p 319

29 AR6, p 319

30 IPCC. (2018). *Global Warming of 1.5 degrees C.* (Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, . a. T. Waterfield, Eds.) Geneva: World Meteorological Organization. Retrieved from https://www.ipcc.ch/sr15/

31 AR6 SOD, 2-35

32 AR6, p 319 and Christy, J., Parker, D., Brown, S., Macadam, I., Stendel, M., & Norris, W. (2001, January). Differential Trends in Tropical Sea Surface and Atmospheric Temperatures since 1979. *Geophysical Research Letters, 28*(1), 183-186. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2000GL011167

33 The Met Office Night Marine Atmospheric Temperature dataset (Met Office , 2021)

34 Junod, R., & Christy, J. (2019, October 10). A new compilation of globally gridded night-time marine air temperatures: The UAHNMATv1 dataset. *RMetS, 40*(5). Retrieved from https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.6354

35 AR6, p 319

pect warming to occur over the globe approximately uniformly, if the sun and other natural factors are not changing. But this is not what has happened recently or in the distant past. The UAH satellite global temperature records show that the Northern Hemisphere is warming 30% faster than the tropics and 49% faster than the Southern Hemisphere since 1979. Figure 9 shows the warming rates for the Northern Hemisphere (NH), the tropics, the globe, and the Southern Hemisphere (SH). All are relative to the respective average from 1990 to 2020, which makes them bunch up a bit, but the differences in warming rates are significant.

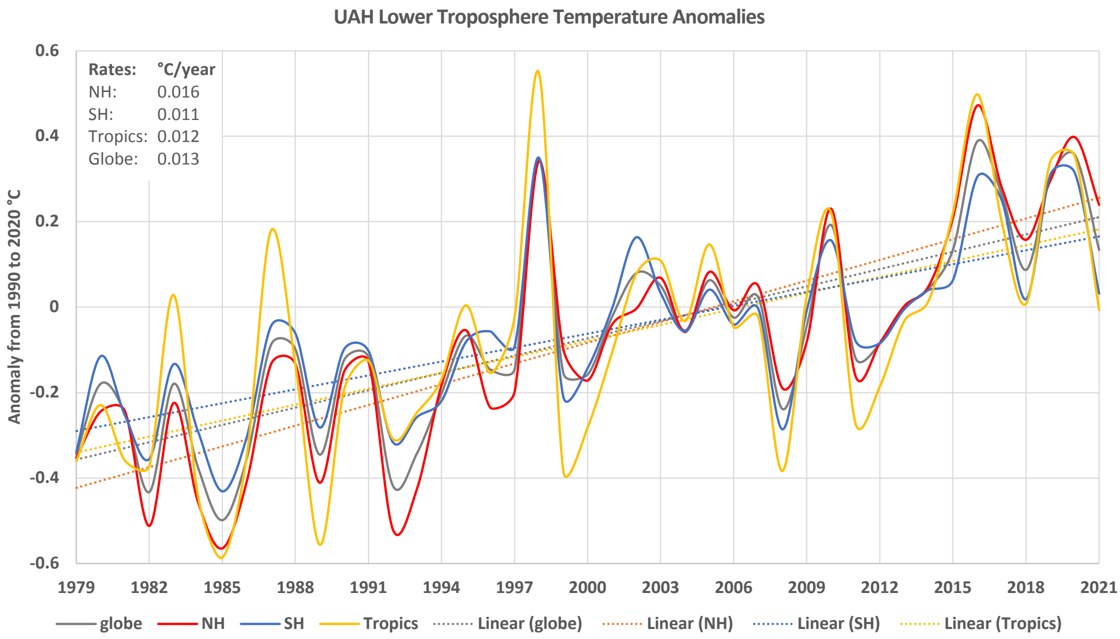


Figure 9: UAH satellite rates from the respective averages over 1990 to 2020. Data source: UAH.

The IPCC does their global temperature comparisons from 1850, the end of what they call the preindustrial era. The year 1850 is also close to the end of the Little Ice Age (LIA). This implies they consider the LIA an optimum temperature, but historian Wolfgang Behringer disagrees. He describes the Little Ice Age as a cold and miserable time for humanity, our modern climate is much better.[36] The LIA was a time when mountain glaciers advanced and swallowed entire towns; plagues, severe droughts, and famine due to poor crops were frequent. Geoffrey Parker estimates that a third of the population in Europe and Asia died during the mid-seventeenth century, the coldest portion of the LIA.[37] Very few informed people would want to return to the climate of the Little Ice Age.

Discussion and Conclusions

There are no observational data to support shifting the GMST warming rate up to compute GSAT, thus the long discussion of GSAT versus GMST in Chapter 2 of AR6 is not necessary. Fortunately, this problem was recognized and GMST was not replaced by an estimated GSAT, we support this decision. However, the confusing differences between GMST and GSAT should be investigated, and not simply dismissed as irrelevant, the differences might be important.

Only a small portion of the surface (defined as the sea floor to the top of the atmosphere and excluding the land surface) heat content is in the atmosphere.[38] The lower atmosphere is very chaot-

36 Behringer, W. (2010). *A Cultural History of Climate.* Cambridge, UK: Polity Press. Retrieved from https://www.amazon.com/Cultural-History-Climate-Wolfgang-Behringer/dp/0745645291

37 Parker, G. (2012). *Global Crisis: War, Climate Change, and Catastrophe in the Seventeenth Century.* Yale University Press. Retrieved from https://www.google.com/books/edition/Global_Crisis/gjdDP15N4FkC?hl=en

38 May, A. (2020e, November 27). *Ocean Temperature Update*. Retrieved from andymaypetrophysicist.com: https://andymaypetrophysicist.com/2020/11/27/ocean-temperature-update/

ic, especially over land areas, and has a yearly range of surface temperatures that exceeds 110°C. The global average surface temperature varies three degrees from January to July every year, and the Northern Hemisphere average temperature varies over 12 degrees.[39] These yearly changes are much more dramatic than any decadal changes discussed in AR6 and have had no adverse effects on humanity.

The atmosphere is a good place to measure weather changes, but not a good place to measure longer term climatic changes. Temperatures measured in the atmosphere, close to the surface, require large corrections, as described by Matthew Menne,[40] these "corrections" introduce uncertainty.[41] In many ways, sea surface temperature measurements have worse problems than land-based temperatures, as described by John Kennedy and colleagues.[42] Problems measuring nighttime marine temperatures are described by Robert Junod and John Christy.[43]

Measurement of changes in bulk ocean temperatures provide a better indicator of the extent of disequilibrium in the climate system. Unfortunately, only since about 2002-2005 have we had good data on ocean temperatures at the surface and at depth.[44] But, going forward, the ocean interior will be the best place to look for a long-term stable record of the radiative disequilibrium that drives climate change.

In answer to the questions posed at the beginning of the chapter, are the estimates of global temperature change in Figure 1 accurate and comprehensive enough to tell us how quickly Earth's entire surface, including the oceans, are warming? *No.* Is the global mean surface temperature a key indicator of climate change? *No*, the measurements used simply reflect local weather and environmental conditions and are affected by the chaotic conditions at the surface. And the total change recorded over the past century is too small relative to the basic measurement accuracy and natural climate variability.

39 Jones, P. D., New, M., Parker, D. E., Martin, S., & Rigor, I. G. (1999). Surface Air Temperature and its Changes over the Past 150 years. *Reviews of Geophysics, 37*(2), 173-199. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.546.7420&rep=rep1&type=pdf

40 Menne, M., & Williams, C. (2009a). Homogenization of Temperature Series via Pairwise Comparisons. *Journal of Climate, 22*(7), 1700-1717. Retrieved from https://journals.ametsoc.org/jcli/article/22/7/1700/32422

41 Scafetta, N. (2021, January 17). Detection of non-climatic biases in land surface temperature records by comparing climatic data and their model simulations. *Climate Dynamics*. Retrieved from https://doi.org/10.1007/s00382-021-05626-x

42 Kennedy, J. J., Rayner, N. A., Smith, R. O., Parker, D. E., & Saunby, M. (2011). Reassessing biases and other uncertainties in sea surface temperature observations measured in situ since 1850; 1. Measurement and sampling uncertainties. *Journal of Geophysical Research, 116*. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010JD015218 and Kennedy, J. J., Rayner, N. A., Smith, R. O., Parker, D. E., & Saunby, M. (2011b). Reassessing biases and other uncertainties in sea surface temperature observations measured in situ since 1850: 2. Biases and homogenization. *J. Geophys. Res., 116*. doi:10.1029/2010JD015220

43 Junod, R., & Christy, J. (2019, October 10). A new compilation of globally gridded night-time marine air temperatures: The UAHNMATv1 dataset. *RMetS, 40*(5). Retrieved from https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.6354

44 May, A. (2020e, November 27). *Ocean Temperature Update*. Retrieved from andymaypetrophysicist.com: https://andymaypetrophysicist.com/2020/11/27/ocean-temperature-update/

4 Controversial Snow Trends

BY CLINTEL TEAM

SUMMARY: Is there less and less snow due to global warming? The general public probably thinks this is the case. However, snow cover data in the Northern Hemisphere show a conflicting picture. In spring and summer a decline is visible, but the well-known Rutgers Data Lab shows an increase in autumn and winter. IPCC introduced a fresh new blended dataset in AR6 that changed the positive trend in the Rutgers dataset into a negative trend all year round. Is this new picture really the best available science or does it mainly demonstrate bias in the IPCC process?

Global temperature has increased by more than 1°C over the past 170 years. Intuitively one might think that a warmer climate would automatically lead to a reduced snow cover on the planet. Several climate scientists have therefore predicted that in some parts of the world, due to global warming, snow will be a thing of the past. But this idea is too simple, because presence or absence of snow on the ground is not just dependent on temperature but also on precipitation, wind and cloud cover. For example, it is little known that Antarctica and large parts of the Arctic are actually classified as so-called 'polar deserts', i.e. regions with limited precipitation (Fig. 1). Especially in the Arctic, an increase in precipitation may therefore easily boost the snow cover extent in this region and in the Northern Hemisphere.

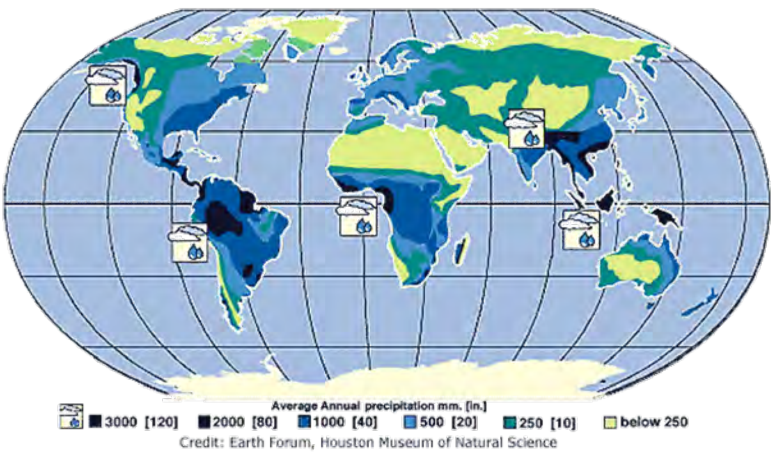


Figure 1: Average annual precipitation. Source: USGS, https://www.usgs.gov/media/images/generalized-world-precipitation-map

Snow Cover Extent in AR6

Chapter 2 of the IPCC's 6th climate assessment report (AR6)[1] reports the 'Changing state of the climate system' (IPCC, 2021). This includes a summary of changes in snow cover extent (SCE) for the Northern Hemisphere (NH). The chapter reveals that SCE trends for autumn and winter are unclear. Whilst NOAA data suggests an increase in SCE (e.g. Hernández-Henríquez et al., 2015), composite ensemble data claims a decrease (e.g. Mudryk et al., 2020). Quote from the AR6 report, sub-chapter 2.3.2.2, page 2-67 (our bold):

1 IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, 2021

"Analysis of the combined in situ observations (Brown, 2002) and the multi-observation product (Mudryk et al. 2020) indicates that since 1922, April SCE in the NH has declined by 0.29 million km² per decade, with significant interannual variability (Figure 2.22) and regional differences (Section 9.5.3.1). [...] ***Analysis using the NOAA Climate Data Record shows an increase in October to February SCE*** *(Hernández-Henríquez et al., 2015; Kunkel et al., 2016) while analyses based on satellite borne optical sensors (Hori et al., 2017) or* ***multi observation products (Mudryk et al., 2020) show a negative trend for all seasons*** *(section 9.5.3.1, Figure 9.23). The greatest declines in SCE have occurred during boreal spring and summer, although the estimated magnitude is dataset dependent (****Rupp et al., 2013; Estilow et al., 2015****; Bokhorst et al., 2016; Thackeray et al., 2016;* ***Connolly et al., 2019****)."*

Interestingly, the IPCC in chapter 2 only illustrates the decreasing trend for April (i.e. spring), where full agreement of all authors exist:

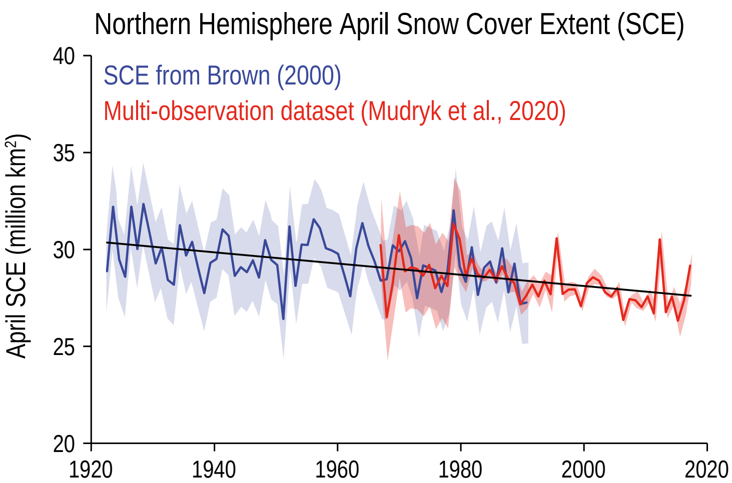


Figure 2: April snow cover extent (SCE) for the Northern Hemisphere. From: AR6, chapter 2.

The theme is being picked up again in Chapter 9 of AR6 (Ocean, cryosphere and sea level change). Here the IPCC authors add a judgment and explicitly favour the decreasing autumn SCE trend, because the increasing SCE trend could not be 'replicated' and is seen as somewhat 'anomalous'. The IPCC concludes: "There is therefore medium confidence that the NH SCE trend for the 1981-2016 period was also negative during these two months [October, November]". Quote from the AR6 report, sub-chapter 9.5.3.1, page 1281 (our bold):

"Compared to numerous studies on spring SCE changes, less attention has been paid to ***changes in NH snow cover during the onset period in the autumn****, a challenging period to retrieve snow information from optical satellite imagery due to persistent clouds and decreased solar illumination at higher latitudes.* ***Positive trends in October and November SCE in the NOAA-CDR*** *(Hernández-Henríquez et al., 2015)* ***are not replicated in other surface, satellite, and model datasets*** *(Brown and Derksen, 2013; Peng et al., 2013; Hori et al., 2017; Mudryk et al., 2017).* ***The positive trends from the NOAA-CDR are also inconsistent with later autumn snow-on dates since 1980*** *(-0.6 to -1.4 days per decade), based on historical surface observations, model-derived analyses and independent satellite datasets (updated from Derksen et al., 2017). Furthermore, the SCE trend sensitivity to surface temperature forcing in the NOAA-CDR* ***is anomalous*** *compared to other datasets during October and November (Mudryk et al., 2017). There is therefore* ***medium confidence that the NH SCE trend for the 1981-2016 period was also negative during these two months*** *(Mudryk et al., 2020)."*

The IPCC visually emphasizes their preference by replicating a figure from Mudryk et al. (2020) in the AR6 report:

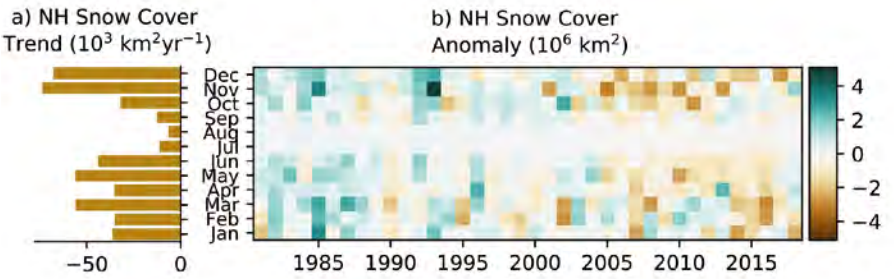


Figure 3: Snow cover extent (SCE) for the Northern Hemisphere. From: AR6, chapter 9, based on Mudryk et al. (2020).

The work of Mudryk et al. (2020)[2] is being explicitly praised by the AR6 authors:

> *"Since the SROCC,* ***progress in characterizing seasonal NH snow cover changes has been made through the combined analysis of datasets from multiple sources*** *(surface observations, remote sensing, land surface models and reanalysis products). A recent combined dataset (****Mudryk et al., 2020****) identified negative NH SCE trends in all months between 1981 and 2018, exceeding -50 × 10^3 km^2 yr^{-1} in November, December, March and May (Figure 9.23a,b)."*

Discrepancy with other studies

The AR6 report clearly favours studies that suggest a *reduction* in NH autumn and winter snow cover extent (SCE) trend. This is surprising because the world authority group on the topic arrives at a very different conclusion. On its website the Rutgers Global Snow Lab[3] provides time series for Northern Hemisphere snow cover extent, separately plotted for autumn, winter and spring. Whilst SCE is decreasing in spring (and summer), it is clearly increasing in autumn and winter in this dataset (Fig. 4).

Rutgers generates their time series based on the Northern Hemisphere SCE CDR v01r01 from the National Centers for Environmental Information (NCEI). The Rutgers Snow Lab data formed also the basis for a NH SCE analysis by Connolly et al. (2019).[4] Not surprisingly, the study found similar results as Rutgers themselves, i.e. an increase in SCE for the NH during autumn and winter (though statistically not significant), and a decrease in spring and summer.

The Rutgers SCE time series is 54 years long, and the one used by Mudryk et al. (2020) only 37 years. The drivers and attribution of the documented fluctuations in SCE are therefore hard to interpret. It is well known that the Northern Hemisphere climate is strongly influenced by Atlantic multidecadal variability (Wyatt et al., 2012).[5] The Atlantic Multidecadal Oscillation (AMO) has a cycle duration of 60-70 years, which is longer than the time series of the available data. For example, it cannot be ruled out that the increase in NH snow cover extent during autumn (Fig. 4) actually reflects the transition of a negative AMO (1965-1995) to a positive AMO (prevailing since late 1990s) (Fig. 5). Notably, multidecadal climate variability is not even addressed in Chapter 3 (Human influence on the climate system) of the AR6 (sub-chapter 3.4.2, pages 470-471).

It is unclear why the IPCC favours the more dramatic version of the NH SCE development, with a reduction in all four seasons. In part this may be related to the fact that the first author of Mudryk et al. (2020), Lawrence Mudryk, is a Contributing Author to chapter 2 of AR6, in which the SCE trends

2 Mudryk, L., Santolaria-Otín, M., Krinner, G., Ménégoz, M., Derksen, C., Brutel-Vuilmet, C., Brady, M., and Essery, R., 2020, Historical Northern Hemisphere snow cover trends and projected changes in the CMIP6 multi-model ensemble: The Cryosphere, v. 14, no. 7, p. 2495-2514.

3 Rutgers Global Snow Lab. „Northern Hemisphere Seasonal Snow Cover Extent." *https://climate.rutgers.edu/snowcover/chart_seasonal.php?ui_set=nhland&ui_season=1* (2022).

4 Connolly, R., Connolly, M., Soon, W., Legates, D. R., Cionco, R. G., and Velasco Herrera, V. M., 2019, Northern Hemisphere Snow-Cover Trends (1967–2018): A Comparison between Climate Models and Observations: Geosciences, v. 9, no. 3, p. 135.

5 Wyatt, M. G., Kravtsov, S., and Tsonis, A. A., 2012, Atlantic Multidecadal Oscillation and Northern Hemisphere's climate variability: Climate Dynamics, v. 38, no. 5-6, p. 929-949.

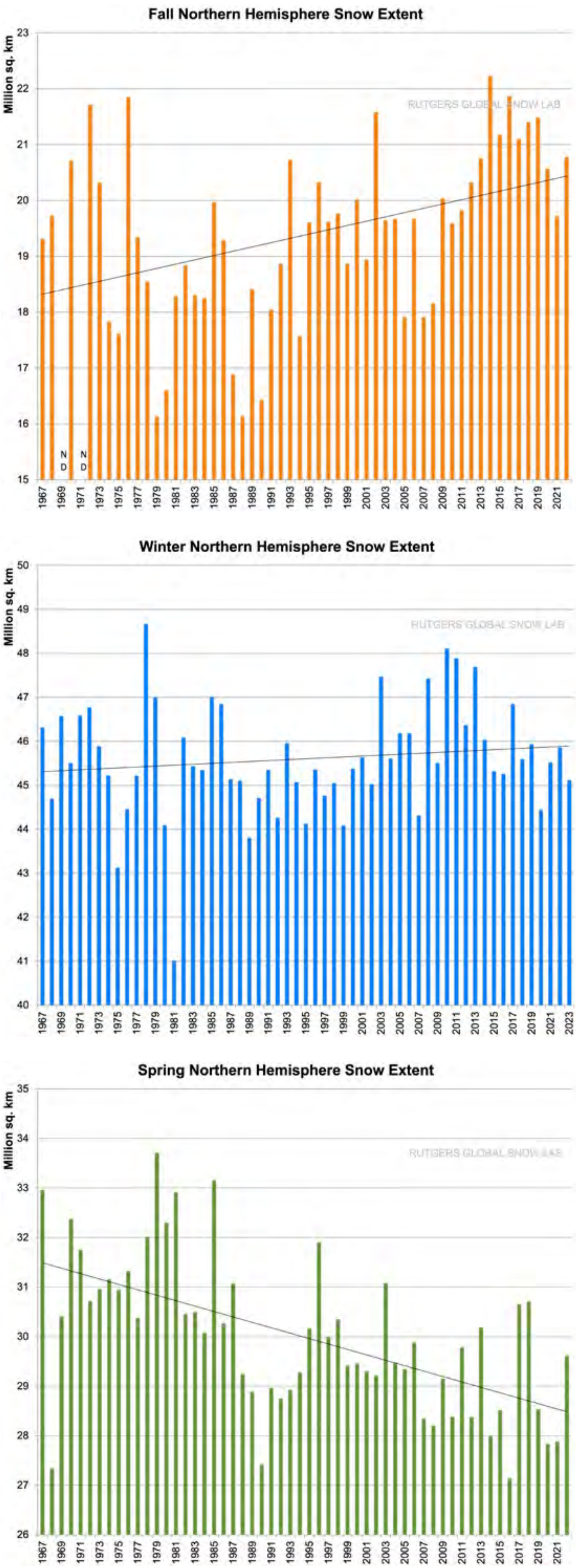


Figure 4: Snow cover extent (SCE) for the Northern Hemisphere for autumn, winter and spring. From: Rutgers Global Snow Lab (2023)

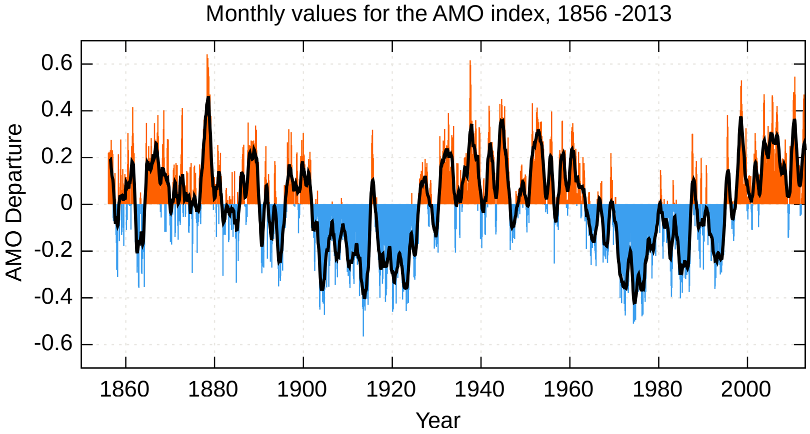


Figure 5: Development of the Atlantic Multidecadal Oscillation (AMO). Source: Wikipedia.

are evaluated. It appears that Mudryk may have favoured his own work over that of Rutgers Global Snow Lab. The lead researcher of Rutgers, David A. Robinson, has been co-author in two papers briefly cited in Chapter 2 of AR6, namely Rupp et al. (2013)[6] and Estilow et al. (2015).[7] However, the two papers are only mentioned in passing in AR6, without a serious attempt to discuss the different results of Rutgers. David A. Robinson was *not* among the authors of AR6, hence did not have the chance to influence the decision on which school of thought to promote in AR6.. On the other hand, Lawrence Mudryk is employed by Environment and Climate Change Canada, the department of the Government of Canada responsible for coordinating environmental policies and programs. A political influence can therefore not be excluded in his research. The author of this article contacted Lawrence Mudryk to better understand the differences in NH SCE trends. Unfortunately, the email remained unanswered by the time of the editorial deadline for this Clintel report.

Statistical issues in Mudryk et al. 2020

Mudryk et al. (2020) produced a new time series of historical Northern Hemisphere snow extent anomalies and trends based on an ensemble of 'six observation-based products'. However, in their table 1, Mudryk et al. (2020) show seven, not six, products. Three are actual observational data. Two are models driven by reanalysis model output, one is an index based on gridded, observed, and reconstructed daily snow depth back to 1922, and one is a reanalysis model. So the composite contains a significant model component that is not purely observational.

Mudryk et al. (2020) do not illustrate the 6 (or 7) individual data products separately, which should have been done in light of transparency. It is therefore not possible to evaluate which of the various datasets actually dominates the final ensemble composite, whether they all agree, or differ greatly from each other. As a consequence, the origin of the new NH SCE composite time series remains a black box. Whilst data are provided by Mudryk et al. (2020) for download[8], few researchers will have the time and motivation to thoroughly evaluate this.

Mudryk et al. (2020) also fail to address the hot topic of autocorrelation, which is a huge and generally overlooked issue in natural datasets. Such datasets tend to be strongly autocorrelated, with major effects on the calculation of uncertainty. Mudryk et al. (2020) made no attempt to adjust for that. Typically, a probability is calculated for the case of a random time series showing a trend. A usual threshold of trends becoming statistically significant is $p<0.05$. Hence, probability values greater than 0.05 bear a greater risk of autocorrelation. Due to the high number of 12 monthly individual data series, multiple comparisons are made. The statistical significance criteria for

6 Rupp, D. E., Mote, P. W., Bindoff, N. L., Stott, P. A., and Robinson, D. A., 2013, Detection and Attribution of Observed Changes in Northern Hemisphere Spring Snow Cover: Journal of Climate, v. 26, no. 18, p. 6904-6914.

7 Estilow, T. W., Young, A. H., and Robinson, D. A., 2015, A long-term Northern Hemisphere snow cover extent data record for climate studies and monitoring: Earth Syst. Sci. Data, v. 7, no. 1, p. 137-142.

8 https://doi.org/10.18164/cc133287-1a07-4588-b3b8-40d714edd90e

such a group of 12 data series can be further tightened. The rational: The greater the number of data series, the greater the chance of trends occurring by chance. It would have been beneficial if Mudryk et al. (2020) had considered the Bonferroni Correction (BC), a method that corrects for the increased error rates when hypotheses are tested with multiple comparisons.

Figure 7 was provided by Willis Eschenbach and shows the NH SCE trends of the blended dataset of Mudryk et al. (2020) separately for all 12 months. The figure also shows the p values taking both autocorrelation and BC into account. The relevant threshold here is 0.05/12 = 0.004. Only five out of the 12 months of the Rutgers dataset have p values below the combined threshold (marked in red in Fig. 6). These are the months in which the trends can be safely considered statistically significant. This, however, does not rule out that other real trends exist, as this test is on the conservative side. Reviewers of Mudryk et al. (2020) should have picked up the autocorrelation analysis issues, which could have led to the rejection of the paper.

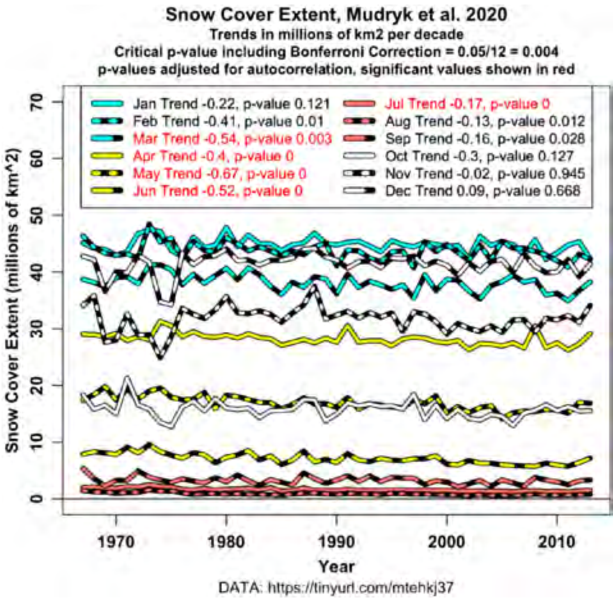


Figure 6: Trends of the new blended NH SCE Mudryk dataset for each month with p-values of trends (autocorrelation and Bonferroni Correction). The figure was prepared by Willis Eschenbach.

To further appreciate how small the differences are, it is also insightful to look at the full year round data from the Rutgers Snow Lab.

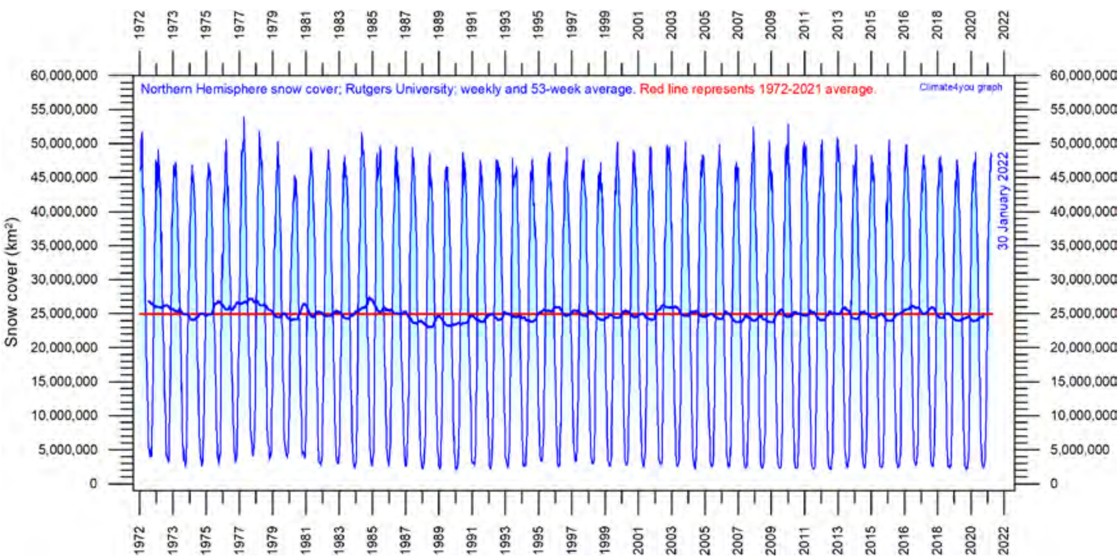


Figure 7: Northern hemisphere weekly snow cover since January 1972 according to the Rutgers University Global Snow Lab (http://climate.rutgers.edu/snowcover), the thin blue line is the weekly data, and the thick blue line is the running 53 week average (approximately 1 year). The horizontal red line is the 1972-2021 average. Last week shown: week 1 in 2022. Last figure update: 11 January 2022. Source: Ole Humlum, climate4you.com

In winter, Northern Hemisphere snow cover can reach values of 50 million km^2. Mudryk et al. (2020) now claims a decline in winter in the order of 50 thousand km^2/year. That is a change of 0.1%/year. Given the apparent variability between different datasets you wonder if such changes can really be detected, let alone attributed to human causes.

Comparison with climate models

In Chapter 9 (Ocean, cryosphere and sea level change) the IPCC suggests that the snow cover extent that was simulated by climate models generally matches well with 'observations' as published by IPCC chapter 2 co-author Lawrence Mudryk and colleagues. Quote from sub-chapter 9.5.3.2, page 1286 (our bold):

> "*Analysis of the available CMIP6 historical simulations for the 1981-2014 shows that on average,* ***CMIP6 models simulate well the observed SCE (Mudryk et al., 2020), except for outliers and a median low bias during the winter months*** *(Figure 9.24a). This is an improvement over CMIP5 (Mudryk et al., 2020), in which many snow-related biases were linked to inadequacies of the vegetation masking of snow cover over the boreal forests (Thackeray et al., 2015). A comparison between CMIP5 and CMIP6 results (Mudryk et al., 2020) shows that there is no notable progress in the quality of the representation of the observed 1981-2014 monthly snow cover trends.*"

However, the conclusion would be very different, if the purely observational data (without major modeling input) of Rutgers Global Snow Lab was considered as reference. Connolly et al.[9] showed that climate models cannot replicate the increasing trend in the Rutgers dataset in the fall and winter.

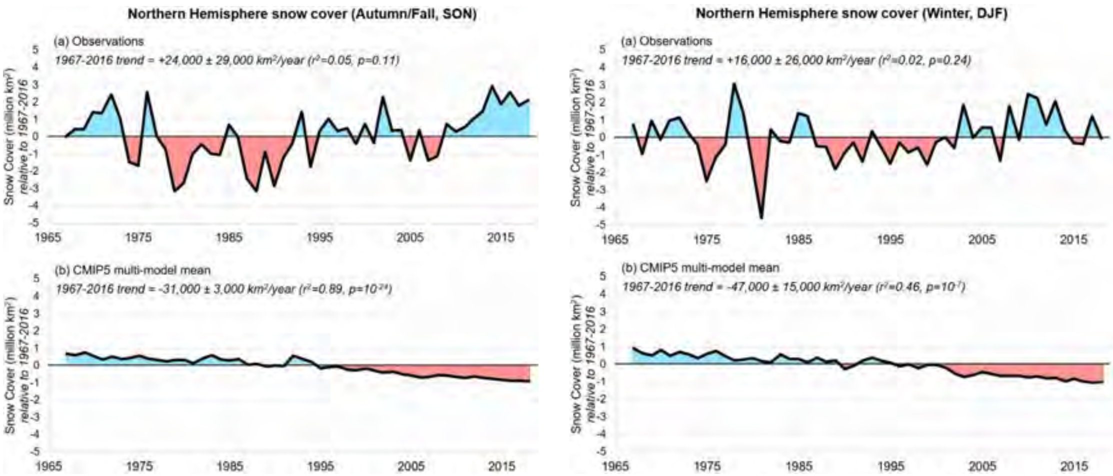


Figure 8: Northern Hemisphere snow cover in Autumn/Fall and winter. Top panel: observations based on the Rutgers Snow Lab data. Bottom panel: based on CMIP5 simulations. Source of the figure: Connolly et al. (2019).

The authors observe that:

> *"None of the current computer models can explain why snow cover might have increased in recent years."*

We note that the Connolly paper is mentioned in the chapter in the following way:

> *"The greatest declines in SCE have occurred during boreal spring and summer, although the estimated magnitude is dataset dependent (Rupp et al., 2013; Estilow et al., 2015; Bokhorst et al., 2016; Thackeray et al., 2016;* ***Connolly et al., 2019****)."*

To highlight Connolly et al. (2019) in this way is misleading. Yes, it also showed the decline in SCE in spring and summer, but the main message of the paper was that climate models can't reproduce

9 Connolly, et al., 2019, Northern Hemisphere Snow-Cover Trends (1967-2018): A Comparison between Climate Models and Observations, Geosciences, 9, 135, doi:10.3390/geosciences9030135

the increasing trend in Autumn/Fall and Winter. AR6 failed to acknowledge this. Are the AR6 authors favouring the results of Mudryk et al. (2020) over those of Rutgers Global Snow Lab because of a better model fit?

CMIP6 climate models also fail to correctly reproduce Northern Hemisphere snow depth trends (Zhong et al., 2022).[10] The simulations suggest decreasing snow depth trends for the last 70 years that contradict the observations. The study of Zhong et al. (2022) revealed that the simulated snow depths are insensitive to precipitation but too sensitive to air temperature. These inaccurate sensitivities could explain the discrepancies between the observed and simulated snow depth trends. Based on these findings, they recommend caution when using and interpreting simulated changes in snow depth and associated impacts. The CMIP6 models may require more detailed and comprehensive treatments of snow physics to more accurately project snow cover.

Discussion

What physical processes could explain the positive NH SCE trends of Rutgers for autumn and winter? Allchin and Déry (2020)[11] have suggested that the changes might be a result of alterations in atmospheric patterns. Today, these patterns during autumn are delivering additional moisture northward to high latitude interior continental areas, where it is cold enough for snow to form. In previous decades, however, these "Arctic deserts" appear to have received less moisture, resulting in reduced snow cover.

IPCC REPORTING

The trends in Northern Hemisphere snow cover extent are just one of many examples of biased reporting in the IPCC AR6 report. The outcome of the assessment is largely decided at the time when report authors are nominated. In this case, the lead author of a key paper, Lawrence Mudryk, was nominated as contributing IPCC author and most likely influenced the direction of the IPCC literature review in his own favour. The Second Order Draft (the last draft that is seen by external/expert reviewers) already showed the results of the Mudryk et al. (2020) paper although that paper at the time had only been submitted to the journal. This is not forbidden under the IPCC rules, however it is clear that this favours the promotion of authors' and lead authors' own work. Also, no (or very few) expert reviewers will go to the effort to ask for the submitted paper so one can safely conclude that these results were not reviewed before they entered as the key claim surrounding snow cover trends in the AR6 report.

IPCC author nominations are typically initiated (at the upper levels, then cascading down) by the IPCC Bureau, a politically-controlled body of all IPCC member states. Lawrence Mudryk is employed by a Canadian government-related institute responsible for coordinating environmental policies and programs. The current Canadian Minister of Environment and Climate Change, Steven Guilbeault, was previously a Director and Campaign Manager for Greenpeace. The case demonstrates the importance of strictly separating science from policy. IPCC author nominations need to be done by politically-independent *scientific* bodies, not by *government*-related panels.

Acknowledgements

We want to thank Willis Eschenbach for contributions on the statistical processing. David Robinson and Nicholas Pepin are thanked for valuable discussions. We are grateful for valuable comments received from two anonymous reviewers.

10 Zhong, X., Zhang, T., Kang, S., and Wang, J., 2022, Snow Depth Trends from CMIP6 Models Conflict with Observational Evidence: Journal of Climate, v. 35, no. 4, p. 1293-1307

11 Allchin, M. I., and Déry, S. J., 2020, The Climatological Context of Trends in the Onset of Northern Hemisphere Seasonal Snow Cover, 1972–2017: Journal of Geophysical Research: Atmospheres, v. 125, no. 17, p. e2019JD032367

5

Accelerated Sea Level Rise: not so fast

BY KIP HANSEN

The IPCC's Sixth Assessment Report (AR6) claims that sea level rise is accelerating. However, the evidence for this is rather thin. The best available evidence for long-term sea level changes comes from tide gauge records. These records typically show remarkably linear behavior for more than a century.

Tide gauges around the world on average show a long term rise of about 1.7 mm/yr while satellite records since 1993 indicate double that rate, around 3.4 mm/yr. Tide gauges directly measure local sea surface height whereas satellite telemetry calculations measure something different, the eustatic sea level. IPCC's accelerating sea level rise seems to rely on "hybrid reconstructions" that combine these disparate datasets and often include modeled data. [1,2]

The IPCC's AR6 makes the following specific claims about present and future global mean sea level (GMSL) rise:

> *"Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018.*
> ***The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr^{-1} between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr^{-1} between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr^{-1} between 2006 and 2018** (high confidence)…."*
> *A.1.7, page SPM-5, Summary for Policymakers IPCC AR6 WGI*
> *(Final Version)*[3]

> *"The SROCC found that four of the five available tide gauge reconstructions that extend back to at least 1902 showed a robust acceleration (high confidence) of GMSL rise over the 20th century, with estimates for the period 1902-2010 (-0.002 to 0.019 mm yr^{-2}) that were consistent with the AR5."*
> *Chapter 9, page 1287 (Final Version)*[4]

The increase of sea level during the past 200 years does not come as a surprise. Sea level was falling in the transition from the Medieval Warm Period (MWP, 850-1250 AD) to the Little Ice Age (LIA, 1450-1850 AD) as large amounts of water were taken up by glaciers and ice caps (Fig. 1).[5] The LIA represents one of the coldest phases of the entire last 10,000 years. After the LIA ended, glaciers and ice caps began to melt again and released water that ended up in the oceans, resulting in rising sea level.[6]

However, the recent further acceleration claimed by the AR6 coincides largely with the switch from pure tide gauge data to satellite data that became available only since 1992. Uncertainties in the calibration of the satellite results and discrepancies with synchronously recording tide

1 Sea Level Research Group University of Colorado https://sealevel.colorado.edu/presentation/what-definition-global-mean-sea-level-gmsl-and-its-rate

2 Rovere, A., Stocchi, P. & Vacchi, M. Eustatic and Relative Sea Level Changes. *Curr Clim Change Rep* 2, 221–231 (2016). https://doi.org/10.1007/s40641-016-0045-7

3 IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

4 IPCC AR6 Chapter 9 p. 1287 https://www.ipcc.ch/report/ar6/wg1/

5 Kopp, R. E., Kemp, A. C., Bittermann, K., Horton, B. P., Donnelly, J. P., Gehrels, W. R., Hay, C. C., Mitrovica, J. X., Morrow, E. D., Rahmstorf, S. (2016): Temperature-driven global sea-level variability in the Common Era: Proceedings of the National Academy of Sciences 113 (11), E1434-E1441.

6 Grinsted, A., Moore, J. C., Jevrejeva, S. (2010): Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD: Climate Dynamics 34 (4), 461-472

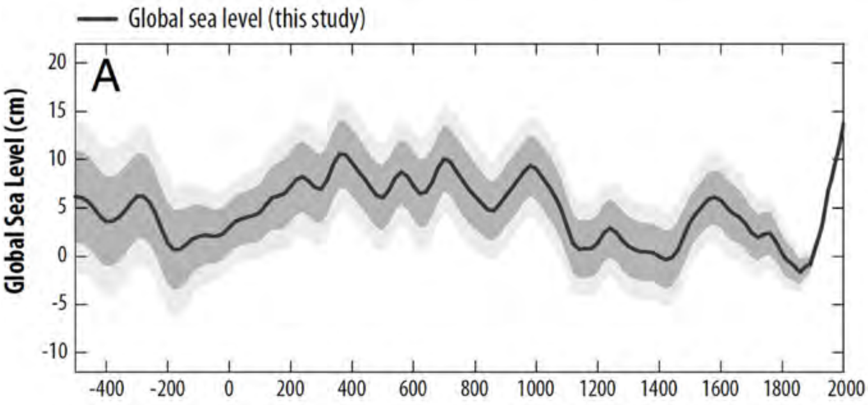


Figure 1: Global sea level reconstruction by Kopp et al. 2016.[5] X-axis shows years BC (negative)/AD (positive values).

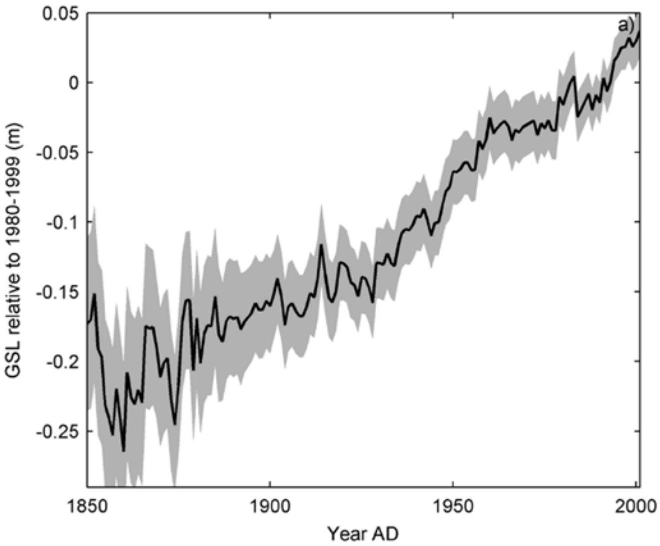


Figure 2: Global sea level reconstruction by Grinsted et al. 2010.[6] Sea level rose more slowly in the decades after the LIA from 1860 to 1940. As the subsequent warm period developed, sea level rose more quicky from mid-20th century onwards.

gauges suggests that at least part of the acceleration may in fact be an artefact due to the change in methodology.

During the 20th century, global sea level rose about 20 cm, at a rate, according to U.S. NOAA, of 1.7 mm/yr (+/- 0.4 mm). Other estimates and reconstructions are all just under 2.0 mm/yr. NOAA's rate is based on tide gauges[7] that directly measure local Relative Sea Level (RSL) – the height of the surface of the ocean relative to the land at the tide gauge location. "RSL is a combination of the sea level rise and the local Vertical Land Motion (VLM)."[8] In order to discover how much of RSL is *actual rise* in the height of the sea surface, which is known as *absolute* sea level (ASL)[9], and not sinking (or subsidence) of the land, tide gauges must be coupled to Continuously Operating Reference Stations (CORS) mounted on the same structure as the tide gauge. This is called Continuous Global Positioning System at Tide Gauges (CGPS@TG).

It is not possible to simply average global tide gauge records and determine a global figure for sea level rise unless these records have all been corrected for vertical land motion, which will not be possible until there are an adequate number of widespread CGPS@TG stations. U.S. NASA records a different metric for global mean sea level which it obtains through remotely sensed satellite telemetry.[10] Since 1993, NASA finds the change in their global mean sea level (GMSL) metric rising

7 Manual on Sea Level Measurement and Interpretation. https://library.wmo.int/doc_num.php?explnum_id=932

8 NOAA Tides and Currents https://tidesandcurrents.noaa.gov/sltrends/

9 CGPS@TG Working Group of the Sea Level Center at the University of Hawaii https://imina.soest.hawaii.edu/cgps_tg/introduction/index.html

10 NASA Earth Observatory https://earthobservatory.nasa.gov/images/147435/taking-a-measure-of-sea-level-rise-ocean-altimetry

at a rate of 3.4 mm/yr. Satellite GMSL however is not a measurement of the height of the surface of the oceans, but rather:

> *"It can also be thought of as the 'eustatic sea level.' The Eustatic Sea Level [ESL] is not a physical sea level (since the sea levels relative to local land surfaces vary depending on land motion and other factors), but it represents the level* ***if all of the water in the oceans were contained in a single basin****."*[11] *(emphasis added)*

This is important because all the oceans are not at the same level or height, for example at the Panama Canal, sea level is 20 cm higher on the Pacific side than on the Atlantic side.[12]

The IPCC's AR6 claims that sea level rise has been accelerating, or rising faster and faster.[13] More specifically, the IPCC says that:

> ***"four of the five available tide gauge reconstructions that extend back to at least 1902 showed a robust acceleration (high confidence) of GMSL rise over the 20th century****, with estimates for the period 1902-2010 (-0.002 to 0.019 mm yr–*^{2}*)" (AR6, page 1287, emphasis added)*

Five sea level research groups did *reconstructions* of the uncorrected global tide gauge data. One of the five groups found **no acceleration**. Four of the five groups found some acceleration of SLR over the 20th century. Their estimates of SLR acceleration range from 2/1000ths to 2/100ths of a millimeter/yr^2. An acceleration of 2/1000ths of a mm/yr^2, for a century, raises sea level by less than an inch (2.54 cm), not a very "robust" finding. An acceleration of 2/100ths of a mm/yr^2 over a century results in an additional 10 cm of sea level rise. Here is what a sea level graph would look with and without these two rates of acceleration over a century:

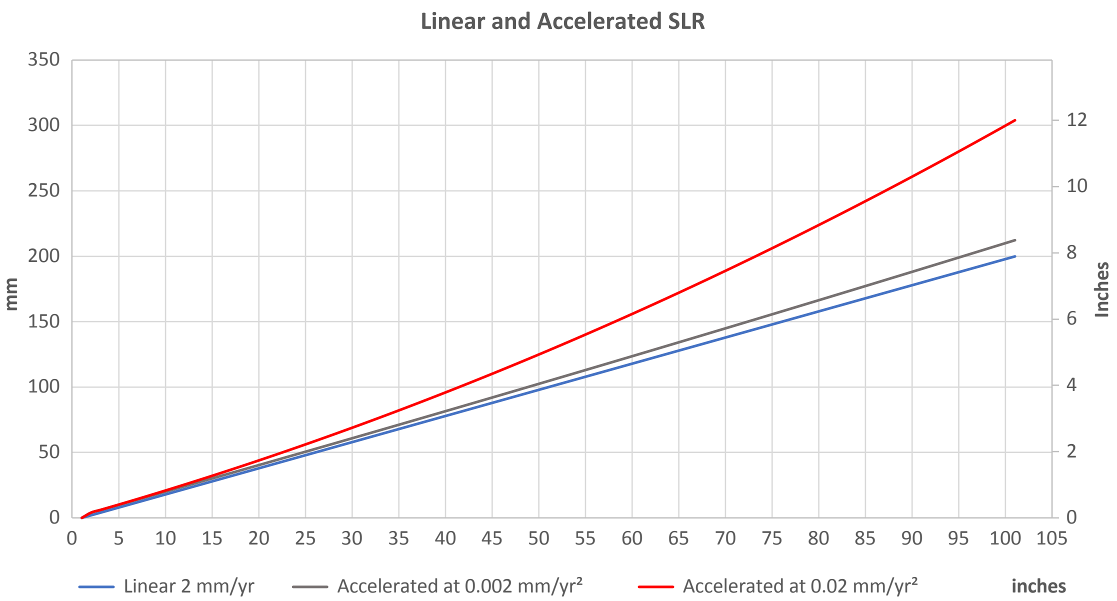


Figure 3: Linear increase (blue trace) at 2 mm/yr produces a straight line. Adding 0.002 mm/yr^2 (black trace) and 0.02 mm/yr^2 (orange trace) produce upward curving lines. End points on right show resulting increase in sea level after 100 years.

We see that the accelerating sea level produces a curved trend, while the steady sea level rise produces a trend that is straight. Here are the two graphs shown in the AR6 report:

11 Sea Level Research Group University of Colorado What is the definition of global mean sea level (GMSL) and its rate? | Sea Level Research Group (colorado.edu). Rovere, A., Stocchi, P. & Vacchi, M. Eustatic and Relative Sea Level Changes. *Curr Clim Change Rep* 2, 221–231 (2016). https://doi.org/10.1007/s40641-016-0045-7

12 Reid, Joseph, 1961, On the temperature, salinity, and density differences between the Atlantic and Pacific oceans in the upper kilometre - ScienceDirect

13 IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

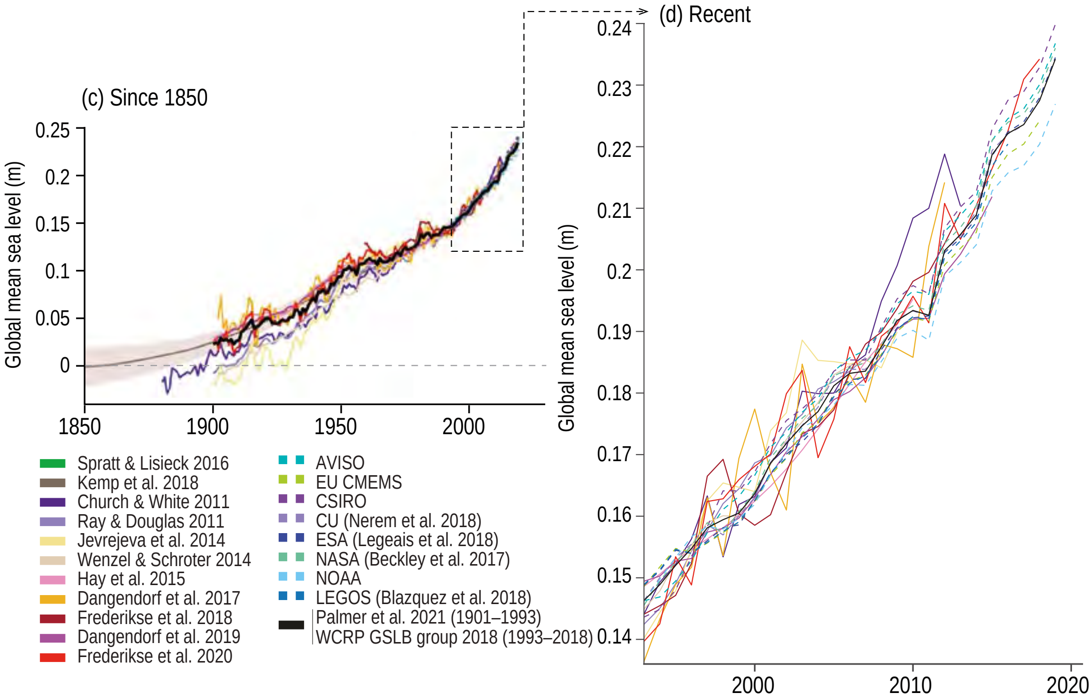


Figure 4: Sea level rise since 1850 and over the satellite era – 1993 to present. Figure 2.28 C and D in AR6, page 354.

This graph reminds us of the so-called spaghetti graphs that are used in millennial proxy reconstructions. The graph shows different data sets and mixes them together. Especially since the satellite era started, the different lines are pretty close to one another, strongly suggesting that reconstructions based on tide gauges confirm the higher satellite trend of 3 mm/yr. In the supplementary material the IPCC is apparently making the data available. But when we checked recently only two out of the twenty datasets were available. Only a few datasets are based on tide gauges (Church & White 2011, Ray & Douglas 2011, Jevrejeva et al 2014) and these datasets end around 2010 in the IPCC graph. But what is not shown is that these tide gauge measurements typically show multidecadal phases of acceleration and deceleration as is shown in the following figure:

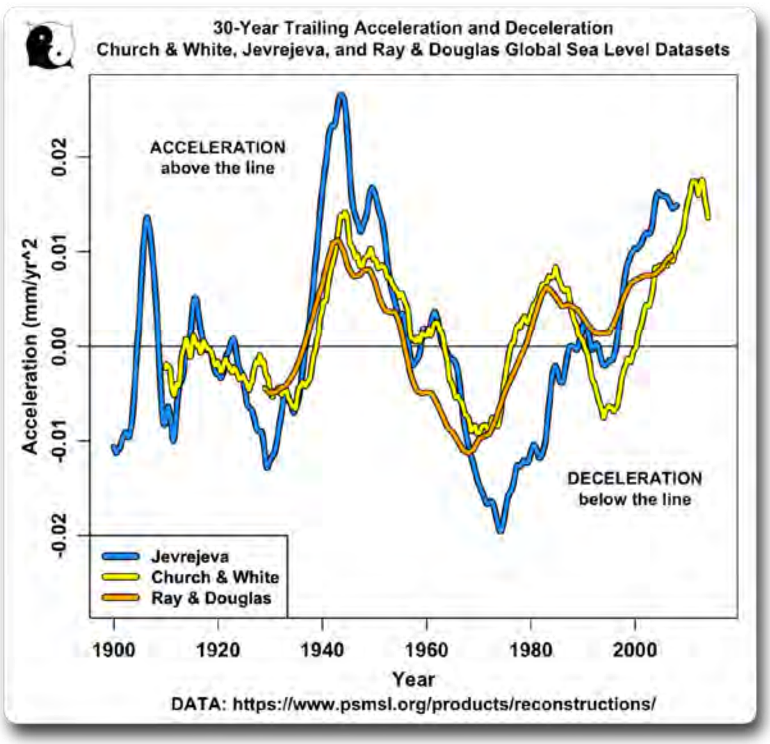


Figure 5: sea level acceleration and deceleration in three tide gauges datasets. Source: Willis Eschenbach

If the IPCC had mentioned the period 1940 to 1980 separately, they then should have mentioned a decreasing rate of sea level rise. The yellow and blue reconstructions show early signs of another period of deceleration, which you would expect based on the historical patterns. The Frederikse et al 2020 paper[14] that is part of the IPCC graph above did show these decadal fluctuations:

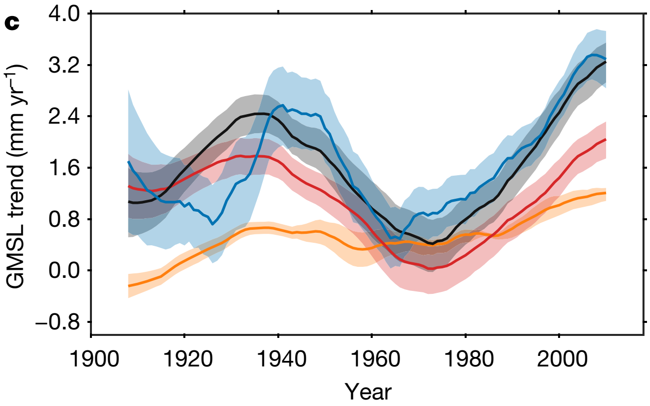


Figure 6: sea level trend based on a so-called sea level budget method as used in Frederikse et al 2020. The thick blue line is the observed trend and black is based on the sum of different components.

Many researchers have cautioned that sea level is associated with natural cycles with a duration of ~60 years.[15] It is possible that the acceleration is actually part of this natural cyclicity.

Relative sea level

As mentioned, tide gauges directly measure relative sea level at a single location. The illustration in Figure 7 shows the three components of local relative sea level: vertical land motion of the regional land mass, subsidence of the tide gauge structure – such as a pier or a dock – and absolute sea level rise, the actual rising of the height of the surface of the sea. Added together they produce

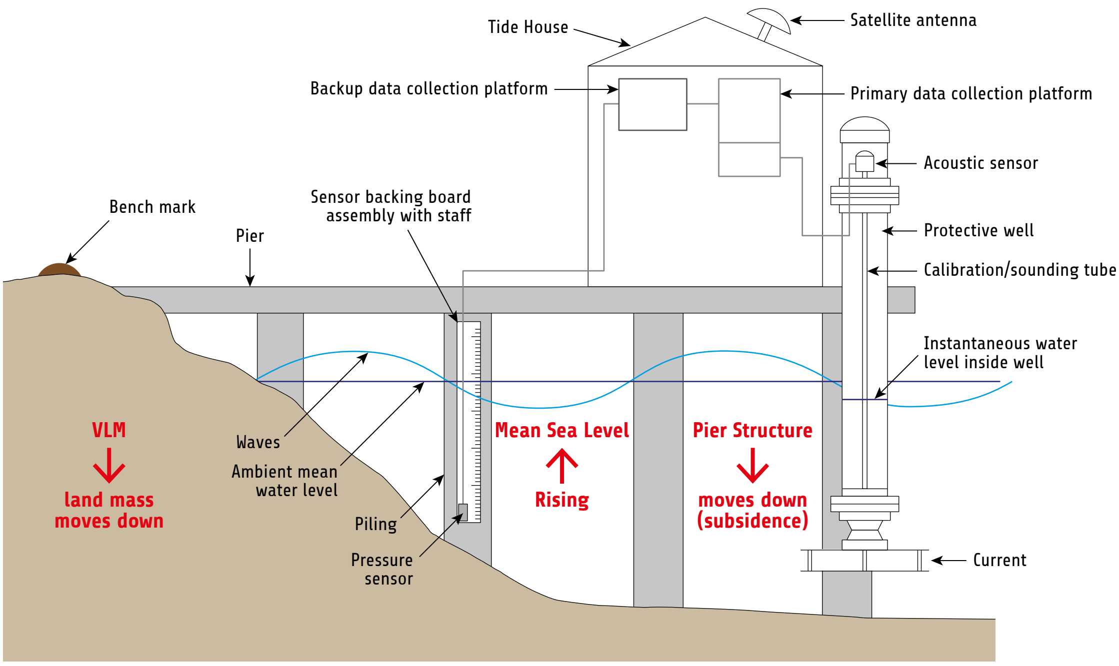


Figure 7: Typical modern tide gauge installation with components which contribute to measured Relative Sea Level rise (RSL).

14 Frederikse, T., Landerer, F. C., Caron, L., Adhikari, S., Parkes, D., & Humphrey, V. (2020). The causes of sea-level rise since 1900. Nature, 584, 393-397. Retrieved from https://www.nature.com/articles/s41586-020-2591-3

15 Ding, H., Jin, T., Li, J., & Jiang, W. (2021). The contribution of a newly unraveled 64 years common oscillation on the estimate of present-day global mean sea level rise. Journal of Geophysical Research: Solid Earth, 126, e2021JB022147. https://doi.org/10.1029/2021JB022147

the change measured by the tide gauge. The local tides, usually two highs and lows a day, can easily be averaged out to find a mean sea level for each day, week, month, and year.

The values are the mean relative sea level for that location. Figure 7 shows the graph of The Battery at New York City, USA.

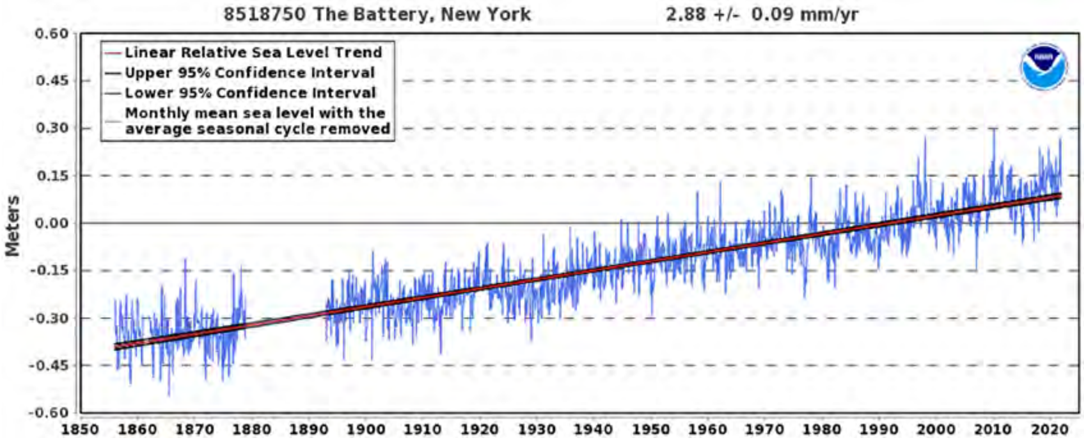


Figure 8: Sea Level trend graph from U.S. NOAA for The Battery at New York City. Linear across the entire 165-year record showing no acceleration.

Though it is highly variable, the graph is clearly linear – showing no acceleration over the entire 165-year record. This is directly measured data, not remotely sensed, and calculated.

Global sea level rise trends are highly variable, changing rates, and even direction decade by decade as the graph from Frederikse et al. shows. And, while it is easy to pick out decades with faster rise and fall, overall, the picture presented by long-term tide gauge records is clear.

The tide gauge record for NY City exhibits a steady rise of just under 3 mm/yr, including the downward vertical land motion which accounts for more than half of the relative sea level.[16]

Countering the IPCC's opinion that they have calculated "a robust acceleration (high confidence) of GMSL rise over the 20th century", are the directly measured, long-term (>50 years) tide gauge records all over the world which show the same linear trends, unaffected by acceleration, neither slowing down nor speeding up. Graphs of these tide gauge records can be found for U.S. and global tide gauges at NOAA's Tides and Currents web site.[17]

In another paper in 2016, Thompson et al.[18] provide the chart illustrating the consistency of relative sea level trends at tide gauges internationally, shown in Figure 9.

The mean of relative sea level trends before correction for vertical land motion is 1.69 mm/yr, very close to NOAA's 1.7 mm/yr, and when corrected, gives an estimate of absolute sea level rise trends, of 1.57 mm/yr.

The only sea level rise of any real concern for mankind is relative sea level at our shorelines, our ports and our cities. Relative sea level, averaged for all 149 U.S. NOAA tide stations and uncorrected for vertical land motion, is 2.01 mm/yr and for all of NOAA's global tide stations, it is 1.4 mm/yr.

16 Snay, Richard, et al. "Using global positioning system-derived crustal velocities to estimate rates of absolute sea level change from North American tide gauge records." Journal of Geophysical Research: Solid Earth 112.B4 (2007). https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2006JB004606

17 For U.S. stations: https://tidesandcurrents.noaa.gov/sltrends/sltrends_us.html and for global stations: https://tidesandcurrents.noaa.gov/sltrends/sltrends_global.html

18 Thompson, P. R., et al. "Are long tide gauge records in the wrong place to measure global mean sea level rise?." Geophysical Research Letters 43.19 (2016): 10-403. https://doi.org/10.1002/2016GL070552

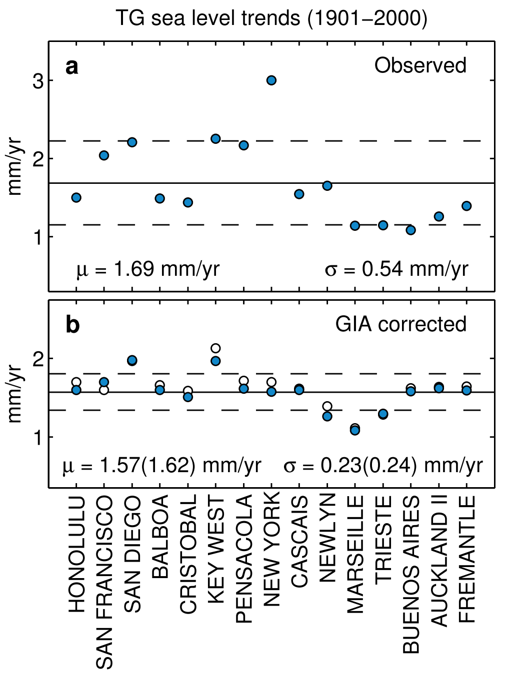


Figure 1. Least squares linear sea level trends during 1901 – 2000. (a) Observed. (b) Corrected for glacial isostatic adjustment (GIA) using the ICE-6G VM5a (blue) and ICE-5G VM2 (white). Solid and dashed lines in both panels represent the mean and 1σ range, respectively. In Figure 1b, the lines correspond to the ICE-6G VM5a correction; values for the mean and standard deviation using the ICE-5G VM2 correction are given in parentheses.

Figure 9: Tide gauge records from around the world show an uncorrected average rate of SLR of 1.69 mm/yr and a rate of 1.57 mm/yr when corrected for VLM. Contradicting the 3.4 mm/yr found by satellites.

Absolute sea level rise

Absolute sea level rise, the actual increase in height of the sea surface, is much smaller than the value derived from tide gauge records corrected for vertical land motion by NOAA's network.[19] Snay et al. (2007)[20] found the average absolute sea level for its 37 corrected U.S. tide stations to be 1.28 mm/yr. Snay et al. (2016)[21] gives an average of vertical land motion for all 1289 CORS stations of minus 1.68 mm/yr – that is downward land movement.

All-in-all, vertical land movement is of the same magnitude as the actual increase in absolute sea level when directly measured by CGPS-corrected tide gauges[22] at places of interest to mankind. That measured increase in the height of the sea surface is found to be far less than 2 mm/yr, and not the 3.4 mm/yr reported for the conceptual eustatic sea level from satellite altimetry. Tide gauge records do not show any acceleration in the rate of either relative sea level or absolute sea level.

Mankind's ports, cities, and seashores have thrived despite the sea level rise of the last century, which in many cases has been ignored. That same slow and steady aspect of global sea level rise and continuing advances in technology make adaptation to future sea level rise eminently possible.

19 NOAA CORS Network (NCN) https://geodesy.noaa.gov/CORS/index.shtml

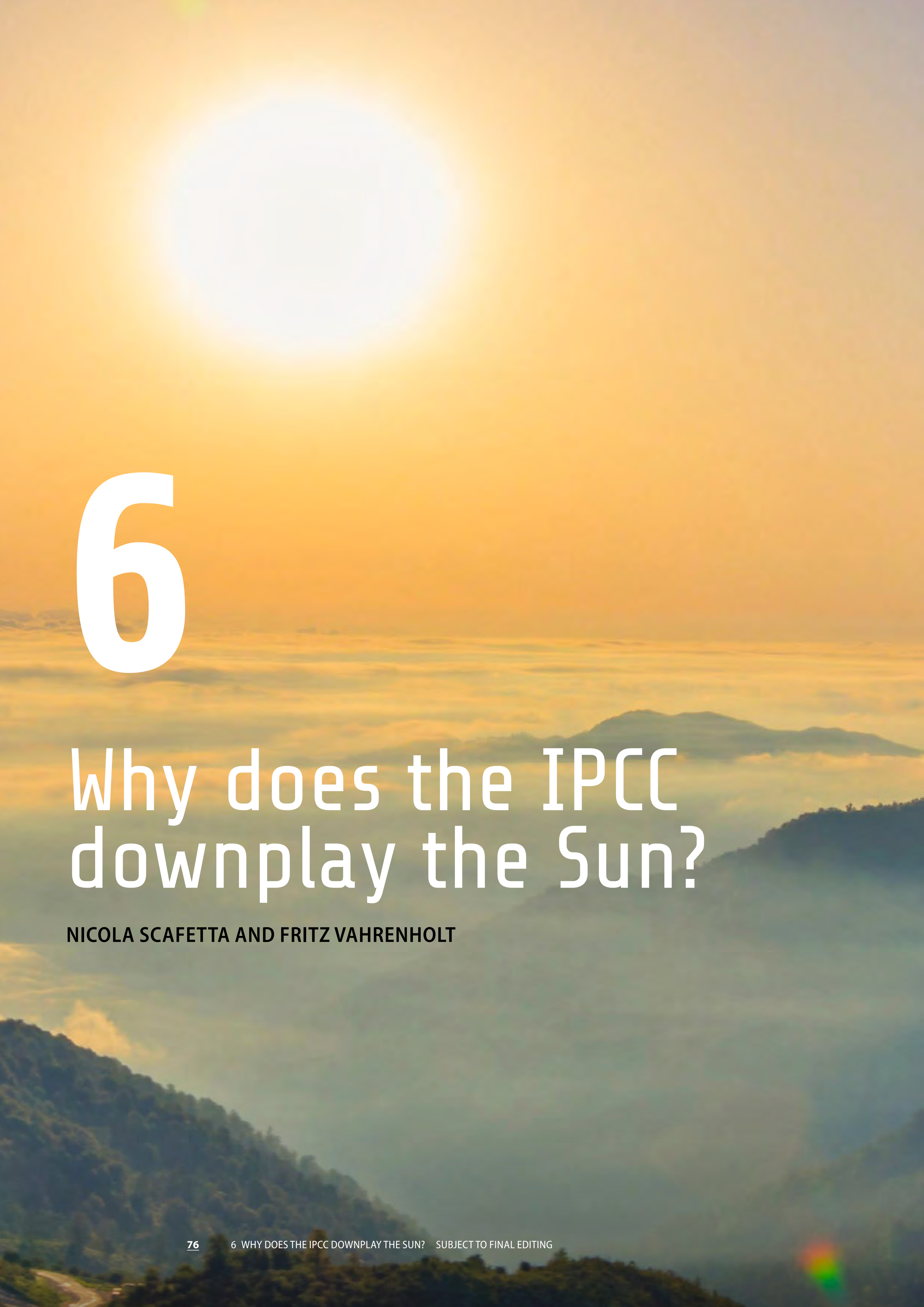
20 Snay, Richard, et al. "Using global positioning system-derived crustal velocities to estimate rates of absolute sea level change from North American tide gauge records." Journal of Geophysical Research: Solid Earth 112.B4 (2007). https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2006JB004606

21 Saleh, Jarir, Yoon, Sungpil, Choi, Kevin, Sun, Lijuan, Snay, Richard, McFarland, Phillip, Williams, Simon, Haw, Don and Coloma, Francine. "1996–2017 GPS position time series, velocities and quality measures for the CORS Network" Journal of Applied Geodesy, vol. 15, no. 2, 2021, pp. 105-115. https://doi.org/10.1515/jag-2020-0041

22 CGPS@TG Working Group of the Sea Level Center at the University of Hawaii https://imina.soest.hawaii.edu/cgps_tg/introduction/index.html

B

Causes of Climate Change



6

Why does the IPCC downplay the Sun?

NICOLA SCAFETTA AND FRITZ VAHRENHOLT

Hardly any other topic in the climate sciences is as controversial as the climate effect of the Sun. Whilst some are firmly convinced that the solar influence on climate is negligible, others attribute all climate change to the Sun. The debate is somewhat reminiscent of the geologists' dispute of the early 19th Century when scholars fervently argued about the origin of rocks. The "Neptunists" were quite certain that all rocks were formed as sedimentary deposits in water, while the "Plutonists" saw only volcanic forces at work. Today we know: the truth is in the middle, there are different ways rocks are formed. We smile today about this episode of scientific history, but can we be sure that history is not repeating itself right in front of our eyes? In this chapter we look at the 6th Climate Assessment Report (AR6) from the IPCC (available here) and compare its statements about the solar influence on climate to the wide spectrum of peer-reviewed scientific literature. It is expected that the regular IPCC reports are a thorough and balanced summary of climate publications where uncertainties and their implications are clearly discussed. How well did the IPCC do its job when it comes to the Sun and its potential role in climate change?

It is undisputed that a very large body of scientific publications from all over the world support the claim that variations in solar activity influence local and global climate. However, there is a heated debate as to whether solar related forcings are sufficiently relevant for interpreting global climatic changes and, in particular, the global warming trend of about 1 °C observed since 1900. More specifically the AR6 report mainly advocates the CMIP6 global circulation model climate change attribution results which conclude that the role of the Sun in 20th century global warming is negligible. Moreover, solar forcing is claimed to have been slightly "negative" since the 1980s, which would exclude any solar contribution to the warming observed over the last 40 years.

Let us briefly discuss this topic and highlight a number of issues that were not properly addressed in the IPCC AR6 report that suggest a significant solar contribution to climate change including the past 40 years. The interested reader can find a more detailed analysis of the ongoing debate about the influence of solar activity on climate in the recent review paper by Connolly et al. (2021)[1], which was co-authored by 23 experts in solar-climate interactions and cites 545 works. The review discusses the current uncertainties regarding both solar and climate data, and concludes that different solar forcings and climatic indicators:

> *"suggest everything from no role for the Sun in recent decades (implying that recent global warming is mostly human-caused) to most of the recent global warming being due to changes in solar activity (that is, that recent global warming is mostly natural)".*

Thus, it appears that the conclusions presented in IPCC-AR6 are consistent only with a portion of the published scientific literature, the portion that minimizes the role of the sun while maximizing the anthropogenic component.

Numerous case studies support solar participation in the climate equation

Let's look at a recent example from Great Britain to illustrate the intriguing relationships found so far.[2] Figure 1 compares the British September temperatures with solar activity. Over many decades a stunning synchronicity of the parameters were observed. Between 1940 and 2000 the match is so good the relationship could have been used to forecast the weather. At the turn of the millennium, however, the correlation broke down, as it did several times in the first half of the 20th century. Quite likely, the two parameters will correlate better again at some point in the future, as the match seems to come and go every few decades. A possible solution to this apparent alternat-

1 Connolly R, Soon W, Connolly M, Baliunas S, Berglund J, Butler CJ, Cionco RG, Elias AG, Fedorov VM, Harde H, et al. How much has the Sun influenced Northern Hemisphere temperature trends? An ongoing debate. *Research in Astronomy and Astrophysics* 2021, 21:131.

2 Lüdecke H-J, Cina R, Dammschneider H-J, Lüning S. Decadal and multidecadal natural variability in European temperature. *Journal of Atmospheric and Solar-Terrestrial Physics* 2020, 205:105294.

ing correlation between the 11-year solar cycle and the corresponding decadal climatic oscillation was proposed by Scafetta[3,4] showing, for example, that globally at the decadal scale the climate system is regulated by two beating oscillations at about 9 and 11 years. The 9-year one appears to be related to long soli-lunar cycles while the 11-year one is related to the solar cycles. The beats between these two (and possible other) close oscillations may produce alternating periods of high and low correlation between solar and climate cycles.

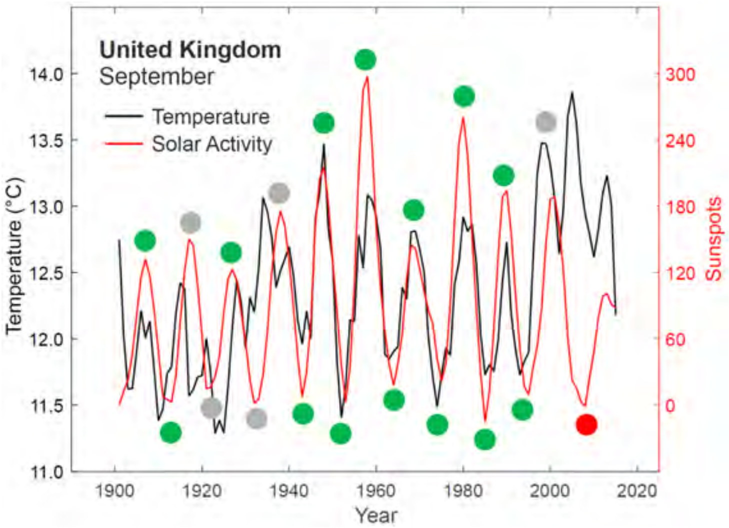


Figure 1: Comparison of September temperatures in the UK (black) and variations in solar activity (red) during the last 120 years. Green dots mark phases of good synchronicity, the red dot shows a contrary development. Graphic modified after Lüdecke, Cina[2].

The result shown in Figure 1 is not unique. There is an extensive literature with empirical case studies on solar influence on climate that shows that a good correlation between temperature development and solar activity exists in various regions of the world.[5,6,7,8,9]

The 11-year Schwabe solar cycle has been documented in numerous climate data series, for example in the westerly winds of Central Europe,[10] in tree rings in southern Germany[11] and Japan,[12] in sedimentary deposits of the Ionian Sea[13] and the Bering Sea,[14] in temperatures of Portugal[15] and

3 IPCC. Special Report on global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways. http://www.ipcc.ch/report/sr15/ 2018.

4 Scafetta, N.: 2010. Empirical evidence for a celestial origin of the climate oscillations and its implications. *Journal of Atmospheric and Solar-Terrestrial Physics*, 72, 951–970.

5 Usoskin IG, Schüssler M, Solanki SK, Mursula K. Solar activity, cosmic rays, and Earth's temperature: A millennium-scale comparison. *Journal of Geophysical Research: Space Physics* 2005, 110.

6 Zherebtsov GA, Kovalenko VA, Molodykh SI, Kirichenko KE. Solar variability manifestations in weather and climate characteristics. *Journal of Atmospheric and Solar-Terrestrial Physics* 2019, 182:217-222.

7 Lüning S, Vahrenholt F. The Sun's Role in Climate. In: *Chapter 16 in "Evidence-Based Climate Science" (Second Edition)*: Elsevier; 2016, 283-305.

8 Engels S, van Geel B. The effects of changing solar activity on climate: contributions from palaeoclimatological studies. *J. Space Weather Space Clim.* 2012, 2:A09.

9 Ibid 1

10 Schwander M, Rohrer M, Brönnimann S, Malik A. Influence of solar variability on the occurrence of central European weather types from 1763 to 2009. *Clim. Past* 2017, 13:1199-1212.

11 Güttler D, Wacker L, Kromer B, Friedrich M, Synal HA. Evidence of 11-year solar cycles in tree rings from 1010 to 1110 AD – Progress on high precision AMS measurements. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 2013, 294:459-463.

12 Miyahara H, Yokoyama Y, Masuda K. Possible link between multi-decadal climate cycles and periodic reversals of solar magnetic field polarity. *Earth and Planetary Science Letters* 2008, 272:290-295.

13 Taricco C, Vivaldo G, Alessio S, Rubinetti S, Mancuso S. A high-resolution δ18O record and Mediterranean climate variability. *Clim. Past* 2015, 11:509-522.

14 Katsuki K, Itaki T, Khim B-K, Uchida M, Tada R. Response of the Bering Sea to 11-year solar irradiance cycles during the Bølling-Allerød. *Geophysical Research Letters* 2014, 41:2892-2898.

15 Morozova AL, Barlyaeva TV. The role of climatic forcings in variations of Portuguese temperature: A comparison of spectral and statistical methods. *Journal of Atmospheric and Solar-Terrestrial Physics* 2016, 149:240-257.

Vancouver Island,[16] in the monsoons of East Asia[17,18] and India,[19] in the North American,[20] European,[21] and Arctic[22] winter climate, in the cyclone frequency of the Pacific coast of Mexico,[23] in the Pacific Walker Circulation,[24] in the oceanic heat content of the upper 700 m water column of the Pacific,[25] in the thunderstorms of Brazil[26] and in the water vapour concentration over the Arabian Peninsula.[27] According to mammal researcher Klaus Hackländer (University of Natural Resources and Applied Life Sciences, Vienna), even the mouse population in the Austrian Weinviertel region is controlled by the solar Schwabe cycle.[28] Due to the varying intensity of the winters, a so-called "mouse peak" occurs there about once per decade.

Sometimes it helps to look at things from a distance. For example, what is the situation in other parts of the solar system? Are other planets and their moons affected by fluctuations in solar activity of any kind? This is indeed the case. The 11-year solar cycle leads to systematic changes in other planetary atmospheres as well. On Uranus and Neptune, the brightness of the atmosphere changes, caused by fluctuations of UV and cosmic radiation.[29,30] In the atmosphere of Saturn's moon Titan the methane concentration changes with the rhythm of the solar cycle.[31]

However, solar variability is characterized by longer cycles as well and these too have been found in the climate system by numerous authors. For example, the solar Gleissberg cycles (90 years)[32] and Suess-DeVries cycles (210 years) were observed in the Atlantic deep water circulation,[33] in the westerly winds of the Falkland Islands,[34] in the climate of the North-East Pacific,[35] in the South American monsoon of Northeast Brazil,[36] in the temperatures of Tibet,[37] in the precipita-

16 Patterson RT, Chang AS, Prokoph A, Roe HM, Swindles GT. Influence of the Pacific Decadal Oscillation, El Niño-Southern Oscillation and solar forcing on climate and primary productivity changes in the northeast Pacific. *Quaternary International* 2013, 310:124-139.

17 Zhao L, Wang J-S. Robust Response of the East Asian Monsoon Rainband to Solar Variability. *Journal of Climate* 2014, 27:3043-3051.

18 Wang J-S, Zhao L. Statistical tests for a correlation between decadal variation in June precipitation in China and sunspot number. *Journal of Geophysical Research: Atmospheres* 2012, 117.

19 van Loon H, Meehl GA. The Indian summer monsoon during peaks in the 11 year sunspot cycle. *Geophys. Res. Lett.* 2012, 39:L13701.

20 Liu Z, Yoshimura K, Buenning NH, He X. Solar cycle modulation of the Pacific–North American teleconnection influence on North American winter climate. *Environmental Research Letters* 2014, 9:024004.

21 Brugnara Y, Brönnimann S, Luterbacher J, Rozanov E. Influence of the sunspot cycle on the Northern Hemisphere wintertime circulation from long upper-air data sets. *Atmos. Chem. Phys.* 2013, 13:6275-6288.

22 Roy I. Solar cyclic variability can modulate winter Arctic climate. *Scientific Reports* 2018, 8:4864.

23 Pazos M, Mendoza B. Landfalling Tropical Cyclones along the Eastern Pacific Coast between the Sixteenth and Twentieth Centuries. *Journal of Climate* 2013, 26:4219-4230.

24 Misios S, Gray LJ, Knudsen MF, Karoff C, Schmidt H, Haigh JD. Slowdown of the Walker circulation at solar cycle maximum. *Proceedings of the National Academy of Sciences* 2019, 116:7186-7191.

25 Wang G, Yan S, Qiao F. Decadal variability of upper ocean heat content in the Pacific: Responding to the 11-year solar cycle. *Journal of Atmospheric and Solar-Terrestrial Physics* 2015, 135:101-106.

26 Pinto Neto O, Pinto IRCA, Pinto O. The relationship between thunderstorm and solar activity for Brazil from 1951 to 2009. *Journal of Atmospheric and Solar-Terrestrial Physics* 2013, 98:12-21.

27 Maghrabi AH. Multi- decadal variations and periodicities of the precipitable water vapour (PWV) and their possible association with solar activity: Arabian Peninsula. *Journal of Atmospheric and Solar-Terrestrial Physics* 2019, 185:22-28.

28 Brickner I. Weinviertel: Von der Klimaerwärmung zur Mäuseplage. *Der Standard, 2.8.2019*, https://www.derstandard.at/story/2000106952286/von-der-klimaerwaermung-zur-maeuseplage 2019.

29 Aplin KL, Harrison RG. Determining solar effects in Neptune's atmosphere. *Nature Communications* 2016, 7:11976.

30 Aplin KL, Harrison RG. Solar-Driven Variation in the Atmosphere of Uranus. *Geophysical Research Letters* 2017, 44:12,083-012,090.

31 Westlake JH, Waite JH, Bell JM, Perryman R. Observed decline in Titan's thermospheric methane due to solar cycle drivers. *Journal of Geophysical Research: Space Physics* 2014, 119:8586-8599.

32 Feynman J, Ruzmaikin A. The Centennial Gleissberg Cycle and its association with extended minima. *Journal of Geophysical Research: Space Physics* 2014, 119:6027-6041.

33 Seidenglanz A, Prange M, Varma V, Schulz M. Ocean temperature response to idealized Gleissberg and de Vries solar cycles in a comprehensive climate model. *Geophys. Res. Lett.* 2012, 39:L22602.

34 Turney CSM, Jones RT, Fogwill C, Hatton J, Williams AN, Hogg A, Thomas ZA, Palmer J, Mooney S, Reimer RW. A 250-year periodicity in Southern Hemisphere westerly winds over the last 2600 years. *Clim. Past* 2016, 12:189-200.

35 Galloway JM, Wigston A, Patterson RT, Swindles GT, Reinhardt E, Roe HM. Climate change and decadal to centennial-scale periodicities recorded in a late Holocene NE Pacific marine record: Examining the role of solar forcing. *Palaeogeography, Palaeoclimatology, Palaeoecology* 2013, 386:669-689.

36 Novello VF, Cruz FW, Karmann I, Burns SJ, Stríkis NM, Vuille M, Cheng H, Lawrence Edwards R, Santos RV, Frigo E, et al. Multidecadal climate variability in Brazil's Nordeste during the last 3000 years based on speleothem isotope records. *Geophysical Research Letters* 2012, 39.

37 Li X, Liang J, Hou J, Zhang W. Centennial-scale climate variability during the past 2000 years on the central Tibetan Plateau. *The Holocene* 2015, 25:892-899.

tion of northwest,[38] northeast,[39] south,[40] and central[41] China, in the nitrate content of the polar ice caps,[42] in the growing season of the northern hemisphere,[43] in the subtropical monsoon of the Northern Hemisphere[44] and in global tree ring data.[45]

There is strong evidence that climatic millennium-scale cycles with periods of 1000-2500 years were caused by the Sun. Actually, the Sun appears to beat with a quasi-millennial cycle (known as the Eddy cycle)[46,47,48] and a quasi-2300-year cycle known as the Bray-Hallstatt cycle.[49] Gerard Bond and colleagues first described the cycles from the North Atlantic and explicitly stated that they were synchronous with solar activity.[50] Since then, the Millennium cycles have been described from all over the world.[51] In many cases, the respective study authors established a connection to solar activity, for example in the USA,[52,53] in Brazil,[54] Patagonia,[55] Peru,[56] Antarctica,[57] South Africa,[58] Morocco,[59] Oman,[60] India,[61] China,[62] Australia,[63] Spain,[64] Austria[65] and Finland.[66]

---

38 Tiwari RK, Rajesh R. Imprint of long-term solar signal in groundwater recharge fluctuation rates from Northwest China. *Geophysical Research Letters* 2014, 41:3103-3109.

39 Chu G, Sun Q, Xie M, Lin Y, Shang W, Zhu Q, Shan Y, Xu D, Rioual P, Wang L, et al. Holocene cyclic climatic variations and the role of the Pacific Ocean as recorded in varved sediments from northeastern China. *Quaternary Science Reviews* 2014, 102:85-95.

40 Zhao K, Wang Y, Edwards RL, Cheng H, Liu D, Kong X. A high-resolved record of the Asian Summer Monsoon from Dongge Cave, China for the past 1200 years. *Quaternary Science Reviews* 2015, 122:250-257.

41 Liu D, Wang Y, Cheng H, Edwards RL, Kong X. Cyclic changes of Asian monsoon intensity during the early mid-Holocene from annually-laminated stalagmites, central China. *Quaternary Science Reviews* 2015, 121:1-10.

42 Ogurtsov MG, Oinonen M. Evidence of the solar Gleissberg cycle in the nitrate concentration in polar ice. *Journal of Atmospheric and Solar-Terrestrial Physics* 2014, 109:37-42.

43 Ogurtsov M, Lindholm M, Jalkanen R, Veretenenko S. Evidence for the Gleissberg solar cycle at the high-latitudes of the Northern Hemisphere. *Advances in Space Research* 2015, 55:1285-1290.

44 Knudsen MF, Jacobsen BH, Riisager P, Olsen J, Seidenkrantz M-S. Evidence of Suess solar-cycle bursts in subtropical Holocene speleothem δ18O records. *The Holocene* 2012, 22:597-602.

45 Breitenmoser P, Beer J, Brönnimann S, Frank D, Steinhilber F, Wanner H. Solar and volcanic fingerprints in tree-ring chronologies over the past 2000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 2012, 313–314:127-139.

46 Kerr, R.A.: 2001, A variable Sun paces millennial climate. *Science* 294, 1431.

47 Neff, U., Burns, S.J., Mangini, A., Mudelsee, M., Fleitmann, D., Matter, A.: 2001, Strong coherence between solar variability and the monsoon in Oman between 9 and 6 kyr ago. *Nature* 411, 290.

48 Ogurtsov, M.G., Nagovitsyn, Y.A., Kocharov, G.E., Jungner, H.: 2002, Long-period cycles of the Sun's activityrecorded in direct solar data and proxies. *Solar Phys.* 211, 371.

49 McCracken, K.G., Beer, J., Steinhilber, F., Abreu, J.: 2013, A phenomenological study of the cosmic ray variations over the past 9400 years, and their implications regarding solar activity and the solar dynamo. *Solar Phys.* 286, 609.

50 Bond G, Kromer B, Beer J, Muscheler R, Evans MN, Showers W, Hoffmann S, Lotti-Bond R, Hajdas I, Bonani G. Persistent Solar Influence on North Atlantic Climate During the Holocene. *Science* 2001, 294:2130-2136.

51 Ibid 7

52 Willard DA, Bernhardt CE, Korejwo DA, Meyers SR. Impact of millennial-scale Holocene climate variability on eastern North American terrestrial ecosystems: pollen-based climatic reconstruction. *Global and Planetary Change* 2005, 47:17-35.

53 Springer GS, Rowe HD, Hardt B, Edwards RL, Cheng H. Solar forcing of Holocene droughts in a stalagmite record from West Virginia in east-central North America. *Geophysical Research Letters* 2008, 35:1-5.

54 Bernal JP, Cruz FW, Stríkis NM, Wang X, Deininger M, Catunda MCA, Ortega-Obregón C, Cheng H, Edwards RL, Auler AS. High-resolution Holocene South American monsoon history recorded by a speleothem from Botuverá Cave, Brazil. *Earth and Planetary Science Letters* 2016, 450:186-196.

55 Kilian R, Lamy F. A review of Glacial and Holocene paleoclimate records from southernmost Patagonia (49–55°S). *Quaternary Science Reviews* 2012, 53:1-23.

56 Bush MB, Hansen BCS, Rodbell DT, Seltzer GO, Young KR, León B, Abbott MB, Silman MR, Gosling WD. A 17 000-year history of Andean climate and vegetation change from Laguna de Chochos, Peru. *Journal of Quaternary Science* 2005, 20:703-714.

57 Crosta X, Debret M, Denis D, Courty MA, Ther O. Holocene long- and short-term climate changes off Adélie Land, East Antarctica. *Geochem. Geophys. Geosyst.* 2007, 8:1-15.

58 outhern Africa. Quaternary *Science Reviews* 2003, 22:2311-2326.

59 Zielhofer C, Köhler A, Mischke S, Benkaddour A, Mikdad A, Fletcher WJ. Western Mediterranean hydro-climatic consequences of Holocene ice-rafted debris (Bond) events. *Clim. Past* 2019, 15:463-475.

60 Fleitmann D, Burns SJ, Mudelsee M, Neff U, Kramers J, Mangini A, Matter A. Holocene Forcing of the Indian Monsoon Recorded in a Stalagmite from Southern Oman. *Science* 2003, 300:1737-1739.

61 Thamban M, Kawahata H, Rao V. Indian summer monsoon variability during the holocene as recorded in sediments of the Arabian Sea: Timing and implications. *Journal of Oceanography* 2007, 63:1009-1020.

62 Wang Y, Cheng H, Edwards RL, He Y, Kong X, An Z, Wu J, Kelly MJ, Dykoski CA, Li X. The Holocene Asian Monsoon: Links to Solar Changes and North Atlantic Climate. *Science* 2005, 308:854-857.

63 McGowan HA, Marx SK, Soderholm J, Denholm J. Evidence of solar and tropical-ocean forcing of hydroclimate cycles in southeastern Australia for the past 6500 years. *Geophysical Research Letters* 2010, 37.

64 Fletcher WJ, Debret M, Goñi MFS. Mid-Holocene emergence of a low-frequency millennial oscillation in western Mediterranean climate: Implications for past dynamics of the North Atlantic atmospheric westerlies. *The Holocene* 2013, 23:153-166.

65 Mangini A, Verdes P, Spötl C, Scholz D, Vollweiler N, Kromer B. Persistent influence of the North Atlantic hydrography on central European winter temperature during the last 9000 years. *Geophysical Research Letters* 2007, 34:n/a-n/a.

66 Ojala AEK, Launonen I, Holmström L, Tiljander M. Effects of solar forcing and North Atlantic oscillation on the climate of continental Scandinavia during the Holocene. *Quaternary Science Reviews* 2015, 112:153-171.

The longer Bray-Hallstatt cycle was also found in a number of climate records.[67,68,69,70] In other cases, the connection with solar development was not checked, so that no statement was made about this for the time being,[71,72,73,74] but a solar climate driver is quite likely.

Despite the uncertainties appropriate to the various climatic records, which for the past are based on proxies, the observed solar-climate oscillations are likely real and not coincidental common patterns produced by complex but independent dynamics. In fact, it has been demonstrated that the typical observed frequencies correspond to the natural gravitational oscillations of the solar system (which are labelled as "invariant inequalities") that appear to simultaneously synchronize both solar activity and climate change from the decadal to the multimillennial scales.[75,76,77]

Why are these natural oscillations so important for accurately interpreting climate change during the last century? Because they reveal a natural climatic variability driven by solar or astronomical forcings that are not fully understood physically. Even so, they highlight some of the serious limitations of the present IPCC climate models (such as the CMIP5 and CMIP6 GCMs) that cannot reproduce them.[78,79,80] Let us discuss this point.

The Past as a Plausibility Check

Let us take a brief look at the Medieval Warm Period (MWP), the last pre-industrial warm period, which in its wider interpretation is dated from 800-1300 AD. Solar activity started increasing around 700 AD and remained high until 1250 AD. Warm MWP and a strong sun - is this again just one of these "coincidences" (Figure 2)? Did the sun spend the first 100 years gradually revving up an inert climate system? Several researchers see the sun as the cause of the MWP warming, for example the authors of a study on the Tibet Plateau, where the MWP was warmer than it is today.[81] Even one of the hockey stick co-authors noted a connection to the sun, one year after the legendary temperature curve was published. In an e-mail (which was discovered in the "Climategate" collection from the University of East Anglia's climate research centre in Norwich, England in 2009) Raymond Bradley acknowledged to his hockey stick supporters and other colleagues that the MWP may have had a similar temperature level as today.[82] He suspected the Sun was the trigger:

67 Bray, J.R.: 1968, Glaciation and solar activity since the fifth century BC and the solar cycle. *Nature* 220, 672.

68 O'Brien, S.R., Mayewski, P.A., Meeker, L.D., et al.: 1995, Complexity of Holocene climate as reconstructed from a Greenland ice core. *Science* 270, 1962.

69 Pestiaux, P., Van Der Mersch, I., Berger, A., Duplessy, J.C.: 1988, Paleoclimatic variability at frequencies ranging from 1 cycle per 10,000 years to 1 cycle per 1000 years: Evidence for nonlinear behavior of the climate system. *Clim. Change* 12, 9.

70 Vasiliev, S.S., Dergachev, V.A.: 2002, The 2400-year cycle in atmospheric radiocarbon concentration: bispectrum of 14C data over the last 8000 years. *Ann. Geophys.* 20, 115.

71 Evangelista H, Gurgel M, Sifeddine A, Rigozo NR, Boussafir M. South Tropical Atlantic anti-phase response to Holocene Bond Events. *Palaeogeography, Palaeoclimatology, Palaeoecology* 2014, 415:21-27.

72 Voigt I, Chiessi CM, Prange M, Mulitza S, Groeneveld J, Varma V, Henrich R. Holocene shifts of the southern westerlies across the South Atlantic. *Paleoceanography* 2015, 30:39-51.

73 Arz HW, Gerhardt S, Pätzold J, Röhl U. Millennial-scale changes of surface- and deep-water flow in the western tropical Atlantic linked to Northern Hemisphere high-latitude climate during the Holocene. *Geology* 2001, 29:239-242.

74 Kemp J, Radke LC, Olley J, Juggins S, De Deckker P. Holocene lake salinity changes in the Wimmera, southeastern Australia, provide evidence for millennial-scale climate variability. *Quaternary Research* 2012, 77:65-76.

75 Scafetta, N.: 2012. Multi-scale harmonic model for solar and climate cyclical variation throughout the Holocene based on Jupiter-Saturn tidal frequencies plus the 11-year solar dynamo cycle. *Journal of Atmospheric and Solar-Terrestrial Physics*, 80, 296–311.

76 Scafetta, N., Milani, F., Bianchini, A., Ortolani, S.: 2016. On the astronomical origin of the Hallstatt oscillation found in radiocarbon and climate records throughout the Holocene. *Earth-Science Reviews*, 162, 24–43.

77 Scafetta, N.: 2020. Solar Oscillations and the Orbital Invariant Inequalities of the Solar System. *Solar Physics*, 295(2), 33.

78 Scafetta, N.: 2013. Discussion on climate oscillations: CMIP5 general circulation models versus a semiempirical harmonic model based on astronomical cycles. *Earth-Science Reviews*, 126, 321–357.

79 Scafetta, N.: 2021. Reconstruction of the Interannual to Millennial Scale Patterns of the Global Surface Temperature. *Atmosphere*, 12, 147.

80 Scafetta, N.: 2021. Testing the CMIP6 GCM Simulations versus Surface Temperature Records from 1980–1990 to 2011–2021: High ECS Is Not Supported. *Climate* 9, 161.

81 He Y, Liu W, Zhao C, Wang Z, Wang H, Liu Y, Qin X, Hu Q, An Z, Liu Z. Solar influenced late Holocene temperature changes on the northern Tibetan Plateau. *Chinese Science Bulletin* 2013, 58:1053-1059.

82 Bradley R. Email. *10.7.2000, http://di2.nu/foia/foia2011/mail/0207.txt* 2000.

"[...] it may be that Mann et al simply don't have the long-term trend right [...] which of course begs the question as to what the likely forcing was 1,000 years ago. (My money is firmly on an increase in solar irradiance...)".

The strong sun during the MWP also reduced the Aleutian Low system,[83] which is otherwise linked to the Pacific Decadal Oscillation (PDO) on shorter time scales.[84] Between 1010 and 1040 AD, during the solar Oort Minimum, the sun weakened briefly for three decades. In several local temperature reconstructions, the temperature also dropped, e.g., in Kenya,[85] Morocco,[86] and Antarctica.[87]

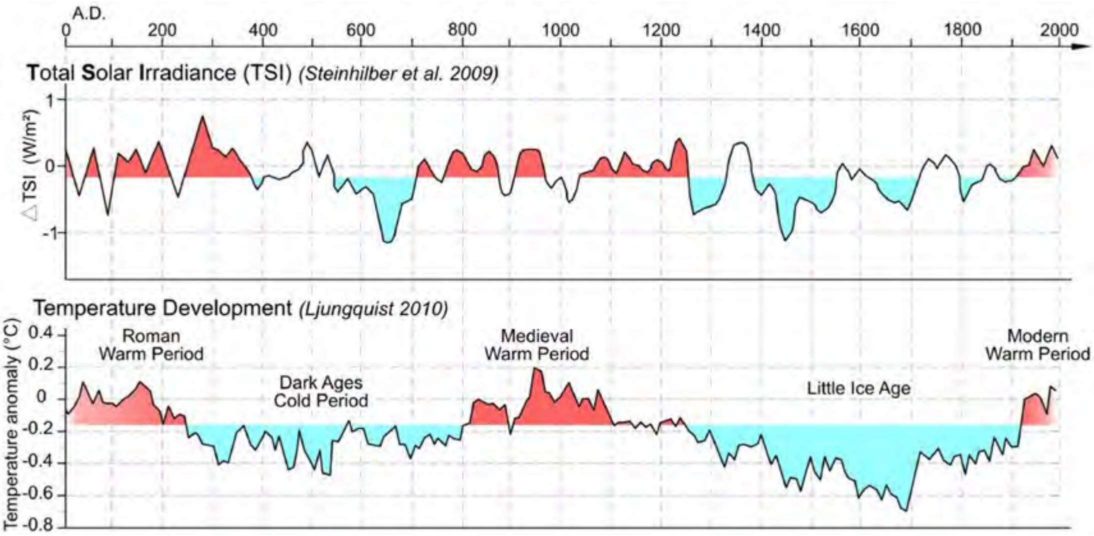


Figure 2: Long-term synchronicity of solar activity[88] and temperature development[89] (non-tropical Northern Hemisphere) over the last 2000 years.

The Little Ice Age (1300-1850 AD) was one of the coldest periods of the last 10,000 years. Solar activity was at a very low level, a level only rarely seen in the last ten millennia.[90] Is this really just a coincidence? Then it would also be purely coincidental that modern warming had its strongest warming impulse in the second half of the 20th century, when solar activity reached one of the highest values of the last 10,000 years.[91] Coincidences are unforeseen events that have a meaning, said the ancient Greek philosopher Diogenes of Sinope.

The Little Ice Age (LIA) offers an exciting research laboratory for solar-climate effects. On several occasions, solar activity fell sharply for several decades and then recovered rapidly. These are the Wolf Minimum (1280-1350), Spörer Minimum (1460-1550), Maunder Minimum (1645-1715), and the Dalton Minimum (1790-1830). Empirical paleoclimatology can be used to investigate how these phases of solar weakness led to climate change. If the sun really does not have a significant effect on the climate—as the AR6 assumes—the solar minima must have had no effect on the cli-

83 Osterberg EC, Mayewski PA, Fisher DA, Kreutz KJ, Maasch KA, Sneed SB, Kelsey E. Mount Logan ice core record of tropical and solar influences on Aleutian Low variability: 500–1998 A.D. *Journal of Geophysical Research: Atmospheres* 2014, 119:11,189-111,204.

84 Dong X, Su T-H, Wang J, Lin R-P. Decadal Variation of the Aleutian Low-Icelandic Low Seesaw Simulated by a Climate System Model (CAS-ESM-C). *Atmospheric and Oceanic Science Letters* 2014, 7:110-114.

85 Berke MA, Johnson TC, Werne JP, Schouten S, Sinninghe Damsté JS. A mid-Holocene thermal maximum at the end of the African Humid Period. *Earth and Planetary Science Letters* 2012, 351–352:95-104.

86 Zielhofer C, Fletcher WJ, Mischke S, De Batist M, Campbell JFE, Joannin S, Tjallingii R, El Hamouti N, Junginger A, Stele A, et al. Atlantic forcing of Western Mediterranean winter rain minima during the last 12,000 years. *Quaternary Science Reviews* 2017, 157:29-51.

87 Noon PE, Leng MJ, Jones VJ. Oxygen-isotope (δ18O) evidence of Holocene hydrological changes at Signy Island, maritime Antarctica. *The Holocene* 2003, 13:251-263.

88 Steinhilber F, Beer J, Fröhlich C. Total solar irradiance during the Holocene. *Geophysical Research Letters* 2009, 36.

89 Ljungqvist FC. A new reconstruction of temperature variability in the extra-tropical northern hemisphere during the last two millennia. *Geografiska Annaler: Series A* 2010, 92:339-351.

90 Steinhilber F, Abreu JA, Beer J, Brunner I, Christl M, Fischer H, Heikkilä U, Kubik PW, Mann M, McCracken KG, et al. 9,400 years of cosmic radiation and solar activity from ice cores and tree rings. *Proceedings of the National Academy of Sciences* 2012, 109:5967-5971.

91 Ibid 5

mate. The pronounced solar minima of the LIA therefore provide an excellent scientific blind test of the solar-climate connection.

The result is surprising. Contrary to expectations, the solar minima caused enormous climatic changes. Studies from Spain[92] and Portugal[93] document significant cooling during the Maunder and Dalton minima. Studies from Slovakia,[94] China,[95] Bhutan[96] and the Canadian Rocky Mountains[97] reported cold periods that occurred at the same time as the Spörer, Maunder, and Dalton periods of solar weakness. During the Wolf, Spörer and Maunder minima, the intermediate water layers of the North Atlantic cooled by 2-3 °C,[98] while the surface water in the tropical North Atlantic off Mauritania cooled by 1 °C.[99] On Sakhalin, Russia's largest island, the lowest temperatures were recorded during the Maunder Minimum.[100] Tree ring surveys in Tasmania, Australia, found cold phases during the Spörer and Maunder Minima.[101]

Even in Antarctica, the repeated drop in solar activity was very noticeable. A Chinese research group led by Yuesong Gao reconstructed the population of Adelie penguins in a bay in East Antarctica for the past 1000 years.[102] They took a sediment core from the seabed near the coast and examined it for penguin droppings. The researchers found that the population was strongly influenced by solar activity. Whenever solar activity decreased, the population collapsed, especially during the Spörer, Maunder, and Dalton minima. In between, the penguins recovered. Lower solar activity decreased the local phytoplankton, reducing the krill population, and that decreased the penguin population.

On a global scale, these alternating warm and cold periods are correlated with secular trends of solar activity.[103,104,105] Moreover, as Figure 2 shows, it appears that such common solar and climate variations are regulated mostly by a millennial cycle[106,107] and by a quasi-115-year cycle. Both cycles are accurately predicted by a combination of the 11-year solar cycle with two of the main gravitational oscillations of the solar system driven by the combined effects of the orbits of Jupiter and Saturn.[108,109]

Regarding the current warm period, as Figure 2 suggests, solar activity has increased from the 18th to the 20th century. The new level may be at a higher level than during the Medieval Warm

92 Tejedor E, Saz MÁ, Cuadrat JM, Esper J, de Luis M. Temperature variability in the Iberian Range since 1602 inferred from tree-ring records. *Clim. Past* 2017, 13:93-105.

93 Santos JA, Carneiro MF, Correia A, Alcoforado MJ, Zorita E, Gómez-Navarro JJ. New insights into the reconstructed temperature in Portugal over the last 400 years. *Clim. Past* 2015, 11:825-834.

94 Büntgen U, Kyncl T, Ginzler C, Jacks DS, Esper J, Tegel W, Heussner K-U, Kyncl J. Filling the Eastern European gap in millennium-long temperature reconstructions. *Proceedings of the National Academy of Sciences* 2013, 110:1773-1778.

95 Shi F, Yang B, Von Gunten L. Preliminary multiproxy surface air temperature field reconstruction for China over the past millennium. *Science China Earth Sciences* 2012, 55:2058-2067.

96 Krusic PJ, Cook ER, Dukpa D, Putnam AE, Rupper S, Schaefer J. Six hundred thirty-eight years of summer temperature variability over the Bhutanese Himalaya. *Geophysical Research Letters* 2015, 42:2988-2994.

97 Luckman BH, Wilson RJS. Summer temperatures in the Canadian Rockies during the last millennium: a revised record. *Climate Dynamics* 2005, 24:131-144.

98 Moffa-Sanchez P, Born A, Hall IR, Thornalley DJR, Barker S. Solar forcing of North Atlantic surface temperature and salinity over the past millennium. *Nature Geosci* 2014, 7:275-278.

99 Kuhnert H, Mulitza S. Multidecadal variability and late medieval cooling of near-coastal sea surface temperatures in the eastern tropical North Atlantic. *Paleoceanography* 2011, 26:PA4224.

100 Wiles GC, Solomina O, D'Arrigo R, Anchukaitis KJ, Gensiarovsky YV, Wiesenberg N. Reconstructed summer temperatures over the last 400 years based on larch ring widths: Sakhalin Island, Russian Far East. *Climate Dynamics* 2015, 45:397-405.

101 Cook E, Bird T, Peterson M, Barbetti M, Buckley B, D'Arrigo R, Francey R. Climatic change over the last millennium in Tasmania reconstructed from tree-rings. *The Holocene* 1992, 2:205-217.

102 Gao Y, Yang L, Yang W, Wang Y, Xie Z, Sun L. Dynamics of penguin population size and food availability at Prydz Bay, East Antarctica, during the last millennium: A solar control. *Palaeogeography, Palaeoclimatology, Palaeoecology* 2019, 516:220-231.

103 Hoyt, D.V.,Schatten,K.H.,1997.TheRoleoftheSunintheClimateChange.Oxford UniversityPress,NewYork.

104 Scafetta, N.,West, B.J.: 2007. Phenomenological reconstructions of the solar signature in the NH surface temperature records since 1600. *Journal of Geophysical Research*, 112, D24S03.

105 Scafetta, N.: 2009. Empirical analysis of the solar contribution to global mean air surface temperature change. *Journal of Atmospheric and Solar-Terrestrial Physics*, 71, 1916–1923.

106 Scafetta, N.: 2014. Discussion on the spectral coherence between planetary, solar and climate oscillations: a reply to some critiques. *Astrophysics and Space Science*, 354, 275–299.

107 Ibid 46

108 Ibid 75

109 Ibid 78

Period[110]. The increase in solar activity correlates well with the current global climate warming.[111,112,113] This is discussed in detail in Connolly et al. (2021)[114].

Sun influences rain

The sun influences not only temperatures, but also rain. In Europe, the solar fingerprint is found in the precipitation during the months of February, April, June, and July.[115] Several studies report on flood phases, which occur mainly at times of low solar activity.[116,117] A solar signature also exists in rainfall in the USA,[118,119] of the Tibet Plateau,[120] the monsoon of South America,[121] the Indian monsoon[122], and the Asian summer monsoon[123]. A solar imprint is also seen in the water flow of rivers in the USA,[124] in Egypt[125], and Brazil.[126] The 11-year solar cycle shapes the flow rates of the Amazon[127] as well as the water levels of the Great Lakes in North America,[128] the Caspian Sea[129,130], and Lake Victoria in East Africa.[131] The influence of the sun on rain is at least as strong as on temperatures and is based upon shifts in wind patterns and clouds.

IPCC's AR6 downplays the Sun

Considering the large number of publications on solar effects in the climate system, one would expect the IPCC to review this subject thoroughly and in great detail. Which climate elements in which parts of the world, during which season show the greatest link to solar activity changes? What are the potential physical processes behind these links? Have climate models been able to reproduce these empirically well-established relationships? Successful model "hindcasts" should reproduce the solar impact on climate correctly. Failure to replicate the observed relationship in

110 Ibid 5

111 Ibid 103

112 Ibid 104

113 Ibid 105

114 Ibid 1

115 Laurenz L, Lüdecke H-J, Lüning S. Influence of solar activity changes on European rainfall. *Journal of Atmospheric and Solar-Terrestrial Physics* 2019, 185:29-42.

116 Czymzik M, Muscheler R, Brauer A. Solar modulation of flood frequency in central Europe during spring and summer on interannual to multi-centennial timescales. *Clim. Past* 2016, 12:799-805.

117 Peña JC, Schulte L, Badoux A, Barriendos M, Barrera-Escoda A. Influence of solar forcing, climate variability and modes of low-frequency atmospheric variability on summer floods in Switzerland. *Hydrol. Earth Syst. Sci.* 2015, 19:3807-3827.

118 Nitka W, Burnecki K. Impact of solar activity on precipitation in the United States. *Physica A: Statistical Mechanics and its Applications* 2019, 527:121387.

119 Jones MD, Metcalfe SE, Davies SJ, Noren A. Late Holocene climate reorganisation and the North American Monsoon. *Quaternary Science Reviews* 2015, 124:290-295.

120 Sun J, Liu Y. Tree ring based precipitation reconstruction in the south slope of the middle Qilian Mountains, northeastern Tibetan Plateau, over the last millennium. *J. Geophys. Res.* 2012, 117:D08108.

121 Vuille M, Burns SJ, Taylor BL, Cruz FW, Bird BW, Abbott MB, Kanner LC, Cheng H, Novello VF. A review of the South American monsoon history as recorded in stable isotopic proxies over the past two millennia. *Climate of the Past* 2012, 8:1309-1321.

122 Kodera K. Solar influence on the Indian Ocean Monsoon through dynamical processes. *Geophysical Research Letters* 2004, 31.

123 Liu D, Wang Y, Cheng H, Edwards RL, Kong X. Remote vs. local control on the Preboreal Asian hydroclimate and soil processes recorded by an annually-laminated stalagmite from Daoguan Cave, southern China. *Quaternary International* 2017, 452:79-90.

124 Wallace MG. Application of lagged correlations between solar cycles and hydrosphere components towards sub-decadal forecasts of streamflows in the Western USA. *Hydrological Sciences Journal* 2019, 64:137-164.

125 Hennekam R, Jilbert T, Schnetger B, de Lange GJ. Solar forcing of Nile discharge and sapropel S1 formation in the early to middle Holocene eastern Mediterranean. *Paleoceanography* 2014, 29:343-356.

126 Mauas PJD, Buccino AP, Flamenco E. Long-term solar activity influences on South American rivers. *Journal of Atmospheric and Solar-Terrestrial Physics* 2011, 73:377-382.

127 Antico A, Torres ME. Evidence of a decadal solar signal in the Amazon River: 1903 to 2013. *Geophysical Research Letters* 2015, 42:10,782-710,787.

128 Watras CJ, Read JS, Holman KD, Liu Z, Song Y-Y, Watras AJ, Morgan S, Stanley EH. Decadal oscillation of lakes and aquifers in the upper Great Lakes region of North America: Hydroclimatic implications. *Geophysical Research Letters* 2014, 41:456-462.

129 Kaftan V, Komitov B, Lebedev S. Analysis of sea level changes in the Caspian Sea related to Cosmo-geophysical processes based on satellite and terrestrial data. *Geodesy and Geodynamics* 2018, 9:449-455.

130 Naderi Beni A, Lahijani H, Mousavi Harami R, Arpe K, Leroy SAG, Marriner N, Berberian M, Andrieu-Ponel V, Djamali M, Mahboubi A, et al. Caspian sea-level changes during the last millennium: historical and geological evidence from the south Caspian Sea. *Clim. Past* 2013, 9:1645-1665.

131 Stager CJ, Ryves D, Cumming FB, Meeker DL, Beer J. Solar variability and the levels of Lake Victoria, East Africa, during the last millenium. *Journal of Paleolimnology* 2005, 33:243-251.

climate models would imply that the solar effect is not understood well enough. In that case, quantification of the solar contribution to climate change of the past 170 years would not be possible.

Surprisingly, none of these topics are adequately addressed in AR6. The Sun appears in only three of the chapters of the AR6 *Climate Change 2021: The Physical Science Basis* volume. Chapter 2 describes changes in solar activity over the past century and millennia, concluding that the variability was much too small to impact climate in a significant way (subchapter 2.2.1). Chapter 7 acknowledges that solar activity changes in the ultraviolet (UV) part of the spectrum are much greater than in the visible part (subchapter 7.3.4.4). Nevertheless, according to the IPCC, even this does not imply a meaningful climate impact. In the same chapter, recent work by Henrik Svensmark and his team on galactic cosmic ray amplifiers of the solar climatic effect are rejected (subchapter 7.3.4.5). Yet, Svensmark and colleagues have recently published a significant new work supporting their hypothesis that cosmic rays have a significant effect on cloud formation.[132] Chapter 10 cites a few case studies in which solar influence on climate is well documented (subchapter 10.1.3.1). However, the AR6 authors do not follow up on these observations and investigate whether climate models are capturing these historical relationships.

Moreover, whilst the IPCC takes for granted strong amplifiers that boost the CO_2 warming effect from 1.1 to 4.0 °C per doubling of CO_2 so that the equilibrium climate sensitivity of the CMIP6 GCMs can vary from 1.8 to 5.7 °C, it denies similar amplifiers to solar forcing. Climate history shows that the sun has a considerable influence on the climate, both in pre-industrial and industrial times. Therefore, amplifiers and/or alternative reconstructions showing larger solar activity variations are clearly needed to explain the empirical data. In any case, the mechanism probably does not work solely through total solar irradiance (TSI). The TSI changes appear insufficient, but the TSI forcing model adopted by the CMIP5 and CMIP6 GCMs only considers the small, short-term, changes in total solar output. The solar magnetic field strength, cosmic rays, and UV radiation vary much more and are good candidates to amplify the solar TSI trends. Let us briefly discuss the possible amplifiers.

The UV Amplifier

UV radiation increases during solar activity maxima, boosting ozone formation in the stratosphere at an altitude of 15 to 50 kilometres. The additional UV energy input converts a larger number of oxygen molecules (O_2) into ozone (O_3). A higher ozone concentration, in turn, intercepts more UV rays and converts their energy into heat, which causes the ozone layer or the stratosphere to warm. The search is now on for a process that combines the strong stratospheric fluctuations with the tropospheric climatic events below an altitude of around 15 kilometres.[133] Some researchers suggest that UV heating of the ozone layer creates anomalies in the atmospheric temperature gradient which are propagated to Earth's surface via intermediate steps.[134,135,136,137,138] Changes in wind patterns and atmospheric circulation apparently play a major role here.[139] For example, in times of low solar activity, westerly winds in the southern hemisphere shift toward the equator.[140]

132 Svensmark, H., Svensmark, J., Enghoff, M.B. et al. Atmospheric ionization and cloud radiative forcing. *Sci Rep* 11, 19668 (2021).

133 Niranjankumar K, Ramkumar TK, Krishnaiah M. Vertical and lateral propagation characteristics of intraseasonal oscillation from the tropical lower troposphere to upper mesosphere. *Journal of Geophysical Research* 2011, 116:1-10.

134 Meehl GA, Arblaster JM, Matthes K, Sassi F, Loon Hv. Amplifying the Pacific Climate System Response to a Small 11-Year Solar Cycle Forcing. *Science* 2009, 325:1114-1118.

135 Ineson S, Scaife AA, Knight JR, Manners JC, Dunstone NJ, Gray LJ, Haigh JD. Solar forcing of winter climate variability in the Northern Hemisphere. *Nature Geoscience* 2011, 4:753-757.

136 Kodera K. The role of dynamics in solar forcing. *Space Science Reviews* 2006, 125:319-330.

137 Gray LJ, Ball W, Misios S. Solar influences on climate over the Atlantic / European sector. *AIP Conference Proceedings* 2017, 1810:020002.

138 Wang W, Matthes K, Tian W, Park W, Shangguan M, Ding A. Solar impacts on decadal variability of tropopause temperature and lower stratospheric (LS) water vapour: a mechanism through ocean–atmosphere coupling. *Climate Dynamics* 2019, 52:5585-5604.

139 Kodera K, Thiéblemont R, Yukimoto S, Matthes K. How can we understand the global distribution of the solar cycle signal on the Earth's surface? *Atmos. Chem. Phys.* 2016, 16:12925-12944

140 Varma V, Prange M, Lamy F, Merkel U, Schulz M. Solar-forced shifts of the Southern Hemisphere Westerlies during the Holocene. *Clim. Past* 2011, 7:339-347.

The Cosmic Ray Amplifier

The basic principle of this amplifier is the influence of fluctuations in the solar magnetic field on global or regional cloud cover. The possible path of action comprises several steps:

1) The strength of the solar magnetic field is coupled to solar activity.
2) The solar magnetic field shields the Earth from cosmic radiation coming from outer space.
3) The cosmic rays create condensation nuclei that help form clouds in the lowest three kilometres of the Earth's atmosphere. Similar to a cloud chamber, the particles charged by cosmic rays become condensation nuclei and attract water vapor.
4) Clouds limit the solar energy hitting the ground and thus the temperature.

In short: The stronger the sun, the stronger the solar magnetic field and the better protected Earth is from cosmic rays. The fewer cosmic rays that penetrate into the Earth's atmosphere, the less condensation and fewer clouds, which leads to warming. The result: a strong sun leads to global warming.

The model of the cosmic ray amplifier has been developed since the late 1990s by the Danish physicist Henrik Svensmark in collaboration with Eigil Friis-Christensen.[141,142,143,144,145,146] As might be expected, Svensmark's model met with fierce resistance in parts of the scientific community, because it was in competition with the dominance of CO_2 postulated by the IPCC. But Svensmark had the empirical data initially clearly on his side. During the period 1983-2002 global cloud cover developed synchronously with the eleven-year solar cycle (see Figure 3). After then, however, the relationship broke down, which led to criticism from Svensmark's scientific opponents. Notably, the temporary divergence of solar and climate trends could well be a consequence of non-linear and time-delayed processes, that have been reported for solar effects in the literature.[147,148]

At the turn of the millennium, the coupling between stratosphere and troposphere changed according to the 60-year cycle of atmospheric circulation, and the stratospheric polar vortex weakened, as Russian researchers have shown.[149,150] This reversed the solar effect on the cloud-generating low-pressure areas. While solar minima with more intense cosmic radiation used to bring more clouds, the cloud cover has now decreased with weak solar activity.[151,152]

The AR6 authors ignore the fact that other researchers have confirmed the Svensmark effect in general. However, the mechanism is probably not as simple and global as originally thought. It became clear that a much stronger differentiation into atmospheric altitudes, latitudes and seasons would be necessary.[153,154] The phase relationships were not uniform either. In some areas a direct

141 Svensmark H. Cosmic rays and earth's climate. *Space Science Reviews* 2000, 93:155-166.

142 Svensmark H, Friis-Christensen E. Variation of cosmic ray flux and global cloud coverage - a missing link in solar-climate relationships. *Journal of Atmospheric and Solar-Terrestrial Physics* 1997, 59:1225-1232.

143 Svensmark H, Pedersen JOP, Marsh ND, Enghoff MB. Experimental evidence for the role of ions in particle nucleation under atmospheric conditions. *Proc. R. Soc. A* 2007, 463:385-396.

144 Svensmark H, Friis-Christensen E. Reply to Lockwood and Fröhlich – The persistent role of the Sun in climate forcing. *Danish National Space Center, Scientific Report 2007*, 3 (2007).

145 Svensmark H. Cosmoclimatology: A New Theory Emerges. *Astronomy & Geophysics* 2007, 48:1.18-11.24.

146 Svensmark J, Enghoff MB, Shaviv NJ, Svensmark H. The response of clouds and aerosols to cosmic ray decreases. *Journal of Geophysical Research: Space Physics* 2016, 121:8152-8181.

147 van Loon H, Brown J, Milliff RF. Trends in sunspots and North Atlantic sea level pressure. *J. Geophys. Res.* 2012, 117:D07106.

148 Gusev AA, Martin IM. Possible evidence of the resonant influence of solar forcing on the climate system. *Journal of Atmospheric and Solar-Terrestrial Physics* 2012, 80:173-178.

149 Veretenenko S, Ogurtsov M. Cloud cover anomalies at middle latitudes: Links to troposphere dynamics and solar variability. *Journal of Atmospheric and Solar-Terrestrial Physics* 2016, 149:207-218.

150 Veretenenko S, Ogurtsov M, Lindholm M, Jalkanen R. Galactic Cosmic Rays and Low Clouds: Possible Reasons for Correlation Reversal. In: Szadkowski Z, ed. *Cosmic Rays*: IntechOpen, https://www.intechopen.com/books/cosmic-rays/galactic-cosmic-rays-and-low-clouds-possible-reasons-for-correlation-reversal; 2018, 79-98.

151 Ibid 149

152 Ibid 150

153 Ibid 48

154 Ibid 67

correlation was found, but in others an inverse one. AR6 decided to reject the simplistic version of the cosmic ray amplifier and remain silent about the complexity. The debate is, however, open as Svensmark and colleagues have recently published a new work further supporting their hypothesis of a significant effect of cosmic rays on cloud formation.[155]

It is also possible that the existence of an additional astronomical forcing of the climate system is related to interplanetary dust falling on Earth. In fact, Scafetta et al. (2020)[156] found that historical records of meteorites present a quasi-60-year oscillation that correlates with the quasi-60-year cycle observed in the climate record. A 60-year cycle is also present in the eccentricity variation of the orbit of Jupiter which may regulate the dust and comets moving toward the inner planets of the solar system. Consequently, it was proposed that an interplanetary-dust forcing of interplanetary ions might modify Earth's cloud system and regulate some climate changes.

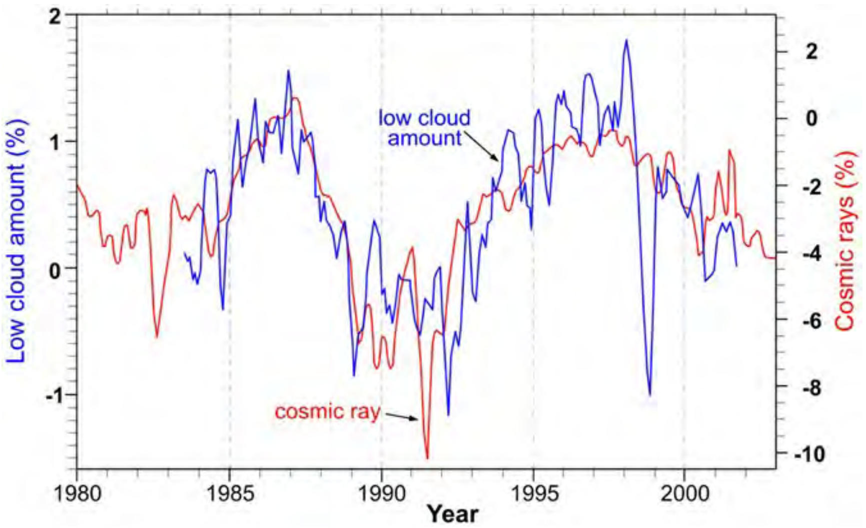


Figure 3: Correlation between cosmic radiation and global low cloud cover from 1980-2003 since the beginning of systematic cloud data collection.[157]

Climate models cannot capture the sun

In addition to the clearly discernible linear climate effects of the sun, an even greater solar influence on the climate is probably achieved via non-linear effects. A growing number of scientists are pointing out the importance of non-linear relationships.[158,159,160,161,162] The complexity of the interaction between the sun (and other astronomical bodies) and Earth's climate is not even remotely considered in the climate models. At present, neither the linear nor the non-linear processes can be formulated physically, because the solar amplifiers are still being explored. In most cases, time delays, phase shifts and climate dipoles also cannot be reproduced by the models. The inconvenient truth is that climate simulations currently have no chance of reproducing, let alone quantifying, the solar influence on Earth's climate. Strong evidence supporting this claim is that climate models fail to properly reconstruct historical warm periods known to have occurred in

155 Ibid 132

156 Scafetta, N.; Milani, F.; Bianchini, A. A 60-year cycle in the Meteorite fall frequency suggests a possible interplanetary dust forcing of the Earth's climate driven by planetary oscillations. *Geophys. Res. Lett.* 2020, 47, e2020GL089954.

157 Ibid 145

158 Ratnam MV, Santhi YD, Kishore P, Rao SVB. Solar cycle effects on Indian summer monsoon dynamics. *Journal of Atmospheric and Solar-Terrestrial Physics* 2014, 121, Part B:145-156.

159 Wurtzel JB, Black DE, Thunell RC, Peterson LC, Tappa EJ, Rahman S. Mechanisms of southern Caribbean SST variability over the last two millennia. *Geophysical Research Letters* 2013, 40:5954-5958.

160 Lu H, Gray LJ, White IP, Bracegirdle TJ. Stratospheric Response to the 11-Yr Solar Cycle: Breaking Planetary Waves, Internal Reflection, and Resonance. *Journal of Climate* 2017, 30:7169-7190.

161 Kossobokov V, Le Mouël J, Courtillot V. On the Diversity of Long-Term Temperature Responses to Varying Levels of Solar Activity at Ten European Observatories. *Atmospheric and Climate Sciences* 2019, 9:498-526.

162 Le Mouël J-L, Lopes F, Courtillot V. A Solar Signature in Many Climate Indices. *Journal of Geophysical Research: Atmospheres* 2019, 124:2600-2619.

the Holocene such as the Medieval Warm Period.[163,164] It sounds like a joke when these historical warm periods are denied using the results of these deficient models.[165,166,167]

The situation is somewhat reminiscent of the debate on plate tectonics more than half a century ago. For a long time, scholars were reluctant to believe that the continents could be mobile and that they would constantly regroup and separate in the course of Earth's history. However, when more and more supporting evidence was found from 1960 onwards, the thinking quickly began to change. Alfred Wegener's idea had posthumously prevailed against all odds.

IPCC has progressively downgraded the sun

IPCC reports have been issued since 1990. In the second report, called SAR, the IPCC attributed a radiative forcing value of +0.30 W/m^2 to solar variability. The greater this value, the larger the solar contribution to warming over the past 170 years. The value remained the same in the third report in 2001. The 4th Assessment report, however, reduced the value to +0.12 W/m^2. In the 5th report, the radiative forcing dropped to +0.05 W/m^2. AR6 also uses a very small value. The value is dwarfed by the suggested warming potential of CO_2 which the AR6 sets at +2.16 W/m^2.

The attribution of the possible one degree C of global warming that occurred since the end of the Little Ice Age in 1850 AD is far from trivial. AR6 acknowledges *"that solar activity during the second half of the 20th century was in the upper decile of the range"* (chapter 2.2.1). Theoretically, this recent boost in solar activity might have contributed to warming if suitable amplifiers were considered. Another AR6 statement, however, is strongly misleading. The IPCC claims: *"New reconstructions of TSI over the 20th century [...] support previous results that the TSI averaged over the solar cycle very likely increased during the first seven decades of the 20th century and decreased thereafter."* Based on sunspots the strongest solar cycle may have indeed occurred around 1960 (Figure 4). However, this heating pulse of a few years is too short to have a long-term effect. Whilst the subsequent solar cycle in the 1970s was weak, the following three sunspot cycles in the late 20th and early 21st century were rather strong (orange lines in Figure 4). Their *cumulative* effect could have helped to warm Earth's climate, if the IPCC allowed suitable solar amplifiers in their equations.

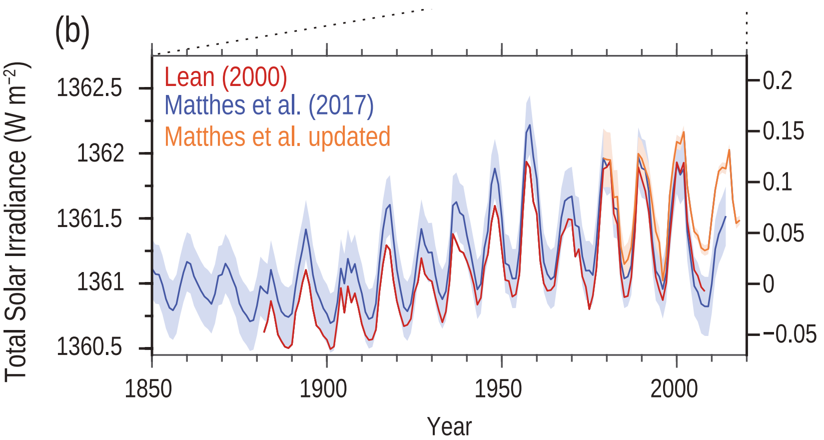


Figure 4: Development of total solar irradiance. This figure is Fig. 2.2b from AR6 (WG1, page 2-172).

163 Ibid 78

164 Ibid 79

165 Feulner G. Are the most recent estimates for Maunder Minimum solar irradiance in agreement with temperature reconstructions? *Geophysical Research Letters* 2011, 38:1-4.

166 IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change:* Cambridge University Press; 2021.

167 Ibid 3

A major problem is that the TSI forcing chosen for the CMIP6 GCMs is that proposed by Matthes et al. (2017)[168]. This TSI record is a combination of two TSI records (NRLTSI2 and SATIRE) that show a very small secular variability while many other TSI reconstructions show a much larger, up to about 10 times, larger secular variability and also slightly different patterns.[169,170,171] Moreover, the TSI recommended for the CMIP6 GCMs also decreases slightly since 1980, which roughly agrees with the TSI satellite composite proposed by PMOD. This decreasing pattern is important because it is usually cited as excluding solar forcing as a driver for the warming observed since the 1980s.

In AR6, the IPCC again fails to properly address the uncertainty and controversies regarding the competing TSI satellite composites from the ACRIM and PMOD science teams. Indeed, the TSI satellite composite proposed by the ACRIM team suggests that TSI has increased from 1980 to 2000 and slightly decreased afterward. The ACRIM TSI decadal pattern correlates well with the global surface temperature record. The main difference between the ACRIM and PMOD TSI satellite composites is that while the former uses the original raw satellite TSI records, the latter is based on TSI satellite records modified with a model. However, the original experimental science teams responsible for the measurements have consistently rejected the PMOD model-based modifications as physically unjustified. Moreover, Scafetta et al. (2019)[172] have recently reviewed the controversy and concluded that even the original NRLTSI2 and SATIRE data, when properly analysed, contradict the data modifications proposed by PMOD. This result calls into question the validity of all three records used by the CMIP6 GCMs to justify their claim that the solar effect on climate is negligible. Connolly et al. (2021)[173] provide more detail on these issues.

Conclusions

The IPCC has once again missed an opportunity to address natural climate drivers in a balanced and fair way. Notably, AR5 argued cautiously that "more than half" of the observed warming of the past 170 years was of anthropogenic origin. This left up to 49% for natural climate drivers. The IPCC Special Report on the 1.5 °C goal (SR15, 2018) then jumped to 100% anthropogenic causes, leaving no room for natural climate change contributions. AR6 stuck to this narrative from three years earlier.

It is very clear from pre-industrial times that significant natural climate change similar to observed modern climate change has existed in the past and probably still exists. In many of the case studies, a solid solar influence was detected. Yet, the AR6 report presents a severely biased view of the solar role in the climate equation: it cherry-picks solar forcing that minimizes the solar effect without properly addressing the uncertainties and controversies surrounding this topic and by ignoring the scientific literature addressing it. The IPCC authors do not appear to be interested in exploring solar amplifiers or alternative solar forcing proposals. Connolly et al. (2021)[174] propose how a properly critical analysis of this debate should be conducted. The views of the IPCC must be revised, it is just a matter of time.

The public should not ignore the fact that the IPCC is a politically controlled organisation in which the IPCC bureau handpicks authors and review editors. Scientists supporting a stronger role of

---

168 Matthes, K., Funke, B., Andersson, M. E., Barnard, L., Beer, J., Charbonneau, P., Clilverd, M. A., Dudok de Wit, T., Haberreiter, M., Hendry, A., Jackman, C. H., Kretzschmar, M., Kruschke, T., Kunze, M., Langematz, U., Marsh, D. R., Maycock, A. C., Misios, S., Rodger, C. J., Scaife, A. A., Seppälä, A., Shangguan, M., Sinnhuber, M., Tourpali, K., Usoskin, I., van de Kamp, M., Verronen, P. T., and Versick, S.: Solar forcing for CMIP6 (v3.2), Geosci. Model Dev., 10, 2247–2302.

169 Egorova, T.; Schmutz,W.; Rozanov, E.; Shapiro, A.I.; Usoskin, I.; Beer, J.; Tagirov, R.V.; Pete, T. Revised historical solar irradiance forcing Revised historical solar irradiance forcing. *A&A* 2018, 615, A85.

170 Hoyt, D.V.; Schatten, K.H. A discussion of plausible solar irradiance variations, 1700–1992. *J. Geophys. Res.* 1993, 98, 895–906.

171 Scafetta, N.; Willson, R.C. ACRIM total solar irradiance satellite composite validation versus TSI proxy models. *Astrophys. Space Sci.* 2014, 350, 421–442.

172 Scafetta, N.; Willson, R.C.; Lee, J.N.; Wu, D.L. Modeling Quiet Solar Luminosity Variability from TSI Satellite Measurements and Proxy Models during 1980–2018. *Remote Sens.* 2019, 11, 2569.

173 Ibid 1

174 Ibid 1

natural climate change in modern climate are typically excluded from the authorship of IPCC reports. But in the long run, facts and observations will prevail and the current uncertainties will be properly solved and the numerous empirical findings supporting a significant solar (or otherwise astronomical) effect on the climate will be confirmed.

Many topics in the climate sciences are poorly understood. The science is far from settled. Nevertheless, evidence for large natural forcings firms up with every year of additional research. It will therefore get easier and easier to fully acknowledge the significant influence that the Sun, ocean cycles ("modes of variability") and other natural drivers have on the complex climate system.

7 Misty Climate Sensitivity

BY MARCEL CROK

How sensitive the climate is for greenhouse gases like CO_2 remains one of the most important issues of our time. In most reports the IPCC claimed a doubling of CO_2 will give 3°C of warming with an uncertainty range of 1.5°C to 4.5°C. In AR6, strongly influenced by one particular 2020 review paper, the best estimate for climate sensitivity remains 3°C but they narrowed the likely range considerably to 2.5°C to 4°C. This strongly suggests that lower values of climate sensitivity, which have also been published in the literature, are now rejected by the IPCC. But is this justified?

The climate sensitivity to CO_2 and other greenhouse gases (GHGs) is arguably one of the most important numbers in the climate change debate. Put very simply, if the climate is very sensitive to greenhouse gases and therefore climate sensitivity is high, then we can expect substantial warming in the coming century if greenhouse gas emissions are not severely reduced. If climate sensitivity is low, then future warming will be substantially lower, as will the rise in sea level.

Climate sensitivity is defined as the amount of global surface warming we get when the concentration of CO_2 in the atmosphere doubles. The term generally refers to the rise in temperature once the climate system has fully warmed up, a process taking over a thousand years due to the enormous heat capacity of the ocean. This so-called 'equilibrium climate sensitivity' (ECS), is the traditional and still most widely used measure. In practice what is more commonly estimated[1] is 'effective climate sensitivity', a close approximation to ECS that is more practical to work with.

A shorter-term measure of sensitivity, transient climate response (TCR), represents the extent of global warming over a 70 year timeframe during which CO_2 concentrations double.[2] TCR can be estimated more easily than ECS, and is more relevant to projections of warming – although not sea level rise – over the rest of this century.[3]

Historically, since the Charney report in 1979[4], the best estimate for climate sensitivity has been remarkably stable (see table 1). The best estimate in the IPCC sixth assessment report (AR6) is similar to the one in the Charney report, although the latter was based on very limited information.

Van der Sluijs (1998)[5] considered the reasons why the range for climate sensitivity has changed so little over a period in which the science has evolved enormously. He concluded that the range was only partly determined by the science itself and that many other factors played a role. One of these was 'a need to create and maintain a robust scientific basis' for policy action. We believe this observation by Van der Sluijs in 1998 is still valid today.

1 Including for global climate models. Note that by convention equilibrium climate sensitivity excludes adjustment by slow components of the climate system (e.g. ice sheets, vegetation).

2 The increase in CO_2 is specified to occur at a constant compound rate over the period, but modest fluctuations in the rate are unimportant. Estimation of TCR is unaffected by the actual rate of increase provided that the increase in global temperature is scaled appropriately, and TCR is little affected by moderate variations in the ramp period: between 60–80 years, at least.

3 Although TCR is easier to estimate, unlike ECS it does not have a useful interpretation in terms of the physics of the climate system. TCR is lower than ECS because heat going into the ocean contributes to the value of ECS but not to TCR.

4

5 J.P. van der Sluijs et al. (1998).

Table 1: Evolution of equilibrium climate sensitivity estimates in the last 42 years and the range for transient climate response since 2007

	ECS RANGE (°C)	ECS BEST ESTIMATE (°C)	TCR RANGE (°C)
Charney Report 1979	1.5–4.5	3	
NAS Report 1983	1.5–4.5	3	
Villach Conference 1985	1.5–4.5	3	
IPCC FAR 1990	1.5–4.5	2.5	
IPCC SAR 1995	1.5–4.5	2.5	
IPCC TAR 2001	1.5–4.5	3	
IPCC AR4 2007	2–4.5[6]	3	1–3[7]
IPCC AR5 2013	1.5–4.5[8]	None given	1–2.5[9]
IPCC AR6 2021	2.5-4	3	1.4-2.2[10]

Table 1 shows the evolution of both the range and the best estimate of ECS over the last 42 years. As one can see, the best estimate did not change much. However, in AR6, the IPCC narrowed its likely range considerably claiming values below 2.5°C are now less likely.

A Sensitive Matter

After the publication of the IPCC AR5 report, the British independent scientist Nic Lewis and the Dutch independent science writer Marcel Crok wrote an extensive report[11] – titled *A Sensitive Matter* – in which they explained how the IPCC "hid good news about global warming". In their report they detailed that during the production process of AR5 several papers had been published, based on observations in the 'historical period' (the period since 1850), that indicated a considerably lower estimate of ECS than those estimates based on General Circulation Models (GCMs). The CMIP5 models, on average, had a climate sensitivity of more than 3°C while observations indicated ECS values between 1.5 and 2°C.

In their report Crok and Lewis observed that the IPCC was confronted with a dilemma:

> In our view, the IPCC WGI scientists were saddled with a dilemma. How should they deal with the discrepancy between climate sensitivity estimates based on models and sound observational estimates that are consistent with the new evidence about aerosol cooling? In conjunction with governments – who have the last say on the wording of the SPM – they appear to have decided to resolve this dilemma in the following way. First, they changed the 'likely' range for climate sensitivity slightly. It was 2–4.5°C in AR4 in 2007. They have now reduced the lower bound to 1.5°C, making the range 1.5–4.5°C. By doing this they went some way to reflect the new, lower estimates that have been published recently in the literature.

They also decided not to give a best estimate for climate sensitivity. The tradition of giving a best estimate for climate sensitivity goes all the way back to the Charney report in 1979, and all subsequent IPCC reports (except the third assessment report in 2001) gave one as well. In AR4 the best estimate was 3°C. At the time of approval of the SPM by governments in September 2013, the decision not to give a best estimate for climate sensitivity was mentioned only in a footnote in the SPM, citing 'a lack of agreement on values across assessed lines of evidence and studies'. Only in the final report, published in January 2014, was a paragraph added in the Technical Summary giving slightly more explanation.

6 Likely (17–83%) range. Prior to AR4, ranges were not clearly defined in probabilistic terms.
7 10–90% range.
8 Likely range.
9 Likely range.
10 The IPCC now also gave a best estimate for TCR of 1.8°C (page 927)
11 A Sensitive Matter, Nicholas Lewis and Marcel Crok, GWPF (2014),

So, to deal with the new estimates for ECS that were based mostly on observations since 1850 (instead of on models) the IPCC *lowered* the lower bound of their likely range back to 1.5°C, where it was most of the times since the Charney report. Furthermore, due to a lack of agreement between different lines of evidence (i.e. mainly between observational estimates and models) they gave no best estimate, which was quite remarkable because the same report claimed the IPCC was more certain than ever that humans were the main cause of global warming.

The AR5 report was published in 2013 and the AR6 Working Group 1 report was published in 2021. So the IPCC community has had eight years of time to figure out how they had to deal with these 'different lines of evidence'.

The importance of high climate sensitivity

Now before we go into the details of how the climate community 'solved' this problem, let's dwell on the importance of a 'high' or 'low' climate sensitivity for a moment. A high climate sensitivity makes the climate problem 'urgent' as we can expect a lot of warming with continuing CO_2 emissions. A high climate sensitivity means the climate models – in which the community has invested a lot, both in terms of money and their credibility – are 'right'. A 'low' climate sensitivity is good news for all, but makes the case for urgent climate measures much weaker.

A 'low' climate sensitivity would also mean that well-known climate sceptics – like Richard Lindzen or Roy Spencer – who have claimed for many years that sensitivity is 'low', were right after all. Stephen Schneider, a well-known climate scientist who passed away in 2010, wrote the book *Science as a Contact Sport*. Of course it is, science is also about careers, citation indexes, funding, fame etc. There is a lot at stake here, a 'low' climate sensitivity would not only mean that the climate community was 'wrong' for a long time, it could also mean that in the future less money will flow to climate science departments.

Suppose for a brief moment that climate change was not a highly polarized and politicized issue. Scientifically speaking we have a quite normal situation that happens all the time in science, a discrepancy between theory and observations. Climate models (theory) have a climate sensitivity of more than 3°C, mainly as a result of positive feedbacks, principally water vapour and cloud feedbacks, which amplify the initial warming that is caused by an increase of CO_2 and other greenhouse gases. However, estimates based on observations over the period 1850 till now indicate that climate sensitivity is much lower, around 2°C or possibly closer to 1.5°C. In 'normal' science, scientists would give the observational estimates the benefit of the doubt. There must be something wrong with the models. However, given all the interests that are at stake – i.e. to keep climate change an urgent issue or as Van der Sluijs wrote in 1998 to 'maintain a robust scientific basis' for policy action – this was not really an option for the climate community and the IPCC. So their 'favoured' outcome was to prove that the historical estimates since 1850 were 'wrong'. And they 'succeeded' in this. It's a fascinating story.

First the outcome. In AR6 the IPCC is back with a best estimate for ECS of 3°C. Looking at Table 1 this doesn't stand out, as this estimate is similar to the estimate in the 1979 Charney report. But in fact it is quite surprising because the observations since 1850 indicate a much lower ECS, between 1.5 and 2°C. So apparently, the IPCC has found a way to discard or adjust those estimates in favour of higher values.

Spectacular new likely range

But even more surprising, indeed 'spectacular', is the new likely range of 2.5 to 4°C. Remember, in AR4 (2007) they raised the lower bound of ECS to 2°C, but then had to lower it back to the 'normal' 1.5°C in AR5 (2013) due to the new observational estimates for ECS. Now they have raised it to 2.5°C and narrowed the likely range to 2.5-4°C. The likely range has never previously been as small (narrow) as this. The message is clear: the IPCC is now more certain about ECS than ever and finds values below 2.5°C and above 4°C unlikely. Or in their words:

> Based on multiple lines of evidence the best estimate of ECS is 3°C, the likely range is 2.5°C to 4°C, and the very likely range is 2°C to 5°C. It is virtually certain that ECS is larger than 1.5°C. [page 926]

It is now tempting to think that the IPCC 'chose' for the ECS of climate models and discarded the observational estimates. But this is not the case. In fact, the IPCC made it clear that climate models (i.e. GCM's) are not considered as a line of evidence in AR6 (our bold):

> All four lines of evidence rely, to some extent, on climate models, and interpreting the evidence often benefits from model diversity and spread in modelled climate sensitivity. Furthermore, high-sensitivity models can provide important insights into futures that have a low likelihood of occurring but that could result in large impacts. But, **unlike in previous assessments, climate models are not considered a line of evidence in their own right** in the IPCC Sixth Assessment Report. [page 1024].

This change of heart regarding models likely reflects an increasing divergence between ECS values in different GCMs; ECS values for the new generation (CMIP6) models used in AR6 range from 1.8°C to 5.6°C. Moreover, a significant number of these GCMs have ECS values exceeding 4.5°C, and are widely considered to be implausibly sensitive.

The Sherwood paper

In 2015 over thirty experts attended a week-long workshop in Ringberg Castle to assess gaps in understanding of Earth's climate sensitivities. The workshop was organised under the auspices of the World Climate Research Programme (WCRP) Grand Science Challenge on Clouds, Circulation and Climate Sensitivity. Nic Lewis attended this workshop and gave a talk.

This WCRP-initiated and supported assessment process culminated in the publication in 2020 of a 92-page review paper by Steven Sherwood and 24 co-authors titled "An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence".[12] The paper has been extremely influential, including in informing the assessment of equilibrium climate sensitivity (ECS) in the 2021 IPCC Sixth Assessment Scientific Report (AR6); it was cited over twenty times in the relevant AR6 chapter 7. Lewis was not asked to be a co-author or reviewer of that paper.

Since the Ringberg workshop was held, Lewis had published papers concerning how to combine multiple lines of evidence regarding climate sensitivity using an Objective Bayesian statistical approach.[13] Disappointingly for Lewis, Sherwood et al. instead used the common Subjective Bayesian method that, while simpler, his research had showed may result in unrealistic estimates and uncertainty ranges. Lewis therefore decided to replicate the Sherwood et al. paper, to implement an Objective Bayesian approach, and also to review the paper's choice of probabilistic estimates for the input assumptions used. In doing so Lewis discovered another, more fundamental and potentially more serious, statistical problem in the Sherwood paper, as well as important conceptual errors and inconsistencies. He also found that after fixing these problems and also substituting values derived from more recent sources of evidence, including AR6, for certain of the data-variable estimates used, the resulting estimate of climate sensitivity fell substantially.

Here is the full abstract of the paper that Lewis published in 2022, so a year after the IPCC report was published (our bold):[14]

12 Sherwood, S.C. et al., 2020: An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence. Reviews of Geophysics, 58(4), e2019RG000678, doi:10.1029/2019rg000678

13 All his peer reviewed papers can be found here: https://nicholaslewis.org/peer-reviewed-publications/

14 Lewis (2022) Objectively combining climate sensitivity evidence. Climate Dynamics, doi.org/10.1007/s00382-022-06468-x

> Recent assessments of climate sensitivity per doubling of atmospheric CO_2 concentration have combined likelihoods derived from multiple lines of evidence. These assessments were very influential in the Intergovernmental Panel on Climate Change Sixth Assessment Report (AR6) assessment of equilibrium climate sensitivity, the likely range lower limit of which was raised to 2.5°C (from 1.5°C previously). This study evaluates the methodology of and results from a particularly influential assessment of climate sensitivity that combined multiple lines of evidence, Sherwood et al. (2020). That assessment used a subjective Bayesian statistical method, with an investigator-selected prior distribution. This study estimates climate sensitivity using an Objective Bayesian method with computed, mathematical priors, since subjective Bayesian methods may produce uncertainty ranges that poorly match confidence intervals. Identical model equations and, initially, identical input values to those in Sherwood et al. are used. This study corrects Sherwood et al.'s likelihood estimation, producing estimates from three methods that agree closely with each other, but differ from those that they derived. Finally, the selection of input values is revisited, where appropriate adopting values based on more recent evidence or that otherwise appear better justified. **The resulting estimates of long-term climate sensitivity are much lower and better constrained (median 2.16°C, 17–83% range 1.75–2.7°C, 5–95% range 1.55–3.2°C) than in Sherwood et al. and in AR6 (central value 3°C, very likely range 2.0–5.0°C).** This sensitivity to the assumptions employed implies that climate sensitivity remains difficult to ascertain, and that **values between 1.5°C and 2°C are quite plausible.**

This is quite spectacular. After correcting the Sherwood et al. methods and revising key input data to reflect more recent evidence, the central estimate for climate sensitivity comes down from 3.1°C per doubling of CO_2 concentration in the original study to 2.16°C in the new paper. The results of Lewis' analysis determined a likely range of 1.75 to 2.7°C for climate sensitivity, even narrower than the new range used by the IPCC (2.5-4°C), but much lower.

The central estimate from Lewis' analysis - 2.16°C - is well below the IPCC AR6 likely range of 2.5-4°C. This large reduction relative to Sherwood et al. shows how sensitive climate sensitivity estimates are to input assumptions. Lewis' analysis implies that climate sensitivity is more likely to be below 2°C than it is to be above 2.5°C. One wonders what would have happened if the Sherwood group (consisting of the who's who in the climate sensitivity field) had invited Nic Lewis to join their effort. Now the estimates in the Sherwood paper have instantly become the new 'golden standard' in the IPCC report and this will remain so until at least the next IPCC report will be published, but that will be only six or seven years from now. So in the coming years policy makers will all assume that a 'low' climate sensitivity is more unlikely than ever since the Charney report in 1979 was published. Although their own method, if used correctly, shows the opposite, that ECS is likely on the low side.

Different lines of evidence

So what did Sherwood et al. use exactly as their evidence? They combined evidence based on several different lines of evidence: process understanding (feedback analysis), the historical period (instrumental) record, and paleoclimate data from both warm and cold periods. The cold paleoclimate evidence concerned changes between the last glacial maximum (LGM) and preindustrial periods. Sherwood et al. analysed paleoclimate data from two warm periods, the mid-Pliocene warm period (mPWP) and the more distant Paleocene-Eocene Thermal Maximum (PETM), but did not use PETM data in their main results. Thus, Sherwood et al. used three main lines of evidence (Process, Historical and Paleoclimate), with LGM and mPWP evidence being combined to represent Paleoclimate evidence.

Lewis agrees that "this is a strong scientific approach, in that it utilizes a broad base of evidence and avoids direct dependence on GCM climate sensitivities. Such an approach should be able to provide more precise and reliable estimation of climate sensitivity than that in previous IPCC assessment reports."[15]

In a detailed explanatory article[16] about the paper Lewis showed how the changes in input data and statistical methods led to different outcomes for climate sensitivity compared to the original paper by Sherwood et al:

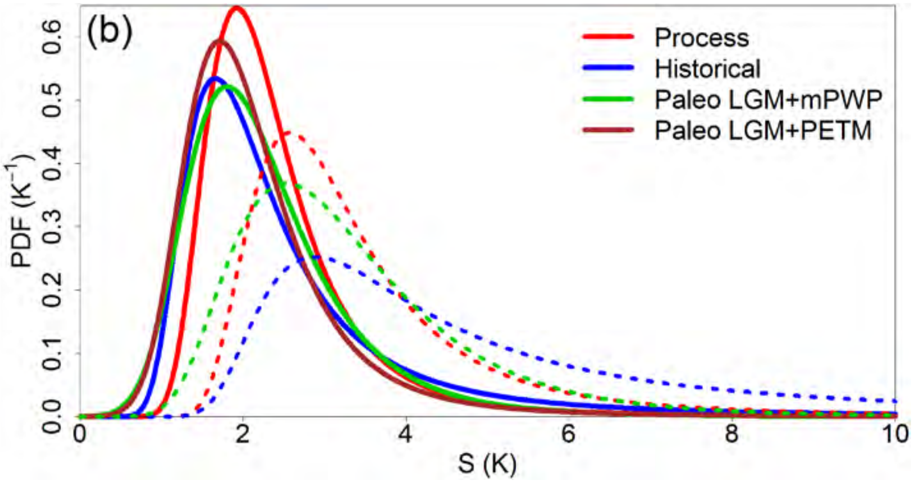


Figure 1: Posterior Probability Density Functions for S (= climate sensitivity) based on the revised (solid lines) and original data variable assumptions (dotted lines).

The probability density functions (representing the probable values of the estimated parameter for climate sensitivity) in the Lewis paper are much more constrained than in the original Sherwood paper and the different lines of evidence also show similar outcomes.

Historical estimates

The 2014 Lewis/Crok report stated that at that moment observational estimates for climate sensitivity, based on the historical (instrumental) period, were 'superior':

> So, to conclude, we think that of the three main approaches for estimating ECS available today (instrumental observation based, palaeoclimate proxy observation based, and GCM simulation/feedback analysis based), instrumental estimates – in particular, those based on warming over a substantial period extending to the twenty-first century – **are superior by far**. Observationally based estimates give the best indication of how our current climate has actually been reacting to the increase in greenhouse gases. [A Sensitive Matter, page 37]

Now of course scientists involved in the IPCC report are free to disagree with that view. In the years since AR5 Lewis together with well-known climate scientist Judith Curry has published two peer reviewed papers[17], based on the historical period since 1850, to estimate both ECS and TCR. The most recent paper was published in 2018 and is referenced several times in the AR6 report. Here is the abstract (our bold):[18]

> Energy budget estimates of equilibrium climate sensitivity (ECS) and transient climate response (TCR) are derived based on the best estimates and uncertainty ranges for forcing pro-

15 Lewis published a detailed commentary about his peer reviewed paper, available here: https://nicholaslewis.org/wp-content/uploads/2022/09/Lewis_Objectively-combining-climate-sensitivity-evidence_2022-Clim-Dyn-Detailed-Summary.pdf

16 https://nicholaslewis.org/wp-content/uploads/2022/09/Lewis_Objectively-combining-climate-sensitivity-evidence_2022-Clim-Dyn-Detailed-Summary.pdf

17 Lewis, N. and J.A. Curry, 2015: The implications for climate sensitivity of AR5 forcing and heat uptake estimates. Climate Dynamics, 45(3–4), 1009–1023, doi:10.1007/s00382-014-2342-y; Lewis, N. and J. Curry, 2018: The Impact of Recent Forcing and Ocean Heat Uptake Data on Estimates of Climate Sensitivity. Journal of Climate, 31(15), 6051–6071, doi:10.1175/jcli-d-17-0667.1.

18 Lewis, N. and J. Curry, 2018: The Impact of Recent Forcing and Ocean Heat Uptake Data on Estimates of Climate Sensitivity. Journal of Climate, 31(15), 6051–6071, doi:10.1175/jcli-d-17-0667.1.

vided in the IPCC Fifth Assessment Report (AR5). Recent revisions to greenhouse gas forcing and post-1990 ozone and aerosol forcing estimates are incorporated and the forcing data extended from 2011 to 2016. Reflecting recent evidence against strong aerosol forcing, its AR5 uncertainty lower bound is increased slightly. Using an 1869–82 base period and a 2007–16 final period, which are well matched for volcanic activity and influence from internal variability, **medians are derived for ECS of 1.50 K** (5%–95% range: 1.05–2.45 K) and for TCR of 1.20 K (5%–95% range: 0.9–1.7 K). These estimates both have much lower upper bounds than those from a predecessor study using AR5 data ending in 2011. Using infilled, globally complete temperature data give slightly higher estimates: **a median of 1.66 K for ECS** (5%–95% range: 1.15–2.7 K) and 1.33 K for TCR (5%–95% range: 1.0–1.9 K). **These ECS estimates reflect climate feedbacks over the historical period, assumed to be time invariant. Allowing for possible time-varying climate feedbacks increases the median ECS estimate to 1.76 K (5%–95% range: 1.2–3.1 K), using infilled temperature data.** Possible biases from non–unit forcing efficacy, temperature estimation issues, and variability in sea surface temperature change patterns are examined and found to be minor when using globally complete temperature data. **These results imply that high ECS and TCR values derived from a majority of CMIP5 climate models are inconsistent with observed warming during the historical period.**

Here is the table with their key results:

Table 2: Best estimates (medians) and uncertainty ranges for ECS and TCR using the base and final periods indicated. Values in roman type compute ΔT using the HadCRUT4v5 dataset; values in italics compute ΔT using the infilled, globally complete Had4_krig_v2 dataset. The preferred estimates are shown in boldface. LC15 refers to the earlier paper by Lewis and Curry in 2015. Source: table 3 in Lewis and Curry 2018.

BASE PERIOD	FINAL PERIOD	ECS BEST ESTIMATE (K)	ECS 17%-83% RANGE (K)	ECS 5%-95% RANGE (K)	TCR BEST ESTIMATE (K)	TCR 17%-83% RANGE (K)	TCR 5%-95% RANGE (K)
1869-82	**2007-16**	**1.50**	**1.2-1.95**	**1.05-2.45**	**1.20**	**1.0-1.45**	**0.9-1.7**
		1.66	***1.35-2.15***	***1.15-2.7***	***1.33***	***1.1-1.6***	***1.0-1.9***
1869-82	1995-2016	1.56	1.2-2.1	1.05-2.75	1.22	1.0-1.5	0.85-1.85
		1.69	*1.35-2.25*	*1.15-3.0*	*1.32*	*1.1-1.65*	*0.95-2.0*
1850-1900	1980-2016	1.54	1.2-2.15	1.0-2.95	1.23	1.0-1.6	0.85-1.95
		1.67	*1.3-2.3*	*1.1-3.2*	*1.33*	*1.05-1.7*	*0.9-2.15*
1930-50	2007-16	1.56	1.2-2.15	1.0-3.0	1.20	0.95-1.5	0.85-1.85
		1.65	*1.25-2.3*	*1.05-3.15*	*1.27*	*1.05-1.6*	*0.9-1.95*
LC15 results for comparison							
1859-82	1995-2011	1.64	1.25-2.45	1.05-4.05	1.33	1.05-1.8	0.9-2.5
1850-1900	1987-2011	1.67	1.25-2.6	1.0-4.75	1.31	1.0-1.8	0.85-2.55

These results are quite spectacular. Depending on the dataset used, their 'preferred' estimate of ECS is either 1.5°C or 1.66°C. Two years later, the IPCC, in AR6, decided that the best estimate for ECS is 3°C, so (almost) double the value found by Lewis and Curry 2018 and far outside its likely range of 1.35-2.15°C. Moreover, the AR6 historical period ECS best estimate using the same 'energy budget' method as Lewis and Curry (2018) is even higher, at 3.5°C.[19] So apparently, the IPCC has reasons to dismiss the 2018 results of Lewis and Curry. What are those reasons?

Part of the explanation is that AR6 revised up the estimated historical rises in aerosol cooling strength, in global surface temperature and in ocean heat uptake, and revised down the estimated warming effect of methane, relative to the best estimates when Lewis and Curry 2018 was produced. Time will tell to what extent these revised data estimates adopted by AR6 are justified.
In his 2022 paper, Lewis used the same surface temperature dataset as Sherwood (2020) while adopting all the other AR6 data estimates save for its major upward revision of AR5's aerosol cooling strength assessment, which (after a detailed review of recent evidence) he partially adopted. Doing so increased the ECS best estimate to just over 2°C. If the AR5 estimate of aerosol cooling strength had been retained, the ECS estimate would have been only 1.8°C. Even adopting all the

19 Section 7.5.2.1, page 997

AR6 data estimate revisions in full would only result in an historical period energy budget ECS estimate of 2.5°C, not actual the AR6 assessment of 3.5°C.

The pattern effect

The explanation for the 1°C further increase is really fascinating. The IPCC invoked a so-called 'pattern effect' to increase the 'low' estimates based on the historical period. Here is what they write in the executive summary of chapter 7 in AR6 (our bold):

> Radiative feedbacks, particularly from clouds, **are expected to become less negative (more amplifying)** on multi-decadal time scales **as the spatial pattern of surface warming evolves, leading to an ECS that is higher than was inferred in AR5 based on warming over the instrumental record.** This new understanding, along with updated estimates of historical temperature change, ERF, and Earth's energy imbalance, reconciles previously disparate ECS estimates (high confidence). [page 926]

As we will explain, this is quite a Houdini act by the IPCC community! Most readers will probably have never heard about a 'pattern effect', which is meant by 'the spatial pattern of surface warming' in the AR6 paragraph above. And it's rather complicated, so let's discuss it step by step. ECS is the long term warming after a doubling of the CO_2 concentration. Since 1850 the CO_2 concentration has been increasing but not yet doubled. A high climate sensitivity of 3°C or higher implies that climate feedbacks are positive, i.e. they amplify the initial radiative warming effect of CO_2 and other greenhouse gases.

The idea that the climate science community has now launched is that initially the climate feedbacks don't operate in full power yet (so they don't amplify to their full potential yet), but eventually they will. However, when you estimate ECS based on the historical period you are misguided because the implied feedbacks over this period are not representative for the full period over which ECS has to be determined (theoretically until a new equilibrium in the climate system has been established, which can take over a thousand years).

Smart readers will now ask: how do we know the feedbacks in the system will eventually get stronger? Good question! The short and simple answer is: because models say so!

We note in passing that Lewis and Curry 2018 also gave an ECS estimate that allowed probabilistically for the pattern effect in GCMs. Doing so increased the main 1.66°C ECS estimate, but only to 1.76°C. So not to 3.5°C.

The Carbon Brief website had a good article[20] explaining the evolving thinking of the climate community with respect to observational estimates over the historical period. Here is a lengthy excerpt from that article (our bold):

> One important insight is that the strength of climate feedbacks is expected to change over time, with s**tronger feedbacks taking longer to emerge**.
> A 2017 paper by Dr Cristian Proistosescu and Prof Peter Huybers at Harvard University found that **amplifying feedbacks** that play a large role in ECS in climate models **have not fully kicked in for current climate conditions**. A similar paper by Prof Kyle Armour of the University of Washington suggests feedbacks will increase by about 25% from today's transient warming as the Earth moves towards equilibrium.
> This means that **sensitivity estimates based on instrumental warming to date would be on the low side, as they would not capture the larger role of feedbacks in future warming.** The authors suggest that "**accounting for these…brings historical records into agreement with model-derived ECS estimates**".

20 https://www.carbonbrief.org/explainer-how-scientists-estimate-climate-sensitivity/

> This is in part because feedbacks **depend strongly on the spatial pattern of warming.** Prof Armour elaborates in a discussion on the Climate Lab Book website:
>
> > "**Nearly all GCMs** [global climate models] show global radiative feedbacks changing over time under forcing, with effective climate sensitivity increasing as equilibrium is approached. As a result, **climate sensitivity estimated from transient warming appears smaller than the true value of ECS…**
> > As far as we can tell, the physical reason for this effect is that the **global feedback depends on the spatial pattern of surface warming, which changes over time**…One nice example is the sea-ice albedo feedback in the Southern Ocean: because warming has yet to emerge there, that positive (destabilising) feedback has yet to be activated.
> > This means that **even perfect knowledge of global quantities** (surface warming, radiative forcing, heat uptake) **is insufficient to accurately estimate ECS**; you also have to predict how radiative feedbacks will change in the future."
>
> Prof Andrew Dessler agrees, telling Carbon Brief that **an understanding of how the pattern of surface warming influences sensitivity is one of the major advances in our understanding of climate sensitivity in recent years.** He suggest that it "allows us to **resolve the discrepancy** between the 20th century [instrumental] estimates and other estimates that give higher values".

You have to admit, from their perspective – cherishing high estimates of climate sensitivity including those based on the GCMs – this is a brilliant way out. They dismiss the 'low' climate sensitivity estimates based on the historical period (the only period in climate history for which we have at least a reasonable amount of measurement data), because feedbacks **will get** stronger in the future. How do they know that? Well, again, the models say so. But how do we know the models are realistic? Answer: we don't know.

Even Prof Amour's 'nice example' of as-yet inactive positive sea-ice albedo feedback in the Southern Ocean (around Antarctica) may well be incorrect. A 2019 paper on this subject concluded that "Observed changes in Antarctic sea ice are poorly understood" and that it was unclear whether Antarctic sea-ice albedo feedback would actually be positive.[21]

Not surprisingly, Nic Lewis has also looked into this 'pattern effect' as it is used against his and other's 'low' estimates of climate sensitivity based on the historical period. So in Lewis and Curry 2018 they responded to these concerns of the climate community concluding:

> We have also shown that various concerns that have been raised about the accuracy of historical period energy budget climate sensitivity estimation are misplaced. We assess **nil bias** from either non–unit forcing efficacy or **varying SST warming patterns**, and that any downward estimation bias when using blended infilled surface temperature data is trivial.

The AR6 authors essentially agreed with Lewis and Curry's assessments on these issues except in relation to 'varying SST warming patterns'. There they doubled down, claiming not only that (per GCMs) greenhouse gas-forced feedbacks would become more positive over time, but that also the historical period SST warming pattern was strongly affected by unforced (natural) internal variability that caused climate feedback to appear abnormally small.

In 2021 Lewis published a paper with Thorsten Mauritsen, who was also lead author of the IPCC chapter 7, dealing specifically with the pattern effect. It's title was "**Negligible unforced historical pattern effect** on climate feedback strength found in HadISST-based AMIP simulations".[22] They concluded (our bold):

21 Frew, RC, et al., 2019: Sea Ice–Ocean Feedbacks in the Antarctic Shelf Seas. Journal of Physical Oceanography 49.9 (2019): 2423-2446. doi:10.1175/JPO-D-18-0229.1

22 Lewis, N. and Mauritsen, T., 2021: Negligible unforced historical pattern effect on climate feedback strength found in HadISST-based AMIP simulations. *Journal of Climate*, 1-52, https://doi.org/10.1175/JCLI-D-19-0941.1

In this study **we have found no evidence for a substantial unforced pattern effect over the historical period**, arising from internal variability, in the available sea surface temperature datasets, save for when the AMIPII and ERSSTv5 datasets are used. Our results imply that the evidence suggesting existing constraints on EffCS from historical period energy budget considerations are biased low due to unusual internal variability in SST warming patterns is too weak to support such conclusion, and suggest that any such bias is likely to be small and of uncertain sign.'

Their paper is mainly a reply to a 2018 paper by Andrews et al.[23] which claims that the pattern effect leads to an underestimation of ECS based on the historical period of 40%. Lewis and Mauritsen showed in their paper that climate feedback estimates are far from robust to choice of historical SST dataset, and that when the widely used HadISST1 dataset is used in place of the AMIPII SST dataset, no unforced historical pattern effect is found with the models they used. They also investigated the unforced historical pattern effect using five other SST datasets, finding a significant estimated effect only in one case. Given these findings, when estimating ECS from historical period data in his 2022 paper, Lewis adopted a small unforced historical pattern effect, in addition to a forced pattern effect estimate that was slightly larger than that used by Andrews et a. (2018). Together these totalled some 70% of the overall pattern effect estimated in AR6.

Mauritsen was a lead author of the relevant chapter 7 in the AR6 report and his and Lewis's 2021 paper is mentioned in the chapter. This is what they had to say about it (our bold):

> Using alternative SST datasets, Andrews et al. (2018) found little change in the value of α' [the change in climate feedback arising from the pattern effect] within two models (HadGEM3 and HadAM3), while Lewis and Mauritsen (2021) found a smaller value of α' within two other models (ECHAM6.3 and CAM5). The sensitivity of results to the choice of dataset represents a major source of uncertainty in the quantification of the historical pattern effect using atmosphere-only ESMs that has yet to be systematically explored, but the preliminary findings of Lewis and Mauritsen (2021) and Fueglistaler and Silvers (2021) suggest that α' could be smaller than the values reported in Andrews et al. (2018).

A clear error by the IPCC

So, the IPCC admitted there was evidence against a large 'pattern effect' as claimed by Andrews et al. 2018. Note that the findings of Mauritsen and Lewis are called 'preliminary' while such a word is not used for the Andrews paper. Nevertheless, the IPCC concluded with 'high confidence' that the pattern effect 'reconciles previously disparate ECS estimates', meaning that there is no longer a disagreement between the 'low' estimates over the historical period and the 'high' estimates based on the models. So the pattern effect, together with a major increase in the estimated aerosol cooling strength, is how the IPCC 'solved' the 'dilemma' that Lewis and Crok discussed in their 2014 report *A Sensitive Matter*.

This of course is very unconvincing. Aerosol cooling strength remains very uncertain. And the 'pattern effect' seems to be a nice example of 'adding an epicycle', a rather ad hoc hypothesis to save an overall scientific theory.[24] Here it looks as if it was introduced to save the overall case for a high instrumental observation based climate sensitivity estimate.

Worse, both Sherwood (2020) and AR6 convert their feedback strength estimates into ECS estimates using a value for the forcing from a doubling of CO_2 concentration that is computed on a basis inconsistent with their feedback estimates. While this inconsistency is likely due to incompetence rather than a deliberate ploy, Lewis (2022) estimates that it artificially increases both the historical period energy budget based, and the process understanding based, ECS estimates

23 Andrews T. et al., 2018 Accounting for changing temperature patterns increases historical estimates of climate sensitivity. Geophys. Res. Lett. https://doi.org/10.1029/2018GL078887

24 https://en.wikipedia.org/wiki/Deferent_and_epicycle#Bad_science

by over 15%. This represents a clear, substantial error in ECS estimation by the authors of both Sherwood (2020) and AR6 chapter 7.[25]

The case for a rather 'low' climate sensitivity (around 2°C) is now even stronger than it was around the time of the AR5 report. Lewis (2022) found that ECS estimates based on paleoclimate proxy data from three past periods, and on process understanding feedback estimates, all clustered around a value slightly over 2°C.The IPCC, instead of clearing up the smoke, drew up a new smoke curtain by claiming a so-called 'pattern effect' could explain the discrepancy between model and observationally based estimates for climate sensitivity, and by using an incorrectly-estimated CO_2 doubling forcing value to convert feedback estimates into ECS estimates.

Ironically, by relying on a pattern effect, the IPCC had to claim that internal variability of the climate over the historical period 'masks' the much higher 'real' climate sensitivity. This is ironic because in the early days of the climate debate, when it was still unclear whether the climate was changing due to CO_2 or due to natural factors, climate sceptics were accused of being misleading by claiming that the changes in the climate were mostly natural. Now, the IPCC itself, needs a 'large effect' from 'internal variability' to save their case for a high climate sensitivity estimate from historical period data.

25 See appendix C of this commentary: https://nicholaslewis.org/wp-content/uploads/2022/09/Lewis_Objectively-combining-climate-sensitivity-evidence_2022-Clim-Dyn-Detailed-Summary.pdf

8

AR6: More confidence that models are unreliable

ROSS MCKITRICK

All climate models simulate amplified warming high up in the tropical troposphere. This area is therefore called the tropical "hot spot". The tropical hot spot provides a unique test for the models as they are not tuned to match observations there. Observations by weather balloons and satellites don't confirm the modelled hot spot. AR6 IPCC acknowledges there is a problem with the hot spot and therefore with the models. However, it does so in such veiled language that no one will notice.

The term "tropical hot spot" refers to the longstanding prediction from climate models that atmospheric warming in the tropics due to external forcing, including rising greenhouse gas (GHG) levels, should be amplified with altitude and should reach a maximum for the global atmosphere in the tropical mid-troposphere. Figure 1 shows the hot spot as generated by the Canadian climate model in a historical simulation of climate change over 1979-2017 in response to observed changes in external climate drivers, including GHG emissions. While the pattern of amplified warming aloft would arise in a model in response to any external positive forcing, the IPCC singles out GHGs as the only one that increased enough over the 20th and 21st centuries to have resulted in substantial atmospheric warming. The red coloration in the center of Figure 1 represents a hindcast of about 0.6 °C/decade of warming, while the model hindcasts around 0.2 to 0.3 °C/decade at the surface.

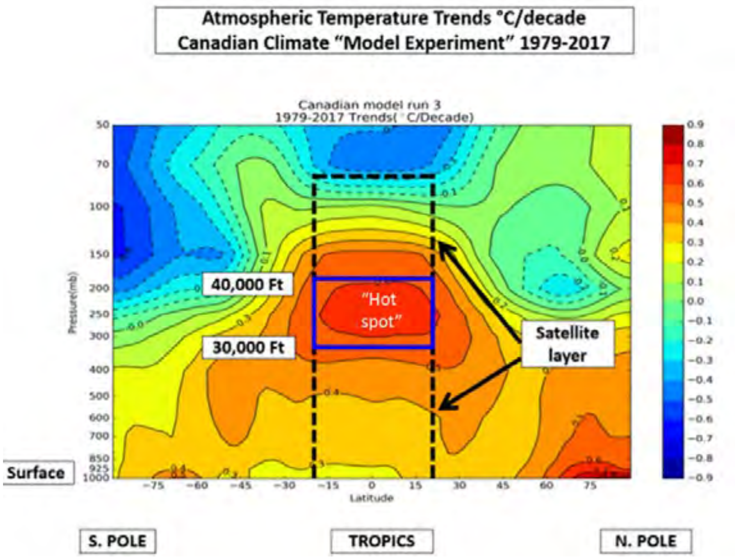


Figure 1: The tropical modeled "hot spot". The model used to generate this figure is the Canadian climate model. Source: (Christy, 2019).[1]

Model-generated warming in both the tropical surface and tropospheric layers exceed observed trends over the period. This can be seen in the atmospheric profile shown in Figure 2, which is from the 2013 IPCC Fifth Assessment Report (IPCC, 2013) or "AR5."[2]

1 Christy, J. (2019, June 18). *Putting Climate Change Claims to the Test*. Retrieved from Global Warming Policy Forum: https://www.thegwpf.com/putting-climate-change-claims-to-the-test/

2 IPCC. (2013). In T. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. Allen, J. Boschung, . . . P. Midgley, *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: Cambridge University Press. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf" https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf

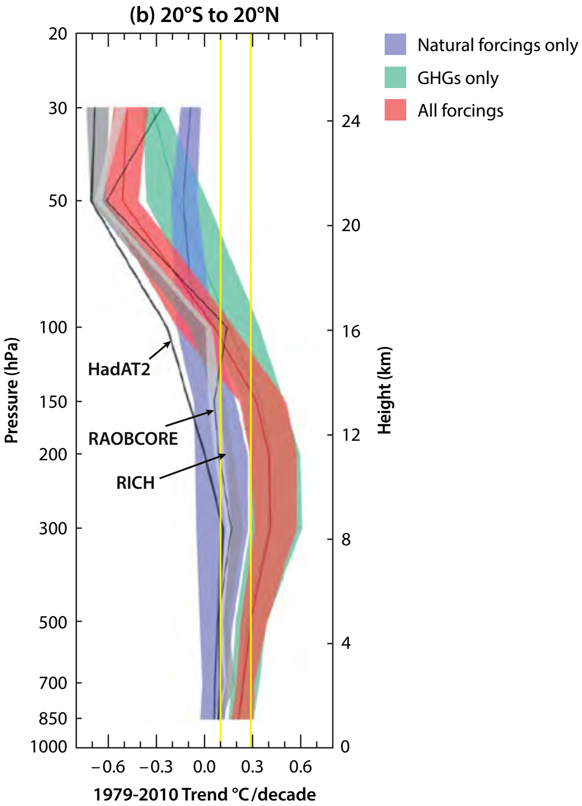


Figure 2: Temperature trends by altitude over 1979 to 2010: models compared to observations. Source: IPCC 2013 Figure 10.SM.1

The warming rates in three weather balloon-derived data sets (HadAT2, RAOBCORE and RICH) are shown.[3] The range of results from models run without greenhouse gas forcing is shown in the blue shaded area. Model results under greenhouse gas forcing only are shown in green and model results combining all climate forcings are shown in red. The "hot spot" region of the tropical troposphere is from around 300 hPa to 200 hPa (8-12 km altitude).

Here the observed warming trends are uniformly below all model runs and, interestingly, coincide best with the "natural only" model runs. In other words, the model runs that best correspond to observations are those in which GHG forcing is omitted altogether. When GHG forcing is included the models exhibit too much warming from the surface up to nearly the top of the troposphere (14 km or 150 hPa). This suggests that climate models are significantly overestimating the impact of GHGs on the climate system.

Note: this figure was published in a supplementary document, not directly in the IPCC AR5 report itself and was therefore seen by very few people. A similar figure is found in AR6, Chapter 3, page 444. The CMIP6 models used in AR6 have moved farther from the observations, not closer. See figure 3.

Is Warming Amplified Higher in the Atmosphere?

There are two aspects to the hot spot prediction that need to be distinguished: whether the observed historical trend rate of warming matches model simulations and whether the warming aloft is amplified relative to the surface. At various points in the debate about whether the hot spot exists, some defenders of the models have argued that even if there is very little observed warming, the hot spot still exists in the sense that the warming aloft is greater than at the surface: there just happens to be very little surface warming. But there is good evidence that models exaggerate both the amplification rate and the resulting mid-troposphere warming rate.

3 HadAT2 is the Hadley Centre Atmospheric Temperature weather reanalysis dataset RAOBCORE is the Radiosonde Observation Correction using Reanalysis, a weather reanalysis dataset (Radanovics, 2010). RICH is the Radiosonde Innovation Composite Homogenization dataset, a weather balloon radiosonde dataset.

Climate observations are discussed in AR6 Chapter 2 (which covers the changing state of the climate system) and in Chapter 3 (which examines the human influence on climate). Chapter 2 Section 2.3.1.2.2 briefly surveys evidence showing that the troposphere has warmed. They point out that evidence from weather balloons goes back to the late 1950s and demonstrates a warming trend. They do not mention the paper by McKitrick and Vogelsang (2014)[4] that came out after AR5 which showed that the warming of the tropical troposphere from 1958 to 2012 was all attributable to a single step-change in the late 1970s, with no significant trend before or after. The IPCC reports with *medium confidence* that the tropical upper troposphere has warmed faster than the surface since 2001 but only *low confidence* for the interval prior to that.

There is no discussion in AR6 of the work of Klotzbach et al. (2009)[5] who showed that models project greater amplification with altitude than is observed. That paper gave rise to an online debate over whether the amplification rates were being correctly calculated, and whether the discrepancy between models and observations was statistically significant. The topic involves very advanced statistical theory and was dealt with by two experts in time series analysis, Vogelsang and Nawaz (2017).[6] They found that Klotzbach's conclusions were valid, and that observed amplification is significantly smaller than the model-projected rates. AR6 makes no mention of this work.

Is the Stratosphere still Cooling?

However, AR6 does refer to evidence that stratospheric cooling (another greenhouse "fingerprint" the IPCC likes to highlight when it is observed) appears to have stopped. They note that the lower stratosphere has not cooled over the past 20 years (with one study even reporting slight warming) and that while the mid- and upper troposphere may have cooled over that interval there is low confidence in the trend magnitude.

In Chapter 3 Section 3.3.1.2 the IPCC picks up on the question of whether the observed tropical tropospheric warming rate is lower than in the models. They say that the AR5 assessed that it was, but only with *low confidence*. Based on evidence published since then they have upgraded their assessment to *medium confidence*. One wonders how much more evidence they need to claim high confidence, since in other areas they jump to that level with much less to go on.

From AR6:

> "Several studies since AR5 have continued to demonstrate an inconsistency between simulated and observed temperature trends in the tropical troposphere, with models simulating more warming than observations (Mitchell et al., 2013, 2020, Santer et al., 2017a, 2017b; McKitrick and Christy, 2018; Po-Chedley et al., 2 2021). … Over the 1979-2014 period, models are more consistent with observations in the lower troposphere, and least consistent in the upper troposphere around 200 hPa, where biases exceed 0.1°C per decade. Several studies using CMIP6 models suggest that differences in climate sensitivity may be an important factor contributing to the discrepancy between the simulated and observed tropospheric temperature trends (McKitrick and Christy, 2020; Po-Chedley et al., 2021), though it is difficult to deconvolve the influence of climate sensitivity, changes in aerosol forcing and internal variability in contributing to tropospheric warming biases (Po-Chedley et al., 2021). Another study found that the absence of a hypothesized negative tropical cloud feedback could explain half of the upper troposphere warming bias in one model (Mauritsen and Stevens, 2015)." (AR6, Chapter 3, p 443)

4 McKitrick, Ross R. and Timothy Vogelsang (2014) "HAC-Robust Trend Comparisons Among Climate Series with Possible Level Shifts" *Environmetrics* DOI: 10.1002/env.2294.

5 Klotzbach PJ, Pielke Sr RA, Pielke Jr RA, Christy JR, McNider RT. 2009. An alternative explanation for differential temperature trends at the surface and in the lower troposphere. *Journal of Geophysical Research* **114**: D21102.

6 Vogelsang, TJ, Nawaz, N 2017 Estimation and inference of linear trend slope ratios with an application to global temperature data. J *Time Series Analysis* 38: 640-667 DOI: 10.1111/jtsa.12209

Within this paragraph are some important admissions, although as is usual in IPCC work, they are minimized in the text. As pointed out in McKitrick and Christy (2018)[7] – though not mentioned in the IPCC's summary thereof – the tropical mid-troposphere is a uniquely important region for testing climate models. The modelers do not tune the models against observations there (as opposed to surface trends) so it is a genuine test of model performance. Also, all models make the same prediction, so it is a test that encompasses the overarching theoretical framework. And if the warming is present, it can only be explained by greenhouse gases since none of the IPCC's natural forcing estimates could account for it (see Figure 2). So, the model-observational discrepancy in the tropical mid-troposphere points to some genuine errors in climate model structure. The IPCC hints at this by mentioning that "differences in climate sensitivity" may be the cause – in other words models have excessively high climate sensitivity to greenhouse gases.

The final sentence refers to the absence of the Lindzen 'Iris Effect' – by which atmospheric warming reduces tropical cloud formation slightly and thus increases infrared radiation to space. When Mauritsen and Stevens (2015)[8] included an iris effect in a model, about half of the discrepancy disappeared.

The IPCC text goes on to point out that "Mitchell et al. (2013) and Mitchell et al. (2020)[9] found a smaller discrepancy in tropical tropospheric temperature trends in models forced with observed [Sea Surface Temperatures or SSTs]." What they mean by this is that perhaps the amplification rate is ok, but the SST trend is too high, so if they constrain the models to have the correct SST trend it will get the mid-troposphere trend correct as well. There are several problems with this line of argument. First, it papers over the problem of excess warming in the mid-troposphere by asking the reader to ignore the problem of excess warming at the sea surface. But the excess warming is present there as well. Second it ignores the studies mentioned above that found evidence of significantly exaggerated amplification. Third, and by implication, even when models are forced to reproduce observed SSTs they generate more warming aloft than observed. This is shown in Figure 3 which is taken from the AR6 Chapter 3 (p 444). The red symbols show temperature trend ranges from models that generate SST trends internally and the blue symbols show the tempera-

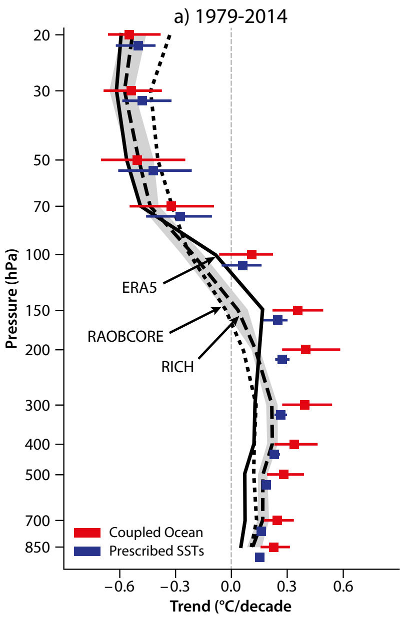


Figure 3: The AR6 CMIP6 models, in red and blue compared to observations in black. The red whisker plots use modeled SSTs and the blue symbols use observed SSTs.

7 McKitrick, Ross R and John Christy (2018) A Test of the Tropical 200-300mb Warming Rate in Climate Models. *Earth and Space Science* doi: 10.1029/2018EA000401.

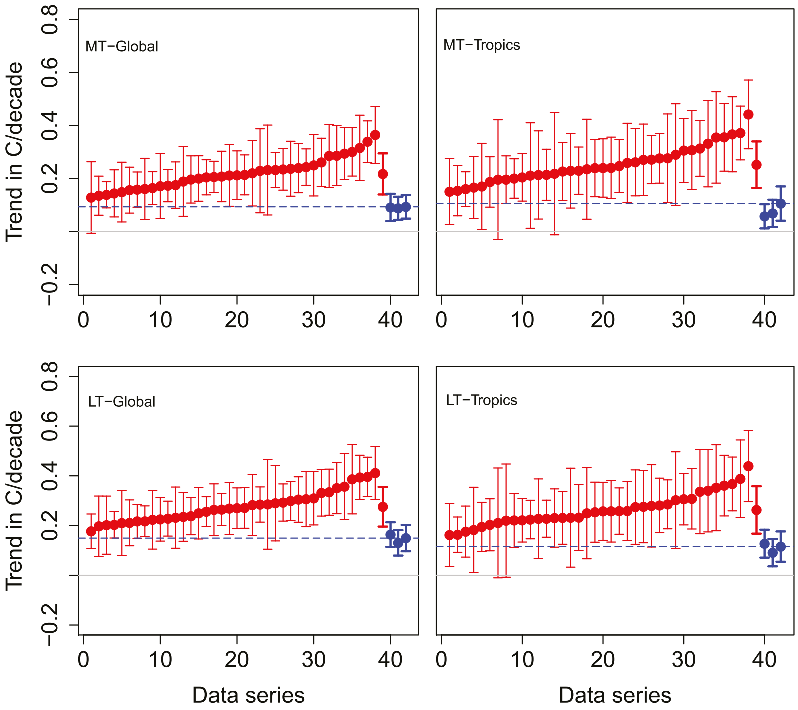
8 Mauritsen, T. and B. Stevens, 2015: Missing iris effect as a possible cause of muted hydrological change and high climate sensitivity in models. *Nature Geoscience*, 8(5), 346–351, doi:10.1038/ngeo241

9 Mitchell, Dann M., Y. T. Eunice Lo, William J. M. Seviour, Leopold Haimberger, en Lorenzo M. Polvani. 'The vertical profile of recent tropical temperature trends: Persistent model biases in the context of internal variability'. *Environmental Research Letters* 15, nr. 10 (oktober 2020): 1040b4. https://doi.org/10.1088/1748-9326/ab9af7.

ture trend ranges from models that are forced to match the observed SST trends. As shown even the latter group exceed the indicated observations for the period 1979-2014 in the critical region 300 hPa to 150 hPa. (IPCC, 2021, pp. 444).

AR6/CMIP6 Models are too Warm Globally

In McKitrick and Christy (2020)[10] we showed that not only do all models overstate warming in the tropical troposphere, but they now overstate it globally as well.



Trends and 95% CI's for individual models (red dots and thin bars), CMIP6 mean (red dot and thick bar), and observational series (blue). Horizontal dashed line shows mean satellite trend.

Figure 4: Models overshoot observed warming in the lower and mid-troposphere in the period 1979-2014, both in the tropics and globally. Source: McKitrick (2020)[11]

We examined the first 38 models in the CMIP6 ensemble, the results are shown in Figure 4. Here are the 1979-2014 warming trend coefficients (vertical axis, degrees per decade) and 95% error bars comparing models (red) to observations (blue). LT=lower troposphere, MT=mid-troposphere. Every model overshoots the observed trend (horizontal dashed blue line) in every sample.

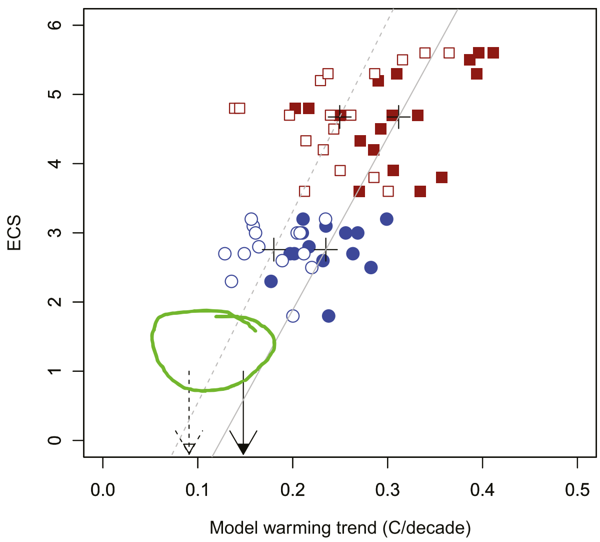
This is to be expected if, as we argued in our 2018 paper, there is a problem with a critical core mechanism in the models. The problem is not simply natural variability or a transient temperature overshoot.

Most of the differences are significant at <5%, and the model mean (thick red) versus observed mean difference is very significant, meaning it's not just noise or randomness. The models as a group warm too much throughout the global atmosphere, even over an interval where modelers can observe both forcings and temperatures.

We found that models with higher Equilibrium Climate Sensitivity (>3.4K) warm faster (not surprisingly), but even the low-ECS group (<3.4K) exhibits warming bias. In the low group the mean ECS is 2.7K, the combined LT/MT model warming trend average is 0.21K/decade and the observed counterpart is 0.15K/decade. This figure (green circle added; see below) shows a more detailed comparison.

10 McKitrick, Ross and John Christy (2020) Pervasive Warm Bias in CMIP6 Tropospheric Layers. *Earth and Space Science* Vol 7(9) September 2020.

11 McKitrick, Ross and John Christy (2020) Pervasive Warm Bias in CMIP6 Tropospheric Layers. *Earth and Space Science* Vol 7(9) September 2020.



Model ECS values plotted against model warming trends. Red squares = high ECS group, blue circles = low-ECS group. Open shape = MT trend, closed shape = LT trend. Inverted triangles = mean observed LT trend (solid), mean observed MT trend (open).

Figure 5: even models with a 'low' climate sensitivity (blue) overestimate the observed warming in the lower and mid-troposphere. Source: McKitrick (2020)

The horizontal axis in figure 5 shows the model warming trend and the vertical axis shows the corresponding model ECS. The red squares are in the high ECS group and the blue circles are in the low ECS group. Filled shapes are from the LT layer and open shapes are from the MT layer. The crosses indicate the means of the four groups and the lines connect LT (solid) and MT (dashed) layers. The arrows point to the mean observed MT (open arrow, 0.09C/decade) and LT (closed arrow, 0.15 C/decade) trends.

While the models in the blue cluster (low ECS) do a better job, they still have warming rates in excess of observations. If we were to picture a third cluster of models with mean global tropospheric warming rates overlapping observations it would have to be positioned roughly in the area I've outlined in green. The associated ECS would be between 1.0 and 2.0K.

Conclusions

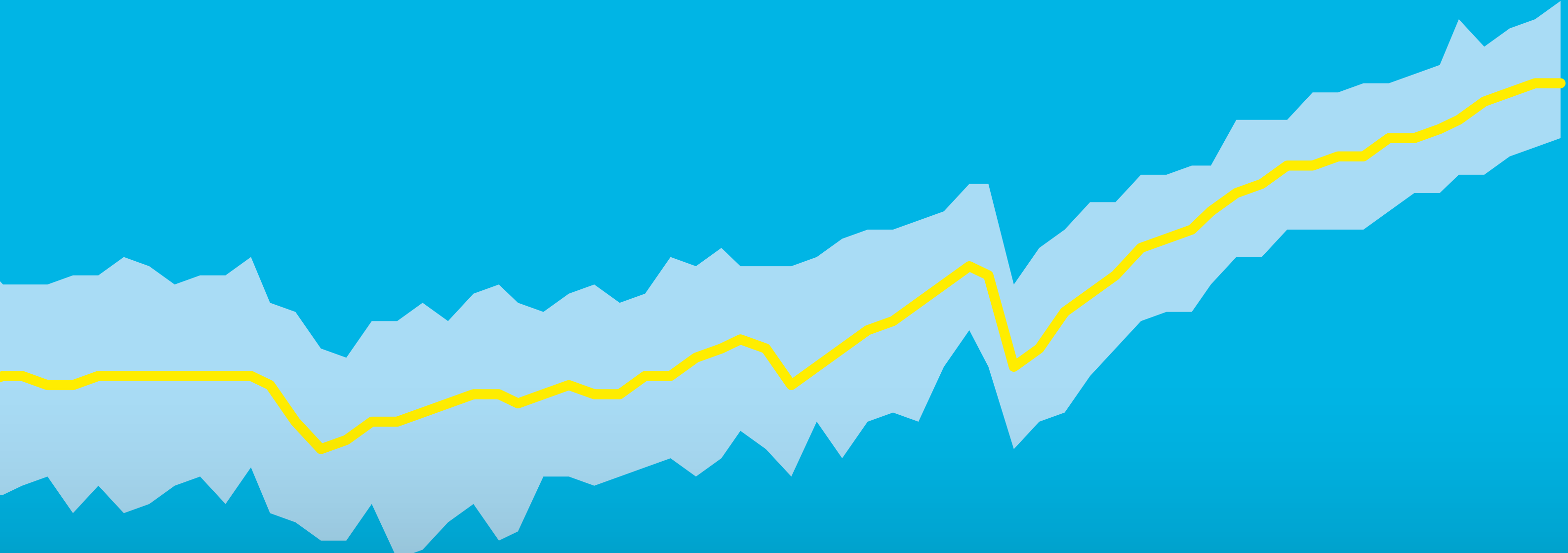
The AR6 discussion has raised its confidence that models overstate tropical tropospheric warming from *low* to *medium*. For everything else, confidence that models give reliable forecasts should therefore move in the opposite direction.

I get it that modeling the climate is incredibly difficult, and no one faults the scientific community for finding it a tough problem to solve. But we are all living with the consequences of climate modelers stubbornly using generation after generation of models that exhibit too much surface and tropospheric warming, in addition to running grossly exaggerated forcing scenarios (e.g. RCP8.5). Back in 2005 in the first report of the then-new US Climate Change Science Program, Karl et al. pointed to the exaggerated warming in the tropical troposphere as a "potentially serious inconsistency." But rather than fixing it since then, modelers have made it worse.

If the discrepancies in the troposphere were evenly split across models between excess warming and cooling we could chalk it up to noise and uncertainty. But that is not the case: it's all excess warming. CMIP5 models warmed too much over the sea surface and too much in the tropical troposphere. Now the CMIP6 models warm too much throughout the global lower- and mid-troposphere. That's bias, not uncertainty, and until the modeling community finds a way to fix it, the economics and policy making communities are justified in assuming future warming projections are overstated, potentially by a great deal depending on the model.

C

Climate Change Scenarios



9 Extreme scenarios

BY MARCEL CROK

The biggest news in the AR6 report is arguably that high-end scenarios like SSP5-8.5 and SSP3-7.0 are now believed to have low likelihood. That is extremely good news as it means that higher rates of warming in 2100 are thus viewed to be less likely than they were only a few years ago. Unfortunately, this news is deeply hidden in the report and few policy makers will see it. Worse, large parts of the report still emphasize these high-end scenarios. How did this happen?

IPCC reports are meant to be "policy relevant" and "policy neutral".[1] Policy makers deal—by definition—with an uncertain future. No one can predict with any certainty what the climate is going to do 50 or 100 years from now. However, climate scientists have tools to explore what the climate might look like in the future. These tools are called scenarios and since the first IPCC report in 1990 scenarios have played an important role in climate policy.

In AR6 we find a table and a figure showing how global temperatures might develop under the five scenarios that were selected for the report. Here is figure SPM.8:

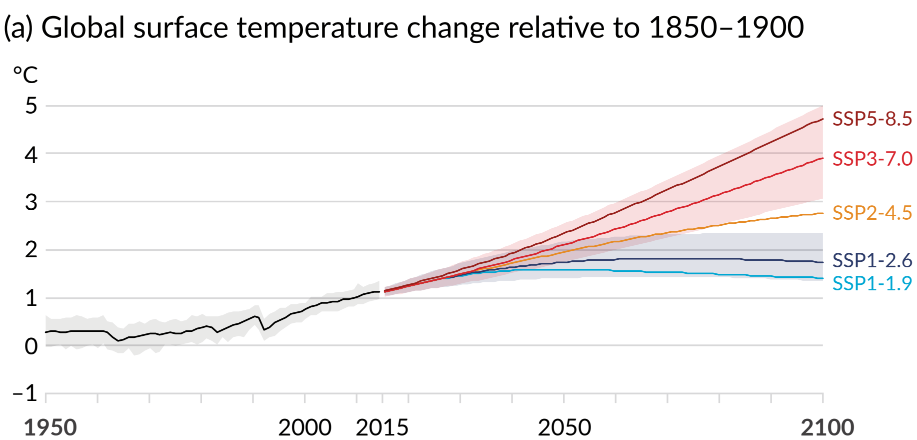


Figure 1: Global surface temperature change relative to 1850-1900 based on different scenarios. Very likely ranges are shown for SSP1-2.6 and SSP3-7.0. Source: AR6 figure SPM.8a.

Here we see that the two higher scenarios SSP3-7.0 and SSP5-8.5 reach 4 to 5°C of warming in 2100. That's quite dramatic. Remember, the IPCC estimates that the world warmed around 1°C since 1850, in a period of 170 years. These scenarios suggest we will get another 3 to 4°C of warming in just the next 80 years. This is a nightmare scenario for those who take the Paris agreement that we should stay below 2°C, or preferably below 1.5°C, seriously.

Therefore, a really important question for policy makers is: how plausible are each of the scenarios that underlie the projections of future climate? Well, this might be a big surprise for you, but the IPCC doesn't address this highly policy relevant question. In chapter 1 (page 238) it says: "In general, no likelihood is attached to the scenarios assessed in this Report."

This is quite an admission and one that actually should have been put in the *Summary for Policy Makers* with a big disclaimer such as: "Note, this report makes extensive use of scenarios. However, the likelihood of these scenarios itself hasn't been assessed!"

It becomes even stranger though. In the next paragraph on the same page there is this claim: "However, the likelihood of high emission scenarios such as RCP8.5 or SSP5-8.5 is considered low

1 "IPCC reports are neutral, policy-relevant but not policy-prescriptive." Source: www.ipcc.ch

in light of recent developments in the energy sector (Hausfather and Peters, 2020a[2], 2020b[3]).” The IPCC has just said the likelihood of its scenarios is not assessed in the report and now it says the likelihood of RCP8.5 and SSP5-8.5 is “low”. These statements are contradictory. How can you not assess the likelihood of the scenarios and then conclude that at least one scenario is low likelihood?

As we will see in this chapter the “low likelihood” of the IPCC extreme scenarios is quite an understatement. The RCP8.5 and the closely related SSP5-8.5 scenarios are – to use terminology of the IPCC itself – extremely implausible and it is more than correct for the IPCC to point this out. Again, this should have been pointed out prominently in the *Summary for Policy Makers* (SPM) with a disclaimer such as: “Note, the likelihood of the high emission scenarios RCP8.5 and SSP5-8.5 is regarded as low.” However, no such disclaimers were shown in the SPM and most of the policy makers who took the effort to read the SPM will not know the highest scenario has a “low likelihood” of coming true.

Baseline Scenario

Let’s take a step back and describe what scenarios are and see how the IPCC used them in the past. The process starts with generating ideas about socioeconomic developments: future population growth, economic growth, technological changes, land use changes. Scientists use so-called Integrated Assessment Models (IAMs) to integrate all these inputs and assumptions. These models can then be used to project greenhouse gas emissions over the course of the century. The output of these models are used by the climate modelling community to project climate changes.

In its first report in 1990 the IPCC used scenarios in the same way as Shell and other energy companies use them. In general, you will have a business-as-usual, or baseline, or reference scenario. That scenario is supposed to show what is likely to happen without climate policies. The other scenarios will have some assumed greenhouse gas emissions reduction. The difference between the baseline and policy scenarios will give an impression of the potential effect of policy changes on global temperature.

In 2000 it was time for the IPCC to update its scenarios. After long discussions it was decided that the new scenarios would be presented without any consideration of their likelihood. This is a spectacular change as it means that each scenario is presented as likely (or unlikely) as the other scenarios. There was no longer a baseline scenario. The advantage was scientists don’t have to go through the difficult process of determining how likely the scenarios are. The disadvantage though is that policy makers who are against strict climate regulations could use lower scenarios to claim things are not so bad and conclude no severe policies are necessary. Environmental NGOs were afraid this attitude would hamper active climate action.

So, in 2005 the process of making new scenarios started all over again. In hindsight this turned out to be a crucial moment. Scenario makers generally need a lot of time to generate new socioeconomic scenarios. However, the climate model community was very impatient and wanted to have the new scenarios as soon as possible. It decided, based on the extensive literature, that four so-called Representative Concentrations Pathways (RCPs) would be selected: one high scenario, one low and two in the middle. Two were put in the middle to prevent people from thinking the middle one was the most likely. These RCPs provide the greenhouse gas concentrations from 2005 until 2100. The climate model community could simply start using these new scenarios which were supposed to be ‘representative’ for different “families” of societal and energy system assumptions, and therefore used to project a small set of different climate futures.

2 Z. Hausfather, G.P. Peters, Emissions – the ‘business as usual’ story is misleading, Nature 577 (7792) (2020) 618–620.

3 Hausfather, Z. and G.P. Peters, 2020b: RCP8.5 is a problematic scenario for near-term emissions. Proceedings of the National Academy of Sciences, 117(45), 27791–27792, doi:10.1073/pnas.2017124117

Meanwhile in parallel the scenario community would start working on the so-called Shared Socio-economic Pathways (SSP), i.e., how could the global population and economy develop to reach the levels of radiative forcing in the four RCPs? However, this process took ten years. So, in 2013, when the fifth IPCC report (AR5) came out, the four RCPs were used without knowing what the fictitious worlds behind the RCP's would look like, or if they were even plausible futures. Nevertheless, the IPCC decided to use the highest of its four scenarios, RCP8.5, as the reference or business-as-usual scenario. As it turned out, this was misleading and unfortunately this error continues today.

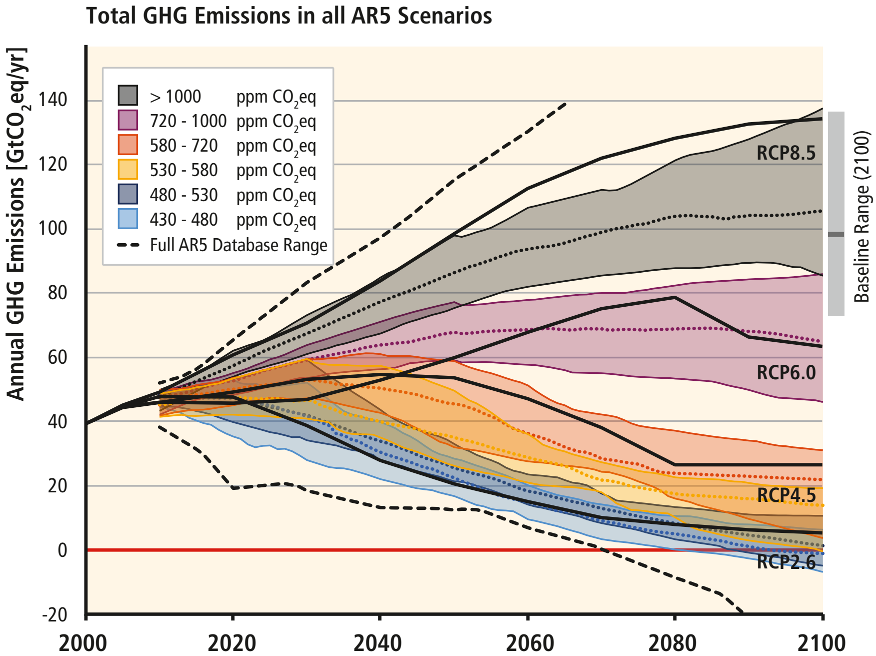


Figure 2: Annual greenhouse gas emissions in the recent past and projected for the future based on the four RCP scenarios. Note how in the top right RCP8.5 was called the baseline range. Source: WG3, AR5, p. 52.

RCP8.5 would quickly become the favourite scenario of the climate model community because it generates such a clear signal-to-noise ratio compared to the background of natural climate variability. In plain English: climate models produce spectacular (or if you like dramatic) results if you feed them with the RCP8.5 scenario. The 8.5 by the way doesn't refer to temperature[4], but to the amount of climate forcing in 2100, i.e., 8.5 W/m^2. This is a huge amount of forcing[5], AR6 estimates the total increase in forcing since preindustrial to be 2.72 W/m^2. This increase took place over the period 1750 to 2020.

It all sounds rather technical, so why should ordinary citizens be bothered with this? Well, hardly a day or week passes without a new scientific paper based on RCP8.5 reaching you through the media. Such papers often have a message of doom and gloom. If you read in your newspaper that something terrible is going to happen with the climate in 2100, it is a pretty safe bet that the underlying research is based on the implausible RCP8.5.

A famous example is how the 2018 National Climate Assessment (NCA) in the US was communicated to its citizens. Here is the CNN headline: "Climate change will shrink US economy and kill thousands, government report warns."[6] The article said: "A new US government report delivers a dire warning about climate change and its devastating impacts, saying the economy could lose hundreds of billions of dollars – or, in the worst-case scenario, more than 10% of its GDP – by the end of the century." At least RCP8.5 is presented as a worst-case scenario—which it was not,

4 Sometimes people incorrectly think the 8.5 means 8.5°C of warming in 2100.

5 Doubling the CO_2-concentration gives a theoretical forcing of around 3.7 W/m^2. So 8.5 W/m^2 is the equivalent of more than two doublings of the CO_2-concentration in the atmosphere. Since preindustrial the CO_2-concentration in the atmosphere has increased from 280 ppm to 415 ppm.

6 https://edition.cnn.com/2018/11/23/health/climate-change-report-bn/index.html

as a worst case scenario also must be plausible—but in this case it was even worse: for the 10% estimate they used is an extreme upper limit of the already extreme RCP8.5 scenario. In that case Earth would warm a whopping 8°C in 2100. But even for RCP8.5 warming of 8°C is extreme. Normal warming rates for RCP8.5 are 4 or 5°C.

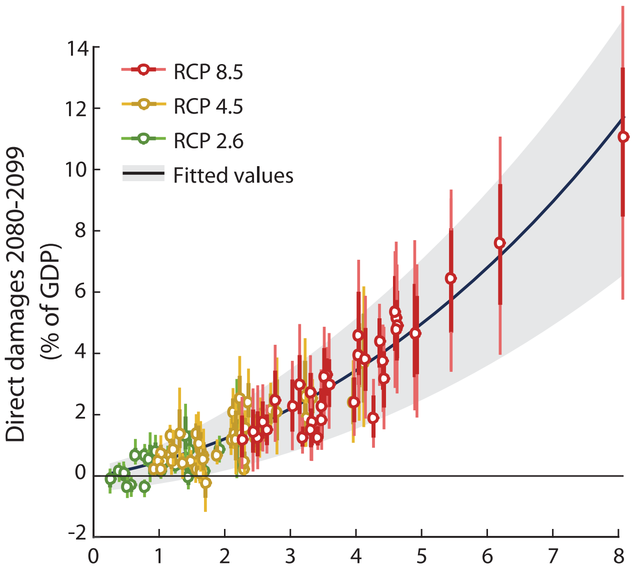


Figure 3: US GDP loss at the end of the century related to global warming rates.[7,8]

The NCA is being disingenuous, the underlying study they used only showed GDP losses of 3 to 4% (see figure 3).

In The Netherlands something similar happened after the publication of AR6. The Dutch KNMI published a report (in Dutch[9]) in which it showed some relevant conclusions from AR6 for Dutch policy makers. The relevant headline at the national public news broadcaster NOS read: "KNMI adjusts expected sea level rise upward".[10] It combined SSP5-8.5 with a very uncertain ice cap instability scenario to claim sea levels along the Dutch coast could rise by 1.2 meters in 2100 or even 2 meters. It was 18 centimetres in the past century with no sign of acceleration. Again, few news consumers (including Dutch policy makers) will realise what kind of assumptions are behind such grotesque predictions.

How Plausible are the Extreme Scenarios?

So how extreme is RCP8.5 and its more recent version SSP5-8.5? Well, just to give you an idea, to get there the world would need to start using six times more coal per capita than we use now. Or to translate it into coal power stations: currently there are around 6000 coal power stations in the world. RCP8.5 (and SSP5-8.5) implies humanity will add another 33,000 between now and 2100. What about the next scenario SSP3-7.0? That still implies the building of 17,000 new coal power plants. Again, highly implausible.

Countries like China and India are still building coal power stations, but western countries are closing them and replacing them with natural gas-powered stations. Globally coal consumption seems to be at a plateau for a decade or so.

7 Hsiang S, Kopp R, Jina A, Rising J, Delgado M, Mohan S, Rasmussen DJ, Muir-Wood R, Wilson P, Oppenheimer M, Larsen K, Houser T. Estimating economic damage from climate change in the United States. Science. 2017 Jun 30;356(6345):1362-1369. doi: 10.1126/science.aal4369. PMID: 28663496.

8 https://fabiusmaximus.com/2018/11/29/scary-but-fake-news-about-the-national-climate-assessment/

9 https://cdn.knmi.nl/knmi/asc/klimaatsignaal21/KNMI_Klimaatsignaal21.pdf

10 KNMI adjusts expected sea level rise upwards

RCP-scenarios start in the year 2005 so there are now 15 years of real-world data to evaluate them. Such an evaluation is clearly something you might expect from the IPCC. After all it is highly policy relevant how their scenarios track with reality in order to know where we are going. However, apart from a short sentence about the likelihood, the IPCC said very little about the plausibility of its scenarios. It only referred to Hausfather and Peters 2020a and 2020b. These are indeed relevant pieces. One is a comment in *Nature*, the other is a reply to another paper in *PNAS*. They are not original peer reviewed works.

Several peer reviewed papers are available in the literature that deal with this issue. However, these papers were all ignored by the IPCC. A good starting point for this discussion is the 2017 paper "Why do climate change scenarios return to coal?" by Justin Ritchie.[11] The paper was very clear about RCP8.5 being an unlikely scenario because it assumes a return to coal. It said: "This paper argues SSP5-RCP8.5 is an exceptionally unlikely endpoint of future CO_2 forcing because it is biased by a return-to-coal hypothesis that distorts the future energy scenarios produced by IAMs [Integrated Assessment Models]." And elsewhere: "These four lines of evidence (i-iv) collectively indicate that RCP8.5 no longer offers a trajectory of 21st-century climate change with physically relevant information for continued emphasis in scientific studies or policy assessments."
This is a spicy remark, of course. Ritchie and his colleague specifically said RCP8.5 should no longer be used in policy assessments. That is, in IPCC reports. However, not only did IPCC ignore this paper, it also ignored the advice. Roger Pielke Jr, a well-known climate and policy scientist, in peer-reviewed papers, and summarized in his blog, documented how often RCP8.5 and SSP5-8.5 were mentioned in the AR6 report. The result is shown in the table below:

SCENARIO	MENTIONS	PCT of MENTIONS
SSP5-8.5 & RCP8.5	1359	41.5%
SSP1-2.6 & RCP2.6	733	22.4%
SSP2-4.5 & RCP4.5	571	17.4%
SSP3-7.0	378	11.5%
SSP1-1.9	200	6.1%
RCP6.0	32	1.0%

Figure 4: mentions of different scenarios in the AR6 report. Source: Roger Pielke Jr.

As you can see, of all the available scenarios, RCP8.5 and SSP5-8.5 are mentioned most. If you add the still extreme SSP3-7.0 scenario to it, then they are more than half of all scenario references in the report. Just to give some examples from the report:

- Under RCP2.6 and RCP8.5, respectively, glaciers are projected to lose 18% ± 13% and 36% ± 20% of their current mass over the 21st century (medium confidence). (77)
- Under RCP8.5/SSP5-8.5, it is likely that most land areas will experience further warming of at least 4°C compared to a 1995–2014 baseline by the end of the 21st century, and in some areas significantly more. (132)
- According to the SROCC, sea level rise in an extended RCP2.6 scenario would be limited to around 1 m in 2300 (low confidence) while multi-metre sea-level rise is projected under RCP8.5 by then (medium confidence). (188)

The reader gets the idea. All the scary messages from the report are based on RCP8.5 and SSP5-8.5. However, there is solid real-world evidence now, published in the peer reviewed literature that this scenario is not plausible. It is low likelihood according to IPCC, based on the implausible assumption of the explosive use of coal. It's a scenario that you simply should not use to inform policy makers. However, in AR6 it's the scenario that is used more than any other. How is this possible? Well, in a way it's quite understandable. IPCC is supposed to review all the available literature that was published in the period leading to the publication of the report.[12] Bloomberg news

11 J. Ritchie, H. Dowlatabadi, Why do climate change scenarios return to coal? Energy 140 (2017) 1276–1291.

12 The deadline for literature for AR6 was 31 January 2021.

did a google scholar search for the use of different scenarios in the literature. The figure below summarizes their results:

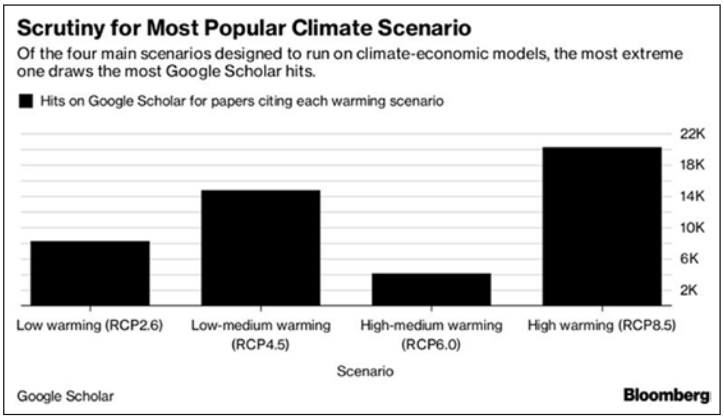


Figure 5: mentions in the literature of the different RCP scenarios.

RCP8.5 is not only the favourite scenario in AR6 but also in the literature. In this sense IPCC is simply doing its job, assessing and reviewing the literature. However, it's still highly problematic since RCP8.5 is such an unrealistic scenario.

Scenario Reality Check

Another paper that was 'missed' by the IPCC was the 2020 paper "IPCC Baseline Scenarios Over-project CO_2 Emissions and Economic Growth" by amongst others Matthew Burgess, Justin Ritchie and Roger Pielke Jr. [13] Title sounds pretty relevant for an IPCC assessment, doesn't it? It showed this figure:

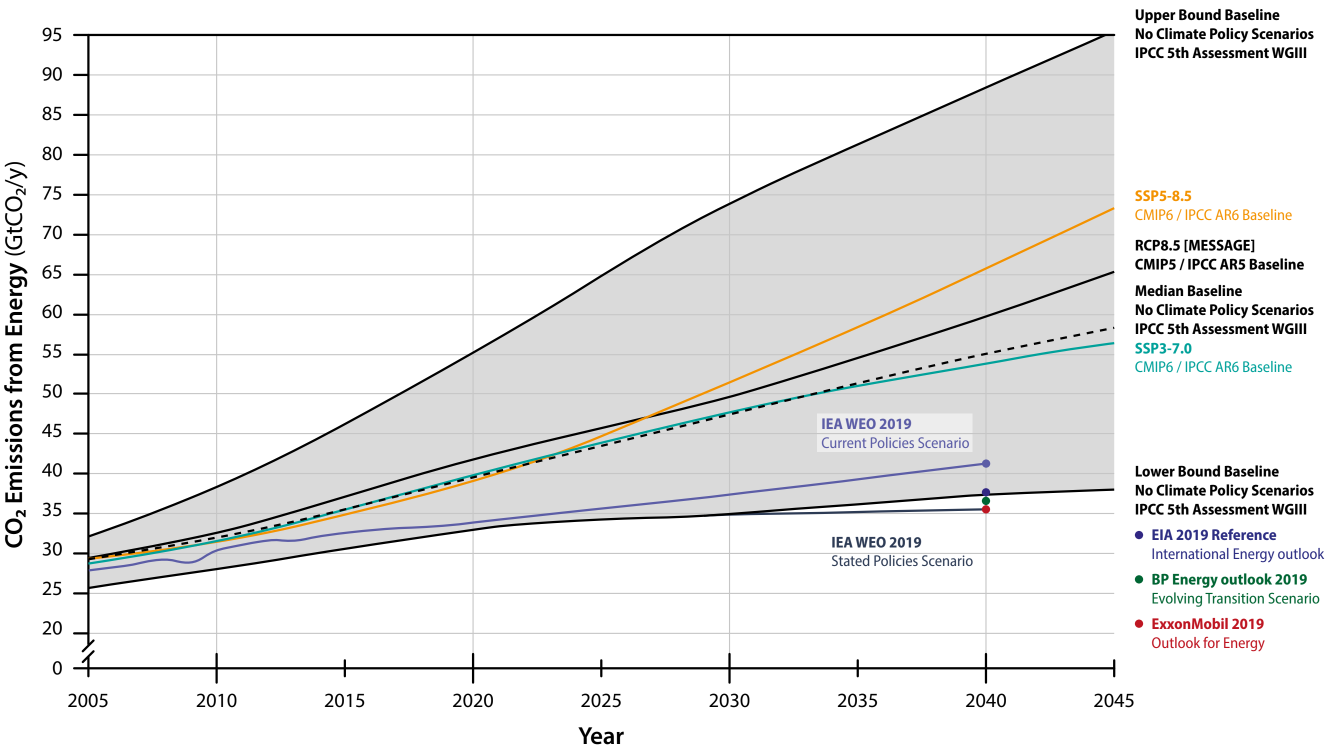


Figure 6: Past and future CO_2 emissions as projected by SSP3-7.0, RCP8.5 and SSP5-8.5 scenarios used by the IPCC. The coloured dots refer to several energy outlook scenarios of the International Energy Agency, the US Energy Information Administration, BP and ExxonMobil.

13 Matthew G. Burgess, Justin Ritchie, John Shapland, and Roger Pielke, Jr. IPCC Baseline Scenarios Over-project CO2 Emissions and Economic Growth. Environ. Res. Lett., 25 November, (2020), https://doi.org/10.1088/1748-9326/abcdd2.

The real-world emissions follow the lower boundary of the grey area closely and move farther and farther away from the SSP3-7.0, RCP8.5, and SSP5-8.5 scenarios. Notice the huge range for the extreme IPCC climate policy scenarios. According to the five SSP's, without climate policies, emissions in 2045 can be slightly higher than they were in 2020 (the lower bound baseline) or much higher. The upper bound is around 80 gigatonnes of CO_2/year in 2045. The SSP3-7.0, RCP8.5 and SSP5-8.5 scenarios all imply huge increases in CO_2 emissions between now and 2045. Increases that are not expected by the International Energy Agency, the US Energy Information Administration, BP, or ExxonMobil.

The Hausfather and Peters comment in *Nature* had a somewhat similar figure, combining emissions with expected temperature:

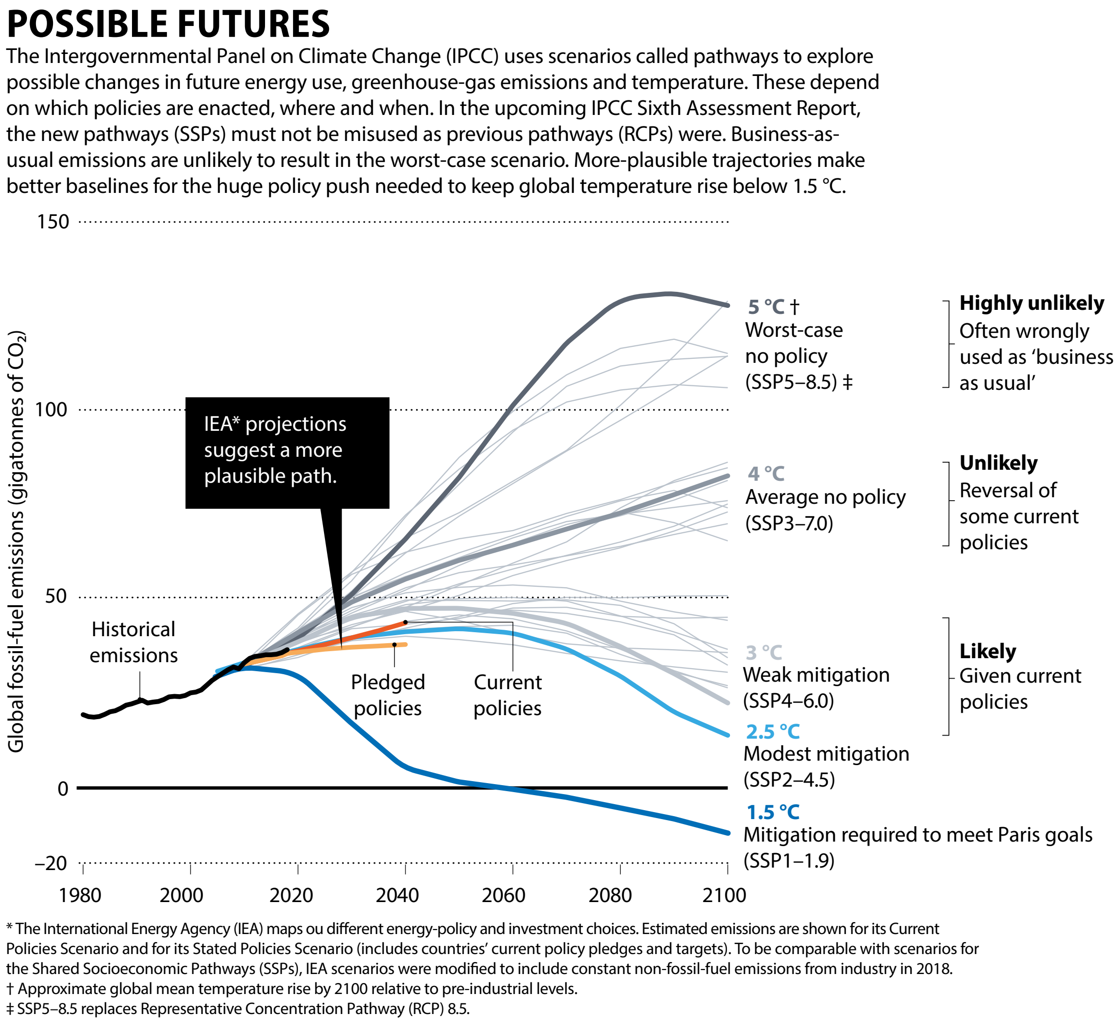


Figure 7: Different scenarios and their potential relation with global temperature. Source Hausfather and Peters 2020.

The Hausfather and Peters' figure makes it clear that SSP5-8.5 is "very unlikely and often wrongly used as business as usual". SSP3-7.0 is "unlikely" as it requires a reversal of current policies, i.e., policies that are already in place independent of climate pledges.

It would have been helpful if a figure like this would have made it into the AR6 report. How else would policy makers have noticed this? There is no disclaimer or warning in the *Summary for Policy Makers* (SPM). There is only a short sentence in Chapter 1 stating that RCP8.5 and SSP5-8.5 have "low likelihood".

How could this have happened? How is it possible that such an extreme scenario became so dominant in the literature and in both the AR5 and AR6 report? The discussion about that has only recently started. A long essay with the revealing title "How Climate Scenarios Lost Touch with Reality" was published in the summer of 2021 by Justin Ritchie and Roger Pielke Jr, after the dead-

line for AR6.[14] It starts as follows: "A failure of self-correction in science has compromised climate science's ability to provide plausible views of our collective future."
One of the most striking sentences in the essay is this one:

> *"The continuing misuse of scenarios in climate research has become pervasive and consequential—so much so that we view it as one of the most significant failures of scientific integrity in the twenty-first century thus far. We need a course correction."*

This is a harsh conclusion. They talk about the "misuse of scenarios" and blame the climate science community for not yet correcting an error that has slipped into the literature. Therefore, they call it a "failure of scientific integrity". In a much longer peer reviewed paper Pielke and Ritchie dive even deeper into this issue.[15] This paper was available in 2020 although not yet officially published. Elsewhere in the report and in drafts the IPCC is not hesitant to use drafts of papers. But in this case they were not eager to fully discuss this issue in the report. The IPCC doesn't seem to be a big fan of the work of Roger Pielke Jr. Although Pielke Jr. has published authoritatively about scenarios, weather extremes, and about normalized damages due to disasters, AR6 only cited one of his papers, a rather old one from 2008. His more recent work is ignored. A recent report by the Global Warming Policy Foundation titled "The Hounding of Roger Pielke Jr" tries to explain where this attitude comes from.[16] In short: it has to do with politics.[17]

Several prominent climate scientists reacted to the essay by Pielke and Ritchie.[18] Chris Field (who has a long involvement with the IPCC) and Marcia McNutt (President of the National Academy of Sciences) rejected the criticism by Pielke and Ritchie. They wrote: "In particular, the high-emissions RCP8.5 scenario has long been described as a "business-as-usual" pathway with a continued emphasis on energy from fossil fuels with no climate policies in place. This remains 100% accurate, even if RCP8.5 does not appear to be the most likely high-emissions pathway."

They do admit that RCP8.5 is not the most likely pathway, but they still think it is right to call it a business-as-usual scenario.

Kate Marvel in her reply said: "I agree with Roger Pielke Jr. and Justin Ritchie's statement that we shouldn't call the high-emissions RCP8.5 scenario "business as usual," and they are right to call for the climate community to end this sloppy wording." However, she disagrees it is a matter of scientific integrity and emphasizes that AR6 doesn't call it that. "Neither the most recent Intergovernmental Panel of Climate Change report nor the National Climate Assessment claims RCP8.5 is "business as usual," but even an unrealistic scenario can yield interesting science if used appropriately."

Pielke and Ritch in their long peer reviewed article "Distorting the view of our climate future: The misuse and abuse of climate pathways and scenarios" show that scenarios such as RCP8.5 have become so endemic in the literature that it is hard to get rid of them. They agree with Marvel that there can be reasons of academic interest to study such 'extreme' scenarios, i.e., to study how the climate could react to such extreme increases in greenhouse gas concentrations. However, such studies should not be highlighted in scientific assessments as if they are plausible pictures of the future that are relevant for policy makers.

14 Jr., Roger Pielke, and Justin Ritchie. "How Climate Scenarios Lost Touch With Reality." Issues in Science and Technology 37, no. 4 (Summer 2021): 74–83 . https://issues.org/climate-change-scenarios-lost-touch-reality-pielke-ritchie/

15 Roger Pielke Jr. and Justin Ritchie, "Distorting the view of our climate future: The misuse and abuse of climate pathways and scenarios," Energy Research & Social Science 72 (2021): 101890.

16 https://www.thegwpf.org/content/uploads/2021/11/Laframboise-Pielke.pdf

17 More about this in chapter 12 about disasters.

18 https://issues.org/climate-scenarios-reality-pielke-jr-ritchie-forum/

Most realistic scenario

At least climate scientists are beginning to openly acknowledge that RCP8.5 is not a realistic scenario. This raises the question, if RCP8.5 is not realistic which scenario is? Hausfather and Peters in their *Nature* comment (see figure 7) indicate that the weak to modest mitigation scenarios (SSP4-6.0 and RCP2-4.5) are currently in the likely range. This leads to warming of about 2.7°C in 2100, a number that is now frequently published as well.[19]

With a long and woolly sentence AR6 seems to agree with Hausfather and Peters:

> *"Studies that consider possible future emission trends in the absence of additional climate policies, such as the recent IEA 2020 World Energy Outlook 'stated policy' scenario (International Energy Agency, 2020), project approximately constant fossil and industrial CO_2 emissions out to 2070, approximately in line with the medium RCP4.5, RCP6.0 and SSP2-4.5 scenarios (Hausfather and Peters, 2020b) and the 2030 global emission levels that are pledged as part of the Nationally Determined Contributions (NDCs) under the Paris Agreement (Section 1.2.2; (Fawcett et al., 2015; Rogelj et al., 2016; UNFCCC, 2016; IPCC, 2018)."*[20]

Pielke, Ritchie and their colleague Matthew Burgess also looked into this issue: which of the scenarios is most likely and what would that imply for global temperatures?[21] In their paper they conclude that another SSP scenario, SSP3.4, fits best with the observed emissions. Note, this suggests that the world is on track for an even lower global forcing in 2100 than the SSP2-4.5 or the SSP4-6.0 that were used in the AR6 report. This SSP3.4 scenario isn't even mentioned in the AR6 report.

The median warming connected to this SSP3.4 scenario is 2.2°C of warming in 2100, close to the target of the Paris agreement. So according to them this would be the most likely warming in 2100. Again, this is very good news. Again and again we hear messages about the coming climate apocalypse in the media. We hear complaints that the world isn't doing enough to fight climate change. However, in reality, while emissions are still high, the world has moved away from the higher emissions doom and gloom world into a more moderate middle of the road scenario, where things don't look so bleak.

The IPCC had all the data and the literature available and should have highlighted this good news. However, for whatever reason, they didn't They make extensive use of a scenario that is completely out of touch with reality and highlight its results all over the report. No disclaimer was included in the *Summary for Policy Makers* warning policy makers of the situation. And week after week new publications appear using this extreme scenario to create screaming news headlines.

How to fix this unfortunate situation is not clear at the moment. If prominent leaders keep using this scenario and funding agencies keep funding research based on it, the use of this exaggerated scenario will continue for many years to come. Tighten your seatbelts.

19 "Earth will warm 2.7 degrees Celsius based on current pledges to cut emissions", https://www.sciencenews.org/article/climate-earth-warming-emissions-gap-pledges

20 AR6, p. 239

21 Pielke, R., Jr, Burgess, M. G., & Ritchie, J. (2021, March 23). Most plausible 2005-2040 emissions scenarios project less than 2.5 degrees C of warming by 2100. https://doi.org/10.31235/osf.io/m4fdu

10

A miraculous sea level jump in 2020

BY OLE HUMLUM

The IPCC launched a sea level projection tool which the public can use to 'make' different sea level scenarios for tide gauge stations around the world. Ole Humlum applied the tool to four Scandinavian capitals and shows the surprising results.

Global, regional, and local sea levels always change. During the last glacial maximum about 20-25,000 years ago, global sea level was around 120 m below the modern sea level. Since the end of the Little Ice Age about 150 years ago, the global sea level has on average increased 1-2 mm/yr, according to tide gauges located at coasts. Observed data from sea level gauges worldwide can be accessed from the PSMSL Data Explorer.[1]

The issue of sea-level change, and in particular the identification of a hypothetical human contribution to that change, is a complex topic. Given the scientific and political controversy that surrounds the matter, people's high interest in this is entirely understandable. Nobody wants to be flooded.

Global (or eustatic) sea-level change is measured relative to an idealised reference level, the geoid, which is a mathematical model of the shape of the earth's surface and indicating a surface of equal gravity acceleration. The ocean surface will always try to adjust to this surface.

Sea-level is a function of the volume of the ocean basins and the volume of water that they contain, and global changes are brought about by three main mechanisms:

- changes in ocean basin volume caused by tectonic forces
- changes in seawater density caused by variations in ocean temperature and salinity
- changes in the volume of water caused by the reduction or growth of ice sheets, ice caps and smaller glaciers

Ocean basin volume changes occur too slowly to be significant over human lifetimes and it is therefore the other two mechanisms that drive contemporary concerns about sea-level rise. It is these mechanisms that IPCC are primarily concerned with in their modelling and discussion of this issue.

Higher temperature in itself is only a minor factor contributing to global sea-level rise, because seawater has a relatively small coefficient of expansion and because, over the timescales of interest, any warming is largely confined to the upper few hundred metres of the ocean surface.

The growth or decay of floating glaciers have no influence on sea level. However, the melting of land-based ice – including both mountain glaciers and the ice sheets of Greenland and Antarctica – is a more significant driver of global sea-level rise. For example, during the glacial–interglacial climatic cycling over the last half-million years, glacial sea-levels were about 120 m lower than the modern shoreline. Moreover, during the most recent interglacial, about 120,000 years ago, global temperature was higher than today, and significant extra parts of the Greenland ice sheet melted. As a consequence, global sea-level was several metres higher than today.

On a regional and local scale, however, factors relating to changes in air pressure, wind and geoid must also be considered. As an example, changes in the volume of the Greenlandic Ice Sheet will affect the geoid in the regions adjacent to Greenland. According to the climate models considered by IPCC, the Greenland Ice Sheet is expected to experience a significant loss of mass in the coming 100 years, caused by a modelled warming climate. In this case the overall mass in Greenland will diminish, the geoid surface will be displaced in direction of the planets centre, and sea level in the regions surrounding Greenland will drop. This will happen even though the overall volume of water in the global oceans will increase corresponding to the net loss of glacier ice.

1 Observed data; PSMSL Data Explorer. https://www.psmsl.org/data/obtaining/map.html

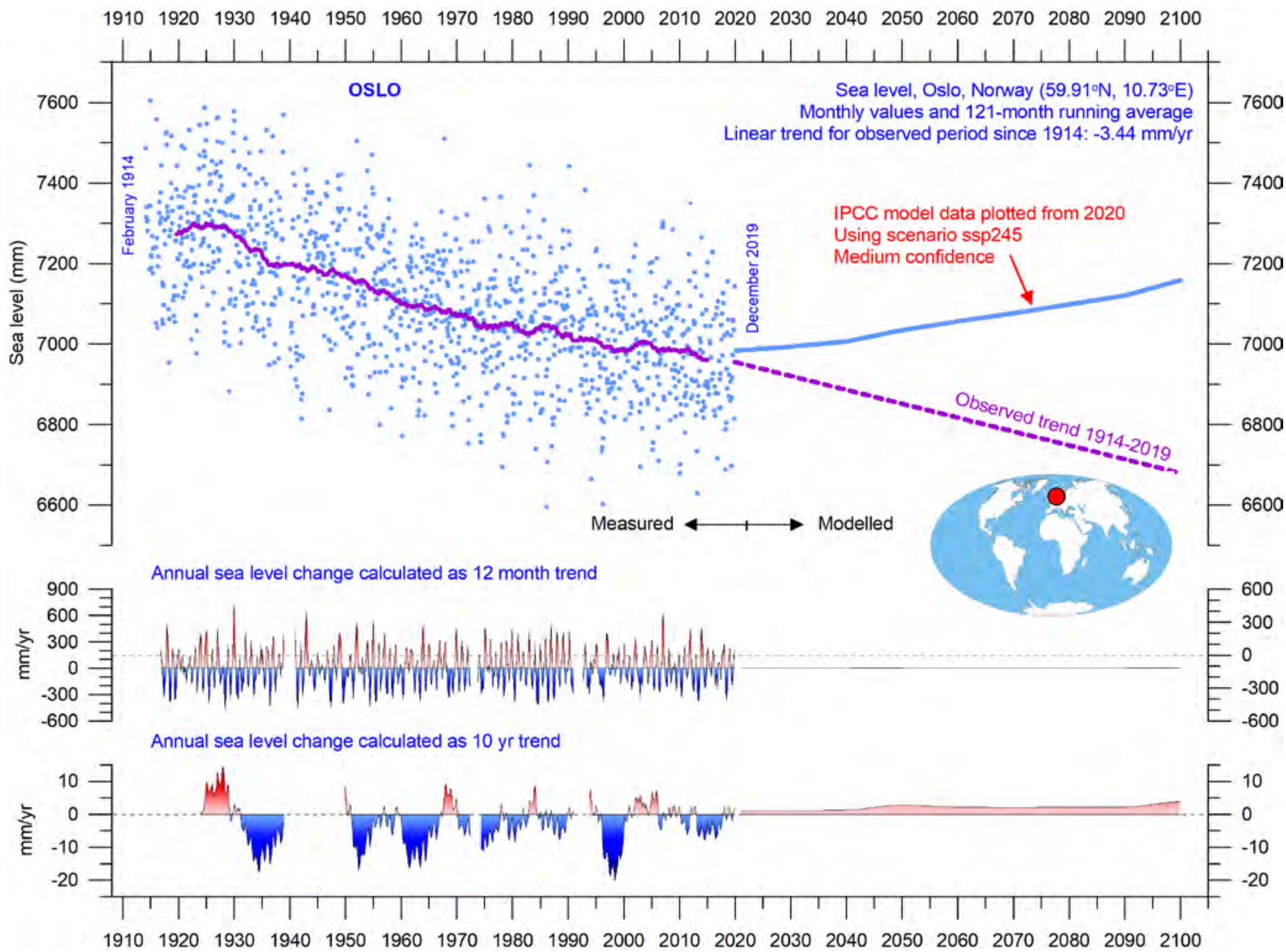
In northern Europe another factor must also be considered when estimating the future sea level. Norway, Sweden, Finland, and Denmark were totally or partly covered by the European Ice Sheet 20-25,000 years ago. Even today the effect of this ice load is clearly demonstrated by the fact that most of this region experiences an ongoing isostatic land rise of several millimetres per year. At many sites this more than compensates for the slow global sea level rise, so a net sea level drop in relation to land is recorded.

The relative movement of sea level in relation to land is what matters for coastal planning and is termed the relative sea level change. This is what is recorded by tide gauges.

AR6 Sea Level Projection Tool

The most recent publication of the IPCC's work, the 6th Assessment Report from Working Group I, was released on August 9th, 2021. Modelled data for global and regional sea level projections 2020-2150 are available from the IPCC AR6 Sea Level Projection Tool.[2] The IPCC data considers the modelled future development of several factors, such as glacier mass change, vertical land movement, water temperature and -storage. Modelled sea level projections for different SSP scenarios are calculated relative to a baseline defined by observations 1995-2014.

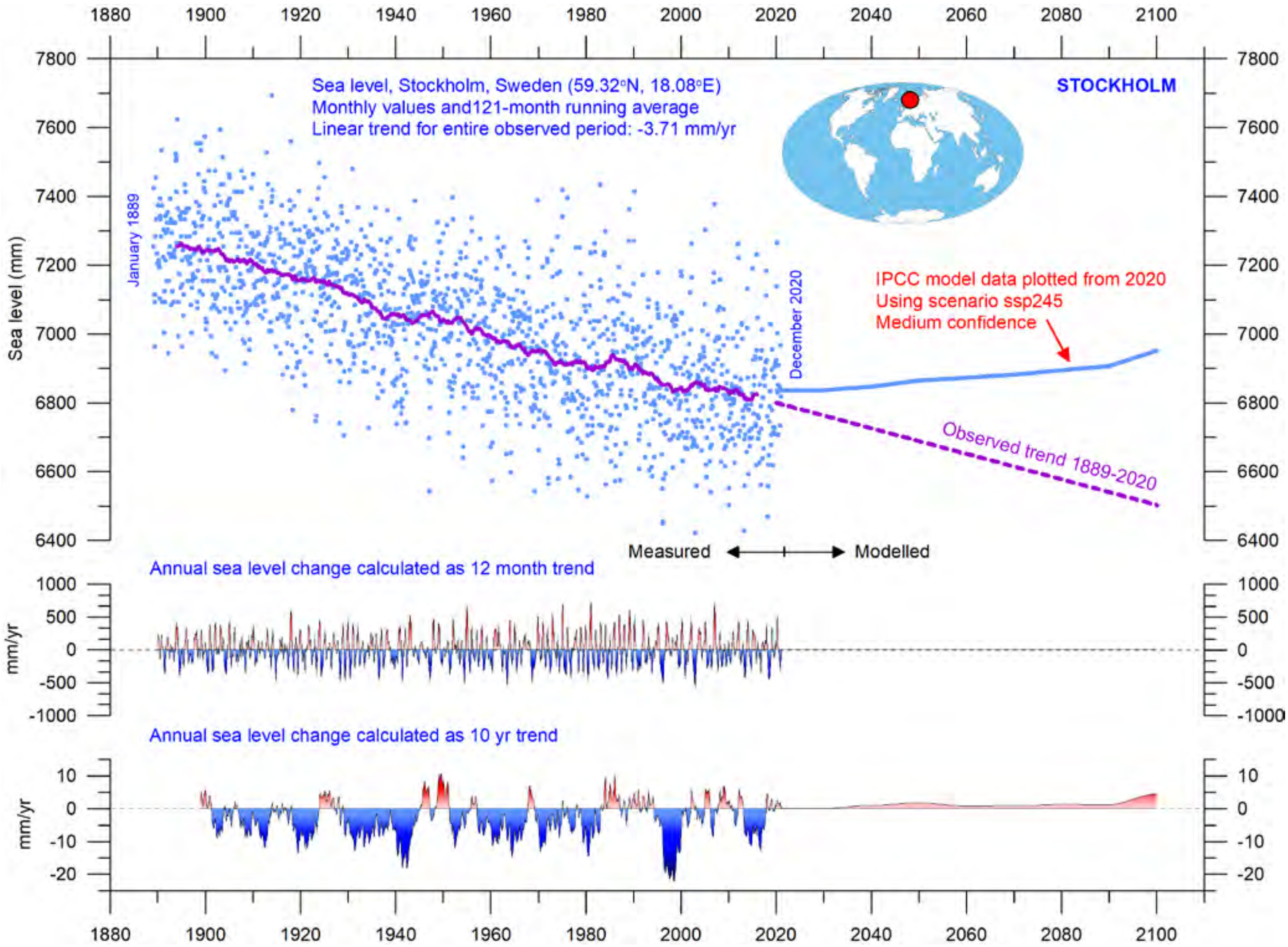
It is instructive to compare the modelled data with observed sea level data, as illustrated below for the capitals of Norway, Sweden, Finland, and Denmark.



Site 1: Oslo, Norway

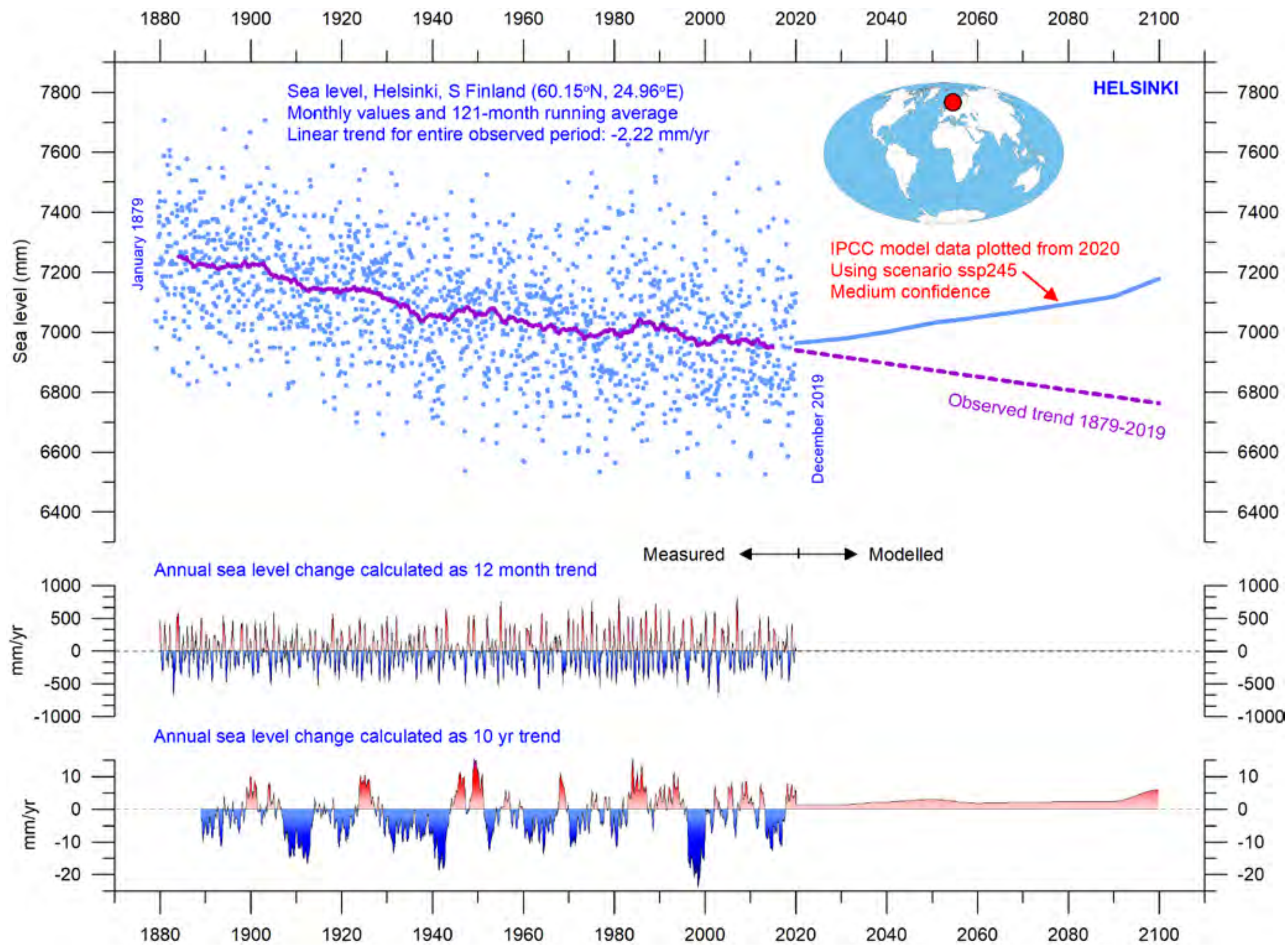
2 Modelled data; IPCC AR6 Sea Level Projection Tool: https://sealevel.nasa.gov/data_tools/17

Observed sea level at Oslo, Norway, February 1914 – December 2019 (blue dots and purple line). If the observed change rate continues (based on more than 100 years of observations), the relative sea level at Oslo (in relation to land) will have dropped by about 28 cm by year 2100, compared to now. In the diagram the blue line indicates the modelled sea level change 2020-2100 for Oslo, using the moderate SSP2-4.5 scenario. According to IPCC relative sea level (in relation to land) at Oslo will have increased about 17 cm by year 2100, returning to the Relative Sea Level seen at Oslo in 1945. Sea level increase is predicted to begin rather suddenly around 2020 at Oslo, in contrast to the previous sea level decrease of about -3.44 mm/yr recorded since 1914.



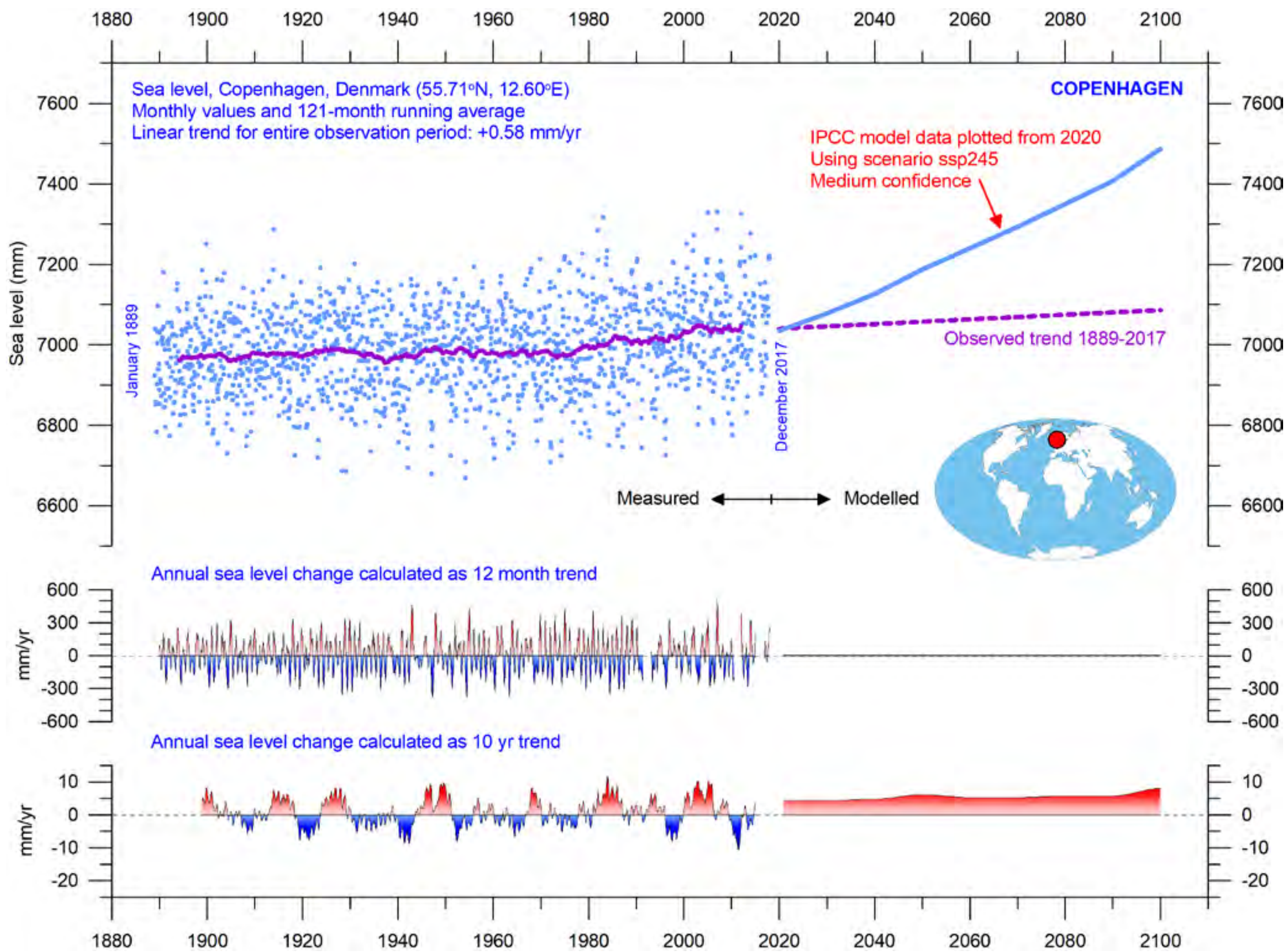
Site 2: Stockholm, Sweden

Observed relative sea level at Stockholm, Sweden, January 1889 – December 2020 (blue dots and purple line). If the observed change rate continues, the relative sea level at Stockholm (in relation to land) will have dropped about 30 cm by year 2100, compared to now. In the diagram the blue line indicates the modelled sea level change 2020-2100 for Stockholm, using the moderate SSP2-4.5 scenario. According to IPCC, the relative sea level (in relation to land) at Stockholm will have increased about 12 cm by year 2100, compared to now. A marked change from relative sea level decrease to -increase is predicted to begin around 2020, in contrast to the steady sea level decrease (about -3.71 mm/yr) recorded since 1889.



Site 3: Helsinki, Finland

Observed relative sea level at Helsinki, Finland, January 1879 – December 2019 (blue dots and purple line). If the observed change rate continues, the relative sea level at Helsinki (in relation to land) will have dropped about 18 cm by year 2100, compared to now. In the diagram the blue line indicates the modelled sea level change 2020-2100 for Helsinki, using the moderate SSP2-4.5 scenario. According to IPCC, the relative sea level (in relation to land) at Helsinki will have increased about 22 cm by year 2100, compared to now. A marked change from relative sea level decrease to increase predicted to begin around 2020, in contrast to the steady sea level decrease (about -2.22 mm/yr) recorded since 1879.



Site 4: Copenhagen, Denmark

Observed relative sea level at Copenhagen, Denmark, January 1889 – December 2017 (blue dots and purple line). Denmark was near the margin of the European Ice Sheet during the last glacial maximum, and the observed relative sea level change rate is therefore positive, although small. If the observed change rate continues, the relative sea level at Copenhagen (in relation to land) will have increased by about 4.6 cm by year 2100, compared to now. In the diagram the blue line indicates the modelled sea level change 2020-2100 for Copenhagen, using the moderate SSP2-4.5 scenario. According to IPCC, the relative sea level (in relation to land) at Copenhagen will have increased about 45 cm by year 2100, compared to now. A marked change in the relative sea level increase is predicted to begin around 2020, in contrast to the previous slow sea level increase recorded since 1889.

Reflections

The step change in relative sea level for all four sites at year 2020 visually appear unrealistic and suggests that the modelled data was not tested appropriately against the measured relative sea level data before publication. This is surprising, as the modelled sea level projections for different SSP scenarios are calculated relative to a baseline defined by observations 1995-2014, for each station. The modellers must therefore have inspected the observed data.

According to the most recent (2021) publication of the IPCC's work, the 6th Assessment Report from Working Group I, human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C (*Summary for Policymakers*, A.1.3). Consequently, according to the IPCC, most or all of the warming experienced since about 1850 is due to man's activities. This IPCC finding is remarkable, as it downgrades the effect of natural climatic variations to nearly zero since 1850.

It is therefore extremely surprising that the modelled effect of this should first appear in 2020 as a rather marked step change in the relative sea level. Had the modellers instead modelled their sea level data from an earlier date, e.g., 1950, which would have been entirely possible, the conflict between measured and modelled data would immediately have become apparent. Usually, model improvements would then have been initiated as the next scientific step. It is highly disappointing that such a simple quality- or sanity check apparently was never requested or performed by the IPCC.

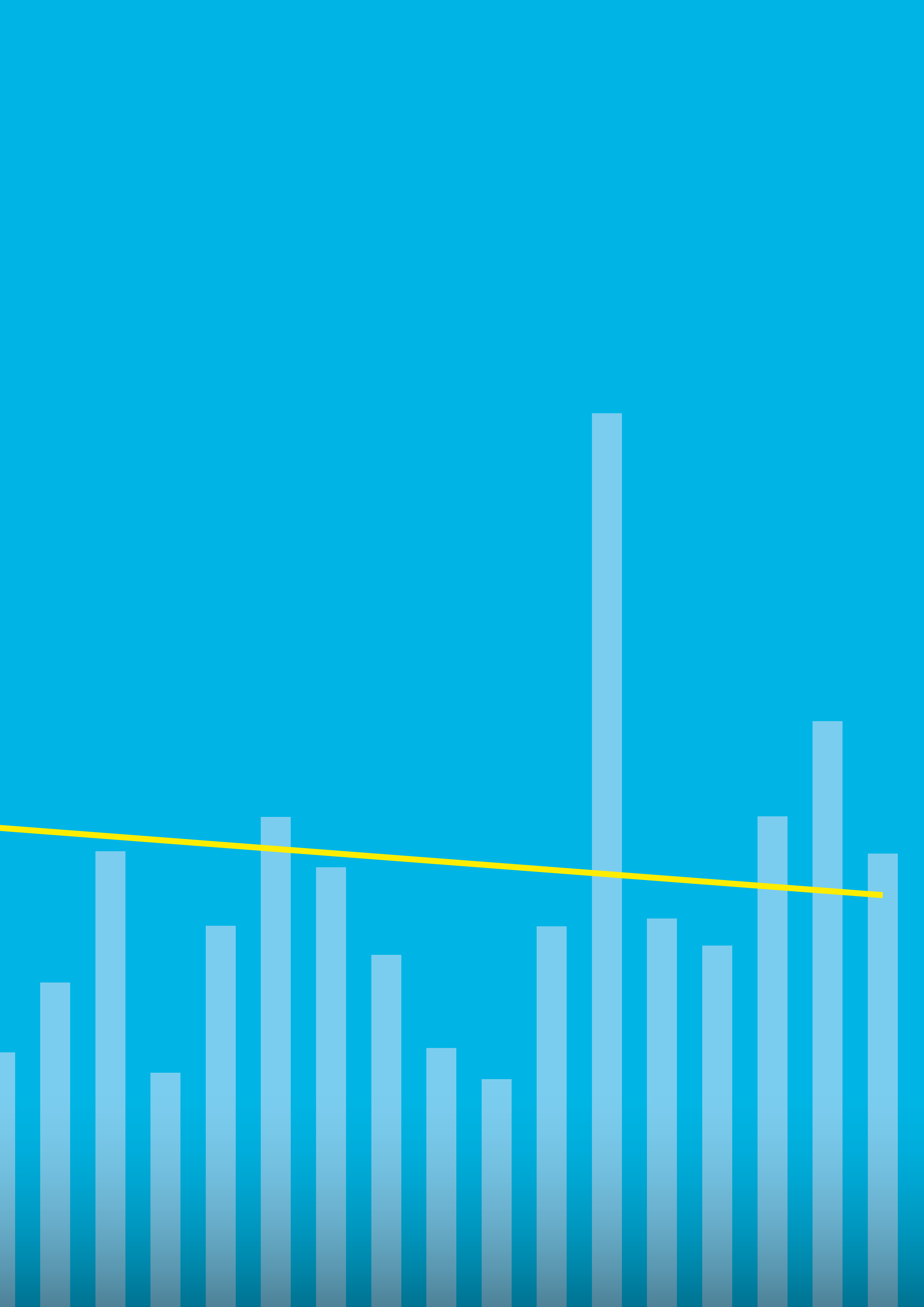
A study of several of the modelled sea level data demonstrates that major geoid changes in regions around Greenland are expected to take place in the future. This indicates a modelled substantial future reduction of the Greenland Ice Sheet. Summer temperature is a main control on the annual mass loss from glaciers, and winter precipitation is a main control on the annual accumulation of mass. The annual net mass balance is the numerical difference between these two numbers for any glacier and determines if the glacier is increasing or decreasing in volume. Erroneous or unrealistic input data for future air temperature and precipitation over Greenland therefor remain a main suspect for the unrealistic sea level modelling published recently by IPCC (the 6th Assessment Report from Working Group I).

Presumably, the startling recent IPCC finding that most or all of the warming experienced since about 1850 is due to man's activities, may have led to modelling of an unrealistic large future air temperature increase. Such erroneous input data may explain the above-described error in sea level modelling. The fundamental IPCC finding of no significant influence of natural variations since about 1850 should therefore be reconsidered.

For coastal planning, as usual, observations from traditional tide gauges remain the main data source to consider for planners and policymakers.

D

Human Impacts



11

Hiding the good news on hurricanes and floods

BY MARCEL CROK

Whenever an extreme weather event causes death and destruction, climate change becomes the culprit. The simple message always is "the climate is getting more extreme". But is that the case? The IPCC must answer such questions in a scientific and impartial way. Here we investigate whether the IPCC in their AR6 report succeeded in that task. The short answer is "no". Although deep inside the WG1 report the IPCC acknowledges some rather good news about extremes – i.e., that hurricanes and floods have not gotten worse – that good news is not communicated clearly to the policy makers and the media. In the WG2 report things got worse, and the IPCC even contradicts some of its own WG1 claims. The IPCC needs to do a much better job.

Ever since hurricane Katrina hit New Orleans in 2005 and caused tremendous damage and deaths, climate change has been linked to extreme weather events. So, whenever a flood, drought, heatwave or hurricane occurs, scientists and the media quickly blame anthropogenic climate change for being the cause of it. Nowadays, there is even a sub discipline, called event attribution, that deals with the question whether a specific extreme event, like the terrible floods in Pakistan in 2022, have been caused by our emissions of CO_2. That is a dangerous question from a political and legal perspective, since countries that suffer loss and damage from an extreme event can consider claiming compensation from developed countries. Their idea is that rich countries have emitted most manmade CO_2 and are therefore to blame for the loss in more vulnerable developing nations. A huge fund for so-called "Loss and Damage" is now being negotiated at the yearly COP-meetings.[1]

So, given the importance of extreme events for the people who endured them, as well as for political, legal, and economic reasons, it is quite important for the IPCC to get the science about this 'right'. In this chapter we analyse what the IPCC has written about trends in extreme events. We compare what is written in the main WG1 and WG2 reports and how this is reflected in the *Summary for Policy Makers* (SPM).

Pielke Jr.'s Assessment

Only days after the WG1 report was published in August 2021, the well-known US scientist Roger Pielke Jr summarised its finding with respect to extreme weather events in a long post on his personal website.[2] Pielke is very familiar with the literature about extreme events but was not involved in this (or any) IPCC report. He produced a table that is very revealing about what the IPCC had to say about all kinds of extreme weather, see table 1.

The IPCC uses 'detection' and 'attribution' as a framework to analyse trends in climate. Detection means that on climatic time scales a statistically significant change in some parameter has been 'detected'. The next step is to identify a 'cause' for that change, which in practice often means 'greenhouse gases', as these are the climate forcings assumed to dominate the total forcings by the IPCC.

1 https://unfccc.int/news/cop27-reaches-breakthrough-agreement-on-new-loss-and-damage-fund-for-vulnerable-countries
2 https://rogerpielkejr.substack.com/p/how-to-understand-the-new-ipcc-report-1e3

Table 1: Summary by Roger Pielke Jr of the AR6 WG1 report detection and attribution findings for different extreme weather phenomena.

	DETECTION	ATTRIBUTION
heat waves	yes	yes
heavy precipitation	yes	yes
flooding	no	no
meteorological drought	no	no
hydrological drought	no	no
ecological drought	yes	yes
agricultural drought	yes	yes
tropical cyclones	no	no
winter storms	no	no
thunderstorms	no	no
tornadoes	no	no
hail	no	no
lightning	no	no
extreme winds	no	no
fire weather	yes	yes

As shown in figure 1, according to the IPCC, greenhouse gases have contributed most to an increase in radiative forcing since 1750. Changes in the sun have contributed close to nothing (for a different perspective about that see our chapter 6). The IPCC then attributes the detected trend to these anthropogenic forcings.

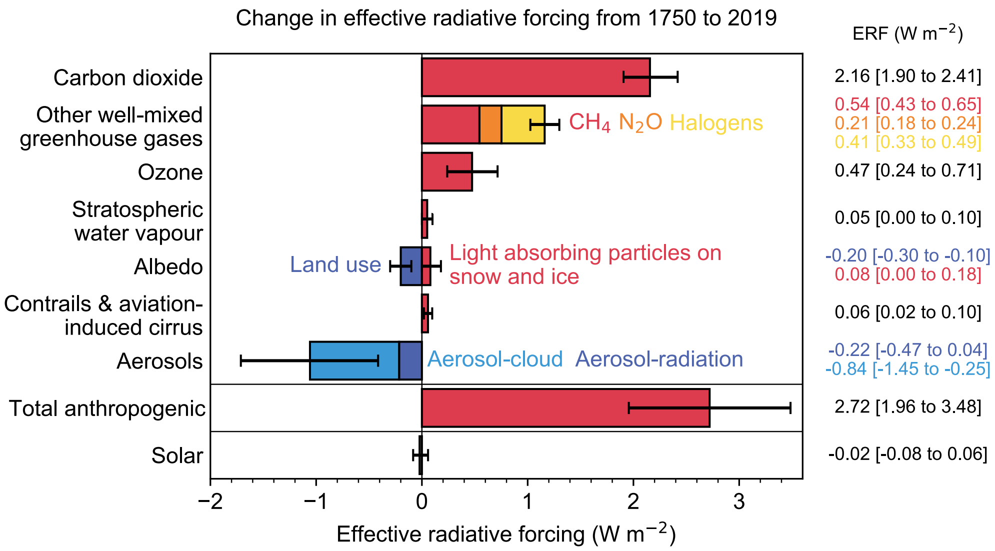


Figure 1: Reproduction of figure 7.6 from the WG1 report showing the change in radiative forcing since 1750.[3]

So, it's no surprise to see that, in the table provided by Pielke, the detected trends are also attributed by the IPCC to greenhouse forcing. However, what is most remarkable, and goes against most of the media coverage of extreme weather, is that for most extreme weather phenomena, no trend is detected. This is true for flooding, drought (meteorological or hydrological), tropical cyclones (in the Atlantic called hurricanes), winter storms, thunderstorms, tornadoes, hail, lightning, or extreme winds (so, storms of any type).

3 https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6

Damage Trends

Globally, most damage by far (around 90%) from extreme weather is due to floods and tropical cyclones. So, Pielke's table, based on the WG1 report, is truly good news. The most damaging extremes, hurricanes, floods and (weather-related) droughts have not changed on climatic time scales. The earth has warmed by slightly more than one degree Celsius, the CO_2 concentration has gone up, but the most dramatic extreme weather events have not (yet) changed.

The IPCC did not provide a handy table like Pielke did in his blog post. They provided written evidence of the lack of trends, in chapter 11 of the WG1 report. We are not going to discuss all of them, but here are some examples from the chapter.

They claim an attributable trend in extreme precipitation but not in flooding. Here are the relevant sections (our bold):

> The **frequency and intensity of heavy precipitation events have increased** over a majority of land regions with good observational coverage since 1950 (high confidence, Box TS.6, Table TS.2). Human influence is likely the main driver of this change (Table TS.2). [TS page 84]
> However, **heavier rainfall does not always lead to greater flooding**. This is because flooding also depends upon the type of river basin, the surface landscape, the extent and duration of the rainfall, and how wet the ground is before the rainfall event (FAQ 8.2, Figure 1). [Page 1155]
> There is low confidence about peak flow trends over past decades on the global scale [Page 1568]
> In summary there is **low confidence in the human influence on the changes in high river flows on the global scale**. [Page 1569]

Citing these sentences Pielke commented on twitter: "So don't claim floods are increasing; Don't say they are "climate driven"."[4]

Tropical cyclones

Next, we look at hurricanes (or tropical cyclones, TC):

> There is low confidence in most reported long-term (multi-decadal to centennial) trends in TC frequency- or intensity-based metrics due to changes in the technology used to collect the best-track data. [Page 1585]

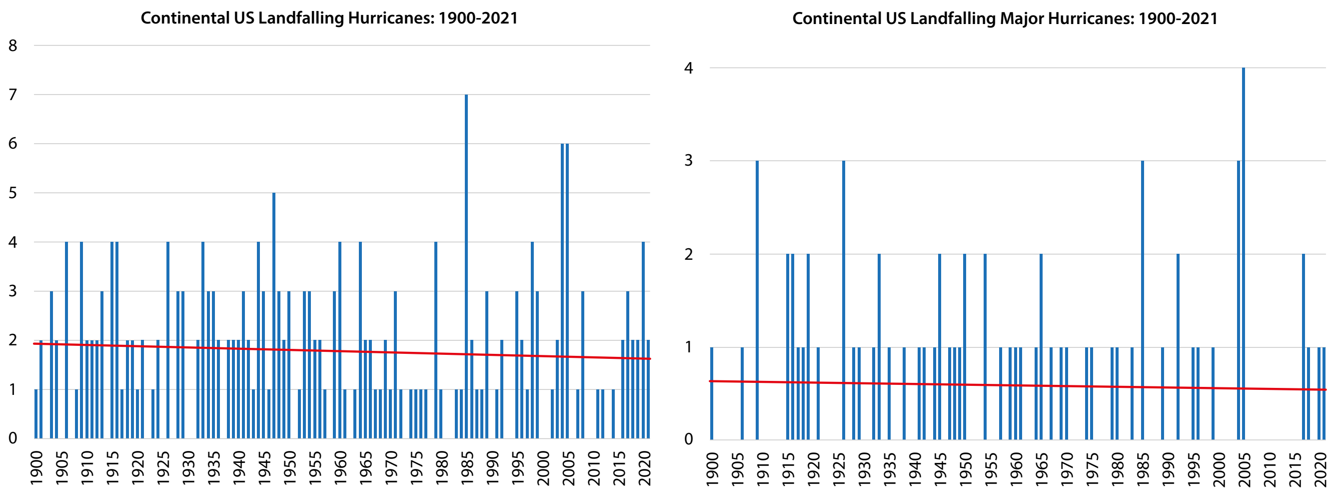


Figure 2: Number of US landfalling hurricanes and major hurricanes between 1900 and 2021. Updated graph from Klotzbach (2018)[5]

4 https://twitter.com/RogerPielkeJr/status/1424735415576104965

5 Klotzbach, Philip J., et al. "Continental US hurricane landfall frequency and associated damage: Observations and future risks." *Bulletin of the American Meteorological Society* 99.7 (2018): 1359-1376.

Pielke commented on the denigrating remark by the IPCC about the best-track data:

> The denigration of the TC "best track" dataset is bizarre. The dataset is the highest quality available on tropical cyclones around the world and widely used in research. It'd be a shame if the IPCC process were to have been used to promote certain work by denigrating the widely recognized best available data.

The IPCC decided not to show a graph in this section of the report, but here is a very relevant one, showing landfalling (major) hurricanes in the US. It shows that if anything there is a small decreasing trend. These graphs have been published in a peer reviewed paper by Phil Klotzbach in 2018 and are shown here in an updated version. The paper is not mentioned in the WG1 report.

This lack of trend in US landfalling hurricanes is important information, because they alone make up 60% of the global historical damage due to extreme weather events.[6]

Strangely, the IPCC decided to say nothing about trends in *global* tropical cyclone (TC) landfalls, although this 2012 paper, "Historical Global Tropical Cyclone Landfalls", by Weinkle et al. seems highly relevant.[7] That paper was co-authored by Roger Pielke Jr and Ryan Maue and concluded: "The analysis does not indicate significant long-period global or individual basin trends in the frequency or intensity of landfalling TCs of minor or major hurricane strength."

That paper showed this graph:

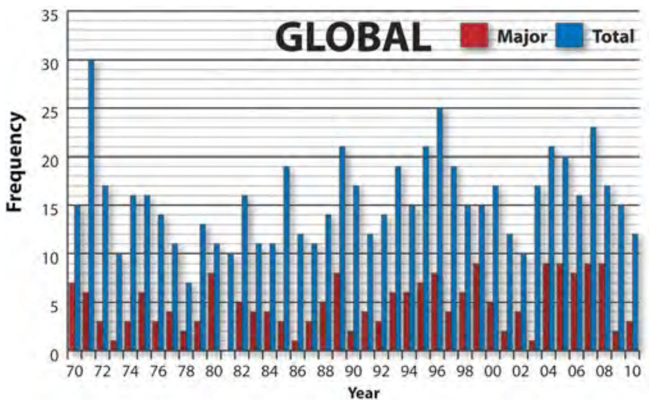


Figure 3: reproduction of figure 2 from Weinkle et al. (2012) showing global total and major hurricane landfalls.

Ryan Maue frequently updates this dataset on his website.[8] Here is the latest one:

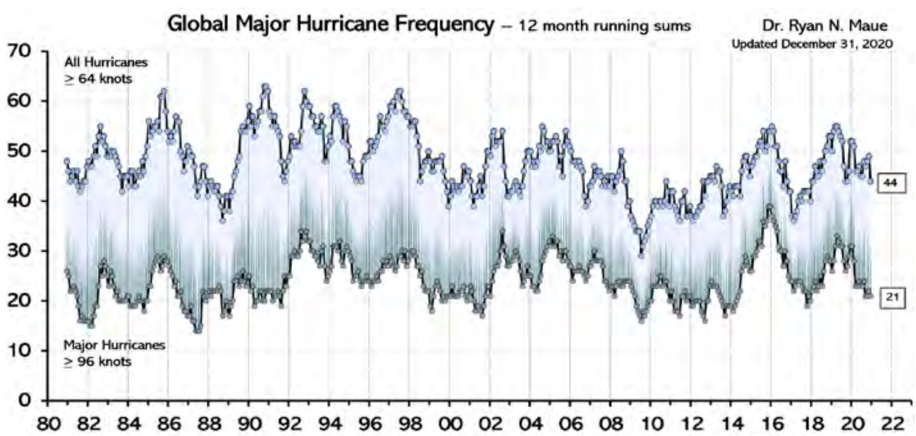


Figure 4: global hurricane frequency. On top all hurricanes, at the bottom major hurricanes. Source: Ryan Maue

6 Mohleji, S., & Pielke Jr, R. (2014). Reconciliation of trends in global and regional economic losses from weather events: 1980–2008. *Natural Hazards Review*, *15*(4), 04014009.

7 Weinkle, J., Maue, R., & Pielke, R. P., Jr (2012). Historical global tropical cyclone landfalls. Journal of Climate, 25(13), 4729–4735. https://doi. org/10.1175/jcli-d-11-00719.1

8 https://climatlas.com/tropical/

Clearly neither all nor major hurricanes show an up or down trend. There is large variability from year to year and from decade to decade. The calendar year with most hurricanes was 59 in 1992 and the least was 38 in 2009. The number of major hurricanes peaked in 2015 with 38 and the least occurred in 1981 with 15.

Now with these graphs the picture is quite clear that nothing unusual is going on with tropical cyclones.

Nevertheless, the IPCC manages to conclude this in their report (our bold):

> In summary, there is mounting evidence that **a variety of TC characteristics have changed over various time periods.** It is likely that the global proportion of Category 3–5 tropical cyclone instances and the frequency of rapid intensification events have increased globally over the past 40 years. [Page 1587]

That paragraph is confusing to say the least, especially without showing the graphs included herein. Pielke commented on twitter that using the latest forty years can also be misleading, as the 1970s and early 1980s were periods with relatively low tropical cyclone activity.

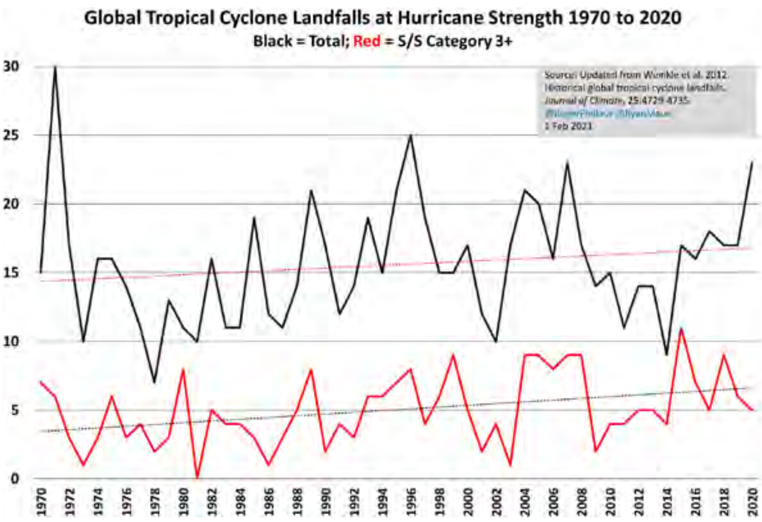


Figure 5: global tropical cyclone landfalls since 1970. Based on Weinkle et al. 2012. Source: Pielke Jr[9]

In figure 5 we see a trend up and it is tempting to think it is due to anthropogenic climate change. A truly global picture is missing before 1970, but there is good data for the North Atlantic and the Western Pacific, and those two areas account for about 70% of the global landfalls. The data for these two basins goes back to 1945:

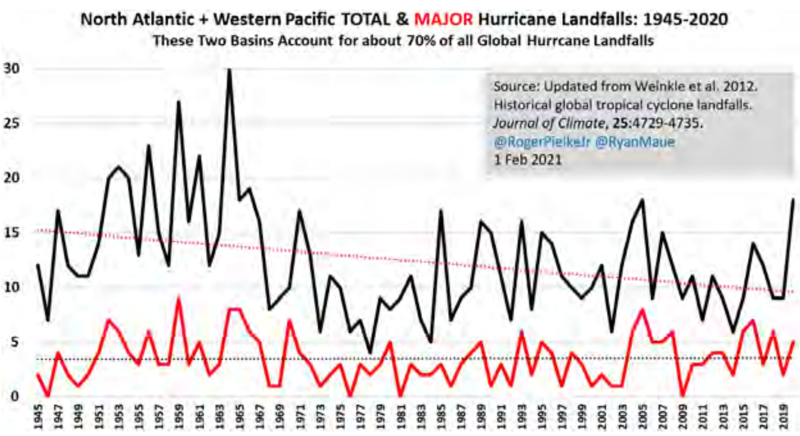


Figure 6: tropical cyclone landfalls in the North Atlantic and Western Pacific since 1945. Source: Pielke Jr

9 https://rogerpielkejr.substack.com/p/a-remarkable-decline-in-landfalling

Suddenly the upward trend that we saw from the 1970s is changed to a downward trend for all hurricanes and no trend for major hurricanes. It clearly shows one should be careful drawing conclusions from shorter periods of time.

Drought

Next is drought. In AR6 the IPCC changed its definitions of drought (AR5 just talked about drought) and now distinguishes meteorological and hydrological drought (no trends) from ecological and agricultural droughts (trend detected).[10] Agricultural and ecological drought is related with abnormal soil moisture deficit (combination of precipitation deficit and excess evapotranspiration), meteorological drought with precipitation deficits and hydrological drought with streamflow deficit.

Here are some of the key conclusions:

On hydrological drought:

> There is still limited evidence and thus low confidence in assessing these trends at the scale of single regions, with few exceptions [Page 1578]

On meteorological drought:

> The regional evidence on attribution for single AR6 regions generally shows low confidence for a human contribution to observed trends in meteorological droughts at regional scale [Page 1579]

On agricultural and ecological drought:

> In summary, human influence has contributed to increases in agricultural and ecological droughts in the dry season in some regions due to increases in evapotranspiration (medium confidence).

So, based on the AR6 WG1 report you cannot simply state that drought in general is increasing.

Extreme hot days and heatwaves

AR6 is most confident about trends in hot days and heatwaves (our bold):

> In summary, it is virtually certain that there has been an increase in the number of warm days and nights and a decrease in the number of cold days and nights on the global scale since 1950. Both the coldest extremes and hottest extremes display increasing temperatures. It is very likely that these changes have also occurred at the regional scale in Europe, Australasia, Asia, and North America. It is **virtually certain that there has been increases in the intensity and duration of heatwaves** and in the number of heatwave days at the global scale.

It is noteworthy though that they use 1950 as a reference year. It is well-known that at least in the US, the 1930s were the hottest. Here is a graph for the US:

10 Here is a footnote from the Technical Summary explaining the differences: "Agricultural and ecological drought (depending on the affected biome): a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general (see Annex VII: Glossary). Observed changes in meteorological droughts (precipitation deficits) and hydrological droughts (streamflow deficits) are distinct from those in agricultural and ecological droughts and are addressed in the underlying AR6 material (Chapter 11)."

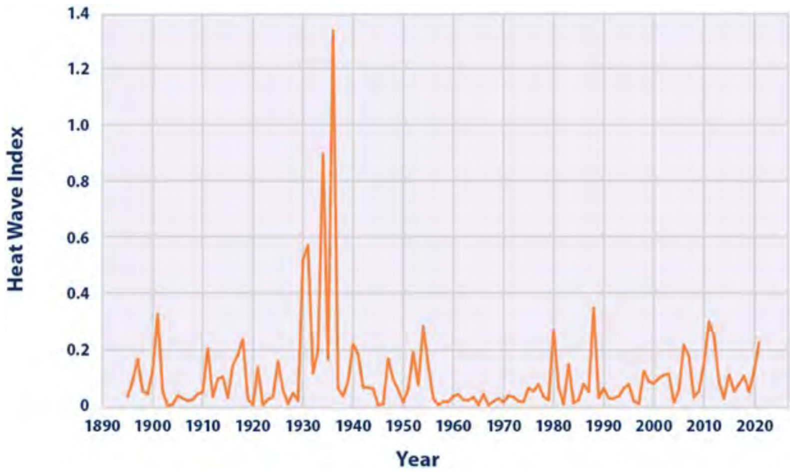


Figure 7: This figure shows the annual values of the U.S. Heat Wave Index from 1895 to 2021. These data cover the contiguous 48 states. An index value of 0.2 (for example) could mean that 20 percent of the country experienced one heat wave, 10 percent of the country experienced two heat waves, or some other combination of frequency and area resulted in this value. Source: EPA[11]

AR6 WG1 Summary for Policy Makers

So, even if we take IPCC at face value and accept that some extremes (heatwaves, extreme precipitation, ecological and agricultural drought are increasing in frequency), the more impactful extremes (in terms of damage and deaths) such as flooding and tropical cyclones are not. This is good news. We are now going to see how the *Summary for Policy Makers*, arguably the most important part of the report, reflects these findings.

First let's look at tropical cyclones, as these, especially those landfalling in the US, dominate global disaster damages.

> Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. **Evidence of observed changes** in extremes such as heatwaves, heavy precipitation, droughts, and **tropical cyclones**, and, **in particular, their attribution to human influence, has strengthened since AR5**. [AR6, SPM, A.3; Page 8]

Now this statement is highly misleading if not simply wrong. IPCC is simply hiding the fact that the frequency and intensity of tropical cyclones has not increased. It even claims the opposite, an observed 'change' in tropical cyclones, that can be attributed to human influence (i.e., the emission of greenhouse gases).

Point A.3.4 of the SPM goes into more detail (our bold):

> It is likely that the **global proportion of major** (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and it is very likely that the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone (medium confidence). **There is low confidence in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones**. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones (high confidence), but data limitations inhibit clear detection of past trends on the global scale.

Their main claim is that the global proportion of major tropical cyclone occurrence is increasing, i.e., that there is a shift towards more powerful hurricanes. As can be seen from figure 4 this might be the case. The total number of hurricanes seems to be decreasing a bit while the number of major hurricanes is going up and down without a clear trend. Given the large year-to-year and decade-to-decade variability and the short timespan (40 years), drawing conclusions such as the

11 https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves#%20

one from the IPCC seems far-fetched. At least they acknowledge in this paragraph the lack of trend in the frequency of tropical cyclones.

Ryan Maue published data on another metric, the so-called ACE, Accumulated Cyclone Energy. It is a measure of the total energy involved in tropical cyclones. If the proportion of major hurricanes increase, one would also expect an increase in the ACE. Here is the graph:

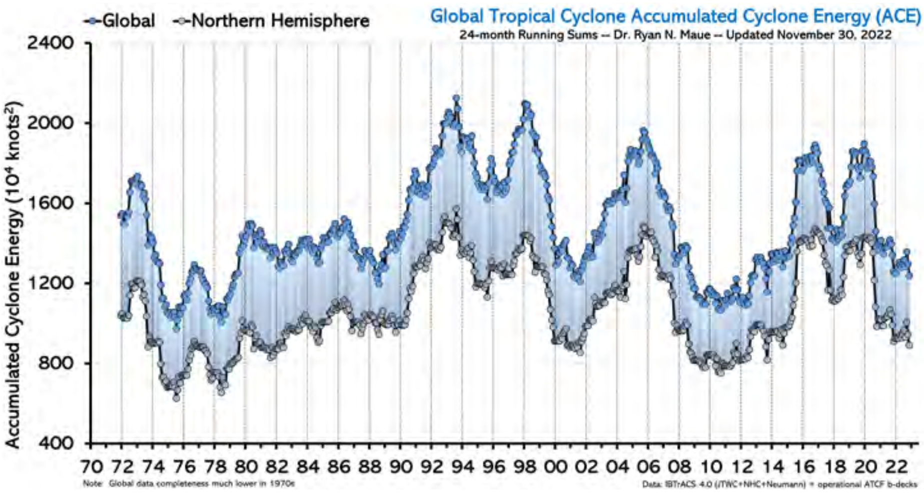


Figure 8: Last 50-years+ of Global and Northern Hemisphere Accumulated Cyclone Energy: 24 month running sums. Note that the year indicated represents the value of ACE through the previous 24-months for the Northern Hemisphere (bottom line/gray boxes) and the entire global (top line/blue boxes). The area in between represents the Southern Hemisphere total ACE. Source: Ryan Maue[12]

Again, we see large year-to-year and decade-to-decade variability but no clear trend. In summary, the IPCC is hiding good news about tropical cyclones.

Floods

There is a statement about compound flooding in the SPM but not about the lack of trends in flooding in general. Remember, this is what the full report said: "In summary there is **low confidence in the human influence on the changes in high river flows on the global scale**." [Page 1569]

A statement like this is not highlighted in the SPM. It does mention this though (our bold):

> Human influence has likely increased the chance of compound extreme events[13] since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale (high confidence), fire weather in some regions of all inhabited continents (medium confidence), and **compound flooding** in some locations (medium confidence).

We can therefore conclude that the two most important extreme events (from the perspective of damage) are not fairly covered in the SPM.

Now let's see if and how the IPCC treats heatwaves. They write:

> It is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with high confidence that human-induced climate change is the main driver of these changes. Some recent hot extremes observed over the past decade would have been extremely unlikely to occur without human influence on the climate system. [A.3.1]

12 https://climatlas.com/tropical/

13 Compound extreme events are the combination of multiple drivers and/or hazards that contribute to societal or environmental risk (Glossary). Examples are concurrent heatwaves and droughts, compound flooding (e.g., a storm surge in combination with extreme rainfall and/or river flow), compound fire weather conditions (i.e., a combination of hot, dry and windy conditions), or concurrent extremes at different locations.

On droughts:

> Human-induced climate change has contributed to increases in **agricultural and ecological droughts** in some regions due to increased land evapotranspiration (medium confidence). [A.3.2]

They mention an increase in agricultural and ecological drought, but not the lack of a trend in hydrological and meteorological droughts.

WG1 Report

In general the WG1 report did a reasonably good job in describing trends in extreme weather events. However, the IPCC seems to be extremely focused on bad news and ignores good news. It tries hard to make the connection between climate change and more extreme weather. Deep inside the report it acknowledges (though grudgingly) that most extremes have not changed, such as flooding, drought (meteorological or hydrological), tropical cyclones, winter storms, thunderstorms, tornadoes, hail, lightning or extreme winds. So, there is a lot of good news available in the report, but one really has to look for it. The good news is not highlighted in the summary of the chapter, let alone in the *Summary for Policy Makers*. And did you ever hear an IPCC contributing scientist publicly acknowledge that there is no trend in tropical cyclones and flooding?

WG2 report

The WG2 report was published nine months after the WG1 report. So, the authors of the WG2 report knew what was inside the WG1 report. WG2 covers the impacts of climate change so logically trends in extremes are also important in that part of the report. Let's focus on some of the most important extreme weather events, tropical cyclones, flooding and drought.

First, here is what WG2 has to say about tropical cyclones (our bold):

> Adverse impacts from **tropical cyclones, with related losses and damages, have increased due to sea level rise and the increase in heavy precipitation** (medium confidence). [SPM, page 9]

And

> Some extreme weather events are increasing in frequency and (or) severity as a result of climate change (Seneviratne et al., 2021) (high confidence). These include extreme rainfall events (Roxy et al., 2017; Myhre et al., 2019; Tabari, 2020); extreme and prolonged heat leading to catastrophic fires (Bowman et al., 2017; Krikken et al., 2019; van Oldenborgh et al., 2020); and **more frequent and stronger cyclones/hurricanes** and resulting extreme rainfall (Griego et al., 2020). These extreme events, coupled with high vulnerability and exposure in many parts of the world, turn into disasters and affect millions of people every year. [Page 588]

This is opposite of what the WG1 report said, namely "[t]here is low confidence in most reported long-term (multi-decadal to centennial) trends in TC frequency- or intensity-based metrics".

Instead of simply citing WG1 the WG2 claim of more frequent and intense hurricanes/cyclones goes to the paper Griego et al. (2020)[14], which has no analysis of hurricane/cyclone frequency or intensity.

WG2 is also claiming that floods are getting worse (our bold):

> Extreme weather events **causing highly impactful floods and droughts have become more likely and (or) more severe due to anthropogenic climate change** (high confidence). {4.2.4, 4.2.5, Cross-Chapter Box DISASTER in Chapter 4} [executive summary chapter 4, page 555]

14 Griego, A.L., A.B. Flores, T.W. Collins and S.E. Grineski, 2020: Social vulnerability, disaster assistance, and recovery: a population-based study of Hurricane Harvey in Greater Houston, Texas. Int. J. Disaster Risk Reduct., 51, 101766, doi:10.1016/j.ijdrr.2020.101766.

Remember what WG1 said, "there is low confidence about human influence on the changes in high river flows on the global scale." [page 1569]

Here is something about drought (our bold):

> **Anthropogenic climate change has contributed to the increased likelihood and severity of the impact of droughts (especially agricultural and hydrological droughts)** in many regions (high confidence). [executive summary chapter 4, page 555]

The WG1 report said human influence on agricultural and ecological drought but no trends in hydrological and meteorological drought. So again, there is a conflict between WG1 and WG2.

Conclusions

If and to what extent extreme weather is changing is a very important question. This question has dominated political debates around climate change. It is therefore extremely important that the IPCC, which is, or should be, politically neutral, gets the science about this right. Here we have shown that in general the WG1 report did a reasonably fair job, except for the *Summary for Policy Makers*. However, the chapter about extremes (chapter 11) had a lot of good news to offer (no trends in hurricanes and flooding), but the IPCC failed to emphasize these results, both in the summary of the chapter and in the *Summary for Policy Makers*.

Policy makers therefore cannot be blamed for being unaware of the good news about recent changes in extreme weather, in particular, that the most impactful events (like hurricanes, floods, and hydrological and meteorological droughts) have not increased. We also show that global disaster losses normalised for GDP have not increased and that climate-related deaths have decreased in other chapters. These facts paint a far less bleak picture of climate change than the doom and gloom seen in the latest IPCC reports.

In WG2 things really get worse, the IPCC even contradicts many its own claims from the WG1 report. In 2010 several errors were discovered in the 2007 AR4 report. Those errors ultimately led to an investigation by the InterAcademy Councel (IAC).[15] The IAC recommended many changes to improve the IPCC process. The bias and errors we have laid bare in this chapter and the chapters about disaster losses and climate-related deaths show that rather than improving, the IPCC, and especially the WG2 report, have deteriorated. It is more focused on advocacy than on a comprehensive, neutral science assessment.

15 Climate Change Assessments, Review of the Processes & Procedures of the IPCC (interacademies.org)

12 Extreme views on disasters

BY MARCEL CROK

Economic losses caused by extreme weather are rising. Most of the scientific literature shows, however, that this increase is mostly due to increasing population and wealth. After normalising the data, evidence that anthropogenic climate change is contributing to the damage is non-existent. This is good news, but the IPCC completely ignored this literature for unknown reasons and instead comes to a cherry-picked alarmist result.

Whenever a storm, flood or heat wave strikes, media reports quickly blame anthropogenic climate change for the disaster. So, an important question is whether extremes and economic losses due to those extremes are increasing. These questions of course have received a lot of attention in the scientific literature. In this chapter we address whether economic losses due to climate related disasters (hurricanes, floods, droughts, wildfires etc.) have increased.

During the past century the global population increased spectacularly from 2 billion to 8 billion people. So, we have a lot more people who can be hit by natural disasters. Potentially this is an explosive situation: if we have more extreme weather that is more severe, and it hits more people, we naturally expect more damage and more loss of life.

It is also quite easy to understand that if more people live in a hurricane prone area like Florida, then more people will suffer damage from hurricane events. So, each new hurricane will probably cause more damage since there are more houses and buildings and they are more expensive. Since 1998 scientists have developed methods to adjust for changes in population, economic growth (GDP), as well as adaption through more strict building codes etc.[1] The method is called 'normalisation' of disaster losses and can be used to check for trends in weather extremes. After all, if there is an increasing trend in, let's say hurricanes, the record of disaster losses, after correcting for societal developments, should also show an increase.

Normalisation of damage

Since the first paper on normalisation in 1998 dozens of papers have been published in the scientific literature. One of the central scientists involved in this discipline, and the author of the first paper in 1998, is Roger Pielke Jr, professor at the University of Colorado in Boulder. In 2020 Pielke decided to review the 'normalisation' literature that has appeared between 1998 and 2020. The resulting paper was published in the journal *Environmental Hazards*.[2] The publication of this paper was rather timely. The IPCC was working on the second part of its sixth assessment report about "Impacts, Adaptation and Vulnerability". But before we delve into that very extensive report let's summarise what Pielke said in his review paper. Here is the full abstract with some sentences highlighted by us in bold:

> **ABSTRACT**
> Nowadays, following every weather disaster quickly follow estimates of economic loss. **Quick blame for those losses, or some part, often is placed on claims of more frequent or intense weather events. However, understanding what role changes in climate may have**

1 Pielke, R. A., & Landsea, C. W. (1998). Normalized hurricane damages in the United States: 1925–95. Weather and Forecasting, 13(3), 621–631. https://doi.org/10.1175/1520-0434(1998)0132.0.CO;2

2 Pielke Jr., R. (2021): Economic 'normalisation' of disaster losses 1998–2020: a literature review and assessment. Environmental Hazards, 20 (2). doi: 10.1080/17477891.2020.1800440

Table 1: Normalisation papers reviewed in Pielke 2020.

Study (ordered by date of publication)	Phenomenon (region)	Detection claimed to be achieved?	Trend direction	Attribution claimed to be achieved?	Period (*italics* = <3 years)
STUDIES FOCUSED ON SPECIFIC PHENOMENA					
	Tropical cyclones				
Martinez (2020)	United States	No	n/a	No	1900–2018
Grinsted et al. (2019)	United States	Yes	Increase	Yes	1900–2018
Chen et al. (2018)	China	No	n/a	No	1983–2015
Ye and Fang (2018)	China	Yes	Decrease	No	*1985–2010*
Weinkle et al. (2018)	United States	No	n/a	No	1900–2017
Klotzbach et al. (2018)	United States	No	n/a	No	1900–2016
Fischer et al. (2015)	China	No	n/a	No	*1984–2013*
Estrada et al. (2015)	United States	Yes	Increase	No	1900–2005
Bouwer and Wouter Botzen (2011)	United States	No	n/a	No	1900–2005
Nordhaus (2010)	United States	Yes	Increase	No	1900–2005
Zhang et al. (2009)	China	No	n/a	No	*1983–2006*
Schmidt et al. (2009)	United States	No	n/a	No	1950–2005
Pielke et al. (2008)	United States	No	n/a	No	1900–2005
Pielke et al. (2003)	Latin America and Caribbean	No	n/a	No	1944–1999
Raghavan and Rajesh (2003)	India	No	n/a	No	*1977–1998*
Collins and Lowe (2001)	United States	No	n/a	No	1900–1999
Pielke and Landsea(1998)	United States	No	n/a	No	1926–1995
	Floods				
Du et al. (2019)	China	Yes	Decrease	No	1990–2017
Paprotny et al. (2018)	Europe	No	n/a	No	1870–2016
Wei et al. (2018)	China	Yes	Decrease	No	*2000–2015*
Fang et al. (2018)	China (Yangtze River)	Yes	Decrease	No	*1998–2014*
Perez-Morales et al. (2018)	Spain	No	n/a	No	1975–2013
Stevens et al. (2016)	United Kingdom	No	n/a	No	1884–2013
Barredo et al. (2012)	Spain	No	n/a	No	1971–2008
Hilker et al. (2009)	Switzerland	No	n/a	No	1972–2007
Chang et al. (2009)	Korea	No	Increase	No	1971–2005
Barredo (2009)	Europe	No	n/a	No	1970–2006
Downton et al. (2005)	United States	Yes	Decrease	No	1926–2000
Fengqing et al. (2005)	China	No	n/a	No	1950–2001
Pielke and Downton (2000)	United States	No	n/a	No	1932–1997
	Extratropical storms				
Andres and Badoux (2019)	Switzerland	No	n/a	No	1972–2016
Stucki et al. (2014)	Switzerland	No	n/a	No	1859–2011
Barredo (2010)	Europe	No	n/a	No	1970–2008
	Tornadoes				
Simmons et al. (2013)	United States	No	n/a	No	1950–2011
Brooks and Doswell (2001)	United States	No	n/a	No	1890–1999
Boruff et al. (2003)	United States	No	n/a	No	1900–2000
	Convective storms				
Sander et al. (2013)	United States	Yes	Increase	No	1970–2009
	Wildfire				
Crompton et al. (2010)	Australia	No	n/a	No	1925–2009

Study (ordered by date of publication)	Region (location & phenomena)	Detection claimed to be achieved?	Trend direction	Attribution claimed to be achieved	Period (*italics* = <3 years)
STUDIES FOCUSED ON PARTICULAR REGIONS					
	Region				
Choi et al. (2019)	Korea (weather)	Yes	Decrease	No	1965–2015
Reyes and Elias (2019)	United States (crop loss)	Yes	Mixed	No	*2001–2016*
McAneney et al. (2019)	Australia (weather)	No	n/a	No	1966–2017
Paul and Sharif (2018)	Texas (hydrometeorological)	No	n/a	No	1960–2016
Bahinipati and Venktachalam (2016)	India (weather)	No	n/a	No	1972–2009
Zhou et al. (2013)	China(natural disasters)	No	n/a	No	*1990–2011*
Crompton and McAneney (2008)	Australia (weather)	No	n/a	No	1967–2006
Choi and Fisher (2003)	United States (weather)	No	n/a	No	1951–1997
	World				
Pielke (2019)	All disasters & weather only	Yes	Decrease	No	*1990–2017*
Watts et al. (2019)	All disasters	No	n/a	No	1990–2016
Daniell et al. (2018)	Multi-hazard	Yes	Decrease	No	1950–2015
Mohleji and Pielke (2014)	All-weather related	No	n/a	No	*1980–2008*
Neumayer and Barthel (2011)	All-weather related	No	n/a	No	*1980–2008*
Visser et al. (2014)	All-weather related	No	n/a	No	1980–2010
Miller et al. (2008)	All-weather related	No	n/a	No	1950–2005

played in increasing weather-related disaster losses is challenging because, in addition to changes in climate, society also undergoes dramatic change. Increasing development and wealth influence exposure and vulnerability to loss – typically increasing exposure while reducing vulnerability. In recent decades a scientific literature has emerged that seeks to adjust historical economic damage from extreme weather to remove the influences of societal change from economic loss time series to estimate what losses past extreme events would cause under present-day societal conditions. In regions with broad exposure to loss, an unbiased economic normalisation will exhibit trends consistent with corresponding climatological trends in related extreme events, providing an independent check on normalisation results. **This paper reviews 54 normalisation studies published 1998–2020 and finds little evidence to support claims that any part of the overall increase in global economic losses documented on climate time scales is attributable to human-caused changes in climate, reinforcing conclusions of recent assessments of the Intergovernmental Panel on Climate Change.**

The abstract is rather clear: there is an increase in economic losses, but after the data have been 'normalised' for societal factors there is little evidence that anthropogenic climate change is a factor in the increase. This is in line with the conclusions of earlier IPCC reports. The paper analyses 54 studies dealing with different extreme weather events in different regions of the world. The paper provides a table showing all the studies. See table 1.

The IPCC uses a two-step process to analyse climate change and its impacts. The first question is whether a statistical change in some climate phenomenon has been 'detected'. If so, then the next question is whether such a trend can be 'attributed' to anthropogenic climate change. If both questions are answered with 'yes', then the IPCC concludes that the human emissions of greenhouse gases have 'caused' the observed change. The table in Pielke 2020 notes several detected trends. The paper explains that eight of those trends are decreasing, five are increasing and one study finds mixed trends. However, of all 53 weather related studies (one deals with earthquakes) only one (Grinsted 2019) claims there is an increasing trend in disaster losses that is attributable to anthropogenic climate change.[3] That paper deals with hurricane losses in America since 1900, a topic that has been studied extensively in the literature. Two more papers (Estrada 2015 and Nordhaus 2010[4]) claim there is an increase in normalised losses due to landfalling hurricanes in the US although they don't attribute these trends to anthropogenic climate change. However, seven other papers described in the Pielke review paper conclude there is no trend in normalised US hurricane losses. So which conclusion is the right one or the more likely one?

Landfalling hurricanes

In such cases it can be helpful to look at the climate records. For the US there is a good record of landfalling hurricanes since 1900. If there is an upward trend in hurricanes, it is more likely that there is also an upward trend in normalised losses.

Figure 1 shows there is no long-term increase in landfalling US hurricanes, either for all hurricanes or just for the major hurricanes. Both trends are slightly down. Surprisingly, these graphs, although they have been published in peer reviewed papers, have never been published in any of the 47 IPCC reports. This is surprising given the importance of US landfalling hurricanes for global disaster losses. Ninety percent of global disaster losses are due to global hurricanes (or cyclones) and floods. And 60% of global disaster losses are due to damage caused by US hurricanes. The reason for this is that so many prosperous people live in hurricane prone States like Florida.

3 Grinsted, A., Ditlevsen, P., & Christensen, J. H. (2019). Normalized US hurricane damage estimates using area of total destruction, 1900–2018. Proceedings of the National Academy of Sciences, 116(48), 23942–23946. https://doi.org/10.1073/pnas.1912277116

4 Estrada, F., Botzen, W. W., & Tol, R. S. (2015). Economic losses from US hurricanes consistent with an influence from climate change. Nature Geoscience, 8(11), 880–884. https://doi.org/10.1038/ ngeo2560 and Nordhaus, W. D. (2010). The economics of hurricanes and implications of global warming. Climate Change Economics, 1(01), 1–20. https://doi.org/10.1142/S2010007810000054

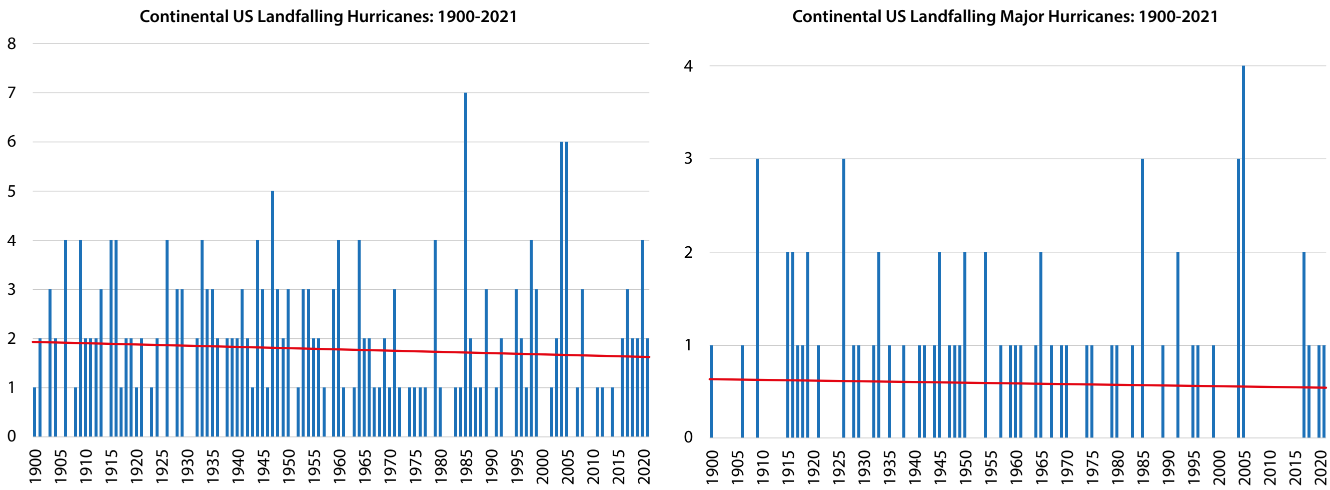


Figure 1: Number of US landfalling hurricanes and major hurricanes between 1900 and 2021. Updated graph from Klotzbach 2018[5]

So, the lack of a trend in hurricanes means that an unbiased normalisation of hurricane losses should also show no increase. This makes it more likely that the seven studies showing no trends in normalised US hurricane losses are correct. Pielke 2020 mentions another paper by Bouwer and Botzen (2011)[6] that concluded that Nordhaus 2010 did not sufficiently adjust for local increases in exposure (e.g., more people and therefore more houses that can be hit). Pielke (2020) also explains how the three papers by Nordhaus, Estrada and Grinsted severely underestimate the historic damage done by the 1926 Miami hurricane when compared to other well accepted estimates. So these studies underestimate historic losses, causing an artificial increase in damage over time, even though the frequency of hurricanes has not changed since 1900.

Earlier IPCC reports

Pielke (2020) cites one of the conclusions of Bouwer and Botzen 2011: 'Our finding is important and indicates that climate change has not resulted in an increase in hurricane damage in the USA in the past.' Pielke then notes that his conclusions and those of Bouwer and Botzen are in line with several IPCC assessments reports. A key paragraph in Pielke (2020) is cited below (our bold):

> Taken together, the results of these studies reinforce and provide much stronger support for the 2014 conclusions of the IPCC that **'economic growth, including greater concentrations of people and wealth in periled areas and rising insurance penetration, is the most important driver of increasing losses'** and **'loss trends have not been conclusively attributed to anthropogenic climate change'** (IPCC, 2014).
>
> The 2014 IPCC assessment reinforced the conclusions of the IPCC (2012) special report on extreme events, providing even stronger evidence: 'There is medium evidence and high agreement that **long-term trends in normalised losses have not been attributed to natural or anthropogenic climate change' and 'Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters** (high confidence)' (IPCC, 2014).

Pielke (2020) is further confirmation of conclusions already drawn in earlier papers and in several IPCC assessments reports. Yes, economic losses due to climate related disasters are increasing, but they do so because there are more people around who can suffer from damage. After you have 'normalised' the data for economic and social development there is no trend left to be attributed to anthropogenic climate change.

5 Klotzbach, Philip J., et al. „Continental US hurricane landfall frequency and associated damage: Observations and future risks." *Bulletin of the American Meteorological Society* 99.7 (2018): 1359-1376.

6 Bouwer, L. M., & Wouter Botzen, W. J. (2011). How sensitive are US hurricane damages to climate? Comment on a paper by WD Nordhaus. Climate Change Economics, 2(01), 1–7. https://doi.org/ 10.1142/S2010007811000188

Global weather losses

Another paper published by Pielke (in 2019) presents a graph with global estimates of normalised disaster losses.[7] Such estimates are relevant in the context of the UN Sustainable Development Goals (SDG). One of the SDG's state the following sub goal:

> By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

This is a reasonable goal. The economy is allowed to grow but we try to decrease disaster losses *relative* to this growth. The paper shows how we are doing so far in this respect. Below is an updated figure from that paper:

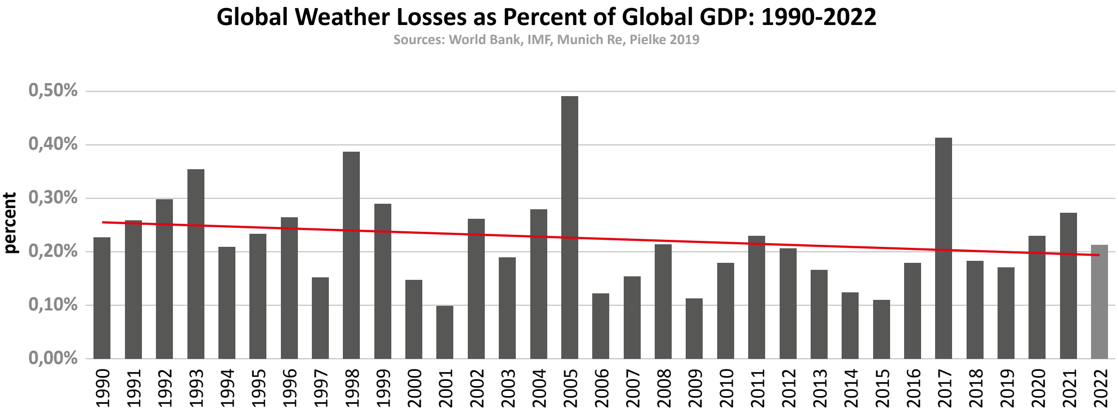


Figure 2: Normalised global disaster losses as a percentage of global GDP. Source: Updated from Pielke (2019), from Pielke's website here.[8]

The trend since 1990 is also down, from about 0.25% of the global GDP in 1990 to now 0.20%. Note that the global economy in this period doubled. So, in absolute numbers the losses increased, but not as a percentage of the GDP. That is also good news.

Working Group 2 report

Now it is time to have a look at the second part of the AR6 report (Working Group 2 report, WG2) titled *Climate Change 2022: Impacts, Adaptation and Vulnerability*.[9] Just like the Working Group 1 report it is a huge report, covering 3068 pages. It was published on 28 February 2022. The report deals with "impacts" and of course there is no bigger impact than a disaster caused by extreme weather. So, terms like "disasters" (598), "loss" (3504), "damage" (1464), "mortality" (1345) and "vulnerability" (3568) are used extensively throughout the report. But let's focus on the "disaster losses" that we have discussed so far in this chapter. That term is surprisingly used only four times.

Here is what the *Summary for Policy Makers* has to say about "losses" (our bold):

> **Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability.** Some development and adaptation efforts have reduced vulnerability. Across sectors and regions, the most vulnerable people and systems are observed to be disproportionately affected. The rise in weather and climate extremes has

7 Pielke, R. (2019). Tracking progress on the economic costs of disasters under the indicators of the sustainable development goals. Environmental Hazards, 18(1), 1–6. https://doi.org/10.1080/ 17477891.2018.1540343

8 https://rogerpielkejr.substack.com/p/weather-and-climate-disaster-losses

9 IPCC AR6, WG2, 2022. https://www.ipcc.ch/report/ar6/wg2/

led to some **irreversible impacts as natural and human systems are pushed beyond their ability to adapt**. (high confidence)

This is the sort of language that policy makers apparently must understand. The first sentence in bold actually contains a pleonasm. The terms "human-induced climate change" and "beyond natural climate variability" have a similar meaning. The IPCC is saying here that the observed changes are not natural anymore, i.e. they are caused by greenhouse gases. Which changes? Well, at least more frequent and intense extreme events. These events cause "losses and damages", but be careful, they don't claim there is a global increase in "losses and damages".

In chapter 1 there is a section (1.4.4.2) titled "Emerging Importance of Loss and Damage". On page 171 it has this to say about losses (our bold):

> There is increasing evidence of economic and non-economic losses due to climate extremes and slow onset events under observed increases in global temperatures (Section 8.3.4; Coronese et al., 2019; **Grinsted et al., 2019**; Kahn et al., 2019)

A rather strange sentence if you read it carefully. And look at the references. Grinsted et al (2019) is the *only* paper out of the 54 studies on normalised losses that Pielke (2020) discussed, that claims there is an increase in losses that is attributable to greenhouse gases. What about the other papers? Kahn (2019)[10] is not about losses due to extremes but about future economic impacts of climate change in general, so it is irrelevant for the discussion about disaster losses. Coronese (2019)[11] is titled "Evidence for sharp increase in the economic damages of extreme natural disasters". As the title clearly indicates, the paper claims a rise in losses due to disasters. Pielke (personal communication) explains that the analysis in Coronese 'forgot' to correct for underreporting of disasters before 2000. Pielke: "It is a horrible paper. They take the EM-DAT database from 1960 without accounting for the fact that it is only complete from 2000."

The following graph was posted on twitter that clearly shows the underreporting before 2000:

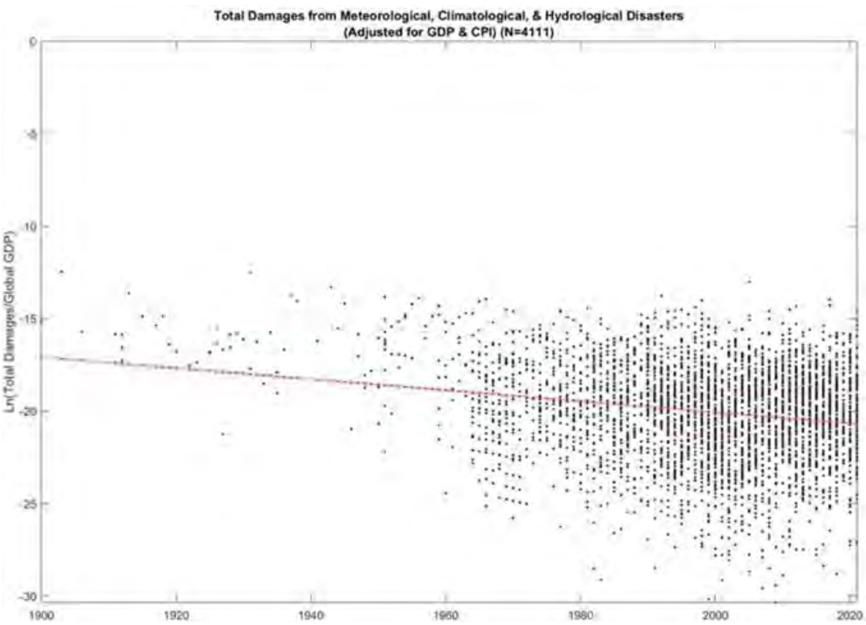


Figure 3: The missing data in the CRED EM-DAT database before 2000. Source: Pielke (twitter)[12]

So, this short paragraph in chapter 1 of the AR6 WG2 report looks like a severe form of cherry picking. It claims an increase in disaster losses without considering the full range of peer-reviewed literature on the subject.

10 Kahn, M., et al., 2019: Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis. doi:10.3386/w26167

11 Coronese, M., et al., 2019: Evidence for sharp increase in the economic damages of extreme natural disasters. Proc. Natl. Acad. Sci., 116(43), 21450, doi:10.1073/pnas.1907826116.

12 https://twitter.com/RogerPielkeJr/status/1591001971221475328

AR6, Pielke Jr., and Normalisation

Let's simply look for the Pielke (2020) review paper in the full report. It is mentioned zero times. The term 'normalisation' is mentioned only once but not in the context of disaster losses. Maybe as a verb? So, we look for "normalised" and "normalized". Finally, a few relevant hits pop up. The most interesting paragraph is this one (our bold):

> **Over the last decades, losses due to natural disasters including those from events related to extreme weather have strongly increased** (Mechler and Bouwer, 2015). There is a need for better assessment of global adaptation costs, funding and investment (Micale et al., 2018). Potential synergies between international finance for disaster risk management (DRM) and adaptation have not yet been fully realised. **Research has almost exclusively focused on normalising losses for changes in exposure, but not for vulnerability, which is a major gap, given the dynamic nature of vulnerability** (Mechler and Bouwer, 2015[13]).

This is the final paragraph of Chapter 2 (page 318), a chapter that deals with "Terrestrial and Freshwater Ecosystems and Their Services". Here they claim that research has almost exclusively focused on "normalising losses for changes in exposure", but then the IPCC, whose task it is to assess the available literature, completely ignores all the published papers about "normalised losses".

Looking deeper and deeper in the report we found two more cases where (normalised) losses were mentioned. The chapter about North America has this to say on the page about economic losses due to hurricanes:

> Studies of US hurricanes since 1900 have found increasing economic losses that are consistent with an influence from climate change (Estrada et al., 2015; Grinsted et al., 2019), although another study found no increase (Weinkle et al., 2018).

Remember, these studies were all discussed in the Pielke (2020) review article. At least the IPCC acknowledges here that there is one other study (Weinkle (2018)) that found no increase. Roger Pielke Jr was co-author of that study. But this is all the IPCC had to say about it, also giving the impression that more studies claim an increase than no increase, while the review article by Pielke gives good reasons why Estrada (2015) and Grinsted (2019) should be dismissed.

The other short mention (page 1626) of a normalised losses study is that by McAneney (2019), a study that is also discussed in the Pielke review paper (our bold):

> **However, there is no trend in normalised losses** because the rising insurance costs are being driven by more people living in vulnerable locations with more to lose (McAneney et al., 2019).

So, it is fair to say that the whole literature about normalising economic losses is completely ignored by the IPCC. This raises a lot of questions of course. How could this happen? Who decided to do this? Why didn't reviewers protest? These questions are beyond the scope of this chapter, in which we merely document the failure of the IPCC to cite relevant literature about disaster losses.

AR6 misrepresents Mechler and Bouwer

There are two names though that pop up frequently in the IPCC WG2 report with respect to this topic. Those are the names Reinhard Mechler and Laurens Bouwer. They both published extensively in the literature on the topic of loss and damage. Mechler, who works in Austria for the International Institute for Applied Systems Analysis (IIASA), was a lead author of chapter 17 (Decision-Making Options for Managing Risk) and a drafting contributing author of the *Summary*

13 Mechler, R. and L. M. Bouwer, 2015: Understanding trends and projections of disaster losses and climate change: is vulnerability the missing link? Climatic Change, 133(1), 23–35.

for Policy Makers. Laurens Bouwer (a Dutchman working in Hamburg) was a contributing author of chapter 17. They both co-edited a 2019 book titled *Loss and damage from climate change*.[14] The AR6 WG2 report frequently cites this book and both Mechler and Bouwer wrote a chapter for it.

The name "Mechler" is mentioned 113 times in the WG2 report and "Bouwer" more than 40 times. The chapter in the book *Loss and damage from climate change* by Bouwer is most relevant for our current discussion on disaster losses. Here is a fragment from its abstract (our bold):

> Studies into drivers of losses from extreme weather show that increasing exposure is the most important driver through increasing population and capital assets. **Residual losses (after risk reduction and adaptation) from extreme weather have not yet been attributed to anthropogenic climate change. For the Loss and Damage debate, this implies that overall it will remain difficult to attribute this type of losses to greenhouse gas emissions.**

This paragraph is fully in line with earlier work by Bouwer, it is also in line with the Pielke 2020 review paper (in which the work of Bouwer is also cited, see our table 1), and with earlier IPCC assessments. Bouwer mentions the work of Pielke extensively in his chapter in the book. However, this important and relevant conclusion of the book "Loss and damage from climate change" was not mentioned in the AR6 WG2 report.

Instead, the chapter by Bouwer was mentioned in the following ways:

> A further increase in the frequency and/or intensity of water-related extremes (Section 4.4) will also increase consequent risks and associated losses and damages (Section 4.5), primarily for exposed and vulnerable communities globally (**Bouwer, 2019**).
> (Chapter 4, page 652)

And

> Cascading and compounding risks arise from multiple climate hazards coinciding to produce impacts, for example, in mountainous regions, where the combination of glacier recession and extreme rainfall result in landslides (Martha et al., 2015). There is robust evidence that this effect has been observed around slow- and rapid-onset climate events related to drought (i.e., rising temperatures, heatwaves and rainfall scarcity), with devastating consequences for agriculture (Vogt et al., 2018; **Bouwer, 2019**).
> (Chapter 8, page 1178)

Bouwer was not involved in these chapters so it is very possible that he was not even aware of how his work was used in those chapters. These two paragraphs, by the way, are not representative of the full chapter by Bouwer. Bouwer also presents a table (his table 3.2) similar to our Table 1. His table was also ignored by the IPCC.

Our analysis matches with that of Steven Koonin in his bestseller book Unsettled.[15] On page 183, Koonin observes (our bold):

> It's clear that media, politicians, and often the assessment reports themselves blatantly misrepresent what the science says about climate and catastrophes. Those failures indict the scientists who write and too casually review the reports, the reporters who uncritically repeat them, the editors who allow that to happen, the activists and their organizations who fan the fires of alarm, **and the experts whose public silence endorses the deception.** The constant repetition of these and many other climate fallacies turns them into accepted "truths."

Here we have also documented clear shortcomings in the assessment and scientists who can know about this, like Mechler and Bouwer, have remained silent.

14 Mechler, R., et al., 2019: Loss and damage from climate change: concepts, methods and policy options. Springer Nature, Berlin Heidelberg

15 Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters, Steven E. Koonin, 2021

Conclusions

The IPCC works according to a set of principles.[16] The most important one is this (our bold):

> The role of the IPCC is to assess on a **comprehensive, objective, open and transparent basis** the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies.

Here we have documented that, with respect to the literature on disaster losses, the latest AR6 WG2 report was neither comprehensive, open and transparent (it ignored most of the published literature on the topic), nor objective (it cherry picked the few studies that claimed an increase of losses due to greenhouse gases while the majority of the published studies show the opposite, no increasing trend after normalisation of the data). This is very poor performance by the IPCC.

In 2010 there was a lot of criticism of the IPCC after several errors were discovered, mainly in the fourth (2007) WG2 report. A well-known error at the time was the claim that the Himalayan glaciers would be gone in 2035, a claim which turned out to be based on a popular science article in *New Scientist*. The exposed errors led to an international investigation into the procedures of the IPCC by the InterAcademy Council.[17] The IAC Review stated upfront that the main conclusions of the IPCC were not questioned.

The most relevant part of the IAC Review is the following section on page 17-18 (our bold):

> **Handling the full range of views**
> An assessment is intended to arrive at a judgment of a topic, such as the best estimate of changes in average global surface temperature over a specified time frame and its impacts on the water cycle. Although all reasonable points of view should be considered, they need not be given equal weight or even described fully in an assessment report. Which alternative viewpoints warrant mention is a matter of professional judgment. Therefore, Coordinating Lead Authors and Lead Authors have considerable influence over which viewpoints will be discussed in the process. **Having author teams with diverse viewpoints is the first step toward ensuring that a full range of thoughtful views are considered.**
>
> **Equally important is combating confirmation bias—the tendency of authors to place too much weight on their own views relative to other views** (Jonas et al., 2001). As pointed out to the Committee by a presenter and some questionnaire respondents, alternative views are not always cited in a chapter if the Lead Authors do not agree with them. Getting the balance right is an ongoing struggle. However, concrete steps could also be taken. For example, chapters could include references to all papers that were considered by the authoring team and describe the authors' rationale for arriving at their conclusions.

It is evident that if a scientist such as Roger Pielke Jr would have been involved in the production of this WG2 report, the clear bias with regards to the normalisation of disaster losses would not have taken place. We asked Pielke Jr if he was ever asked to contribute to an IPCC report. He wrote back that a senior US IPCC contributor had once told him that "he would never be involved in IPCC".

If the IAC—12 years after their review—were asked to do another review and they took the treatment of "disaster losses" in the WG2 report as a test case, they would conclude that the IPCC didn't

16 https://www.ipcc.ch/site/assets/uploads/2018/09/ipcc-principles.pdf

17 Climate change assessments, review of the processes and procedures of the IPCC, IAC Review, 2010 (The report is surprisingly hard to find online nowadays. The IPCC doesn't seem to have it archived although a preprint can be found here: https://www.ipcc.ch/site/assets/uploads/2018/03/doc07_p32_report_IAC.pdf)

implement their recommendations. They would also conclude that the more recent reports have made far more consequential errors than those that led to their 2010 review.

13

Say goodbye to climate hell, welcome climate heaven

BY MARCEL CROK

"We are on a highway to climate hell", said UN-boss Guterres recently. But an in depth look at mortality data shows that climate-related deaths are at an all-time low. Well-known economist Bjorn Lomborg published this excellent news in a 2020 peer-reviewed paper, but the IPCC, again, chose to ignore it.

"We are on a highway to climate hell with our foot on the accelerator", said UN Secretary-General Antonio Guterres during his speech to delegates of the COP27 conference in Egypt.[1] "A climate hell", what would that mean? It can't be a good thing for sure. When global leaders talk about climate change, by which they mean anthropogenic climate change, they are using ever stronger and stronger language. A climate hell must mean death and destruction.

In the former chapter about disaster losses, we have documented how the IPCC failed to report honestly about disaster losses as it relates to greenhouse gases. The underlying literature is nearly unequivocal, after normalising the data for GDP there is no trend left in economic losses due to climate disasters. Apparently, the IPCC didn't want to bring this 'good news' to its readership.

Bjorn Lomborg

In this short chapter we will have a look at climate-related deaths. Before we look into the IPCC AR6 WG2 report, we again start with an interesting scientific paper that covers this topic. It is by Bjorn Lomborg, a very well-known economist in the public and political arena, and the founder of the Copenhagen Consensus Center. In 2020 Lomborg published the paper "Welfare in the 21st century: Increasing development, reducing inequality, the impact of climate change" part of which discusses climate-related deaths.[2] The key graph is figure 17 in his paper, reproduced here as our figure 1:

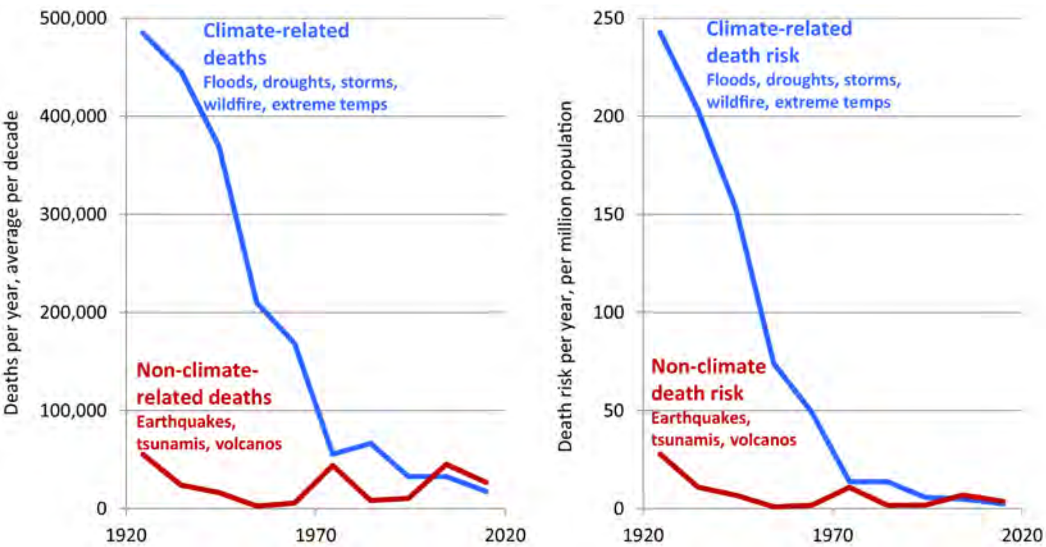


Figure 1: Climate and non-climate-related deaths and death risks from disasters 1920–2018, averaged over decades. Data comes from EM-DAT (2019), using floods, droughts, storms, wildfire, and extreme temperatures for climate-related deaths, and earthquakes, tsunamis, and volcanos for non-climate-related deaths. Source: Lomborg (2020).

1 https://www.youtube.com/watch?v=T4bpyjcFLVo

2 Bjorn Lomborg, Welfare in the 21st century: Increasing development, reducing inequality, the impact of climate change, and the cost of climate policies, Technological Forecasting and Social Change, Volume 156, 2020, 119981, ISSN 0040-1625, https://doi.org/10.1016/j.techfore.2020.119981.

On the left absolute numbers of deaths (averaged over decades) are shown, in blue for climate or weather-related disasters (such as floods, hurricanes and droughts) and in red for non-climate-related disasters such as earthquakes, tsunamis and volcanos. The steep decline of the blue line is remarkable (a 96% decrease), even more so if you realise that the world population increased from two to eight billion over the period. So even when extreme weather didn't increase, which the IPCC itself admits is true for hurricanes, floods and meteorological and hydrological droughts (see chapter 11) one would expect that more people would lead to more weather-related deaths. The opposite is the case. Around 1920 around *half a million* people died yearly due to extreme weather events. Droughts were especially deadly. In the past decade this declined to 20.000 on average and the past few years these numbers were even lower, around 6000 per year.[3] To put such numbers in perspective, yearly 1.2 million people die due to road injuries, more than 750,000 people die from suicide, more than 400,000 from homicide, and 237,000 people drown.[4] Extreme weather in that respect is a minor risk.

In relative terms the numbers are even more spectacular. Risk of death due to extreme weather has declined *99%* over the past century.

Climate heaven

How is this possible? This is far from Guterres' climate hell, it is more a 'climate heaven'. Lomborg himself has this to say about these trends (our bold):

> It is to be expected that it is much harder to avoid death from non-climate-related disasters, since these are mostly earthquakes that are hard to predict. Hence, only better building standards can help. However, the large reduction in climate-related deaths from disasters shows a dramatic increase in climate resilience, **likely mostly brought about by higher living standards, a reduction in poverty, improvement in warning systems, and an increase in global trade, making especially droughts less likely to turn into widespread famines**.

Lomborg finishes that section of his paper with the following observation (our bold):

> Fig. 17 shows that **we are now much less vulnerable to climate impacts than at any time in the last 100 years**. It is possible that climate change has made impacts worse over the last century (although the discussion on floods, droughts, wildfire, and hurricanes suggests this is not the case), but **resiliency from higher living standards has entirely swamped any potential climate impact**.

These are important observations, based on data from a well-known database (EM-DAT) and published in a peer reviewed paper in 2020. Let's now move on to the WG2 report and see how the IPCC reported on climate-related deaths.

A first search for the term "climate-related death" gives zero results as does "Lomborg". So, his paper is not mentioned. The term "deaths" gives a lot of hits (298) as does "mortality" (1345). We can't discuss them all of course but let's look at some claims in the *Summary for Policy Makers* (our bold):

> Widespread, pervasive impacts to ecosystems, people, settlements, and infrastructure have resulted from observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land and in the ocean, heavy precipitation events, drought and fire weather (high confidence). Increasingly since AR5, these observed impacts have been attributed to human-induced climate change particularly through increased frequency and severity of extreme events. These include increased heat-related human **mortality** (medi-

3 Lomborg is frequently updating figure 1 on his social media accounts like Linkedin, see e.g.: https://www.linkedin.com/feed/update/urn:li:activity:7028351713191342082?updateEntityUrn=urn%3Ali%3Afs_feedUpdate%3A%28V2%2Curn%3Ali%3Aactivity%3A7028351713191342082%29

4 https://ourworldindata.org/causes-of-death

um confidence), warm-water coral bleaching and mortality (high confidence), and increased drought-related tree mortality (high confidence). [B.1.1]

And:

Climate change has adversely affected physical health of people globally (very high confidence) and mental health of people in the assessed regions (very high confidence). Climate change impacts on health are mediated through natural and human systems, including economic and social conditions and disruptions (high confidence). In all regions extreme heat events have resulted in **human mortality** and morbidity (very high confidence). [B.1.4]

And:

Between 2010–2020, **human mortality from floods, droughts and storms** was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability (high confidence). [B.2.4]

And:

Climate change and related extreme events will significantly increase ill health and **premature deaths** from the near- to long-term (high confidence). [B.4.4]

EM-DAT database

So, there are all kinds of claims that climate change is leading to or will lead to more deaths. But what about the EM-DAT database and the fact that those data suggest a strong decrease in climate-related deaths? EM-DAT is mentioned only 7 times in AR6. The IPCC does show data from EM-DAT. Here is the figure:

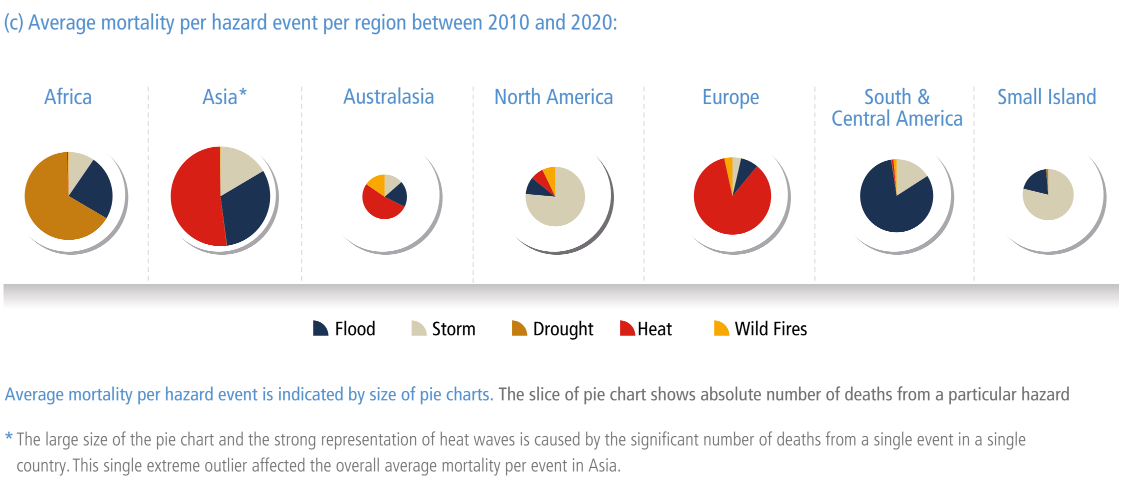


Figure 2: reproduction of figure TS.7(C) of the WG2 AR6 report (p 77), showing relative mortality per hazard on different continents for the period 2010-2020.

They only show the average mortality per hazard for the period 2010-2020, and the pie charts are quite odd. Heat-related deaths dominate in Europe. However, in Africa, South America and the Small Island states, there are no heat-related deaths at all. How (un)likely is that? Their message is fair: less developed continents are more vulnerable to extreme events than richer continents. However, the IPCC fails to mention or reproduce the very important peer-reviewed figure from Bjorn Lomborg based on the same EM-DAT database. We learn more from what the IPCC leaves out, than from what it includes.

However, somehow the good news did slip into the report, on page 2435 (of 3068!) the IPCC mentions a paper by Formetta and Feijen which has the revealing title *Empirical evidence of declining global vulnerability to climate-related hazards* (our bold):[5]

> Formetta and Feyen (2019) **demonstrate declining global all-cause mortality and economic loss due to extreme weather events over the past four decades**, with the greatest reductions in low-income countries, and with reductions correlated with wealth.

The research for this paper was funded by the European Commission and therefore coming from an unsuspected source. Here are the highlights mentioned at the top of the paper (our bold):

> Highlights
> - We quantified the dynamics of socio-economic vulnerability to climate-related hazards.
> - **A decreasing trend in both human and economic vulnerability is evident**.
> - **Global average mortality and loss rates have dropped by 6.5 and nearly 5 times, respectively, from 1980 to 1989 to 2007–2016**.
> - Results also show a clear negative relation between vulnerability and wealth.

This is, as far as we know, the only place in the report where the IPCC reveals the good news about global mortality due to climate-related events. However, these important results didn't make it into the *Summary for Policy Makers* (SPM) or the Technical Summary (TS) of the WG2 report, let alone the press release or headline statements.

So again, the IPCC is ignoring a key paper (by Bjorn Lomborg in this case), that shows very good news about the decreasing impact on humans from extreme weather. It fails to bring this good news, either in the full report or in the *Summary for Policy Makers*. As a result, policy makers get an overly negative picture of climate change and its impacts on humans. There is no excuse for this. The IPCC is aware of the EM-DAT database and Bjorn Lomborg is one of the most visible public voices about climate. The IPCC deliberately chose to ignore this good news.

Looking at disaster losses and climate-related deaths the IPCC could have easily repeated its conclusions from the AR5 WG2 report (chapter 10, executive summary)(our bold):

> For most economic sectors, **the impact of climate change will be small relative to the impacts of other drivers** (medium evidence, high agreement). Changes in population, age, income, technology, relative prices, lifestyle, regulation, governance, and many other aspects of socioeconomic development will have an impact on the supply and demand of economic goods and services that is large relative to the impact of climate change. {10.10}

5 Giuseppe Formetta, Luc Feyen, Empirical evidence of declining global vulnerability to climate-related hazards, Global Environmental Change, Volume 57, 2019, 101920, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2019.05.004.

Epilogue

BY ANDY MAY

It has been over two years since Marcel and I began working on this book. In that time, we learned a great deal from the IPCC and the writers and reviewers of the chapters herein. We find it notable that this is a review of the *sixth* major IPCC Report on climate change in the thirty-two years since the first IPCC report was published in March 1990. In total the IPCC has produced 47 reports[1] and either spent or caused many billions of dollars[2] to be spent since March 1990.

All these reports attempted to convince the public, news media, and politicians that their "CO_2 control knob"[3] hypothesis is correct. This hypothesis concludes that observed climate change is caused by mankind and their emissions of key non-condensing greenhouse gases, mainly CO_2, which they claim regulate the "planetary temperature, with water vapor concentrations as a feedback."[4]

The current CO_2 control knob hypothesis has its origins in the 1960s and 1970s and culminated in the U.S. National Research Council's "*Charney Report*" in 1979.[5] Arguably, as you can see in this volume, the uncertainty regarding the effect of additional CO_2 and other non-condensing greenhouse gases is just as uncertain as it was in 1979. This lack of measurable progress after 43 years is a sign that the hypothesis is missing a major component and/or process. Have the IPCC developed "tunnel vision?" Are they so devoted to their hypothesis they are missing the obvious? Scientists sometimes suffer from confirmation bias and cannot see the weaknesses in their hypotheses.

The AR6 report reveals that they have ignored the very important multi-decadal ocean oscillations discovered in the 1990s and 2000s[6] long after the IPCC had focused exclusively on anthropogenic causes. These ocean oscillations, collectively, have a large effect on our climate, but are unrelated to "non-condensing greenhouse gases." AR6 states that "there has been negligible long-term influence from solar activity and volcanoes,"[7] and acknowledges no other natural influence on multidecadal climate change despite the recent discoveries, a true case of tunnel vision.

We were promised IPCC reports that would objectively report on the peer-reviewed scientific literature, yet we find numerous examples where important research was ignored. In Ross McKitrick's chapter on the "hot spot," he lists many important papers that are not even mentioned in AR6. Marcel gives examples where unreasonable emissions scenarios are used to frighten the public in his chapter on scenarios, and examples of bias and hiding good news in his chapters on extreme weather and snowfall. Nicola Scafetta and Fritz Vahrenholt document that over 100 papers showing solar activity correlates with climate change have been ignored by the IPCC. Numerous other examples are documented in other chapters. These deliberate omissions and distortions of the truth do not speak well for the IPCC, reform of the institution is desperately needed.

1 https://www.ipcc.ch/reports/
2 https://www.heritage.org/environment/commentary/follow-the-climate-change-money
3 (Lacis, et al. 2010 & 2013) and (AR6, page 179).
4 AR6, page 179.
5 (Charney, et al., 1979)
6 (Vinós, 2022) and (Wyatt & Curry, 2014)
7 AR6, page 67.

Perhaps this is why, after 47 reports and 32 years, they have yet to convince a majority of the people on Earth,[8] or in the United States,[9] that manmade climate change is our most important and serious societal problem. Other problems are always considered more important and urgent. In a 2018 Pew Research poll[10] climate change ranked 18th, of 19 issues in importance, in a similar 2014 poll,[11] climate change ranked 14th in a list of priorities. A 2022 poll by the Pew Research Center[12] also found climate change ranked 14th. In the UN *My World 2015 Report*, a poll of 10 million people around the world, climate change ranked last of 16 issues in importance. Minds are not being changed.

Are we at a fork in the road? Will the United Nations, the IPCC, and politicians finally realize that their 50-year-old hypothesis is out of date and incorporate the new natural warming forces discovered in the past thirty years into their work and projections? In the past the IPCC has fought off attempts to independently review their work.[13] It is unfortunate, but the IPCC has an opaque process for choosing their lead authors and contributing authors, the very people who choose what is included and what is ignored in each report. As one of our authors, Ross McKitrick has written:

> "The [IPCC] Bureau has, effectively, a free hand in picking Coordinating Lead Authors, Lead Authors and Contributing Authors of the report.
>
> Past Lead Author selections have been criticized by other Lead Authors as being overly dominated by political considerations.
>
> Coupled with the deficiencies in the peer review process, this opens up the possibility that the IPCC Bureau can pre-determine the conclusions of the report by its selection of Lead Authors."[14]

Any like-minded group, with inadequate infusions of new blood, runs the risk of becoming fossilized in their thinking. Independent, open, honest, and transparent peer-review is essential to good science. There are indications that this is not happening in the IPCC. Ray Bates, a long-time expert reviewer of major IPCC reports is particularly critical of the IPCC review process.[15] Bates points out that very eminent scientists, such as Prof. Aksel Wiin-Nielsen, have been excluded from IPCC leadership because they would not "toe the party line."

After every major IPCC report, the same complaints surface over and over again. The choice of lead authors and authors is "arbitrary,"[16] the IPCC's own procedures are often not followed.[17] Yet, time and again, nothing changes. Improper political interference during the second IPCC report was widely criticized when a past president of the United States National Academy of Sciences, Frederick Seitz, called the report a "Major Deception on Global Warming."[18] The third report included the deceptive and incorrect "Hockey Stick,"[19] a flaw *repeated* in AR6. The fourth report

8 https://news.gallup.com/opinion/gallup/321635/world-risk-poll-reveals-global-threat-climate-change.aspx, also see the UN My World 2015 report (http://about.myworld2030.org/my-world-2015/)

9 https://www.washingtonpost.com/politics/2022/10/10/half-voters-say-climate-change-is-important-midterms-poll-finds/

10 https://www.investors.com/politics/columnists/global-warming-polls-priorities/

11 https://news.gallup.com/poll/167843/climate-change-not-top-worry.aspx

12 https://www.pewresearch.org/politics/2022/02/16/publics-top-priority-for-2022-strengthening-the-nations-economy/

13 https://climateaudit.org/2011/06/18/ipcc-sabotages-an-interacademy-recommendation/

14 (McKitrick, 2011)

15 (Bates, 2020)

16 InterAcademy Council, 2010, Climate change assessments, Review of the processes and procedures of the IPCC, Link: http://intleval.cipa.cornell.edu/simulation/Climate%20Change%20Assessments,%20Review%20of%20the%20Processes%20&%20Procedures%20of%20the%20IPCC.pdf

17 McKitrick, Ross, 2010, "Submission to the Inter-Academy Council Independent Review of the Policies and Procedures of the Intergovernmental Panel on Climate Change." Link: http://www.rossmckitrick.com/uploads/4/8/0/8/4808045/iac.ross_mckitrick.pdf

18 May, Andy, 2020, *Politics and Climate Change: A History*, page 234, link: https://www.amazon.com/POLITICS-CLIMATE-CHANGE-ANDY-MAY-ebook/dp/B08LJSBVBC/ref=sr_1_3?crid=GJLUTQV2YMKQ&keywords=Politics+and+Climate+Change&qid=1674065419&sprefix=politics+and+climate+change%2Caps%2C87&sr=8-3 and in the *Wall Street Journal*, June 12, 1996.

19 Montford, Andrew, 2010, The Hockey Stick Illusion, link: https://www.amazon.com/Hockey-Stick-Illusion-W-Montford/dp/0957313527/ref=sr_1_1?crid=1CBSL88079DOV&keywords=The+Hockey+Stick+Illusion&qid=1674065645&sprefix=the+hockey+stick+illusion%2Caps%2C88&sr=8-1

resulted in the critical InterAcademy Council report,[20] and so on. AR6 repeats past flaws and is, in many ways, worse than the previous reports.

All the chapters in this volume have been independently peer-reviewed. All reviewer comments have been carefully considered and dealt with appropriately. This is not to say that all the authors and peer-reviewers agree on every point, disagreements among us remain in some cases, but we all had an opportunity to freely and openly debate our views. Consider this volume an independent assessment of the most important parts of AR6, an assessment that, unfortunately, was not done within the IPCC.

Works Cited

- Bates, R. (2020). Should Ireland Relinquish Authority over its Vital National Interests to the Intergovernmental Panel of Climate Change (IPCC)? *Irish Times*.
- Charney, J., Arakawa, A., Baker, D., Bolin, B., Dickinson, R., Goody, R., . . . Wunsch, C. (1979). *Carbon Dioxide and Climate: A Scientific Assessment.* National Research Council. Washington DC: National Academy of Sciences.
  Retrieved from http://www.ecd.bnl.gov/steve/charney_report1979.pdf
- McKitrick, R. (2011). *What is Wrong with the IPCC.* The Global Warming Policy Foundation. Retrieved from https://www.thegwpf.org/images/stories/gwpf-reports/mckitrick-ipcc_reforms.pdf
- Vinós, J. (2022). *Climate of the Past, Present and Future, A Scientific Debate.* Spain: Critical Science Press. Retrieved from https://www.amazon.com/Climate-Past-Present-Future-scientific-ebook/dp/B0BCF5BLQ5/ref=sr_1_1?crid=3DADACCQN7CX3&keywords=Climate+of+the+Past%2C+Present+and+Future%2C+A+Scientific+Debate&qid=1669221503&sprefix=climate+of+the+past%2C+present+and+future%2C+a
- Wyatt, M., & Curry, J. (2014, May). Role for Eurasian Arctic shelf sea ice in a secularly varying hemispheric climate signal during the 20th century. *Climate Dynamics, 42*(9-10), 2763-2782. Retrieved from https://link.springer.com/article/10.1007/s00382-013-1950-2#page-1

20 InterAcademy Council, 2010, Climate change assessments, Review of the processes and procedures of the IPCC, Link: http://intleval.cipa.cornell.edu/simulation/Climate%20Change%20Assessments,%20Review%20of%20the%20Processes%20&%20Procedures%20of%20the%20IPCC.pdf

clintel.org