



## **Global Warming Has Accelerated. Why? What Are the Consequences?**

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Once upon a time, Earth Sciences was blessed to have brilliant, articulate, scientific leaders, such as Jule Charney and Francis Bretherton,<sup>1</sup> whose knowledge and overview of climate science commanded respect. And there were many other scientists with deep understanding of the scientific method, who helped spur progress in the field and assure that progress was recognized. Top science writers, such as Walter Sullivan, could rely on such scientific researchers for perceptive descriptions of the major issues and progress in addressing them. We recall fondly learning from Charney's colleague at MIT, Peter Stone, who served as the principal adviser for climate research at NASA Goddard Institute for Space Studies, back in the days when Charney was trying to decide whether global equilibrium climate sensitivity to doubled atmospheric CO<sub>2</sub> was more like 2°C or 4°C. The correct answer would have enormous practical implications.

The Intergovernmental Panel on Climate Change (IPCC),<sup>2</sup> set up by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) in 1988, and endorsed by the United Nations that year, produces comprehensive climate assessments about every six or seven years. The reports contain a large amount of useful information; the most recent report on the physical science basis of climate change, the Sixth Assessment Report (IPCC AR6),<sup>3</sup> was published in August 2021. IPCC's approach to climate analysis came to be dominated by use of global climate models (GCMs) for climate simulations of the past 1-2 centuries. We have taken a complementary approach, placing comparable emphasis on paleoclimate data, GCM modeling, and modern observations of climate processes, as described in our three main papers published in the past decade: (1) "[Ice melt, sea level rise and superstorms](#),"<sup>4</sup> (2) "[Global warming in the pipeline](#),"<sup>5</sup> and (3) "[Global warming has accelerated](#)."<sup>6</sup> The third of these, published last week, was long, as it tied all three together, especially via its [Supplementary Material](#) (SM),<sup>7</sup> which usually houses only secondary material. Here is a link to the [Abstract + Paper + SM](#) as a single document. Below, we first provide a plain language summary of the three principal conclusions of this paper and then address questions raised in the media by kibitzers.

### **1. The leap of global temperature in 2023-2024 is explained; no new physics is required.**

The 0.4°C increase of global temperature in 2023-24 was caused equally by increase of absorbed solar radiation and a weak El Nino. Increase of absorbed sunlight was mainly spurred by reduction of aerosols (tiny particles), especially those emitted by ships, as the International Maritime Organization imposed a strict limit on the sulfur content of ship fuels beginning in 2020.<sup>8</sup> Aerosols serve as cloud formation nuclei; the induced clouds reflect sunlight and cause global cooling that offsets part of the global warming caused by increasing greenhouse gases. This cooling offset has long been described as a “Faustian bargain” because aerosols constitute particulate air pollution that kills millions of people every year. Our Faustian payments – an increase of global warming – come due when we reduce health-damaging air pollution and thus reduce aerosol cooling.

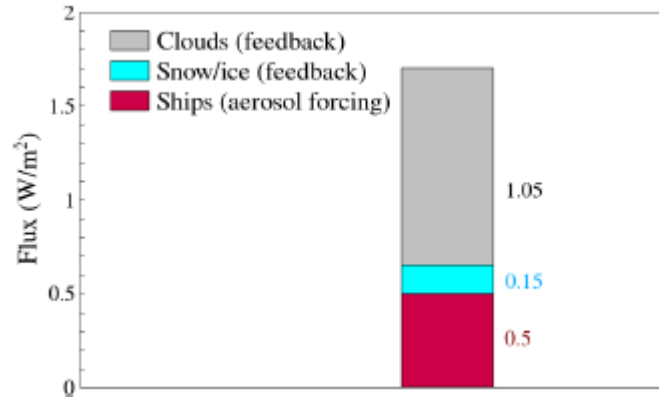
### **2. Climate sensitivity is 50 percent larger than the best estimate of IPCC.**

We show that the climate sensitivity required to yield best agreement with observed global warming in the past century is 4.5°C for doubled CO<sub>2</sub>, which is 50% larger than IPCC’s best estimate of 3°C. Together, conclusions 1 and 2 imply that near-term global temperature will decrease very little: thus, averaged over the El Nino/La Nina cycle, the 1.5°C limit has been reached. IPCC’s estimate of climate sensitivity depended on the assumption that aerosol climate forcing was unchanging during the period 1970-2005, but we show that aerosol forcing increased (became more negative) during that period as aerosols spread more globally, including over pristine ocean areas where their effect is greater. If aerosols were fixed, greenhouse gases are the only forcing and the climate sensitivity required to match observed warming would be about 3°C for doubled CO<sub>2</sub>. But the net forcing was actually smaller during that period because the negative aerosol forcing was growing, so a larger climate sensitivity is required to match observed warming of the past century. Our estimated climate sensitivity coincides with the sensitivity derived from glacial-to-interglacial climate change, the portion of the paleoclimate record for which precise knowledge of greenhouse gases is available.

### **3. Accelerated warming increases ice melt and upper ocean warming, threatening to shut down North Atlantic overturning circulation by mid-century and cause large sea level rise.**

We show that observed ice melt over the past 20 years was similar to assumed ice melt in climate simulations of “Ice Melt, Sea Level Rise, and Superstorms.”<sup>4</sup> The rate of ice melt did not increase in the past decade, but, given the leap of global temperature to +1.5°C above preindustrial, we expect ice melt to accelerate, especially in regions such as southeast Greenland where ice melt is injected directly into the Irminger Sea, a region where deepwater forms. The North Atlantic is warming at depths beneath the surface wind-mixed ocean layer, with warmer water penetrating beneath the sea ice and ice shelves. Paleoclimate data suggest that such sub-ice warming can lead to sudden loss of regional sea ice and thus increased warming and summer rainfall on lower reaches of the Greenland ice sheet and increased freshwater injection into the ocean. Our climate simulations<sup>4</sup> suggest that such increased ice melt and rapid surface warming can shut down the overturning ocean circulation by mid-century, which would be the “Point of No Return” because shutdown is irreversible in less than centuries. Large sea level rise would become inevitable, as heat normally transported into the North Atlantic would remain in the Southern Hemisphere and speed melting of the West Antarctic ice sheet. Global warming acceleration increases this danger because the increased heating both reduces the density of the upper layer of the ocean and increases the rate of ice melt.

**Fig. SM15. Inferred Contributions to Reduced Earth Albedo**



**Reactions.** How would Charney, Bretherton and other scientific leaders of yore have responded to these papers and assertions, and how would the media have responded? It’s a pretty safe bet they would conclude that the papers are a serious analysis. They would think about what observations are needed to confirm and illuminate the issues that are raised. Instead, much reaction in the media seems closer to the continual squealing of farm animals. It is hard to fault the science writers; their stories reflect what they are told by the scientists who are willing or even eager to respond to their inquiries. We find many responses to be unscientific and surprising, given the intergenerational issues that are raised. An illuminating example is the response to Seth Borenstein, the climate science writer for the largest news organization in the world (Associated Press), who was told by 5 of his 6 go-to climate experts that he should not even write about our paper “Ice Melt, Sea Level Rise, and Superstorms;” thus he did not. The paper was also blackballed by the IPCC AR6 report; not a single mention in the several-thousand-page report. Below we speculate about reasons for this treatment, but first let’s respond to current reactions to our “Acceleration” paper.

**Reaction 1. Feedbacks.** It is claimed that we neglect climate feedbacks, which cause most of the warming and cause the largest warming to be in the Southern Hemisphere, not the Northern Hemisphere, where the ship aerosol effect is largest. In fact (see our Fig. 10), the largest sea surface warming is at latitudes 30-50N in the Northern Hemisphere, where ship aerosol forcing is largest. The total ocean heat content gain may be larger in the more massive Southern Hemisphere ocean, but that supports our interpretation. Most increased energy flux into the planet is from climate feedbacks. We evaluated the contributions of forcings and feedbacks that affect Earth’s albedo (Fig. SM15, in the [Supplementary Material](#) of our current paper) and energy imbalance. Over the period (since 2000) of precise satellite measurements of Earth’s albedo (reflectivity), Earth has darkened by 1.7 W/m<sup>2</sup>. Based on the geographical and temporal distribution of the darkening, we infer that about 0.5 W/m<sup>2</sup> of this darkening is the ship aerosol forcing. About 0.15 W/m<sup>2</sup> is ice/snow albedo feedback, due to reduced sea ice area, which is well-defined. Thus, by subtraction, most of Earth’s darkening must be the cloud feedback that is expected with global warming. It is a huge feedback for the 20-year period with satellite data. If we over-estimated the aerosol forcing, the cloud feedback is even larger.

This simple bar graph (Fig. SM15) has another story to tell, which Charney and Bretherton would have recognized instantly: the large cloud feedback in a brief period implies that climate sensitivity is much higher than 3°C for doubled CO<sub>2</sub>. Charney’s comparison of climate models with 2°C and

4°C sensitivity revealed that a 2°C response is provided by doubled CO<sub>2</sub> forcing plus water vapor feedback and small sea ice feedback. Addition of only modest cloud feedback raises the sensitivity to 3°C, as an amplifying feedback enhances all other amplifying feedbacks.<sup>9</sup> Thus, the large cloud feedback in the past two decades provides independent confirmation of high climate sensitivity.

**Reaction 2. IPCC AR6 models yield realistic global warming acceleration without a ship aerosol effect.** The person making this claim – and asserting that it contradicts our conclusions – apparently does not realize that there is a big difference between IPCC’s best estimate for aerosol forcing history and the aerosol forcing in GCMs participating in CMIP6 and IPCC AR6 climate simulations. The IPCC best estimate aerosol forcing is shown in our paper in Fig. 3 and in Figs. 13 and SM1 as updated by Forster et al. (2024). This IPCC aerosol forcing includes the direct aerosol forcing and the larger indirect effect on clouds. This IPCC aerosol forcing is used in the literature for various purposes, e.g., in derivation of an “emergent constraint” on climate sensitivity;<sup>10</sup> these authors assume, consistent with the IPCC aerosol forcing estimate, that aerosol forcing is nearly unchanging over the period 1970-2005. Then, based on observed global warming and assuming that greenhouse gases are the only significant changing forcing in that period, they infer an “emergent constraint” on climate sensitivity: specifically, sensitivity must be close to 3°C for doubled CO<sub>2</sub>.

However, if they allowed the aerosol forcing to change during that period, they would have found quite different results. We showed that there is a one-to-one relation between the climate sensitivity that gives best fit to observed warming and the trend of aerosol forcing in the period 1970-2005: if the aerosol forcing is constant, the sensitivity is ~3°C; if the aerosol forcing increases as in Bauer’s Matrix aerosol model (almost 0.5 W/m<sup>2</sup>), the sensitivity is ~4.5°C; if the aerosol forcing increases as in Bauer’s OMA aerosol model, the sensitivity is ~6°C (see Figs. 17 and 18). Given this one-to-one relation between climate sensitivity and the aerosol forcing change during 1970-2005, the “emergent constraint” that climate sensitivity is near 3°C amounts to the following: “if we assume that climate sensitivity is near 3°C, we find that climate sensitivity is near 3°C.”

For the sake of estimating climate sensitivity, we made climate simulations for 1850-2024 with two free parameters (climate sensitivity and the change of aerosol forcing during 1970-2005) and two constraints (1.6°C global warming between 1850 and 2024, and 0.18°C/decade warming during 1970-2005). The best fit was obtained with sensitivity ~4.5°C for doubled CO<sub>2</sub> and an increase of aerosol forcing during 1970-2005 similar to that in Bauer’s Matrix model.

After all this explanation, what is wrong with the assertion that CMIP/IPCC models already yield recent acceleration of global warming? Answer: many of the models in the CMIP/IPCC ensemble are not using the IPCC aerosol forcing history. The ensemble includes models that use the Bauer aerosol forcings, e.g., which were steeply increasing during 1970-2005 before stopping growth entirely or even switching to change of the opposite sign. Thus, the average of IPCC models yields global warming acceleration, but it cannot match observed acceleration and the results certainly do not support IPCC’s best estimate for aerosol forcing.

**Reaction 3. Range of model fog.** Another reaction is that observed rapid warming falls in the range of all CMIP/IPCC climate simulations, so there is no basis to question IPCC assumptions. CMIP/IPCC models include the good, the bad, and the ugly. Yet IPCC takes the distribution of model results as a probability distribution for the real world, using this distribution for mathematical

analyses that separate IPCC from the possibility of widespread public understanding, much like the Wizard of Oz tried to overpower Dorothy and her friends. For their purpose, a “merit” of the huge range of this model fog is that IPCC will always be “right,” the real world will fall somewhere within that huge fog. Oops! Maybe not. In a paper<sup>11</sup> that perhaps provided the “rationale” for IPCC to blackball our “Ice Melt” paper, 15 authors, representing leading GCM groups, used 21 climate projections from eight “...state-of-the-science, IPCC class...” GCMs to conclude that “...the probability of an AMOC collapse is negligible. This is contrary to a recent modeling study [*Hansen et al., 2016*] that used a much larger, and in our assessment unrealistic, Northern Hemisphere freshwater forcing... According to our probabilistic assessment, the likelihood of an AMOC collapse remains very small (<1% probability) if global warming is below ~5K...”. Here, even the range of model results does not seem to encompass all realistic possibilities: few climate experts would assert that 5°C global warming, sufficient to melt most of the ice on the planet, would be unlikely to shut down AMOC (Atlantic Meridional Overturning Circulation). Their models likely obtain AMOC stability only because injection of cold freshwater into the polar oceans in the models is underestimated or based on too-lethargic ice sheet models.

Models are essential for understanding ongoing climate change and projections for the future, but by themselves they are inadequate and unable to provide an adequate assessment. The models will be a much more powerful tool, if they are used along with an equally heavy emphasis on paleoclimate data and observations of ongoing climate processes, and the information from all of these combined with mindfulness of climate physics.

**Reaction 4. We overlooked the role of decreased aerosols from China.** The direct radiative effect of aerosol change is shown in clear-sky measurements of the global increase of absorbed solar radiation (Fig. SM8). The global effect of aerosol change in 2020-2023 relative to 2000-2010 is less than 0.1 W/m<sup>2</sup>, after the effect of changes in sea ice is removed. China may provide a large fraction of that flux change, but even in total this is a small effect. Change of all-sky absorbed solar radiation (Fig.9) is an order of magnitude larger and the temporal and spatial footprint coincides with the ship aerosol change, and clearly not with change of emissions from China, where the largest decrease was in 2005-2015. The spatial and temporal pattern of SST change (Figure 10) further support the dominance of ship aerosols. It is not surprising that the ship aerosols are much more effective; they are emitted into the lower part of the atmosphere in unpolluted ocean skies, where they have the most effect on clouds.

Bretherton and Charney would not have been confused about the role of Chinese aerosols, which they would recognize has no effect on our three main conclusions above. (1) most aerosol change in China occurred prior to 2020-2023 (Fig. 13), with negligible effect on the sudden global warming in 2023. (2) Our inference of an increasing global aerosol forcing during 1970-2005 and derivation of 4.5°C climate sensitivity are independent of the source of increased aerosol forcing. (3) Our conclusion that the danger of passing the “point of no return” (AMOC shutdown and large sea level rise) is increased by the accelerated North Atlantic warming is straightforward: the increased heating reduces the density of the upper layer of the ocean and increases the rate of ice melt – conclusions that do not depend on uncertainties about aerosols from China.

**Reaction 5. Our results are an outlier.** When we have answered all the questions, the critics always resort to “they are an outlier,” with results outside those of the “mainstream” climate research community. This is stated in a way that makes it seem that we are unlikely to be right, even when the real world offers ample evidence in support of our conclusions. The media is then forced to go along with the critics because they outnumber us (there are exceptions, e.g., the [comprehensive article by Carrington in the Guardian](#)).<sup>12</sup> However, that’s not the way science works. Science does advance as data become available. Eventually this leads to corrections of the mainstream view – some minor, some major. The difficulty in the case of climate change is that slowness to recognize reality is particularly harmful to young people and future generations because of climate’s delayed response and the danger of passing the point of no return, as we emphasized in the [video introduction](#) to our paper.

One clarification is needed: our statement that “2°C is dead” was qualified with the phrase “unless a miracle occurs.” It is true that we do not expect a miracle, but the qualification should be included. It is also true that 2°C could be avoided via temporary purposeful cooling to reduce the massive geoengineering (geotransformation, if you prefer) that humanity is presently inflicting upon our home planet – but we do not have the knowledge to recommend such action and the public is nowhere near a point of endorsing such action. The closest thing to a miracle that is conceivable soon would be adoption of cost-free carbon fee-and-dividend<sup>13</sup> policy that we have advocated for almost two decades, as required to underlie and unleash the millions of changes needed to move the world as rapidly as practical to carbon-free energy and a declining level of atmospheric greenhouse gases. Presidents Obama and Biden each had the opportunity to initiate such a revenue-neutral action as part of economic actions required to address economic crises early in their administrations. Instead, Obama did little for climate and Biden borrowed massive amounts of money from future generations (via deficit funding) to subsidize already mature (solar and wind) technologies, an approach that spurred inflation and invited a whiplash energy policy response from the competing political party.

**Summary.** How is it that we can be cast as “outliers,” if the real world supports our interpretation of ongoing climate change? In part, we suspect, it is because of the “cottage” industry (quotation marks because it is not a small industry) that has built up in support of IPCC. It’s easy to understand how IPCC went down the track of low climate sensitivity, as early climate models had simple cloud treatments that produced only modest climate feedback. For those low-sensitivity climate models to match observed global warming during the several decades of steady warming since 1970, they required that (unmeasured) aerosol forcing remain almost unchanging in that period. We now have evidence that aerosol forcing was actually increasing (becoming more negative) during that period, which is consistent with paleoclimate evidence that climate sensitivity is high. It is difficult for such a huge industry to change its position, but in the end physics will rule.

**On a programmatic note:** We have long realized that our conclusion that modern nuclear power needs to play an important role in decarbonizing global energy systems limits our ability to obtain public and philanthropic support for CSAS. Now, it seems, this situation is much aggravated by any open discussion that purposeful global cooling may eventually be needed. It’s reminiscent of an analysis once made by JEH’s oldest grandson at age 10: “If we keep doing what we are doing now then the environment will be ruined when the people who are kids now are grownups. And unless

we can figure out how to make a time machine that actually works, there will be no way to go back in time to fix it. It's not fair that the grownups now are ruining the atmosphere for the grownup in the future. Grownups now are scared of nuclear power but they should be scared of what will happen if they keep doing what they're doing now because we know the ways to use nuclear power safe and we know that using fossil fuels is not safe. It's very dangerous." It seems that "grownups," have now decided that, after tying one arm behind the back of young people (by setting back nuclear R&D several decades; nuclear power has the potential to be our least expensive 24/7 power source, as well as having the smallest environmental footprint), they should also tie their other arm behind their back by prohibiting research on purposeful cooling, in case the grownups screwed up again and did not leave a time machine.

The tactics of the kibitzers seem to work on most of the media and some of our prior supporters. Apparently, the kibitzers have learned from politicians that it doesn't matter if what you say is true or not, and even ad hominem attacks are allowed – if enough people repeat the arguments often enough, they are accepted. Our attitude has usually been that we don't have time to deal with all the disinformation and also focus on our scientific research – because eventually the truth will come out. The problem with this assumption is that continuation of the United Nations approach is dangerous. The current policy approach, and belief that it can lead to climate stabilization and cooling by mid-century, is inexorably putting young people into an untenable position. We believe that it is important, despite the advice the UN gets from their massive scientific support group, to clarify where the approach of the United Nations Conferences of the Parties is taking young people.

We are very grateful to those people who continue to support Climate Science, Awareness and Solutions.

- <sup>1</sup> Charney and Bretherton, and some of their accomplishments, are described in *Sophie's Planet* (in preparation).
- <sup>2</sup> [Intergovernmental Panel on Climate Change](#)
- <sup>3</sup> IPCC. *Climate Change 2021: The Physical Science Basis* [Masson-Delmotte V, Zhai P, Pirani A et al. (eds)]. Cambridge and New York: Cambridge University Press, 2021
- <sup>4</sup> J. Hansen, M. Sato, P. Hearty et al., "[Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2C global warming is highly dangerous](#)," *Atmos Chem Phys* 16 (2016): 3761-812; paper title is that of the submitted paper.
- <sup>5</sup> J.E. Hansen, M. Sato, L. Simons et al., "[Global warming in the pipeline](#)," *Oxford Open Clim. Chan.* 3 (1) (2023): doi.org/10.1093/oxfclm/kgad008
- <sup>6</sup> J.E. Hansen, P. Kharecha, M. Sato et al., "[Global warming has accelerated: are the United Nations and the public well-informed?](#)" *Environment: Science and Policy for Sustainable Development*, 67(1), 6–44, 2025, <https://doi.org/10.1080/00139157.2025.2434494>
- <sup>7</sup> [Supplementary Material](#): "Global Warming Has Accelerated: Are the United Nations and the Public Well-Informed?"
- <sup>8</sup> The increase of absorbed solar radiation includes a smaller, but not negligible, boost from the 11-year solar cycle of solar irradiance, which is presently at a maximum.
- <sup>9</sup> J. Hansen, A. Lacis, D. Rind et al., "[Climate sensitivity: analysis of feedback mechanisms](#)," In: J.E. Hansen, T. Takahashi (eds). *AGU Geophysical Monograph 29 Climate Processes and Climate Sensitivity*. Washington: American Geophysical Union (1984): 130-63
- <sup>10</sup> D. Jiménez-de-la-Cuesta and T. Mauritsen, [Emergent constraints on Earth's transient and equilibrium response to doubled CO<sub>2</sub> from post-1970s global warming](#). *Nature Geoscience*, 12(11), 902–905, 2019, doi:10.1038/s41561-019-0463-y
- <sup>11</sup> Bakker P, Schmittner A, Lenaerts JTM et al. [Fate of the Atlantic Meridional Overturning Circulation: strong decline under continued warming and Greenland melting](#). *Geophys Res Lett* 2016;**43**:12252-60
- <sup>12</sup> D. Carrington, "Climate change target of 2C is "dead," says renowned climate scientist," *Guardian*, 4 February 2025.
- <sup>13</sup> Hansen J. [Storms of My Grandchildren](#). ISBN 978-1-60819-502-2. New York: Bloomsbury, 2009