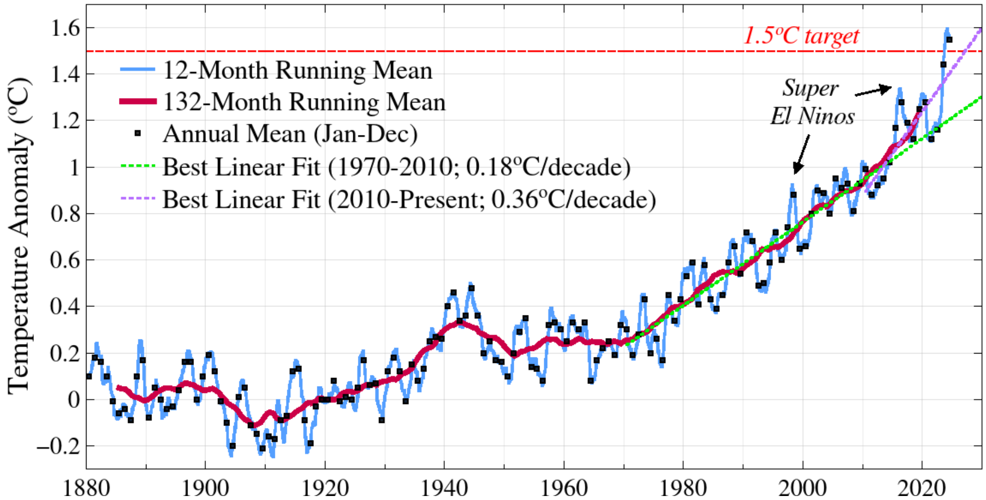
Figure 1. Global Surface Temperature Relative to 1880-1920[1]



The Acid Test: Global Temperature in 2025

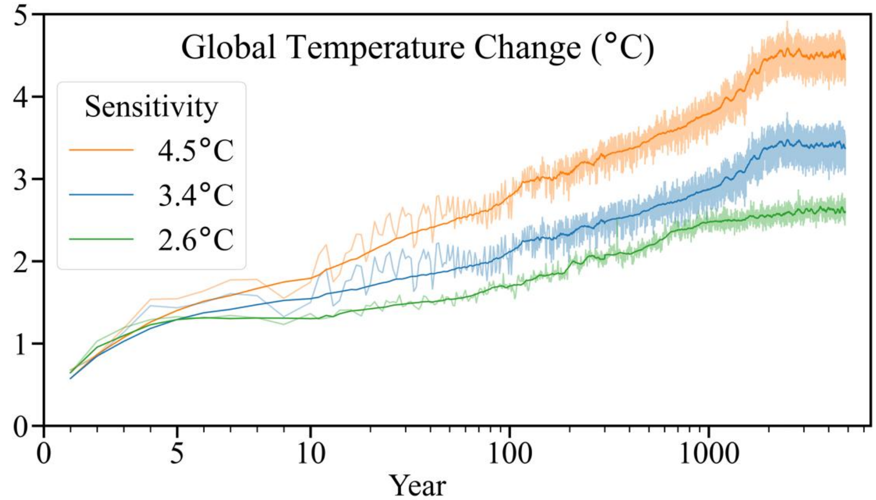
James Hansen and Pushker Kharecha 20 February 2025

The unprecedented leap of global temperature in 2023 and early 2024 exceeded 0.4°C (Fig. 1). We and coauthors[2] interpret that uniquely large warming as being due about equally to a moderate El Nino and reduction of ship aerosols, with a smaller contribution from the present solar maximum (our entire paper, including Abstract & Supplementary Material is available in a single compressed PDF here). An "acid" test of our interpretation will be provided by the 2025 global temperature: unlike the 1997-98 and 2015-16 El Ninos, which were followed by global cooling of more than 0.3°C and 0.2°C, respectively, we expect global temperature in 2025 to remain near or above the 1.5°C level. Indeed, the 2025 might even set a new record despite the present weak La Nina. There are two independent reasons. First, the "new" climate forcing due to reduction of sulfate aerosols over the ocean remains in place, and, second, high climate sensitivity (~4.5°C for doubled CO_2) implies that the warming from recently added forcings is still growing significantly.

The impact of high climate sensitivity warrants clarification. High climate sensitivity implies a large contribution from amplifying feedbacks: water vapor, surface albedo (sea ice/snow) and clouds. The feedbacks do not come into play immediately in response to a climate forcing, but rather in response to the global warming caused by the forcing. That warming takes time, and it takes longer for higher sensitivity.[3] Thus, response to a forcing in the first few years depends little on climate sensitivity, as shown by the response functions for three climate sensitivities (Fig. 2); early response is due mainly to the forcing itself, not feedbacks. But as temperature change grows, feedbacks come into play and are the main cause of the continued, growing, response.[a] The relevant point here is that feedbacks stretch out the response time, so, within a decade or two, higher climate sensitivity yields a

[a] The rapid early response to a forcing amounts to about 1/3 of the equilibrium (eventual) response, another third occurs within about a century, and the final third takes millennia. Slow response is due to the ocean's thermal inertia, the time needed for the upper ocean and the deep ocean to change temperature. If we reduce the net human-made climate forcing rapidly enough, these slow responses need never occur. However, in reality, the net climate forcing is accelerating.

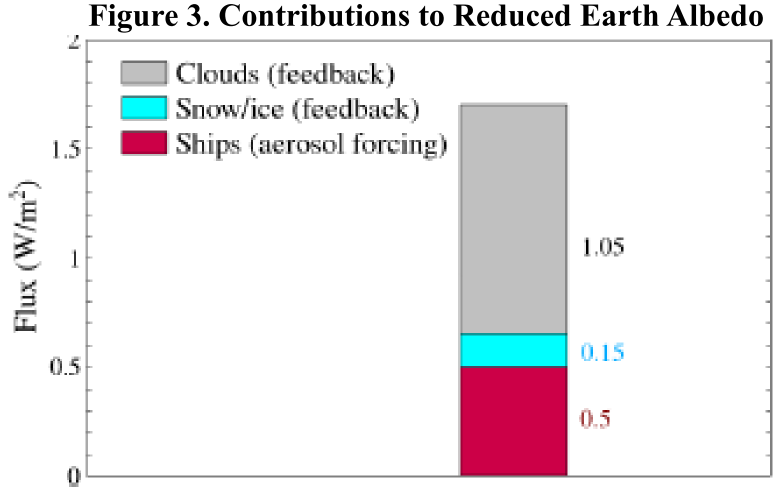
Figure 2. Global Temperature Response to 2×CO_2



significantly greater response. If climate sensitivity is 3°C or less, the rapid, early, response to the ship aerosol forcing introduced in 2020 is complete in 2025, but if climate sensitivity is high, there is still substantial "juice" in the aerosol forcing change, which can thus offset tropical cooling.[b]

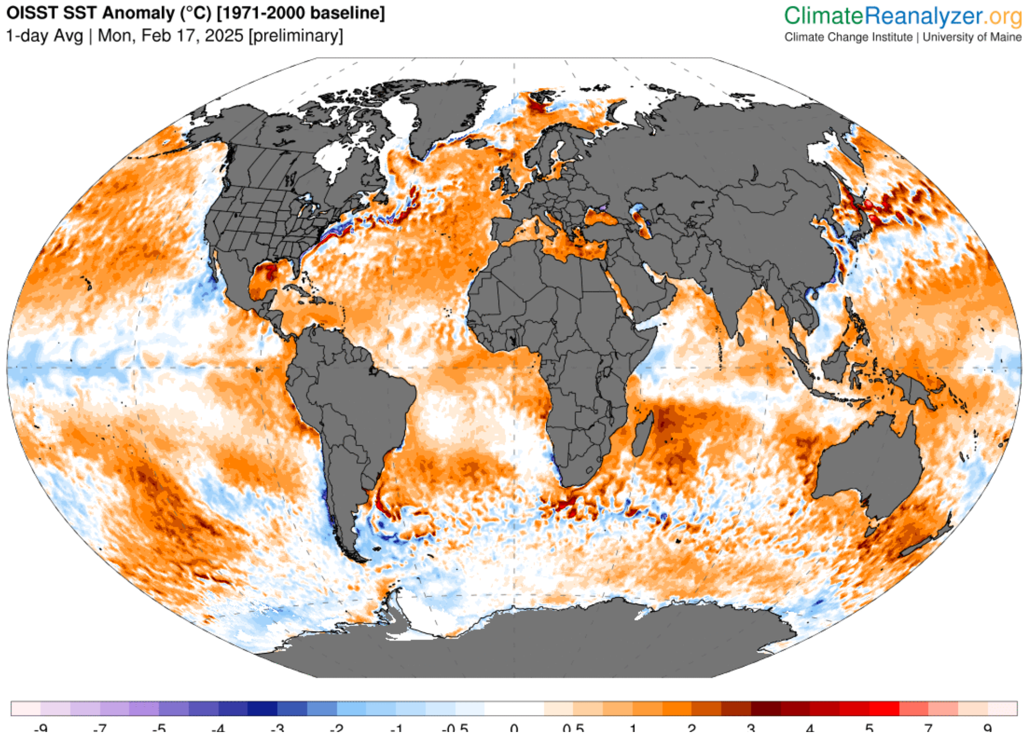
Why are we confident that climate sensitivity is high? We have shown that in three independent ways: (1) climate sensitivity 4.8°C ± 0.6°C (1σ) based on comparison of glacial and interglacial climate states,[4] (2) sensitivity of 4.5°C ± 0.5°C (1σ) based on temperature from 1750 through 2024,[2] (3) the large "darkening" (reduced albedo) of Earth between 2000 and 2024, which implies a strong cloud feedback (Fig. 3) – and strong cloud feedback implies high climate sensitivity.[2]

Figure 3. Contributions to Reduced Earth Albedo



[b] It would be informative if all GCMs (global climate models) in the CMIP and IPCC studies reported their response function (Fig. 2); this would aid understanding the model and understanding climate change. The response function for sensitivity 4.5°C (Fig. 2) is only an estimate based on the 3.4°C sensitivity model. There is need to understand how a strong amplifying cloud feedback alters the response function. Prior advocacy of the response function focused on ocean mixing; effects of ocean mixing and climate sensitivity on the response function need to be distinguished.

Fig. 4. Sea surface temperature anomaly 17 February 2025 (°C) [NOAA & Univ. Maine][5]



What is the expected effect of large ship aerosol forcing (which is about a third of the darkening) and amplifying feedbacks (about two thirds of the darkening)? This forcing is located mainly at 30-50°N latitudes, but the global feedbacks (clouds and water vapor) provide the larger flux of energy into the climate system. Thus, SSTs will remain high globally, with numerous hotspots (Fig. 4). It may appear in Fig. 4 that the warming is greater in the Southern Hemisphere, but the zonal-mean SSTs (Fig. 5) has maximum warming at 30-50°N since 2020, as expected (Fig. 5 shows 12-month running means; data go through January 2025, the 12-month mean ends in July 2024). The El Nino has faded, but the response in the ship aerosol region continues to grow.

Figure 5. GISS/NOAA Zonal-Mean 12-Month Running-Mean SST Anomaly

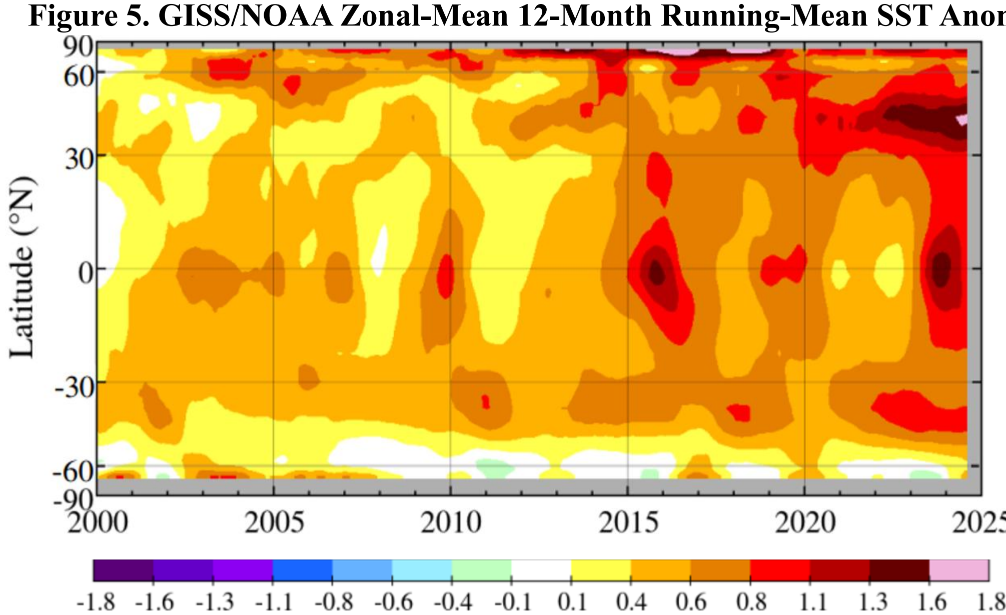
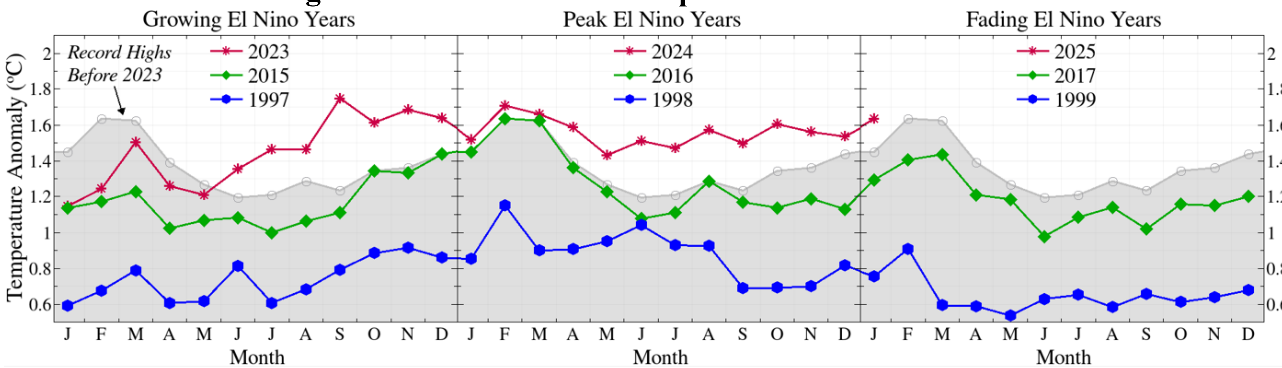


Figure 6. Global Surface Temperature Relative to 1880-1920



An acid test for these acidic aerosols will be provided by the 2025 global temperature. January 2025 is the warmest January in the record (Fig. 6) despite the current weak La Nina (which may fade into an ENSO-neutral state in the next few months), but February so far is much cooler than in 2024. Nevertheless, we expect the ship aerosol forcing and high climate sensitivity to provide sufficient push to largely offset the effect of the El Nino cycle. Indeed, we expect 2025 to be in competition with 2024 for the warmest year, and we would not be surprised if 2025 is a new record high.

What is the importance of these high global temperatures and the acceleration of global warming? Along with growing impacts on society and ecosystems caused by increasing climate extremes, our main concern is the danger of passing the point of no return, when the warming induces shutdown of the Atlantic Meridional Overturning Circulation (AMOC) and that, in turn, locks in sea level rise of several meters. If accelerated warming (Fig. 1) is not arrested, it will accelerate ice melt and freshwater injection onto the North Atlantic. Such increased freshwater injection, rising temperature of the ocean surface layer, and increased rainfall over the North Atlantic Ocean – all certain to occur if accelerated warming is allowed to continue – are the elements that are predicted to drive AMOC shutdown within 2-3 decades.[6]

This is a time – as the world focuses on cultural and shooting wars – to gain the scientific understanding needed to address climate change, if and when the world comes to its senses. To increase the chance of success, it is important to maintain and initiate crucial Earth observations. Among these are continuation of precise global measurements of Earth's radiation budget and expansion of Argo autonomous float measurements under sea ice and ice shelves.

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[1] Temperature is from the Goddard Institute for Space Studies analysis described by N.J.L. Lenssen et al., "A NASA GISTEMPv4 Observational Uncertainty Ensemble," *J. Geophys. Res. Atmos.* 129, (2024) e2023JD040179, and J. Hansen et al., "Global surface temperature change," *Rev. Geophys.* 48, (2010): RG4004

[2] 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

[3] Hansen J, Russell G, Lacis A *et al.* Climate response times: dependence on climate sensitivity and ocean mixing. *Science* 1985;**229**:857-9

[4] 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

[5] Authors' download from University of Maine Climate Reanalyzer: https://climatereanalyzer.org/clim/sst_daily/

[6] 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 2 C global warming could be dangerous," *Atmos Chem Phys* 16 (2016): 3761-812. See also the Supplementary Material of reference 2