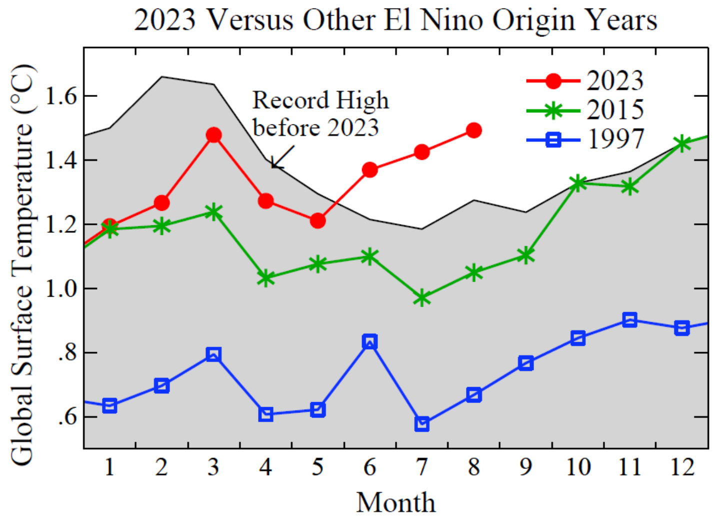

Fig. 1. Global temperature (relative to 1880-1920 mean for each month) during the El Nino origin year for the 1997-98, 2015-16 and 2023-24 El Ninos. The impact of El Nino on global temperature usually peaks early in the year following the year when the El Nino originated.

Global Warming is Accelerating. Why? Will We Fly Blind?

14 September 2023

James Hansen, Makiko Sato, Reto Ruedy, and Leon Simons

Abstract. Global temperature in the current El Nino exceeds temperature in the prior (2015-16) El Nino by more than the expected warming (0.14℃ in 8 years) for the global warming rate since 1970 (0.18℃/decade). Proximate cause of accelerated warming is an increase of Earth's Energy Imbalance (EEI), but what caused that? Indirect evidence points to a decline in the cooling effect of human-made aerosols. Failure to measure aerosol climate forcing is partly compensated by precise monitoring of EEI details. However, there are no adequate plans to continue even this vital EEI monitoring – which will become even more important as humanity realizes its predicament and the fact that we must cool the planet to avoid disastrous consequences and restore a bright future for young people – let alone plans for adequate aerosol monitoring.

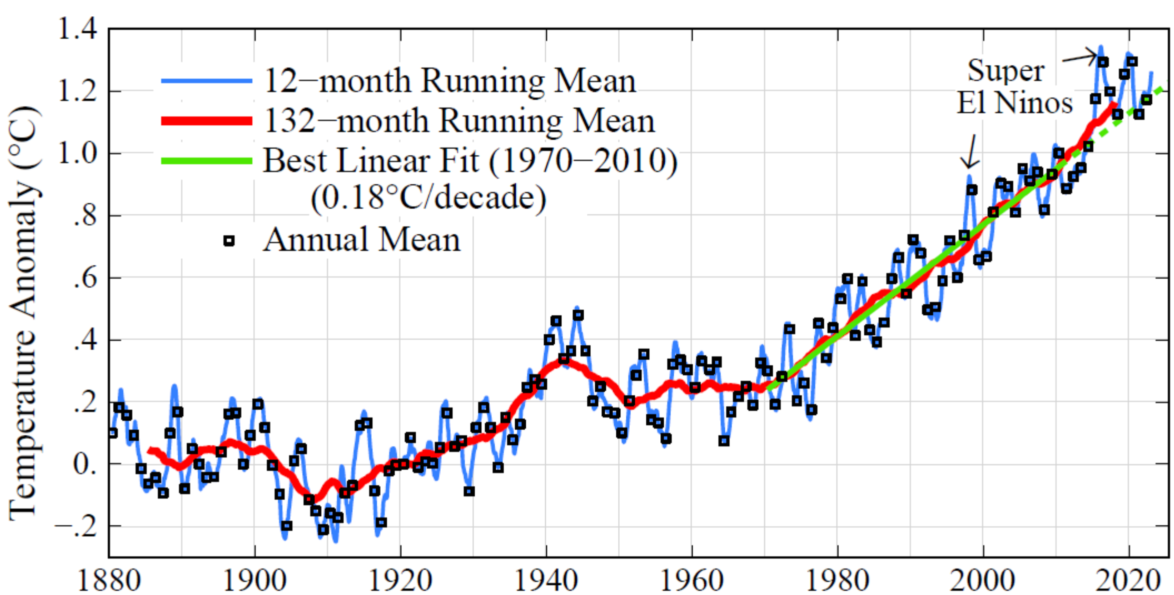

Fig. 2. Global temperature relative to 1880-1920 based on the GISS analysis.[1,2]

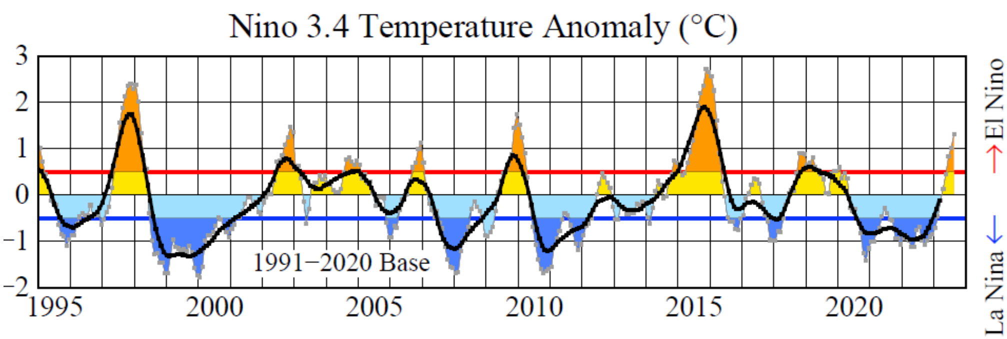

Fig. 3. Temperature in the tropical Pacific region used to define El Nino strength. El Nino (La Nina) is nominally defined to occur when Nino 3.4 is > 0.5°C (< –0.5°C).

Suspicion that global warming was accelerating was created by the warming rate between the 1997-98 and 2015-16 El Ninos.[3] The rate of warming between those super El Ninos was 0.24℃/decade, exceeding the 1970-2010 rate of 0.18℃/decade (Fig. 2). So far, the present El Nino, only 8 years after the 2015-16 El Nino, suggests substantial further increase in the rate of global warming. It is too soon to say how strong the present El Nino will be, but its seasonality is normal (Fig. 3). Global temperature anomalies lag the Nino3.4 index by several months, so it is also early to estimate the peak warming, which is expected to occur in the first half of 2024. However, global temperature in the first few months of the El Nino is so extreme (Fig. 1) it is now almost certain that the 12-month running mean temperature will exceed 1.5℃ by May 2024 or earlier.

The proximate cause of the global warming is Earth's energy imbalance (EEI): there is more energy coming in (absorbed sunlight) than energy going out (heat radiated to space). EEI increased greatly in the past decade (Fig. 4). The imbalance so far in the 2020s (1.36 W/m^2) is almost double the rate (0.71 W/m^2) during the calibration period (mid-2005 through mid-2015) in which satellite data[4] for EEI (with great precision in temporal change) are put on an absolute scale via decadal-mean in situ (Argo float) ocean heat storage data.[5] The principal mechanism for global warming over the past century has been the reduction of Earth's outgoing heat radiation caused by increasing greenhouse gases, which makes the atmosphere more opaque at infrared wavelengths that emit heat radiation. Heat radiation to space thus arises from higher, colder, levels, which reduces energy loss to space, causing the planetary energy imbalance and therefore global warming.

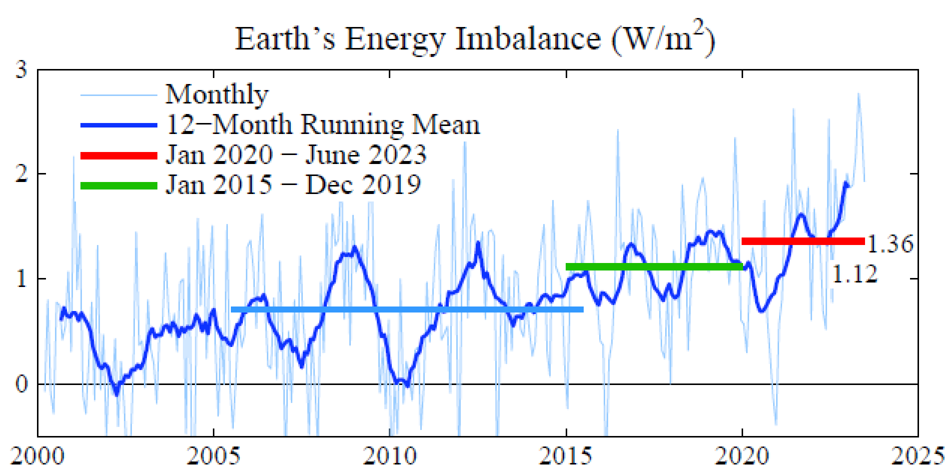

Fig. 4. 12-month running-mean of Earth's energy imbalance from CERES satellite data[4] normalized to 0.71 W/m^2 mean for July 2005 – June 2015 (blue bar) from in situ data.[5]

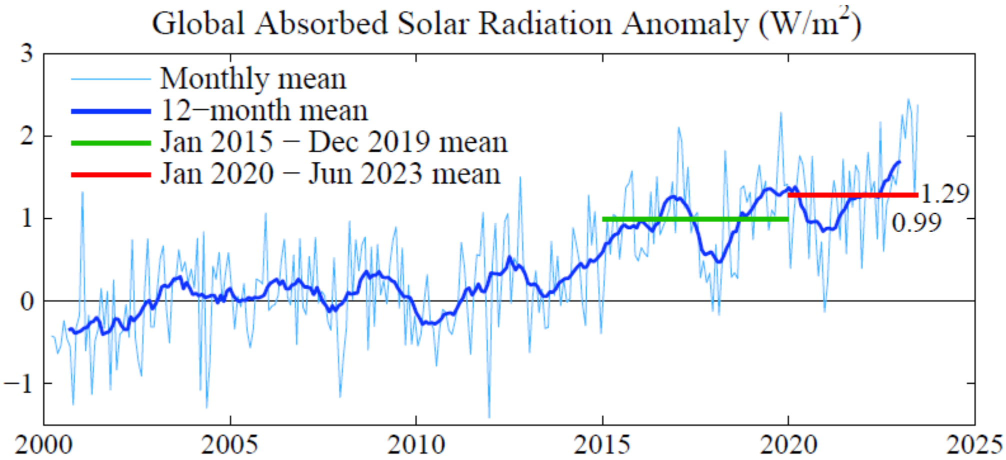

Fig. 5. Global absorbed solar radiation (W/m^2) relative to mean of the first 120 months of CERES data. CERES data are available at http://ceres.larc.nasa.gov/order_data.php Global absorbed solar radiation anomalies are 0.99 and 1.29 W/m^2 in the indicated intervals.

However, greenhouse gases are not the cause of increased EEI since 2015. How do we know? The (CERES) satellite instrument measures both the change of emitted heat radiation and the change of reflected solar radiation. The change since 2015 is a decrease of sunlight reflected by Earth, thus an increase of solar radiation absorbed by Earth (Fig. 5). Absorbed solar radiation in 2015-2019 was 0.99 W/m^2 greater than in the calibration period (2005-15), and since January 2020, the imbalance is even greater (1.29 W/m^2). Increased EEI did not occur because of an increase of solar irradiance. On the contrary, during the 5 years 2015-19 the Sun's brightness declined by an amount decreasing absorbed solar radiation by about 0.15 W/m^2, followed by an increase since 2020 of about 0.2 W/m^2 (Fig. 6, right scale). Changes of sea ice area affect EEI, but sea ice changes in the past decade have been small, except the decrease of Southern Hemisphere sea ice in the past 2 years.[6] The Hunga Tonga volcanic eruption in early 2022 also affects the past two years. Jenkins *et al*.[7] estimate that water vapor injected into the stratosphere caused a small warming forcing (+0.12 W/m^2), but Schoeberl *et al*.[8] found that the cooling effect of stratospheric aerosols injected by Hunga Tonga yielded a net cooling effect, with forcing peaking in mid-2022 at about –0.5 W/m^2. Averaged over 2022, Hunga Tonga may have been about –0.3 W/m^2, but by today it is smaller.

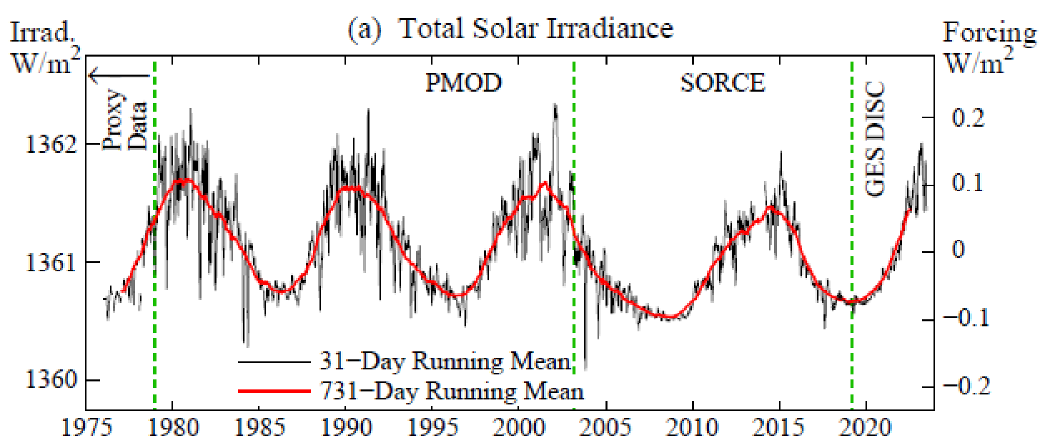

Fig. 6. Solar irradiance and climate forcing, the latter being 0.175 ×irradiance change, where 0.175 = (1 – Earth's albedo)/4, where Earth's albedo = 0.3. Data sources: Physikalisch Meteorologisches Observatorium, Davos, University of Colorado Solar Radiation and Climate Experiment, and Total Irradiance Monitor on the International Space Station (GES DISC).

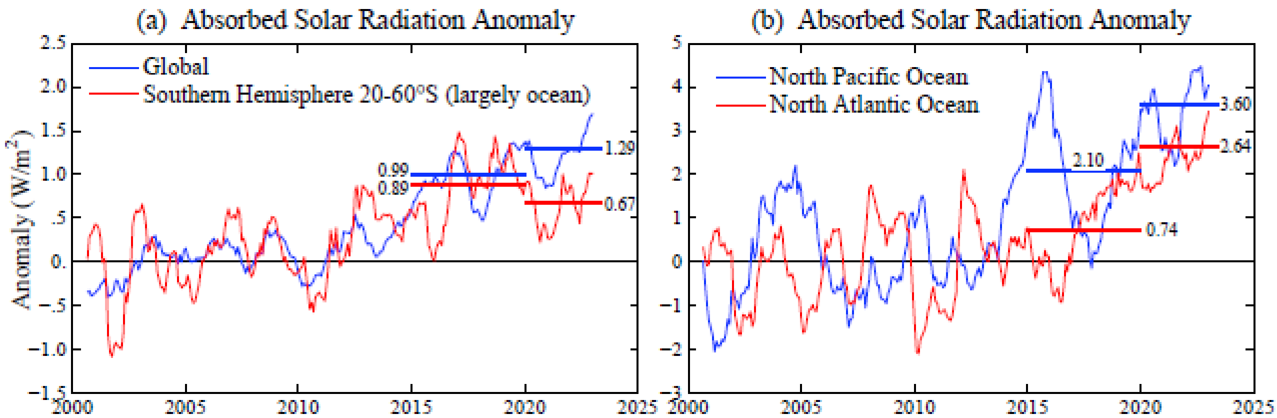

Fig. 7. Absorbed solar radiation for indicated regions relative to first 120 months of CERES data. Southern Hemisphere 20-60°S is 89% ocean. North Atlantic is (20-60°N, 0-60°W) and North Pacific is (20-60°N, 120-220°W). Data source: http://ceres.larc.nasa.gov/order_data.php

We conclude that, although the solar and Hunga Tonga forcings are not negligible, they do not account for the large, persistent increase of absorbed solar radiation since 2015. The only known mechanism capable of such a large forcing is a decrease of cloud albedo. Indeed, we concluded elsewhere[9] that decreased particulate air pollution in the past decade should cause such a decrease of cloud albedo and thus an acceleration of global warming in the post-2010 period. The most distinct and probably the most effective aerosol reduction is due to limitations on the sulfur content of ship fuels imposed by the International Maritime Organization (IMO) in January 2015 and strengthened in January 2020. The change of global absorbed solar radiation suggests that the 2015 change had the larger effect, but that appearance may be misleading. Clouds, and thus planetary albedo (reflectivity), have a large natural variability, e.g., cloud change correlated with the Pacific Decadal Oscillation (PDO). The PDO shifted to its positive phase in 2015, which favors decreased cloud cover and increased global absorption of solar radiation.[10] The PDO shifted back to its negative phase in 2020 (Fig. 8), which favors increased clouds and reduced absorption of solar radiation. Yet the post 2020 EEI has increased (Fig. 4), as has absorbed solar radiation (Fig. 5).

The upshot is strong indirect evidence that an ongoing decrease of particulate air pollution is in the process of increasing absorption of solar energy by Earth, which adds to greenhouse gas global warming. We predict at least a 50 percent increase of the post-2010 global warming rate, compared to the 1970-2010 rate of 0.18°C/decade.[9] This is a partial payment in return for the Faustian bargain that humanity made when it chose to build its economies on fossil fuel energy.[11]

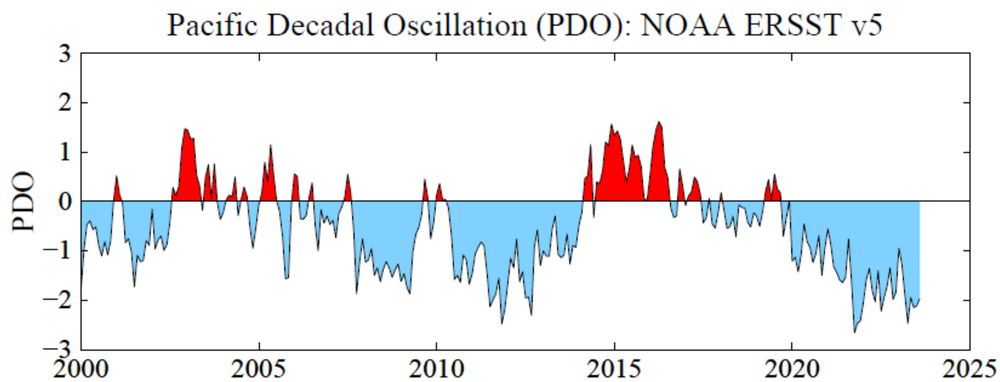

Fig. 8. Pacific Decadal Oscillation.[12]

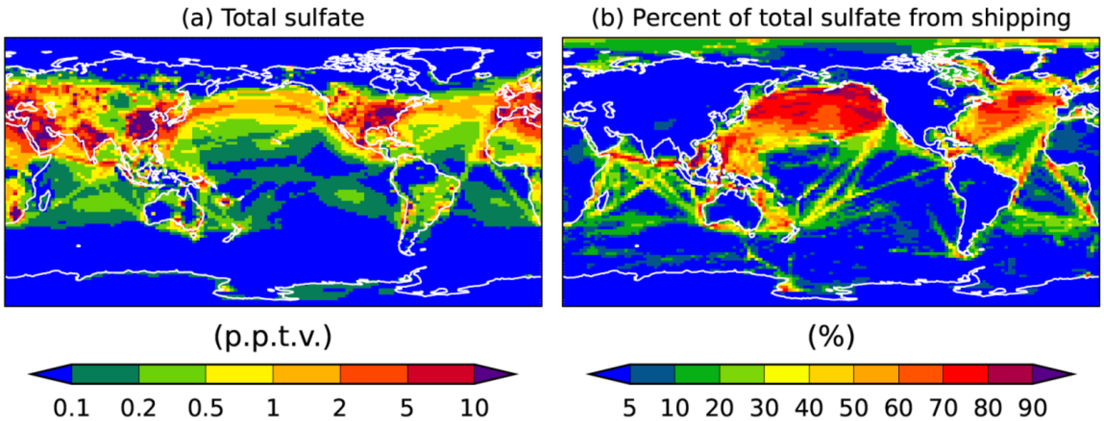

Fig. 9. Total sulfate (parts per trillion by volume) and percentage of total sulfate provided by shipping in simulations of Jin et al.[13] prior to IMO regulations on sulfur content of fuels.

Absorbed solar radiation measured by the CERES satellite instruments, together with the IMO regulations on ship sulfate emissions, provides another indirect way to evaluate aerosol effects. The fraction of total sulfate emissions that arise from ships is large in the North Pacific and North Atlantic (Fig. 9), so study of that region should help quantify the aerosol effect. Fig. 9b suggests that the aerosol effect on cloud albedo is large, although a longer record is needed to overcome the "noise" due to natural variability of clouds.

"This is crazy," you must be saying, "why don't you measure the aerosol climate forcing, instead of this round-about inference via detailed effect on EEI and absorbed solar energy?" Good question. The short answer is that we (the first author and others) tried, but, in career-long failure could not persuade NASA to fly a small satellite with the two instruments (a high precision polarimeter and an infrared spectrometer) needed to monitor the aerosol and cloud microphysics that define the aerosol climate forcing.[14] The short explanation is that NASA preferred large, slow, multi-billion dollar missions as needed to support the budgets of the large NASA Centers. Throw in a climate-denier NASA Administrator, who, in angry response to our persistence, struck out the first line of the NASA Mission Statement "To Understand and Protect the Home Planet."[15]

It's still worth pursuing aerosol and cloud monitoring of the required precision, but the most urgent task is assuring continuation of the CERES or CERES-like monitoring of Earth's radiation balance. As yet there are no firm adequate plans for long-term continuation of these observations. NASA tends to think of itself as an agency that develops scientific and instrumental techniques, while long-term observations should be carried on by others. However, long-term observations are the climate science. It is crucial that NASA make plans to continue these essential measurements.

Measurements in the ocean are equally essential. The Argo program that distributed about 4,000 autonomous, deep-diving floats around the world ocean needs to be continued and enhanced. More measurements are needed especially in the polar regions where some of the most significant climate changes are beginning to occur, changes that will affect the entire planet. The U.S. National Atmospheric and Oceanic Administration (NOAA) has provided a large fraction of the Argo floats, but many other nations contribute; the programs should continue their development.

Without such data, we will be flying blind into a future fraught with dangers. At the very least, we owe young people the knowledge of what we are getting them into.

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