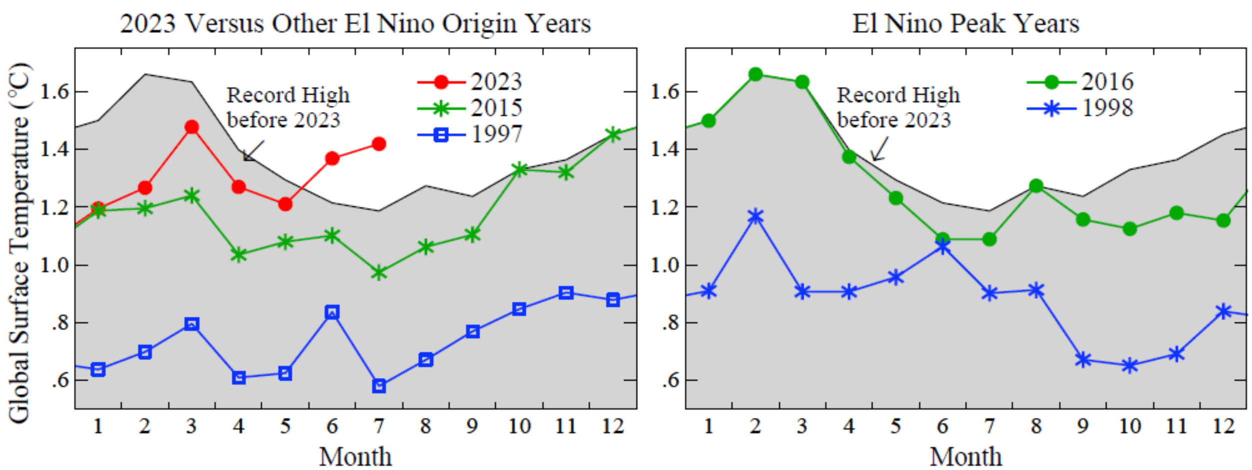


**Fig. 1. Global temperature (relative to 1880-1920 mean for each month) for the 1997-98, 2015-16 and 2023-24 El Ninos. The impact of El Nino on global temperature usually peaks early in the year (El Nino Peak Year) following the year in which the El Nino originated.**

# Uh-Oh. Now What? Are We Acquiring the Data to Understand the Situation?

14 August 2023

James Hansen, Makiko Sato and Reto Ruedy

**<u>Abstract</u>.** Global temperature in June and July (Fig. 1) shot far above the prior records for those months for the 140 years of good instrumental data. Early indications are that warming exceeds expectation based on only the long-term trend due to increasing greenhouse gases (GHGs) plus the emerging El Nino. Three additional mechanisms will have a near-term effect, with a result that the 12-month mean global temperature likely will pierce the 1.5°C warming level before this time next year. Uncertainties in present analyses draw attention to the inadequacy of and the precarious state of crucial global observations.

Suspicion that global warming was accelerating was already created by the warming rate between the 1997-98 and 2015-16 El Ninos.[1] Global warming between 1970 and 2010 was 0.18°C/decade (Fig. 2), but the rate increased to 0.24°C/decade between these two super El Ninos.[2]

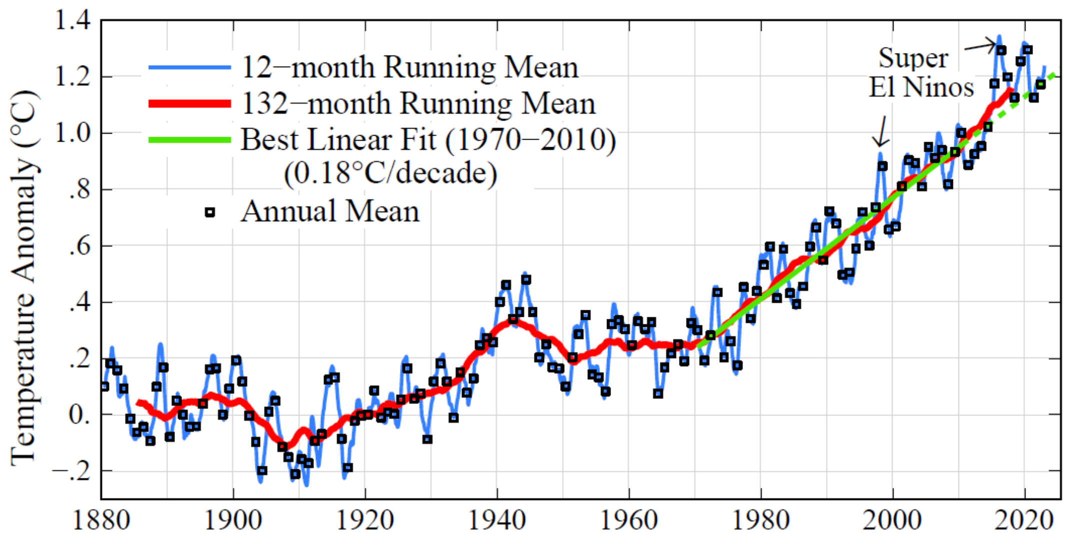


**Fig. 2. Global temperature relative to 1880-1920 based on the GISS analysis.[3,4]**

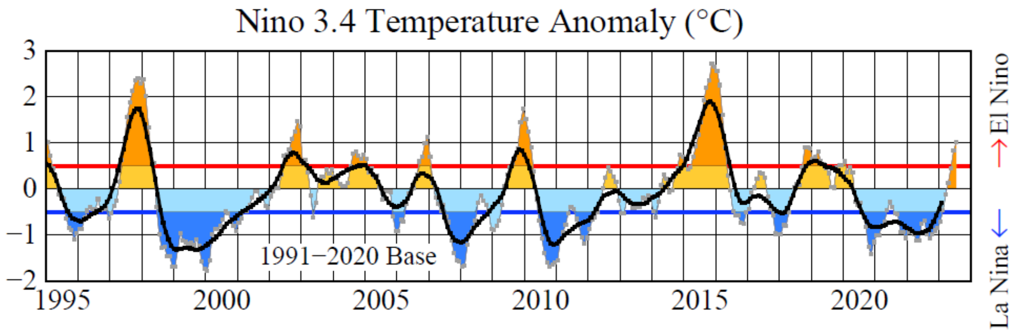


**Fig. 3. Temperature in the tropical Pacific region used to define El Nino strength. El Nino (La Nina) is nominally defined to occur when Nino 3.4 is > 0.5°C (< –0.5°C).**

**<u>El Nino and aerosols</u>.** The strength of the current El Nino remains to be seen (Fig. 3). If the budding El Nino proves to be comparable to the two super El Ninos of the past three decades, it will provide a measuring stick for the current rate of global warming. We anticipate acceleration of the long-term global warming rate by at least 50%, i.e., to at least 0.27°C/decade, mainly due to reduction of human-made aerosols (fine airborne particles).[2,5] Aerosols have a cooling effect by increasing reflection of sunlight to space (primarily via aerosol effects on cloud brightness and cloud lifetime), so a reduction of aerosols increases global warming. Global cloud properties are not measured with the precision needed to define aerosol climate forcing. There is enough theoretical and anecdotal evidence for the sense and approximate magnitude of aerosol climate forcing to confirm that aerosols are the second greatest human-made climate forcing, but better knowledge of aerosol climate forcing is required for reliable climate projections.

**<u>Sun's brightness</u>.** Solar irradiance changes cause a small but non-negligible climate forcing that is relevant to interpretation of global temperature change in the next few years. Fortunately, the Sun has been well-measured from space since 1979 (Fig. 4). The solar cycle is approaching solar maximum and the irradiance already exceeds that of the prior cycle, adding a forcing of the order of +0.1 W/m$^2$ relative to the mean irradiance. The solar cycle has negligible effect on the long term, but it adds of the order of +0.1 W/m$^2$ to the energy imbalance today and will add perhaps a few hundredths of a degree Celsius to global temperature in the next year.

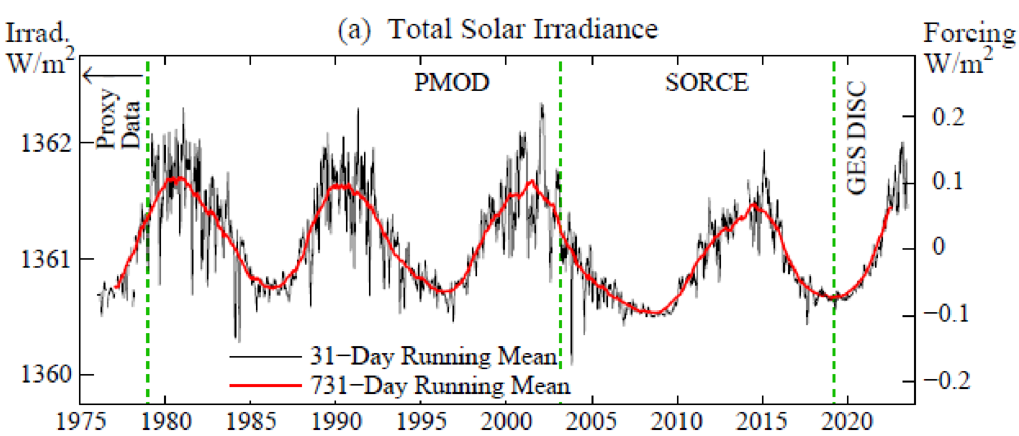


**Fig. 4. Solar irradiance and climate forcing, the latter being 0.175 ×irradiance change, where 0.175 = (1 – Earth's albedo)/4, where Earth's albedo = 0.3. Data sources: [Physikalisch Meteorologisches Observatorium, Davos], University of Colorado [Solar Radiation and Climate Experiment], and [Total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

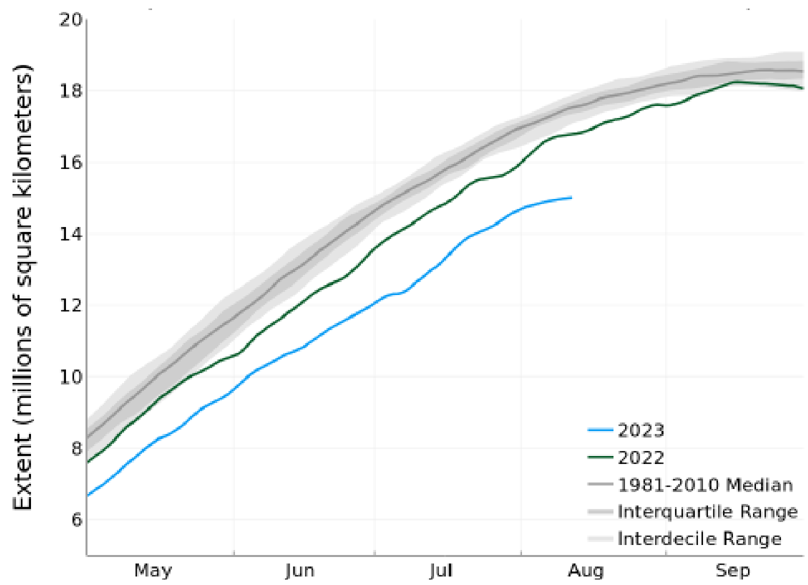


**Fig. 5. Antarctic sea ice extent (area of ocean with at least 15% sea ice). Source: [NOAA National Snow and Ice Data Center](), University of Colorado, Boulder.**

**Feedbacks.** As the Sun rises in the sky this year, as seen from Antarctica and the Southern Ocean, the flux of energy from the Sun will beat down on a surface that is notably darker than at any time in the satellite era (i.e., since the 1970s), thus surely darker than at any time in the period of good temperature data. Sea ice cover in the Southern Hemisphere has declined dramatically to a level well below prior records (Fig. 5). Increased absorption of sunlight will increase Earth's energy imbalance further and increase global warming. The effect on sea surface temperature will be less than the effect on surface air temperature, so temperature compilations (such as GISTEMP) that use sea surface temperature rather than surface air temperature, will not register the full effect on surface air. The important matter is the effect on Earth's energy imbalance, which is now being measured reasonably well by the combination of satellite measurement of planetary radiation balance and in situ measurement of ocean heat content (Fig. 6). We have not yet calculated the expected effect of the reduced sea ice on Earth's energy imbalance (EEI) because it depends crucially on how sea ice cover changes as the Sun rises high in the sky as seen from the Southern Ocean. The calculation needs to accurately account for cloud shielding. However, it is clear that the reduced sea ice cover will cause a significantly increased drive for global warming.

There is another major, largely unmeasured, climate feedback: cloud change in response to global warming. The recent revelation (Global warming in the pipeline[6]) from paleoclimate data that equilibrium climate sensitivity (ECS) is 4.8°C ± 1.2°C for 2×$CO_2$ implies that clouds provide a strong amplifying climate feedback, as, without cloud feedbacks, ECS would be ~2.5-3°C for 2×$CO_2$. The task of extracting accurate knowledge from observed cloud changes is made more difficult by the fact that clouds are also reacting to changing atmospheric aerosols. In both cases, the cloud changes involve changes of cloud microphysics, i.e., changes in the size distribution and phase of cloud particles. Although global monitoring of aerosol and cloud microphysics has been proposed,[7] it has not been achieved. Nevertheless, much progress in understanding is possible via combination of cloud modeling with existing and planned observations, including the spatial and temporal changes of Earth's energy imbalance.

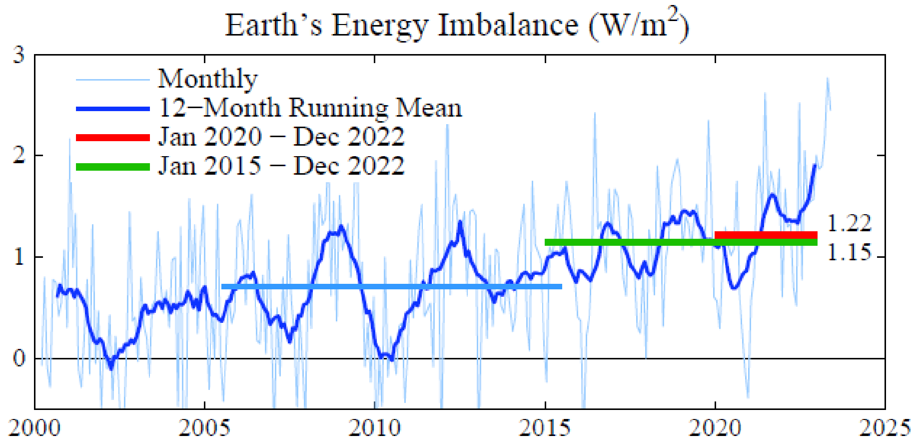


**Fig. 6. 12-month running-mean of Earth's energy imbalance from CERES satellite data[8] normalized to 0.71 W/m$^2$ mean for July 2005 – June 2015 (blue bar) from in situ data.[9]**

**Crucial observations.** Despite the obvious importance of understanding the reasons for climate change and the actions needed to restore a propitious climate, continuation and improvement of some of the most fundamental observations are at risk. The observations required to produce Fig. 6 are essential for the sake of understanding our current climate predicament.

[Political leaders at the United Nations COP (Conference of the Parties) meetings give the impression that progress is being made and it is still feasible to limit global warming to as little as 1.5°C. That is pure, unadulterated, hogwash, as exposed by minimal understanding of Fig. 6 here and Fig. 27 in reference 6. It is important that the remarkable observations that allowed construction of Fig. 6 are continued and improved – which is a greater challenge than governments may be aware of. Precise observations are needed from space and throughout the global ocean.]

Measurements of Earth's radiation budget from space were largely a product of the burst of government spending in the 1990s on NASA's Earth Observing System. 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 continued long-term observations should be carried on by others. However, in the case of climate change, long-term observations are the science. It is crucial that NASA make plans to continue these essential measurements.

Measurements in the ocean are equally important. 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.

**A new climate frontier.** The leap of global temperature in the past two months is no ordinary fluctuation. It is fueled by the present extraordinarily large Earth's energy imbalance (EEI). EEI is the proximate cause of global warming. The large imbalance suggests that each month for the rest of the year may be a new record for that month. We are entering a new climate frontier.

When the first author gave a TED talk 10 years ago, EEI was about 0.6 W/m$^2$, averaged over six years (that may not sound like much, but it equals the energy in 400,000 Hiroshima atomic bombs per day, every day). Now EEI has approximately doubled. Most of that energy is going into the ocean. If Southern Hemisphere sea ice cover remains low, much of that excess energy will be poured into the Southern Ocean, which is one of the last places we would want it to go.

That does not mean that the problem is unsolvable. It is possible to restore Earth's energy balance. Perhaps, if the public finds the taste of the new climate frontier to be sufficiently disagreeable, we can begin to consider the actions needed to restore a propitious climate.

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