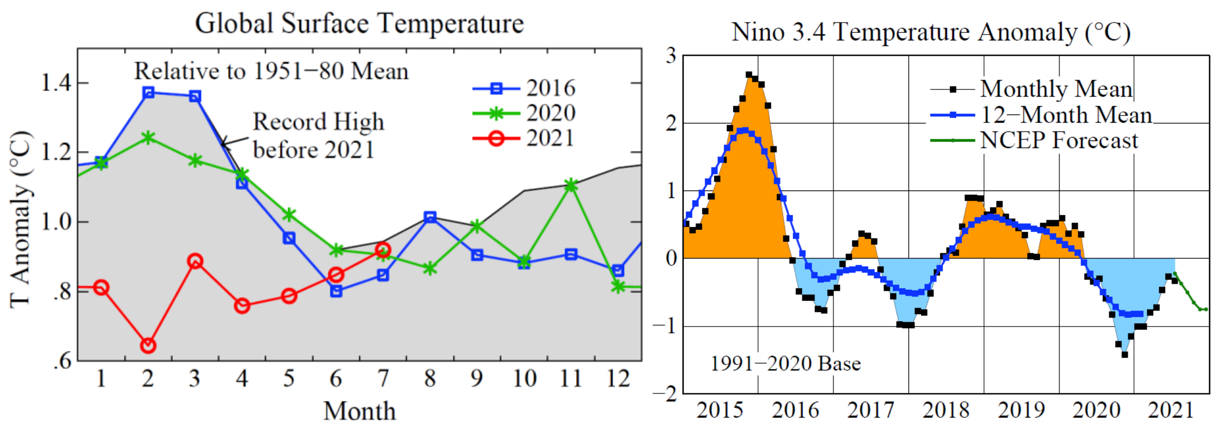

Fig. 1. Left: monthly global temperature anomalies. Right: Nino 3.4 temperature anomaly for past six years and 7 months, and NCEP forecast (green line).

July Temperature Update: Faustian Payment Comes Due

13 August 2021

James Hansen and Makiko Sato

July global temperature (+1.16°C relative to 1880-1920 mean) was within a hair (0.02°C) of being the warmest July in the era of instrumental measurements (Fig. 1, left). That's remarkable because we are still under the influence of a fairly strong La Nina (Fig. 1, right). Global cooling associated with La Ninas peaks five months after the La Nina peak,[1] on average.

Something is going on in addition to greenhouse warming. The 12-month running mean global temperature (blue curve in Fig. 2) has already reached its local minimum. Barring a large volcano that fills the stratosphere with aerosols, the blue curve should rise over the next 12 months because Earth is now far out of energy balance – more energy coming in than going out.

How far is the recent global temperature above the 50-year warming trend? The best measure is probably the average deviation from the trend line of the two El Nino maxima and the two La Nina minima that followed. That average is 0.14°C. That's a lot, and we know that it's a forced change, driven by a growing planetary energy imbalance.

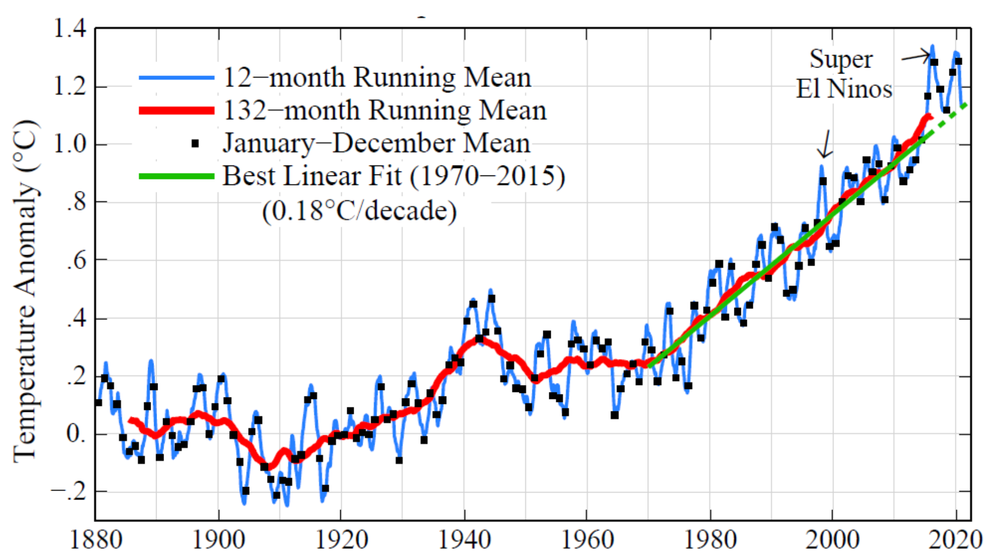

Fig. 2. Global surface temperature relative to 1880-1920 average.

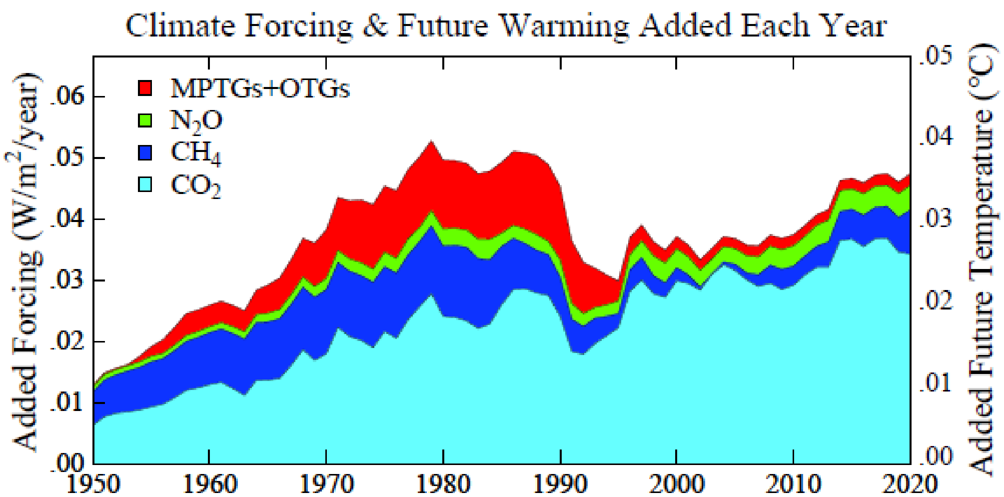

Fig. 3. Annual growth of GHG climate forcing (red is trace gases, mainly CFCs). Graph shows 5-year means, except 2019 value is the 3-year mean and 2020 is 1-year mean.

Global temperature doesn't change that much due to meteorological noise. The ocean is a huge heat reservoir and can burp up heat – indeed, that's the cause of most interannual variability of global temperature. However, over the past several years the ocean has not been giving up heat – on the contrary, it is gaining heat at the fastest rate on record. Global warming is being forced.

None of the measured forcings can account for the global warming acceleration. The growth rate of climate forcing by well-mixed greenhouse gases (GHGs) is near the 40-year mean (Fig. 3). Solar irradiance is just beginning to rise from the recent solar minimum; it is still below the average over the last few solar cycles.

It follows that the global warming acceleration is due to the one huge climate forcing that we have chosen not to measure: the forcing caused by imposed changes of atmospheric aerosols.

Leon Simons – Director of Club of Rome Netherlands – sent a message to me several months ago describing regulations being imposed by the International Maritime Organization on sulfur emissions from ships. Some reductions were required by 2015 and stiffer restrictions were imposed globally in 2020. The reductions are imposed for the sake of human health; the World Health Organization reports that 3-4 million people per year die from outdoor air pollution.

It's a shame that we are not measuring the aerosol climate forcing to take advantage of this vast geophysical experiment to improve our understanding. The human-made aerosol forcing is almost as large as the CO_2 forcing, but it is of the opposite sign, i.e., aerosols cause cooling.

Aerosols cause cooling by reflecting sunlight to space, thus by itself an increase of aerosols causes a temporary energy imbalance – more energy going out than coming in. Earth restores energy balance by cooling off, thus reducing heat radiation to space.

The aerosol climate forcing is complex, as the largest part of their effect seems to be via their role as cloud condensation nuclei. Added condensation nuclei tend to make the average cloud particle smaller; that tends to make brighter, longer-lived clouds, but it's a complicated story. For the moment, let me just remind you that ships produce just a fraction of human-made aerosols. Global aerosol production is expected to decline substantially in the next several decades as we phase down fossil fuel emissions.

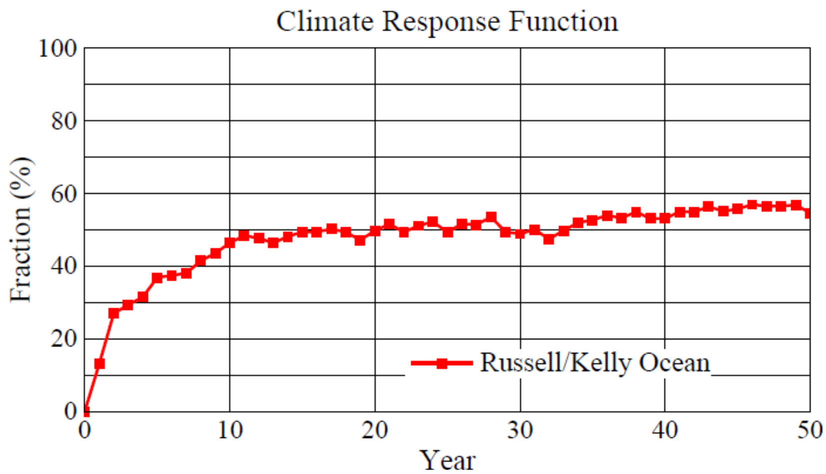

Fig. 4. Climate response function, R(t), i.e., the fraction (%) of equilibrium surface temperature response for GISS model E-R with Russell/Kelly ocean.[2]

Also, we have so far only felt a fraction of the eventual warming due to the presumed decrease of aerosols of the past several years. The climate response function of GISS model ER (Fig. 4), typical of most climate models, suggests that we have only received about a third of the warming due to the presumed reduction of ship emissions since 2015. Fortunately, a large part of the as-yet-unrealized warming is in the slow response of the climate system over decades and centuries, dubbed the recalcitrant response by Isaac Held.[3] That provides us the opportunity to avoid most of the warming – if we are only wise enough – by phasing down our present enormous geoengineering of the planet.[4]

For the moment – in the absence of adequate aerosol measurements – let's use Earth's measured energy imbalance to estimate the impact of aerosol reductions on global warming. Earth's energy imbalance is measured to a good accuracy via precise monitoring of the rising global ocean temperature because the ocean is the repository for about 90 percent of the excess energy. Von Schuckmann et al. (2020)[5] report that the average imbalance over the period 1971-2018 was 0.47 ±0.1 W/m^2, but in period 2010-2018 the imbalance was 0.87 ±0.1 W/m^2.

Additional information on the energy imbalance is provided by combining the absolute calibration provided by measuring the change in the ocean heat content with the spatial and temporal information provided by satellite-borne radiometers. The CERES (Clouds and the Earth's Radiant Energy System) instruments[6] measure outgoing radiation – both reflected sunlight and emitted terrestrial heat radiation. CERES cannot measure the tiny imbalance between the incoming and outgoing fluxes of radiation, but the stability of its sensors is sufficient to infer valuable information about the planet's energy imbalance.

Specifically, the CERES data – in addition to having temporal variation of Earth's energy imbalance consistent with the ocean data of von Schuckmann et al. – show that most of the increased imbalance since 2015 is due to an increase of absorbed solar energy, i.e., a decrease in Earth's reflectivity. That is consistent with the expectation that the largest effect of aerosols on Earth's radiation balance and climate is via their effect on clouds.

Such consistency is hardly a substitute for actual aerosol and cloud measurements. It is possible to measure from space detailed microphysical information (particle size, shape, refractive index) for aerosols and cloud particles. Extraction of full information in reflected sunlight – including opacity of the aerosol layer and aerosol single-scatter reflectivity – requires observations of a given area from a wide range of scattering angles, in several spectral bands over the solar spectrum from the near-ultraviolet to the near-infrared, and with polarization of the reflected light measured to an accuracy of the order of 0.1 percent. NASA once launched a mission with that capability, but it ended up on the floor of the Southern Ocean near Antarctica rather than in space, when satellite failed to separate from the launch vehicle. No replacement satellite was built – that's a sad story for another time.[7]

For now, we can only infer that Earth's energy imbalance – which was less than or about half a watt per square meter during 1971-2015 – has approximately doubled to about 1 W/m^2 since 2015. This increased energy imbalance is the cause of global warming acceleration. We should expect the global warming rate for the quarter of a century 2015-2040 to be about double the 0.18°C/decade rate during 1970-2015 (see Fig. 2), unless appropriate countermeasures are taken.

The Faustian payment that we noted in 1990[8] and is discussed in detail elsewhere[9] is now due. Dr. Faustus had to pay the debt himself. We have willed it to our children and grandchildren.

Fig. 5. Dr. Faustus contemplates his bargain with Mephistopheles.

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