

## Accelerated Global Warming

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In the past five years global temperature has jumped well above the trend which has been stable at about 0.18°C per decade for the past half century (see figure above). This deviation is too large to be explained by unforced climate variability.

The immediate suspect is human-made greenhouse gases and amplifying climate feedbacks, but that explanation does not work. Yes, the growth rate of the greenhouse gas (GHG) climate forcing has experienced a disturbing uptick in the past several years (Fig. 2), starkly inconsistent with global pledges to reduce emissions, creating an enormous burden for today's young people.<sup>1</sup> However, there is another variable forcing that is being measured accurately: solar irradiance.

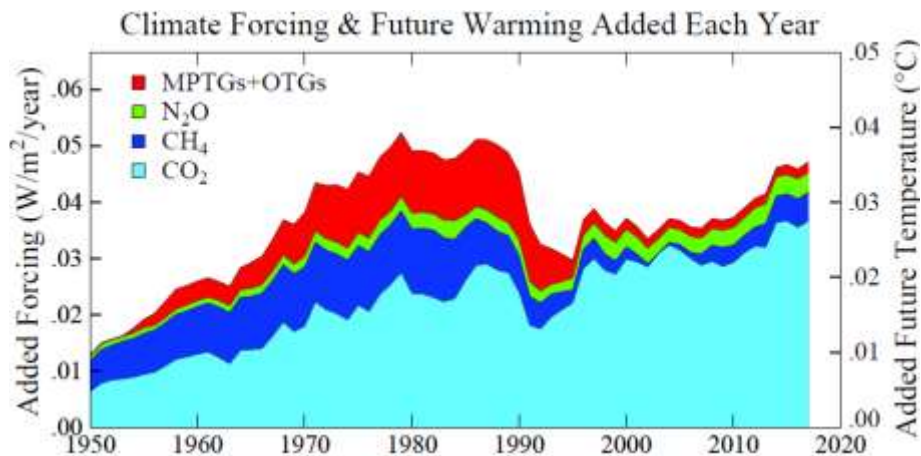
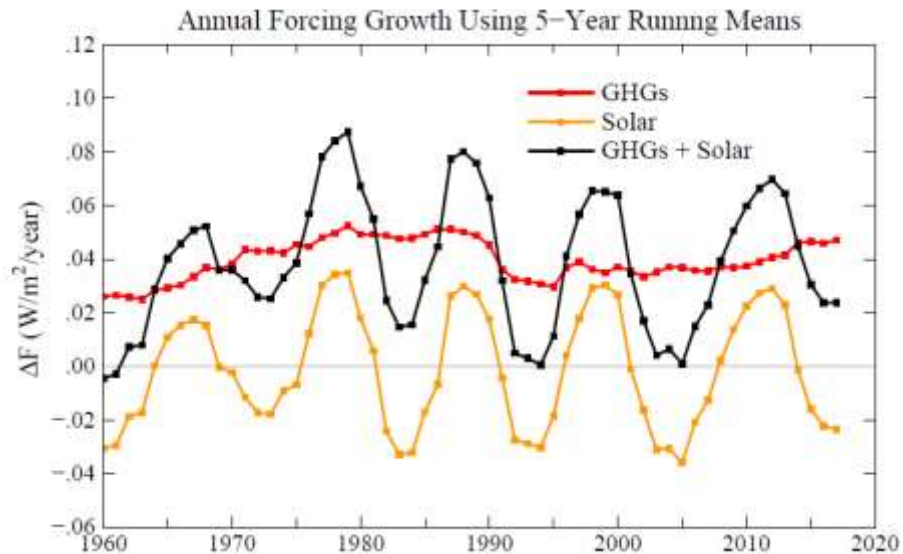


Fig. 2. Annual growth of GHG climate forcing (red area is trace gases, mainly CFCs).



**Fig. 3. Annual growth of GHG and solar climate forcings and the sum of these two.**

There is no significant trend in solar irradiance during the past half-century, but there is a solar cycle (10-13 year) with a full amplitude of about  $0.25 \text{ W/m}^2$  with annual changes within a range of about  $\pm 0.03 \text{ W/m}^2$ . This cyclical solar variability is unimportant for long-term climate change, but it is important for interpretation of the global warming acceleration that has occurred over the past five years.

When we add the two well-measured climate forcings, GHGs and solar irradiance, we get the black curve in Fig. 3 for the annual climate forcing growth. It is apparent that the measured climate forcings cannot account for an acceleration of global warming.

We will draw the conclusion that the warming acceleration must be due to the one other large climate forcing, atmospheric aerosols, which has intentionally been left unmeasured. However, first let's examine other possibilities.

First, is there another place in the climate system capable of supplying such added heat? Yes, there is one: the ocean. In that case the ocean interior would have lost heat content during the period of accelerated surface warming. Thanks to international cooperation in the Argo floats program, we are able to measure ocean heat content change, which makes up about 90% of Earth's energy imbalance. What we find is that Earth's energy imbalance **increased** from  $0.6 \text{ W/m}^2$  in 2005-2010<sup>2</sup> to  $0.87 \text{ W/m}^2$  in the past decade.<sup>3</sup> Therefore, Earth's energy imbalance provides **additional evidence** that the total climate forcing has been increasing.

Second, could the accelerated global warming be a result of a sudden jump in the magnitude of fast feedbacks? The biggest fast feedback, atmospheric water vapor amount, is a smooth function of atmospheric temperature – there is no basis for faster growth of atmospheric water vapor in the absence of an increased forcing that drives an increased rate of global warming.

The other substantial fast feedback, sea ice cover, is not quite as easily dismissed, because sea ice responds more slowly to global temperature change and is capable of sudden change as the

ocean temperature profile changes. However, Arctic sea ice shows little trend since 2007.<sup>4</sup> Antarctic sea ice decreased during the past five years, but recently it has grown back close to the prior levels. We have shown that melting ice shelves have a substantial cooling effect on the Southern Ocean.<sup>5</sup> This effect has kept Southern Hemisphere sea ice cover approximately stable, and as Antarctic melt increases the sea ice cover is likely to increase. Southern Hemisphere sea ice cover does not provide an explanation for accelerated global warming.

We conclude that the accelerated warming is caused by an increasing global climate forcing, specifically by the one large unmeasured forcing: atmospheric aerosols. This topic is discussed in detail in Chapter 33 of *Sophie's Planet*. We will make a draft available later this week and welcome any criticisms.

You can sign up for our monthly global temperature updates [here](#).

You can sign up for my other Communications [here](#).

I opened a Twitter account @DrJamesEHansen, (<https://twitter.com/drjamesehansen>), but I am focusing mainly on finishing *Sophie's Planet*.

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<sup>1</sup> Hansen, J., M. Sato, P. Kharecha, K. von Schuckmann, D.J. Beerling, J. Cao, S. Marcott, V. Masson-Delmotte, M.J. Prather, E.J. Rohling, J. Shakun, P. Smith, A. Lacis, G. Russell and R. Ruedy: [Young people's burden: requirement of negative CO2 emissions](#). *Earth Syst. Dynam.*, **8**, 577-616, 2017.

<sup>2</sup> Hansen, J., M. Sato, P. Kharecha and K. von Schuckmann: [Earth's energy imbalance and implications](#). *Atmos. Chem. Phys.*, **11**, 13421-13449, 2011.

<sup>3</sup> von Schuckmann, K., Cheng, L., Palmer, M. D., Hansen, J., Tassone, C., Aich, V., Adusumilli, S., Beltrami, H., Boyer, T., Cuesta-Valero, F. J., Desbruyères, D., Domingues, C., García-García, A., Gentile, P., Gilson, J., Gorfer, M., Haimberger, L., Ishii, M., Johnson, G. C., Killoch, R., King, B. A., Kirchengast, G., Kolodziejczyk, N., Lyman, J., Marzeion, B., Mayer, M., Monier, M., Monselesan, D. P., Purkey, S., Roemmich, D., Schweiger, A., Seneviratne, S. I., Shepherd, A., Slater, D. A., Steiner, A. K., Straneo, F., Timmermans, M.-L., and Wijffels, S. E.: Heat stored in the Earth system: where does the energy go?, *Earth Syst. Sci. Data*, 12, 2013–2041, <https://doi.org/10.5194/essd-12-2013-2020>, 2020.

<sup>4</sup> <http://www.columbia.edu/~mhs119/SeaIceArea/>

<sup>5</sup> Hansen, J., M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J. Cao, E. Rignot, I. Velicogna, B. Tormey, B. Donovan, E. Kandiano, K. von Schuckmann, P. Kharecha, A.N. Legrande, M. Bauer and K.-W. Lo: [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**, 3761-3812, 2016.