opinion

Is climate sensitive to solar variability?

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The causes of global warming—the increase of approximately 0.8±0.1 °C in the average global temperature near Earth's surface since 1900—are not as apparent as some recent scientific publications and the popular media indicate. We contend that the changes in Earth's average surface temperature are directly linked to two distinctly different aspects of the Sun's dynamics: the short-term statistical fluctuations in the Sun's irradiance and the longer-term solar cycles. This argument for directly linking the Sun's dynamics to the response of Earth's climate is based on our research and augments the interpretation of the causes of global warming presented in the United Nations 2007 Intergovernmental Panel on Climate Change (IPCC) report.[1]

The most debated issue in contemporary science is the cause or causes of global warming, with the popular media contending that the issue has been resolved and that the majority of scientists concur. The "majority opinion" is based on the analysis of global warming done using large-scale computer codes that incorporate all identified physical and chemical mechanisms into global circulation models (GCMs) in an attempt to re-create and understand the variability in Earth's average temperature. The IPCC report[1] concludes that the contribution of solar variability to global warming is negligible, to a certainty of 95%. It is reported that the "majority" believes the average warming observed since the beginning of the industrial era is due to the increase in anthropogenic greenhouse gas concentrations in the atmosphere.

Modeling TSI variability

Earth's atmosphere, landmasses, and oceans absorb and redistribute the total solar irradiance (TSI) by means of coupled nonlinear hydrothermal, geochemical, and radiative dynamic processes that produce Earth's globally averaged temperature at a given time. Versions of those physical mechanisms are included in the GCMs, but what is not addressed in the simulations are the statistics of the time series. Those series consist of the monthly values of temperature anomalies. The statistical variability in Earth's average temperature is interpreted as noise; the temperature fluctuations are thought to contain no useful information and are consequently smoothed to emphasize the presumably more important long-time changes in the average global temperature, typically on the order of years. According to the central limit theorem, the statistics of the fluctuations in such large-dimensional networks ought to be Gaussian.[2] The fact that they are not remains unexplained. The non-Gaussian behavior prompted us to study temperature fluctuations as a problem in nonequilibrium statistical physics wherein statistical fluctuations often provide useful information about the transport properties of complex phenomena. An example would be the fluctuation–dissipation theorem, in which the response of a network to a perturbation is determined by the network's unperturbed autocorrelation function.

The variations in TSI are indicative of the Sun's turbulent dynamics, as evidenced by changes in the number, duration, and intensity of solar flares and sunspots, and by the intermittency in the time intervals between dark spots and bright faculae. That time variation in TSI induces similar changes in Earth's average temperature and produces trends that move the global temperature up and down for tens or even hundreds of years. Our conclusions depart from those of the GCM simulations. We maintain that the variations in Earth's temperature are not noise, but contain substantial information about the source of variability, in particular the variations in TSI. Establishing this direct connection between the complex dynamics of the Sun and Earth requires a new kind of linking—one associated with the transfer of information between complex networks, even when the linking is extremely weak, as it is in the Sun–Earth network.

We showed that the stochastic properties of the average global temperature are linked to the statistics of TSI.[2] It is the linking of the complexity of Earth to the complexity of the Sun that forces Earth's temperature anomalies to adopt the TSI statistics. Consequently, both the fluctuations in TSI, using the solar flare time series as a surrogate, and Earth's average temperature time series are observed to have inverse power-law statistical distributions. Specifically, if t is the time between events, where an event is a solar flare or a fluctuation in Earth's temperature, the distribution of time intervals between events $P(t)$ is an inverse power law; that is, $P(t) \approx A/t^{\alpha}$, where A is a normalization constant. The inverse power-law index α turns out to be the same for both the solar flare and temperature anomaly time series, even though the cross-correlation of the two vanishes except at the lowest frequencies, where quasi-periodic solar cycles dominate the dynamics.

The scaling of the statistical distribution of the TSI time series was tested by randomly changing the order of the data points. If the time series were internally correlated, the resulting distribution would have changed from the original, but that did not happen. The invariance of the distribution under shuffling indicates that the statistics of the time series is non-Poisson and renewal—meaning that with the generation of each new event, the process is renewed. The same was determined to be true of the global temperature time series.

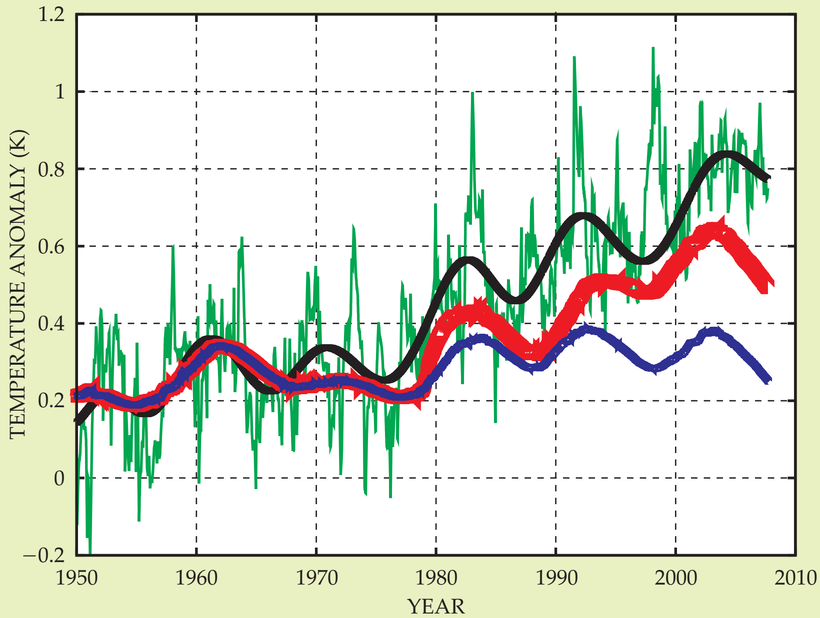
Complexity matching

The statistics of solar flares, which we used as a surrogate for the fluctuations in TSI, are described by a non-Gaussian distribution. The behavior of such limit distributions requires a generalization of the central limit theorem to the case in which the second moment of the variate diverges. Such processes were studied by Paul Lévy before World War II, and now bear his name. The solar flare statistics were shown to be describable by such a Lévy distribution and we assumed that intermittent solar flares perturb the intrinsic fluctuations in Earth's average temperature. The end result of this perturbation is that the statistics of the temperature anomalies inherit the statistical structure that was evident in the intermittency of the solar flare data.[2] The inverse power-law index α for solar flares was determined to be 2.14, whereas α for the air temperature was 2.11 globally, 2.20 for the Northern Hemisphere, 2.09 for the Southern Hemisphere, 2.21 over land, and 2.06 over the ocean. The near equivalence in indices occurs because of a newly identified phenomenon, the complexity-matching effect,[3] described below, and suggests the presence of a subtle but persistent solar signature in climate fluctuations on short time scales. Note that this climate response to complexity is separate and distinct from the response to solar cycles.

Thus, the Sun's influence on Earth's temperature is subtle because it is not just an energy transport process but also an information transfer. According to linear response theory in statistical physics, a network S responds to a perturbation P by means of a linear transfer equation, whose kernel, the response function, is determined by the fluctuation–dissipation theorem given that the perturbation is sufficiently weak. When S and P are non-Poisson renewal processes, the response of S is maximal when the complexity of the two networks, as measured by the inverse power-law indices, is matched.[3] For the Sun–Earth one-way linking, S is the Earth and P is the Sun. The complexity-matching effect in the Sun–Earth network is evident in the equality of the inverse power-law indices.

Solar cycles

Incorporating the influence of solar cycles into this thermodynamically closed climate modeling strategy reveals coordinated variability over even longer time scales. Recent heuristic studies indicate that the climate time response parameter τ, analogous to the Onsager relaxation time in statistical physics, might be 5–10 years.[4,5] By using a climate time response τ of 7.5 years and the phenomenological 0.1 °C amplitude of the 11-year solar cycle (see reference 1, page 674, for details) as constraints on a simple two-parameter model in the tradition of the earliest climate models, we recently showed that it is possible to reconstruct a phenomenological solar signature (PSS) of climate for the last four centuries.[5] In the figure, the interval from 1950 to 2010 is displayed with two such PSS reconstructions derived from two alternative TSI inputs. The figure shows excellent agreement between the 11-year PSS cycles and the cycles observed in the smoothed average global temperature data; a 22-year cycle component in the temperature also matches the 22-year PSS cycle very well. In particular, since 2002 the temperature data present a global cooling, not a warming! This cooling seems to have been induced by decreased solar activity from the 2001 maximum to the 2007 minimum as depicted in two distinct TSI reconstructions.



Global surface temperature (GST) anomaly. The green curve is the difference between the measured GST and the time average of GST between 1890 and 1910; it emphasizes the observed warming since 1900. The GST anomaly data are low-pass filtered to remove any volcanic signal and smoothed to stress the 11-year modulation (black curve). Two alternative PSS constructions[5] are shown that use a TSI proxy reconstruction until 1978 and two alternative TSI satellite composites after 1978. (Data for the red curve are from http://www.cru.uea.ac.uk and http://www.acrim.com and for the blue curve are from http://www.pmodwrc.ch.)

Thus the average global temperature record presents secular patterns of 22- and 11-year cycles and a short timescale fluctuation signature (with apparent inverse power-law statistics), both of which appear to be induced by solar dynamics. The same patterns are poorly reproduced by present-day GCMs and are dismissively interpreted as internal variability (noise) of climate. The nonequilibrium thermodynamic models we used suggest that the Sun is influencing climate significantly more than the IPCC report claims. If climate is as sensitive to solar changes as the above phenomenological findings suggest, the current anthropogenic contribution to global warming is significantly overestimated. We estimate that the Sun could account for as much as 69% of the increase in Earth's average temperature, depending on the TSI reconstruction used.[5] Furthermore, if the Sun does cool off, as some solar forecasts predict will happen over the next few decades, that cooling could stabilize Earth's climate and avoid the catastrophic consequences predicted in the IPCC report.

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