Global warming trend and multi-decadal climate variability

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Introduction

Climate evolution during the last century has shown strong evidence of multi-decadal variability. In particular, periods of increasing global-mean surface temperature [GST] (1910–1940, 1976–2005) have been punctuated by stretches of uniform or even decreasing temperature (e.g., 1940–1976) — see **Fig. 1**.

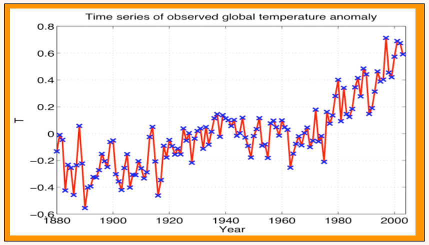

Fig. 1. Time series of global-mean atmospheric surface temperature(GST) anomaly (using Goddard Institute for Space Studies [GISS] data set): http://data.giss.nasa.gov/gistemp/.

One possible interpretation of the non-uniformity in the GST trend is that the temperature record is due to a superposition of human-induced warming and a multi-decadal climate oscillation (M. Ghil 1998 — personal communication; Marcus et al. 1999). Evidence for such intrinsic variability has been found in observations and coupled general circulation models (Schlesinger and Ramankutty 1994; Delworth and Mann 2000).

The purpose of the present study is to quantify the above hypothesis about the nature of observed global warming and estimate potential predictability of GST associated with multi-decadal signal.

Idea:

Use the concept of a *delayed-feedback oscillator* (e.g., Ghil and Childress 1987, Chapter 10) to represent "intrinsic" multi-decadal climate signal: The delay τ can be estimated by constructing smoothed time series of GST and its tendency and turns out to be approximately $\tau \approx 15$ yr (**Fig. 2**).

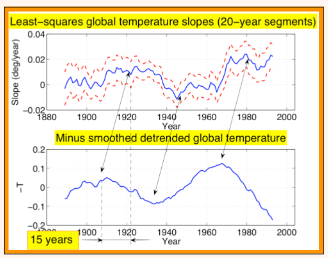

Fig. 2. Top: Least-squares slopes of GST estimated using moving 20-yr window. Bottom: corresponding estimates of the smoothed GST multiplied by –1. Note the slope (dT/dt) time series lags the $-T$ time series by about 15 yr.

Statistical model and results

$$\dot{T} = k_1 + k_2(\overline{T}(t-\tau) - k_1 t) + N \qquad (1)$$

The proposed statistical model has the form (1), and involves 3 free parameters: k_1, k_2, and τ; the latter parameter has already been estimated to be 15 yr (see **Fig. 2**). The parameters k_1 and k_2 are also estimated using data shown in **Fig. 2** by minimizing root-mean-square distance between left- and right-hand side of (1) over the total length of the available time series. The term N on the right-hand side of (1) denotes a normally distributed random variable, with zero mean and standard deviation σ, the latter being determined from the observed time series as well. The estimated values of the parameters are k_1=0.0033 °C year^{-1}, k_2= –0.226 year^{-1}, and σ=0.05 °C year^{-1}. In subsequent integrations of the statistical model, we use the time step of 1 year, so that the time derivative at a given time t is given by $T(t+1\ \text{yr})-T(t)$. The overline on the right-hand side of (1) denotes a smoothing operator; we have used, in our simulations, a simple averaging over 16-yr-long rectangular window centered at time $t-\tau$.

In **Fig. 3**, we show four different randomly chosen realizations of simulated GST time series, all simulations using the same initial conditions. Some of the simulations (e.g., the last one) closely mimic the observed time dependence (about 20% of simulations are qualitatively similar to this simulation in terms of the proximity to the observed time series). Others resemble the observed time series less. An important property of all simulations, however, is that all of them show local (i.e., relatively short-term, 20-yr) trends with a rate-of-change of temperature similar to the one actually observed during the period between 1980 and 2000.

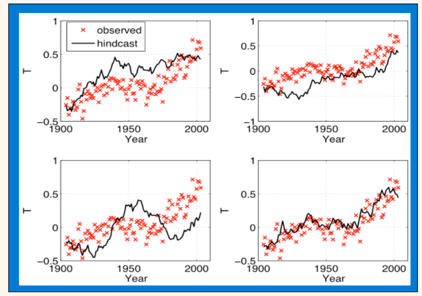

Fig. 3. Four different realizations of GST produced by statistical model (1) [black curves], along with the observed GST time series [red x-symbols]. All four simulations used the same (observed) initial conditions.

The ensemble average among the first 40% of all simulations ranked according to (small) root-mean-square distance between the observed and simulated time series is shown as a black curve superimposed onto the observed time series in **Fig. 4**. Our model does a fairly good job in capturing the observed trends; i.e., it seems to be a fairly probable representation of observations.

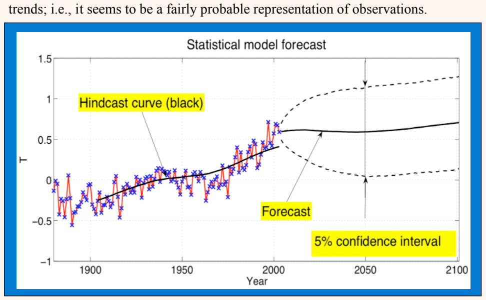

Fig. 4. Predictions of GST using statistical model (1). The "hindcast" curve was constructed, for illustration purposes, by ensemble averaging over about 4000 out of 10000 simulations, all of which started from the same initial conditions as the simulations in **Fig. 3**. These 4000 simulations were chosen based on their small root-mean-square distance from the actual time series of GST. On the other hand, the forecast curve is the ensemble average over 10000 simulations using most recent initial condition in the data set. Dashed curves show 5% confidence interval.

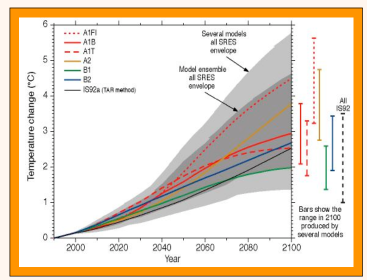

Fig. 5. Forecasts of GST evolution produced by several coupled general circulation models (GCMs). This figure is taken from the website of Intergovernmental Panel on Climate Change (IPCC): http://www.ipcc.ch/present/graphics.htm. Note that the GST at year 2100 is shown relative to that at year 1990. All of the simulations shown predict a much more substantial (order-of-magnitude larger) warming at year 2100 than that predicted by our simple statistical model.

Finally, we use our model to forecast the GST evolution during 21st century (**Fig. 4**). Note that the forecast curve shows a non-uniform trend, with decreasing temperatures during the first 50 years of simulation, and a small positive trend afterwards. The statistical model assumes, by construction, external forcings, including carbon dioxide emissions, to remain at present level, and predicts a fairly small warming by year 2100 — the one, which is an order of magnitude smaller than that predicted by coupled GCMs (**Fig. 5**).

Discussion

Rapid multi-decadal climate change, at a rate consistent with that actually observed during 1980–2005, is due, in our simple statistical model of global surface temperature (GST) evolution, to a combination of a linear trend (presumably associated with human-induced warming) and warming phases of intrinsic multi-decadal oscillation. The theory of delayed-feedback oscillators predicts that the period of the oscillation can typically be 2–3 times the delay τ or longer, depending on model parameters; our statistical analysis thus argues for the presence of intrinsic oscillation with a period of about 40–70 yr, consistent with analyses by Schlesinger and Ramankutty (1994), Marcus et al. (1999), Delworth and Mann (2000), and others.

The above interpretation and ensuing statistical analysis results in that the estimate of human-induced warming rate of $k_1 \approx 0.3$ °C per century is about twice as small as the simple linear regression estimate of the slope. More importantly, however, the recent increased warming rate is interpreted as the consequence of intrinsic dynamics of the climate system, rather than "most up-to-date" estimate of the anthropogenic climate change. The latter difference in interpretations may be one of the key reasons for enormous future warming seen in GCMs.

References

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