Global Temperature in 2011, Trends, and Prospects

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James Hansen, Reto Ruedy, Makiko Sato and Ken Lo

The annual 2011 surface air temperature anomaly relative to base period 1951-1980 is shown in Figure 1 at both the 1200 km and 250 km resolutions of the GISS analysis (Hansen et al., 2010). The global mean anomaly, averaged over the area with a defined anomaly is 0.51°C for 1200 km resolution and 0.44°C for 250 km resolution. The 1200 km resolution analysis, because it fills in estimated anomalies in Africa, Canada, Siberia, and especially in the Arctic, is believed to provide the better estimate for the full global anomaly, as discussed by Hansen et al. (2010).[1]

The global temperature anomaly from 1880 through 2011 is shown in Figure 2 for the standard (1200 km resolution data) GISS analysis.[2] The year 2011 is the 9th warmest in the GISS analysis. Nine of the ten warmest years are in the 21st century, the only exception being 1998, which was warmed by the strongest El Nino of the past century.

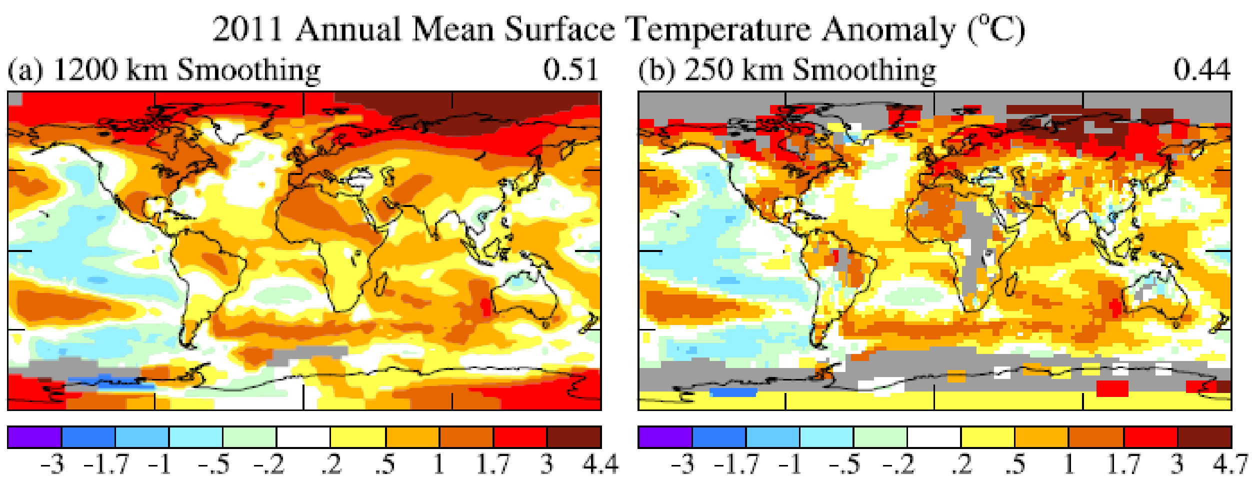

Figure 1. Surface air temperature anomaly in 2011 relative to the 1951-1980 base period at (a) 1200 km resolution, and (b) 250 km resolution.

[1] Arctic sea ice insulates the atmosphere from the ocean, allowing the atmosphere to become very cold, as much as tens of degrees below freezing. If warming yields thinner sea ice and areas of open water, these changes allow heat to escape from the ocean more readily. Thus surface air can warm substantially as the sea ice cover thins, even though the ocean (water) temperature changes little. It is the surface air temperature that is most relevant to humans and it is the surface air temperature change that is presented in most global climate model simulations. Exchange of continental and marine air masses in the Arctic implies that coastal meteorological stations should provide a better estimate of surface air temperature change than would measurements of ocean temperature. Satellite infrared observations, as discussed by Hansen et al. (2010), support our conclusion that the GISS analysis does not exaggerate Arctic temperature anomalies, indeed, the anomalies seem to be conservative.

[2] The GISS analysis employs three input data sets: GHCN (Global Historical Climatology Network) meteorological station measurements, satellite measurements of ocean surface temperature, and Antarctic research station measurements. The data illustrated by Hansen et al. (2010) used GHCN version 2 (GHCN.v2). GHCN.v3, which corrects a number of flaws in GHCN.v2, is the only GHCN record that NOAA NCDC continues to update, so the GISS analysis since November 2011, for the entire 1880-present period, has been based on GHCN.v3. Global mean temperature anomalies from the GHCN.v2 and GHCN.v3 data sets differ by at most a few hundredths of a degree Celsius, which is less than the error estimate for the global temperature anomaly.

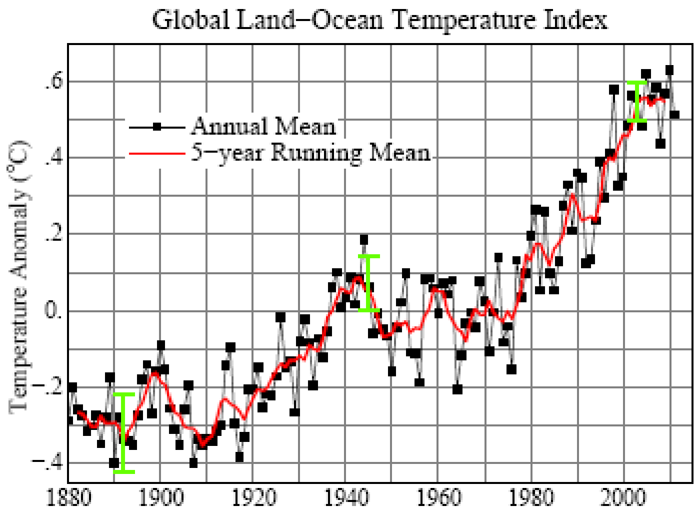

Figure 2. Global surface air temperature anomalies relative to 1951-1980 base period for annual and 5-year running means. Green vertical bars are 2σ error estimates (Hansen et al., 2010).

The two-standard-deviation uncertainty (2σ, 95% confidence interval) for comparison of global temperatures in nearby recent years is estimated to be 0.05°C (Hansen et al., 2010). The size of this uncertainty and the small temperature differences among different years (Figure 2) is one reason that alternative analyses yield different rankings for the warmest years. However, the magnitude of global temperature change of the past century is in good agreement among the GISS, NCDC (NOAA National Climatic Data Center), and HadCRUT (UK Met Office Hadley Centre and the University of East Anglia Climatic Research Unit) temperature analyses.

The 12-month running mean (Figure 3a) provides a useful alternative measure of temperature change on the annual time scale, and 60-month (5-year) and 132-month (11-year) running means (Figure 3b) reduce the variability caused by the Southern Oscillation (El Nino-La Nina cycle) and the solar cycle. The current status of these running means (Figure 3) adds some weak evidence for the frequent assertion that the rate of global warming has been less in the 21st century than in the last two decades of the 20th century. However, that impression is dependent on the end point, which is heavily influenced by the strong La Ninas in the past three years. If an El Nino occurs in the next few years, which is likely as we discuss below, the mean warming rate will probably exhibit no slowdown on the decadal time scale.

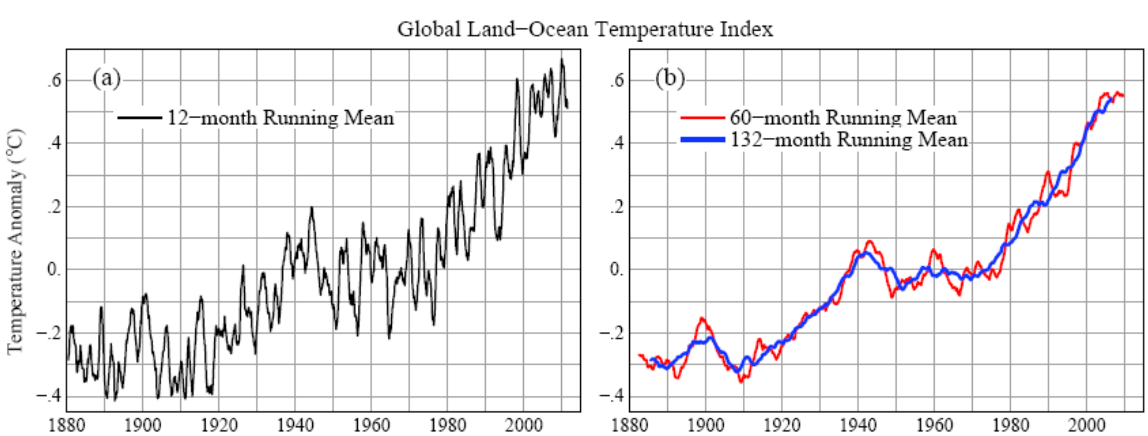

Figure 3. Global surface air temperature anomalies relative to 1951-1980 base period for (a) the 12-month running mean, and (b) the 60-month and 132-month running means.

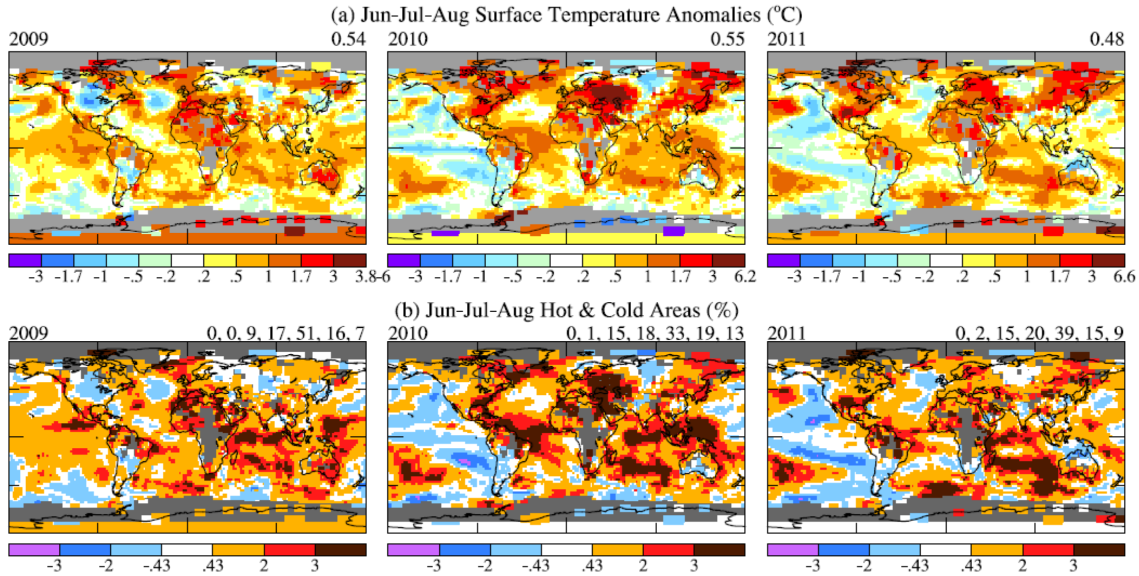

Figure 4. Jun-Jul-Aug surface temperature anomalies in 2009-2011 in units of °C (a), and in units of the local standard deviation of local seasonal-mean temperature (b).

Seasonal-Mean Temperature Anomalies

Global surface air temperature anomalies in Jun-Jul-Aug (Northern Hemisphere summer) in the past three years are shown in Figure 4a in degrees Celsius and again in Figure 4b in units of the local standard deviation. We point out elsewhere (Hansen et al., 2012) that summer, when most biological productivity occurs, is the most important season for humanity, and that global warming has led to a large increase of extreme temperature anomalies (3σ or larger).

Oklahoma-Texas-Northern Mexico in 2011 and the Moscow region in 2010 provide examples of summer heat anomalies that exceeded 3σ relative to the 1951-1980 climatology. In the 1951-1980 period of climatology the area with temperature anomaly exceeding +3σ was only a few tenths of one percent. However, the area covered by such extreme anomalies has increased with global warming. +3σ anomalies covered 7% of the area with observations in Jun-Jul-Aug 2009, 13% in 2010, and 9% in 2011 (Hansen et al., 2012). Increased occurrence of such extreme anomalies as a result of global warming, by more than a factor of 10, implies that we can attribute such recent extreme anomalies, including that in Texas and Oklahoma, to global warming.

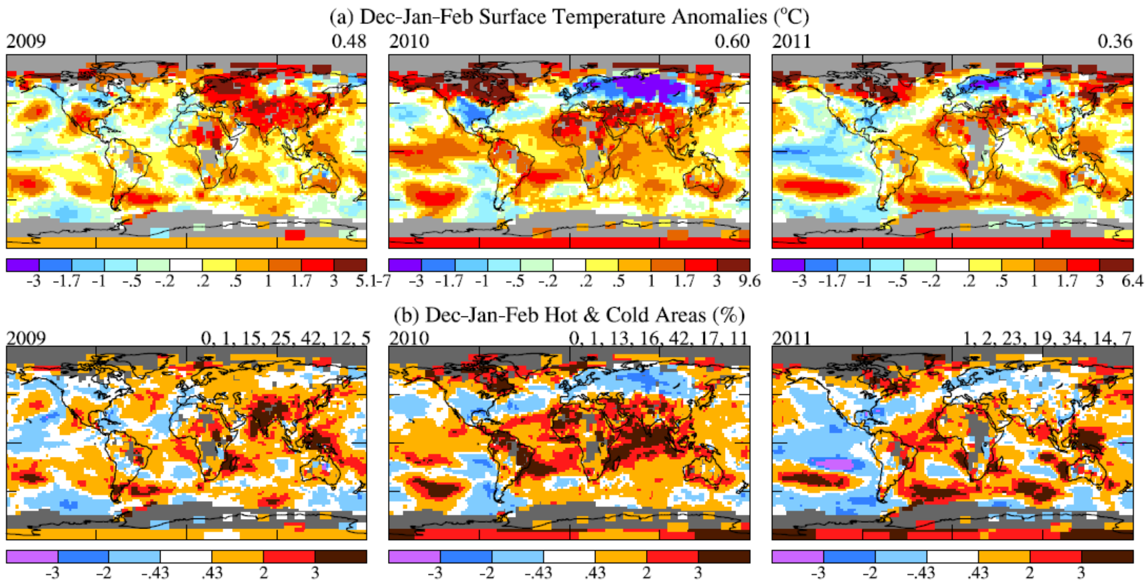

Figure 5. Dec-Jan-Feb surface temperature anomalies in the past three Northern Hemisphere winters in units of °C (a), and in units of the local standard deviation of local seasonal-mean temperature (b).

Global surface air temperature anomalies in Dec-Jan-Feb (Northern Hemisphere winter) are shown in Figure 5a for the past three years (Northern Hemisphere winters of 2008-2009, 2009-2010, 2010-2011) and again in Figure 5b in units of the local standard deviation. The unusually cold winters in the United States and Europe in the latter two years contributed to increased public skepticism about the reality of global warming.

Does the data support skepticism? Well, as Figure 5b shows, the unusually cold winter of 2010, shockingly cold to much of the public, had a negative anomaly in the United States, Europe and northern Asia that amounted to only about -1σ. There was a small area in northern Asia where the anomaly reached -2σ. So the 2010 winter was quite cold even by 1951-1980 standards, but it was a level of cold that occurred fairly often at that earlier time (1951-1980). There were no regions on the planet with a cold anomaly that reached -3σ except in 2011, where there is such an area in the tropical Pacific Ocean in the summer hemisphere. Because of the small natural variability of temperature in that ocean area, a temperature anomaly of only about 1°C is needed to produce a 3σ anomaly.

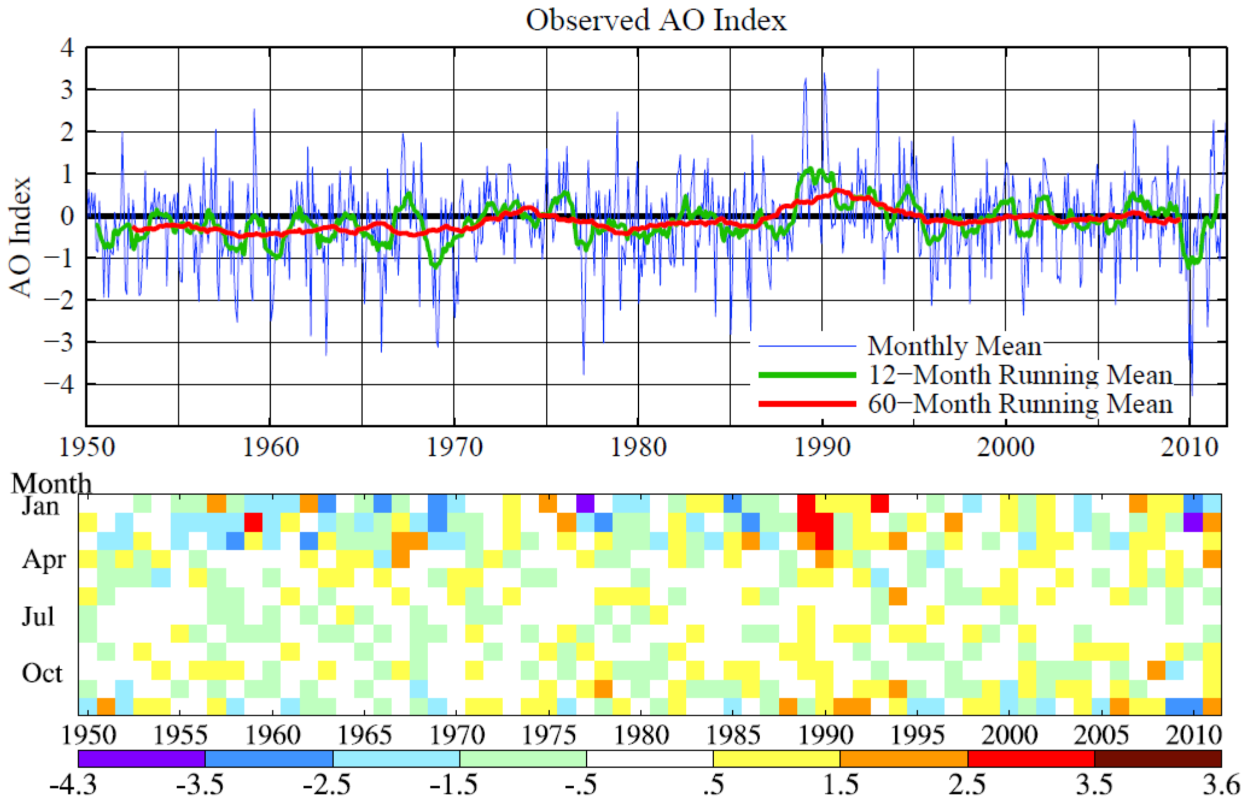

Figure 6. Arctic Oscillation (AO) index. Negative values of the AO index indicate high pressure in the polar region and thus a tendency for weak zonal winds that facilitate cold air outbreaks to middle latitudes. Blue line is the monthly mean and the red curve is the 60-month (5-year) running mean.

Variability of the Arctic Oscillation (AO) index (Figure 6) provides some insight into the significance of the prior two unusually cold winters. The AO index holds practically no predictive value, rather it is simply a convenient way of summarizing how the meteorological situation influenced the potential for movement of cold Arctic air. Unusually cold winters at middle latitudes tend to occur when surface pressure in the Arctic is high, because the weak zonal (jet stream) winds that occur along with high Arctic pressure tend to facilitate outbreaks of cold Arctic air into middle latitudes.

The most extreme negative AO index in the record (more than a century long) occurred in the 2009-2010 winter (Figure 6) and a less extreme but still strongly negative index occurred in the 2010-2011 winter. Although there has been speculation about possible effects of reduced Arctic sea ice on outbreaks of Arctic air, Figure 6 provides little support for that hypothesis. Several years had low sea ice cover in the past decade, yet most of those years were warm at middle latitude winters by 1951-1980 standards. Given the fact that winters are much "noisier" (greater natural variability) than summers, the past two unusually cool winters in the United States and Europe do not alter the expectation that middle latitude winters will tend to become warmer as global warming continues.

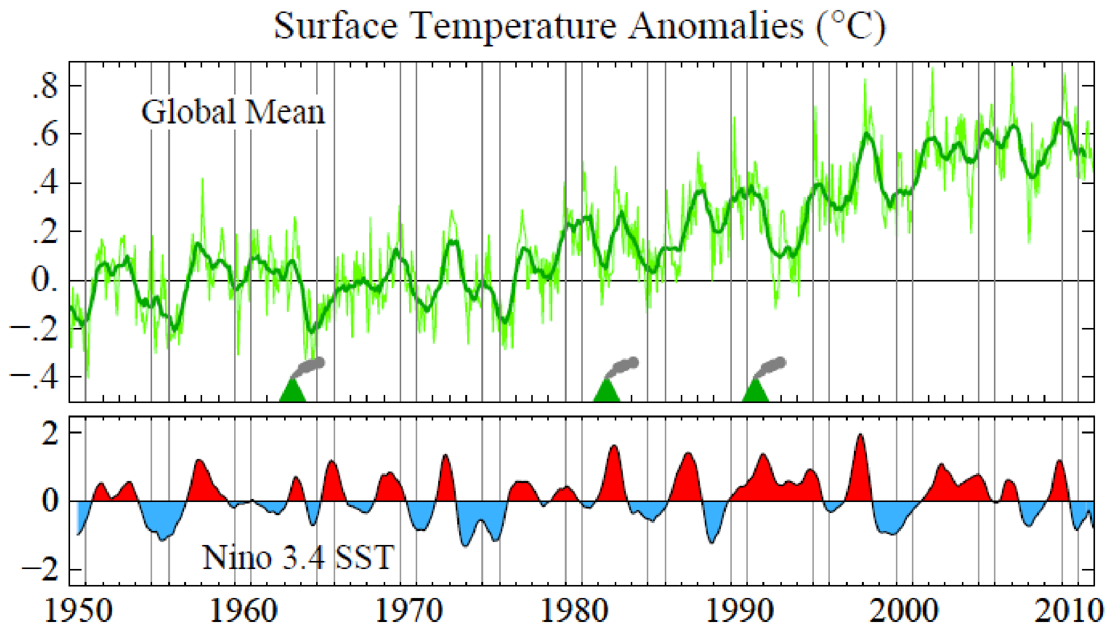

Figure 7. Global monthly and 12-month running mean surface temperature anomalies relative to 1951-1980 base period, and 12-month running mean of the Nino 3.4 index.

Has Global Warming Slowed in the Past Decade?

Figure 7 helps us examine the issue of whether global warming has "stopped" in the past decade or at least slowed down from the rate of the prior two decades. Global temperature in 2011 was lower than in 1998. However, global temperature has a strong interannual variability tied to the Southern Oscillation (El Nino-La Nina cycle), as is apparent in Figure 7.

Hansen et al. (2010) showed that the correlation of 12-month running-mean global temperature and Nino 3.4 index is maximum with global temperature lagging the Nino index by 4 months. Thus the 1997-1998 "El Nino of the century" had a timing that maximized 1998 global temperature. In contrast, the 2011 global temperature was dragged down by a strong La Nina. Indeed, the strength of the current double-bottomed La Nina, being based on ocean surface temperature relative to base period 1951-1980, is under-emphasized by the long-term trend toward higher temperature.

Thus, although the current global warming graphs (Figures 2, 3 and the upper part of Figure 7) are suggestive of a slowdown in global warming, this apparent slowdown may largely disappear as a few more years of data are added. In particular we need to see how high global temperature rises in response to the next El Nino, and we also need to consider the effect of the 10-12 year cycle of solar irradiance. This raises the question of when the next El Nino will occur and the status of the solar cycle.

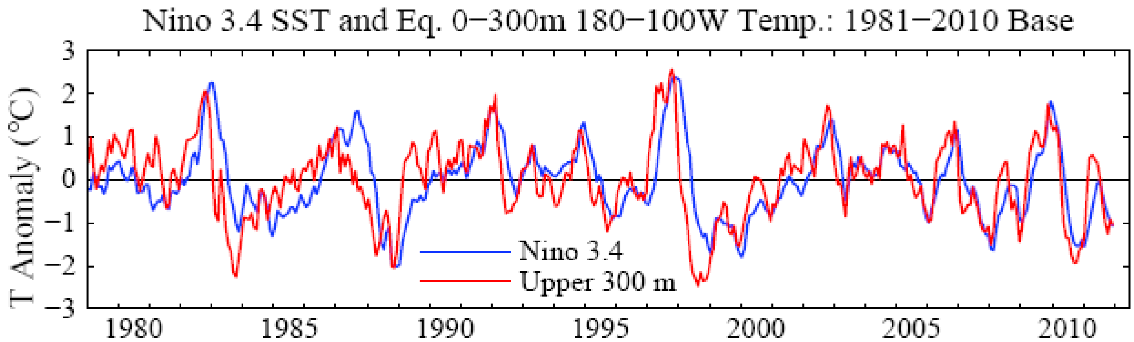

Figure 8. Monthly Nino 3.4 index and heat content of the upper 300 m in the Nino region of the equatorial Pacific Ocean. Correlation is 80% with Nino lagging heat content by two months.

El Nino Cycle

Hansen et al. (2010) argued, in anticipation of the inevitable shift from the then beginning La Nina to the next El Nino, that "The 12-month running mean global temperature in 2010 has reached a new record level for the period of instrumental data. It is likely that the 12-month mean will begin to decline in the second half of 2010. The subsequent minimum in the 12-month running mean is likely to be in 2011-2012 and not as deep as the 2008 minimum. The next maximum, likely to be in 2012-2014, will probably bring a new record global temperature, because of the underlying warming trend."

The heat content of the upper 300 m of the equatorial Pacific Ocean (Figure 8) is useful data for anticipating the next El Nino, because it precedes the Nino index by two months, which in turn precedes global temperature by four months. The data in Figure 8, and data for the entire past century, also indicate that the El Nino cycle, although notoriously variable, seldom goes straight from a deep La Nina into a strong El Nino. More commonly there is a build up over a few years. Thus, although the ocean heat content increased in the first half of 2011, reaching a positive anomaly level in mid-2011, it then fell back into La Nina conditions. This current La Nina is not as deep as the one a year earlier and upper ocean heat content as of January 2012 has begun increasing again.

Thus there is a good chance of moving into El Nino conditions in the latter half of 2012, and in any case within the next 2-3 years. Because of the 6 month lag between tropical ocean heat content and global temperature, and the relatively cool state of global climate at the beginning of 2012, the next maximum global temperature is more likely to be in 2013 or 2014, rather than 2012.

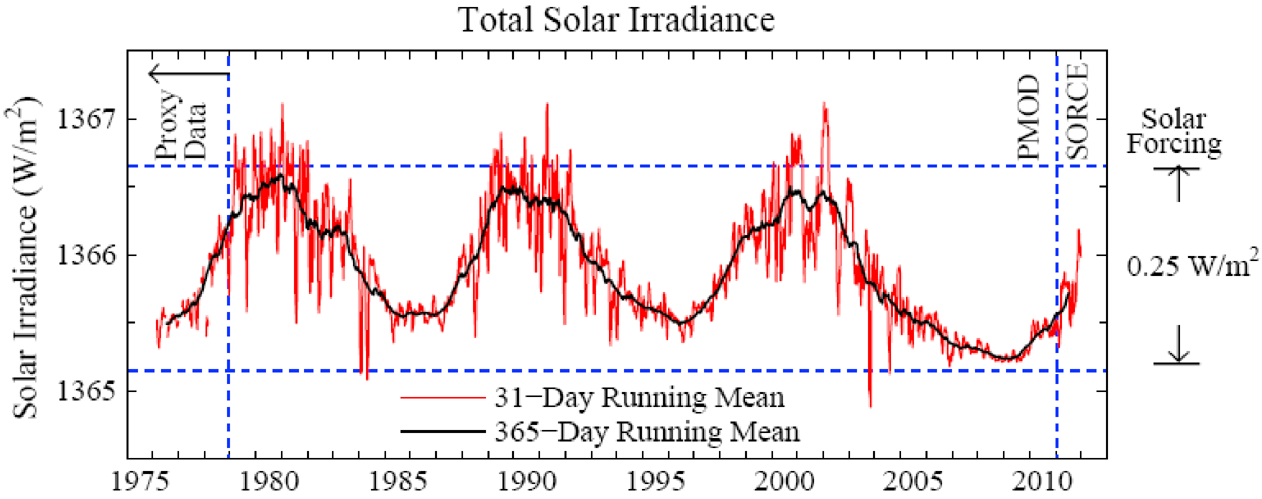

Figure 9. Solar irradiance from composite satellite-based time series. Data sources: For 1976/01/05 to 2011/02/02 Physikalisch Meteorologisches Observatorium Davos, World Radiation Center and for 2011/02/03 to 2012/01/11 University of Colorado Solar Radiation & Climate Experiment. Data are concatenated using the 2010/02/03 to 2011/02/02 period.

Solar Cycle

Figure 9 reveals that solar irradiance is beginning to emerge from a protracted minimum, at least two years longer than prior minima of the satellite era, making the sun a significant source for cooling during the past several years. The magnitude of the solar forcing, which varies about 0.25 W/m^2 from solar minimum to solar maximum, is much smaller than the forcing by human-made greenhouse gases. However, the most relevant comparison of the solar forcing is with Earth's energy imbalance, 0.58 ± 0.15 W/m^2 (Hansen et al., 2011), because the combined effect of all forcings is less than that of greenhouse gases alone, and much of the greenhouse gas forcing has been "used up" in causing the warming of the past century. It is apparent that the solar forcing is not negligible in comparison with the net climate forcing.

Because of the ocean's thermal inertia, global temperature change caused by solar variability lags solar irradiance by about 18 months. Thus the influence of the sun in 2011 continued to be a cooling effect. However, the sun's influence will change rapidly to a warming effect over the next 3-5 years.

Other Climate Forcings

Human-made atmospheric aerosols (fine particles in the air) are a wild card. The aerosol forcing relative to pre-industrial conditions is about half the magnitude of the greenhouse gas forcing (Hansen et al. , 2011), but opposite in sign. However, for all practical purposes we are ignorant of how the aerosol forcing is changing, because the first satellite mission able to make aerosol measurements with the needed accuracy (Mishchenko et al., 2007) suffered a launch failure.

The largest single source of aerosols is believed to be sulfur in coal burning, which has probably increased in China and developing countries during the past decade. The short-term effect of increased coal use is thus one of cooling, but the long-term effect is warming as the long life of atmospheric CO_2 overtakes the cooling effect of short-lived aerosols. It seems untenable that the aerosol forcing remains practically unmeasured, but as long as that is the case it will be difficult to project how the net climate forcing will change in the future.

Summary

2011 was only the ninth warmest year in the GISS analysis of global temperature change, yet nine of the ten warmest years in the instrumental record (since 1880) have occurred in the 21st century. The past year has been cooled by a moderately strong La Nina. The 5-year (60-month) running mean global temperature hints at a slowdown in the global warming rate during the past few years. However, the cool La Nina phase of the cyclically variable Southern Oscillation of tropical temperatures has been dominant in the past three years, and the deepest solar minimum in the period of satellite data occurred over the past half dozen years. We conclude that the slowdown of warming is likely to prove illusory, with more rapid warming appearing over the next few years.

Reference

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Contacts

Please address media inquiries regarding the GISS surface temperature analysis to Ms. Leslie McCarthy by e-mail at Leslie.M.McCarthy@nasa.gov or by phone at 212-678-5507.

Scientific inquiries about the analysis may be directed to James.E.Hansen@nasa.gov