If It's That Warm, How Come It's So Darned Cold?

An Essay on Regional Cold Anomalies within Near-Record Global Temperature

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Overview. Public skepticism about global warming was reinforced by the extreme cold of December 2009 in the contiguous 48 United States and in much of Eurasia. The summer of 2009 was also unusually cool in the United States. But when a cold spell hits, we need to ask:

* Cold compared to what. Our memory of the past few winters? Winters of our childhood? Winters earlier in the 20th century?

* Cold where and for how long? Regional cold snaps are expected even with large global warming. Weather fluctuations can be 10, 20 or 30 degrees, much larger than average global warming.

* The reality of seasons. As the plot of Earth we live on turns away from the sun, in winter or at night, it cools off. That's true even with global warming, albeit not quite so much.

Before addressing these matters, we note that scientists reporting global warming have come under attack for a supposed conspiracy to manufacture evidence of global warming. Perhaps because some members of the public accept these charges as reality, vicious personal messages are sent to the principal scientists almost daily.

The spiral into an almost surrealistic situation with ad hominem attacks on scientists may have originated in part with vested interests who do not want society to address climate change. But there is more than that – including honest, wishful thinking that climate change is not really happening. But wishing does not alter facts.

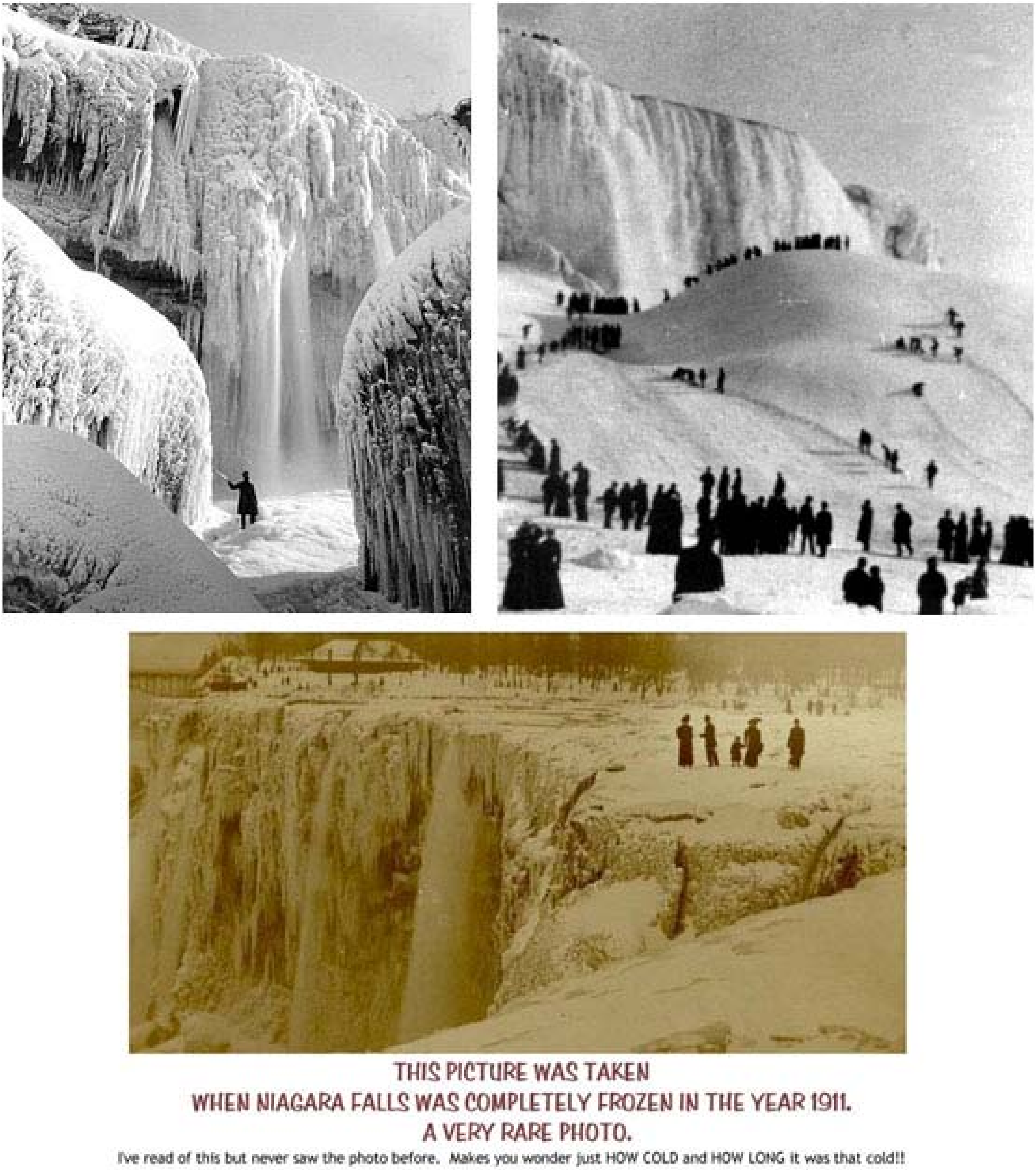
The scientific method practically defines integrity. [Albert Einstein: "The right to search for truth implies also a duty; one must not conceal any part of what one has recognized to be true." Richard Feynman: "The first principle is that you must not fool yourself – and you are the easiest person to fool."] All scientists make honest mistakes, but the scientific method is designed to correct them. The skeptical nature of the scientific method causes conclusions to be reexamined as new data appears. Cases of deliberate fudging of data, of scientific fraud, are so rare that these infrequent episodes live in infamy for decades and even centuries.

We know of no cases of fraud in analyses of global temperature measurements. Despite unfounded accusations, we believe that our best approach is simply to continue to report our scientific results as clearly as possible. Most of the public continue to respect scientists for what they do and how they do it. We presume that most of the public can separate science from political commentary.

Our data show that 2009 was tied for the second warmest year in the 130 years of near-global instrumental measurements – and the Southern Hemisphere had its warmest year in that entire period. Before discussing these data, and their reconciliation with regional cold anomalies, we must consider the time frame of comparison.

If we look back a century, we find cold anomalies that dwarf current ones. Figure 1 shows photos of people walking on Niagara Falls in 1911. Such an extreme cold snap is unimaginable today. About a decade earlier, in February 1899, temperature fell to -2°F in Tallahassee, Florida, -9°F in Atlanta, Georgia -30°F in Erasmus, Tennessee, -47°F in Camp Clark, Nebraska, and -61°F in Fort Logan, Montana. The Mississippi River froze all the way to New Orleans, discharging ice into the Gulf of Mexico.

As we will show, climate is changing, especially during the past 30 years. The changes are perceptible, even though average temperature change is smaller than weather fluctuations. The answer to the simple question: "How come it's so damned cold" turns out to be simple: "Because it's winter."



THIS PICTURE WAS TAKEN
WHEN NIAGARA FALLS WAS COMPLETELY FROZEN IN THE YEAR 1911.
A VERY RARE PHOTO.

I've read of this but never saw the photo before. Makes you wonder just HOW COLD and HOW LONG it was that cold!!

Figure 1. Photographs of Niagara Falls in 1911.

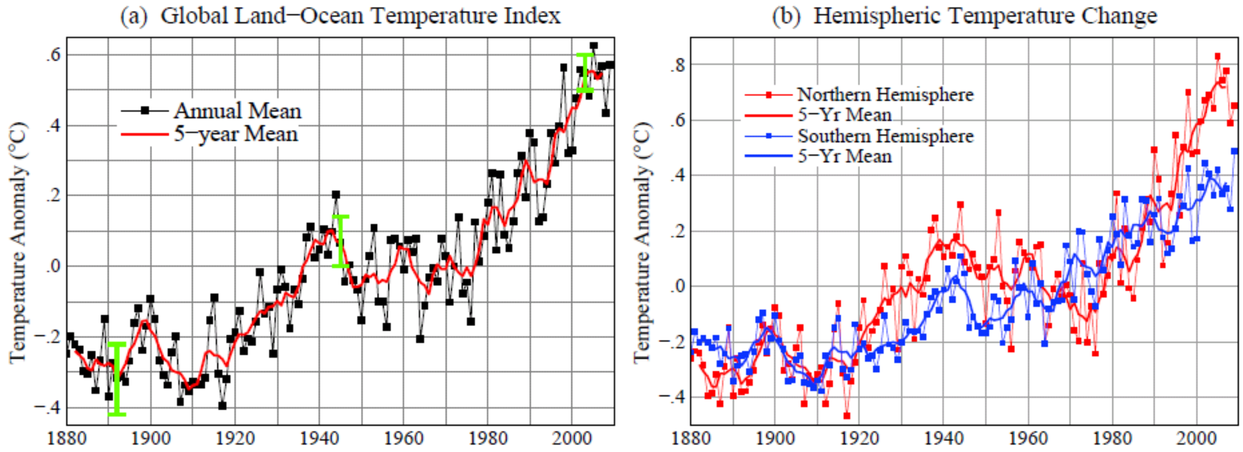


Figure 2. GISS analysis of (a) global and (b) hemispheric surface temperature change (°C). Green vertical bar is estimated 95 percent confidence range (two standard deviations) for annual global temperature change. (Base period is 1951-1980, as in all GISS temperature analysis papers. Base period 1961-1990 is used for comparison with HadCRUT analyses in Figures 4 and 5.)

GISS Global Temperature Analysis

Background. Global temperature change can be defined more accurately than global temperature. The reason is simple: temperature varies strongly from one place to another, depending on surface properties, the slope of the ground, etc. Temperature change is a smoother field, so it can be defined with measurements at a smaller number of locations.

Temperature change is defined relative to some base period. The NASA Goddard Institute for Space Studies (GISS) analysis uses 1951-1980 as the base period. This was the base period being used to define "climatology", average weather, in the 1980s when GISS scientists began making climate simulations for comparison with observations. It seems best to keep this base period fixed, because it has been used in many publications. Also many of today's adults grew up during 1951-1980, so it provides an appropriate period for analysis of how climate has changed in human lifetimes. Finally, extensive Antarctic measurements did not begin until the 1950s, so use of an earlier base period would produce a large gap in the Southern Hemisphere.

The GISS temperature analysis is updated each month upon electronic receipt of data from three sources: (1) weather data for several thousand meteorological stations, (2) satellite observations of sea surface temperature, and (3) Antarctic research station measurements. These three data sets are the input for a program that produces a global map of temperature anomalies relative to the mean for that month during the period of climatology, 1951-1980.

The analysis method has been described fully in a series of refereed papers (Hansen et al., 1987, 1999, 2001, 2006). Successive papers updated the data and in some cases made minor improvements to the analysis. A central concept of the analysis is that temperature anomalies present a smoother geographical field than temperature itself. The distance over which temperature anomalies are highly correlated is of the order of 1000 kilometers at middle and high latitudes, as we illustrated in our 1987 paper. Correlation distances, for monthly temperature anomalies, are shorter at low latitudes, because of the scales of atmospheric dynamics – but sampling studies show that the coverage of low latitude measurements is not a major factor affecting accuracy of long-term global temperature trends.

Although the three input data streams that we use are publicly available from the organizations that produce them, we began preserving the complete input data sets each

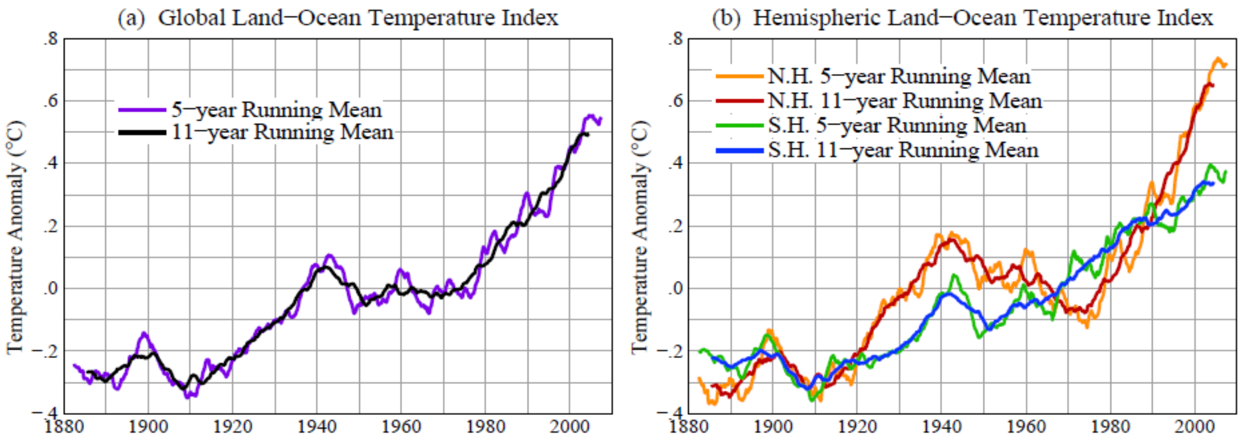


Figure 3. 60-month (5-year) and 132 month (11-year) running mean temperatures in the GISS analysis of (a) global and (b) hemispheric surface temperature change (°C). (Base period is 1951-1980.)

month in April 2008. These data sets, which cover the full period of our analysis, 1880-present, are available to parties interested in performing their own analysis or checking our analysis.

The computer program used in our analysis can be downloaded from the GISS web site.

Results. The past year, 2009, tied as the second warmest year in the 130 years of global instrumental temperature records (Figure 2a), in the GISS surface temperature analysis. The Southern Hemisphere set a record as the warmest year for that half of the world (Figure 2b).

Global mean temperature was 0.57°C (1.0°F) warmer than the climatologic average (the mean for the 1951-1980 base period). Southern Hemisphere mean temperature was 0.49°C (0.88°F) warmer than the mean for the base period.

The global record warm year was 2005, for the period with near-global instrumental measurements (since the late 1800s). Sometimes it is asserted that 1998 was the warmest year. The origin of this confusion is discussed below.

There is a high degree of interannual (year-to-year) and decadal variability in both global and hemispheric temperatures. Underlying this variability, however, is a long-term warming trend that has become strong and persistent over the past three decades.

The long-term trends are more apparent when temperature is averaged over several years. The 60-month (5-year) and 132 month (11-year) running mean temperatures are shown in Figure 3 for the globe and the hemispheres. The 5-year mean is sufficient to reduce the effect of the El Nino – La Nina cycles of tropical climate. The 11-year mean minimizes the effect of solar variability – the brightness of the sun varies by a measurable amount over the sunspot cycle, which is typically of 10-12 year duration.

There is a contradiction between the observed continued warming trend and popular perceptions about climate trends. Frequent statements include: “There has been global cooling over the past decade.” “Global warming stopped in 1998.” “1998 is the warmest year in the record.” Such statements have been repeated so often that most of the public seems to accept them as being true. However, based on our data, such statements are not correct.

The origin of this contradiction probably lies in part in differences between the GISS and HadCRUT temperature analyses (HadCRUT is the joint Hadley Centre, University of East Anglia Climatic Research Unit temperature analysis). Indeed, HadCRUT finds 1998 to be the warmest year in their record. In addition, popular belief that the world is cooling is reinforced by cold weather anomalies in the United States in the summer of 2009 and cold anomalies in much of the Northern Hemisphere in December 2009.

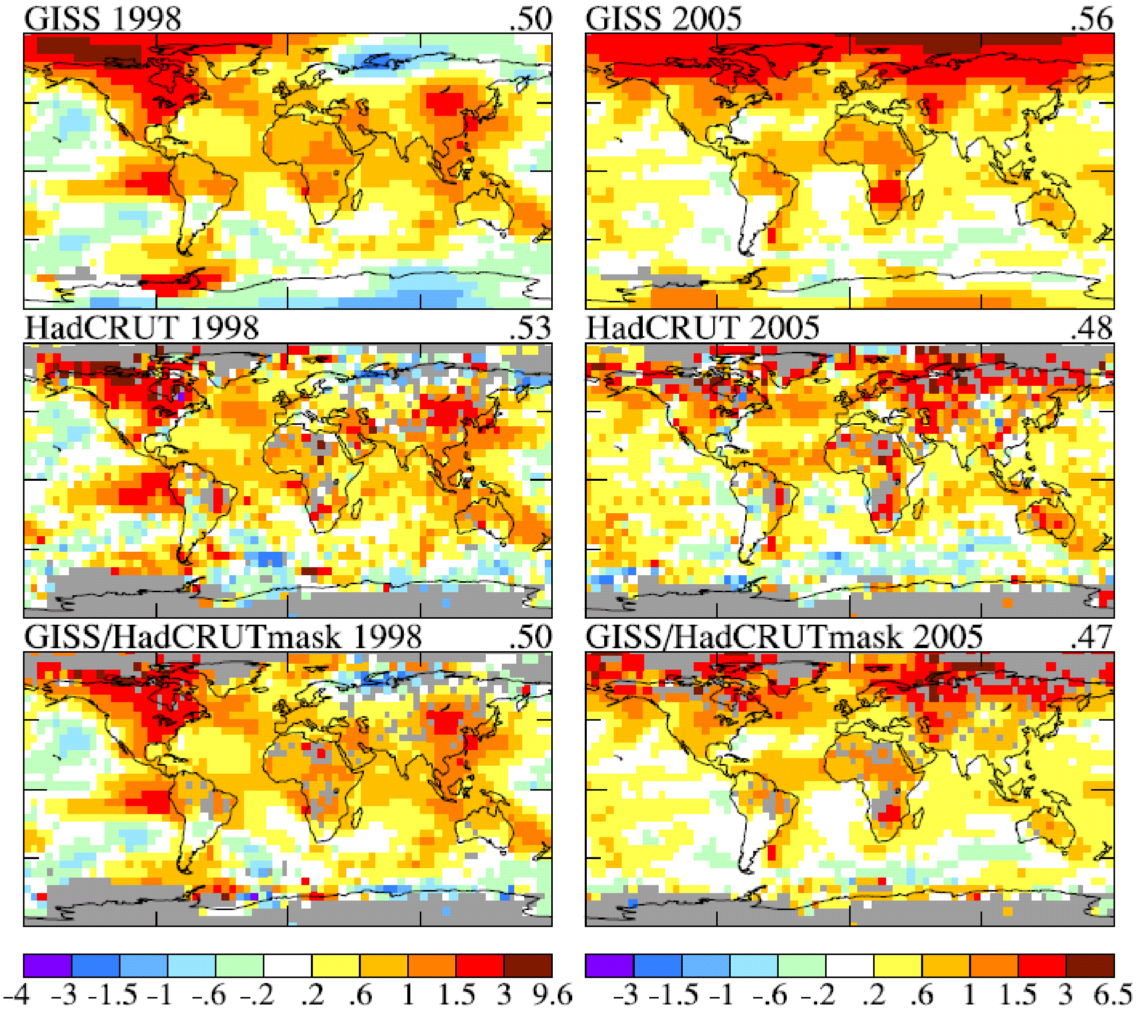


Figure 4. Temperature anomalies (°C) in 1988 (left) and 2005 (right). Top row is GISS analysis, middle row HadCRUT analysis, and bottom row the GISS analysis masked to the same area and spatial resolution as the HadCRUT analysis. Areas with missing data are gray. [Base period is 1961-1990.]

Comparison of GISS and HadCRUT results. Figure 4 shows maps of GISS and HadCRUT 1998 and 2005 temperature anomalies relative to base period 1961-1990 (the base period used by HadCRUT). The temperature anomalies are at a 5 degree-by-5 degree (latitude-longitude) resolution for the GISS data to match that in the HadCRUT analysis. In the lower two maps we display the GISS data masked to the same area and resolution as the HadCRUT analysis.

The "masked" GISS data let us quantify the extent to which the difference between the GISS and HadCRUT analyses is due to the data interpolation and extrapolation that occurs in the GISS analysis. The GISS analysis assigns a temperature anomaly to many gridboxes that do not contain measurement data, specifically all gridboxes located within 1200 km of one or more stations that do have defined temperature anomalies.

The rationale for this aspect of the GISS analysis is based on the fact that temperature anomaly patterns tend to be large scale. For example, if it is an unusually cold winter in New York, it is probably unusually cold in Philadelphia too. This fact suggests that it may be better to assign a temperature anomaly based on the nearest stations for a gridbox that contains no observing stations, rather than excluding that gridbox from the global analysis. Tests of this assumption are described in our papers referenced below.

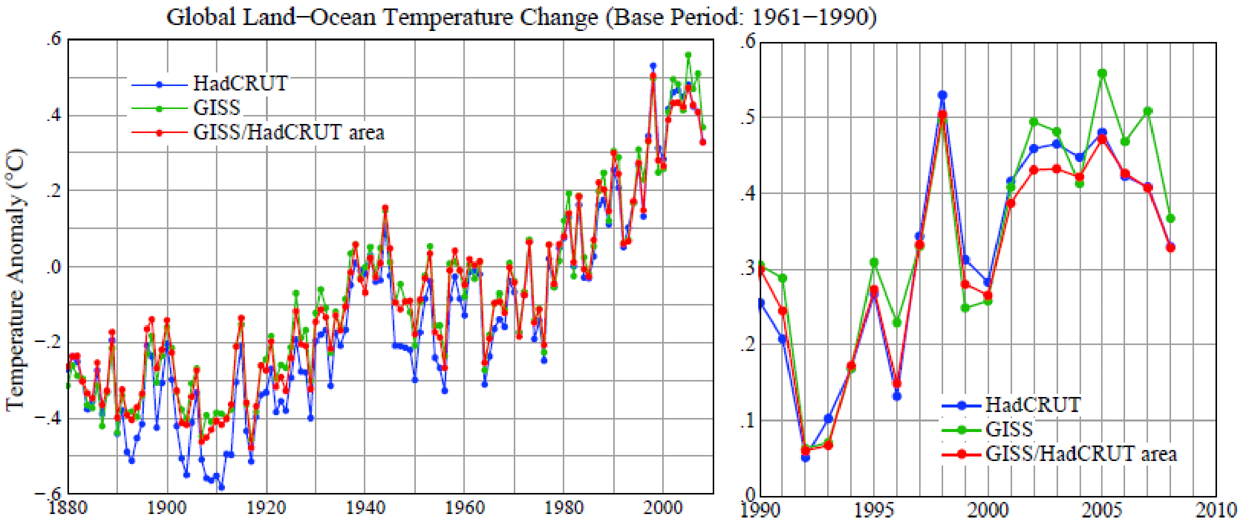


Figure 5. Global surface temperature anomalies (°C) relative to 1961-1990 base period for three cases: HadCRUT, GISS, and GISS anomalies limited to the HadCRUT area. [To obtain consistent time series for the HadCRUT and GISS global means, monthly results were averaged over regions with defined temperature anomalies within four latitude zones (90N-25N, 25N-Equator, Equator-25S, 25S-90S); the global average then weights these zones by the true area of the full zones, and the annual means are based on those monthly global means.]

Figure 5 shows time series of global temperature for the GISS and HadCRUT analyses, as well as for the GISS analysis masked to the HadCRUT data region. This figure reveals that the differences that have developed between the GISS and HadCRUT global temperatures during the past few decades are due primarily to the extension of the GISS analysis into regions that are excluded from the HadCRUT analysis. The GISS and HadCRUT results are similar during this period, when the analyses are limited to exactly the same area. The GISS analysis also finds 1998 as the warmest year, if analysis is limited to the masked area.

The question then becomes: how valid are the extrapolations and interpolations in the GISS analysis? If the temperature anomaly scale is adjusted such that the global mean anomaly is zero, the regions warmer and cooler than average have realistic-looking meteorological patterns, providing qualitative support for the data extensions. However, we would like a quantitative measure of the uncertainty in our estimate of the global temperature anomaly caused by the fact that the spatial distribution of measurements is incomplete. One way to estimate that uncertainty, or possible error, can be obtained via use of the complete time series of global surface temperature data generated by a global climate model that has been demonstrated to have realistic spatial and temporal variability of surface temperature. We can sample this data set at only the locations where measurement stations exist, use this sub-sample of data to estimate global temperature change with the GISS analysis method, and compare the result with the "perfect" knowledge of global temperature provided by the data at all gridpoints.

Table 1. Two-sigma error estimate versus period for meteorological stations and land-0cean index.

	1880-1900	1900-1950	1960-2008
Meteorological Stations	0.2	0.15	0.08
Land-Ocean Index	0.08	0.05	0.05

Table 1 shows the derived error due to incomplete coverage of stations. As expected, the error was larger at early dates when station coverage was poorer. Also the error is much larger when data are available only from meteorological stations, without ship or satellite measurements for ocean areas. In recent decades the 2-sigma uncertainty (95 percent confidence of being within that range, ~2-3 percent chance of being outside that range in a specific direction) has been about 0.05°C. The incomplete coverage of stations is the primary cause of uncertainty in comparing nearby years, for which the effect of more systematic errors such as urban warming is small.

Additional sources of error become important when comparing temperature anomalies separated by longer periods. The most well-known source of long-term error is "urban warming", human-made local warming caused by energy use and alterations of the natural environment. Various other errors affecting the estimates of long-term temperature change are described comprehensively in a large number of papers by Tom Karl and his associates at the NOAA National Climate Data Center. The GISS temperature analysis corrects for urban effects by adjusting the long-term trends of urban stations to be consistent with the trends at nearby rural stations, with urban locations identified either by population or satellite-observed night lights. In a paper in preparation we demonstrate that the population and night light approaches yield similar results on global average. The additional error caused by factors other than incomplete spatial coverage is estimated to be of the order of 0.1°C on time scales of several decades to a century, this estimate necessarily being partly subjective. The estimated total uncertainty in global mean temperature anomaly with land and ocean data included thus is similar to the error estimate in the first line of Table 1, i.e., the error due to limited spatial coverage when only meteorological stations are included.

Now let's consider whether we can specify a rank among the recent global annual temperatures, i.e., which year is warmest, second warmest, etc. Figure 2a shows 2009 as the second warmest year, but it is so close to 1998, 2002, 2003, 2006, and 2007 that we must declare these years as being in a virtual tie as the second warmest year. The maximum difference among these in the GISS analysis is ~0.03°C (2009 being the warmest among those years and 2006 the coolest). This range is approximately equal to our 1-sigma uncertainty of ~0.025°C, which is the reason for stating that these five years are tied for second warmest.

The year 2005 is 0.061°C warmer than 1998 in our analysis. So how certain are we that 2005 was warmer than 1998? Given the standard deviation of ~0.025°C for the estimated error, we can estimate the probability that 1998 was warmer than 2005 as follows. The chance that 1998 is 0.025°C warmer than our estimated value is about (1 – 0.68)/2 = 0.16. The chance that 2005 is 0.025°C cooler than our estimate is also 0.16. The probability of both of these is ~0.03 (3 percent). Integrating over the tail of the distribution and accounting for the 2005-1998 temperature difference being 0.061°C alters the estimate in opposite directions. For the moment let us just say that the chance that 1998 is warmer than 2005, given our temperature analysis, is no more than about 10 percent. Therefore, we can say with a reasonable degree of confidence that 2005 is the warmest year in the period of instrumental data.

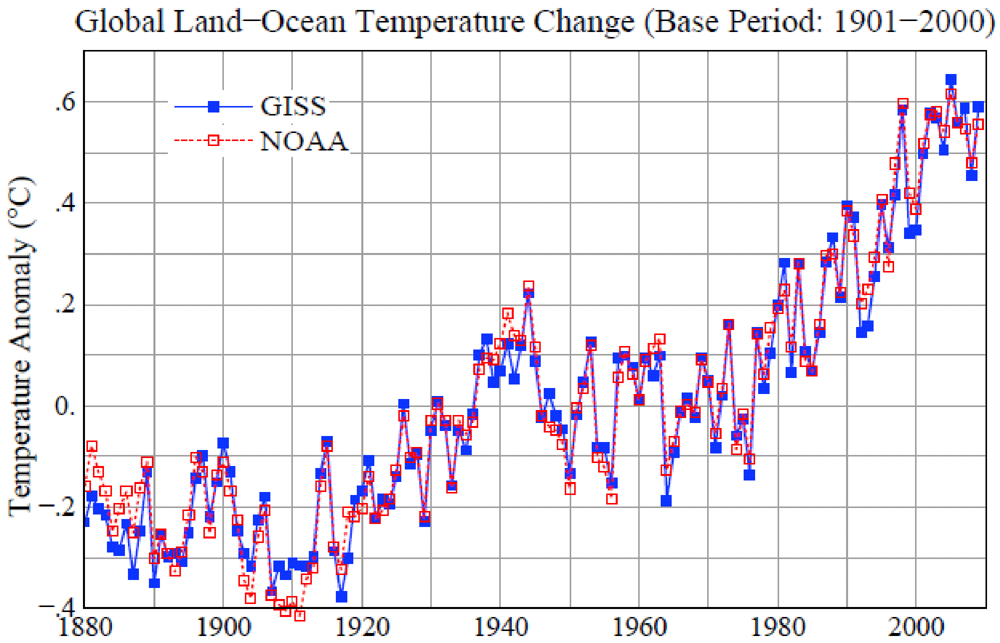


Figure 6. Global surface temperature anomalies in GISS and NOAA analyses. [Base period: 1901-2000]

Comparison of GISS and NOAA global temperature change. NOAA recently announced http://www.ncdc.noaa.gov/sotc/?report=global that 2009 was the fifth warmest year in their analysis. At face value this result may seem to disagree with the GISS conclusion that 2009 tied with several other years for the second warmest year. So we compare the GISS and NOAA results in Figure 6, in which, following the NOAA convention, we have defined the baseline as the mean temperature for the past century, 1901-2000.

Figure 6 reveals that the NOAA and GISS analyses are in good agreement, within the estimated uncertainties. Both analyses find 2005 to be the warmest year. The discrepancy in ranking of individual years is due in part to the GISS preference to describe as statistical ties those years with global temperatures differing by a few hundredths of a degree or less. Although quantitative analysis of the reasons for differences between these two analyses may be warranted, it is beyond the scope of this essay.

Global cooling in the past decade? That question can be addressed with a much higher degree of confidence than the ranking of individual years. The reason is that error due to incomplete spatial coverage of data becomes smaller for data averaged over several years. The 2-sigma error in the 5-year running-mean temperature anomaly shown in Figure 3, is about a factor of two smaller than the annual mean uncertainty, thus only 0.02-0.03°C. Given that the change of 5-year-mean global temperature anomaly is almost 0.2°C over the past decade, we can conclude that the world has become warmer over the past decade, not cooler.

Why are some people so readily convinced of a false conclusion, that the world is really experiencing a cooling trend? That misimpression may have a lot to do with regional short-term temperature fluctuations, which are an order of magnitude larger than global average annual anomalies. Yet many lay people do understand the distinction between regional short-term anomalies and global trends. For example, here is comment posted by "frogbandit" at 8:38 p.m. 1/6/2010 on City Bright blog (http://blog.seattlepi.com/robertbrown/archives/190211.asp):

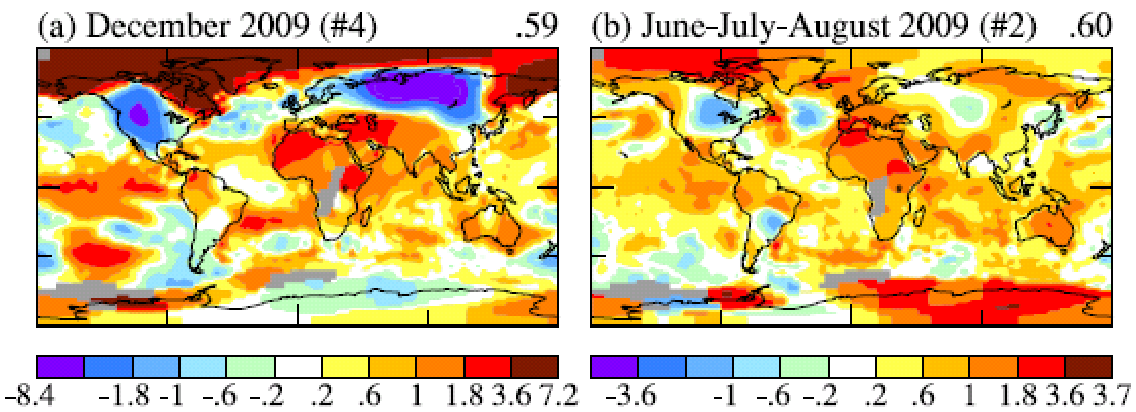


Figure 7. (a) global map of December 2009 anomaly, (b) global map of Jun-Jul-Aug 2009 anomaly (°C). #4 and #2 indicate that December 2009 and JJA are the 4th and 2nd warmest globally for those periods.

"I wonder about the people who use cold weather to say that the globe is cooling. It forgets that global warming has a global component and that its a trend, not an everyday thing. I hear people down in the lower 48 say its really cold this winter. That ain't true so far up here in Alaska. Bethel, Alaska, had a brown Christmas. Here in Anchorage, the temperature today is 31. I can't say based on the fact Anchorage and Bethel are warm so far this winter that we have global warming. That would be a really dumb argument to think my weather pattern is being experienced even in the rest of the United States, much less globally."

What frogbandit is saying is illustrated by the global map of temperature anomalies in December 2009 (Figure 7a). There were strong negative temperature anomalies at middle latitudes in the Northern Hemisphere, as great as -8°C in Siberia, averaged over the month. But the temperature anomaly in the Arctic was as great as +7°C. The cold December perhaps reaffirmed an impression gained by Americans from the unusually cool 2009 summer. There was a large region in the United States and Canada in June-July-August with a negative temperature anomaly greater than 1°C, the largest negative anomaly on the planet.

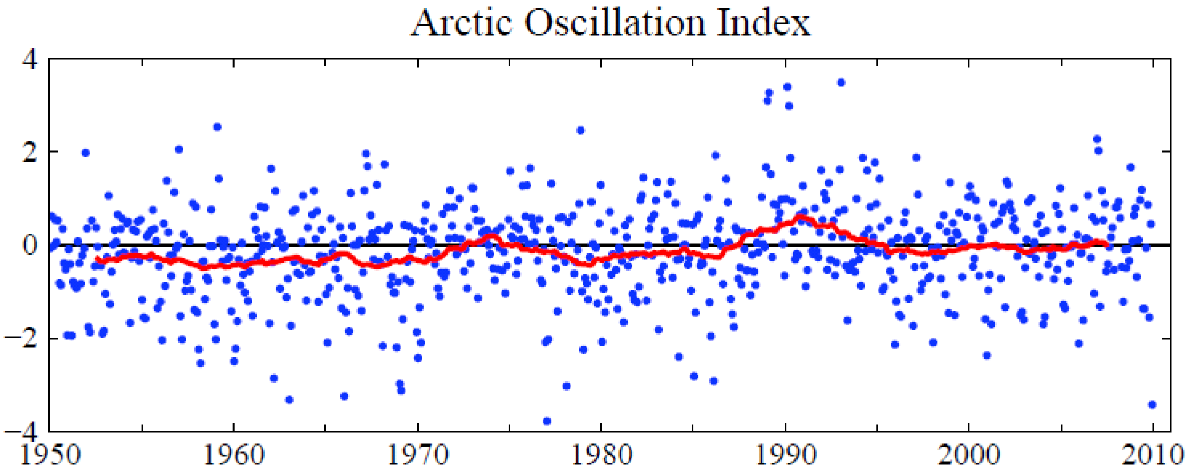


Figure 8. Arctic Oscillation (AO) Index. Negative values of the AO index indicate high pressure in the polar region and thus a tendency for weak zonal winds that facilitate cold air outbreaks to middle latitudes. Blue dots are monthly means and the red curve is the 60-month (5-year) running mean.

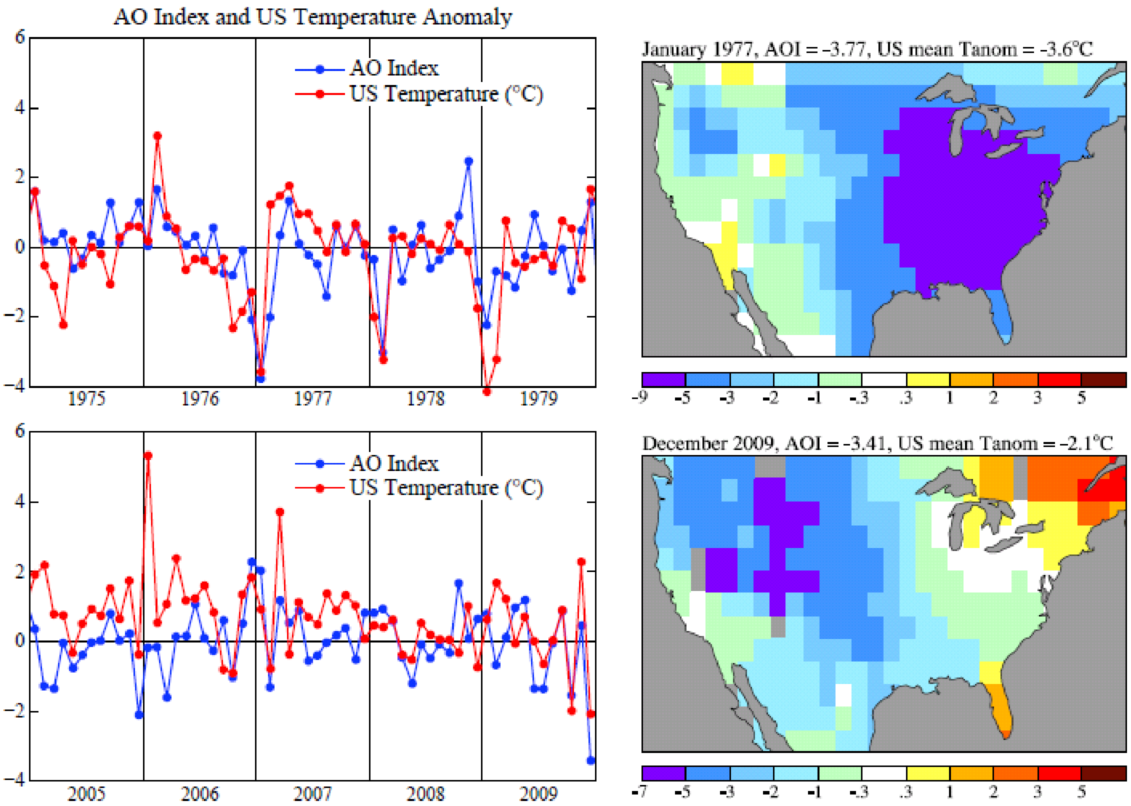


Figure 9. Temperature anomaly (°C) from GISS analysis and AO index from NOAA National Weather Service Climate Prediction Center. United States mean refers to the 48 contiguous states. (http://www.cpc.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao.index.b50.current.ascii.table).

Regional anomalies. How do these large regional temperature anomalies stack up against an expectation of, and the reality of, global warming? How unusual are these regional negative fluctuations? Do they have any relationship to global warming? Do they contradict global warming?

It is obvious that in December 2009 there was an unusual exchange of polar and mid-latitude air in the Northern Hemisphere. Arctic air rushed into both North America and Eurasia, and, of course, it was replaced in the polar region by air from middle latitudes.

The degree to which Arctic air penetrates into middle latitudes is related to the Arctic Oscillation (AO) index, which is defined by surface atmospheric pressure patterns and is plotted in Figure 8. When the AO index is positive surface pressure is low in the polar region. This helps the middle latitude jet stream to blow strongly and consistently from west to east, thus keeping cold Arctic air locked in the polar region. When the AO index is negative there tends to be high pressure in the polar region, weaker zonal winds, and greater movement of frigid polar air into middle latitudes.

Figure 8 shows that December 2009 was the most extreme negative Arctic Oscillation since the 1970s. Although there were ten cases between the early 1960s and mid 1980s with an AO index more extreme than -2.5, there were no such extreme cases since then until December 2009. It is no wonder that the public became accustomed to the absence of extreme blasts of cold air.

Figure 9 shows the AO index with greater temporal resolution for two 5-year periods. It is obvious that there is a high degree of correlation of the AO index with temperature in the United States, with any possible lag between index and temperature anomaly less than the

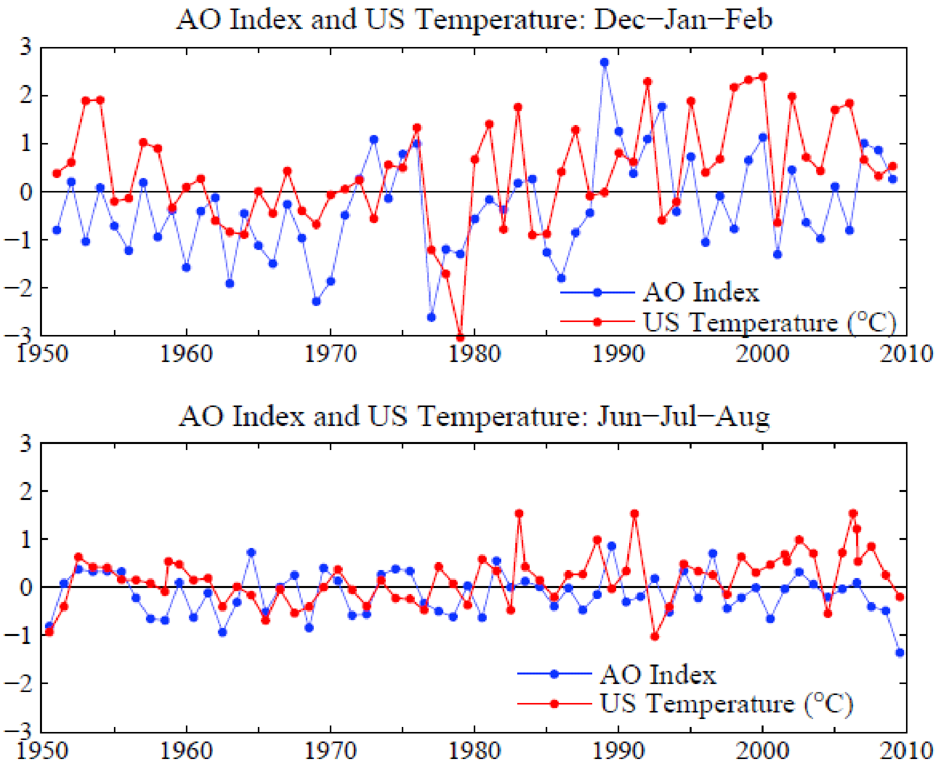


Figure 10. Arctic Oscillation index and United States (48 states) surface temperature anomaly for December-January-February (above) and June-July-August (below).

monthly temporal resolution. Large negative anomalies, when they occur, are usually in a winter month. Note that the January 1977 temperature anomaly, mainly located in the Eastern United States, was much stronger than the December 2009 anomaly.

The AO index is not so much an explanation for climate anomaly patterns as it is a simple statement of the situation. However, John (Mike) Wallace and colleagues have been able to use the AO description to aid consideration of how the patterns may change as greenhouse gases increase. A number of papers, by Wallace, David Thompson (e.g., Thompson and Wallace, 2000), and others, as well as by Drew Shindell and others at GISS (Shindell et al., 2001), have pointed out that increasing carbon dioxide causes the stratosphere to cool, in turn causing on average a stronger jet stream and thus a tendency for a more positive Arctic Oscillation. Overall, Figure 8 shows a weak tendency in the expected sense.

Figure 10 shows the AO index for Dec-Jan-Feb and Jun-Jul-Aug. Variability is much greater in the winter. There is weak correlation of the AO index and U.S. temperature in the winter, but no significant correlation in the summer. An unusually large negative AO was associated with the 2009 cool summer in the United States. Loss of Arctic summer sea ice is likely to affect Northern Hemisphere continental temperatures, but sea ice loss so far is too small and for too few years to allow empirical assessment.

We conclude that December 2009 was a highly anomalous month. High pressure in the polar region can be described as the “cause” of the extreme December weather. But there is no apparent basis for expecting frequent repeat occurrences of December 2009 conditions. On the contrary – the weak winter trend is toward a more positive AO, as expected with increasing greenhouse gases. But month-to-month fluctuations of the AO are much larger than its long term trend, so high winter variability including cold snaps will surely continue.

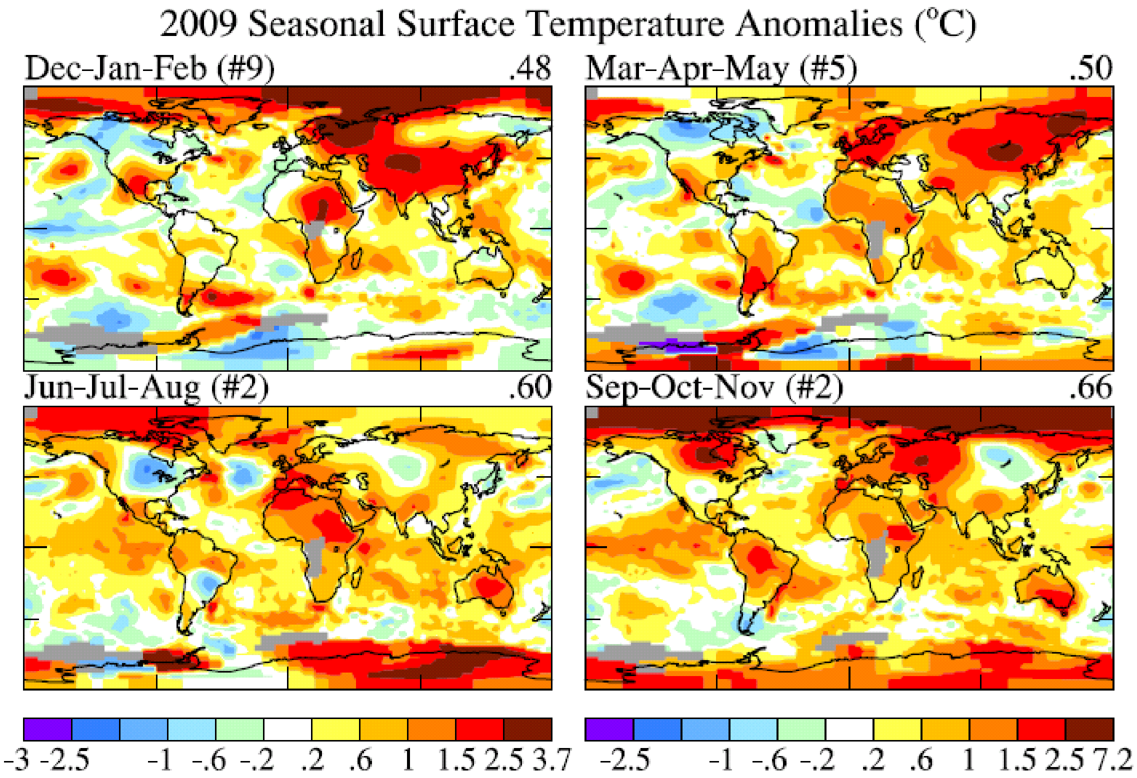


Figure 11. Global maps 4 season temperature anomalies (°C) for ~2009. (Note that Dec is December 2008. Base period is 1951-1980.)

However, other factors than the AO, including pervasive global warming due to increasing greenhouse gases, affect the climate trends. Figure 10 shows that in the U.S. only one of the past 10 winters and two of the past 10 summers were cooler than the 1951-1980 climatology. Let's look at global maps of recent regional temperature anomalies and temperature trends to help assess whether the U.S. tendency is an expected result due to global warming. Figure 11 shows seasonal temperature anomalies for the past year and Figure 12 shows seasonal temperature change since 1950 based on local linear trends. The temperature scales are identical in Figures 11 and 12.

The outstanding characteristic in comparing these two figures is that the magnitude of the 60 year change is similar to the magnitude of seasonal anomalies. What this tells us is that the climate "dice" are already strongly loaded. The change in the probability that the seasonal mean temperature at any given location will fall in the category that was defined as unusually warm during the period of climatology (1951-1980) has increased from 30 percent during the period of climatology to about 60 percent today, as we illustrate in an upcoming publication.

The magnitude of monthly temperature anomalies is typically 1.5 to 2 times greater than the magnitude of seasonal anomalies. So it is not yet quite as easy to see global warming if one's figure of merit is monthly mean temperature. Daily temperature change due to weather fluctuations is even much larger than global mean warming. Yet it is already possible to notice the effect by comparing the frequency of days with record warm temperature to days with record cold temperature – days with record high temperature now exceed days with record cold by about a two to one ratio (Meehl et al., 2009).

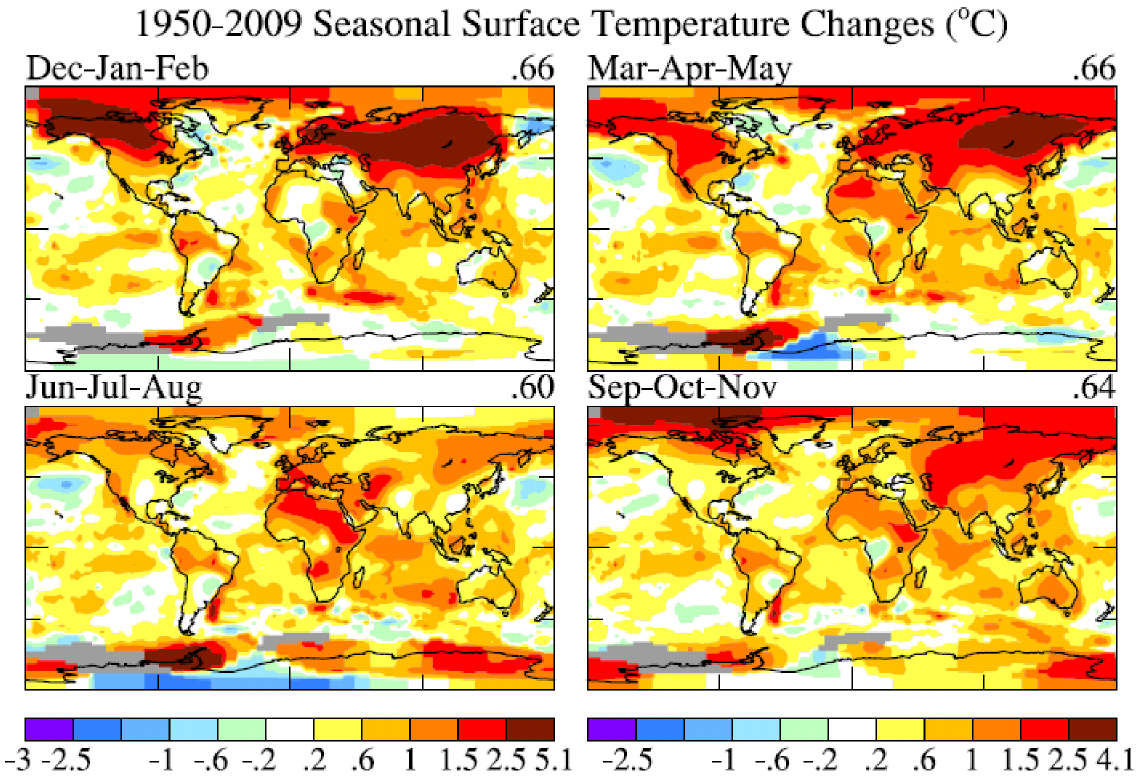


Figure 12. Global maps 4 season temperature anomaly trends (°C) for period 1950-2009.

Summary

The bottom line is this: the Earth has been in a period of rapid global warming for the past three decades. The assertion that the planet has entered a period of cooling in the past decade is without foundation. On the contrary, we find no significant deviation from the warming trend of the past three decades.

Weather fluctuations exceed the magnitude of average global warming over the past half century. However, the perceptive person should be able to notice that climate is warming on decadal time scales. The global temperature trend over the past few decades has been strong enough that there is a noticeable "loading" of the climate dice that define the probability of unusually warm or cool seasons.

Acknowledgements. The Niagara Falls photos belong to Moisha Blechman. John Hiddema and Richard Brenne, respectively, suggested the need for the bulleted items and a response to widespread accusations of "hoax" in an Overview. The need for an overview was also suggested by participants on ClimateProgress.org. Many people provided useful technical criticisms of the first draft.

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