Global Surface Air Temperature in 1995: Return to Pre-Pinatubo Level

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Abstract. Global surface air temperature has increased about 0.5°C from the minimum of mid-1992, a year after the Mt. Pinatubo eruption. Both a land-based surface air temperature record and a land-marine temperature index place the meteorological year 1995 at approximately the same level as 1990, previously the warmest year in the period of instrumental data. As El Niño warming was small in 1995, the solar cycle near a minimum, and ozone depletion near record levels, the observed high temperature supports the contention of an underlying global warming trend. The pattern of Northern Hemisphere temperature change in recent decades appears to reflect a change of atmospheric dynamics.

Introduction

Surface air temperature change is a primary measure of global climate change. Studies of near-global surface temperature change have been made using the land-based meteorological station network (Jones, 1994; Hansen and Lebedeff, 1987, hereafter HL87) and by combining land and marine records (Parker et al., 1994; Folland et al., 1992). References to other analyses are given in these papers.

We update the analysis of HL87. We address the primary deficiency of this record which limits the precision with which temperatures of different years can be compared, specifically the poor coverage in ocean areas. Finally, we discuss the significance of the unusual global warmth of 1995.

Update of Meteorological Station Record

Our land-based analysis is based on meteorological station data, the Monthly Climatic Data of the World (MCDW), supplemented for recent months by near-real-time Global Telecommunications System (GTS) data. Both data sets are obtained from the NOAA National Climatic Data Center. Although GTS data are not intended for climatological studies, monthly global-mean anomalies obtained from MCDW and GTS agree within 0.03°C if GTS data are processed under the assumption that recent reporting procedures (rounding, diurnal averaging, etc.) were the same as one year earlier (HL88).

Our present annual mean results are for the meteorological year, December-November, which is convenient to compare with seasonal climate simulations. Calendar year results are little different. We provide both cases in our data set available over the internet (http://www.giss.nasa.gov/Data/GISTEMP).

Annual-mean surface air temperature anomalies based on the meteorological stations are given in Fig. 1. Anomalies are defined as deviations from the 1951-1980 mean. The data show warming from the 1880s to 1940, a weak cooling trend from 1940 to 1965, and a sharp warming from 1965 to the present, characteristics consistently found in previous analyses (Hansen et al., 1981; Jones et al., 1982; HL87; Jones, 1994).

Inclusion of Marine Temperatures

Uncertainty in global temperature due to poor spatial sampling (Karl et al., 1994) indicates mainly a need for data in ocean areas. Coverage is improved by including ocean in situ (ship and buoy) air temperature observations (Folland et al., 1992; Parker et al., 1994), but in situ data introduce other errors. Ship heights and speeds have changed in the past century, as have methods of measurement. Use of sea surface temperature (SST) anomalies as a proxy for air temperature adds another uncertainty, but SSTs have the advantage of also being measured by satellites.

Satellites provide uniform sampling of SST, but their temporal coverage is limited and care is needed to avoid biases. Reynolds and Smith (1994) developed an optimum interpolation (OI) SST analysis for 1982-present using satellite and in situ data. The satellite data provide high resolution while the in situ data provide bias correction. We compared OI with the in situ analysis of Parker et al. (1994), finding significant large-scale differences only in the southern oceans, especially the South Pacific, where few, if any, in situ observations exist.

Smith et al. (1996) developed an interpolation method using spatial patterns from empirical orthogonal functions (EOFs) to improve SST analyses for 1950-81, when satellite data were not available. The method produces spatial EOFs from OI analyses for 1982-1993. The dominant EOF modes are used as basis functions and fit, in least squares sense, to the in situ data to determine the time dependence of each mode. The SST field reconstructed from these spatial and temporal modes is confined to 59°N-45°S because of limited in situ data at higher latitudes.

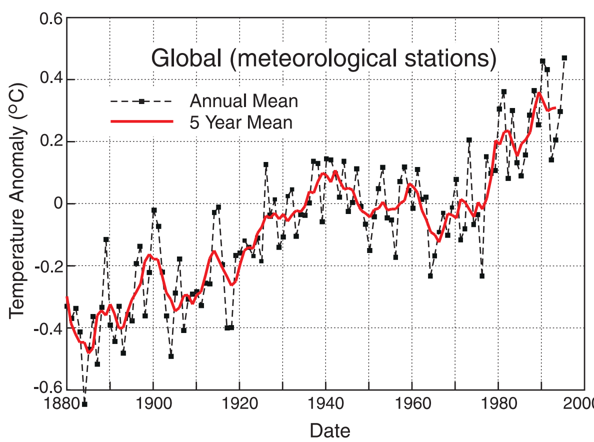

Figure 1. Global annual-mean (Dec-Nov) surface air temperature change based on meteorological station network.

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Paper number 96GLxxxxx
0095-xxxx/96/96GL-xxxxx$03.00

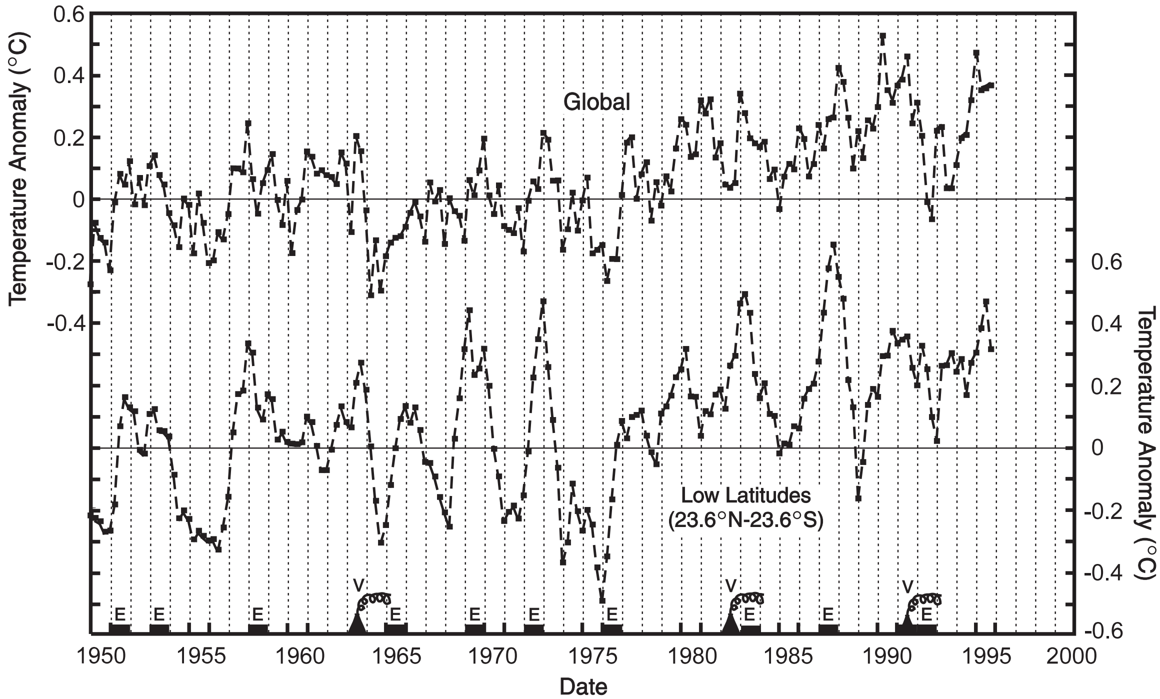

Figure 2. Change of land-ocean temperature index at seasonal resolution. The index combines SSTs between 59°N and 45°S and surface air temperatures of meteorological stations. E and V mark the years of major El Niños and volcanoes.

We have combined EOF SSTs for 1950-1981 and OI for 1982-1995 with meteorological station surface air temperature data to produce a surface temperature index for 1950-1995. The analysis method, as in HL87, divides the world into 8000 equal-area boxes. A box over land receives diminishing influence from stations up to 1200 km distant. A box over ocean between 59°N and 45°S uses the local SST, because of the complete coverage. A coastal box uses a meteorological station if one is located within 100 km of the box center.

The land-ocean temperature anomaly index is shown in Fig. 2 for the globe and low latitudes. El Niño signals are most prominent at low latitudes, but also leave a signature on global temperature. Comparing temperatures since 1978 with earlier decades, we note that recent temperatures are elevated as much between El Niños as during El Niños. Thus the data suggest a sustained tropical warmth, rather than simply an increased intensity of El Niños.

Temperature change of recent decades can be described as a jump occurring in the late 1970s or as a rather steady increase since the mid 1960s with superposed fluctuations. Although the latter interpretation seems more plausible, either description is valid until a longer record is available.

The 1995 land-ocean temperature index (0.39°C) exceeds the previous high, in 1990, by 0.01°C. Tables of this temperature index are included in our data available on the internet.

Urban Warming and Other Measurement Problems

Errors in surface air temperature due to changes of instrumentation, station location, and diurnal sampling can be substantial at individual locations and require continuing attention (Karl and Williams, 1987). The most serious problem is probably urban heat island effects, which tend to be systematic. HL87 found the global warming of the past century in their analysis to be reduced 0.1°C when cities of population more than 100,000 were excluded, and they estimated the total global-mean urban effect to be 0.1-0.2°C. A more precise test for the United States, based on comparing rural and MCDW stations, revealed large differences in certain regions such as southern California, but averaged over the contiguous United States the temperature change of MCDW and rural stations differed by only 0.1°C (Hansen et al., 1991).

It is important to attempt to correct for urban and other sources of error, as Jones' et al. (1990) have done by comparing neighboring stations on a case-by-case basis, in a procedure called "homogenization" of the data set. It is also useful to compare corrected and uncorrected data sets. If the correction were substantial compared to the net change, it would call into question the reality of that change.

We compared our uncorrected analysis and the Jones analysis (available ftp cdiac.esd.ornl.gov), averaging over all gridboxes where both analyses have data. Over 1935-1990 the two analyses differed by 0.02°C, based on the linear trends, and over 1900-1990 they differed by 0.09°C. These differences are small compared to the estimated global temperature change. This comparison indicates that urban warming and other local anthropogenic effects do not dominate observed change.

The reality of global surface warming in this century is supported by a variety of proxy evidence including ground temperature measurements in widely distributed boreholes (Deming, 1995) and near global retreat of alpine glaciers. Oerlemans (1994) used the trends of 48 world-wide glaciers to estimate from glacier dynamics a global warming rate of 0.66±0.2°C per century. We conclude that, although urban warming and other errors deserve careful study, global warming is not an artifact. This is reaffirmed by the spatial distribution of the warming illustrated below.

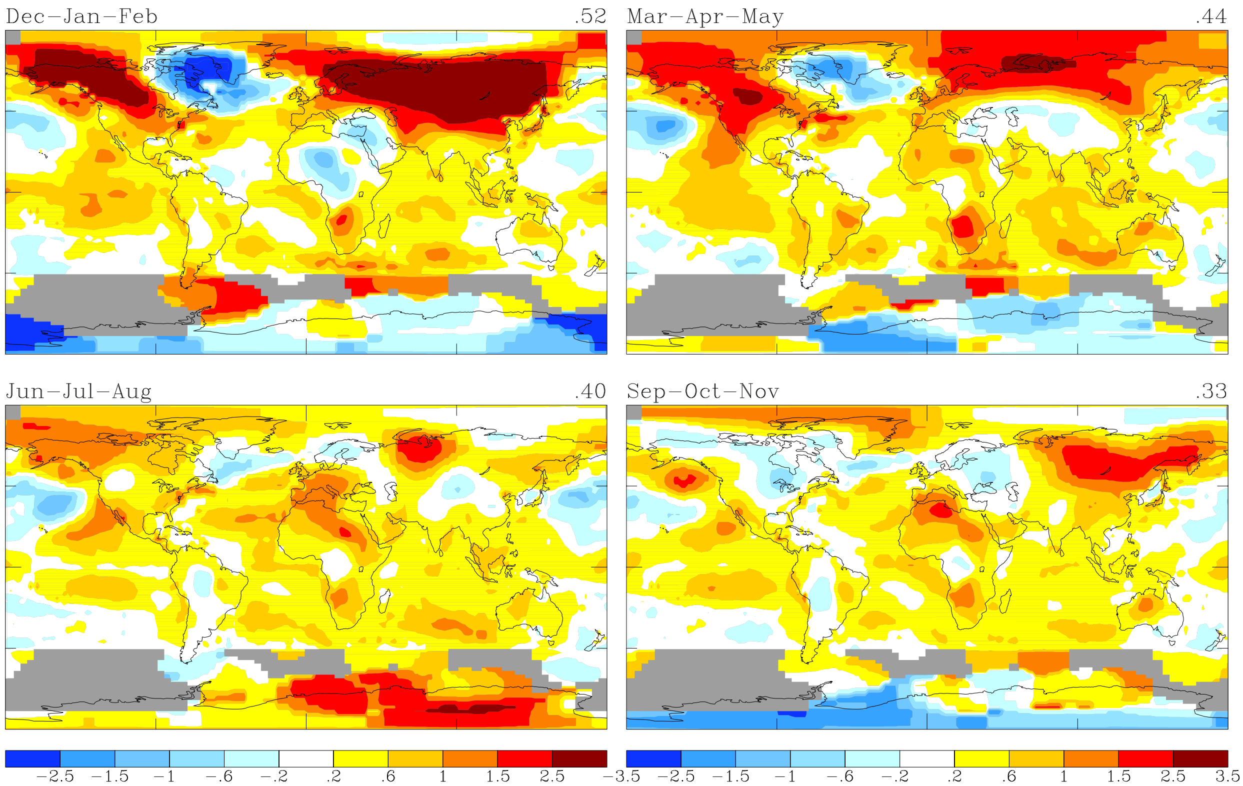

Figure 3. Seasonal mean change of the land-ocean temperature index based on the linear trend for the period 1965-1995.

Global Distribution of Temperature Change

The geographical and seasonal distribution of recent temperature change for 1965-1995 is shown in Fig. 3. The greatest warming occurs in Northern Hemisphere winter over Eurasia and North America. Intense cooling occurs in the midlatitude central Pacific and in a region between Hudson Bay and Greenland stretching into the North Atlantic. The magnitude of the cooling decays in the summer and fall.

At lower latitudes there is extensive warming over the oceans, and, with more seasonal variation, warming over the continents. There is a warming trend in the geographical regions of El Niños, but there is a warming trend over almost the entire tropical oceans. Thus the tropical warming of recent decades is both sustained (Fig. 2) and geographically pervasive (Fig. 3), i.e., it represents more than an increase of the frequency or intensity of El Niños.

Discussion

Global mean. Global surface temperature in meteorological year 1995 is the warmest in our record, barely edging out 1990. The 1990 and 1995 temperatures are sufficiently close in value that their relative rank may vary from one analysis to another due to differences in sampling, measurement errors, and various choices in the analysis methods (Hansen and Wilson, 1993). The important point is that global surface temperature has recovered to about the level of 1990, previously the warmest year of the century.

Record surface temperature does not imply expectation of similar warming at upper air levels. In the lower stratosphere the dominant cause of decadal temperature change is believed to be ozone depletion, which causes a cooling trend over the past 15 years (McCormack and Hood, 1994; Hansen et al., 1995). In the troposphere a return to a warming trend is expected within 1-2 years but not record warmth in 1995, because the troposphere is affected more than the surface by the local cooling due to ozone depletion near the tropopause (Hansen et al., 1995) and because the troposphere is affected more by tropical SSTs, so that its highest temperatures occur in conjunction with El Niños (Folland et al., 1992).

The chief implication of the high 1995 global surface temperature is reaffirmation of a long-term global warming trend. That such warmth occurs in a year when the recent El Niño faded (Trenberth and Hoar, 1996), near a minimum of the 10-11 year cycle of solar irradiance variations, and at a time of record ozone depletion makes it especially noteworthy. Bassett and Lin (1993) showed that, with global temperature falling in 1992 well below the 1990 level, a new record within several years was unlikely to occur by chance. Hansen et al. (1993) argue that record surface temperatures are predictable for the latter half of the 1990s, despite the vagaries of natural climate fluctuations, due to the strong radiative forcing and unrealized warming resulting from past increases in greenhouse gases. If their argument is correct, the 1995 warmth may be a prelude to significantly higher temperatures within the next several years.

Regional patterns. Observed patterns of temperature change contain hints about recent climate change mechanisms. But the patterns of change reflect atmosphere and ocean interactions and feedbacks, thus entangling cause and effect and making interpretation speculative. And unforced interannual variability of regional temperature exceeds decadal trends, further confusing the layman, if not the climatologist.

The patterns in the North Atlantic are of special interest. Broecker (1995) points out paleoclimate evidence for periods of reduced North Atlantic deep water formation, which caused North Atlantic surface waters and Europe to be unusually cold. This has led to speculation that, if greenhouse warming freshens North Atlantic surface waters, it may reduce deep water formation, causing cold conditions in the North Atlantic and Europe. Climate simulations with increasing CO_2 (Manabe and Stouffer, 1994) have found reduced deep water formation, though not a cooling sufficient to overcome greenhouse warming.

Observed temperature change patterns (Fig. 3) do not suggest a driving of climate by ocean circulation changes during the past three decades. There is a cooling stretching into the Atlantic, but it is centered in Baffin Bay. It is most intense in the cold season and is reminiscent of a winter atmospheric Rossby wave pattern, with its influence on SST decaying to a small anomaly in summer and fall. Perhaps this is only a short term fluctuation, as it corresponds to an intense positive phase of the North Atlantic Oscillation (Hurrell, 1995). It is possible that this pattern could arise as unforced variability due to stochastic dynamic processes (Wallace et al., 1995). Also the pattern is similar to that found by Robock and Mao, 1995) after large volcanoes, but, we find that the recent pattern persists even if the period excludes Pinatubo and/or Agung.

We suggest consideration of an alternative interpretation. The pervasiveness of warming at low latitudes is qualitatively consistent with global forcing by increasing greenhouse gases, as is enhanced warming over high latitude land. When observed SSTs are used to drive atmospheric models (Kumar et al., 1994; Graham, 1995), the models reproduce warming over North America, with simulated warming over Asia being weaker than observed. But forcing due to increasing greenhouse gases is most effective over large continental regions, suggesting that simulations with observed SSTs should include this factor. Speculating further, if increasing greenhouse gases are the ultimate driving factor, as has also been suggested by Graham (1995), then the Northern Hemisphere temperature anomaly pattern may persist or even strengthen, rather than switch to the opposite phase of the North Atlantic Oscillation. These issues have practical import, for example, the recent temperature anomalies increase the meridional temperature gradient (Fig. 3) and should tend to increase the strength of the jet stream across North America and the Atlantic, thus, for example, occasionally fueling powerful storms that can move rapidly into Europe. If this interpretation is correct, Europe may face continued warming on decadal time scales, and an increased likelihood of strong Atlantic storms, but no danger of a nascent ice age.

Acknowledgments. This work was supported by the NASA EOS and Climate Modeling programs. We thank Ken Lo for comparing the NOAA SST analyses with other ocean temperature data sets, B. Cairns, N. Graham, M. Hoffert, M. MacCracken, D. Neelin, P. Stone, K. Trenberth and W. Washington for comments on our paper, and C. Koizumi for desktop publishing.

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