U.S. and Global Temperature

Identification

1. Indicator Description

This indicator describes changes in average air temperature for the United States and the world from 1901 to 2011. In this indicator, temperature data are presented as trends in anomalies. Air temperature is an important component of climate, and changes in temperature can have wide-ranging direct and indirect effects on the environment and society.

Components of this indicator include:

- Changes in temperature in the contiguous 48 states over time (Figure 1)
- Changes in temperature worldwide over time(Figure 2)
- A map showing rates of temperature change across the United States (Figure 3)

2. Revision History

April 2010: Indicator posted
December 2011: Updated with data through 2010
May 2012: Updated with data through 2011

Data Sources

3. Data Sources

This indicator is based on temperature anomaly data provided by the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC).

4. Data Availability

The long-term surface time series in Figures 1, 2, and 3 were provided to EPA by NOAA's NCDC. NCDC calculated these time series based on monthly values from a set of NCDC-maintained databases: the U.S. Historical Climatology Network (USHCN) Version 2, the Global Historical Climatology Network–Monthly (GHCN-M) Version 3.1 (for global time series), and GHCN-Daily Version 2.92 (for Alaska and Hawaii maps). These databases can be accessed online. To supplement Figures 1 and 2, EPA obtained satellite-based measurements from NCDC's public website.

Contiguous 48 States (Surface)

Underlying temperature data for the contiguous 48 states come from the USHCN. Currently, the data are distributed by NCDC on various computer media (e.g., anonymous FTP sites), with no confidentiality issues limiting accessibility. Users can link to the data online at: www.ncdc.noaa.gov/oa/climate/research/ushcn/#access. Appropriate metadata and "readme" files are appended to the data. For example, see: ftp://ftp.ncdc.noaa.gov/pub/data/ushcn/v2/monthly/readme.txt.

Alaska, Hawaii, and Global (Surface)

GHCN temperature data can be obtained from NCDC over the Web or via anonymous FTP. This indicator is specifically based on a combined global land-sea temperature data set that can be obtained from: www.ncdc.noaa.gov/ghcnm/v3.php. There are no known confidentiality issues that limit access to the data set, and the data are accompanied by metadata.

Satellite Data

EPA obtained the satellite trends from NCDC's public website at: www.ncdc.noaa.gov/oa/climate/research/msu.html.

Methodology

5. Data Collection

This indicator is based on temperature measurements. The global portion of this indicator presents temperatures measured over land and sea, while the portion devoted to the contiguous 48 states shows temperatures measured over land only.

Surface data for this indicator were compiled from thousands of weather stations throughout the United States and worldwide using standard meteorological instruments. Data for the contiguous 48 states were compiled in the USHCN. Data for Alaska, Hawaii, and the rest of the world were taken from the GHCN. Both of these networks are overseen by NOAA and have been extensively peer reviewed. As such, they represent the most complete long-term instrumental data sets for analyzing recent climate trends. More information on these networks can be found below.

Contiguous 48 States (Surface)

USHCN Version 2 contains monthly averaged maximum, minimum, and mean temperature data from approximately 1,200 stations within the contiguous 48 states. The period of record varies for each station but generally includes most of the 20th century. One of the objectives in establishing the USHCN was to detect secular changes of regional rather than local climate. Therefore, stations included in the network are only those believed to not be influenced to any substantial degree by artificial changes of local environments. Some of the stations in the USHCN are first-order weather stations, but the majority are selected from U.S. cooperative weather stations (approximately 5,000 in the United States). To be included in the USHCN, a station had to meet certain criteria for record longevity, data availability (percentage of available values), spatial coverage, and consistency of location (i.e., experiencing few station changes). An additional criterion, which sometimes compromised the preceding criteria, was the desire to have a uniform distribution of stations across the United States. Included with the data set are metadata files that contain information about station moves, instrumentation, observing times, and elevation. NOAA's website (www.ncdc.noaa.gov/oa/climate/research/ushcn) provides more information about USHCN data collection.

Alaska, Hawaii, and Global (Surface)

GHCN-M Version 3.1 contains monthly climate data from weather stations worldwide. Monthly mean temperature data are available for 7,280 stations, with homogeneity-adjusted data available for a subset (5,206 mean temperature stations). Data were obtained from many types of stations. For the global component of this indicator, the GHCN land-based data were merged with an additional set of long-term sea surface temperature data; this merged product is called the extended reconstructed sea surface temperature (ERSST) data set, Version #3b (Smith et al., 2008).

NCDC has published documentation for the GHCN. For more information, including data sources, methods, and recent improvements, see: www.ncdc.noaa.gov/ghcnm/v3.php and the sources listed therein. Additional background on the merged land-sea temperature data set can be found at: www.ncdc.noaa.gov/cmb-faq/anomalies.html.

Satellite Data

In Figures 1 and 2, surface measurements have been supplemented with satellite-based measurements for the period from 1979 to 2011. These satellite data were collected by NOAA's polar-orbiting satellites, which take measurements across the entire globe. Satellites equipped with the necessary measuring equipment have orbited the Earth continuously since 1978, but 1979 was the first year with complete data. This indicator uses measurements that represent the lower troposphere, which is defined here as the layer of the atmosphere extending from the Earth's surface to an altitude of about 8 kilometers.

NOAA's satellites use the Microwave Sounding Unit (MSU) to measure the intensity of microwave radiation given off by various layers of the Earth's atmosphere. The intensity of radiation is proportional to temperature, which can therefore be determined through correlations and calculations. NOAA uses different MSU channels to characterize different parts of the atmosphere. Note that since 1998, NOAA has used a newer version of the instrument called the Advanced MSU.

For more information about the methods used to collect satellite measurements, see: www.ncdc.noaa.gov/oa/climate/research/msu.html and the references cited therein.

6. Indicator Derivation

Surface Data

NOAA calculated monthly temperature means for each site. In populating the USHCN and GHCN, NOAA adjusted the data to remove biases introduced by differences in the time of observation. NOAA also employed a homogenization algorithm to identify and correct for substantial shifts in local-scale data that might reflect changes in instrumentation, station moves, or urbanization effects. These adjustments were performed according to published, peer-reviewed methods. For more information on these quality assurance and error correction procedures, see Section 7.

In this indicator, temperature data are presented as trends in anomalies. An anomaly represents the difference between an observed value and the corresponding value from a baseline period. This indicator uses a baseline period of 1901 to 2000. The choice of baseline period *will not* affect the shape or the statistical significance of the overall trend in anomalies. For temperature (absolute anomalies), it only moves the trend up or down on the graph in relation to the point defined as "zero."

To generate the temperature time series, NOAA converted measurements into monthly anomalies in degrees Fahrenheit. The monthly anomalies then were averaged to determine an annual temperature anomaly for each year.

To achieve uniform spatial coverage (i.e., not biased toward areas with a higher concentration of measuring stations), NOAA averaged anomalies within grid cells on the map to create “gridded” data sets. The graph for the contiguous 48 states (Figure 1) and the map (Figure 3) are based on an analysis using grid cells that measure 2.5 degrees latitude by 3.5 degrees longitude. The global graph (Figure 2) comes from an analysis of grid cells measuring 5 degrees by 5 degrees. These particular grid sizes have been determined to be optimal for analyzing USHCN and GHCN climate data; see: http://www.ncdc.noaa.gov/oa/climate/research/ushcn/gridbox.html for more information.

Figures 1 and 2 show trends from 1901 to 2011, based on NOAA’s gridded data sets. Although earlier data are available for some stations, 1901 was selected as a consistent starting point.

The map in Figure 3 shows long-term rates of change in temperature over the United States for the period 1901–2011 except for Alaska and Hawaii, for which widespread and reliable data collection did not begin until 1918 and 1905, respectively. A regression was performed on the annual anomalies for each grid cell. Trends were calculated only in those grid cells for which data were available for at least 66 percent of the years during the full period of record. The slope of each trend (rate of temperature change per year) was calculated from the annual time series by ordinary least-squares regression and then multiplied by 100 to obtain a rate per century. No attempt has been made to portray data beyond the time and space in which measurements were made.

Satellite Data

NOAA’s satellites measure microwave radiation at various frequencies, which must be converted to temperature and adjusted for time-dependent biases using a set of algorithms. Various experts recommend slightly different algorithms. Accordingly, Figure 1 and Figure 2 show globally averaged trends that have been calculated by two different organizations: the Global Hydrology and Climate Center at the University of Alabama in Huntsville (UAH) and Remote Sensing Systems (RSS). For more information about the methods used to convert satellite measurements to temperature readings for various layers of the atmosphere, see: www.ncdc.noaa.gov/oa/climate/research/msu.html and the references cited therein. Both the UAH and RSS data sets are based on updated versions of analyses that have been published in the scientific literature. For example, see Christy et al. (2000, 2003), Mears et al. (2003), and Schabel et al. (2002).

NOAA provided data in the form of monthly anomalies. EPA calculated annual anomalies, then shifted the entire curves vertically in order to display the anomalies side-by-side with surface anomalies. Shifting the curves vertically does not change the shape or magnitude of the trends; it simply results in a new baseline. No attempt has been made to portray satellite-based data beyond the time and space in which measurements were made. The satellite data in Figure 1 are restricted to the atmosphere above the contiguous 48 states.

7. Quality Assurance and Quality Control

Both the USHCN and the GHCN have undergone extensive quality assurance procedures to identify errors and biases in the data and either remove these stations from the time series or apply correction factors.

Contiguous 48 States (Surface)

Quality control procedures for the USHCN are summarized at: www.ncdc.noaa.gov/oa/climate/research/ushcn/#processing. Homogeneity testing and data correction methods are described in numerous peer-reviewed scientific papers by NOAA's NCDC. A series of data corrections was developed to specifically address potential problems in trend estimation of the rates of warming or cooling in USHCN Version 2. They include:

- Removal of duplicate records
- Procedures to deal with missing data
- Adjusting for changes in observing practices, such as changes in observation time
- Testing and correcting for artificial discontinuities in a local station record, which might reflect station relocation, instrumentation changes, or urbanization (e.g., heat island effects)

Alaska, Hawaii, and Global (Surface)

QA/QC procedures for GHCN temperature data are described in detail in Peterson et al. (1998) and Menne and Williams (2009), and at: www.ncdc.noaa.gov/ghcnm/v3.php. GHCN data undergo rigorous QA reviews, which include pre-processing checks on source data; removal of duplicates, isolated values, and suspicious streaks; time series checks that identify spurious changes in the mean and variance via pairwise comparisons; spatial comparisons that verify the accuracy of the climatological mean and the seasonal cycle; and neighbor checks that identify outliers from both a serial and a spatial perspective.

Satellite Data

NOAA follows documented procedures for QA/QC of data from the MSU satellite instruments. For example, see NOAA's discussion of MSU calibration at: www.star.nesdis.noaa.gov/smcd/spb/calibration/msu/msucal.pdf and: www.star.nesdis.noaa.gov/star/documents/meetings/NIST2008/Zou_MSU_Calibration_20080114.pdf.

Analysis

8. Comparability Over Time and Space

Both the USHCN and the GHCN have undergone extensive testing to identify errors and biases in the data and either remove these stations from the time series or apply scientifically appropriate correction factors to improve the utility of the data. In particular, these corrections address changes in the time-of-day of observation, advances in instrumentation, and station location changes.

Contiguous 48 States (Surface)

Homogeneity testing and data correction methods are described in more than a dozen peer-reviewed scientific papers by NCDC. Data corrections were developed to specifically address potential problems in trend estimation of the rates of warming or cooling in the USHCN (see Section 7 for documentation). Balling and Idso (2002) compare the USHCN data with several surface and upper-air data sets and show that the effects of the various USHCN adjustments produce a significantly more positive, and likely spurious, trend in the USHCN data. In contrast, a subsequent analysis by Vose et al. (2003) found that USHCN station history information is reasonably complete and that the bias adjustment models have low residual errors.

Further analysis by Menne et al. (2009) suggests that:

> …the collective impact of changes in observation practice at USHCN stations is systematic and of the same order of magnitude as the background climate signal. For this reason, bias adjustments are essential to reducing the uncertainty in U.S. climate trends. The largest biases in the HCN are shown to be associated with changes to the time of observation and with the widespread changeover from liquid-in-glass thermometers to the maximum minimum temperature sensor (MMTS). With respect to [USHCN] Version 1, Version 2 trends in maximum temperatures are similar while minimum temperature trends are somewhat smaller because of an apparent overcorrection in Version 1 for the MMTS instrument change, and because of the systematic impact of undocumented station changes, which were not addressed [in] Version 1.

USHCN Version 2 represents an improvement in this regard.

Some observers have expressed concerns about other aspects of station location and technology. For example, Watts (2009) expresses concern that many U.S. weather stations are sited near artificial heat sources such as buildings and paved areas, potentially biasing temperature trends over time. In response to these concerns, NOAA analyzed trends for a subset of stations that Watts had determined to be "good or best," and found the temperature trend over time to be very similar to the trend across the full set of USHCN stations (www.ncdc.noaa.gov/oa/about/response-v2.pdf). While it is true that many stations are not optimally located, NOAA's findings support the results of an earlier analysis by Peterson (2006) that found no significant bias in long-term trends associated with station siting once NOAA's homogeneity adjustments have been applied.

Alaska, Hawaii, and Global (Surface)

The GHCN applied similarly stringent criteria for data homogeneity (like the USHCN) in order to reduce bias. In acquiring data sets, the original observations were sought, and in many cases where bias was identified, the stations in question were removed from the data set. See Section 7 for documentation.

For data collected over the ocean, continuous improvement and greater spatial resolution can be expected in the coming years, with corresponding updates to the historical data. For example, there is a known bias during the World War II years (1941–1945), when almost all ocean temperature measurements were collected by U.S. Navy ships that recorded ocean intake temperatures, which can give warmer numbers than the techniques used in other years. Future efforts will aim to adjust the data more fully to account for this bias.

Satellite Data

NOAA's satellites cover the entire Earth with consistent measurement methods. Procedures to calibrate the results and correct for any biases over time are described in the references cited under Section 7.

9. Sources of Uncertainty

Surface Data

Uncertainties in temperature data increase as one goes back in time, as there are fewer stations early in the record. However, these uncertainties are not sufficient to undermine the fundamental trends in the data.

Error estimates are not readily available for U.S. temperature, but they are available for the global temperature time series. See the error bars in NOAA's graphic online at: http://www.ncdc.noaa.gov/sotc/service/global/global-land-ocean-mntp-anom/201001-201012.gif. In general, Vose and Menne (2004) suggest that the station density in the U.S. climate network is sufficient to produce a robust spatial average.

Satellite Data

Methods of inferring tropospheric temperature from satellite data have been developed and refined over time. Several independent analyses have produced largely similar curves, suggesting fairly strong agreement and confidence in the results.

Error estimates for the UAH analysis have previously been published in Christy et al. (2000, 2003). Error estimates for the RSS analysis have previously been published in Schabel et al. (2002) and Mears et al. (2003). However, error estimates are not readily available for the updated version of each analysis that EPA obtained in 2012.

10. Sources of Variability

Annual temperature anomalies naturally vary from location to location and from year to year as a result of normal variation in weather patterns, multi-year climate cycles such as the El Niño–Southern Oscillation and Pacific Decadal Oscillation, and other factors. This indicator accounts for these factors by presenting a long-term record (more than a century of data) and averaging consistently over time and space.

11. Statistical/Trend Analysis

This indicator uses ordinary least-squares regression to calculate the slope of the observed trends in temperature, but does not indicate whether each trend is statistically significant. A simple t-test indicates that some of the observed trends are significant to a 95 percent confidence level, while others are not. To conduct a more complete analysis, however, would potentially require consideration of serial correlation and other more complex statistical factors.

12. Data Limitations

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

1. Biases in surface measurements may have occurred as a result of changes over time in instrumentation, measuring procedures (e.g., time of day), and the exposure and location of the instruments. Where possible, data have been adjusted to account for changes in these variables. For more information on these corrections, see Section 8. Some scientists believe that the empirical debiasing models used to adjust the data might themselves introduce non-climatic biases (e.g., Pielke et al., 2007).
2. Uncertainties in surface temperature data increase as one goes back in time, as there are fewer stations early in the record. However, these uncertainties are not sufficient to mislead the user about fundamental trends in the data.

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