Sea Surface Temperature

Identification

1. Indicator Description

This indicator describes global trends in sea surface temperature (SST) from 1880 to 2012. Temperature is an important physical attribute of the world's oceans, with effects on global climate as well as marine ecosystems. As an example, this indicator also provides a map showing average SST across the world for the calendar year 2011.

2. Revision History

April 2010: Indicator posted
December 2011: Updated with data through 2010
January 2012: Updated with data through 2011
April 2012: Updated with revised data through 2011
July 2012: Updated example map
August 2013: Updated Figure 1 on EPA's website with data through 2012

Data Sources

3. Data Sources

This indicator is based on the Extended Reconstructed Sea Surface Temperature (ERSST) analysis developed by the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC). The reconstruction model used here is ERSST version 3b (ERSST.v3b), which covers the years 1880 to 2012 and was described in Smith et al. (2008).

Data for the example map came from the Hadley Centre at the UK Met Office. This map is adapted from a map originally published in Sumaila et al. (2011).

4. Data Availability

NCDC and the National Center for Atmospheric Research (NCAR) provide access to monthly and annual SST and error data from the ERSST.v3b reconstruction, as well as a mapping utility that allows the user to calculate average anomalies over time and space (NOAA, 2013a). EPA used global data (all latitudes), which can be downloaded from: ftp://ftp.ncdc.noaa.gov/pub/data/cmb/mlost/pdo/. Specifically, EPA used the ASCII text file "aravg.ann.ocean.90S.90N.asc," which includes annual anomalies and error variance. A "readme" file in the same FTP directory explains how to use the ASCII file. The ERSST.v3b reconstruction is based on in situ measurements, which are available online through the International Comprehensive Ocean-Atmosphere Data Sets (ICOADS) (NOAA, 2013b).

Data for the example map were downloaded from: http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_hadisst (UK Met Office, 2012). This website provides access to monthly global grids in ASCII format, along with documentation.

Methodology

5. Data Collection

This indicator is based on in situ instrumental measurements of water temperature worldwide from 1880 to 2012. When paired with appropriate screening criteria and bias correction algorithms, in situ records provide a reliable long-term record of temperature. The long-term sampling was not based on a scientific sampling design, but was gathered by "ships of opportunity" and other ad hoc records. Records are particularly sparse or problematic prior to the 20th century and during the two World Wars. Since about 1955, the in situ sampling has become more systematic and measurement methods have continued to improve. SST observations from drifting and moored buoys were first used in the late 1970s. Buoy observations became more plentiful following the start of the Tropical Ocean Global Atmosphere (TOGA) program in 1985. Locations have been designed to fill in data gaps where ship observations are sparse.

A summary of the relative availability, coverage, accuracy, and biases of the different measurement methods is provided in Reynolds et al. (2002). Sampling and analytical procedures are documented in several publications that can be accessed online. NOAA has documented the measurement, compilation, quality assurance, editing, and analysis for the underlying ICOADS sea surface dataset at: http://icoads.noaa.gov/publications.html.

In the original update from ERSST v2 to v3, satellite data were added to the analysis. However, ERSST version 3b no longer includes satellite data. The addition of satellite data caused problems for many users. Although the satellite data were corrected with respect to the in situ data, there was a residual cold bias that remained. The bias was strongest in the middle and high latitude Southern Hemisphere where in situ data are sparse. The residual bias led to a modest decrease in the global warming trend and modified global annual temperature rankings.

This indicator is global in scale and offers a broad overview of SST. By design, the indicator does not focus on any one region or set of sensitive areas. However, as NOAA's analysis continues to improve the resolution of data, future analyses may provide more detailed data that are more useful to the assessment of specific coastal regions and ecosystems.

Data for the example map are based on a combination of in situ instrumental measurements and remote sensing via satellite. These data are analyzed on a 1-degree global grid.

6. Indicator Derivation

This indicator is based on the ERSST, a reconstruction of historical SST using in situ data. The reconstruction methodology has undergone several stages of development and refinement. This indicator is based on the most recent data release, version 3b (ERSST.v3b).

This reconstruction involves filtering and blending datasets that use alternative measurement methods and include redundancies in space and time. Because of these redundancies, this reconstruction is able to fill spatial and temporal data gaps and correct for biases in the different measurement techniques (e.g., uninsulated canvas buckets, intakes near warm engines, uneven spatial coverage). Locations have been combined to report a single global value, based on scientifically valid techniques for averaging over areas. Specifically, data have been averaged over 5-by-5-degree grid cells as part of NOAA's Merged Land-Ocean Surface Temperature Analysis (MLOST) (www.esrl.noaa.gov/psd/data/gridded/data.mlost.html). Daily and monthly records have been averaged to find annual anomalies. Thus, the combined set of measurements is stronger than any single set. Reconstruction methods are documented in more detail by Smith et al. (2008). Smith and Reynolds (2005) discuss and analyze the similarities and differences among various reconstructions, showing that the results are generally consistent. For example, the long-term average change obtained by this method is very similar to those of the "unanalyzed" measurements and reconstructions discussed by Rayner et al. (2003).

This indicator shows the extended reconstructed data as anomalies, or differences, from a baseline "climate normal." In this case, the climate normal was defined to be the average SST from 1971 to 2000. No attempt was made to project data beyond the period during which measurements were collected.

Additional information on the compilation, data screening, reconstruction, and error analysis of the reconstructed SST data can be found at: www.ncdc.noaa.gov/ersst/.

The example map was created by obtaining monthly grids for the 12 months of 2011, then averaging the grids together to create an annual mean grid. Any grid cell that was listed as "ice-covered" for one or more months of 2011 (which meant it did not have an SST measurement for those months) was excluded from the analysis to avoid biasing the annual mean SST toward the warmer portions of the year. This step is the reason why many grid cells near the poles have been left blank.

7. Quality Assurance and Quality Control

Thorough documentation of the quality assurance and quality control (QA/QC) methods and results is available in the technical references for ERSST.v3b at NOAA's NCDC (www.ncdc.noaa.gov/ersst/).

Analysis

8. Comparability Over Time and Space

Presenting the data at a global and annual scale reduces the uncertainty and variability inherent in SST measurements, and therefore, the overall reconstruction is considered to be a good representation of global SST. This dataset covers the Earth's oceans with sufficient frequency and resolution to ensure that overall averages are not inappropriately distorted by singular events or missing data due to sparse in situ measurements or cloud cover. The confidence interval reports the estimated degree of accuracy associated with the estimates over time and suggests later measurements may be used with greater confidence than pre-20th century estimates.

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 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.

Comparisons by researchers Smith and Reynolds (2005) with other similar reconstructions using alternative methods yield consistent results, albeit with narrower uncertainty estimates. Hence, the indicator presented here may be more conservative than alternative methods.

9. Sources of Uncertainty

The extended reconstruction dataset includes an error variance for each year, which is associated with the biases and errors in the measurements and treatments of the data. NOAA has separated this variance into three components: high-frequency error, low-frequency error, and bias error. For this indicator, the total variance was used to calculate a 95-percent confidence interval (see Figure 1) so that the user can understand the impact of uncertainty on any conclusions that might be drawn from the time series. For each year, the square root of the error variance (the standard error) was multiplied by 1.96, and this value was added to or subtracted from the reported anomaly to define the upper and lower confidence bounds, respectively. As Figure 1 shows, the level of uncertainty has decreased dramatically in recent decades owing to better global spatial coverage and increased availability of data.

The model has largely corrected for measurement error, but some uncertainty still exists. Contributing factors include variations in sampling methodology by era as well as geographic region, and instrument error from both buoys as well as ships.

Uncertainty measurements are also available for some of the underlying data. For example, several articles have been published about uncertainties in ICOADS in situ data; these publications are available from: www.noc.soton.ac.uk/JRD/MET/coads.php.

10. Sources of Variability

Sea surface temperature varies seasonally, but this indicator has removed the seasonal signal by calculating annual averages. Temperatures can also vary as a result of interannual climate patterns such as the El Niño-Southern Oscillation.

11. Statistical/Trend Analysis

Figure 1 shows a 95 percent confidence interval that has been computed for each annual anomaly. Analysis by Smith et al. (2008) confirms that the increasing trend apparent from Figure 1 over the 20th century is statistically significant.

12. Data Limitations

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

1. The 95 percent confidence interval is wider than other methods for long-term reconstructions; in mean SSTs, this interval tends to dampen anomalies.

2. The geographic resolution is coarse for ecosystem analyses but reflects long-term and global changes as well as shorter-term variability.
3. The reconstruction methods used to create this indicator remove most random "noise" in the data. However, the anomalies are also dampened when and where data are too sparse for a reliable reconstruction. The 95 percent confidence interval reflects this "dampening effect" and uncertainty caused by possible biases in the observations.
4. Data screening results in loss of multiple observations at latitudes higher than 60 degrees north or south. Effects of screening at high latitudes are minimal in the context of the global average; the main effect is to lessen anomalies and widen confidence intervals.

References

NOAA (National Oceanic and Atmospheric Administration). 2013a. Extended reconstructed sea surface temperature (ERSST.v3b). National Climatic Data Center. Accessed February 2013. www.ncdc.noaa.gov/ersst/.

NOAA (National Oceanic and Atmospheric Administration). 2013b. International comprehensive ocean-atmosphere data sets (ICOADS). Accessed February 2013. http://icoads.noaa.gov/.

Rayner, N.A., D.E. Parker, E.B. Horton, C.K. Folland, L.V. Alexander, D.P. Rowell, E.C. Kent, and A. Kaplan. 2003. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. J. Geophys. Res. 108:4407.

Smith, T.M., and R.W. Reynolds. 2005. A global merged land air and sea surface temperature reconstruction based on historical observations (1880–1997). J. Climate 18(12):2021-2036. www.ncdc.noaa.gov/oa/climate/research/Smith-Reynolds-dataset-2005.pdf.

Smith, T.M., R.W. Reynolds, T.C. Peterson, and J. Lawrimore. 2008. Improvements to NOAA's historical merged land-ocean surface temperature analysis (1880–2006). J. Climate 21(10):2283–2296. www.ncdc.noaa.gov/ersst/papers/SEA.temps08.pdf.

Sumaila, U.R., W.W.L. Cheung, V.W.Y. Lam, D. Pauly, and S. Herrick. 2011. Climate change impacts on the biophysics and economics of world fisheries. Nature Climate Change 1:449–456.

UK Met Office. 2012. Hadley Centre, HadISST 1.1: Global sea ice coverage and sea surface temperature (1870-present). NCAS British Atmospheric Data Centre. Accessed May 2012. http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_hadisst.

Xue, Y., T.M. Smith, and R.W. Reynolds. 2003. Interdecadal changes of 30-yr SST normals during 1871–2000. J. Climate 16:1601-1612. www.ncdc.noaa.gov/ersst/papers/xue-etal.pdf.