Indicator: Sea Surface Temperature (344)

Sea surface temperature (SST) is a critical physical attribute of coastal ecological systems. Water temperature directly affects process rates, water column stability, and the species of plants (such as algae, seagrasses, marsh plants, and mangroves) and animals (microscopic animals, larger invertebrates, fish, and mammals) that live in a particular region. Increases in temperature are thought to be associated with the degradation of coral reefs (bleaching) and may increase the frequency or extent of blooms of harmful algae. On longer time scales (decades to centuries), such changes may be related to decreases in the supply of nutrients to surface waters from the deep sea and a cascade of effects from decreases in primary production to declines in fish production. Changes in temperature may result from long-term cycles in ocean circulation or secular trends in climate (Committee on the Bering Sea Ecosystem et al., 1996).

This indicator, developed by the National Ocean Service of the National Oceanographic and Atmospheric Administration (NOAA) (The Heinz Center 2002) describes whether SST is above or below average. The indicator tracks how much regional average temperatures in any given year deviate from the average for a 14-year period of record for waters within 25 miles of the coast.

Data from 1985 through 1998 were obtained using Advanced Very High Resolution Radiometers onboard several NOAA Polar Orbiting Environmental Satellites. Data were acquired on a grid of square pixels nominally 10 kilometers (about 6 miles) on a side. Both day and nighttime data were processed to remove clouds using an “erosion filter,” and averaged to produce monthly means, which then were averaged to produce seasonal means.

To calculate the index: (1) the seasonal average SST of near-shore water (shoreline out to 25 miles) was calculated for the warmest season in each region (termed the “seasonal mean maximum”), which typically occurred during summer or fall; (2) the long-term mean (during the warmest seasons) for the period of observation (1985–1998) was calculated; and (3) the long-term mean was then subtracted from the seasonal mean maxima. Values greater than zero are positive “anomalies” (i.e., deviations from the long-term average), and those less than zero are negative anomalies. Systematic errors are rare in such analyses, and the source data (daily averages from NOAA satellites) are expected to be within 0.3 to 0.5^{o}C of actual temperatures. Annual anomalies should be even more accurate, because averaging data reduces overall uncertainty. A “1.1”index score means that the SST for that region in that year was 10 percent warmer than the 14-year average for that region. The indicator defines “average SST” for a region as the average temperature for the warmest season in that region.

What the Data Show

While SST varies noticeably from year to year, and there are individual reports of gradually increasing temperatures in several of these ocean regions (Barry et al., 1995; Levitus et al., 2000), the index shows no noticeable trends (Figure 344-1).

Indicator Limitations

- At the time the Heinz Center compiled this indicator, complete data were not available for 1996 and 1997.

- SST data are available back to 1979, but the data are not yet comparable to the series beginning in 1985.

Data Sources

Data are available from NASA at http://podaac.jpl.nasa.gov/sst/.

References

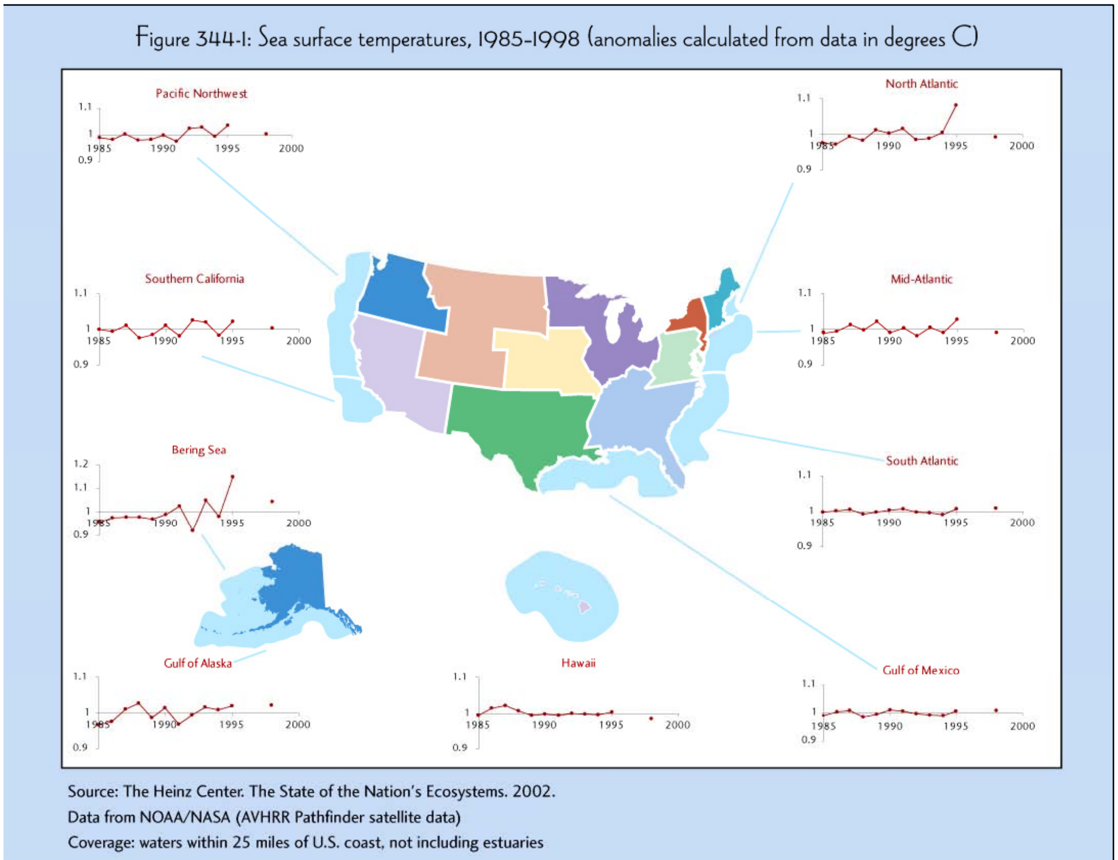
Barry, J.P., C.H. Baxter, R.D. Sagarin, and S.E. Gilman. 1995. Climate-related, long-term faunal changes in a California rocky intertidal community. Science 267:672–675.

Committee on the Bering Sea Ecosystem, Polar Research Board, Commission on Geosciences, Environment and Resources, and National Research Council. The Bering Sea Ecosystem. 1996. National Academy Press, Washington, D.C. pp. 196-237.

Levitus, S., J.I. Antonov, T.P. Boyer, and C. Stephens. 2000. Warming of the world ocean. Science 287:2225–2229.

Graphics

Figure 344-1. Sea surface temperatures, 1985-1998



Note: 1996, 1997, and some post–1998 data are expected to be available following the Heinz Center's online update in late 2005.

R.O.E. Indicator QA/QC

Data Set Name: SEA SURFACE TEMPERATURE
Indicator Number: 344 (139049)
Data Set Source:
Data Collection Date:
Data Collection Frequency:
Data Set Description: Sea Surface Temperature
Primary ROE Question: What are the trends in the critical physical and chemical attributes of the Nation's ecological systems?

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

This indicator uses measurements of sea surface temperature (SST) made with satellite technology. The National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautical and Space Administration (NASA) collected these data in a joint effort using Advanced Very High Resolution Radiometers (AVHRR) onboard several of NOAA s Polar Orbiting Environmental Satellites. The 5-channel AVHRR specifically measures the infrared (thermal) radiation given off by the surface layer of the ocean, which is a direct reflection of water temperature. NASA s Jet Propulsion Laboratory (JPL) provides an online user s guide with detailed information about SST data collection equipment and methodology (http://podaac.jpl.nasa.gov/pub/sea_surface_temperature/avhrr/pathfinder/doc/usr_gde4_0_toc.html). This document includes supporting references. Supplementary documentation sites: (1) Main SST data site: http://podaac.jpl.nasa.gov/sst/ (2) Various SST data user s guides: http://podaac.jpl.nasa.gov/sst/sst_doc.html (3) Additional documentation of AVHRR Pathfinder data products: http://podaac.jpl.nasa.gov/cgi-bin/dcatalog/fam_summary.pl?sst+pfsst). These websites also include a link to several supporting references (http://podaac.jpl.nasa.gov/sst/sst_ref.html).

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

The sampling design for this indicator has been carefully developed over the years to collect high-quality data at high resolution, both spatially and temporally. NOAA s satellites collect data using a grid, where each data point or pixel represents a square of ocean surface that nominally measures between 9 and 10 kilometers (km) on a side. NOAA also collects data at other resolutions ranging from 18 km to 4 km, but the Heinz Center (2002) uses the 9-10 km data for this indicator (http://www.heinzctr.org/ecosystems/coastal_technotes/coasts_sea_srf_temp.shtml). NOAA s data set covers the world s ocean surface in its entirety, which allows this indicator to include all U.S. coastal waters, from the Bering Sea to the Gulf of Mexico. NOAA s satellites cover the entire grid on a daily basis. The sampling plan includes a systematic means of detecting data points that happen to be obscured by clouds, since these cannot be included in the final data set (clouds block the infrared radiation emitted by the ocean surface). The Jet Propulsion Laboratory s SST website discusses sample design and provides a list of references that offer more detailed support of NOAA s SST monitoring plan (sample design at http://podaac.jpl.nasa.gov/cgi-bin/dcatalog/fam_summary.pl?sst+pfsst; references at http://podaac.jpl.nasa.gov/sst/sst_ref.html).

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

The analytical model for this indicator, which is an index of the annual deviation of SST above or below a long-term average, consists of three main steps: (1) Conversion of raw thermal data to SSTs. NOAA performs this conversion based on models that show the relationship between water temperature and the thermal properties observed by satellite. NASA s online SST data user s guide describes this algorithm in detail (http://podaac.jpl.nasa.gov/pub/sea_surface_temperature/avhrr/pathfinder/doc/usr_gde4_0_toc.html). NOAA and NASA note that algorithms for converting satellite data to SSTs have improved since the first year of data included in this indicator (1985) (http://podaac.jpl.nasa.gov/sst/), and they have taken steps to ensure that the full historic SST dataset reflects the most up-to-date methodology. According to the data website: This dataset represents a historical reprocessing of the entire AVHRR time series using consistent SST algorithms, improved satellite and inter-satellite calibration, quality control and cloud detection (http://podaac.jpl.nasa.gov/sst/). NOAA and NASA specifically cite the work of the project s algorithm team, headed by Professor Robert Evans at the University of Miami Rosenstiel School of Marine and Atmospheric Sciences. (2) Calculation of seasonal means. NOAA divided SST data pixels from near-shore U.S. waters (up to 25 miles offshore) into 9 geographic regions. From daily SST data, NOAA calculated mean SST values for the warmest season in each year (summer or fall, depending on the region). These annual values are labeled seasonal mean maxima. From these data the Heinz Center calculated a long-term mean for each geographic region, consisting of the average of all seasonal mean maxima over the full period of observation (currently, 1985-1998) (Heinz Center, 2002). Climate researchers commonly convert daily SST data into seasonal, annual, and long-term means in order to evaluate inter-annual trends; this implies general acceptance of the data manipulation steps involved in the creation of this indicator by the scientific community. (3) Creation of an index to depict variation from the long-term mean. For each geographic region, the Heinz Center (2002) reports this indicator in terms of an anomaly that is, the percentage by which each year s seasonal mean maximum deviates from the long-term mean. The Heinz Center (2002) sets up the index so that the long-term mean receives a value of 1. If one year receives a value of 0.9, it means that the anomaly is 0.1, and for the year in question, the SST is 10 percent cooler than average. By emphasizing relative rather than absolute temperatures, this reporting method allows data from several regions to be compared on the same graph, even if their average temperatures differ greatly in absolute terms. The scientific community commonly uses this type of index to quantify relative changes in SST (for example, see the various climate databases compiled by Columbia University s

Lamont-Doherty Earth Observatory at http://ingrid.ldeo.columbia.edu/).

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

This indicator documents an important physical attribute of the nation s coastal ocean ecosystems. As discussed in the Heinz Center s 2002 report (http://www.heinzctr.org/ecosystems/coastal/sea_surf_temp.shtml), changes in SST can cause coral bleaching and changes in algal blooms, and long-term SST shifts can lead to large changes in nutrient cycling and food chain dynamics (The Bering Sea Ecosystem. Commission on Geosciences, Environment and Resources (CGER), Polar Research Board (PRB), 1996. pp. 196-237). This data set covers U.S. coastal waters with sufficient frequency and resolution to ensure that overall averages are not inappropriately distorted by singular events or missing data due to occasional cloud cover. NOAA collects samples as points on a grid of squares, each 9-10 km on a side. Satellite orbiting patterns ensure that measurements can be taken day and night for every location on the grid. The Heinz Center s (2002) SST indicator includes complete data from 1985 to 1995 and complete data from 1998. [The next web update of the Heinz Report is expected to occur in late 2005, and should incorporate full SST data from 1996, 1997, and 1999-2003.]

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

This indicator offers a broad overview of sea-surface temperature (SST). By design, it does not focus on any one sensitive population. However, because NOAA s analysis divides data by geographic region, it may be possible to assess SST threats to particular populations of concern.

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

A defined baseline is used to generate the SST index for this indicator: the long-term mean of warm seasons from 1985 to 1998 (14 years), which serves as a basis for the graphical representation of relative shifts in SST. Because paleo-climatological evidence shows that air and sea surface temperatures have varied throughout geological time (McElroy, 2002), it is not possible to compare recent SST trends with any background data that specifically represents a natural state. McElroy, M. B. The Atmospheric Environment: Effects of Human Activity. Princeton University Press. 2002.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

(1) Data collection. NOAA and NASA collected raw satellite imagery using the Advanced Very High Resolution Radiometers (AVHRR) onboard several of NOAA s Polar Orbiting Environmental Satellites. The 5-channel AVHRR specifically measures the infrared (thermal) radiation given off by the surface layer of the ocean, which is a direct reflection of water temperature. NASA s Jet Propulsion Laboratory provides an

online user s guide with detailed information about data collection equipment and methodology (http://podaac.jpl.nasa.gov/pub/sea_surface_temperature/avhrr/pathfinder/doc/usr_gde4_0_toc.html; specifically, see Appendix A). Earlier editions of the user s guide are posted at http://podaac.jpl.nasa.gov/sst/sst_doc.html. Supplementary documentation sites: - Main SST data site: http://podaac.jpl.nasa.gov/sst/ - Additional documentation on Pathfinder AVHRR data: http://podaac.jpl.nasa.gov/cgi-bin/dcatalog/fam_summary.pl?sst+pfsst). (2) Conversion of raw thermal data to SST. NOAA performs this conversion based on models that show the relationship between water temperature and the thermal properties observed by satellite. The current SST data user s guide describes this algorithm in detail (http://podaac.jpl.nasa.gov/pub/sea_surface_temperature/avhrr/pathfinder/doc/usr_gde4_0_toc.html; specifically, see the section entitled Algorithms and Data Processing). Although processing algorithms have changed since the onset of data collection (1985), NOAA and NASA report that the full SST dataset now reflects the most up-to-date methodology. According to the data website: This dataset represents a historical reprocessing of the entire AVHRR time series using consistent SST algorithms, improved satellite and inter-satellite calibration, quality control and cloud detection (http://podaac.jpl.nasa.gov/sst/). (3) Calculation of seasonal means. NOAA divided SST data from near-shore U.S. waters (up to 25 miles offshore) into 9 geographic regions. From daily SST data, NOAA calculated mean SST values for the warmest season in each year (summer or fall, depending on the region). These annual values are labeled seasonal mean maxima. The Heinz Center used these data to calculated a long-term mean for each geographic region, consisting of the average of all seasonal mean maxima over the full period of observation (currently, 1985-1998). The Heinz Center provides a general description of mathematical processes in the 2002 technical note for this indicator (http://www.heinzctr.org/ecosystems/coastal_technotes/coasts_sea_srf_temp.shtml). According to the Heinz Center s (2002) general description of coastal indicators, NOAA divided data pixels in accordance with regions as defined under EPA s Environmental Monitoring and Assessment Program, which match the regions established under public law 101-593 for regional marine research (http://www.heinzctr.org/ecosystems/coastal/intro4.shtml). The Heinz Center s description includes a map delineating these regions. (4) Creation of an index to depict variation from the long-term mean. For each geographic region, the Heinz Center (2002) reports this indicator in terms of an anomaly that is, the percentage by which each year s seasonal mean maximum deviates from the long-term mean. The Heinz Center documents the basis of this index within its 2002 report.

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

NOAA and NASA allow free online access to the full global SST dataset derived from its AVHRR satellite imagery. Data are available at http://podaac.jpl.nasa.gov/cgi-bin/dcatalog/fam_summary.pl?avhrr+pfsst; this site can also be accessed through links from the main SST website, located at http://podaac.jpl.nasa.gov/sst/. These sites currently contain daily, 8-day average, and monthly data from 1985 to June 2003 (as of

December 2004). NOAA and NASA do not provide online access to the raw thermal imagery collected by the AVHRR equipment. However, NOAA maintains these raw data, as it reports that it recently revisited raw data to re-calculate historic SSTs using an improved algorithm (see also T1Q3 and T3Q1). Neither the Heinz Center nor NOAA/NASA provides online access to the specific subset of SST data points included in this indicator. However, NOAA can provide such metadata upon request, including SST by pixels (within 25 miles of the U.S. coast), SST by region, and seasonal mean maxima by region. For data requests or questions, a good contact at NOAA is Rick Stumpf (Richard.Stumpf@noaa.gov). The Heinz Center has published the exact numerical data that are represented in the graphics for this indicator: http://www.heinzctr.org/ecosystems/coastal/datasets/sst_west.shtml; http://www.heinzctr.org/ecosystems/coastal/datasets/sst_east.shtml.

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

Although historical data cannot be re-collected, NOAA has provided sufficient documentation of processing algorithms to allow full reproduction of SST figures from the raw data. The Heinz Center (2002) also presents information to enable seasonal means, long-term means, and overall SST indices to be reproduced. Geographic data sorting can be reproduced using the regional delineation discussed at http://www.heinzctr.org/ecosystems/coastal/intro4.shtml.

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

NOAA and NASA document quality assurance and quality control procedures for AVHRR satellite imagery in the current SST data user s guide (http://podaac.jpl.nasa.gov/pub/sea_surface_temperature/avhrr/pathfinder/doc/usr_gde4_0_toc.html; other user s guides linked from http://podaac.jpl.nasa.gov/sst/sst_doc.html). The user s guide includes an appendix specifically devoted to quality flagging of data points.

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

In developing this indicator, the Heinz Center (2002) has not made any effort to portray data beyond the spatial and temporal range of the chosen data subset. This indicator involves both spatial and temporal generalization, but in both forms, generalization essentially amounts to calculating averages. Spatially, the figures reported by this indicator represent averages by geographic region. Temporally, this indicator requires that SST data be averaged across the warmest season in each year. This represents a mathematical way to generalize broad trends within the data, as this indicator aims to do.

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

NOAA and NASA currently report that they expect temperatures to be measured within 0.3 to 0.5 degrees Celsius of actual values (http://podaac.jpl.nasa.gov/sst/). According to Richard Stumpf of NOAA (personal communication, 2005), the following statement best describes this uncertainty: The source daily data for the monthly means has an accuracy of 0.3 to 0.5 degrees C. According to the current SST data user s guide, NOAA is still in the process of determining the accuracy of its data (http://podaac.jpl.nasa.gov/pub/sea_surface_temperature/avhrr/pathfinder/doc/usr_gde4_0_toc.html; see section 2.2, Accuracy of AVHRR-derived SSTs, which includes supporting references). However, a future revision of uncertainty figures should not negatively impact this indicator, because NOAA anticipates that its recalculations will reveal an actual uncertainty that is lower than the figure currently reported (Richard Stumpf, NOAA, personal communication, 2005).

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

SST data naturally include day-to-day variability, but the Heinz Center has designed this indicator to reflect broader trends. Seasonal averaging reduces the impact of day-to-day variability. NOAA and NASA report uncertainty of 0.3 to 0.5 degrees Celsius in their SST data, which reflects the high precision and accuracy of NOAA s technologically advanced measuring equipment (http://podaac.jpl.nasa.gov/sst/). Cloud cover represents the main source of unquantified uncertainty in the raw satellite data. However, NOAA and NASA have a set of standard QA/QC procedures to filter out data tainted by clouds (see T3Q4). Thus, this uncertainty should not affect the utility of the processed SST data or the overall indicator. The SST data website notes two additional sources of error within NOAA s AVHRR survey (http://podaac.jpl.nasa.gov/sst/sst_prob.html), but they do not affect the utility of the indicator, as noted in the descriptions that follow: (1) In some locations, the Pathfinder processing algorithm incorrectly flags coastal ocean pixels as land. However, the largest of these areas are concentrated around South America and Australia, not the United States. NOAA has processed all SST data using the same algorithm. Thus, at worst, this error means that a few small areas very close to the shore have consistently been excluded from the data set. This does not introduce any year-to-year uncertainty into the SST indicator. (2) NOAA has identified some errors in SST at high latitudes, particularly SST measured below 6 degrees Celsius (specifically due to low brightness temperatures in channel 4 of the AVHRR on the NOAA-14 satellite). More information on this error can be found in Podesta et al. (2003). However, the SST indicator measures relative temperature change, not absolute temperature. Because this indicator also focuses on warm-season temperatures, this error, at worst, would affect data from far northern areas like the Bering Sea, and does not represent a major source of uncertainty. Podestá, G.P., M. Arbelo, R. Evans, K. Kilpatrick, V. Halliwell and J. Brown. 2003. Errors in high-latitude SSTs and other geophysical products linked to NOAA-14 AVHRR channel 4 problem. Geophysical Research Letters 30 (11): 1548

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

(1) Measures effects, not causes. Trends in this indicator do not necessarily implicate global climate change of anthropogenic or non-anthropogenic origin. Naturally occurring climate oscillations can cause noticeable fluctuations in sea surface temperature in U.S. coastal waters (see information and references related to the Pacific Decadal Oscillation, given on the website of the University of Washington s Joint Institute for the Study of the Atmosphere and Ocean: http://www.jisao.washington.edu/pdo/). (2) Limited to SSTs from warmest season only. By measuring temperature changes during only one season, this indicator may not address the full range of ways in which temperature changes can impact the health of the nation s coastal ecosystems. For example, warming in the cool season might allow a population to survive when otherwise, it would have died off or migrated to warmer waters. Warming and cooling in all seasons may affect nutrient cycling and migration patterns (Hayward, 1996; Blackbourn, 1987). Blackbourn D.J. 1987. Sea Surface Temperature and the Pre-Season Prediction of Return Timing in Fraser River Sockeye Salmon (Oncorhynchus nerka). In Smith HD., Margolis L., & Wood CC. [Ed.] Sockeye Salmon (Oncorhynchus nerka) Population, Biology, and Future Management. Canadian Special Publication of Fisheries and Aquatic Sciences, # 96. Hayward, T.L. 1996. Meeting Report: Long-term change in the North Pacific. CalCOFI Rep., Vol. 37. http://www.calcofi.org/newhome/publications/CalCOFI_Reports/v37/pdfs/Vol_37_Hayward.pdf (3) Data limitations. As currently presented by the Heinz Center (2002), this indicator covers the period 1985-1998, and it lacks any data for 1996 and 1997. According to the Heinz Center (2002), data are available for the period 1979-1984, but they are not sufficiently comprehensive to be included in this indicator. [The next web update of the Heinz Report is expected to occur in late 2005, and should incorporate full SST data available from NOAA/NASA for 1996, 1997, and 1999-2003.]