Chesapeake Bay Program | Indicator Analysis and Methods Document
Air Temperature (Average Temperature) | Updated September 2018

Indicator Title: Air Temperature (Average Temperature)

Relevant Outcome(s): Climate Monitoring and Assessment

Relevant Goal(s): Climate Resiliency

Location within Framework (i.e., Influencing Factor, Output or Performance): Influencing Factor for other Outcomes. These indicators are "Outputs" themselves, called for in the Climate Monitoring and Assessment Outcome of the 2014 Watershed Agreement.

A. Data Set and Source

(1) Describe the data set. What parameters are measured? What parameters are obtained by calculation? For what purpose(s) are the data used? This metric is based on temperature measurements collected from land-based weather stations, using standard meteorological instruments. Data were compiled in the *n*ClimDiv data set, which is overseen by the U.S. National Oceanographic and Atmospheric Administration (NOAA) and maintained by its National Centers for Environmental Information (NCEI). NOAA's *n*ClimDiv gridded analysis averages climate data over climate regions over the entire United States. Using these climate division-specific data, the slope of each temperature trend was calculated from the annual climate division anomalies by ordinary least-squares regression and then multiplied by 100 to obtain a rate of change per century.

This part of the indicator has been adapted from a national indicator maintained by the U.S. EPA. For more detailed information about EPA's indicator, see www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature.

(2) List the source(s) of the data set, the custodian of the source data, and the relevant contact at the Chesapeake Bay Program.
- Source: NOAA NCEI
- Custodian: Michael Kolian, Office of Atmospheric Programs, U.S. EPA
- Chesapeake Bay Program Contact (name, email address, phone number): Laura Drescher, Indicators Coordinator; drescher.laura@epa.gov, 410-267-5713

(3) Please provide a link to the location of the data set. Are metadata, data-dictionaries and embedded definitions included?
The map in this indicator is based on *n*ClimDiv monthly data by climate division, which are publicly available from NOAA at: www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp. For access to underlying

*n*ClimDiv data and documentation, see: www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php. Processed results for the nation are available in spreadsheet and map files on EPA's "Climate Change Indicators in the United States" website at www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature.

B. Temporal Considerations

(4) Data collection date(s): Data are collected continuously using standard meteorological instruments at permanent weather stations. Data have been collected since the 1800s at many stations. This indicator uses 1901 as a consistent starting point to balance the number of sites and the length of record.

(5) Planned update frequency (e.g., annual, biannual, etc.):
- Source Data: NOAA *n*ClimDiv climate data updated monthly and compiled annually for the previous full year
- Indicator: To be determined through further discussion with EPA

(6) Date (month and year) next data set is expected to be available for reporting: *n*ClimDiv annual data update expected in January 2019

C. Spatial Considerations

(7) What is the ideal level of spatial aggregation (e.g., watershed-wide, river basin, state, county, hydrologic unit code)? NOAA's data are spatially aggregated within climate divisions. Each state in the contiguous 48 states has one to 10 climate divisions. NOAA's algorithm is optimized to provide topographically sensitive spatial averages at this scale.

(8) Is there geographic (GIS) data associated with this data set? If so, indicate its format (e.g., point, line polygon). Yes, polygon data.

(9) Are there geographic areas that are missing data? If so, list the areas. No, all climate divisions within the Chesapeake Bay watershed are presented, but data collection is exclusively land-based.

(10) Please submit any appropriate examples of how this information has been mapped or otherwise portrayed geographically in the past. See the map published as part of EPA's national indicator at www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature.

D. Communicating the Data

(11) What is the goal, target, threshold or expected outcome for this indicator? How was it established? No explicit target. Temperature regimes are expected to change as regional and global circulation patterns change with a warmer global climate. The purpose of this indicator is to monitor the extent to which this key aspect of regional climate is changing—which can inform management decisions designed to increase climate resiliency and protect human and ecological health.

(12) What is the current status in relation to the goal, target, threshold or expected outcome? Not applicable.

(13) Has a new goal, target, threshold or expected outcome been established since the last reporting period? Why? Not applicable.

(14) Has the methodology of data collection or analysis changed since the last reporting period? How? Why? No.

(15) What is the long-term data trend (since the start of data collection)? Of the 33 climate divisions that lie at least partly within the Chesapeake Bay watershed, all but one have experienced a temperature increase that is statistically significant (to a 95 percent confidence level).

(16) What change(s) does the most recent data show compared to the last reporting period? To what do you attribute the change? Is this actual cause or educated speculation? This indicator views data in a long-term context suitable for climatological analysis. Authoritative scientific literature (e.g., assessments by the Intergovernmental Panel on Climate Change and the U.S. Global Change Research Program) has established that climate change is contributing to increases in mean annual temperature.

(17) What is the key story told by this indicator? All parts of the Chesapeake Bay watershed have experienced an increase in average air temperature since 1901. Rates of increase range from 0.4°F per century in southern West Virginia to more than 2.5°F per century in Delaware. In general, areas closer to the mainstem Chesapeake Bay have experienced more warming than some areas farther upstream.

E. Adaptive Management

(18) What factors influence progress toward the goal, target, threshold or expected outcome? Factors that can influence regional temperatures include: the precipitation and humidity regimes of surrounding regions; regional and global atmospheric circulation patterns; the magnitude and frequency of inter-annual and decadal-scale oscillation patterns (such as El Niño, La Niño, Pacific Decadal Oscillation, etc.); land use; and climate change. To reduce the influence of some of

the non-climatic factors on this indicator, this indicator uses data from land-based weather stations that are sited to minimize the influence of orientation, vegetation, and physical obstructions that could skew temperature measurements.

(19) What are the current gaps in existing management efforts? Mitigation of climate change requires coordinated global action that is beyond the purview of the Chesapeake Bay Program, but local and regional actions to reduce greenhouse gas emissions can still contribute to these broader solutions.

(20) What are the current overlaps in existing management efforts? Urban tree canopy, green roofs, controlling the growth of impervious paved surfaces, and other strategies to manage the built environment can yield multiple benefits, including stormwater management, water quality improvement, and reduction of local "heat islands" that are otherwise exacerbated by overall increases in regional air temperature.

(21) According to the management strategy written for the outcome associated with this indicator, how will we (a) assess our performance in making progress toward the goal, target, threshold or expected outcome, and (b) ensure the adaptive management of our work? Not applicable to this outcome.

F. Analysis and Interpretation

Please provide appropriate references and location(s) of documentation if hard to find.

(22) What method is used to transform raw data into the information presented in this indicator? Please cite methods and/or modeling programs. NOAA calculated monthly temperature means for each site. In populating the GHCN and *n*ClimDiv, 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.

The analysis that supports this indicator involves converting observed temperature data into anomalies. Thus, the final map actually presents trends in anomalies. An anomaly represents the difference between an observed value and the corresponding value from a baseline period. Thus, like any analysis that uses anomalies, this analysis requires selection of a baseline period for comparison. This particular indicator uses a baseline period of 1901 to 2000, which means a temperature equal to the 1901–2000 average would be an anomaly of 0, and a temperature 1 degree higher than that long-term average would be an anomaly of +1. NOAA selected 1901–2000 as a baseline for consistency across a variety of climatological data products that the NCEI produces. While NOAA could have used the average over the entire period of record (1901–2017) as the long-term baseline, that would mean the baseline period would change every year, which would require recalculation of every historical year's anomalies every year because of an ever-changing baseline. A consistent 1901–2000 baseline offers more stability. The choice of baseline period will not affect the shape or the statistical significance of the overall trend in anomalies. If one were to look at the annual average temperature anomaly at each site as a time series, a different baseline would just shift the curve up or down but not change its shape.

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 calculated area-weighted averages of grid-point estimates interpolated from station data. The map shows the overall change in temperature over the United States for the period from 1901 to 2017. It is based on the *n*ClimDiv gridded data set, which is derived from a high-resolution (5-kilometer) interpolated grid that accounts for station density and topography. See: ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt for more information.

The slope of each climate division's temperature trend was calculated from annual climate division anomalies (in degrees Fahrenheit) by ordinary least-squares regression and multiplied by 100 to get the trend in degrees per century. The regression slope was calculated over the entire period of record (117 years), but the results are presented in terms of a rate of change per century (100 years) for communication purposes. Specifically, presenting rates in terms of annual change would lead to very small numbers that are difficult to understand and arguably harder for the typical reader to grasp the magnitude of: for example, 0.02 degrees per year. In contrast, people can more readily perceive and understand a difference of 2 degrees, which the text explains is the amount of change that has occurred over a 100-year period.

(23) Is the method used to transform raw data into the information presented in this indicator accepted as scientifically sound? If not, what are its limitations? Yes. The *n*ClimDiv methods have been peer reviewed for publication in the scientific literature, and a national version of this indicator has also been peer reviewed for inclusion in EPA's climate change indicator suite, which requires each indicator to meet a set of 10 criteria for data quality (see the technical documentation overview at www.epa.gov/climate-indicators/downloads-indicators-technical-documentation).

One acknowledged methodological limitation is that 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.

(24) How well does the indicator represent the environmental condition being assessed? This indicator uses an acknowledged method to analyze trends in precipitation, although it is not the only method of doing so. Another option would be to compare shorter timespans or non-linear statistical methods to detect changes in the shape of the trend (e.g., acceleration) over time. Each approach has advantages and disadvantages.

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

- As noted above, biases in measurements may have occurred as a result of changes over time in instrumentation, measuring procedures, and the exposure and location of the instruments. Where possible, data have been adjusted to account for changes in these variables. However, some scientists believe that the empirical debiasing models used to adjust the data might themselves introduce non-climatic biases.

- Uncertainties in surface temperature data increase as one goes back in time, as there are fewer stations early in the record. These uncertainties are not sufficient, however, to mislead the user about fundamental trends in the data.

(25) Are there established reference points, thresholds, ranges or values for this indicator that unambiguously reflect the desired state of the environment? No.

(26) How far can the data be extrapolated? 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)? No attempt has been made to extrapolate data beyond the sampled sites and the timeframe of analysis. The *n*ClimDiv algorithm that forms the foundation of this indicator involves interpolation between stations to develop a high-resolution gridded temperature product. This method was carefully designed to account for topography and other factors, and it has been peer reviewed.

G. Quality

Please provide appropriate references and location(s) of documentation if hard to find.

(27) Were the data collected and processed according to a U.S. Environmental Protection Agency-approved Quality Assurance Project Plan? If so, please provide a

link to the QAPP and indicate when the plan was last reviewed and approved. **If not, please complete questions 29-31.** No.

(28) *If applicable:* Are the sampling, analytical and data processing procedures accepted as scientifically and technically valid? Yes. All measurements are made according to standard NOAA procedures. Analytical and data processing procedures have been peer reviewed and accepted as valid.

(29) *If applicable:* What documentation describes the sampling and analytical procedures used? See the technical documentation for EPA's "U.S. and Global Temperature" indicator at www.epa.gov/climate-indicators/downloads-indicators-technical-documentation, as well as the NOAA and scientific literature references cited therein.

(30) *If applicable:* To what extent are procedures for quality assurance and quality control of the data documented and accessible? NCEI's databases have undergone extensive quality assurance procedures to identify errors and biases in the data and to either remove these stations from the time series or apply correction factors. The *n*ClimDiv data set follows the U.S. Historical Climatology Network's (USHCN's) methods to detect and correct station biases brought on by changes to the station network over time. The transition to a grid-based calculation did not significantly change national averages, but it has led to improved historical temperature values in certain regions, particularly regions with extensive topography above the average station elevation—topography that is now being more thoroughly accounted for. An assessment of the major impacts of the transition to *n*ClimDiv can be found at: www.ncdc.noaa.gov/monitoring-references/docs/GrDD-Transition.pdf.

(31) Are descriptions of the study design clear, complete and sufficient to enable the study to be reproduced? Yes. The technical documentation for EPA's "U.S. and Global Temperature" indicator at www.epa.gov/climate-indicators/downloads-indicators-technical-documentation, as well as the NOAA and scientific literature references cited therein, provide thorough documentation to allow methods to be reproduced.

(32) Were the sampling, analytical and data processing procedures performed consistently throughout the data record? Yes, except as corrected for and described in question (30).

(33) If data sets from two or more sources have been merged, are the sampling designs, methods and results comparable? If not, what are the limitations? Not applicable, as all data derive from one source.

(34) Are levels of uncertainty available for the indicator and/or the underlying data set? If so, do the uncertainty and variability impact the conclusions drawn from the data or the utility of the indicator? Uncertainties in temperature data increase as one goes back in time, as there are fewer stations early in the record. These uncertainties are not sufficient, however, 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: 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.

Annual temperature anomalies naturally vary from location to location and from year to year as a result of normal variations 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.

Vose, R.S., and M.J. Menne. 2004. A method to determine station density requirements for climate observing networks. J. Climate 17(15):2961–2971.

(35) For chemical data reporting: How are data below the MDL reported (i.e., reported as 0, censored, or as < MDL)? If parameter substitutions are made (e.g., using orthophosphate instead of total phosphorus), how are data normalized? How does this impact the indicator? Not applicable, as no chemical data have been collected.

(36) Are there noteworthy limitations or gaps in the data record? No.

H. Additional Information (*Optional)*

(37) Please provide any further information you believe is necessary to aid in communication and prevent any potential misrepresentation of this indicator. This indicator uses ordinary least-squares regression to calculate the slope of the observed trends in temperature. A simple t-test indicates that 32 of the 33 climate divisions shown in the map have statistically significant temperature trends based on ordinary least-squares linear regression and a 95-percent confidence threshold ($p < 0.05$). All of these significant trends represent increases in temperature.