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

Indicator Title: Air Temperature (Unusually Hot Temperatures)

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 Global Historical Climatology Network, Daily edition (GHCN-Daily), which is a data set overseen by the U.S. National Oceanographic and Atmospheric Administration (NOAA) and maintained by its National Centers for Environmental Information (NCEI).

This metric is based on calculations performed on the GHCN-Daily data for weather stations with sufficient long-term data. The methods for this indicator involve calculating percentiles for daily maximum temperatures; identifying exceedances of those percentiles, which represent "unusually hot" days; and calculating trends in the prevalence of unusually hot days over time. Methods are described in more detail below in question (22).

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-high-and-low-temperatures.

(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? Data for this map came from Version 3.22 of NCEI's GHCN-Daily data set, which provided the optimal format for processing. Within the contiguous 48 states, the GHCN pulls data directly from a dozen separate data sets maintained at NCEI. NCEI explains the variety of databases that feed into the GHCN for U.S.-based stations in online metadata and at www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn. The data for this indicator can be obtained online via FTP at ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/hcn. Appropriate metadata and "readme" files are available at ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily.

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 analysis is limited to the period from 1948 to present because it enabled inclusion of most stations from the U.S. Historical Climatology Network (USHCN), which is a key contributing database to the GHCN-Daily.

(5) Planned update frequency (e.g., annual, biannual, etc.):
- Source Data: NOAA GHCN-Daily climate data updated throughout the year; summary statistics 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: GHCN 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)? This indicator works best as a disaggregated map that shows trends at each individual monitoring site. The data are not designed for aggregation into larger spatial units.

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

(9) Are there geographic areas that are missing data? If so, list the areas. No, but station density varies depending on where weather stations with high-quality long-term data happen to be located.

(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-high-and-low-temperatures.

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)? Most of the long-term weather stations in this part of the country have not experienced a significant change in the number of unusually hot days per year since 1948, based on this definition of an unusually hot day.

(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 generally contributing to increases in the frequency and intensity of hot temperature extremes.

(17) What is the key story told by this indicator? Based on the definition of an unusually high temperature used for this metric, these types of extremely hot days have become more common in some parts of the country, but not in the Chesapeake region. However, other metrics such as the "tropical nights" analysis (which the CBP is considering adding to this indicator in the future)—which examines trends in nighttime minimum temperatures rather than daily maxima—show a clear warming trend in the Chesapeake region.

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 amplify the effects of extremely high temperatures.

(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. First, data are filtered for quality. Station data are included only for years in which data are reported (one or more days) in six or more months. If a station reported data from fewer than six months, data from the entire year are removed. After filtering for individual years, stations are removed from further consideration if fewer than 48 years of data are included. Years need not be consecutive. As a result, the map shows trends for approximately 1,093 stations.

Next, the change in the number of days per year on which the daily maximum temperature exceeded the 95th percentile temperature is determined through the following steps:

1. At each monitoring station, the 95th percentile daily maximum temperature is determined for the full period of record (starting in 1948).

2. For each station, the number of days in each calendar year on which the maximum daily temperature exceeded the station-specific 95th percentile temperature is determined.

3. The average rate of change over time in the number of >95th percentile days is estimated from the annual number of >95th percentile days using ordinary least-squares linear regression.

4. Regression coefficients (the average change per year in >95th percentile days) for regressions significant at the 90-percent level ($p \leq 0.1$) are multiplied by the number of years in the analysis to estimate the total change in the number of annual >95th percentile days over the full period of record. Where $p > 0.1$, coefficients are set to zero. These values (including "zero" values for stations with insignificant trends) are mapped to show trends at each climate station.

(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. GHCN compilation and bias correction 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 unusually high temperatures, although it is not the only method of doing so. Other studies have used different percentiles, defined the percentiles differently (for example, based on only certain months of the year), used fixed temperature thresholds instead of percentiles, focused on multi-day heat waves, or focused on daily minimum rather than daily maximum temperatures (so as to capture the presence or absence of nighttime cooling, which is important for human physiology). Each approach has advantages and disadvantages.

Factors that may impact the confidence, application, or conclusions drawn from this indicator include biases in measurements, which, as noted above, 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.

(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. No attempt has been made to interpolate results between sampled sites. It is most appropriate to focus this indicator on the specific sites where data have been collected.

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 "High and Low Temperatures" 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? NOAA's National Weather Service has documented methods for collecting data at NOAA and cooperative (COOP) weather stations, including training manuals and maintenance of equipment, at https://training.weather.gov/coop.php. These training materials also discuss quality control of the underlying data set. Data from weather stations go through a variety

of additional quality assurance and quality control (QA/QC) procedures before they can be added to historical data sets such as the USHCN and GHCN. Procedures that were used to address specific potential problems in trend estimation in the most recent version of the USHCN are summarized at www.ncdc.noaa.gov/ushcn/introduction. Homogeneity testing and data correction methods are described in numerous peer-reviewed scientific papers by NCEI. 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 and beyond. 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).

QC procedures for GHCN-Daily data are described at www.ncdc.noaa.gov/ghcn-daily-methods. GHCN-Daily data undergo rigorous QA reviews, starting with pre-screening for data and station appropriateness. The URL listed previously also provides a detailed description of the data integration process. Further QA procedures for individual data points include removal of duplicates, isolated values, suspicious streaks, and excessive or unnatural values; 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. Data that fail a given QC check (0.3 percent of all values) are marked with flags, depending on the type of error identified.

(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 "High and Low Temperatures" 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). NOAA's Climate Reference Network (www.ncdc.noaa.gov/crn), a set of optimally-sited stations completed in 2008, can be used to test the accuracy of recent trends. While it is true that some stations are not optimally located, NOAA's findings support the results of an earlier analysis by Peterson (2006), who found no significant bias in long-term trends associated with station siting once NOAA's homogeneity adjustments were applied. An independent analysis by the Berkeley Earth Surface Temperature (BEST) project

(http://berkeleyearth.org/summary-of-findings) used more stations and a different statistical methodology, yet found similar results.

Peterson, T.C. 2006. Examination of potential biases in air temperature caused by poor station locations. B. Am. Meteorol. Soc. 87:1073–1080. http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-87-8-1073.

(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 this particular analysis.

Inter-annual temperature variability results from normal year-to-year variation in weather patterns, multi-year climate cycles such as the El Niño–Southern Oscillation and Pacific Decadal Oscillation, and other factors. This indicator presents long-term rates of change to reduce the year-to-year "noise" inherent in the data. Temperature patterns also vary spatially. This indicator provides information on geographic differences using location-specific trends.

(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. No additional information recommended.