Seasonal Temperature

Identification

1. Indicator Description

This indicator describes changes in average seasonal air temperature for the United States from 1896 to 2023. Temperature data for each season (winter, spring, summer, fall) are presented as trends in anomalies. Air temperature is an important indicator of climate, and changes in temperature can have wide-ranging direct and indirect effects on the environment and society. Evidence of a warming climate often begins with average surface temperature (Marvel et al., 2023).

Components of this indicator include:

- Changes in average air temperature by season in the contiguous 48 states over time (Figure 1).
- Maps showing the total change in average air temperature by state and by season, across the contiguous 48 states (Figure 2).
- A comparison of long-term trends in the contiguous 48 states for all four seasons (Figure 3).

2. Revision History

April 2021:	Indicator published.
July 2022:	Updated indicator with data through 2021.
June 2024:	Updated indicator with data through 2023.

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 Centers for Environmental Information (NCEI), formerly the National Climatic Data Center (NCDC). Specifically, all three figures in this indicator use data from NCEI's *n*ClimDiv data set, which is based on data from the daily version of the Global Historical Climatology Network (GHCN-Daily). GHCN-Daily data undergo more extensive processing by NCEI on a monthly basis for inclusion in *n*ClimDiv.

4. Data Availability

The *n*ClimDiv data used in each figure can be accessed online, along with descriptions and metadata. Surface temperature time series data for the contiguous 48 states (Figure 1 and Figure 3) and by state (Figure 2) are based on *n*ClimDiv data that were obtained from NCEI's "Climate at a Glance" web interface (www.ncdc.noaa.gov/cag). For access to underlying *n*ClimDiv data and documentation, see: www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php.

EPA downloaded data in February 2024, at which point data for all four seasons were available through 2023 (where winter 2023 is the season running from December 2022 through February 2023).

Methodology

5. Data Collection

This indicator is based on surface temperature measurements that were compiled from thousands of weather stations throughout the United States using standard meteorological instruments. All of the stations are overseen by NOAA, and their methods of site selection and quality control have been extensively peer reviewed. Data from these stations for the contiguous 48 states were compiled in the *n*ClimDiv data set, which represents the most complete long-term instrumental data set for analyzing recent climate trends in the contiguous 48 states.

The *n*ClimDiv divisional data set incorporates temperature data from GHCN-Daily stations in the contiguous 48 states and Alaska. This data set includes stations that were previously part of the U.S. Historical Climatology Network (USHCN), as well as additional stations that were able to be added to *n*ClimDiv as a result of quality-control adjustments and digitization of paper records. Altogether, *n*ClimDiv incorporates data from more than 10,000 stations. These stations are spread among 357 climate divisions in the contiguous 48 states and Alaska.

In addition to incorporating more stations, the *n*ClimDiv data set differs from the USHCN because it incorporates a grid-based computational approach known as climatologically aided interpolation (Willmott & Robeson, 1995), which helps to address topographic variability. Data from individual stations are combined in a grid that covers the entire contiguous 48 states and Alaska with 5-kilometer resolution. These improvements have led to a new data set that maintains the strengths of its predecessor data sets while providing more robust estimates of area averages and long-term trends. The *n*ClimDiv data set is NOAA's official temperature data set for the contiguous 48 states and Alaska, replacing USHCN.

The *n*ClimDiv data set starts in 1895. This indicator starts in 1896 for consistency, due to the way winter is defined (see more details in Section 6). To learn more about *n*ClimDiv, see: www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00005 and: www.ncei.noaa.gov/access/monitoring/reference-maps/conus-climate-divisions.

6. Indicator Derivation

General Data Processing Steps

NOAA calculated monthly temperature means for each station represented in the *n*ClimDiv data set. In populating the data set, 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.

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 surface time series for the contiguous 48 states (Figure 1) is based on the *n*ClimDiv gridded data set, which reflects a high-resolution (5-kilometer) interpolated grid that accounts for station density and topography. Results were initially averaged within each climate division, then aggregated by state and for the contiguous 48 states as a whole based on an area-weighted average of climate divisions. See: www.ncei.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt for more information.

In this indicator, the four seasons correspond with the meteorological seasons. Winter corresponds to the months December–February, spring is March–May, summer is June–August, and fall is September–November. NOAA averaged monthly means across each three-month period to derive seasonal temperature data points for each year. Winter data are nominally assigned to the year in which the winter ended; for example, "1896" refers to the consecutive three-month period of December 1895, January 1896, and February 1896. Because the *n*ClimDiv data set does not include data for December 1894, the seasonal temperature time series in this indicator start in the year 1896 to allow for consistency across all four seasons.

Figure 1. Average Seasonal Temperatures in the Contiguous 48 States, 1896–2023

Figure 1 presents temperature data across the contiguous 48 states in terms of anomalies for each season. 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 a sufficiently long-term average or baseline period (e.g., at least 30 years) will not substantially affect the shape or the statistical significance of the overall trend in anomalies. For absolute anomalies in degrees, it only moves the trend up or down on the graph in relation to the point defined as "zero."

Figure 2. Change in Seasonal Temperatures by State, 1896–2023

The maps in Figure 2 show the long-term change in temperature by state for each season for the period from 1896 to 2023. The slope of each temperature trend was calculated from the three-month climate division anomalies by ordinary least-squares regression and then multiplied by the change in years (2023 - 1896 = 127) to estimate the total change over the period of record.

Figure 3. Temperature Change by Season in the Contiguous 48 States, 1896–2023

Figure 3 presents long-term temperature changes in all four seasons. The graph shows the total change for each season, derived from the ordinary least-squares regression slope (°F per year) multiplied by 127 years.

Indicator Development

NOAA continually refines historical data points in the GHCN and *n*ClimDiv, often as a result of improved methods to reduce bias and exclude erroneous measurements. As EPA updates this indicator to reflect these upgrades, slight changes to some historical data points may become apparent. No attempt has been made to portray data beyond the time and space in which measurements were made.

7. Quality Assurance and Quality Control

NCEI's databases 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. The *n*ClimDiv data set follows the 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 and totals, 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.

Analysis

8. Comparability Over Time and Space

Both *n*ClimDiv 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. See Section 7 for documentation.

All GHCN-Daily stations are routinely processed through a suite of logical, serial, and spatial quality assurance reviews to identify erroneous observations. For *n*ClimDiv, all such observations were set to "missing" before computing monthly values, which in turn were subjected to additional serial and spatial checks to eliminate residual outliers. Stations having at least 10 years of valid monthly data since 1950 were used in *n*ClimDiv.

For temperature, bias adjustments were computed to account for historical changes in observation time, station location, temperature instrumentation, and siting conditions. As with USHCN, the method of Karl et al. (1986) was applied to remove the observation time bias from the COOP network, and the pairwise method of Menne and Williams (2009) was used to address changes in station location and instrumentation in all networks. Because the pairwise method also largely accounts for local, unrepresentative trends that arise from changes in siting conditions, *n*ClimDiv contains no separate adjustment in that regard.

For more documentation about *n*ClimDiv, see: www.ncei.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt.

9. 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. These uncertainties are not sufficient, however, to mislead the user about fundamental trends in the data (Vose & Menne, 2004).

3. Alaska, Hawaii, and U.S. territories are not included in this indicator. Alaska data are included in the *n*ClimDiv data set, but sufficient data are not available before 1925. Hawaii and U.S. territories also have limited data, and *n*ClimDiv spatial interpolation methods have not been developed and validated for these regions.

10. Sources of Uncertainty

Error estimates are not readily available for U.S. temperature. 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. Vose and Menne (2004) suggest that the station density in the U.S. climate network is sufficient to produce a robust spatial average.

11. Sources of Variability

Seasonal 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 minimizes the effect of these factors by presenting a long-term record (more than a century of data) and averaging consistently over time and space.

12. Statistical/Trend Analysis

This indicator uses ordinary least-squares regression to calculate the slope of the observed trends in temperature for each season. This slope is the basis for presenting total long-term change in Figures 2 and 3. Table TD-1 shows the resulting regression coefficients and the corresponding p-values (via simple t-test) for the contiguous 48 states, which are significant at the 95 percent confidence level ($p < 0.05$) in all four seasons. Table TD-1 also summarizes the results of state-level significance testing. All significant state trends showed increasing temperatures.

Table TD-1. Linear Regression of Seasonal Average Temperature Data, 1896–2023

Season	Contiguous 48 states		State-specific trends	
	Slope (°F/year)	P-value	Number of states with significant change ($p < 0.05$)	Number of states with no significant change
Winter	0.023	< 0.0001	42	6
Spring	0.015	< 0.0001	38	10
Summer	0.013	< 0.0001	31	17
Fall	0.013	< 0.0001	32	16

Use of linear regression and a simple t-test inevitably requires some assumptions about the shape and underlying characteristics of the data. These tests are used to provide initial approximations about the statistical attributes of this indicator.

References

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