U.S. and Global Precipitation

Identification

1. Indicator Description

This indicator describes changes in total precipitation over land for the United States and the world from 1901 to 2023. In this indicator, precipitation data are presented as trends in anomalies. Precipitation is an important component of climate, and changes in precipitation can have wide-ranging direct and indirect effects on the environment and society. As average temperatures at the Earth's surface rise, more evaporation occurs, which, in turn, increases overall precipitation. Therefore, a warming climate is expected to increase precipitation in many areas. However, factors such as shifting wind patterns and changes in the ocean currents that drive the world's climate system will also cause some areas to experience decreased precipitation.

Components of this indicator include:

- Changes in precipitation in the contiguous 48 states over time (Figure 1).
- Changes in worldwide precipitation over land through time (Figure 2).
- A map showing the percent change in total annual precipitation since the early 20th century across the contiguous 48 states and Alaska (Figure 3).

2. Revision History

April 2010:	Indicator published.
December 2012:	Updated indicator with data through 2011.
August 2013:	Updated indicator with data through 2012.
June 2015:	Updated Figures 1 and 3 with data through 2014; updated Figure 2 with data through 2013.
August 2016:	Updated indicator with data through 2015.
April 2021:	Updated indicator with data through 2020 for Figures 1 and 3 and through 2019 for Figure 2.
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 precipitation 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), and the Deutscher Wetterdienst's (German Meteorological Service's) Global Precipitation Climatology Centre (GPCC). Specifically, this indicator uses the following data sets:

- Figure 1, contiguous 48 states precipitation; Figure 3, precipitation map: *n*ClimDiv.

- Figure 2, global precipitation: GPCC.

*n*ClimDiv is based on data from the daily version of the Global Historical Climatology Network (GHCN-Daily). These data undergo more extensive processing by NCEI on a monthly basis for inclusion in *n*ClimDiv.

4. Data Availability

All of the underlying data sets can be accessed online, along with descriptions and metadata. Specific data sets were obtained as follows.

Contiguous 48 States Time Series

Precipitation time series data for the contiguous 48 states (Figure 1) are based on *n*ClimDiv data that were obtained from NCEI's "Climate at a Glance" web interface (www.ncei.noaa.gov/access/monitoring/climate-at-a-glance). For access to underlying *n*ClimDiv data and documentation, see: www.ncei.noaa.gov/access/monitoring/reference-maps/conus-climate-divisions.

Global Time Series

GPCC global precipitation data (Figure 2) are presented in NCEI's annual "State of the Climate" analysis, which is published in a special edition of the *Bulletin of the American Meteorological Society* every summer. EPA obtained the most recent data from NCEI staff, reflecting GPCC global precipitation anomalies through 2023. A version of this analysis appears in "State of the Climate in 2022" (Blunden et al., 2023). However, the analysis shown in EPA's indicator differs because it covers a longer period ("State of the Climate" only displays this particular data set from 1979 forward and only extends through 2022). For access to underlying GPCC data and documentation, see: www.dwd.de/EN/ourservices/gpcc/gpcc.html.

Contiguous 48 States and Alaska Map

The map in this indicator (Figure 3) is based on *n*ClimDiv monthly data by climate division, which are publicly available from NCEI at: www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/divisional/mapping.

Methodology

5. Data Collection

This indicator is based on precipitation measurements collected from thousands of land-based weather stations throughout the United States and worldwide, using standard meteorological instruments. Data for the contiguous 48 states and Alaska were compiled in the *n*ClimDiv data set. Data for the rest of the world were taken from GPCC data sets. All of the networks cited here are overseen by NOAA, and their methods of site selection and quality control have been extensively peer reviewed. As such, they represent the most complete long-term instrumental data sets for analyzing recent climate trends. More information on these networks can be found below.

Contiguous 48 States Time Series; Contiguous 48 States and Alaska Map

The *n*ClimDiv divisional data set incorporates precipitation 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.

To learn more about *n*ClimDiv, see: www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00005, www.ncei.noaa.gov/access/monitoring/reference-maps/conus-climate-divisions, and Vose et al. (2014). Also see Vose et al. (2017) for details of the more recent effort to apply *n*ClimDiv methods to Alaska.

Global Time Series

GPCC compiles monthly climate data from up to 84,000 weather stations worldwide—about 40,000 of which are considered to have complete data. GPCC's monthly precipitation analysis products are based on anomalies from the climatological normals at the stations. The anomalies are spatially interpolated and GPCC applies climatological infilling for regions where an entire grid is without any station for the analysis month given. Deutscher Wetterdienst has published documentation for GPCC. For more information, including data sources, methods, and recent improvements, see: www.dwd.de/EN/ourservices/gpcc/gpcc and the sources listed therein.

6. Indicator Derivation

Contiguous 48 States and Global Time Series

NOAA calculated monthly precipitation totals for each site. In populating the GHCN and *n*ClimDiv, NOAA 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.

In this indicator, precipitation data are presented as trends in anomalies. 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 for the contiguous 48 states and global data, and a baseline period of 1925 to 2000 for Alaska data due to sparse data prior to 1925. The choice of baseline period will not affect the shape or the statistical significance of the overall trend in anomalies. For absolute anomalies in inches, it only moves the trend up or down on the graph in relation to the point defined as "zero."

To generate the precipitation time series, NOAA converted total annual precipitation measurements, measured in millimeters, into anomalies. EPA converted NOAA's final results from millimeters to inches.

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 precipitation 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. See: www.ncei.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt for more information. The global graph (Figure 2) comes from an analysis of grid cells measuring 1 degree by 1 degree. See: https://opendata.dwd.de/climate_environment/GPCC/html/download_gate.html for more information.

Figures 1 and 2 show trends from 1901 to 2023 based on NOAA and GPCC's gridded data sets, respectively. Although earlier data are available for some stations, 1901 was selected as a consistent starting point.

Contiguous 48 States and Alaska Map

The map in Figure 3 shows the overall change in precipitation over the United States for the period from 1901 to 2023, except for Alaska, for which widespread and reliable data collection did not begin until 1925 (therefore the map shows 1925–2023 for Alaska). Hawaii and U.S. territories are not included in this figure, due to insufficient data completeness or length of the measurement record. This map is based on NOAA's *n*ClimDiv gridded analysis, with results averaged within each climate division. The slope of each precipitation trend was calculated from annual climate division anomalies (in inches) by ordinary least-squares regression, then multiplied by the length of the entire period of record to get total change in inches. The total change was then converted to percent change, using average precipitation during the standard baseline period (1901–2000 for the contiguous 48 states; 1925–2000 for Alaska) as the denominator.

Indicator Development

NOAA initially released the *n*ClimDiv data set in 2014, which allowed this indicator to use climate divisions in Figure 3 and a high-resolution climate division-based gridded analysis for Figure 1. Previous versions of EPA's indicator presented a contiguous 48 states time series and a United States map based on a coarse grid analysis, which was the best analysis available from NOAA at the time.

NOAA is continually refining 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 to either remove these stations from the time series or apply correction factors.

Contiguous 48 States Time Series; Contiguous 48 States and Alaska Map

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.

Global Time Series

QA/QC procedures for GPCC precipitation data are described by Schneider et al. (2013). Gridded gauge-analysis products provided by GPCC are not bias corrected for systematic gauge measuring errors. However, GPCC provides estimates for that error.

Analysis

8. Comparability Over Time and Space

Both *n*ClimDiv and GPCC have undergone extensive testing to identify errors and biases in the data and either remove problematic stations from the time series or apply scientifically appropriate correction factors to improve the utility of the data. In particular, these corrections address advances in instrumentation and station location changes. See Section 7 for documentation.

Contiguous 48 States Time Series; Contiguous 48 States and Alaska Map

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

Global Time Series

GPCC uses a variable number of stations per grid cell over time, based on fluctuating data availability. However, all methods have been applied consistently over time and space. See "Quality Assurance and Quality Control" for documentation.

9. Data Limitations

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

1. 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. For more information on these corrections, see Section 7.

2. As noted in Section 10, uncertainties in precipitation data increase as one goes back in time, as there are fewer stations early in the record. However, these uncertainties are not sufficient to undermine the fundamental trends in the data.

10. Sources of Uncertainty

Uncertainties in precipitation data increase as one goes back in time, as there are fewer stations early in the record. However, these uncertainties are not sufficient to undermine the fundamental trends in the data.

Error estimates are not readily available for U.S. or global precipitation. 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

Annual precipitation anomalies naturally vary from location to location and from year to year as a result of normal variation 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.

12. Statistical/Trend Analysis

This indicator uses ordinary least-squares regression to calculate the slope of the observed trends in precipitation. A simple t-test indicates that the following observed trends are significant at the 95-percent confidence level:

- Contiguous 48 states precipitation, 1901–2023: +0.018 inches/year ($p = 0.002$).
- Global precipitation, 1901–2023: +0.003 inches/year ($p = 0.02$).

Among the individual climate divisions shown in Figure 3, 148 divisions (41 percent) have statistically significant precipitation trends, based on ordinary least-squares linear regression and a 95-percent confidence threshold. Significant trends include both increases and decreases.

References

Blunden, J., Boyer, T., & Bartow-Gillies, E. (2023). State of the climate in 2022. *Bulletin of the American Meteorological Society*, *104*(9), S1–S516. https://doi.org/10.1175/2023BAMSStateoftheClimate.1

Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Ziese, M., & Rudolf, B. (2013). GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle. *Theoretical and Applied Climatology*, *115*(1–2), 15–40. https://doi.org/10.1007/s00704-013-0860-x

Vose, R. S., Applequist, S., Squires, M., Durre, I., Menne, M. J., Williams, C. N., Fenimore, C., Gleason, K., & Arndt, D. (2014). Improved historical temperature and precipitation time series for U.S. climate divisions. *Journal of Applied Meteorology and Climatology*, *53*(5), 1232–1251. https://doi.org/10.1175/JAMC-D-13-0248.1

Vose, R. S., & Menne, M. J. (2004). A method to determine station density requirements for climate observing networks. *Journal of Climate*, *17*(15), 2961–2971. https://doi.org/10.1175/1520-0442(2004)017<2961:AMTDSD>2.0.CO;2

Vose, R., Squires, M., Arndt, D., Durre, I., Fenimore, C., Gleason, K., Menne, M., Partain, J., Jr, W., Bieniek, P., & Thoman, R. (2017). Deriving historical temperature and precipitation time series for Alaska climate divisions via climatologically aided interpolation. *Journal of Service Climatology*, *10*(1). https://doi.org/10.46275/JoASC.2017.10.001

Willmott, C. J., & Robeson, S. M. (1995). Climatologically aided interpolation (CAI) of terrestrial air temperature. *International Journal of Climatology*, *15*(2), 221–229. https://doi.org/10.1002/joc.3370150207