Heavy Precipitation

Identification

1. Indicator Description

This indicator tracks the frequency of heavy precipitation events in the United States between 1895 and 2015. Heavy precipitation is a useful indicator because climate change can affect the intensity and frequency of precipitation. Warmer oceans increase the amount of water that evaporates into the air, and when more moisture-laden air moves over land or converges into a storm system, it can produce more intense precipitation—for example, heavier rain and snow storms (Tebaldi et al., 2006). The potential impacts of heavy precipitation include crop damage, soil erosion, flooding, and diminished water quality.

Components of this indicator include:

- Percent of land area in the contiguous 48 states experiencing abnormal amounts of annual precipitation from one-day events (Figure 1).
- Percent of land area in the contiguous 48 states with unusually high annual precipitation (Figure 2).

2. Revision History

April 2010:	Indicator published.
December 2012:	Updated indicator with data through 2011.
August 2013:	Updated indicator on EPA's website with data through 2012.
May 2014:	Updated indicator with data through 2013.
June 2015:	Updated indicator on EPA's website with data through 2014.
August 2016:	Updated indicator with data through 2015.

Data Sources

3. Data Sources

This indicator is based on precipitation measurements collected at weather stations throughout the contiguous 48 states. These data are compiled and managed by the National Oceanic and Atmospheric Administration's (NOAA's) National Centers for Environmental Information (NCEI), formerly the National Climatic Data Center (NCDC). Indicator data were obtained from NCEI.

4. Data Availability

Individual station precipitation data are maintained at NOAA's NCEI, and the data are distributed on various computer media (e.g., anonymous FTP sites), with no confidentiality issues limiting accessibility. Individual station measurements and metadata are available through NCEI's website (www.ncdc.noaa.gov/data-access/land-based-station-data).

Figure 1. Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2015

NOAA has calculated each of the components of the U.S. Climate Extremes Index (CEI) and has made these data files publicly available. The data set for extreme precipitation (CEI step 4) can be downloaded from: http://www.ncdc.noaa.gov/extremes/cei/graph.

Figure 2. Unusually High Annual Precipitation in the Contiguous 48 States, 1895–2015

Standardized Precipitation Index (SPI) data are publicly available and can be downloaded from: ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/. This indicator uses 12-month SPI data, which are found in a file with a name in the format "climdiv-sp12dv-v1.0.0-20160105." This FTP site also includes "readme" files that explain the contents of the data files.

Constructing Figure 2 required additional information about smaller regions called climate divisions (each state has one to 10 climate divisions, except Alaska, which has 13). The land area of each climate division can be found by going to: www.ncdc.noaa.gov/oa/pub/data/inventories/DIV-AREA.TXT. For a guide to the numerical codes assigned to each state, see: ftp://ftp.ncdc.noaa.gov/pub/data/inventories/COOP-STATE-CODES.TXT.

Methodology

5. Data Collection

This indicator is based on precipitation measurements collected by a network of thousands of weather stations spread throughout the contiguous 48 states. These stations are currently overseen by NOAA, and they use standard gauges to measure the amount of precipitation received on a daily basis. Some of these stations are automated stations operated by NOAA's National Weather Service. The remainder are Cooperative Observer Program (COOP) stations operated by other organizations using trained observers and equipment and procedures prescribed by NOAA. For an inventory of U.S. weather stations and information about data collection methods, see: www.ncdc.noaa.gov/data-access/land-based-station-data, the technical reports and peer-reviewed papers cited therein, and the National Weather Service technical manuals at: www.nws.noaa.gov/om/coop/training.htm.

Figure 1 is based largely on data from a specific quality-controlled subset of long-term stations that NCEI has designated as its U.S. Historical Climatology Network (USHCN) dataset (www.ncdc.noaa.gov/extremes/cei/data-used), along with some supplementary sites discussed in Section 6. Figure 2 is based on larger quality-controlled set of long-term stations that NCEI has designated as its *n*ClimDiv dataset (www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php).

6. Indicator Derivation

Heavy precipitation can be examined in many different ways. For example, the prevalence of extreme individual events can be characterized in terms of the number of 24-hour events exceeding a fixed precipitation threshold (e.g., 1 or 2 inches), the number of 24-hour events considered "extreme" based on the historical distribution of precipitation events at a given location (i.e., a percentile-based approach), the proportion of annual precipitation derived from "extreme" 24-hour events, or other approaches. This indicator uses a percentile-based approach in Figure 1 because it accounts for regional differences in what might be considered "heavy" precipitation (e.g., 1 inch in a day might be common in some places but not in others) and because the data are readily available as part of NOAA's CEI. Figure 2 complements this analysis by considering total annual precipitation, which reflects the cumulative influence of heavy precipitation events occurring throughout the year.

Figure 1 and Figure 2 are based on similar raw data (i.e., daily precipitation measurements), but were developed using two different models because they show trends in extreme precipitation from two different perspectives.

Figure 1. Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2015

Figure 1 was developed as part of NOAA's CEI, an index that uses six different variables to examine trends in extreme weather and climate. This figure shows trends in the prevalence of extreme one-day precipitation events, based on a component of NOAA's CEI (labeled as Step 4) that looks at the percentage of land area within the contiguous 48 states that experienced a much greater than normal proportion of precipitation derived from extreme one-day precipitation events in any given year.

In compiling the CEI, NOAA applied more stringent criteria to select only those stations with data for at least 90 percent of the days in each year, as well as 90 percent of the days during the full period of record. Applying these criteria resulted in the selection of a subset of USHCN stations. To supplement the USHCN record, the CEI (and hence Figure 1) also includes data from NOAA's Cooperative Summary of the Day (TD3200) and pre-1948 (TD3206) daily precipitation stations (Gleason et al., 2008). This resulted in a total of more than 1,300 precipitation stations.

NOAA scientists computed the data for the CEI and calculated the percentage of land area for each year. They performed these steps by dividing the contiguous 48 states into a 1-degree by 1-degree grid and using data from one station in each grid box, rather than multiple stations. This was done to eliminate many of the artificial extremes that resulted from a changing number of available stations over time.

For each grid cell, the indicator looks at what portion of the total annual precipitation occurred on days that had extreme precipitation totals. Thus, the indicator essentially describes what percentage of precipitation is arriving in short, intense bursts. "Extreme" is defined as the highest 10^{th} percentile, meaning an extreme one-day event is one in which the total precipitation received at a given location during the course of the day is at the upper end of the distribution of expected values (i.e., the distribution of all one-day precipitation totals at that location during the period of record). After extreme one-day events were identified, the percentage of annual precipitation occurring on extreme days was calculated for each year at each location. The subsequent step looked at the distribution of these percentage values over the full period of record, then identified all years that were in the highest 10^{th} percentile. These years were considered to have a "greater than normal" amount of precipitation derived from extreme precipitation events at a given location. The top 10^{th} percentile was chosen so as to give the overall index an expected value of 10 percent. Finally, data were aggregated nationwide to determine the percentage of land area with greater than normal precipitation derived from extreme events in each year.

The CEI can be calculated for individual seasons or for an entire year. This indicator uses the annual CEI, which is shown by the columns in Figure 1. To smooth out some of the year-to-year variability, EPA applied a nine-point binomial filter, which is plotted at the center of each nine-year window. For example, the smoothed value from 2002 to 2010 is plotted at year 2006. NOAA NCEI recommends this approach and has used it in the official online reporting tool for the CEI.

EPA used endpoint padding to extend the nine-year smoothed lines all the way to the ends of the period of record. As recommended by NCEI, EPA calculated smoothed values as follows: if 2015 was the most recent year with data available, EPA calculated smoothed values to be centered at 2012, 2013, 2014, and 2015 by inserting the 2015 data point into the equation in place of the as-yet-unreported annual data points for 2016 and beyond. EPA used an equivalent approach at the beginning of the time series.

The CEI has been extensively documented and refined over time to provide the best possible representation of trends in extreme weather and climate. For an overview of how NOAA constructed Step 4 of the CEI, see: www.ncdc.noaa.gov/extremes/cei. This page provides a list of references that describe analytical methods in greater detail. In particular, see Gleason et al. (2008).

Figure 2. Unusually High Annual Precipitation in the Contiguous 48 States, 1895–2015

Figure 2 shows trends in the occurrence of abnormally high annual total precipitation based on the SPI, which is an index based on the probability of receiving a particular amount of precipitation in a given location. Thus, this index essentially compares the actual amount of annual precipitation received at a particular location with the amount that would be expected based on historical records. An SPI value of zero represents the median of the historical distribution; a negative SPI value represents a drier-than-normal period and a positive value represents a wetter-than-normal period.

NOAA calculates monthly values of the SPI for each of the 344 climate divisions within the contiguous 48 states. They calculate the SPI for various time periods ranging from one month to 24 months. This indicator uses the 12-month SPI data reported for the end of December of each year (1895 to 2015). The 12-month SPI is based on precipitation totals for the previous 12 months, so a December 12-month SPI value represents conditions over the full calendar year.

As part of its *n*ClimDiv analysis, NOAA uses station data and interpolation between stations to create a 5-km grid across the contiguous 48 states for each variable in the dataset, including SPI. Divisional averages are derived by averaging the grid cells within each climate division. This approach ensures that divisional SPI values are not biased towards areas that happen to have more stations clustered close together.

To create Figure 2, EPA identified all climate divisions with an SPI value of +2.0 or greater in a given year, where +2.0 is a suggested threshold for "abnormally high" precipitation (i.e., the upper tail of the historical distribution). For each year, EPA then determined what percentage of the total land area of the contiguous 48 states these "abnormally high" climate divisions represent. This annual percentage value is represented by the thin curve in the graph. To smooth out some of the year-to-year variability, EPA applied a nine-point binomial filter, which is plotted at the center of each nine-year window. For example, the smoothed value from 2002 to 2010 is plotted at year 2006. NOAA NCEI recommends this approach and has used it in the official online reporting tool for the CEI (the source of Figure 1).

EPA used endpoint padding to extend the nine-year smoothed lines all the way to the ends of the period of record. As recommended by NCEI, EPA calculated smoothed values as follows: If 2015 was the most recent year with data available, EPA calculated smoothed values to be centered at 2012, 2013, 2014, and 2015 by inserting the 2015 data point into the equation in place of the as-yet-unreported annual data points for 2016 and beyond. EPA used an equivalent approach at the beginning of the time series.

Like the CEI, the SPI is extensively documented in the peer-reviewed literature. The SPI is particularly useful with drought and precipitation indices because it can be applied over a variety of time frames and because it allows comparison of different locations and different seasons on a standard scale.

For more information about NOAA's processing methods, see the metadata file at: ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/divisional-readme.txt. For an overview of the SPI and a list of resources describing methods used in constructing this index, see: www.wrcc.dri.edu/spi/explanation.html.

General Discussion

This indicator does not attempt to project data backward before the start of regular data collection or forward into the future. All values of the indicator are based on actual measured data. No attempt has been made to interpolate days with missing data. Rather, the issue of missing data was addressed in the site selection process by including only those stations that had very few missing data points.

7. Quality Assurance and Quality Control

Data from weather stations go through a variety of quality assurance and quality control (QA/QC) procedures before they can be added to historical datasets such as USHCN and *n*ClimDiv in their final form. NOAA's *n*ClimDiv dataset follows strict QA/QC procedures to identify errors and biases in the data and then either remove these stations from the time series or apply correction factors. Procedures for *n*ClimDiv are summarized at: www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php. These procedures build upon procedures that were used to address specific potential problems in trend estimation in the most recent version of the USHCN, including:

- Removal of duplicate records.
- Procedures to deal with missing data.
- Testing and correcting for artificial discontinuities in a local station record, which might reflect station relocation or instrumentation changes.

Additional QA/QC procedures are not readily available for the CEI and SPI, but both of these indices have been published in the peer-reviewed literature, indicating a certain degree of rigor.

Analysis

8. Comparability Over Time and Space

To be included in the USHCN and *n*ClimDiv datasets, a station had to meet certain criteria for record longevity, data availability (percentage of missing values), spatial coverage, and consistency of location (i.e., experiencing few station changes). The period of record varies for each station but generally includes most of the 20th century. One of the objectives in establishing these datasets was to detect secular changes in regional rather than local climate. Therefore, these datasets only include stations that are believed to not be influenced to any substantial degree by artificial changes of local environments.

9. Data Limitations

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

1. Both figures are national in scope, meaning they do not provide information about trends in extreme or heavy precipitation on a local or regional scale.

2. Weather monitoring stations tend to be closer together in the eastern and central states than in the western states. In areas with fewer monitoring stations, heavy precipitation indicators are less likely to reflect local conditions accurately.

3. The indicator does not include Alaska, which has seen some notable changes in heavy precipitation in recent years (e.g., Gleason et al., 2008). Although NOAA designated 13 climate divisions for Alaska in 2015, historical CEI and SPI calculations are not yet available for Alaska.

10. Sources of Uncertainty

Error estimates are not readily available for daily precipitation measurements or for the CEI and SPI calculations that appear in this indicator. In general, uncertainties in precipitation data increase as one goes back in time, as there are fewer stations early in the record. These uncertainties should not be sufficient, however, to undermine the fundamental trends in the data. The USHCN and *n*ClimDiv 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 addition, both parts of the indicator have been restricted to stations meeting specific criteria for data availability.

11. Sources of Variability

Precipitation varies 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 (a century of data) and aggregating consistently over time and space.

12. Statistical/Trend Analysis

EPA has determined that the time series in Figure 1 has an increasing trend of approximately 0.6 percentage points per decade ($p < 0.001$) and the time series in Figure 2 has an increasing trend of approximately 0.2 percentage points per decade ($p = 0.019$). Both of these trends were calculated by ordinary least-squares regression, which is a common statistical technique for identifying a first-order trend, and both trends are statistically significant to a 95-percent confidence level.

References

Gleason, K.L., J.H. Lawrimore, D.H. Levinson, T.R. Karl, and D.J. Karoly. 2008. A revised U.S. climate extremes index. J. Climate 21:2124–2137.

Tebaldi, C., K. Hayhoe, J.M. Arblaster, and G.A. Meehl. 2006. Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. Climatic Change 79:185–211.