Length of Growing Season

1 Describe the physical, chemical, or biological measurements upon which this indicator is based. Are these measurements widely accepted as scientifically and technically valid? Explain.

The length of the growing season—i.e., the number of days when plants can grow—depends on factors such as air temperatures, frosts, precipitation, or daylight hours. This indicator focuses on the timing of frosts, specifically the last frost in spring and the first frost in fall. It was developed by analyzing minimum daily temperature records from weather stations throughout the contiguous 48 states.

Daily minimum temperature measurements come from weather stations in the National Oceanic and Atmospheric Administration's (NOAA's) Cooperative Observer Program (COOP), which measure temperature using standard instruments. The COOP data set represents the core climate network of the United States (Kunkel et al., 2005). Data collected by COOP sites are referred to as U.S. Daily Surface Data or Summary of the Day data. General information on COOP weather data can be found at: www.nws.noaa.gov/os/coop/what-is-coop.html.

2 Describe the sampling design and/or monitoring plan used to collect the data over time and space. Is it based on sound scientific principles? Explain.

COOP stations generally measure temperature at least hourly, and they record the minimum temperature for each 24-hour time span. COOP stations are located throughout the United States, but the indicator includes only stations in the contiguous 48 states. Cooperative observers include state universities, state and federal agencies, and private individuals whose stations are managed and maintained by NOAA's National Weather Service (NWS). Observers are trained to collect data, and the NWS provides and maintains equipment to gather these data.

The study on which this indicator is based includes data from 794 stations in the contiguous 48 states. These stations were selected because they met criteria for data availability; each station had to have less than 10 percent of temperature data missing over the period from 1895 to 2000. For a map of these station locations, see Kunkel et al. (2004). Pre-1948 COOP data were previously only available in hard copy, but were recently digitized by NOAA's National Climatic Data Center (NCDC), thus allowing analysis of more than 100 years of weather and climate data.

3 Describe the conceptual model used to transform these measurements into an indicator. Is this model widely accepted as a scientifically sound representation of the phenomenon it indicates? Explain.

For this indicator, the length of the growing season is defined as the period of time between the last frost of spring and the first frost of fall, when the air temperature drops below the freezing point of 32ºF. Minimum daily temperature data from the COOP data set were used to determine the dates of last spring frost and first fall frost using an inclusive threshold of 32ºF. Methods for producing regional and national trends were designed to weight all regions evenly regardless of station density. Kunkel et al. (2004) describes the calculation of trends in detail.

Figure 1 shows trends in the overall length of the growing season, which is the number of days between the last spring frost and the first fall frost. Figure 2 shows trends in the length of growing season for the eastern United States versus the western United States, using 100ºW longitude as the dividing line between the two halves of the country. Figure 3 shows trends in the timing of the last spring frost and the first fall frost, also using units of days.

All three figures show the deviation from the 1895–2007 long-term average, which is set at zero for reference. Thus, if spring frost timing in year *n* is shown as -4, it means the last spring frost arrived four days earlier than usual. Note that the choice of baseline period *will not* affect the shape or the statistical significance of the overall trend; it merely moves the trend up or down on the graph in relation to the point defined as "zero."

To smooth out some of the year-to-year variability and make the results easier to understand visually, all three figures plot 11-year moving averages rather than annual data. EPA chose this averaging period to be consistent with the recommended averaging method used by Kunkel et al. (2004) in an earlier version of this analysis. Each average is plotted at the center of the corresponding 11-year window. For example, the average from 1997 to 2007 is plotted at year 2002. Data were actually available for the years 1895 to 2007, meaning the figures show averages from 1900 to 2002. The figure captions use the latter set of dates (1900 to 2002) to avoid confusion and to be consistent with the apparent temporal range of the time series plotted in the graphs.

EPA calculated long-term trends by ordinary least-squares regression to support statements in the "Key Points" text.

4 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

Temperature monitoring procedures are described in the full metadata for the COOP data set available at: www.ngdc.noaa.gov/nmmrview/xmls/fgdc.jsp?id=gov.noaa.ncdc:C00314&view=html#Metadata_Reference_Information. Pre-1948 data from the COOP data set were digitized over the last few years; quality control procedures for digitized data are described in Kunkel et al. (2005). Kunkel

et al. (2004) provide a complete description of the analytical procedures used to determine length of growing season trends.

5 To what extent is the complete data set accessible, including metadata, data-dictionaries, and embedded definitions? Are there confidentiality issues that may limit accessibility to the complete data set?

EPA obtained the data for this indicator from Dr. Ken Kunkel at the Desert Research Institute (kenneth.kunkel@dri.edu). Dr. Kunkel had published an earlier version of this analysis (Kunkel et al., 2004), but provided EPA with an updated file containing growing season data through 2007.

All raw COOP data are maintained by the NCDC. Complete COOP data, embedded definitions, and data descriptions can be downloaded from the Web at: www.ncdc.noaa.gov/doclib/. State-specific data can be found at: www7.ncdc.noaa.gov/IPS/coop/coop.html;jsessionid=312EC0892FFC2FBB78F63D0E3ACF6CBC. There are no confidentiality issues that could limit accessibility, but some portions of the data set might need to be formally requested. Complete metadata for the COOP data set can be found at: www.ngdc.noaa.gov/nmmrview/xmls/fgdc.jsp?id=gov.noaa.ncdc:C00314&view=html.

6 Are the descriptions of the study or survey design clear, complete, and sufficient to enable the study or survey to be reproduced? Explain.

Clear descriptions of the survey design and analysis are available in Kunkel et al. (2004). Quality control analysis of pre-1948 data used in this indicator is described in Kunkel et al. (2005). A reader could reproduce this study using available COOP data and the information provided in the aforementioned papers.

7 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

NOAA follows extensive quality assurance and quality control (QA/QC) procedures for collecting and compiling COOP weather station data. For documentation of COOP methods, including training manuals and maintenance of equipment, see: www.nws.noaa.gov/os/coop/training.htm. QC of the underlying data set is also discussed at: www.ngdc.noaa.gov/nmmrview/xmls/fgdc.jsp?id=gov.noaa.ncdc:C00314&view=html#quality. Pre-1948 COOP data were recently digitized from hard copy. Kunkel et al. (2005) discuss QC steps associated with digitization and other factors that might introduce error into the growing season analysis.

The data used in this indicator were carefully analyzed in order to identify and eliminate outlying observations. A value was identified as an outlier if a climatologist judged the value to be physically impossible based on the surrounding values, or if the value of a data point was more

than five standard deviations from the station's monthly mean. Readers can find more details on QC analysis for this indicator in Kunkel et al. (2004) and Kunkel et al. (2005).

8 What statistical methods, if any, have 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)? Are these methods scientifically appropriate?

Data from individual weather stations were averaged in order to determine national and regional trends in the length of growing season and the timing of spring and fall frosts. To ensure spatial balance, national and regional values were computed using a spatially weighted average, and as a result, stations in low-station-density areas make a larger contribution to the national or regional average than stations in high-density areas. See Kunkel et al. (2004) for a complete description of methods used to generalize data over space.

No attempt has been made to represent data outside the contiguous 48 states or to estimate trends before or after the 1895–2007 period.

9 What uncertainty measurements or estimates are available for the indicator and/or the underlying data set?

Kunkel et al. (2004) present uncertainty measurements for an earlier (but mostly similar) version of this analysis. For example, the authors determined that the overall increase in growing season was statistically significant at a 95 percent confidence level in both the East and the West.

To test worst-case conditions, Kunkel et al. (2004) computed growing season trends for a thinned-out subset of stations across the country, attempting to simulate the density of the portions of the country with the lowest overall station density. The 95 percent confidence intervals for the resulting trend in length of growing season were ±2 days. Thus, there is very high likelihood that observed changes in growing season are real and not an artifact of sampling.

10 To what extent do uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

Extensive QA/QC measures have been used to ensure high-quality data. As described in the response to Question 9, uncertainty analysis shows that the trends in this indicator are statistically significant. Thus, uncertainty and variability should not impact the conclusions that can be inferred from the trends shown in this indicator.

11 Describe any limitations or gaps in the data that may mislead a user about fundamental trends in the indicator over space or over the time period for which data are available.

1. Changes in measurement techniques and instruments over time can affect trends. However, these data were carefully reviewed for quality, and values that appeared invalid were not included in the indicator. This indicator only includes data from weather stations that did not have many missing data points.
2. The urban heat island effect can potentially influence growing season data; however, these data were carefully quality controlled and outlying data points were not included in the calculation of trends.

12 References

Kunkel, K.E., D.R. Easterling, K. Hubbard, and K. Redmond. 2004. Temporal variations in frost-free season in the United States: 1895–2000. Geophys. Res. Lett. 31:L03201.

Kunkel, K.E., D.R. Easterling, K. Hubbard, K. Redmond, K. Andsager, M.C. Kruk, and M.L. Spinar. 2005. Quality control of pre-1948 Cooperative Observer Network data. Journal of Atmospheric and Oceanic Technology 22:1691–1705.