Snow Cover

Identification

1. Indicator Description

This indicator measures changes in the amount of land in North America covered by snow. The amount of land covered by snow at any given time is influenced by climate factors such as the amount of snowfall an area receives, the timing of that snowfall, and the rate of melting on the ground. Thus, tracking snow cover over time can provide a useful perspective on how the climate may be changing. Snow cover is also climatically meaningful because it exerts an influence on climate through the albedo effect (i.e., the color and reflectivity of the Earth's surface).

Components of this indicator include:

- Average annual snow cover since 1972 (Figure 1).
- Average snow cover by season since 1972 (Figure 2).

2. Revision History

April 2010:	Indicator posted.
January 2012:	Updated with data through 2011.
February 2012:	Expanded to include snow cover by season (new Figure 2).
August 2013:	Updated on EPA's website with data through 2012.
March 2014:	Updated with data through 2013.
June 2015:	Updated on EPA's website with data through 2014.

Data Sources

3. Data Sources

This indicator is based on a Rutgers University Global Snow Lab (GSL) reanalysis of digitized maps produced by the National Oceanic and Atmospheric Administration (NOAA) using their Interactive Multisensor Snow and Ice Mapping System (IMS).

4. Data Availability

Complete weekly and monthly snow cover extent data for North America (excluding Greenland) are publicly available for users to download from the GSL website at: http://climate.rutgers.edu/snowcover/table_area.php?ui_set=2. A complete description of these data can be found on the GSL website at: http://climate.rutgers.edu/snowcover/index.php.

The underlying NOAA gridded maps are also publicly available. To obtain these maps, visit the NOAA IMS website at: www.natice.noaa.gov/ims.

Methodology

5. Data Collection

This indicator is based on data from instruments on polar-orbiting satellites, which orbit the Earth continuously and are able to map the entire surface of the Earth. These instruments collect images that can be used to generate weekly maps of snow cover. Data are collected for the entire Northern Hemisphere; this indicator includes data for all of North America, excluding Greenland.

Data were compiled as part of NOAA's IMS, which incorporates imagery from a variety of satellite instruments (Advanced Very High Resolution Radiometer [AVHRR], Geostationary Satellite Server [GOES], Special Sensor Microwave Imager [SSMI], etc.) as well as derived mapped products and surface observations. Characteristic textured surface features and brightness allow for snow to be identified and data to be collected on the percentage of snow cover and surface albedo (reflectivity) (Robinson et al., 1993).

NOAA's IMS website (www.natice.noaa.gov/ims) lists peer-reviewed studies and websites that discuss the data collection methods, including the specific satellites that have provided data at various times. For example, NOAA sampling procedures are described in Ramsay (1998). For more information about NOAA's satellites, visit: www.nesdis.noaa.gov/about_satellites.html.

6. Indicator Derivation

NOAA digitizes satellite maps weekly using the National Meteorological Center Limited-Area Fine Mesh grid. In the digitization process, an 89-by-89-cell grid is placed over the Northern Hemisphere and each cell has a resolution range of 16,000 to 42,000 square kilometers. NOAA then analyzes snow cover within each of these grid cells.

Rutgers University's GSL reanalyzes the digitized maps produced by NOAA to correct for biases in the data set caused by locations of land masses and bodies of water that NOAA's land mask does not completely resolve. Initial reanalysis produces a new set of gridded data points based on the original NOAA data points. Both original NOAA data and reanalyzed data are filtered using a more detailed land mask produced by GSL. These filtered data are then used to make weekly estimates of snow cover. GSL determines the weekly extent of snow cover by placing an 89-by-89-cell grid over the Northern Hemisphere snow cover map and calculating the total area of all grid cells that are at least 50 percent snow-covered. GSL generates monthly maps based on an average of all weeks within a given month. Weeks that straddle the end of one month and the start of another are weighted proportionally.

EPA obtained weekly estimates of snow-covered area and averaged them to determine the annual average extent of snow cover in square kilometers. EPA obtained monthly estimates of snow-covered area to determine the seasonal extent of snow cover in square kilometers. For each year, a season's extent was determined by averaging the following months:

- Winter: December (of the prior calendar year), January, and February.
- Spring: March, April, and May.
- Summer: June, July, and August.
- Fall: September, October, and November.

EPA converted all of these values to square miles to make the results accessible to a wider audience.

NOAA's IMS website describes the initial creation and digitization of gridded maps; see: www.natice.noaa.gov/ims. The GSL website provides a complete description of how GSL reanalyzed NOAA's gridded maps to determine weekly and monthly snow cover extent. See: http://climate.rutgers.edu/snowcover/docs.php?target=vis and http://climate.rutgers.edu/snowcover/docs.php?target=cdr. Robinson et al. (1993) describe GSL's methods, while Helfrich et al. (2007) document how GSL has accounted for methodological improvements over time. All maps were recently reanalyzed using the most precise methods available, making this the best available data set for assessing snow cover on a continental scale.

7. Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) measures occur throughout the analytical process, most notably in the reanalysis of NOAA data by GSL. GSL's filtering and correction steps are described online (http://climate.rutgers.edu/snowcover/docs.php?target=vis) and in Robinson et al. (1993). Ramsey (1998) describes the validation plan for NOAA digitized maps and explains how GSL helps to provide objective third-party verification of NOAA data.

Analysis

8. Comparability Over Time and Space

Steps have been taken to exclude less reliable early data from this indicator. Although NOAA satellites began collecting snow cover imagery in 1966, early maps had a lower resolution than later maps (4 kilometers versus 1 kilometer in later maps) and the early years also had many weeks with missing data. Data collection became more consistent with better resolution in 1972, when a new instrument called the Very High Resolution Radiometer (VHRR) came online. Thus, this indicator presents only data from 1972 and later.

Mapping methods have continued to evolve since 1972. Accordingly, GSL has taken steps to reanalyze older maps to ensure consistency with the latest approach. GSL provides more information about these correction steps at: http://climate.rutgers.edu/snowcover/docs.php?target=cdr.

Data have been collected and analyzed using consistent methods over space. The satellites that collect the data cover all of North America in their orbital paths.

9. Data Limitations

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

1. Satellite data collection is limited by anything that obscures the ground, such as low light conditions at night, dense cloud cover, or thick forest canopy. Satellite data are also limited by difficulties discerning snow cover from other similar-looking features such as cloud cover.

2. Although satellite-based snow cover totals are available starting in 1966, some of the early years are missing data from several weeks (mainly during the summer), which would lead to an inaccurate annual or seasonal average. Thus, the indicator is restricted to 1972 and later, with all years having a full set of data.

3. Discontinuous (patchy) snow cover poses a challenge for measurement throughout the year, particularly with spectrally and spatially coarse instruments such as AVHRR (Molotch and Margulis, 2008).

4. Summer snow mapping is particularly complicated because many of the patches of snow that remain (e.g., high in a mountain range) are smaller than the pixel size for the analysis. This leads to reduced confidence in summer estimates. When summer values are incorporated into an annual average, however, variation in summer values has relatively minimal influence on the overall results.

10. Sources of Uncertainty

Uncertainty measurements are not readily available for this indicator or for the underlying data. Although exact uncertainty estimates are not available, extensive QA/QC and third-party verification measures show that steps have been taken to minimize uncertainty and ensure that users are able to draw accurate conclusions from the data. Documentation available from GSL (http://climate.rutgers.edu/snowcover/docs.php?target=vis) explains that since 1972, satellite mapping technology has had sufficient accuracy to support continental-scale climate studies. Although satellite data have some limitations (see Section 9), maps based on satellite imagery are often still superior to maps based on ground observations, which can be biased due to sparse station coverage—both geographically and in terms of elevation (e.g., a station in a valley will not necessarily have snow cover when nearby mountains do)—and by the effects of urban heat islands in locations such as airports. Hence, satellite-based maps are generally more representative of regional snow extent, particularly for mountainous or sparsely populated regions.

11. Sources of Variability

Figures 1 and 2 show substantial year-to-year variability in snow cover. This variability naturally results from variation in weather patterns, multi-year climate cycles such as the El Niño–Southern Oscillation and Pacific Decadal Oscillation, and other factors. Underlying weekly measurements have even more variability. This indicator accounts for these factors by presenting a long-term record (several decades) and calculating annual and seasonal averages.

Generally, decreases in snow cover duration have been most pronounced along mid-latitude continental margins where seasonal mean air temperatures range from -5 to +5°C (Brown and Mote, 2009).

12. Statistical/Trend Analysis

EPA performed an initial assessment of trends in square miles (mi^2) per year using ordinary least-squares linear regression, which led to the following results:

- Annual average, 1972–2014: -3,095 mi^2/year ($p = 0.058$).
- Winter, 1972–2014: +4,161 mi^2/year ($p = 0.16$).

- Spring, 1972–2014: -6,062 mi^2/year ($p = 0.044$).
- Summer, 1972–2014: -14,436 mi^2/year ($p < 0.001$).
- Fall, 1972–2014: +4,024 mi^2/year ($p = 0.12$).

Thus, long-term linear trends in spring and summer snow cover are significant to a 95 percent level ($p < 0.05$), while annual average, winter, and fall trends are not. To conduct a more complete analysis would potentially require consideration of serial correlation and other more complex statistical factors.

References

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