Lake Ice

Identification

1. Indicator Description

This indicator measures the amount of time that ice is present on lakes in the United States between approximately 1850 and 2010. If lakes remain frozen for longer periods, it can signify that the climate is cooling. Conversely, shorter periods of ice cover suggest a warming climate.

Components of this indicator include:

- Trends in the duration of ice cover on selected U.S. lakes since 1850 (Figure 1)
- Trends in first freeze dates of selected U.S. lakes since 1850 (Figure 2)
- Trends in ice breakup dates of selected U.S. lakes since 1850 (Figure 3)

2. Revision History

April 2010: Indicator posted
December 2011: Updated with data through winter 2010–2011

Data Sources

3. Data Sources

This indicator is based on data from the Global Lake and River Ice Phenology Database, which was compiled by the North Temperate Lakes Long-Term Ecological Research program at the Center for Limnology at the University of Wisconsin–Madison from data submitted by participants in the Lake Ice Analysis Group (LIAG). The database is hosted on the Web by the National Snow and Ice Data Center (NSIDC), and it currently contains ice cover data for 750 lakes and rivers throughout the world, some with records as long as 150 years.

4. Data Availability

All of the lake ice observations used for this indicator are publicly available from NSIDC's Global Lake and River Ice Phenology Database. Users can access this database at: http://nsidc.org/data/lake_river_ice. Database documentation can be found at: http://nsidc.org/data/docs/noaa/g01377_lake_river_ice.

Users can also view descriptive information about each lake or river in the Global Lake and River Ice Phenology Database. The Global Lake and River Ice Phenology Database contains the following fields, although many records are incomplete:

- Lake or river name
- Lake or river code
- Whether it is a lake or a river

- Continent
- Country
- State
- Latitude (decimal degrees)
- Longitude (decimal degrees)
- Elevation (meters)
- Mean depth (meters)
- Maximum depth (meters)
- Median depth (meters)
- Surface area (square kilometers)
- Shoreline length (kilometers)
- Largest city population
- Power plant discharge (yes or no)
- Area drained (square kilometers)
- Land use code (urban, agriculture, forest, grassland, other)
- Conductivity (microsiemens per centimeter)
- Secchi depth (Secchi disk depth in meters)
- Contributor

Access to the Global Lake and River Ice Phenology Database is unrestricted, but users are encouraged to register so they can receive notification of changes to the database in the future.

Methodology

5. Data Collection

This indicator examines three parameters related to ice cover on lakes:

- The annual "ice on" or freeze date, defined as the first date on which the water body was observed to be completely covered by ice.
- The annual "ice off," thaw, or breakup date, defined as the date of the last breakup observed before the summer open water phase.
- The annual duration of ice cover, defined as the number of days that a water body is completely covered with ice. If a lake thawed for several days in mid-winter and then froze again, the duration would equal the number of days from ice on to ice off minus those days when the lake thawed.

Observers have gathered data on lake ice throughout the United States for many years—in some cases, more than 100 years. The types of observers can vary from one location to another. For example, some observations might have been gathered and published by a local newspaper editor**;** others compiled by a local resident. Some lakes have benefited from multiple observers, such as residents on both sides of the lake who can compare notes to determine when the lake is completely frozen or thawed. At some locations, observers have kept records of all three parameters of interest ("ice on," "ice off," and total ice duration); others might have tracked only one or two of these parameters.

To ensure sound spatial and temporal coverage, EPA limited this indicator to U.S. water bodies with the longest and most complete historical records. After downloading data for all lakes and rivers within the United States, EPA sorted the data and analyzed each water body to determine data availability for the three parameters of interest. As a result of this analysis, EPA identified eight water bodies—all lakes—with particularly long and rich records. Special emphasis was placed on identifying water bodies with many consecutive years of data, which can support moving averages and other trend analysis. EPA selected the following eight lakes for trend analysis:

- Detroit Lake, Minnesota
- Lake George, New York
- Lake Mendota, Wisconsin
- Lake Michigan (Grand Traverse Bay), Michigan
- Lake Monona, Wisconsin
- Lake Otsego, New York
- Mirror Lake, New York
- Shell Lake, Wisconsin

Together, these lakes span much of the Great Lakes region and upstate New York.

6. Indicator Derivation

To smooth out some of the variability in the annual data and to make it easier to see long-term trends in the display, EPA did not plot annual time series but instead calculated nine-year moving averages (arithmetic means) for each of the parameters. EPA chose a nine-year period because it is consistent with other indicators and comparable to the 10-year moving averages used in a similar analysis by Magnuson et al. (2000). Average values are plotted at the center of each nine-year window. For example, the average from 1990 to 1998 is plotted at year 1994. EPA did calculate averages over periods that were missing a few data points. Early years sometimes had sparse data, and the earliest averages were calculated only around the time when many consecutive records started to appear in the record for a given lake.

EPA used endpoint padding to extend the nine-year smoothed lines all the way to the ends of the analysis period for each lake. For example, if annual data were available through 2010, EPA calculated smoothed values centered at 2007, 2008, 2009, and 2010 by inserting the 2006–2010 average into the equation in place of the as-yet-unreported annual data points for 2011 and beyond. EPA used an equivalent approach at the beginning of each time series.

For consistency, all data points in Figures 1, 2, and 3 are plotted at the base year, which is the year the winter season began. For the winter of 2010 to 2011, the base year would be 2010, even if a particular lake did not freeze until early 2011.

EPA did not attempt to interpolate missing data points and did not attempt to calculate duration in cases where only the ice on and ice off date were provided. Such manipulations would have been based on unfounded assumptions. This indicator also does not attempt to portray data beyond the time periods of observation or beyond the eight lakes that were selected for the analysis.

Magnuson et al. (2000) and Jensen et al. (2007) describe methods of processing lake ice observations for use in calculating long-term trends.

7. Quality Assurance and Quality Control

The LIAG performed some basic quality control checks on data that were contributed to the database, making corrections in some cases. Additional corrections continue to be made as a result of user comments. For a description of some recent corrections, see the database documentation at: http://nsidc.org/data/docs/noaa/g01377_lake_river_ice.

Ice observations rely on human judgment. Definitions of "ice on" and "ice off" vary, and the definitions used by any given observer are not necessarily documented alongside the corresponding data. Where possible, the scientists who developed the database have attempted to use sources that appear to be consistent from year to year, such as a local resident with a long observation record.

Analysis

8. Comparability Over Time and Space

Historical observations have not been made systematically or according to a standard protocol. Rather, the Global Lake and River Ice Phenology Database—the source of data for this indicator—represents a systematic effort to compile data from a variety of original sources.

All three parameters were determined by human observations that incorporate some degree of personal judgment. Definitions of the three parameters can also vary over time and from one location to another. Human observations provide an advantage, however, in that they enable trend analysis over a much longer time period than can be afforded by more modern techniques such as satellite imagery. Overall, human observations provide the best available record of seasonal ice formation and breakup, and the breadth of available data allows analysis of broad spatial patterns as well as long-term temporal patterns.

9. Sources of Uncertainty

Ice observations rely on human judgment, and definitions of "ice on" and "ice off" vary, which could lead to some uncertainty in the data. For example, some observers might consider a lake to have thawed once they can no longer walk on it, while others might wait until the ice has entirely melted. Observations also depend on one's vantage point along the lake, particularly a larger lake—for example, if some parts of the lake have thawed while others remain frozen. In addition, the definitions used by any given observer are not necessarily documented alongside the corresponding data. Therefore, it is not possible to ensure that all variables have been measured consistently from one lake to another—or even at a single lake over time—and it is also not possible to quantify the true level of uncertainty or correct for such inconsistencies.

Accordingly, the Global Lake and River Ice Phenology Database does not provide error estimates for historical ice observations. Where possible, however, the scientists who developed the database have attempted to use sources that appear to be consistent from year to year, such as a local resident who collects data over a long period. Overall, the Global Lake and River Ice Phenology Database represents

the best available data set for lake ice observations, and limiting the indicator to eight lakes with the most lengthy and complete records should lead to results in which users can have confidence.

10. Sources of Variability

For a general idea of the variability inherent in these types of time series, see Magnuson et al. (2000) and Jensen et al. (2007)—two papers that discuss variability and statistical significance for a broader set of lakes and rivers, including some of the lakes in this indicator. Magnuson et al. (2005) discuss variability between lakes, considering the extent to which observed variability reflects factors such as climate patterns, lake morphometry (shape), and lake trophic status. The timing of freeze-up and break-up of ice appears to be more sensitive to air temperature changes at lower latitudes (Livingstone et al., 2010), but despite this, lakes at higher latitudes appear to be experiencing the most rapid reductions in duration of ice cover (Latifovic and Pouliot, 2007).

To smooth out some of the interannual variability and to make it easier to see long-term trends in the display, EPA did not plot annual time series but instead calculated nine-year moving averages (arithmetic means) for each of the parameters, following an approach recommended by Magnuson et al. (2000).

11. Statistical/Trend Analysis

Figures 1, 2, and 3 show trends for each of the eight lakes. No attempt was made to aggregate the eight lakes together. EPA calculated trends over time by ordinary least-squares regression, a common statistical method, to support some of the statements in the "Key Points" section of the indicator. EPA has not calculated the statistical significance of these particular long-term trends, although Magnuson et al. (2000) and Jensen et al. (2007) found that long-term trends in freeze and breakup dates for many lakes were statistically significant ($p<0.05$).

12. Data Limitations

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

1. Although the Global Lake and River Ice Phenology Database provides a lengthy historical record of freeze and thaw dates for a much larger set of lakes and rivers, some records are incomplete, ranging from brief lapses to large gaps in data. Thus, this indicator is limited to eight lakes with relatively complete historical records. Geographic coverage is limited to sites in four states (Minnesota, Wisconsin, Michigan, and New York).
2. Data used in this indicator are all based on visual observations. Records based on visual observations by individuals are open to some interpretation and can reflect different definitions and methods.
3. Historical observations for lakes have typically been made from the shore, which might not be representative of lakes as a whole or comparable to more recent satellite-based observations.

References

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