Antarctic Sea Ice

Identification

1. Indicator Description

This indicator tracks changes in the February and September average extent of sea ice on the Southern Ocean around Antarctica since 1979. The extent of area covered by Antarctic sea ice is considered a useful indicator of global climate because a warmer climate will generally reduce the amount of sea ice present, although climate can also affect sea ice in other more complex ways. This indicator also provides a comparison to Arctic sea ice and a general sense of global sea ice conditions. The trends in global sea ice extent are negative overall in every season and every month, which provides a direct contribution toward decreasing the Earth's reflectivity (known as albedo) (Parkinson, 2014).

2. Revision History

August 2016:	Indicator published.
April 2021:	Updated indicator with data through 2018.
July 2022:	Updated indicator with data through 2021.
December 2024:	Updated indicator with data through 2024.

Data Sources

3. Data Sources

This indicator is based on monthly average sea ice extent data provided by the National Snow and Ice Data Center (NSIDC). NSIDC's data are derived from satellite imagery collected and processed by the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC).

4. Data Availability

Users can access monthly map images, geographic information system (GIS)–compatible map files, and gridded daily and monthly satellite data, along with corresponding metadata, at: https://nsidc.org/data/seaice_index/data-and-image-archive. From this page, users can also download monthly extent and area data. Select "South" under the "Monthly Images" heading, which will lead to a public FTP site (ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/south/monthly/data/).[1] The .csv files with "02" and "09" in their names represent the February and September data, respectively, that were used in this indicator. To see a different version of the graph in Figure 1 (plotting percent anomalies rather than square miles), go up a level to the "images" directory (ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/south/monthly/images/) and open the "…plot.png" images in the February and September folders.

[1] Users should be aware that many new versions of web browsers block FTP addresses. The FTP can be accessed using an FTP client, the command line, or a Python script. For more details, see: https://nsidc.org/support/64231694-FTP-Client-Data-Access.

NSIDC's Sea Ice Index documentation page (https://nsidc.org/data/g02135) describes how to download, read, and interpret the data. It also defines database fields and key terminology. Gridded source data developed by NASA GSFC can be found at: https://nsidc.org/data/nsidc-0051 and: https://nsidc.org/data/nsidc-0081.

Methodology

5. Data Collection

This indicator is based on maps of sea ice extent in the ocean around Antarctica, which were developed using brightness temperature imagery in the microwave wavelengths collected by satellites. Data from October 1978 through June 1987 were collected using the Nimbus-7 Defense Meteorological Satellite Program (DMSP) Scanning Multi Channel Microwave Radiometer (SMMR) instrument, and data since July 1987 have been collected using a series of successor DMSP Special Sensor Microwave/Imager (SSM/I) instruments. In 2008, the DMSP Special Sensor Microwave Imager and Sounder (SSMIS) replaced the SSM/I as the source for sea ice products. These instruments can identify the presence of sea ice because sea ice and open water have different passive microwave signatures.

The satellites that supply data for this indicator orbit the Earth continuously, collecting images that can be used to generate daily maps of sea ice extent. They are able to map the Earth's surface with a resolution of 25 kilometers. The resultant maps have a nominal pixel area of 625 square kilometers. Because of the curved map projection, however, actual pixel sizes range from 382 to 664 square kilometers.

The satellites that collect the data cover most of the Antarctic region in their orbital paths; however, the sensors cannot collect data from a circular area immediately surrounding the South Pole due to orbit inclination. A similar spatial gap requires correction for the Arctic Sea Ice indicator, but it does not affect the Antarctic Sea Ice indicator, where the "pole hole" is entirely over land.

For documentation of passive microwave satellite data collection methods, see the summary and citations at: https://nsidc.org/data/g02135.

6. Indicator Derivation

Satellite data are used to develop daily ice extent and concentration maps using an algorithm developed by NASA. Data are evaluated within grid cells on the map. Image processing includes quality control features such as two weather filters based on brightness temperature ratios to screen out false positives over open water, an ocean mask to eliminate any remaining sea ice in regions where sea ice is not expected, and a coastal filter to eliminate most false positives associated with mixed land/ocean grid cells.

From each daily map, analysts calculate the total "extent" and "area" covered by ice. These terms are defined differently as a result of how they address those portions of the ocean that are partially but not completely frozen:

- **Extent** is the total area covered by all pixels on the map that have at least 15 percent ice concentration, which means at least 15 percent of the ocean surface within that pixel is frozen over. The 15 percent concentration cutoff for extent is based on validation studies that showed that a 15 percent threshold provided the best approximation of the "true" ice edge and the lowest bias. In practice, much of the area covered by sea ice exceeds the 15 percent threshold, so using a higher cutoff (e.g., 20 or 30 percent) would yield different totals but similar overall trends (for example, see the Arctic analysis by Parkinson et al., 1999).

- **Area** represents the actual surface area covered by ice. If a pixel's area were 600 square kilometers and its ice concentration were 75 percent, then the ice area for that pixel would be 450 square kilometers. At any point in time, total ice area will always be less than total ice extent.

EPA's indicator addresses extent rather than area. Both of these measurements are valid ways to look at trends in sea ice, but in this case, EPA chose to look at the time series for extent because it is more complete than the time series for area. In addition, extent is consistent with the Arctic Sea Ice indicator, where "pole hole" limitations made it necessary to focus on extent rather than area.

NASA's processing algorithm includes steps to deal with occasional days with data gaps due to satellite or sensor outages. These days were removed from the time series and replaced with interpolated values based on the total extent of ice on the surrounding days.

From daily maps and extent totals, NSIDC calculated monthly average extent in square kilometers. EPA converted these values to square miles to make the results accessible to a wider audience. By relying on monthly averages, this indicator smooths out some of the variability inherent in daily measurements.

NSIDC's mapping for this indicator covers the entire zone from 39.23°S to 90°S latitude, so it is technically a Southern Hemisphere data product, rather than exclusively limited to waters adjacent to Antarctica (see spatial extent documentation at: https://nsidc.org/data/g02135). In practice, though, the vast majority of detectable sea ice within this zone occurs around Antarctica. Thus, this data product is frequently referred to as "Antarctic sea ice."

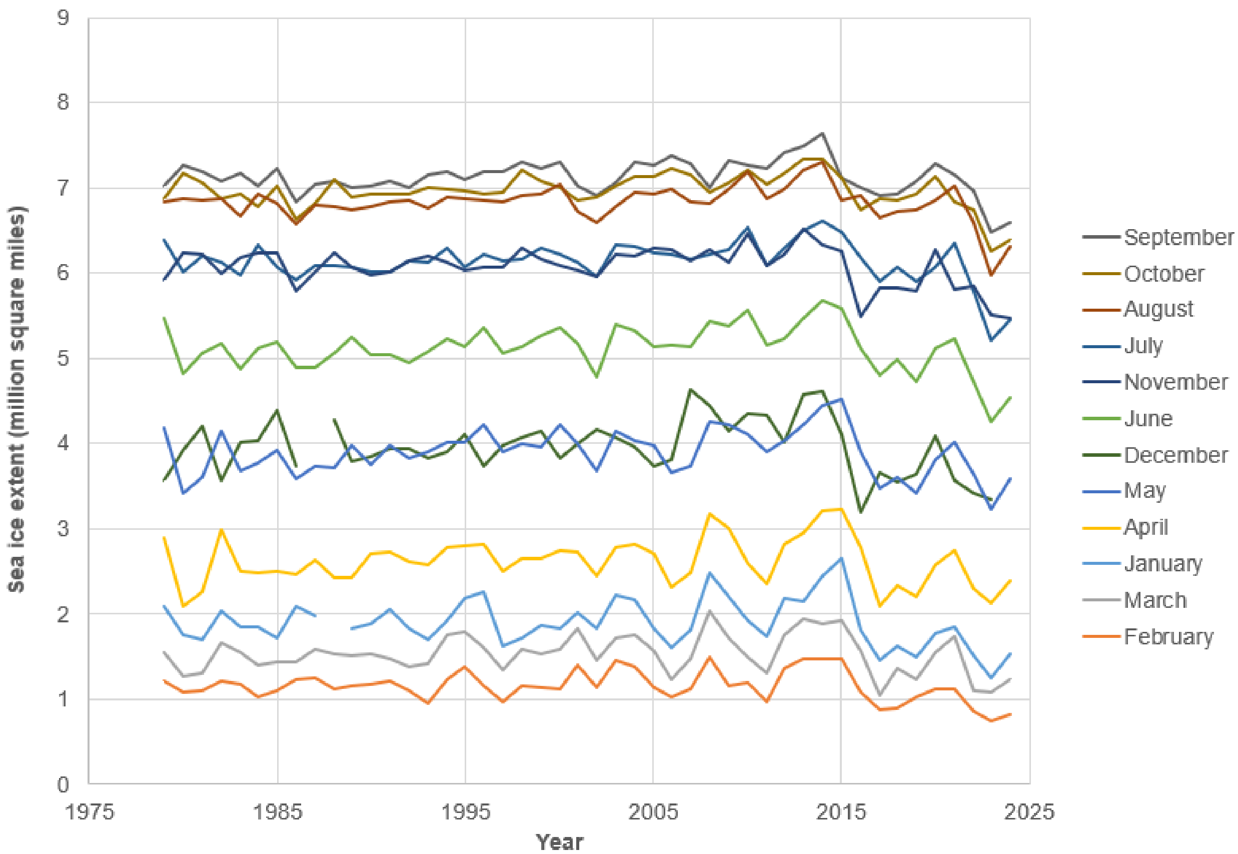
Figure 1 shows trends in February and September average sea ice extent. February is when Antarctic sea ice typically reaches its annual minimum, after melting during the summer months. By looking at the month with the smallest extent of sea ice, this indicator focuses attention on the time of year when limiting conditions would most affect wildlife in the Antarctic region. Antarctic sea ice typically reaches its annual maximum in late September or early October, after cold winter months freeze new ice. September has the highest monthly average extent. Presenting the month with the greatest extent of sea ice highlights the extent to which the Antarctic region recovers melted sea ice.

This indicator does not attempt to estimate values from before the onset of regular satellite mapping in October 1978 (which makes 1979 the first year with February and September data for this indicator). It also does not attempt to project data into the future.

For documentation of the NASA Team algorithm used to process the data, see Cavalieri et al. (1984) and: https://nsidc.org/data/nsidc-0051. For more details about NSIDC methods, see the Sea Ice Index documentation and related citations at: https://nsidc.org/data/g02135.

Other months of the year were considered for this indicator, but EPA chose to focus on February and September, which represent the annual minimum and maximum extent of sea ice. Other months of the year have similar patterns, as illustrated by Figure TD-1, which shows mean values for all months based on the same NSIDC data source.

Figure TD-1. Antarctic Sea Ice Extent for Each Month, 1979–2024



Data source: NSIDC: https://nsidc.org/data/seaice_index/data-and-image-archive. Accessed December 2024.

7. Quality Assurance and Quality Control

Image processing includes a variety of quality assurance and quality control (QA/QC) procedures, including steps to screen out false positives (i.e., ice is detected where it is not actually present). These procedures are described in NSIDC's online documentation at: https://nsidc.org/data/g02135 as well as in some of the references cited therein.

NSIDC Antarctic sea ice data have three levels of processing for QC. NSIDC's most recent data come from the Near Real-Time SSM/I Polar Gridded Sea Ice Concentrations (NRTSI) data set. NRTSI data go through a first level of calibration and QC to produce a preliminary data product. The final data are processed by NASA's GSFC, which uses a similar process but applies a higher level of QC. Switching from NRTSI to GSFC data can result in slight changes in the total extent values—on the order of 50,000 square kilometers or less for total sea ice extent.

GSFC processing requires several months of lag time. At the time EPA last updated this indicator, the GSFC data for 2024 had not yet been finalized.

Analysis

8. Comparability Over Time and Space

This indicator is based on data collection methods and processing algorithms that have been applied consistently over time and space. NASA's satellites cover the entire area of interest.

9. Data Limitations

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

1. Variations in sea ice are not entirely due to changes in atmospheric or ocean temperature. Other conditions, such as fluctuations in oceanic and atmospheric circulation, precipitation change, and natural annual and decadal variability, can also affect the extent of sea ice. These complex non-temperature factors are thought to exert a more significant influence on sea ice in the Antarctic region than they do in the Arctic (IPCC, 2013).

2. Many factors can diminish the accuracy of satellite mapping of sea ice. Although satellite instruments and processing algorithms have improved somewhat over time, applying these new methods to established data sets can lead to trade-offs in terms of reprocessing needs and compatibility of older data. Hence, this indicator does not use the highest-resolution imagery or the newest algorithms. Trends are still accurate, but should be taken as a general representation of trends in sea ice extent, not an exact accounting.

3. As described in Section 6, the threshold used to determine extent—15 percent ice cover within a given pixel—represents an arbitrary cutoff without a particular scientific significance. Nonetheless, studies have found that choosing a different threshold would result in similar overall trends. Thus, the most important part of Figure 1 is not the absolute extent reported for any given year, but the size and shape of the trend over time.

10. Sources of Uncertainty

NSIDC has calculated standard deviations along with each monthly ice concentration average. NSIDC's Sea Ice Index documentation (https://nsidc.org/data/g02135) describes several analyses that have examined the accuracy and uncertainty of passive microwave imagery and the NASA Team algorithm used to create this indicator. For example, a 1991 analysis estimated that ice concentrations measured by passive microwave imagery are accurate to within 5 to 9 percent, depending on the ice being imaged. Another study suggested that the NASA Team algorithm underestimates ice extent by 4 percent in the winter and more in summer months. A third study that compared the NASA Team algorithm with new higher-resolution data found that the NASA Team algorithm underestimates ice extent by an average of 10 percent. For more details and study citations, see: https://nsidc.org/data/g02135. Certain types of ice conditions can lead to larger errors, particularly thin or melting ice. For example, a melt pond on an ice floe might be mapped as open water. The instruments also can have difficulty distinguishing the interface between ice and snow or a diffuse boundary between ice and open water. Using the February minimum minimizes many of these effects because melt ponds and the ice surface become largely frozen by then. These errors do not affect trends and relative changes from year to year.

NSIDC has considered using a newer algorithm that would process the data with greater certainty, but doing so would require extensive research and reprocessing, and data from the original instrument (pre-1987) might not be compatible with some of the newer algorithms that have been proposed. Thus, for the time being, this indicator uses the best available science to provide a multi-decadal representation of trends in Antarctic sea ice extent. The overall trends shown in this indicator have been corroborated by numerous other sources, and readers should feel confident that the indicator provides an accurate overall depiction of trends in Antarctic sea ice over time.

11. Sources of Variability

Many factors contribute to variability in this indicator. In constructing the indicator, several choices have been made to minimize the extent to which this variability affects the results. The apparent extent of sea ice can vary widely from day to day, both due to real variability in ice extent (growth, melting, and movement of ice at the edge of the ice pack) and due to ephemeral effects such as weather, clouds and water vapor, melt on the ice surface, and changes in the character of the snow and ice surface. The intensity of the Southern Annular Mode (a specific pattern of variability in atmospheric circulation) may also have a year-to-year impact on Antarctic sea ice. Certain conditions could either promote or hinder the northward drift of ice into warmer waters that would speed melting.

According to NSIDC's documentation at: https://nsidc.org/data/g02135, extent is a more reliable variable than ice concentration or area. The weather and surface effects described above can substantially impact estimates of ice concentration, particularly near the edge of the ice pack. Extent is a more stable variable because it simply registers the presence of at least a certain percentage of sea ice in a grid cell (15 percent). For example, if a particular pixel has an ice concentration of 50 percent, outside factors could cause the satellite to measure the concentration very differently, but as long as the result is still greater than the percent threshold, this pixel will be correctly accounted for in the total "extent." Monthly averages also help to reduce some of the day-to-day "noise" inherent in sea ice measurements.

12. Statistical/Trend Analysis

EPA used ordinary least-squares linear regression to identify trends in February and September ice extent to support statements in the Key Points. Over the full period shown in Figure 1, February extent decreased at a rate of 2,414 square miles per year ($p = 0.233$) and September extent decreased at a rate of 1,073 square miles per year ($p = 0.641$). Thus, neither trend is significant to the 95 percent level that EPA uses as a threshold for significance throughout this suite of indicators. Other publications have performed linear regressions on previous versions of these data and have reported statistically significant increases. For example, Parkinson and Cavalieri (2012) reported increases in Southern Hemisphere sea ice extent that were statistically significant to a 99 percent level for winter (July–September), spring (October–December), and annual averages (after adjusting for the seasonal cycle), and significant to a 95 percent level for the fall (April–June). However, these reports of significant increases in the literature predate the last few years of noticeable decreases as shown in Figure 1 of this indicator.

References

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