Arctic Sea Ice

Identification

1. Indicator Description

This indicator tracks the extent, age, and melt season length of sea ice on the Arctic Ocean. The extent of Arctic sea ice is considered a particularly sensitive indicator of global climate because a warmer climate will reduce the amount of sea ice present. The proportion of sea ice in each age category can indicate the relative stability of Arctic conditions as well as susceptibility to melting events. The timing of melt and freeze onset dates and the length of melt season are also important indicators of Arctic sea ice conditions. An earlier melt onset allows for earlier development of open water areas that in turn enhance the ice-albedo feedback (Markus et al., 2009). The open water season is important for certain human activities (e.g., boating, access to natural resources) but restricts other activities (e.g., indigenous populations' hunting and transportation on ice) and affects wildlife (e.g., polar bear access to food sources).

Components of this indicator include:

- Changes in the March and September average extent of sea ice in the Arctic Ocean since 1979 (Figure 1).
- Changes in the proportion of Arctic sea ice in various age categories at the September weekly minimum since 1984 (Figure 2).
- Changes in the start, end, and total length of the Arctic sea ice melt season since 1979 (Figure 3).

2. Revision History

April 2010:	Indicator published.
December 2012:	Updated indicator with data through 2012.
May 2014:	Updated indicator with data through 2013.
June 2015:	Updated indicator with data through 2014. Added annual March sea ice extent to Figure 1 with data through 2015.
December 2015:	Updated indicator with data through September 2015.
April 2016:	Updated indicator with data through March 2016.
August 2016:	Added Figure 3 to show melt season length.
November 2016:	Updated Figure 1 with data through September 2016.
April 2021:	Updated Figures 1 and 2 with data through September 2020. Updated Figure 3 with data through 2019.
July 2022:	Updated Figures 1 and 2 with data through October 2021. Updated Figure 3 with data through 2020.

3. Data Sources

Figure 1 (extent of sea ice) 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). NSIDC also provided Figure 2 data (age distribution of sea ice), which are derived from weekly NASA satellite imagery and processed by the team of Maslanik and Tschudi at the University of Colorado, Boulder. Data in Figure 3 come from an analysis conducted by NASA. It is an updated version of an analysis originally published by Markus et al. (2009).

4. Data Availability

Figure 1. March and September Monthly Average Arctic Sea Ice Extent, 1979–2021

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/archives. From this page, users can also download monthly extent and area data. From this page, select the public FTP site location at: ftp://sidads.colorado.edu/DATASETS/NOAA/G02135. To obtain the March or September monthly data that were used in this indicator, select the "north" directory, then the "monthly" directory, and then the "data" directory. Choose the "N_03_extent…" and "N_09_extent…" CSV files with the data.

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.

Figure 2. Age of Arctic Sea Ice at Minimum September Week, 1984–2021

NSIDC published a version of Figure 2 with data from 1985 to 2021 in a news release at: https://nsidc.org/arcticseaicenews/2021/10/september-turning. Previous editions of the graph, some with data back to 1984, have appeared in prior years' news releases. EPA obtained the data shown in the figure by contacting NSIDC User Services. The data are typically processed by Dr. Mark Tschudi at the University of Colorado, Boulder, and provided to NSIDC. Earlier versions of this analysis appeared in Maslanik et al. (2011) and Maslanik et al. (2007).

Satellite data used in historical and ongoing monitoring of sea ice age can be found at the following websites:

- Defense Meteorological Satellite Program (DMSP) Scanning Multi Channel Microwave Radiometer (SMMR): https://nsidc.org/data/nsidc-0071.
- DMSP Special Sensor Microwave/Imager (SSM/I): https://nsidc.org/data/nsidc-0001.
- DMSP Special Sensor Microwave Imager and Sounder (SSMIS): https://nsidc.org/data/nsidc-0001.
- NASA Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E and AMSR2): https://nsidc.org/data/amsre.

- Advanced Very High Resolution Radiometer (AVHRR): https://nsidc.org/data/nsidc-0745.

Age calculations also depend on wind measurements and on buoy-based measurements and ice motion vectors. Wind measurements (as surface flux data) are available at: https://psl.noaa.gov/data/reanalysis/reanalysis.shtml. Data and metadata are available online at: https://iabp.apl.uw.edu/data.html and: http://nsidc.org/data/nsidc-0116.

Figure 3. Arctic Sea Ice Melt Season, 1979–2020

Figure 3 is based on many of the same satellite data sets as Figures 1 and 2, including the SMMR, SSM/I, SSMIS, and AMSR. Gridded data sets, summary graphs, and the regionally aggregated numbers used for this indicator are publicly available at: https://earth.gsfc.nasa.gov/cryo/data/arctic-sea-ice-melt. This indicator uses source data version #731, which NASA posted on 2/23/2021.

Methodology

5. Data Collection

This indicator is based on maps of sea ice extent in the Arctic Ocean and surrounding waters, 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 SMMR instrument, and data since July 1987 have been collected using a series of successor SSM/I instruments. In 2008, the 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. They can also identify the surface temperature and detect whether free water is present on the surface of the ice or within the snowpack on top of the ice—information that helps to identify the start and end dates of the melt season.

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 Arctic region in their orbital paths, but the sensors cannot collect data from a circular area immediately surrounding the North Pole due to orbit inclination. From 1978 through June 1987, when coverage was from the SMMR instrument, this "pole hole" measured 1.19 million square kilometers. From July 1987 through December 2007, when coverage was from the SSM/I instrument, it measured 0.31 million square kilometers. Since January 2008, using SSMIS, it has measured 0.029 million square kilometers. For more information about this spatial gap and how it is corrected in the final data, see Section 6.

To calculate the age of ice (Figure 2), the SSM/I, SSMIS, and SMMR imagery have been supplemented with three additional data sets:

- AVHRR satellite data, which come from an optical sensing instrument that can measure sea ice temperature and heat flux, which in turn can be used to estimate thickness. AVHRR also covers the "pole hole."

- Maps of wind speed and direction at 10 meters above the Earth's surface, which were compiled by the National Oceanic and Atmospheric Administration's (NOAA's) National Centers for Environmental Prediction (NCEP).

- Motion vectors that trace how parcels of sea ice move, based on data collected by the International Arctic Buoy Programme (IABP). Since 1979, the IABP has deployed a network of 14 to 30 *in situ* buoys in the Arctic Ocean that provide information about movement rates at six-hour intervals.

While direct estimates of sea ice thickness can be obtained from airborne and satellite systems using laser and radar altimeters, as well as from submarines using sonar, these data sources cannot provide sufficiently long and consistent time series to be used as an indicator for sea ice thickness.

For documentation of passive microwave satellite data collection methods, see the summary and citations at: https://nsidc.org/data/g02135. For further information on AVHRR imagery, see: www.avl.class.noaa.gov/release/data_available/avhrr/index.htm. For motion tracking methods, see Maslanik et al. (2011), Fowler et al. (2004), and: https://nsidc.org/data/nsidc-0116.

6. Indicator Derivation

Figure 1. March and September Monthly Average Arctic Sea Ice Extent, 1979–2021

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, most of the area covered by sea ice in the Arctic far 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 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 (the area within the 15-percent concentration contour) rather than area (the area-integrated concentration). 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, the available area data set does not include the "pole hole" (the area directly above and surrounding the North Pole that the satellites cannot cover)—and the size of this unmapped region has changed as a result of the instrumentation changes in 1987 and 2008, creating a discontinuity in the area data. In contrast, the extent time series assumes that the entire "pole hole" area is covered with at least 15 percent ice, which is a reasonable assumption based on other observations of this area. See the Sea Ice Index user guide for more information about the "pole hole" and how NASA's data address it at: https://nsidc.org/data/g02135.

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 30.98°N to 90°N latitude, so it is technically a Northern Hemisphere data product, rather than exclusively limited to the Arctic Ocean (see spatial extent documentation at: https://nsidc.org/data/g02135). In practice, though, the vast majority of detectable sea ice within this zone occurs in the Arctic region—particularly during the many months of the year when the Arctic is the only area cold enough to support ice. Thus, this data product is frequently referred to as "Arctic sea ice."

Figure 1 shows trends in March and September average sea ice extent. September is when Arctic 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 and human societies in the Arctic region. Six months later, March is when Arctic sea ice typically reaches its annual maximum, after cold winter months freeze new ice. Presenting the month with the greatest extent of sea ice highlights the extent to which the Arctic region recovers melted sea ice.

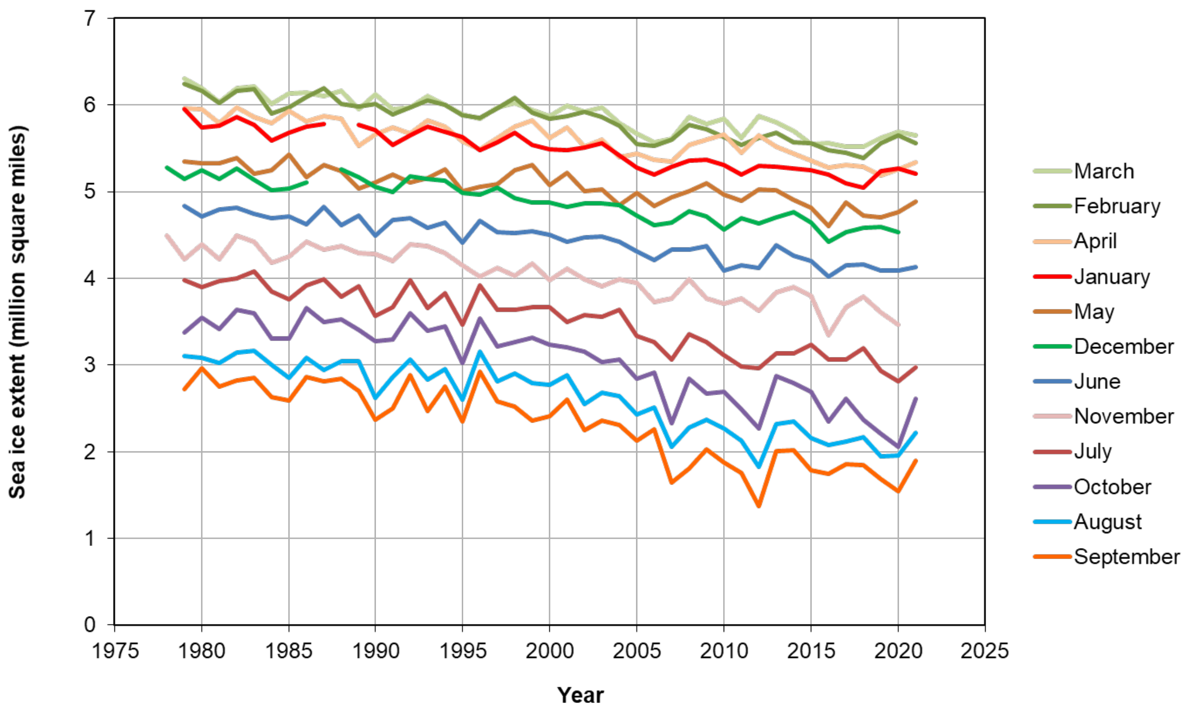
This indicator does not attempt to estimate values from before the onset of regular satellite mapping in October 1978 (which makes 1979 the first year with March and September data for this indicator). It also does not attempt to project data into the future.

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 March and September, which typically represent the annual maximum and minimum extent of sea ice, respectively. September extent is often used as an indicator. One reason is because as temperatures start to get colder, there may be less meltwater on the surface than during the previous summer months, thus leading to more reliable remote sensing of ice extent, as the passive microwave signal is influenced by surface meltwater. Increased melting during summer months leads to changes in the overall character of the ice (i.e., age and thickness) and these changes have implications throughout the year. Thus, September conditions are particularly important for assessing the overall health of Arctic sea ice. Conversely, March is the month when sea ice typically experiences its peak extent for the year.

Evidence shows that the extent of Arctic sea ice has declined in all months of the year. Comiso (2012) examined the seasonal pattern in Arctic sea ice extent for three decadal periods plus the years 2007, 2009, and 2010 and found declines throughout the year. Figure TD-1 shows monthly means based on an analysis from NSIDC—the source of data for this indicator. It reveals that Arctic sea ice extent has generally declined over time in all months, with the most pronounced decline in the summer and fall.

Figure TD-1. Arctic Sea Ice Extent for Each Month, 1978/1979–2021



Data source: NSIDC: https://nsidc.org/data/seaice_index/archives. Accessed November 2021.

Figure 2. Age of Arctic Sea Ice at Minimum September Week, 1984–2021

A research team at the University of Colorado at Boulder processes daily sequential SSM/I, SMMR, AMSR-E, and AVHRR satellite data from NASA, then produces maps using a grid with 12 kilometer (km)-by-12 km cells. The AVHRR data help to fill the "pole hole" and provide information about the temperature and thickness of the ice. Like Figure 1, this method classifies a pixel as "ice" if at least 15 percent of the ocean surface within the area is frozen over. Using buoy data from the IABP, motion vectors for the entire region are blended via optimal interpolation and mapped on the gridded field. NCEP wind data are also incorporated at this stage, with lower weighting during winter and higher weighting during summer, when surface melt limits the performance of the passive microwave data. Daily ice extent and motion vectors are averaged on a weekly basis. Once sea ice reaches its annual minimum extent (typically in early September), the ice is documented as having aged by one year. For further information on data processing methods, see Maslanik et al. (2011), Maslanik et al. (2007), and Fowler et al. (2004). Although the most recently published representative study does not utilize AMSR-E brightness data or NCEP wind data for the calculation of ice motion, the results presented in Figure 2 and the NSIDC website incorporate these additional sources.

Figure 2 shows the extent of ice that falls into several age categories. Whereas Figure 1 extends back to 1979, Figure 2 can show trends only back to 1984 because it is not possible to know how much ice is five or more years old (the oldest age class shown) until parcels of ice have been tracked for at least five years. Regular satellite data collection did not begin until October 1978, which makes 1984 the first year in which September minimum ice can be assigned reliably to the full set of age classes shown in Figure 2.

Like Figure 1, Figure 2 is based on the most recent data available.

Figure 3. Arctic Sea Ice Melt Season, 1979–2020

Figure 3 depends on a consistent definition of “start date” and “end date” for the annual Arctic sea ice melt season. Start date refers to the date on which free water begins to be consistently present within the snowpack on the surface of the ice (i.e., wet snow). Consistency is important to distinguish this melt onset date from earlier melt events that might not have persisted. End date refers to the date on which the surface temperature begins to stay consistently at the freezing point of water, and ice begins to form in the open ocean. Consistency is important to distinguish the freeze date from early freeze events. Markus et al. (2009) provide more detail about these definitions and how they relate to definitions used in other analyses.

NASA conducted the analysis by dividing the Arctic Ocean into a grid and determining each year’s melt-season start and end dates for each individual grid cell. NASA averaged the dates across all grid cells to derive an average start date and an average end date for the entire Arctic region. Figure 3 shows the aggregated regionwide averages. For additional detail about these methods, see Markus et al. (2009).

NASA reports start and end dates in terms of Julian days (i.e., the number of days since January 1). Figure 3 is based on Julian days, but the corresponding non-leap year calendar dates have been added to the y-axis to provide a more familiar frame of reference. This means that a melt date of May 31 in a leap year will actually be plotted at the same level as June 1 from a non-leap year, for example, and it will appear to be plotted at June 1 with respect to the y-axis. Plotting the data this way facilitates consistent year-to-year comparison.

Indicator Development

Multiple methods for evaluating the start date and end date of the Arctic sea ice melt season have been published. Method distinctions include differences in source data and melt criteria and, in some cases, the physical phenomena used to define melt season (e.g., surface melting versus ice break-up). As a result of these distinctions, the start dates and end dates identified by each method can vary considerably. However, the overall trends from different methods tend to be qualitatively similar: many publications have reported earlier start dates and later end dates for Arctic sea ice melt season regardless of the method used (USGCRP, 2017).

Bliss et al. (2017) compared Markus et al.’s (2009) method for identifying melt start date with an earlier method developed by Drobot and Anderson (2001). Both methods identify melt start dates using passive microwave brightness temperature data from the SMMR, SSM/I, and SSMIS satellite sensors. However, Markus et al.’s (2009) algorithm uses three separate criteria to identify start dates, whereas Drobot and Anderson’s (2001) algorithm uses a single criterion. Other distinctions include differences in how each method prevents false detection of melting and how each method identifies locations with sea ice.

Bliss et al. (2017) compared the results from both methods across 13 different Arctic regions over 1979–2012. They found that both methods performed best over the central Arctic, and that both methods performed less consistently over first-year and marginal ice regions where uncertainty in the brightness temperature data was higher.

Across the entire Arctic, Bliss et al. (2017) found that Drobot and Anderson's (2001) method yielded melt start dates that were on average 20.2 days earlier than those produced by Markus et al.'s (2009) method. However, both methods reported the same general trend of earlier start dates over time across the entire Arctic, and the trends from both methods were significant at the 95-percent confidence level. Per Bliss et al.'s (2017) analysis, neither method provided clearly superior results for identifying melt season start date.

For simplicity, EPA's indicator shows results only from Markus et al.'s (2009) method. Unlike Drobot and Anderson's (2001) method, Markus et al.'s (2009) method includes an algorithm for calculating melt season end date in addition to melt season start date, and thus provides a more complete depiction of Arctic sea ice melt season length.

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 Arctic 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 quality control 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 published this version of the indicator, the GSFC data for 2021 had not yet been finalized.

Melt-season data for Figure 3 undergo a set of key QA/QC procedures as described in Markus et al. (2009). For example, to eliminate spurious data points, the results from each individual grid cell are compared with results from neighboring cells. Wide discrepancies between neighbors lead to potentially erroneous data points being excluded from subsequent analysis. NASA also checks results through comparisons with other similar data sets.

Analysis

8. Comparability Over Time and Space

All three figures for this indicator are 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 with the exception of the "pole hole" for Figure 1. Even though the size of this hole has changed over time, EPA's indicator uses a data set that corrects for this discontinuity.

The total extent shown in Figure 2 (the sum of all the stacked areas) differs from the total extent shown for September in Figure 1 because Figure 2 shows conditions during the specific week in September when minimum extent is reached, while the series in Figure 1 shows average conditions over the entire month of September. It would not make sense to convert Figure 2 to a monthly average for September because all ice is “aged” one year as soon as the minimum has been achieved, which creates a discontinuity after the minimum week.

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 and natural annual and decadal variability, can also affect the extent of sea ice, and by extension the sea ice age metric.

2. Changes in the age and thickness of sea ice—for example, a trend toward younger or thinner ice—might increase the rate at which ice melts in the summer, making year-to-year comparisons more complex.

3. 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.

4. 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.

5. Using ice surface data and motion vectors allows only the determination of a maximum sea ice age. Thus, as presented, the Figure 2 indicator indicates the age distribution of sea ice only on the surface and is not necessarily representative of the age distribution of the total sea ice volume.

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 September minimum minimizes many of these effects because melt ponds and the ice surface have largely begun to refreeze 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 Arctic 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 Arctic sea ice over time.

Accuracy of ice motion vectors depends on the error in buoy measurements, wind fields, and satellite images. Given that buoy locational readings are taken every six hours, satellite images are 24-hour averages, and a "centimeters per second (cm/sec)" value is interpolated based on these readings, accuracy depends on the error of the initial position and subsequent readings. NSIDC proposes that "the error would be less than 1 cm/sec for the average velocity over 24 hours" (https://nsidc.org/data/nsidc-0116).

Uncertainty has not been fully quantified for the detection and analysis of ice melt, although Bliss et al. (2017) have documented inter-method comparisons and ground-truthing against surface air temperatures for selected case studies. While absolute error may be fairly high in a given location for a given year, when considering the trends and variability for the entire basin over a long time series, the results provide a fairly accurate indicator of change.

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 Northern Annular Mode (NAM) conditions and changes to the Arctic Oscillation (specific patterns of variability in atmospheric circulation) also have a strong year-to-year impact on ice movement. Under certain conditions, older ice might move to warmer areas and be subject to increased melting. Weather patterns can also affect the sweeping of sea ice out of the Arctic entirely. For a more complete description of major thermodynamic processes that impact ice longevity, see Maslanik et al. (2007) and Rigor and Wallace (2004).

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

The key points associated with Figure 3 report total change in melt dates, freeze dates, and melt season duration. These changes are all based on ordinary least-squares linear regression slopes for the full period of record (1979–2020). All three trends are significant to at least a 95-percent confidence level ($p < 0.05$). Specific trends are as follows:

- Start date: -0.212 days/year ($p < 0.001$)
- End date: +0.731 days/year ($p < 0.001$)
- Duration: +0.943 days/year ($p < 0.001$)

This indicator does not report on the slope of the apparent trends in sea ice extent and age distribution, nor does it calculate the statistical significance of these trends. However, several other peer-reviewed publications (e.g., Cavalieri and Parkinson, 2012; Parkinson, 2014), have performed linear regressions on these data and reported statistically significant decreases in both monthly sea ice extent and the extent of multi-year sea ice. NSIDC's website provides the standard deviation for each trend shown in the monthly sea ice extent anomaly graphs at: https://nsidc.org/data/seaice_index.

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