Sea Ice

Sea ice is frozen seawater that floats on the ocean surface. Blanketing millions of square kilometers, sea ice forms and melts with the polar seasons, affecting both human activity and biological habitat. In the Arctic, some sea ice persists year after year, whereas almost all Southern Ocean or Antarctic sea ice is "seasonal ice," meaning it melts away and reforms annually.

While both Arctic and Antarctic ice are of vital importance to the marine mammals and birds for which they are habitats, sea ice in the Arctic appears to play a more crucial role in regulating climate.

Because they are composed of ice originating from glaciers, icebergs are not considered sea ice. Most of the icebergs infesting North Atlantic shipping lanes originate from Greenland glaciers. Visit Larsen Ice Shelf Breakup Events for information on icebergs in the Southern Ocean.

Global Sea Ice Extent and Concentration:

What sensors on satellites are telling us about sea ice

Sea ice regulates exchanges of heat, moisture and salinity in the polar oceans. It insulates the relatively warm ocean water from the cold polar atmosphere except where cracks, or leads, in the ice allow exchange of heat and water vapor from ocean to atmosphere in winter. The number of leads determines where and how much heat and water are lost to the atmosphere, which may affect local cloud cover and precipitation.

The seasonal sea ice cycle affects both human activities and biological habitats. For example, companies shipping raw materials such as oil or coal out of the Arctic must work quickly during periods of low ice concentration, navigating their ships towards openings in the ice and away from treacherous multiyear ice that has accumulated over several years. Many arctic mammals, such as polar bears, seals, and walruses, depend on the sea ice for their habitat. These species hunt, feed, and breed on the ice. Studies of polar bear populations indicate that declining sea ice is likely to decrease polar bear numbers, perhaps substantially (Stirling and Parkinson 2006).

Ice thickness, its spatial extent, and the fraction of open water within the ice pack can vary rapidly and profoundly in response to weather and climate. Sea ice typically covers about 14 to 16 million square kilometers in late winter in the Arctic and 17 to 20 million square kilometers in the Antarctic Southern Ocean. On average, the seasonal decrease is much larger in the Arctic, with only about 3 to 4 million square kilometers remaining at summer's end, compared to approximately 7 million square kilometers in the Antarctic. Over the past several years, Arctic minima have been only 4 to 6 million square kilometers. These maps provide examples of late winter and late summer ice cover in the two hemispheres.
Passive Microwave Remote Sensing Instruments

**SMMR and SSM/I**
NASA launched the Scanning Multichannel Microwave Radiometer (SMMR) in 1978, and the Defense Meteorological Satellite Program (DMSP) launched the first of the Special Sensor Microwave/Imager (SSM/I) sensors in 1987. Scientists at the Goddard Space Flight Center have combined the SMMR and SSM/I data sets to provide a time series of sea ice data spanning over 30 years. For related data sets at NSIDC, visit Nimbus-7 SMMR Polar Gridded Radiances and Sea Ice Concentrations, DMSP SSM/I Daily Polar Gridded Brightness Temperatures, and Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data.

The SMMR and SSM/I data sets reveal considerable regional, seasonal, and inter-annual variability in ice cover. Grids of sea ice concentrations, as well as summaries using data from both SMMR and SSM/I depicting annual cycles of ice extent (all areas with at least 15 percent ice cover), ice covered area (the ocean area actually covered by ice), and departures from the monthly means or anomalies are available from NSIDC via ftp.

**AMSR-E**
The National Snow and Ice Data Center (NSIDC) also archives and distributes daily sea ice data products from the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) sensor on NASA's

Passive microwave satellite data represent the best method to monitor sea ice because of the ability to show data through most clouds and during darkness. Passive microwave data allow scientists to monitor the inter-annual variations and trends in sea ice cover.

Observations of polar oceans derived from these instruments are essential for tracking the ice edge, estimating sea ice concentrations, and classifying sea ice types. In addition to the practical use of this information for shipping and transport, these

**Sea ice climatologies:** Arctic and Antarctic sea ice concentration climatology from 1979-2000, at the approximate seasonal maximum and minimum levels based on passive microwave satellite data. Image provided by National Snow and Ice Data Center, University of Colorado, Boulder.
Decline in Arctic Sea Ice Extent

Passive microwave satellite data reveal that, since 1979, winter Arctic ice extent has decreased about 3 to 4 percent per decade (Meier et al. 2006). Antarctic ice extent is increasing (Cavalieri et al. 2003), but the trend is small.

Satellite data from the SMMR and SSM/I instruments have been combined with earlier observations from ice charts and other sources to yield a time series of Arctic ice extent from the early 1900s onward. While the pre-satellite records are not as reliable, their trends are in good general agreement with the satellite record and indicate that Arctic sea ice extent has been declining since at least the early 1950s.

Mean sea ice anomalies, 1953-2010: Sea ice extent departures from monthly means for the Northern Hemisphere. For January 1953 through December 1979, data have been obtained from the UK Hadley Centre and are based on operational ice charts and other sources. For January 1979 through September 2010, data are derived from passive microwave (SMMR / SSM/I). Image by Walt Meier and Julienne Stroeve, National Snow and Ice Data Center, University of Colorado, Boulder.

In recent years, satellite data have indicated an even more dramatic reduction in regional ice cover.
September Average Extents, 2002-2010: Calculated by Walt Meier, National Snow and Ice Data Center. All values in table estimated based on the NSIDC Sea Ice Index.

The Arctic sea ice September minimum extent reached new record lows in 2002 (15.3 percent below the 1979-2000 average), 2005 (20.9 percent below), and 2007 (39.2 percent below). In 2007, Arctic sea ice broke all previous records by early August—a month before the end of melt season (see Arctic Sea Ice Shatters All Previous Record Lows). In 2008, the September minimum was 4.67 million square kilometers (1.80 million square miles), the second lowest in the satellite record. In 2009, the September minimum was 5.36 million square kilometers (2.07 million square miles), the fourth-lowest in the satellite record. In 2010, the September minimum was 4.60 million square kilometers (1.78 million square miles), the third-lowest in the satellite record (see Arctic sea ice extent falls to third-lowest extent; downward trend persists).

Extent comparisons: This graph compares 5-day running means for Arctic sea ice extent (area of ocean with ice concentration of at least 15 percent) for the long-term mean (1979-2000), the record low (2007), and the extents for 2005, 2008, 2009, and 2010. Sea ice extent was second-lowest in 2008, and third-lowest in 2010. Image provided by National Snow and Ice Data Center, University of Colorado, Boulder.
Extent anomaly maps, 2002-2010: Sea ice conditions for the month of September, 2002 through 2010, derived from the NSIDC Sea Ice Index. Each image shows the concentration anomaly (see color key) and the 1979-2000 mean September ice edge (pink line). Nearly every year, the ice edge is well north of its mean position off the coasts of Alaska and Siberia. Image provided by National Snow and Ice Data Center, University of Colorado, Boulder.

Combined with record low summertime extent, Arctic sea ice exhibited a new pattern of poor winter recovery. In the past, a low-ice year would be followed by a rebound to near-normal conditions, but 2002 was followed by two more low-ice years, both of which almost matched the 2002 record (see Arctic Sea Ice Decline Continues). Although wintertime recovery of Arctic sea ice improved somewhat after 2006, wintertime extents have remained below the long-term average.

A study published in 2007 found a dramatic change in the age of sea ice in the central Arctic Basin since the mid-1980s. In 1987, 57 percent of the ice pack was at least 5 years old, and a quarter of that ice was at least 9 years old. By 2007, only 7 percent of the ice pack was at least 5 years old, and virtually none of the ice was at least 9 years old (Maslanik et al, 2007).

In March 2009, Arctic sea ice averaged 15.16 million square kilometers—above the record low wintertime extent from 2006 but below the 1979-2000 average. Moreover, most of the Arctic sea ice at the beginning of the 2009
melt season was first-year ice, so it was thin and especially vulnerable to melt.

Old v. new ice in Arctic, February 2009: These maps show the median age of February sea ice from 1981-2009 (left) and February 2009 (right). As of February 2009, ice older than two years accounted for less than 10 percent of the ice cover. Data provided by J. Maslanik, C. Fowler, University of Colorado, Colorado Center for Astrodynamics Research.

Northwest Passage, September 2007: The summer of 2007 saw the opening of the Northwest Passage. Navigated with great difficulty between 1903 and 1906, the passage opened to standard ocean-going vessels a century later. On September 15, 2007, the same time Arctic sea ice reached its record low, the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Terra satellite captured this relatively cloud-free image of the open passage. Image courtesy Jeff Schmaltz, MODIS Rapid Response Team, NASA GSFC. Visit Arctic Mosaic for a MODIS mosaic of the entire Arctic from September 15-16.

Northwest Passage: The maroon line marks the route of the Northwest Passage that opened up in 2007. Image courtesy University of Bremen.
Arctic concentrations, 1979-2010: View minimum and maximum sea ice extent animations from 1979 through 2010.

Antarctic concentrations, 1979-2010: View minimum and maximum sea ice extent animations from 1979 through 2010.

Arctic and Antarctic Standardized Anomalies and Trends
Jan 1979 - Jul 2009

Arctic and Antarctic Sea Ice Extent, 1979-2009: Although Arctic sea ice extent underwent a strong decline from 1979 to 2009, Antarctic sea ice underwent a slight increase. The Antarctic ice extent increases were smaller in magnitude than the Arctic increases, and some regions of the Antarctic experienced strong declining trends in sea ice extent. See the Arctic Sea Ice FAQ for more information. Image provided by National Snow and Ice Data Center, University of Colorado, Boulder.

Antarctic concentrations, 1979-2010: View minimum and maximum sea ice extent animations from 1979 through 2010.
**Decline in Arctic Sea Ice Thickness**

Sea ice thickness likewise showed substantial decline in the latter half of the 20th century (Rothrock et al. 1999). Using data from submarine cruises, Rothrock and collaborators determined that the mean ice draft (the ice extending below the water surface) at the end of the melt season in the Arctic decreased by about 1.3 meters between the 1950s and the 1990s.

**ICESat Thickness Estimates**

Estimates based on measurements taken by NASA's ICESat laser altimeter, first-year ice that formed after the autumn of 2007 had a mean thickness of 1.6 meters. The ice formed relatively late in the autumn of 2007. NSIDC researchers had actually anticipated this first-year ice to be thinner, but it nearly equaled the thickness of 2006 and 2007. Snow accumulation on sea ice helps insulate the ice from frigid air overhead, so sparse snowfall during the winter of 2007-2008 might have actually accelerated the sea ice's growth.

A recent study examined sea ice thickness records from submarines and ICESat observations from 1958 to 2008 (Kwok and Rothrock 2009). Examining 42 years of submarine records (1958 to 2000), and a five years of ICESat records (2003 to 2008), the authors determined that mean Arctic sea ice thickness declined from 3.64 meters in 1980 to 1.89 meters in 2008—a decline of 1.75 meters.

[Image: Decline in Arctic Sea Ice Thickness]

Decline Causes

Greenhouse gases emitted through human activities and the resulting increase in global mean temperatures are the most likely underlying cause of the sea ice decline, but the direct cause is a complicated combination of factors resulting from the warming, and from climate variability. The \textit{Arctic Oscillation} (AO) is a see-saw pattern of alternating atmospheric pressure at polar and mid-latitudes. The positive phase produces a strong \textit{polar vortex}, with the mid-latitude \textit{jet stream} shifted northward. The negative phase produces the opposite conditions. From the 1950s to the 1980s, the AO flipped between positive and negative phases, but it entered a strong positive pattern between 1989 and 1995. So the acceleration in the sea ice decline since the mid 1990s may have been partly triggered by the strongly positive AO mode during the preceding years (Rigor et al. 2002 and Rigor and Wallace 2004) that flushed older, thicker ice out of the Arctic, but other factors also played a role.

Since the mid-1990s, the AO has largely been a neutral or negative phase, and the late 1990s and early 2000s brought a weakening of the \textit{Beaufort Gyre}. However, the \textit{longevity} of ice in the gyre began to change as a result of warming along the Alaskan and Siberian coasts. In the past, sea ice in this gyre could remain in the Arctic for many years, thickening over time. Beginning in the late 1990s, sea ice began melting in the southern arm of the gyre, thanks to warmer air temperatures and more extensive summer melt north of Alaska and Siberia. Moreover, ice movement out of the Arctic through \textit{Fram Strait} continued at a high rate despite the change in the AO. Thus warming conditions and wind patterns have been the main drivers of the steeper decline since the late 1990s. Sea ice may not be able to recover under the current persistently warm conditions, and a tipping point may have been
passed where the Arctic will eventually be ice-free during at least part of the summer (Lindsay and Zhang 2005).

Examination of the long-term satellite record dating back to 1979 and earlier records dating back to the 1950s indicate that spring melt seasons have started earlier and continued for a longer period throughout the year (Serreze et al. 2007). Even more disquieting, comparison of actual Arctic sea ice decline to IPCC AR4 projections show that observed ice loss is faster than any of the IPCC AR4 models have predicted (Stroeve et al. 2007).

Last updated: 27 October 2010