Analyzing Sea Ice Extent in the Arctic and Antarctic

Overview

Students analyze data from graphs for sea ice extent (area) in both polar regions (Arctic and Antarctic) to learn about seasonal variations and over a 30-year period to learn about longer-term trends. This lesson is modified from Window To The Universe’s “Graphing Sea Ice Extent Arctic and Antarctica.”

Learning Objectives

- Students will make and test claims.
- Students will demonstrate an understanding of seasonal differences at the poles.
- Students will learn about variations in the climate of Earth’s polar regions.

Why Does NASA Study This Phenomenon?

Located in the Arctic near the North Pole, Greenland is covered by a massive ice sheet three times the size of Texas and a mile deep on average. Greenland is warming almost twice as fast as Antarctica, which is causing the ice to melt and raise global sea levels. NASA is monitoring Greenland’s ice sheet from high up in space to the ocean floor below to provide data for scientists studying the global impact of all its melting ice.
The creation of ICESat-2 is allowing NASA’s scientists to make accurate maps of polar ice sheets. These maps help them make informed predictions about weather patterns, climate change, and the effects of changing ice structures. The maps are so accurate they can measure to within 3 centimeters of an ice sheet’s actual thickness from a huge distance!

Learn how the second generation of the Ice, Cloud, and Land Elevation Satellite, better known as ICESat-2, is being used to map the ice structures in the world’s polar regions. Manipulating the distribution of photons by lasers to create accurate images of these frozen structures allows scientists to study their changes and impact on Earth’s climate.

**Essential Questions**

- How large are the ice sheets?
- How fast are the ice sheets changing?
- How does change in the Cryosphere affect changes in other parts of the Earth System?
- How and why does NASA monitor the Cryosphere?

**Materials Required**

- Google Jamboard
- Google Slide
- Graph Paper or Student Handouts (Note: The Google Slide offers a virtual graph image for students to create plots online.)

**Technology Requirements**

- Standalone Lesson (no technology required)
- Internet Required
- One-to-One (tablet, laptop, or CPU)
- One-to-a-Group
- Teacher computer/projector only

**Teacher Background Information**

**What is the difference between sea ice area and extent?**

*(Credit: [Frequently Asked Questions on Arctic sea ice](https://www.arctic.noaa.gov/aa/qa/qa_area_extent.html))*

Area and extent are different measures and give scientists slightly different information. Extent is always a larger number than area, and there are pros and cons associated with each method.

A simplified way to think of extent versus area is to imagine a slice of swiss cheese. Extent would be a measure of the edges of the slice of cheese and all of the space inside it. Area would be the measure of where there is cheese only, not including the holes. That is why if you compare the extent and area in the same time period, the extent is always bigger. A more precise explanation of extent versus area gets more complicated.

Extent defines a region as “ice-covered” or “not ice-covered.” For each satellite data cell, the cell is said to either have ice or to have no ice, based on a threshold. The most common threshold (and the one NSIDC uses) is 15 percent, meaning that if the data cell has greater than 15 percent ice
concentration, the cell is considered ice covered; less than that and it is said to be ice free. Example: Let’s say you have three 25 kilometer (km) x 25 km (16 miles x 16 miles) grid cells covered by 16% ice, 2% ice, and 90% ice. Two of the three cells would be considered “ice covered,” or 100% ice. Multiply the grid cell area by 100% sea ice and you would get a total extent of 1,250 square km (482 square miles).

Area takes the percentages of sea ice within data cells and adds them up to report how much of the Arctic is covered by ice; area typically uses a threshold of 15%. So in the same example, with three 25 km x 25 km (16 miles x 16 miles) grid cells of 16% ice, 2% ice, and 90% ice, multiply the grid cell areas that are over the 15% threshold by the percent of sea ice in those grid cells, and add it up. You would have a total area of 662 square km (255.8 square miles).

Scientists at NSIDC report extent because they are cautious about summertime values of ice concentration and area taken from satellite sensors. To the sensor, surface melt appears to be open water rather than water on top of sea ice. So, while reliable for measuring area most of the year, the microwave sensor is prone to underestimating the actual ice concentration and area when the surface is melting. To account for that potential inaccuracy, NSIDC scientists rely primarily on extent when analyzing melt-season conditions and reporting them to the public. That said, analyzing ice area is still quite valuable. Given the right circumstances, background knowledge, and scientific information on current conditions, it can provide an excellent sense of how much ice there really is “on the ground.”

Seasonal Predictions

When students predict the seasonal effects on sea ice, they should realize that the ice melts and shrinks in the summer and freezes and grows in the winter. They will likely set their minimum sea ice values somewhere around the summer months, and their predicted maximum values should be somewhere around the winter. In the Arctic, the yearly maximum generally occurs towards the end of winter or early spring, usually in March. The maximum is not in the middle of winter, when the temperatures are coldest. The ice pack continues to grow throughout the winter, thus reaching its maximum extent late in the winter season. When making predictions (hypotheses) about Antarctic sea ice extent on a monthly basis, many students may not take into account (or may not understand) the differences in seasons between the Northern and Southern Hemispheres. This can provide you with a very “teachable moment”, and a great opportunity to discuss the cause of the seasons (the Earth’s axial tilt, NOT variations in Earth’s distance from the Sun; if the latter was the cause, both hemispheres should have the same seasons).

Water’s property of thermal inertia also plays an important role. The Arctic Ocean does not cool down as quickly as does the air in the Arctic. Most students probably will not take these factors into account when they make their predictions, and may thus predict that the sea ice maximum occurs in December, January, or February. If some perceptive students do take this lag into account in their predictions, it would be good to call upon them to explain their predictions to the rest of the class. If none of your students take this lag into account when forming their hypotheses, make sure to point out the discrepancy between their predictions and the plot of actual data. Lead the students through a discussion of this lag and the causes of it. Likewise, their predictions for the time of minimum sea ice extent may be sometime in the middle of the summer, instead of the actual minimum which usually occurs in September. In a manner similar to the winter “lag”, the summer temperatures, though highest in mid-summer, remain above freezing throughout the summer and into early fall, so the sea ice continues to melt and its extent continues to shrink. Also, the Arctic Ocean, which warms throughout the summer, holds its heat longer than does the atmosphere into the cooling autumn.
There are substantial differences between the Arctic and Antarctic that influence the extent of sea ice packs in the two opposite polar regions. The central portion of the Arctic is all ocean, whereas Antarctica has a continent in the middle. The sea ice area in the Arctic includes the area closest to the pole, while the sea ice area in the Antarctic is just the fringes around the edge of the continent and doesn't include the coldest region in the "center" nearest the South Pole. Also, the heat retention properties of a large landmass and huge ice sheet (in Antarctica) are very different than those of a large body of water (the Arctic Ocean). The net effects of these differences are not straightforward but can be used as discussion points with your class.

**Status of Sea Ice Extent**

Arctic sea ice extent is declining while permafrost is warming and thawing over parts of the Arctic. Some of these changes, such as the replacement of white reflective sea ice with dark open water, are set in motion feedbacks that contribute to even further warming. As the Arctic warms, some animal species are finding the region more hospitable, while others are seeing declines in their habitat. The Arctic region is becoming imbalanced, with ramifications for the rest of the hemisphere.

The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost 150 to 250 cubic kilometers (36 to 60 cubic miles) of ice per year between 2002 and 2006, while Antarctica lost about 152 cubic kilometers (36 cubic miles) of ice between 2002 and 2005. Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades.

Credit: NASA Satellite Comparisons of Arctic Change

**Prerequisites Student Knowledge**

- Cause of Earth’s seasons
- Seasonal variations in Northern and Southern Hemisphere
- The poles are covered with sea ice.

**Student Misconception**

The phenomenon of the seasons is caused by Earth’s axial tilt, **NOT** variations in Earth's distance from the Sun; if the latter was the cause, both hemispheres should have the same seasons.

**Procedure**

1. Engage prior knowledge of students' ideas about how sea ice changes over the year. Virtual teachers: Students capture their ideas in the Jamboard.
   - How does sea ice change over the seasons?

2. Explain to students that sea ice is commonly measured in two ways using satellite imagery:
   1.) sea ice extent (a measurement of the ocean's sea ice including from the edges of the sea
ice and all of the space inside) and 2.) sea ice area (a measurement of the area of the ocean only covered by ice). Teachers: See the Teacher Background for an analogy using Swiss cheese to address these differences.

3. Tell your students that they will be doing an activity in which they will first predict sea ice extent of the Arctic and Antarctic over time, and then use NASA satellite data to verify or dispute their claims.

4. Direct your students to brainstorm and make hypotheses about the extent of sea ice throughout the year for both the Arctic and Antarctic regions. Guide students to think about and predict which month will have the greatest amount of sea ice, and which month will have the least.

5. Direct your students to make a hypothesis about the extent of sea ice throughout the year. Have them predict which month will have the greatest amount of sea ice, and which month will have the least for both the Arctic and Antarctic. Give your students Graphing Sheets. (Virtual teachers, students may also use the graph image in Google Slides to create their line plots.) Have the students predict the shapes of the graphs of sea ice extent over time by sketching in a curve on each sheet how they think the sea ice extent varied during this three-year period.

- Tell students that during the time period represented by their graphs (2018 through 2020) the maximum extent was about 17 million km$^2$, and the minimum was about 4 million km$^2$.

1. What months will have the highest values in the Northern Hemisphere? Lowest values?

2. What months will have the highest values in the Southern Hemisphere? Lowest values?

6. Review students’ graphs and then facilitate group/class discussions on students’ predictions of the data.

1. When do students anticipate maximum values for the Arctic region? minimum values for the Arctic region? Why?
2. When do students anticipate maximum values for the Antarctic region? minimum values for the Antarctic region? Why?

7. Now, show the line plots individually (or show the combined line plot, if developmentally appropriate) and have your students compare their hypotheses (the "prediction curves" they sketched in) with the plots of NASA satellite data. Discuss any discrepancies between predictions and results, differences between the curves for the opposite hemispheres, and possible sources of those discrepancies and differences. Also, have them compare the curves for the Antarctic with those for the Arctic. It is likely that students may have some confusion regarding the causes of seasons and how the seasons differ between the Northern and Southern Hemispheres; you may want to review these concepts at this point in the lesson.

Monthly Sea Ice Extent (millions of km²) vs. Time (Southern Hemisphere)
8. Data analysis of the graph can be **extended** to include variation in data. Display to students the same plot with the error bars showing. Explain to students that people add error bars through points on a graph to show uncertainty or variation in the data. These bars help to communicate: 1.) how variable the data represented are from the mean/average value and 2.) how well the mean value represents the data. The longer the error bar’s length, the larger the variety of data from the mean value indicating that the mean is less reliable; the smaller the length, the smaller variation there are of the represented data from the mean. A shorter error bar means that the mean's value more accurately represents the data, thus being more
9. Ask students what data patterns that they see about the data's reliability using the error bars' length as indicators. Students should brainstorm about claims that they can make about the sea ice extent in the Southern and Northern Hemispheres, as well as claims that they cannot make reliable.

10. Now that students have a sense of the seasonal variation in sea ice extent in each of the two hemispheres, direct them look at longer-term trends in the graph below. Note: Southern Hemisphere data are represented in purple while the Northern Hemisphere is represented in blue. The x-axis on this worksheet lists individual years from 1979 through 2020; the y-axis shows the sea ice extent in millions of square kilometers. Direct students to analyze how the sea ice extent values are different in the Hemispheres, as well as in the spring and fall. Additionally, have students analyze how these data have changed over the decades.
11. Ask your students whether they see any long-term trends in these data. They should notice that there appears to be a gradual decline in sea ice extent (both at the minimum in September and at the maximum in March) in the Arctic. Scientists who have done a rigorous mathematical analysis of this trend report an average rate of decrease in the extent of the Arctic sea ice pack in September from 1979 through 2020. On the other hand, there is not an obvious trend, either an increase or a decrease, in the maximum or the minimum extent of Antarctic sea ice (within the levels of uncertainty or normal interannual variation).

12. The models that climate scientists use to predict the effects of global climate change indicate that the warming of Earth’s climate will be most severe at high latitudes and that the effects will be noticed earlier in the polar regions than at other places on our planet. Most climate scientists believe these effects are already being felt in the Arctic, and that changes in sea ice extent are one such noticeable effect. You may want to discuss these issues with your students at this point.

13. Ask your students to predict, based on these data, in what year they think the Arctic would be ice-free in September if the current trend continues. Ask them how reliable they think their prediction might be. Note: A simple, linear extrapolation based on such a limited set of data probably is not especially reliable. You may want to discuss, at this point, various mathematical and scientific concepts, such as functions/curves that are linear versus curves/trends that are not straight lines; uncertainty, error bars, and other intermittent fluctuations in data sets that make it difficult to make predictions based on small numbers of data points; the scientific phenomena that underlie these mathematical representations of sea ice extent, and how those phenomena are often complicated combinations that can have powerful feedbacks that produce non-linear effects (for example, less ice cover means that less incoming sunlight is reflected away, and thus more heat is absorbed, potentially speeding
up the warming process in a positive feedback loop).