SEA ICE OR FLOATING FROZEN "SEA WATER": COMPARING EXTENT VS. AREA

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Abstract

Sea ice, a part of the Earth's cryosphere, is measured by two different methods - extent and area. Sea ice is produced by freezing seawater, which is essentially a salt solution of sodium chloride (NaCl). Here we examine the differences in the two measurements and their changes over recent times for both polar regions.

Introduction

Sea ice at the two geographic poles on Earth behave differently, and scientists have two different ways of measuring sea ice coverage. We will examine monthly and yearly means for 44 years of data with scatter to extract seasonal cycles and behavior over time for the two polar regions. The error between the two measurement methods will also be investigated. This is big scattered (messy) data provided and analyzed in Google Sheets from the National Snow and Ice Data Center, NSIDC. We will explore graphical behavior of linear, sinusoidal, probability, polynomial, and piecewise functions. All data discussed will be provided in Google Sheets spreadsheets and posted on the Sea Level Change website.

The objectives of this activity are given below:

1. Explore the Earth's cryosphere (ice).
2. Briefly examine the freezing process ($FP_{seawater}$ = -2 ^{o}C) and ice desalination (no contribution to sea level change from sea ice!). This is a nice piecewise function!
3. Discover the difference in polar geography using maps of the poles (north pole - water surrounded by land, south pole - land surrounded by water).
4. Discover how extent and area are measured and how they compare.
5. Examine a probability model for extent vs. area measurements.
6. Examine seasonal cycles for sea ice in the Arctic (NH) and Antarctic (SH) regions.
7. Explore the trends for both polar regions over recent times (1979-2023).

This project can start from raw data (graph, analyze, and explain) or students could be provided graphical results with regressions and work from there. The objectives could be assigned to small groups as well, with groups presenting their results, and having a class discussion.

The Earth's Cryosphere

Where on Earth does ice exist for most of the year? Mainly at the polar regions, both Antarctic (south pole) and Arctic (north pole). Glacial ice is the largest source of freshwater. For more on glacial ice and its changes over time, see Sinex (2023). Sea ice is floating frozen seawater, which covers about an equal area at both poles, and does not contribute to changing sea level. The differences between glacial and sea ice are summarized in Figure 1.

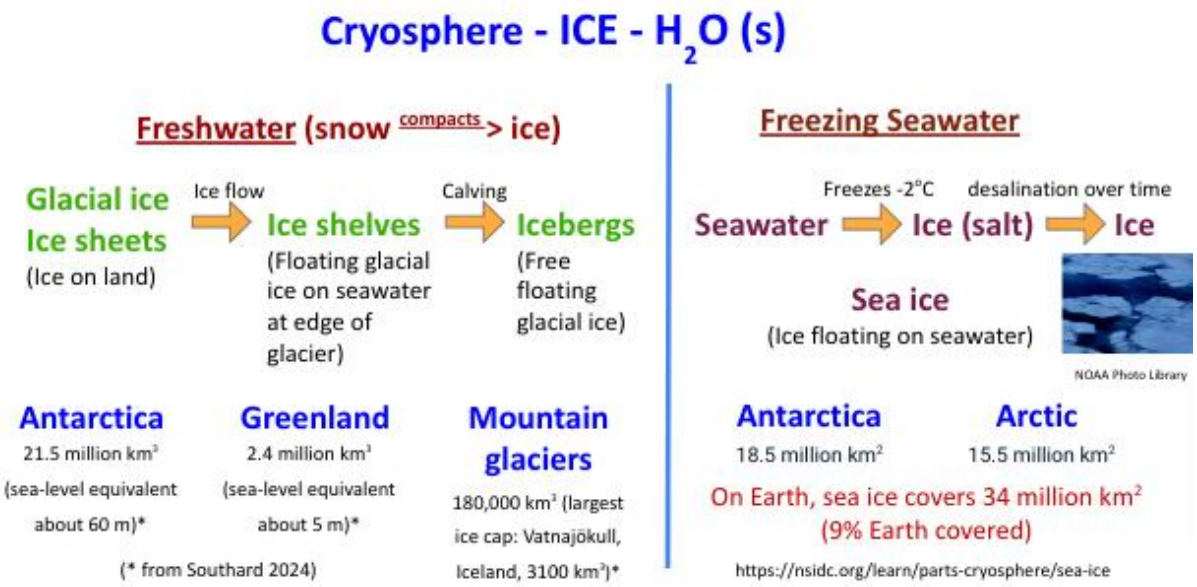

Figure 1 - Earth's cryosphere - ice

Freezing Seawater

Seawater is a multi-component salt solution with sodium chloride (table salt) as the major component. For every kilogram (1000 g) of seawater, there is 35 g of salt dissolved in water. The salt content influences the freezing point of seawater and some salt is trapped in the ice structure. Let's examine the freezing point of seawater and address the question: How does the salt content, salinity, influence the freezing point (FP) of seawater? Open The Making of Sea Ice spreadsheet and "make a copy" to be able to use the interactive features.

How does the salt content, salinity, influence the freezing point (FP) of seawater? Figure 2 gives the freezing point of seawater and a simple solution of just NaCl as salinity increases. Typical ocean salinities vary from 32-37 g/kg yielding a freezing point near -2°C.

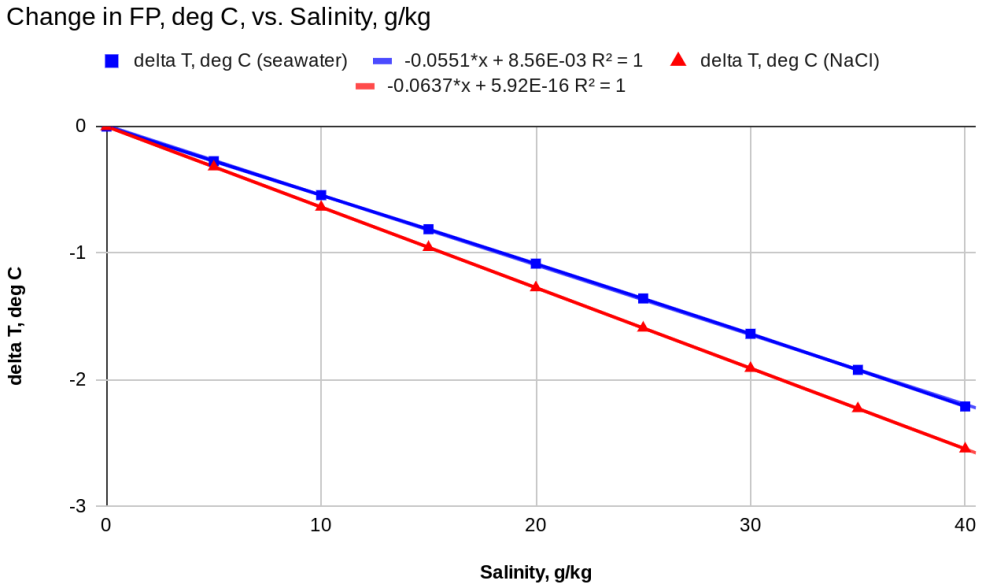

Figure 2 - Freezing point of seawater as a function of salinity

What happens to the salt as seawater is frozen? Salt, at low concentrations, would normally be expelled from the solid structure upon freezing. This is not the case for sea ice (Figure 3)

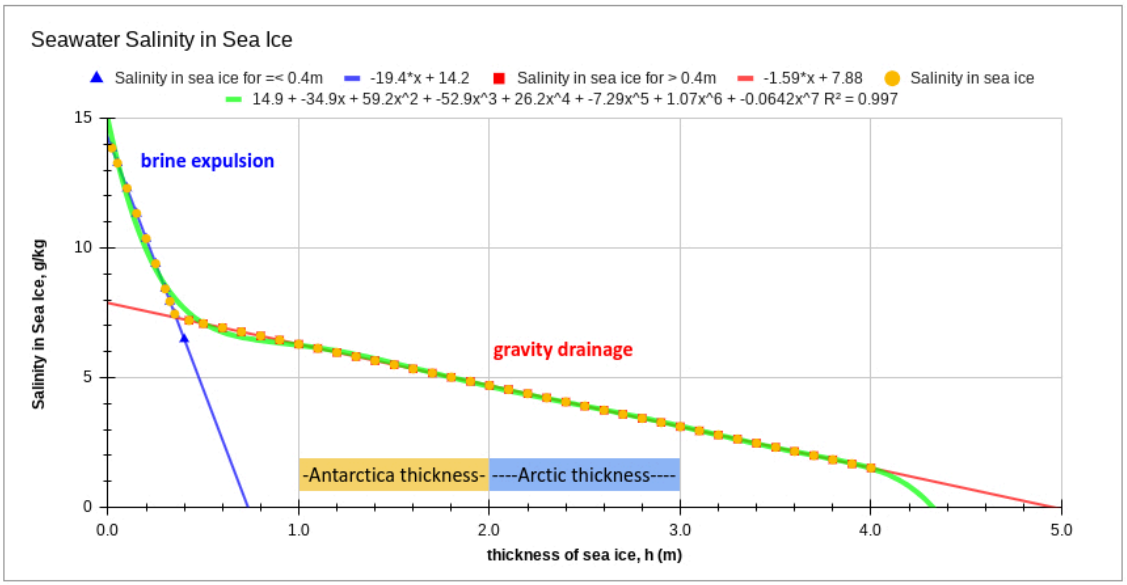

Figure 3 - Salinity content of sea ice as a function of ice thickness

due to the high salt content. Sea ice undergoes a desalination process that changes as the ice thickness increases. The mechanism of desalination changes from brine expulsion (blue) to gravity drainage (red) (Cox & Weeks. 1974). The piece-wise behavior can be fit with a 7th order polynomial. Typical sea ice thicknesses are also shown on the graph.

Polar Geography

In simple terms, the north pole, or Arctic, is water surrounded by land, while the south pole, or Antarctica, is land surrounded by water as seen in Figure 4. The seasons are reversed for the northern and southern hemispheres due to the tilt of the Earth's rotation axis.

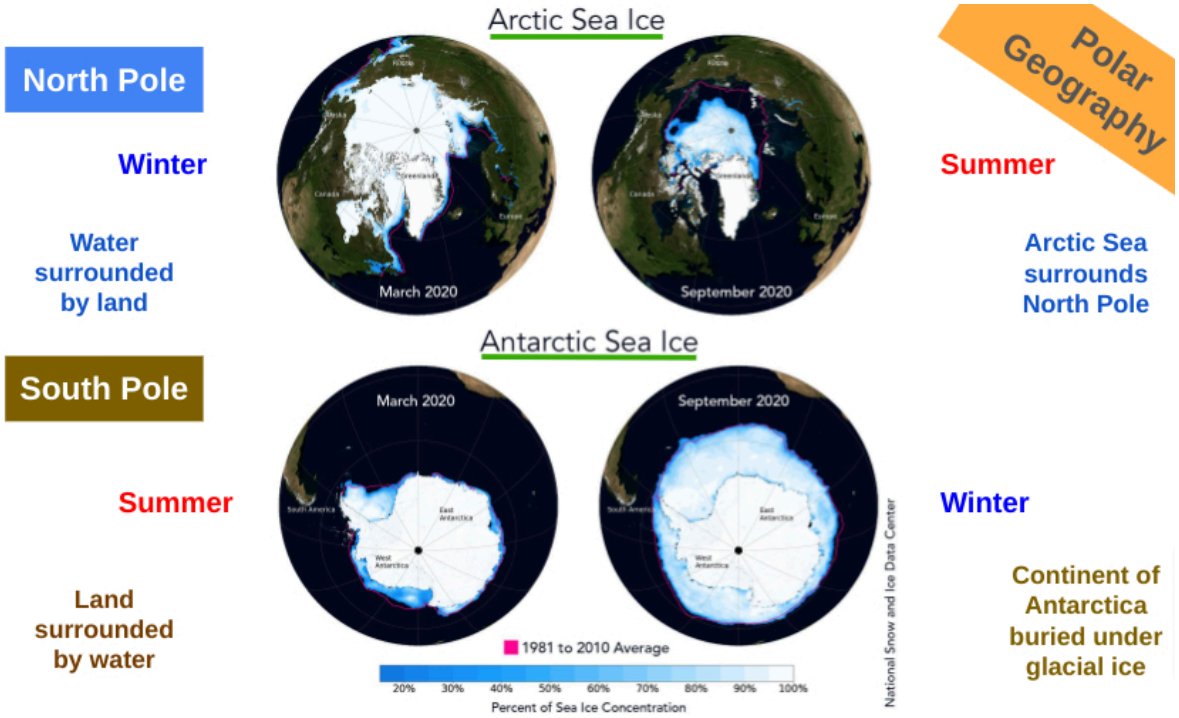

Figure 4 - Crash course in polar geography (map from NSIDC)

Measuring Sea Ice: Extent vs. Area: A Probability Model

Here are the *verbatim* definitions from EUMETSAT OSISAF at https://osisaf-hl.met.no/v2p1-sea-ice-index.

> **Sea Ice Extent (SIE)** is defined as the area covered by a significant amount of sea ice, that is the area of ocean covered with more than 15% Sea Ice Concentration (SIC).

Sea Ice Area (SIA) is the total ocean area covered by any amount of ice (0% SIC threshold).

Sea Ice Concentration (SIC) is the fractional coverage of a grid cell that is covered with sea ice.

At hemispherical scales, SIE and SIA are often reported with units of 10^6 sq km (millions square kilometers).

Burgard (2020) has eloquently described the sea ice extent and area that has been used to develop the interactive Sea Ice: Extent vs. Area spreadsheet (see Figure 5 for a screenshot). Sea ice extent is a binary condition where if >15% ice, cell is counted as 100% and if ≤15% ice, cell is counted as zero ice. So the model sets up a 100 km by 100 km grid where each cell is 100 km^2 and in each cell of the grid is this formula: =100*rand()*R3 this generates a random number between 0-100, which is the area of ice. The R3 term is the probability of ice occurring and is originally set to one. Lowering the probability lessens the chances of ice forming, such as would occur if temperature rises. Use the **ctrl-r keys** to regenerate the random numbers and examine the behavior. How does sea ice extent compare to sea ice area?

Measuring Sea Ice: Extent vs. Area: The Data

Now let's examine data for extent and area of sea ice at both polar regions. The data are available on the Sea Ice or Floating Frozen "Sea Water" spreadsheet, which contains the monthly and annual means for 1979 to 2022. Figure 6, a smooth line graph, shows the monthly means for extent and area plotted for each month. The seasonal trends as given by the graph. The phase shift is due to when the northern hemisphere is in the summer, the southern hemisphere is in the winter. The amplitude is due to the colder temperatures in Antarctica. The measured ice extent is always greater than the measured ice area as seen earlier. Notice the trend in sea ice extent and area seem to follow each other nicely.

The sea ice extent and area measurements can be plotted on a comparison plot where the y = x line is plotted. The y = x line has a slope = 1 and a y-intercept = 0 if the two measurements are in perfect agreement. Disagreement where slope ≠ 1 (proportional systematic error) and/or y-intercept ≠ 0 (constant systematic error) can indicate the type of error between the measurements. Both errors are positive since extent is greater than area. See Figure 6 and Table 2 for error analysis.

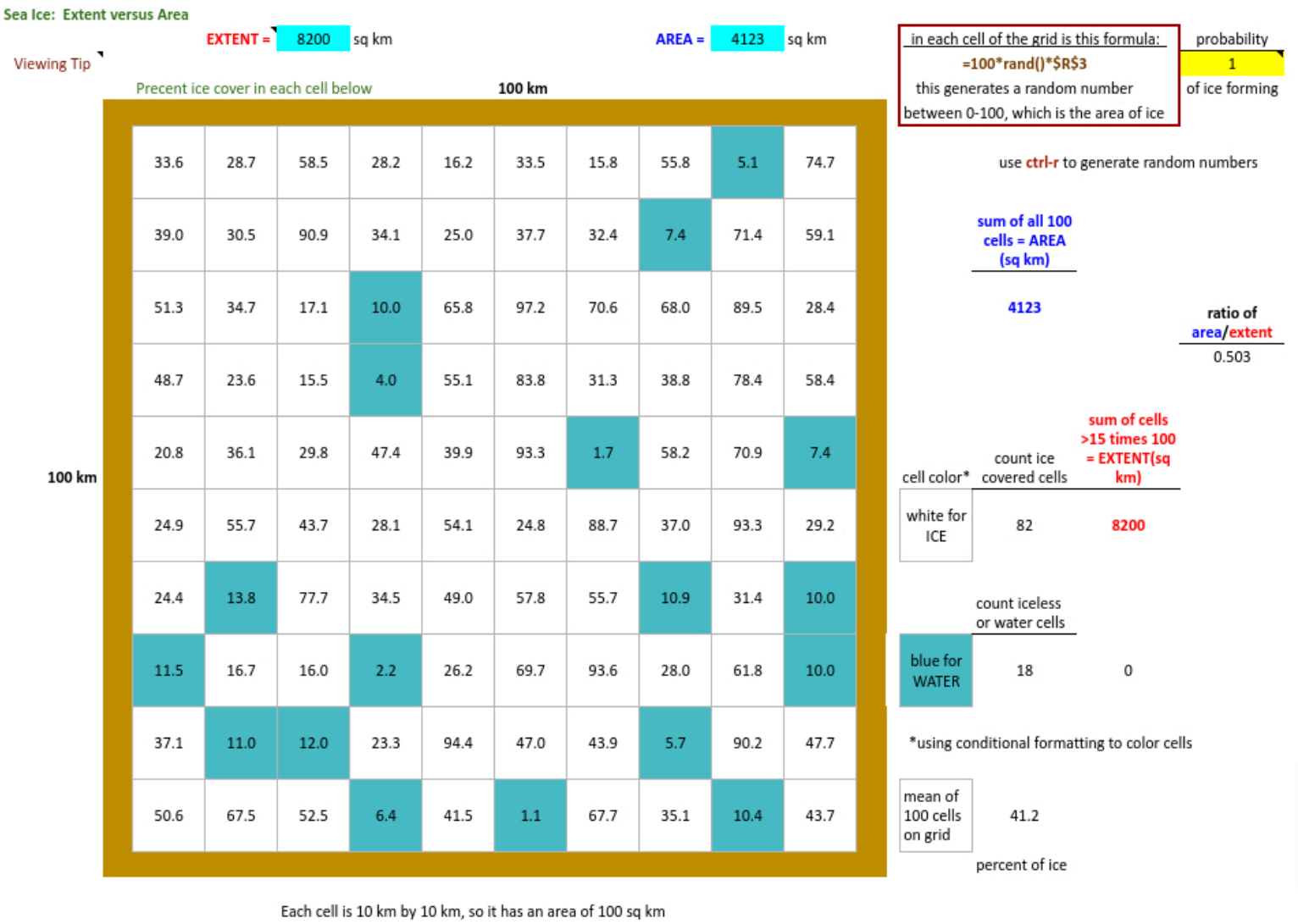

Figure 5 - Probability model comparing sea ice extent vs. area based on Burgard (2020)

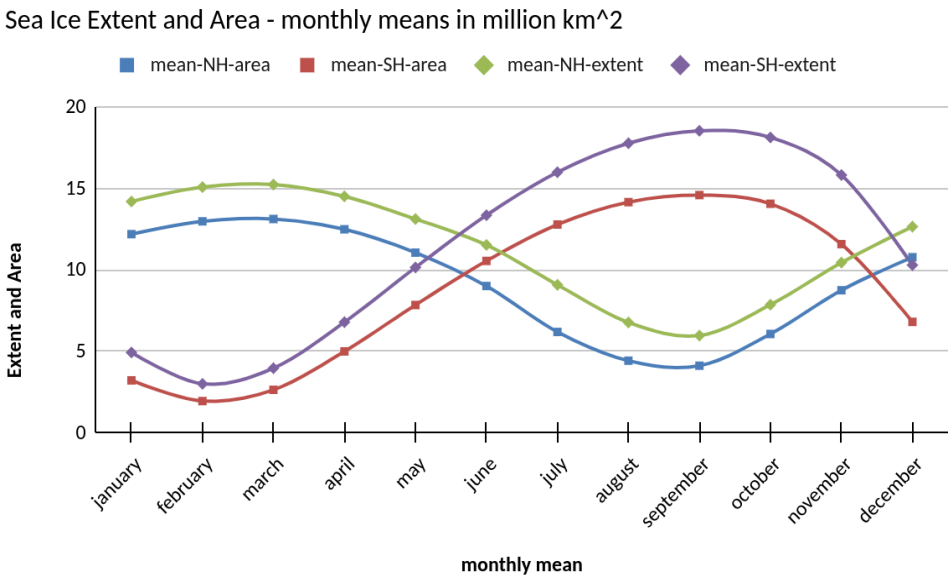

Figure 6 - Monthly means for extent and area for both polar regions

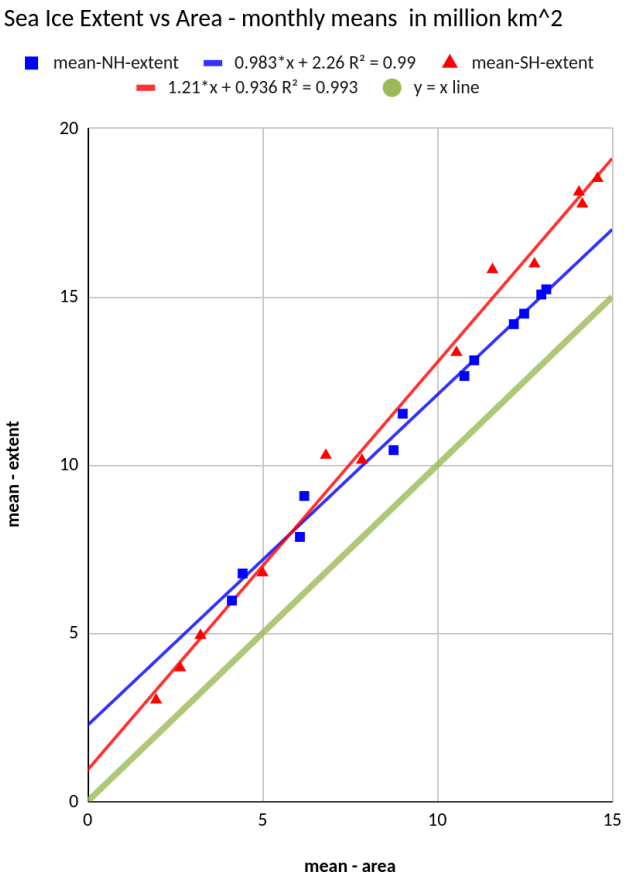

Figure 7 - Comparison plot of the measurements: extent vs. area for both hemispheres

Table 2 - Error analysis of y = x comparison plot for extent and area (see Figure 7 above).

measurement	slope	y-intercept	Type of error	Comments
extent-NH	0.983 ~ 1	2.26 > 0	Positive* constant systematic	High r^2 values for both measurements, random error is small
extent-SH	1.21 > 1	0.936 > 0	Positive* proportional and constant systematic	

Both errors are positive in Table 2 because they are above the y = x line. The probability model in Figure 5 overestimated extent as well. For a discussion and graphical illustration of types of errors, see Sinex (2005) and see the Ruler and Measurement Error Excelet to explore the types of errors in a variety of ways.

Now let's consider how extent and area for both polar regions varied with time. The annual means for extent and area for Antarctica (SH) and the Arctic (NH) are illustrated in Figure 8.

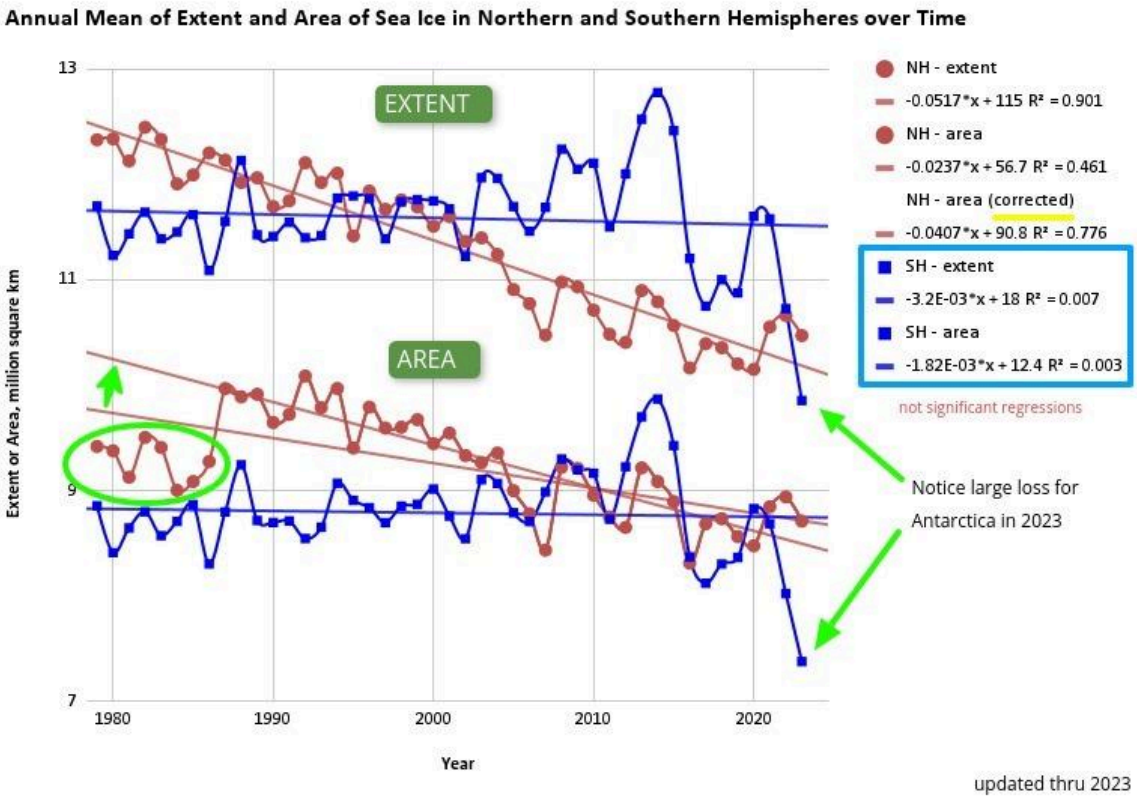

Figure 8 - Sea ice extent and area for northern (red) and southern (blue) hemispheres

Let's consider Antarctic sea ice (blue curves) where from 1980-2000 both extent and area show essentially constant for sea ice. From 2000-2014, sea ice increased in both extent and area, plus showed an enhanced cycle (much greater amplitude), and then started to plummet, especially in 2022 and again 2023! Got your 2024 prediction?

For the Arctic sea ice (red curves) the data for extent and area are typically correlated nicely (see Figure 8); however, notice the area data for 1979-1987 seem to be much lower in value. Is there a possible error? If the errant area data is removed from the regression, the new regression has a slope of -0.0407, which is reasonably comparable to -0.0517 for the extent data.

Final Thoughts

Sea ice in polar regions is experiencing the consequence of climate change. The unfortunate extra that comes with melting sea ice, is that a very reflective material is replaced by seawater, a very non-reflective or absorbing material.

Getting big data sets with big scatter is an important aspect that needs consideration and integration in mathematics and science courses, see Sinex (2024). Dealing with data that involves a more multivariable approach is also needed. A variety of climate change data sets are available at https://sites.google.com/view/ssinex/home/sea-level-change. All the data sets have been downloaded into Google Sheets spreadsheets.

For interactive Google Sheets spreadsheets (simulations) that cover a variety of climate change concepts, see Climate Change Sheetslets. These are great discovery learning tools for students, especially combined with "what-if" questions.

Acknowledgements

The author wishes to thank Catherine Mejia Sinex, retired mathematics teacher, for providing invaluable comments on this paper.

References

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S.A. Sinex (2023) Exploring the Data for Delineating the Causes of Global Sea Level Rise in Electronic Proceedings of the ICTCM Conference, Vol. 34, 20pp.

S.A. Sinex (2024) Messy Data and a More Real-World Function Machine in Electronic Proceedings of the ICTCM Conference, Vol. 35, 12pp.

John Southard (2024) Chapter 7 Glaciers in The Environment of the Earth's Surface

Classroom Resources (all accessed June 2024)

The Making of Sea Ice spreadsheet

Sea Ice: Extent vs. Area spreadsheet (probability model)

Sea Ice or Floating Frozen "Sea Water" spreadsheet

Ruler and Measurement Error Excelet to explore all the possible ways to mess up with a ruler! Examines relative and absolute errors, illustrates the errors, and shows how the y = x comparison behaves due to errors.

National Snow and Ice Data Center (NSIDC) source of all data used in this article with specific references given on the spreadsheet at
https://nsidc.org/learn/parts-cryosphere/sea-ice

Sea Level Change and its causes from other global problems: Real-world Data Analysis and Mathematical Modeling Spreadsheet Projects at
https://sites.google.com/view/ssinex/home/sea-level-change

Dealing with Scientific Data in Google Sheets: Data > Model > Simulation
https://sites.google.com/view/ssinex/home/dealing-with-data-in-gsheets

Climate Change Sheetslets: Interactive animated Google Sheets spreadsheets
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