Arctic Sea Ice and Linear Equations

Background
European explorers, beginning with Cabot's 1497 attempt to sail to the Orient from England, searched for the *Northwest Passage*, a route through the Arctic Ocean along the coast of Canada. See Figure 1. The Norwegian explorer Roald Amundsen was the first to complete the journey, though it took from 1903 to 1906. In 1957, the U.S. Coast Guard Cutter *Storis* became the first U.S. vessel to circumnavigate the North American continent, a 22,000 mile trek.

The problem is the Arctic Ocean is covered by a sea ice pack nearly all the time---the passage is closed. Since the beginning of the Industrial Revolution, global temperature averages have risen overall causing more of the ice pack to melt in the summer. NASA's *National Snow and Ice Data Center* at the University of Colorado, Boulder, has collected data provided by satellites, over-flights, submarines, and other observations measuring the amount of sea ice in the Arctic Ocean for several decades. The amount of ice is at a minimum in September, the end of summer. Figure 2 shows the September average extent of total Arctic sea ice area in millions of square kilometers versus the year from 1979 to 2011. Clearly the extent of ice is decreasing.

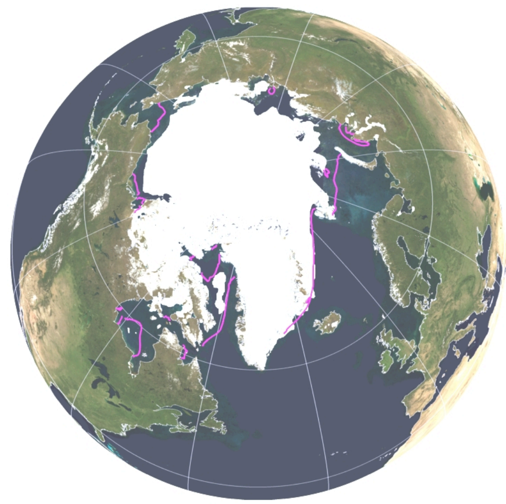

Figure 1: Arctic Sea Ice[1]

Melting sea ice provides an example of a positive feedback loop (also called non-linear feedback). As the ice melts, it leaves more ocean open. Ice is very reflective giving the arctic region a high *albedo*; ice reflects up to 70% of the sun's energy. The ocean is darker, reflecting only 6% of the sun's energy, so as the ice pack retreats, the area's albedo gets lower. More energy is absorbed by ocean water than by sea ice increasing the temperature, causing more ice to melt leading to more open water, creating a positive feedback loop.

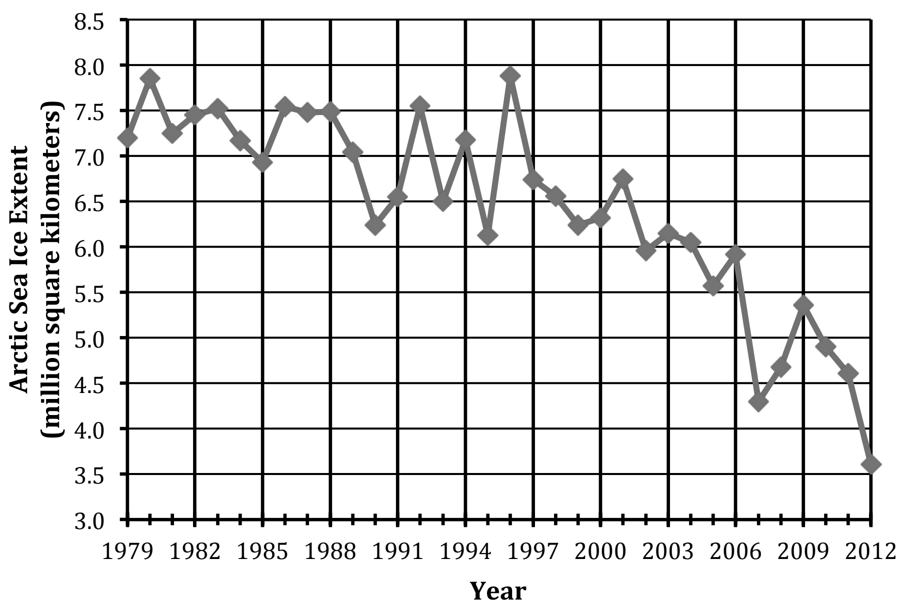

Figure 2: Average September Arctic Sea Ice Extent, 1979 to 2012.

Questions:

1. From the data given in Figure 2, how much ice was in the Arctic in September 1988, September 1998 and September 2008? What are the units? What is the overall trend in the amount of sea ice during this time period?

2. On Figure 2, draw the line that looks to give the best fit to the data.

3. From your drawing, calculate the slope of the line. How does your estimate connect with the overall trend?

4. Figure 3 shows both the equation and the graph of the line of best fit: $y = -0.0921\ t + 190.12$ Use this mathematical model (the equation of the line of best fit) to find the amount of ice in September 2003 and in September 2012. How do these values compare to the actual data values?

5. What is the slope of this line? How close was the slope of your line in (2) to the slope of the best fit line?

6. What are the units for the slope? What does the slope tell us about the rate at which extent of sea ice is changing?

7. If present trends continue, how much Arctic sea ice will there be in September 2020? In what year does your model predict that the Arctic will be ice free in September?

8. Looking at the data, do you think this prediction is accurate? Discuss.

9. What do you consider as the pros and cons of having an open Arctic passage?

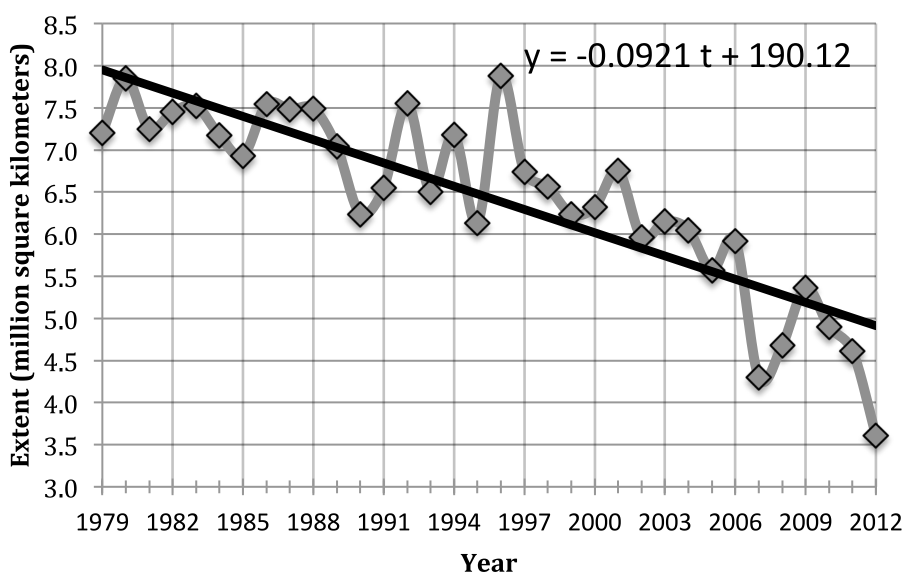

Figure 3: Best fit curve to Average September Arctic Sea Ice Extent

---

[1] All images courtesy of NASA and the National Snow and Ice Data Center, U.C., Boulder. (http://nsidc.org). Lesson plan by William Bauldry, Appalachian State University, Victor Donnay, Bryn Mawr College, and Thomas J. Pfaff, Ithaca College.