Sea Ice; Nature's Polar Quilt

I'm Ben Holt and my research is in polar oceanography. I use satellite data to study the frozen seas in the Arctic and Antarctic. Mostly I work in my comfortable office examining satellite images of the polar regions from my computer terminal. Occasionally I have taken field trips to different locations in the Arctic to study sea ice "up close and personal" [Fig. 1]. How could stuff so cold and weird and so far away be interesting enough to study for a career? Seeing, being on, and pondering spectacularly beautiful sea ice in the oceans is absolutely wonderful, dynamic, and intriguing. Sea ice is also an important piece to the puzzle of understanding the Earth's climate, because it affects the storage and exchange of global heat. Currently I am involved with two related projects to study how sea ice melts. But before I tell you more about how ice melts, I should tell you first how it freezes!

Figure 2. Sea water starting to freeze; this is known as 'grease ice' because it looks greasy. The water surface is filled with floating ice crystals which have not yet become solidly connected together.

Sea ice freezes [Fig. 2] out from the ocean when the ocean is at the freezing point which is usually -1.8°C. This is colder than 0°C because the salty ocean moves the freezing point downward. Water ice crystals are the most extraordinary in the entire universe since water is the only molecule that expands when frozen, which means that it floats rather than sinks! Recently formed ice can be very neat [Figs. 3 & 4]. Floating ice acts as a blanket in the winter, keeping the comparatively warm ocean from releasing all its heat to the colder atmosphere. Also, the white snow on the ice [Fig. 5] is a strong reflector of incoming solar radiation (sunlight) so snow keeps the ice cover from melting. You can walk on floating ice, which is a wonderful experience that is often exciting [Fig. 6]. Sea ice is not as hard as ice on freshwater

Figure 1. Ben Holt, standing on a bit of old ice that has got stuck in shallow water, overlooking melt ponds on first-year ice which is ice that formed the previous fall.

Figure 3. Recently formed new or grease ice crystals can agglomerate into small floes (less than 2 meters in diameter) which are called 'pancakes'. The floes are rounded because they keep bumping into each other as they bob around on the ocean waves.

Figure 4. Young ice - very thin pancake ice that has frozen together.

Figure 5. An ice camp for scientists on old ice seen from a helicopter. This is in early summer (early June) and the ice is still covered with snow. Very little of the sun's energy gets through to melt the ice because it is all reflected by the very white snow.

lakes or rivers, so it needs to be at least 20 cm thick before it is really safe to walk on. Ice thinner than 20 cm is actually flexible and will bend under your weight. Sea ice gradually thickens over the winter. It also gets pushed around by the wind and ocean and breaks into smaller and smaller, rounder and rounder bits of ice, known as floes. Over time the floes bang into each other and often form ridges or piles of broken ice floes [Fig. 7]. Floes can move apart from each other, exposing open ocean. These cracks, that expose the ocean, are called leads and in winter they freeze over quickly [Figs. 8 & 9]. The ice is so varied that a person travelling on sea ice with a sled (only a few feet from the cold ocean underneath!) may cross level smooth ice floes, then have to pull the sled over powerful blocky ridges 3-5 meters high and then have to figure out how to go around or across the leads. For more neat sea ice stuff, see http://southport.jpl.nasa.gov/polar.

Figure 6. A person collecting a core of ice for analysis of physical properties such as salinity and crystal structure that indicate the age of the ice. The coring device is turned by hand or small engine to cut downward into the ice, surrounding a core of ice that can be pulled up and stored for later analysis in a small laboratory.

You may wonder what happens in the summer when the air temperatures go up. The warm air and the sun's energy melts the thin cover of snow first and then the ice surface starts to melt. This produces melt water that can cover large areas of smooth ice [Fig. 10]. On rougher ice meltwater collects into ponds [Figs. 11 & 12]. Snow reflects solar radiation, but the wet ice and surface ponds absorb radiation so the melting speeds up. Heat from the atmosphere can enter the ice and the increased open water areas between the ice. The change in heat absorption from the winter situation is a key factor in the Earth's climate balance [Fig. 13]. Eventually the melt water [Fig. 14] drains either through very tiny (1 mm in diameter) holes in the ice or runs off the ice into leads and through holes that seals keep open for breathing! Over the course of the summer, the ice floes become thinner and smaller (i.e., they get thinner both vertically and horizontally) [Fig. 13], since the surrounding water is also being warmed by the air. Much of the ice will melt away completely, especially around the margins of the Arctic and almost entirely from around the Antarctic continent [Fig. 15].

Figure 7. A long ridge of ice that has formed when two floes of thick ice have been squeezed together by wind or ocean currents, with the ice breaking into chunks that pile upward and also downward below the ice. This ice is difficult to cross on foot or with sleds or snowmobiles.

My two current research projects are focused on understanding when, where and how ice can melt at the edges, or horizontally. The thinning of sea ice is fairly well understood and occurs all over the polar oceans. However,

Figure 8. A lead which is a crack in the ice can form when two floes move apart. In winter, new ice forms rapidly in the open water . In places you can see where the ice has squeezed together again and sheets of thin ice have slid over each other (called finger rafting). The small white clumps on the gray-colored ice close to you are clumps of ice crystals called "frost-flowers".

Figure 9. More finger rafting. This ice form is known as finger rafting because it looks like fingers when you slide your hands together so your fingers overlock. Pancake ice has become frozen into the ice cover in the foreground.

Figure 10. All of the snow has melted on this very smooth first-year ice. Because the snow has gone and the surface is relatively dark, much more of the sun's energy can be absorbed so the ice melts faster than when it is covered with snow.

Figure 11. Ponds of melt-water on old ice seen from a helicopter. If you look carefully you can see a tent and people making measurements of ice physical properties. This is the same ice camp as in Figure 5, but you can see that the surface is now much darker due to melt water so more of the sun's energy is available to melt the ice.

Figure 12. Ponds of melt water on old ice. This was a very thick, old ice floe. We never knew how thick it was, but it was more than 4 meters. In the distance you can see some old, very large ridging.

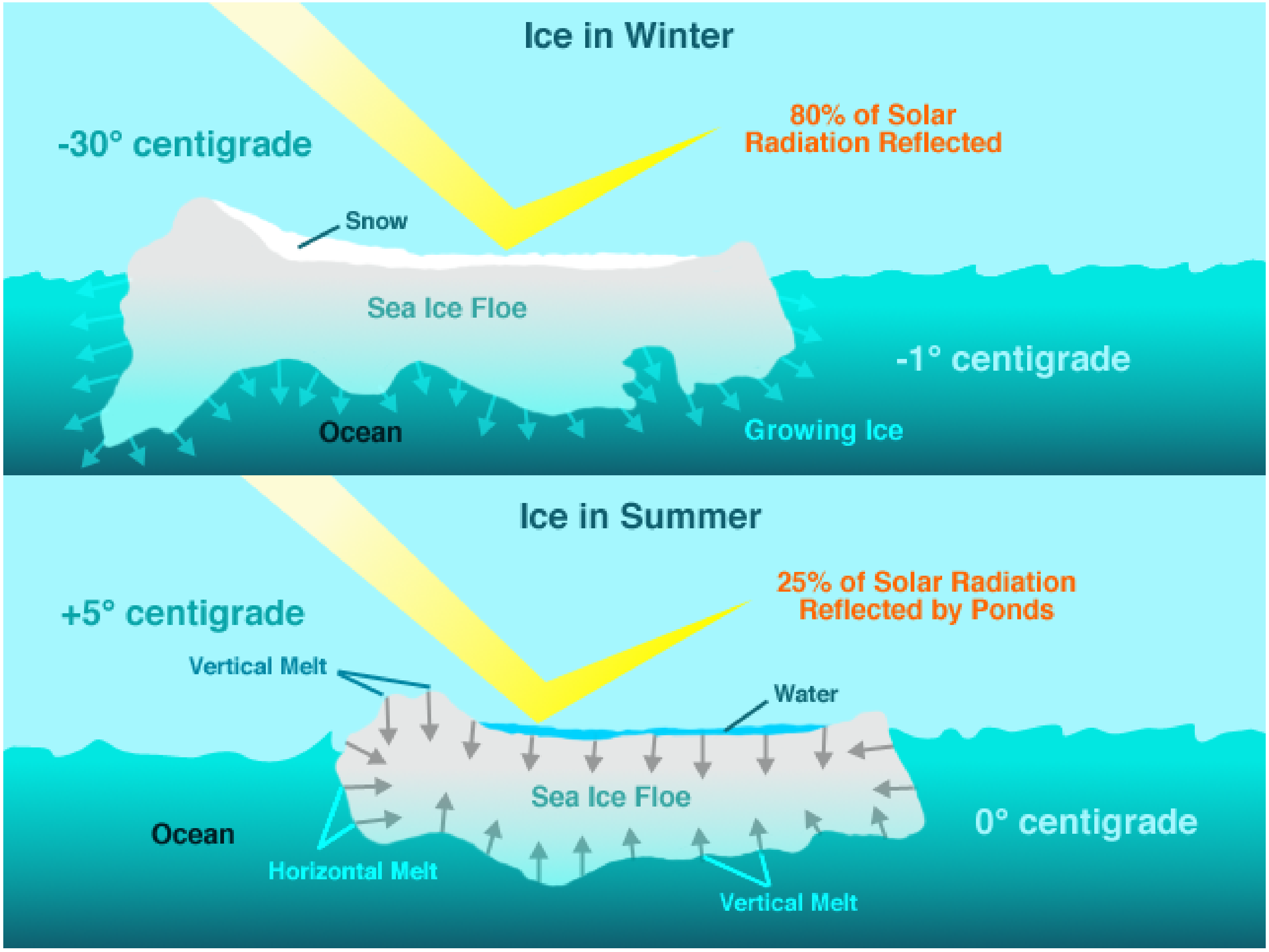


Figure 13. Ice floes grow in the winter and melt in the summer because of the change of the temperature and solar radiation.

horizontal or lateral melt can only happen where the ice floe is in contact with surrounding warmed open water. Here's one way to think about it: Take a 10 km by 10 km box in the ocean which is 90% ice covered. If it is covered by a few big floes, then there are not many ice edges in contact with the 'warm' ocean. Now suppose the same 95% surface area is composed of much smaller floes [Fig. 16]. Since the floes are generally round, that means that a lot more ice edges are in contact with "warm" water than if the ice were in a few big floes. When there are many small floes there will be more lateral melt, and more open water, which means that the upper ocean will heat up more than when it is covered by larger floes [Fig. 16].

For my research, I am measuring the size distribution of floes, in different regions of the Arctic during the summer months, to determine the amount of open water between the floes [Figs. 17 & 18]. I am using satellite data from a radar sensor that makes images using microwave radar signals [link to radar section] and I have a computer program that identifies floes and measures them. This works well in winter, but in summer, the ice is wet, making it difficult to distinguish ice from open water so the computer has trouble isolating individual floes.

My other approach to measuring floe size is to get more reliable measurements but over a smaller area. I am doing this as part of an experiment called the Surface Heat Budget Experiment in the Arctic

(SHEBA). The experiment, which started in September 1997, involves an ice breaker that is stuck (on purpose!) in the sea ice for a 12-month experiment in the Beaufort Sea. One of the types of data that the SHEBA scientists are collecting is floe size. The SHEBA web site (http://sheba.apl.washington.edu) provides daily updates of the weather and position of the drifting ship as well as measurements and photographs.

These two approaches work well together. The scientists on the ship are able to get very accurate measurements of the atmosphere, ice, and ocean near the ship, and the satellite measurements let my team extend the on-ice measurements to a larger region. With

Figure 14. This person is actually safe although he is walking on water! Under the water is first-year ice that is 2 meters thick. This water all came from melted snow and it only took a few days for most of it to drain through to the ocean underneath through seal breathing holes and leads.

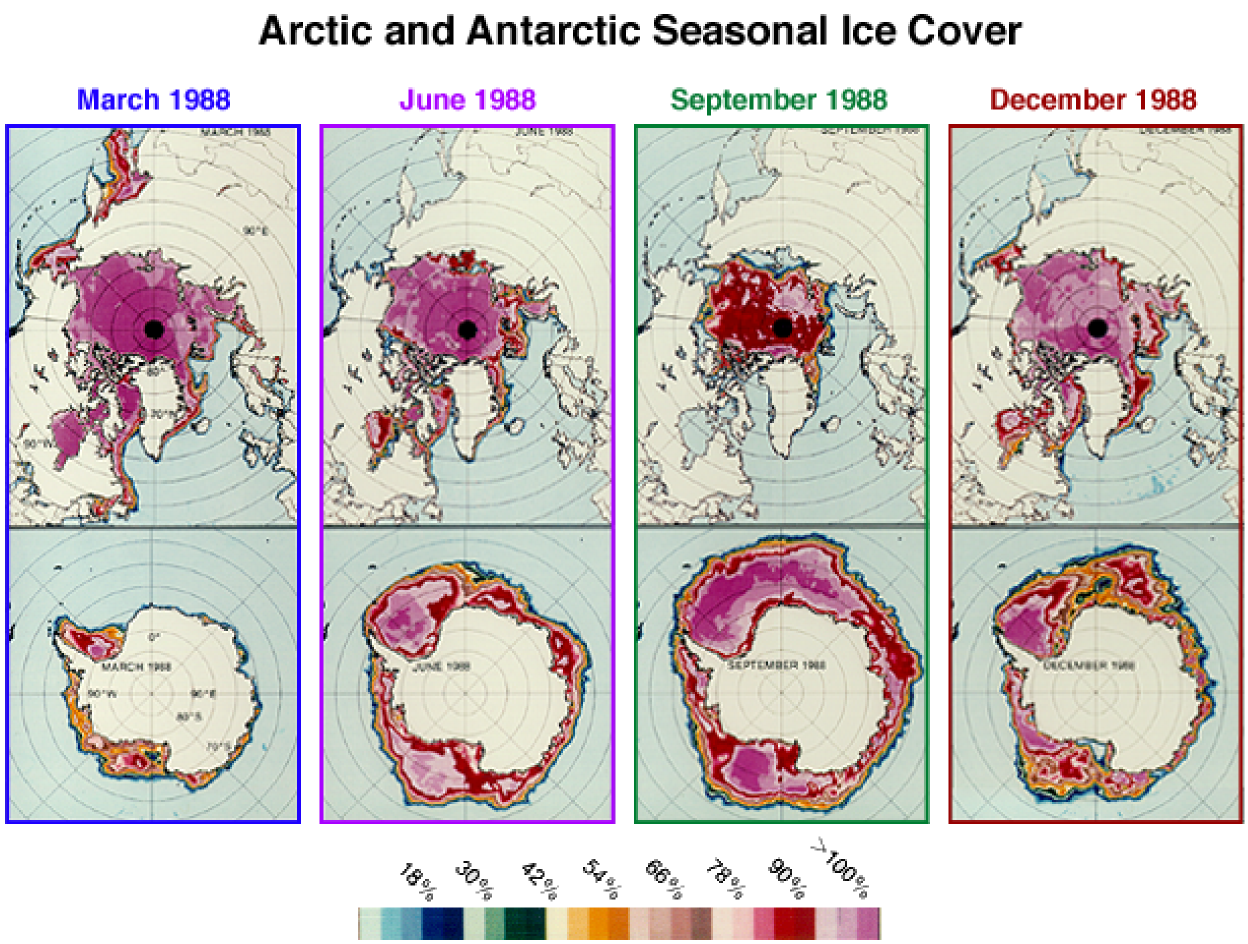


Figure 15. This figure shows the percentage of ice cover in both the Arctic and Antarctic as measured by a satellite instrument called the SSM/I (Special Sensor Microwave/Imager). Each panel shows a monthly average for March, June, September, and December 1988 at both polar regions.

our floe and open water measurements from combined data sources, my colleagues and I hope to understand the importance of lateral melt over the Arctic and how it affects the heat storage in the ocean during the summer period.

Acknowledgments

Photos courtesy of Ben Holt and Susan Digby.

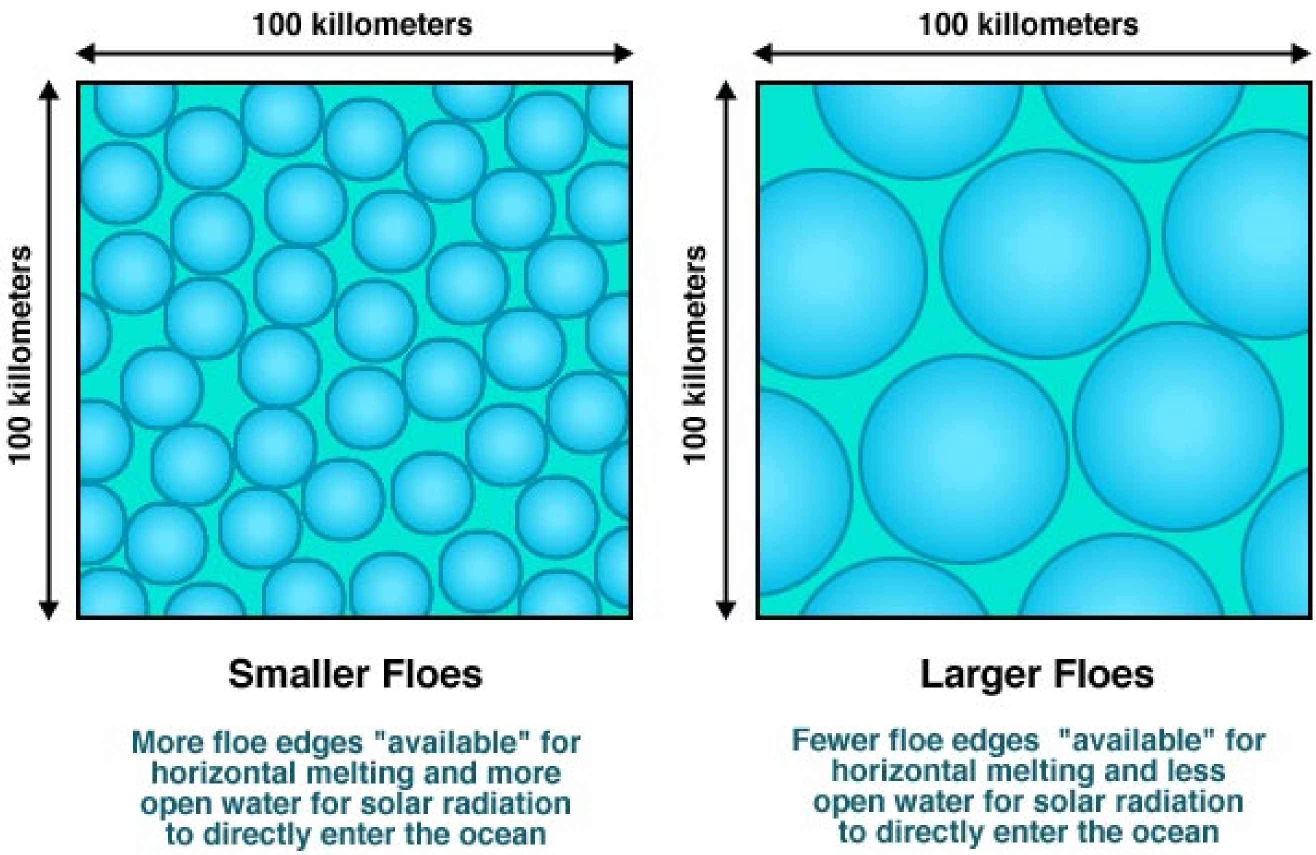
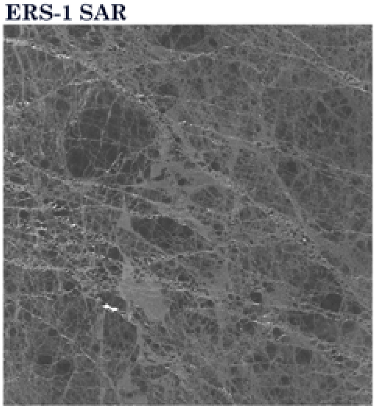


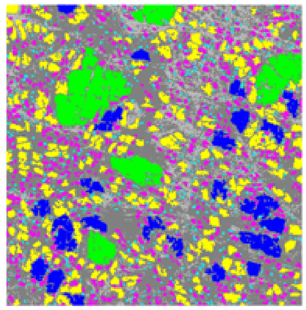
Figure 16. An area of ice that is one large floe has less edges that can be melted by the ocean, the air and solar radiation than an area of ice that is broken up into smaller floes.

June 18

ERS-1 SAR



Floe Size Distribution



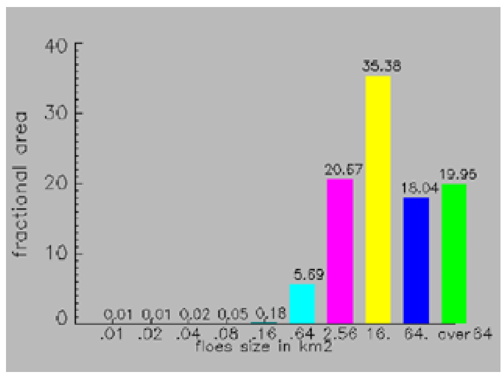
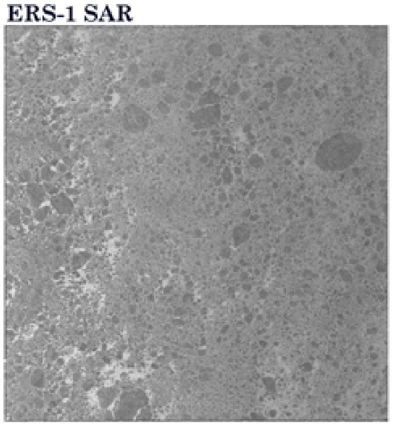


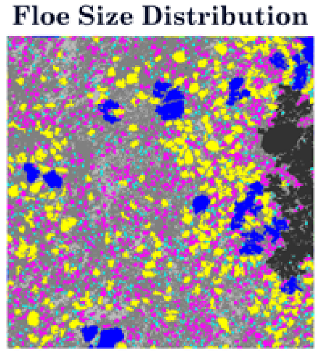
Figure 17. The left image shows a radar image taken by the European Space Agency's Earth Remote Sensing satellite (ERS-1) on June 18, 1992 over the Beaufort Sea (76.2°N, 160.5°W). The image on the right-hand side is derived from the original image. The adjacent panel shows the locations of various floe sizes, and a bar graph made from this data. From this data you can see that there are a few areas of large floes which are over 60 km^2 and that they cover almost 20% of the sea.

August 26

ERS-1 SAR



Floe Size Distribution



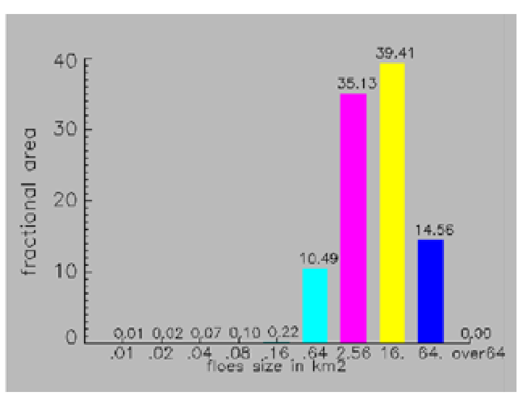


Figure 18. Same as Figure 17, except that the image was obtained on August 26, 1992 over the Beaufort Sea (78°N, 163.7°W). In comparing the results between the two days, note the shift in overall distribution from larger to medium-sized floes. This suggests a general reduction in the size of floes over time due to melt and breakage due to wind pushing floes against each other.