Arctic sea ice: 6 not so easy questions

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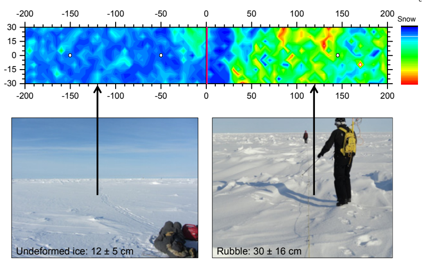
Introduction

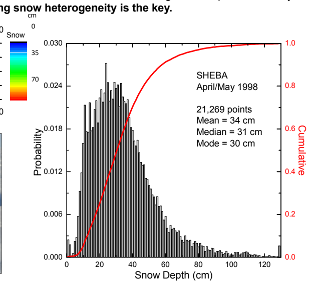
The Arctic sea ice cover is both an indicator and a potential amplifier of climate change. The ice cover is undergoing a transition. Summer sea ice extent is decreasing, the ice is getting thinner, and there is a fundamental shift from relatively robust multiyear ice to less resilient first year ice. These changes are impacting human activities right now. The properties and processes of the ice cover must be observed and understood to improve our ability to predict the future state of the ice on a range of spatial and temporal scales. Six significant sea ice questions of current interest are presented. All of these questions are complicated by the shift from multiyear ice to first year ice.

1. How do we describe snow properties and processes?

Arctic sea ice is covered by snow for much of the year. The snow cover is an important component of the sea ice system. It is a superb reflector and a snow depth of about 10 cm is optically thick. It is also an excellent thermal insulator. There is significant spatial variability in snow depth depending on ice topography and age. **Properly representing snow heterogeneity is the key.**



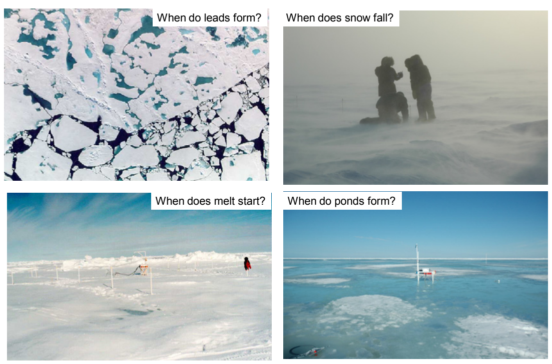
Spatial heterogeneity of snow depth on undeformed and deformed first year ice.



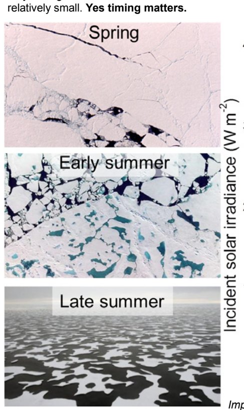
Distribution of snow depth on multiyear ice.

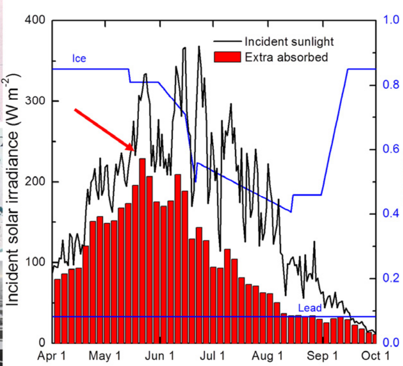
2. Does timing matter?

There are major events in the life of sea ice: fall freezeup, summer melt, snowfall, pond formation, and floe breaking. These events matter, but how important is the timing of the event?



Consider leads. It certainly matters whether a lead forms in winter or summer. In winter leads are sources of huge turbulent fluxes from the ocean to the atmosphere. In summer leads absorb large amounts of solar radiation. What about a more subtle difference, say between late spring and early summer. The impact of timing of a summer lead on solar energy input is examined below. The impact is a combination of the incident solar irradiance and the contrast in albedo between the ice and lead. The greatest impact occurs in late-May through June, when incident solar irradiance is large and the ice-lead albedo difference is great. After late-August the impact is relatively small. **Yes timing matters.**

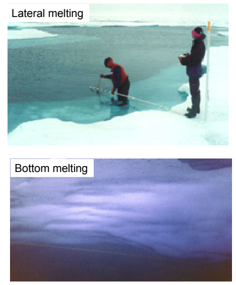




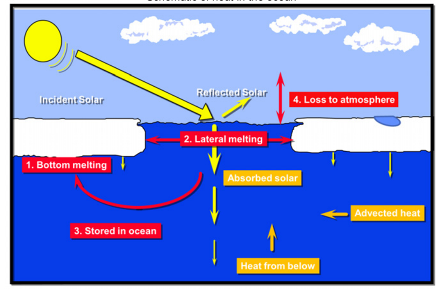
Impact on solar radiation input of a lead opening. Data are from the Beaufort Sea.

3. What is the source and fate of heat in the ocean?

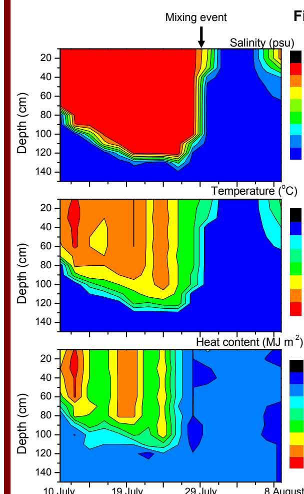
Heat in the ocean plays a major role in the evolution of the ice cover. Much of the ocean heat is from locally absorbed solar radiation. This heat can be lost to the atmosphere, be stored in the ocean, and contribute to bottom and lateral melting. Determining this partitioning is of critical importance for sea ice thermodynamics.



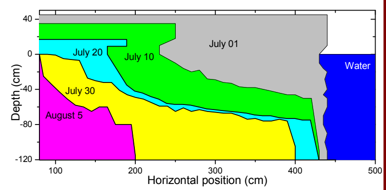
Schematic of heat in the ocean



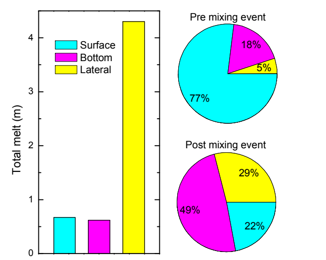
Field observations



Time series of observed salinity, temperature, and heat content in the lead pictured above.



Wall profile on edge of floe showing lateral melting

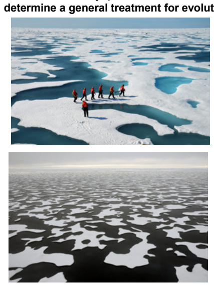


Left panel: Total summer melt. Right panel: Relative contributions to changes in ice volume before and after the mixing event.

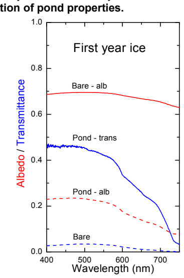
For much of July conditions were quiescent and the lead freshened and warmed, storing solar heat in the upper ocean. At the end of July, a small storm increased ice motion mixing the water in the lead. There was a large increase in lateral melting at this time. Over the summer the total amount of lateral melting was 4.3 m compared to 0.67 m of surface melt and 0.62 of bottom melt. Before the event ice volume losses were dominated by surface melting. Afterwards bottom and lateral melting were larger than surface melt.

4. What about melt ponds?

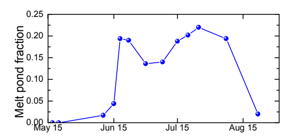
Melt ponds have a major impact on the ice cover. They decrease the albedo, increase transmitted light, store freshwater, and are mechanical flaws in the ice. Key questions are how do they form, how do they evolve, and how best can they be treated in large scale models. **Need to determine a general treatment for evolution of pond properties.**



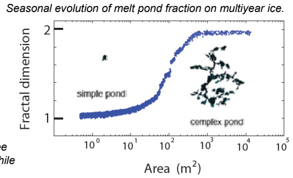
Ponds deepen and widen as melt progresses.



Bare ice reflects more than three times as much light as pond, while ponds can transmit an order of magnitude more than bare ice.



Seasonal evolution of melt pond fraction on multiyear ice.

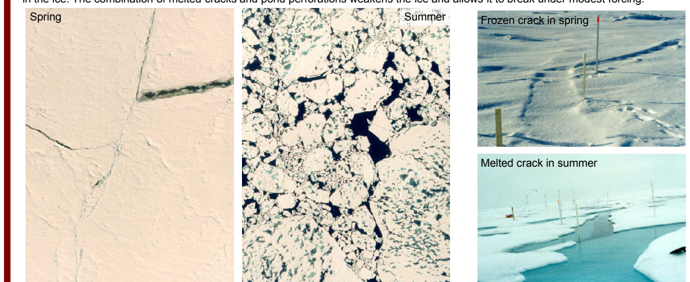


Shape and fractal dimension of ponds change as they grow

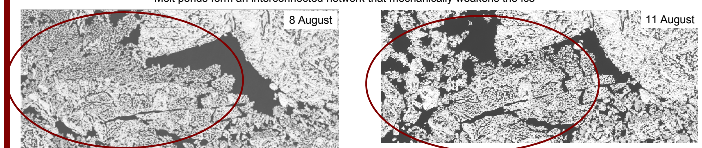
5. How does the floe size distribution evolve?

In winter and spring the ice cover consists of large, rectilinear plates of ice separated by linear lines. By summer the surface is a complex, evolving mosaic of ice and open water. There are rounded floes of various sizes and shapes with a complex lace of open water.

How do these floes breakup in summer when mechanical forces are minimal and the ice is often in free drift? It is a combination of winter dynamics and summer thermodynamics. Crack form in the winter, freeze and melt in the summer. Melt ponds form a pattern of perforations in the ice. The combination of melted cracks and pond perforations weakens the ice and allows it to break under modest forcing.

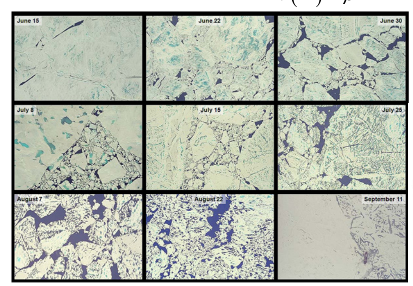


Melt ponds form an interconnected network that mechanically weakens the ice

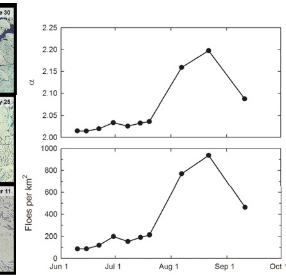


This evolution can be described in terms of a floe size distribution, which is governed by lateral melting of the floes and breaking of the floes. Lateral melting decreases the ice area and perimeter and keeps the number of floes constant (or possibly smaller). Breaking keeps the area constant and increases the number of floes and the total floe perimeter. **Need to determine the breaking function.** The cumulative floe size (diameter D) distribution is assumed to be a power law of the form

$$N(D) = \beta D^{-\alpha}$$



Sequence of photos showing summer breakup of ice floes.



Observed number of floes and α during the melt season.

6. How do ice changes impact primary productivity?

Simplifying somewhat, ice algae and phytoplankton need nutrients and light. In nutrient rich waters, light levels determine productivity. The photographs below illustrate three scenarios. A) Snow-covered multiyear ice where not enough light penetrates to support productivity. B) First year ice with a thin snow cover where enough light penetrates to support shade adapted algae. C) Melting, ponded first year ice, where the algae has sloughed off and there is enough light reaching the upper ocean to support a major phytoplankton bloom. **Need to consider the marine ecosystem response to an underice phytoplankton bloom.**