Integrated SAR and lidar observations of the sea ice cover: Resolving the contributions of thermodynamics and dynamics to the ice thickness distribution

R. Kwok

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

Abstract

The response of the ice cover to large-scale gradients in atmospheric and oceanic forcing is concentrated along narrow zones of failure (up to tens of kilometers in width) resulting in openings, closings, and shearing (see Fig. 1). In winter, openings dominate the local brine production and heat exchange between the atmosphere and the underlying ocean. Convergence or closing of the pack ice forces the ice to raft or pile up into pressure ridges and to be forced down into keels, increasing the ice-ocean and ice-atmosphere drag. A mixture of openings and closings is typical when ice floes with irregular boundaries are sheared relative to one another. The significance of ice deformation is that it increases the volume of sea ice that could be stored within a given area of the Arctic Ocean. Together with thermodynamic growth, these mechanical processes shape the unique character of the thickness distribution of the ice cover, and have profound impacts on the strength of the ice and its mechanical properties over a wide range of temporal and spatial scales. Accurate quantification and simulation of the relative contributions of the thermodynamics and dynamics to the ice thickness distribution are thus crucial for understanding the behavior and the vulnerability of the polar ice covers in a warming climate.

With sea ice kinematics derived from high resolution Synthetic Aperture Radar (SAR) imagery, we are able to approach the spatial length and time-scales appropriate for observing these mechanical processes. Launched in November of 1996, the wide-swath coverage of the RADARSAT imaging radar offers a tool capable of providing high-resolution (~100 m) observations of the Arctic ice cover. Since 1997, routine 3-day RADARSAT imagery of the Arctic Ocean has been acquired for scientific use. Based on this data stream, a joint project of the Alaska Satellite Facility and the Jet Propulsion Laboratory (funded under the NASA REASoN and MEaSUREs programs) has been producing fine-scale sea ice motion products [*Kwok*, 1998]. The science objective is to provide a dataset suitable for understanding the basin-scale behavior of sea ice kinematics on a seasonal and inter-annual time scale, for improving ice dynamics, for documenting changes, and for assimilation into coupled ice-ocean models. The decade-long ice motion data set from this program has allowed a more detailed and unprecedented look at the small-scale time-varying deformation of the ice cover [*Kwok*, 2001]. The observations point to the importance of understanding the consequence of the ice pack as an anisotropic material with large-scale oriented fracture patterns. With the increasing resolution of coupled ice-ocean

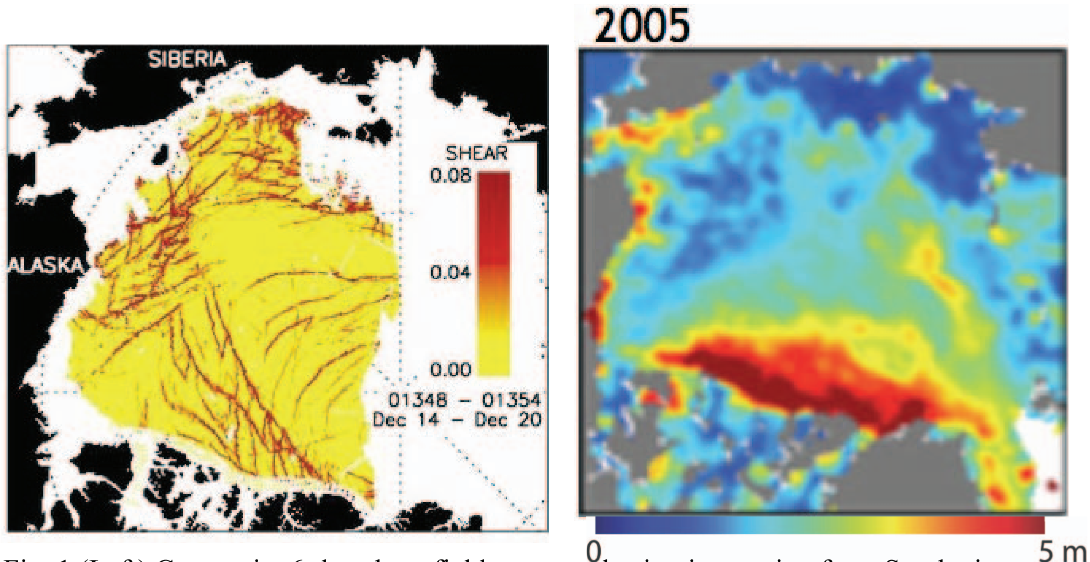

Fig. 1 (Left) Composite 6-day shear field computed using ice motion from Synthetic Aperture Radar imagery. (Right) Spatial field of winter sea ice thickness from one 33-day ICESat campaign over the Arctic Ocean in 2005.

models that approaches the widths of leads, high-resolution observations are needed for model development and validation [*Kwok et al.,* 2008]. Simulation results can now be examined in detail. For climate studies, the impact of an anisotropic ice cover on surface heat and mass balance is not well understood. This high-resolution dataset is a crucial component in the testing of new models that accounts for the spatial and temporal characteristics of these fracture patterns, and for feeding future data assimilation schemes.

Separately, recent work [*Kwok and Cunningham*, 2008; *Kwok et al*., 2009] has demonstrated the feasibility of retrieving freeboard and ice thickness (see Fig. 1) from ICESat data and documented the recent changes in Arctic sea ice thickness and volume. The estimation procedure uses accurate altimetric freeboard and the assumption of hydrostatic equilibrium to determine ice thickness. Even though ICESat provided a basin-scale picture of Arctic sea ice thickness, the temporal sampling has been restricted – due of laser life - to two to three 33-day campaigns over the duration of the mission. Because of this limitation, the thickness fields are not able to provide the sampling density required for understanding the shorter time scale seasonal processes associated with changes in ice thickness and volume due to ice dynamics.

At this time, the derivation and limitations of sea ice motion and thickness estimates from spaceborne data are fairly mature and well understood. The DESDynI mission, to be launched late in this decade, will provide integrated and routine observations of ice kinematics and ice thickness over Arctic and Southern Oceans at the appropriate spatial and temporal scales. With a wide-swath synthetic aperture radar and a lidar system, the mission will be designed to address the shortcomings of present observational systems and to provide a climate quality data set. The combined observations will allow us to resolve the contributions of thermodynamics and dynamics to the ice thickness distribution for process studies and model improvements, and to provide a data set that is suitable for assimilation into global models.

The high-level sea ice requirements for DESDynI mission are summarized below:

1. Measure the thickness of sea ice to better than 0.5 m over a length scale of 25 km.
2. Provide sea ice motion (100 m/day accuracy; 5 km sampling) for understanding the redistribution of sea ice thickness and mass associated with mechanical convergence, divergence, and shear.

In this talk, I will describe the current state of high-resolution observations of the sea ice cover, the challenges, and what the DESDynI will offer to the science community.

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