Monitoring Fram Strait Sea Ice Outflow and Thin Ice Thickness

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Abstract

We propose to: 1) use sequential SAR maps to monitor the profile of sea ice motion through Fram Strait over the period 2003 through 2005; and, 2) explore the potential of using L-band polarimetric data to determine the thickness of thin ice over the same region. PALSAR with its ScanSAR mode and its 2-day subcycle will be able to monitor the motion profile at a high enough temporal frequency to resolve nearly all temporal and spatial variability. Previous work using airborne L-band polarimetric data have demonstrated the potential of unambiguously identification of areas of open water/thin ice from that of thicker ice. There is also the possibility that one could infer the thickness of thin ice, but this is dependent on the noise level of the polarimetric radar. Here, we propose to evaluate the use of L-band polarimetric observations for the discrimination of open water/thin ice from thicker ice and the retrieval of thin ice thickness.

Introduction

Fram Strait Ice Flux

The examination of ice flux through Fram Strait pertains to a much larger problem: the episodic freshening of the surface waters of the Greenland and Labrador seas and the control these events have on the global ocean thermohaline circulation [*Dickson et al.*, 1988]. Anomalous outflows from the Arctic Ocean of surface freshwater and sea ice are significant contributors to this freshening. The budget presented by *Aagaard and Carmack* [1989] lists ice flux through Fram Strait as the largest single component of the Greenland-Iceland-Norwegian (GIN) Sea freshwater balance. The important role of this flux is well-established, even though its magnitude is still in question. Estimates purporting to give a mean volume flux through Fram Strait vary from 1900 to 5000 km^3 yr^{-1} (0.06 to 0.16 Sv). The range of area flux estimates is smaller.

To estimate the volume flux one ideally would want time dependent profiles across the strait of the normal component of velocity and of ice thickness. Both have proven difficult to obtain. Climatological velocity profiles have been extracted from drifting buoy data [*Vinje and Finnekåsa*, 1986; *Moritz*, 1988] and seasonal profiles have been extracted from AVHRR [*Martin*, 1996]. *Kwok and Rothrock* [1999] have recently estimated the profile from ice motion derived from low-resolution passive microwave data and estimated the winter and volume flux. The details of the motion profiles below 50 km are not resolved - an important consideration when examining the area and volume flux close to the Greenland coast. Ice draft data continue to be the most sparse; those obtained from submarine sonar data give some cross-strait variations [*Wadhams*, 1983; *Vinje and Finnekåsa*, 1986] and those obtained more recently from moored sonars resolve six years of temporal variability [*Vinje et al.*, 1998]. There is also considerable variability in the north-south direction along the direction of flow. The ice appears to diverge as it flows southward through the strait. The different lines across which the flux has been estimated accounts for some of the differences between estimates by different investigators.

This proposal seeks to measure the ice motion profile using high resolution ScanSAR data from the PALSAR on ALOS for the years 2003 through 2005. The data set will provide a first high-resolution view of the Fram Strait motion profile with a spatial/temporal sampling frequency that allows us to understand the spatial/temporal variability of the ice motion. We plan to estimate volume flux and area flux using this data set.

Discrimination of Open water/thin ice and Retrieval of Ice Thickness

Turbulent heat flux from the ocean to the atmospheric boundary layer is a function of sea ice thickness with an especially strong dependence on sea ice with thickness in the 0-100cm range [*Maykut*, 1984]. Within this range, the heat flux can increase by at least an order of magnitude as the thickness approaches zero. Even though the areal fraction of thin ice is small (2-3%) in the Arctic, the integrated magnitude of heat flux through this ice can be comparable to that of the thicker ice types. The brine flux into the ocean is also important due to the growth rate at this thickness range. To date, operational airborne or spaceborne sensors have not been able to provide direct observation of thin ice thickness. Instead, coarse ice type categories derived from remote sensing data have been used as a proxy indicator of ice thickness. However, the difficulty of unambiguously discrimination of the different types of thin ice from active or passive microwave measurements remains [*Kwok et al.*, 1992; *Cavalieri et al.*, 1991]. More recently, a first glimpse at the thin ice thickness distribution in the Arctic Ocean produced from RADARSAT data is based on an algorithm that infers ice thickness from ice deformation [*Kwok*, 1999].

Studies of airborne polarimetric SAR data indicate that combinations of frequency and polarization enhance our ability to distinguish ice with different properties (*Drinkwater et al.*, [1991]; *Kwok et al.*, [1991]). *Rignot and Drinkwater* [1993] have evaluated the extraction of ice type from multi-parameter SAR data and discussed the limitation of single-frequency and single-polarization SAR modes for this purpose. Ideally, an ice thickness retrieval process should be based on a theoretical understanding on how the microwave polarimetric signature of thin ice is affected by its physical and electromagnetic properties. Then, an inversion process can be mechanized to estimate the ice thickness from polarimetric observations. A number of studies have used a model-based approach to interpret the polarimetric SAR signatures. In particular *Winebrenner et al.* [1995] discussed the response of L-band polarimetric SAR signatures to sea ice thickness in Arctic leads, and *Kwok et al.* [1995] suggested a model-based approach to retrieve thin ice thickness. However, the lack of any data acquisition campaigns since 1988 have discouraged further attempts at demonstrating the potential of polarimetric SAR data in monitoring the polar regions.

Here, we propose to carry on the work of evaluating the potential of polarimetric SAR data by using the data acquired by the polarimetric mode of PALSAR. Our approach is to further characterize the polarimetric sea ice signatures and determine the utility of L-band SAR data for monitoring the sea ice cover.

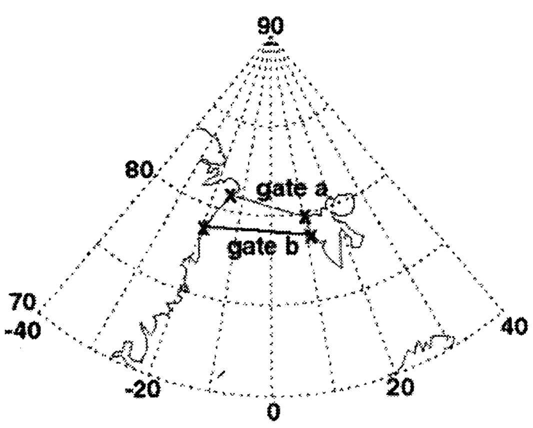

Fig. 1 Flux gates through Fram Strait

Details of Research

The primary objectives are:

- To measure the spatial profile of ice motion through the Fram Strait and to monitor this profile over a three-year period from 2003 to 2005, and to estimate the volume flux using available thickness data from other sources (upward-looking sonar and altimeter measurements).
- To demonstrate the potential of discrimination of open water/thin ice from thicker ice and to explore the feasibility of retrieval of thin sea ice thickness ice using L-band polarimetric signatures from spaceborne synthetic aperture radar. The limitations of the noise floor and calibration accuracy will be considered.

Ice Flux. The RADARSAT and ERS radars have provided some high resolution glimpses of the ice motion through Fram Strait, but the cost of data or swath width have limited the monitoring of the motion profile at a high enough temporal frequency to resolve its temporal and spatial variability. PALSAR with its ScanSAR mode and its 2-day subcycle offer to provide a solution to these obstacles. The ice motion will be produced by an operational sea ice tracker described in *Kwok* [1999]. The focus here is to measure the ice motion profile through the Fram Strait with a sampling frequency of two to three days using the ScanSAR mode of the PALSAR on ALOS. We define two flux gates across the Fram Strait. Flux gate *a* is positioned along a 400 km line, roughly along 81°N, drawn across the passage between Antarctic Bay in northeast Greenland and the northwestern tip of Svalbard (Fig. 1). Flux gate *b*, positioned further south is closer to where most upward-looking sonars are moored. We place flux gate *a* at 81°N since the area flux estimate across this line is more indicative of area export from the Arctic Ocean. Further south, ice area is typically added due to divergence of the ice cover. The quality of the ice motion derived will be validated with ice motion from drifting buoys.

Using the motion profiles retrieved from the PALSAR data set, we will estimate the area flux through the two flux gates. We will also use available ice thickness data from moored upward-looking sonar data and thickness data from other sources (possibly altimeter data from ERS) to estimate the volume flux. Together with available upward-looking sonar data, we will be able to produce the best possible estimate of ice volume flux through this passage between the Arctic Ocean and the East Greenland Sea.

Thin Ice Thickness. Thin ice is important because this is crucial range that produces the most ice growth, the most turbulent heat flux to the atmosphere and the most salt flux to the ocean. Several investigations in the past [e.g. *Winebrenner et al.*, 1995, *Kwok et al.*, 1995] have studied the dependence of L-band polarimetric signatures on the thickness of sea ice. It has been demonstrated that copolar ratios (VV/HH) and copolar phases ($\theta_{VV\text{-}HH}$) vary strongly with ice thickness. Observable differences between copolar phase shifts and copolar ratios have been measured in polarimetric L-band observations of new ice features and first year ice. Thus, polarimetric SAR measurements have the potential of providing discrimination of open water and ice, first-year ice and multiyear ice, and possibly the thickness of thinner ice types.

Available L-band polarimetric data of sea ice is limited to those acquired by airborne radar programs. These data sets provide a very restricted view of the Arctic Ocean in terms of spatial and seasonal extents. Polarimetric SAR data from PALSAR will offer us an opportunity to perform an in-depth evaluation of the use of polarimetric data sets to monitor the Arctic Ocean sea ice cover. We will use ice kinematics to define areas of openings in the ice cover to estimate the thickness of sea ice in these areas for validation of the polarimetric signatures. We also propose to use co-incident AVNIR-2 data for identification of ice types to support our interpretation of the ice type and thickness of the sea ice cover.

Research Plan

Acquistion Plans (2002-2003). The period will be devoted to planning activities and adjustment of data acquisition plans.

Evaluate and produce motion profiles (2003-2005). The ice motion profiles will be evaluated as soon as the data becomes available. The routine production of motion profiles will be carried out for the three years starting in 2003.

Analysis of polarimetric signatures (2004-2005). The L-band polarimetric signatures will be analyzed with model based calculations and compared to AVNIR observations.

Define ice thickness retrieval process (2004-2005). An ice thickness retrieval procedure will be evaluated.

Data Request

We require ScanSAR coverage of a 400 km by 400 km region in the vicinity of Fram Strait (Fig. 1), centered at 80°N and 0°E, every two days using the 2-day subcycle of the ALOS spacecraft. The repeat coverage of the polar regions should be much higher than in polar latitudes. This requirement is critical for monitoring the ice motion in this highly variable area of the Arctic Ocean. This translates into a minimum of 3600 scenes (max. 4500) of ScanSAR over three years. We also require a smaller number of polarimetric scenes (650-975) and AVNIR-2 scenes (650-975), acquired over the same area, for supporting the studies of sea ice type discrimination and sea ice thickness retrieval.

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