Synthetic Aperture Radar Remote Sensing of Bottom-Fast ice in the Mackenzie Delta Region, Northwest Territories, Canada

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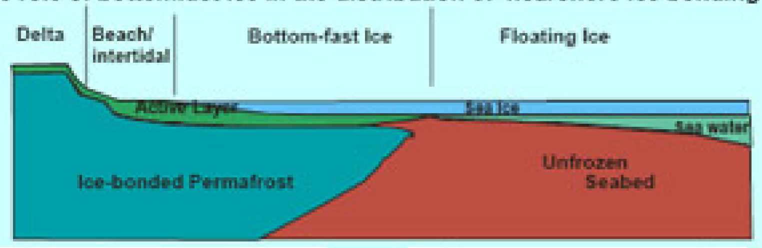
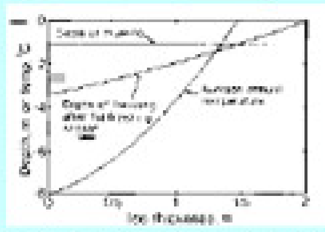
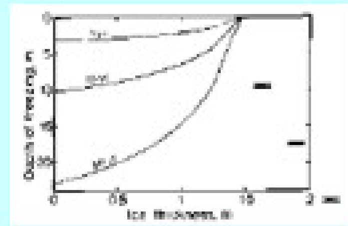
Background

Bottom-fast ice (BFI) refers to sea- or lake-ice that freezes to the sea- or lake-bed during the course of the winter season. The timing and distribution of BFI controls the mean annual temperature of the upper sediment column and therefore the potential for development and maintenance of permafrost and the thickness of the sub-bottom active layer. Air- and satellite-borne Synthetic Aperture Radar (SAR) imagery has been used to identify and map the distribution of BFI in Alaskan lakes (e.g. Jeffries et al., 1996) and more recently in the nearshore of the Laptev Sea (Eicken et al., 2005). It has been demonstrated that relatively high backscatter of SAR signals in lacustrine environments is caused by a combination of a strong reflection from the ice-water interface and scattering by tubular bubble inclusions within the ice. Lower backscatter regions are found where ice is frozen to the bed and the SAR signal passes into and is absorbed by the soil beneath. Some estuarine environments (e.g. the Lena Delta-Laptev Sea) are characterised by sufficiently freshwater in the shallow nearshore that the SAR signal should behave in the same manner. This poster describes the application of these concepts shallow water environment along the Mackenzie Delta, Beaufort Sea coastline. Ice thickness measurements, and interpretation of ground-penetrating radar (GPR) are used to validate the interpretations from SAR imagery.

The role of bottomfast ice in the distribution of nearshore ice bonding



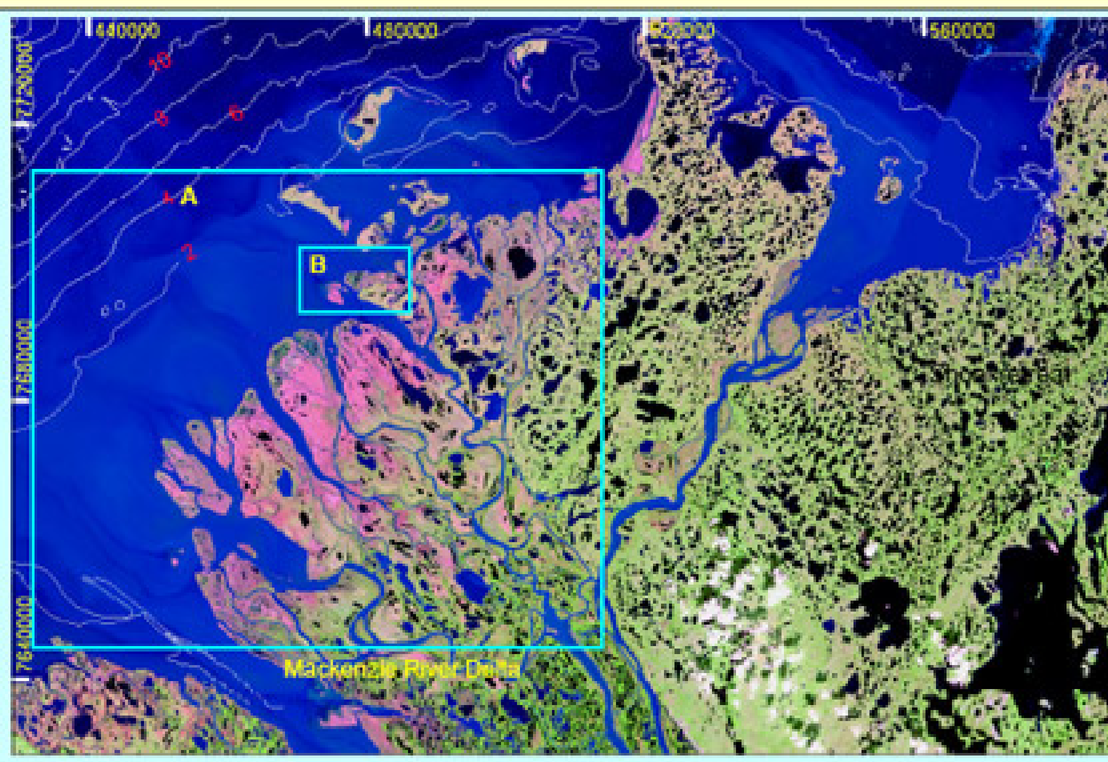




Ice thickness and water depth act together to control the development of BFI, which, in turn, controls the distribution of ice-bonding in the nearshore. Based on temperature-depth-ice thickness curves, Dyke (1991) shows the theoretical thickness of seabed freezing (bottom right) and the depth of freezing for varying amounts of time for varying ice thicknesses. Permafrost is shown to aggrade in water depths up to 1.5 m. Very small variations in depth have a significant impact on seasonal freezing and permafrost development

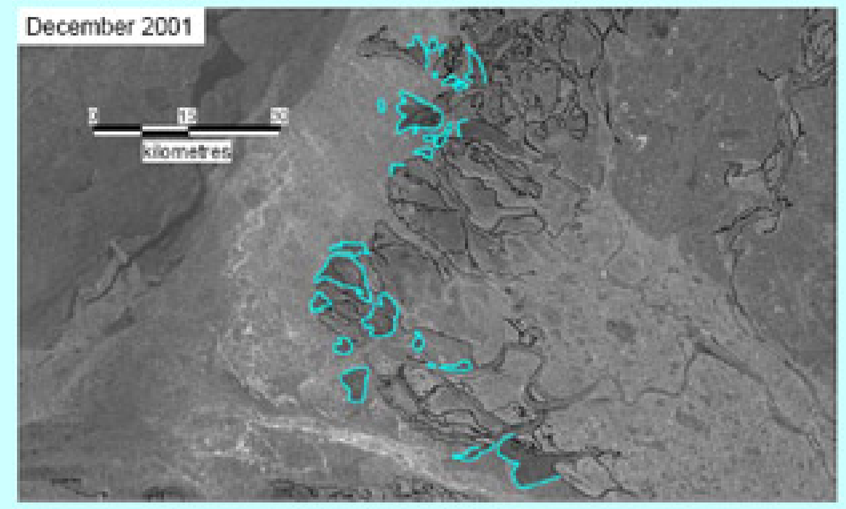
Index map

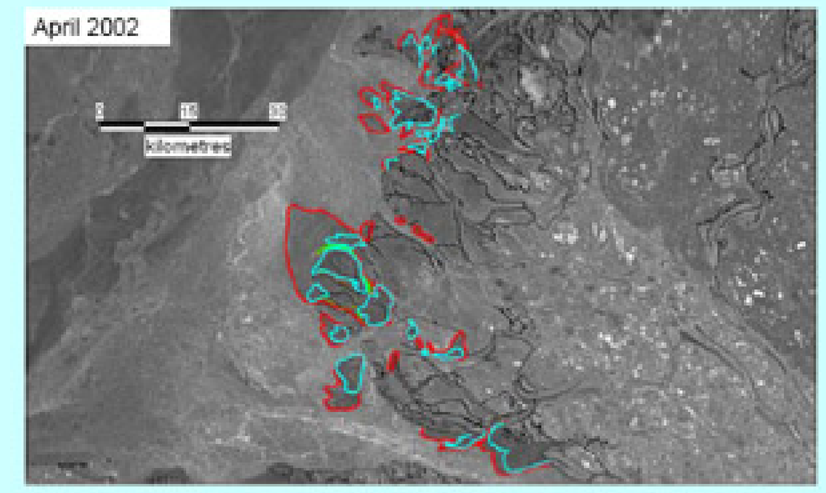
The study area encompasses the Mackenzie Delta region of the Beaufort Sea in NW Canada.

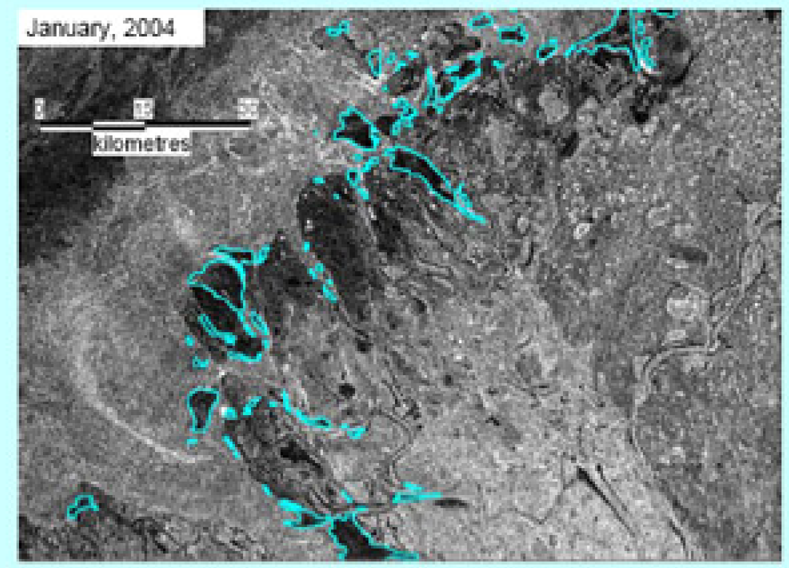


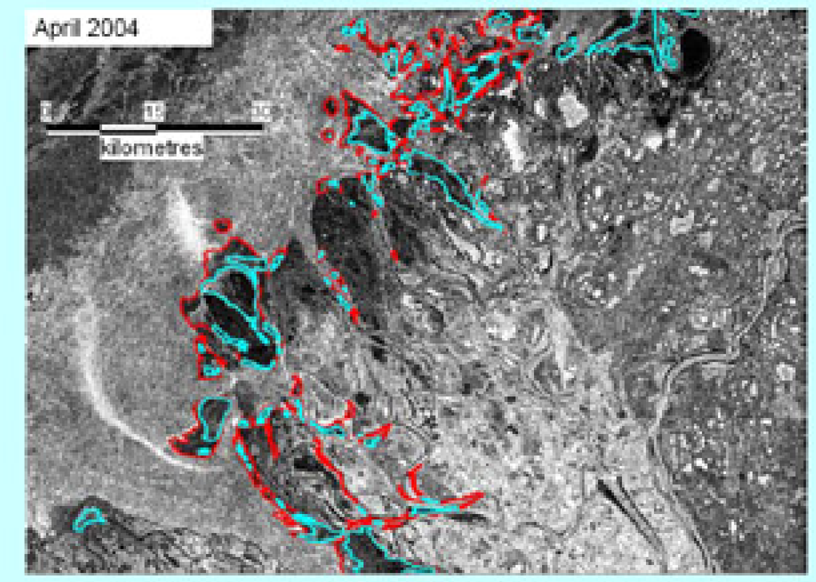
A. Temporal change in BFI

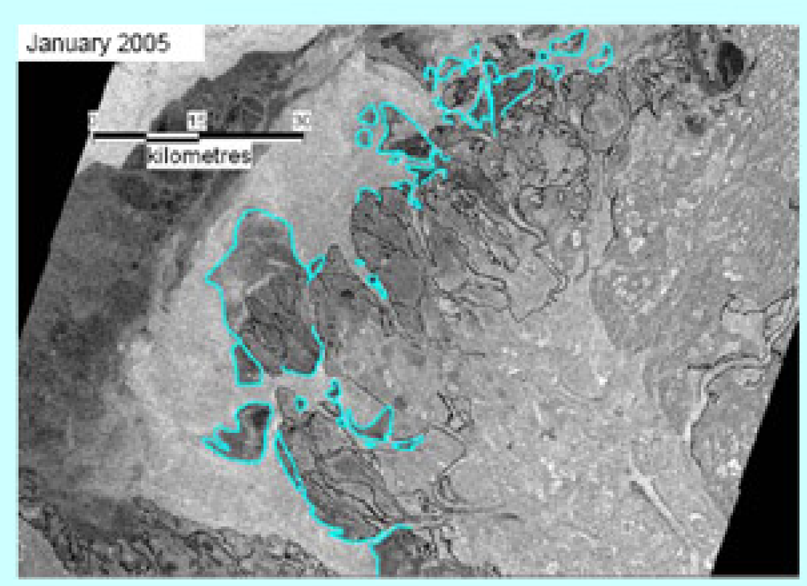
The series of images shown below depict seasonal and interannual changes in the extent of bottomfast ice as interpreted from SAR imagery (Radarsat ScanSAR wide in 2001-02 and 20003-04 winters; EnviSat ASAR in 2004-05 winter). Variations in the extent of BFI depend on ice thickness and water depth. Very extensive early season ice extent in 2004-05 may be the result of lower than average water depths over the inshore waters off the Mackenzie Delta due to persistent offshore winds. The mean water level in November 2003 was 0.64 m (re: chart datum) and in November 2004 it was 0.23 m (long-term monthly average for November is 0.27 m). Near maximum ice thicknesses (as determined by ground penetrating radar and augering) also differed between the two winters (1.4-1.5 m in 2003-04 and 1.6-1.7 m in 2004-05). The combination of the 2 factors resulted in a dramatic increase in BFI extent by the end of the 2004-05 ice season compared with previous years. Cyan vectors represent early season BFI extent, red vectors show late season BFI extent.

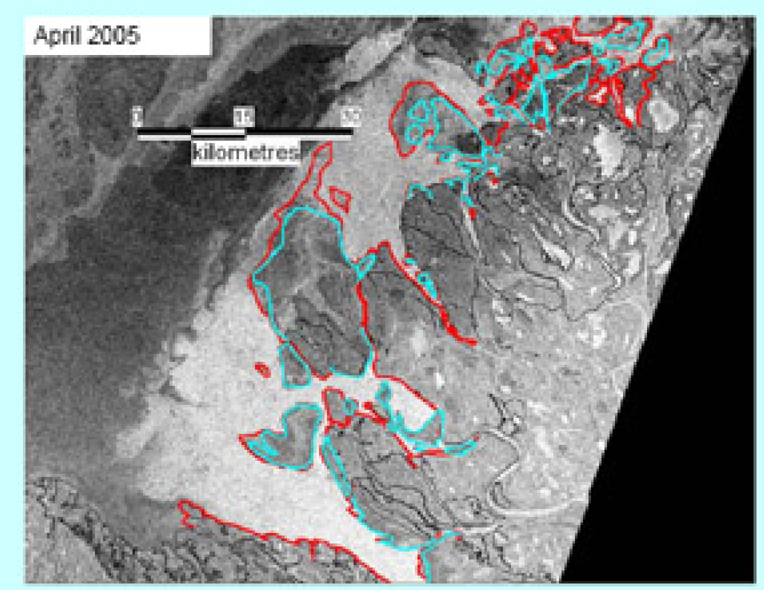






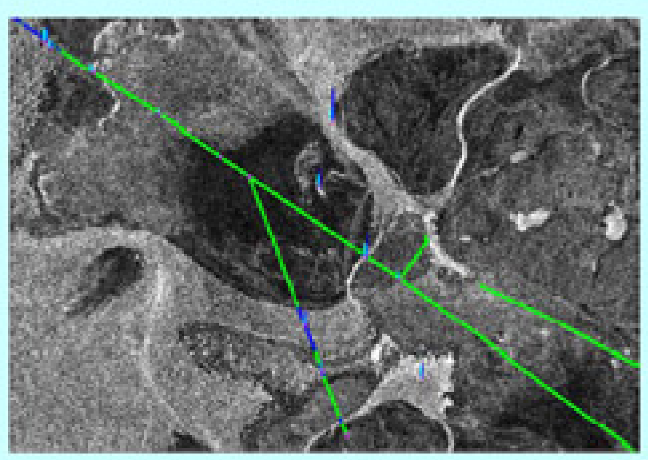


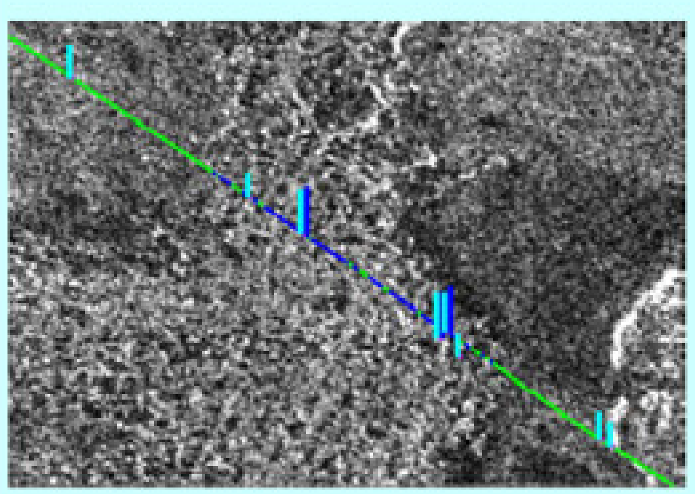


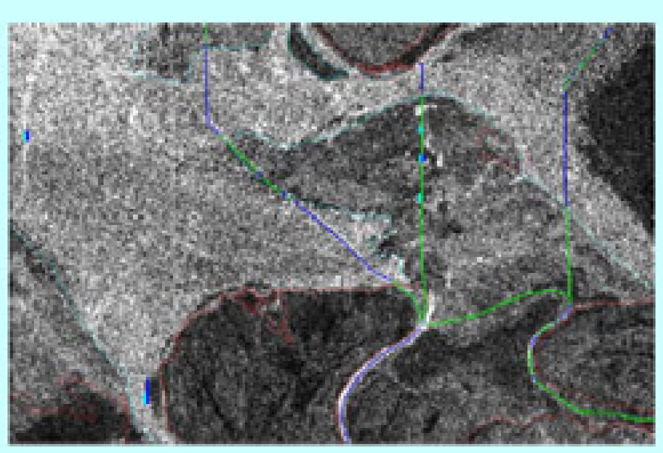


B Ground Penetrating Radar

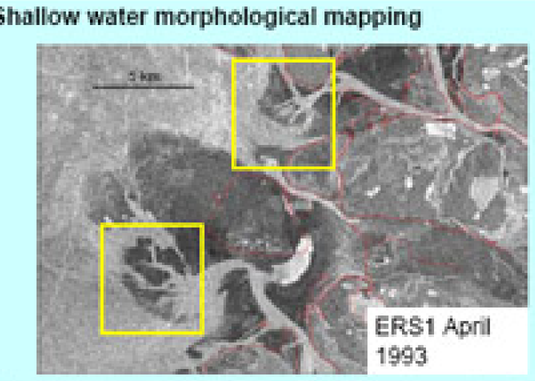
Commercial ground penetrating radar (GPR) data and augers were used to assist in the validation of the SAR-based interpretations of BFI. BFI extent based on GPR is shown in green and floating ice is depicted in blue. Envisat ASAR imagery acquired on 4 March 2005 shows areas of low backscatter (dark) where GPR is interpreted to depict BFI. Cores in the region collected at the end of March 2005 corroborate the GPR interpretation of BFI. Ice thickness is represented by the cyan bar; water depth (where present beneath the ice) by the blue bar. Ice thickness in the area varied from 1.6-1.7 m. Variable bottomfast and floating ice occur where subtle variations in bathymetry control the extent of bottom freezing (below left).







B Shallow water morphological mapping



The ability to map BFI represents a unique view of the the morphology of delta features in very shallow environments. Bars with superimposed channels (yellow rectangles) can be observed at the mouths of active distributary channels (shoals and land areas are outlined in red).

Conclusions

While there are some discrepancies between the interpretations of BFI from satellite data, GPR, boreholes and bathymetry, SAR imagery from satellites such as Envisat ASAR and Radarsat provides useful information on the distribution of bottomfast ice in the nearshore region of the Mackenzie Delta. This information is critical in order to understand the potential for the development of nearshore permafrost and a submarine aqueous active layer. Other applications of the technique include change detection, water volume estimation in lakes (cf. Jeffries et al., 1996) and planning for seismic surveys. The SAR data provide a unique and unprecedented ability to map morphological features and potential geotechnical hazards in the difficult-to-access shallow waters in this region.

References

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Acknowledgements

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