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River ice mapping and monitoring using SAR satellites

Joost van der Sanden, Natural Resources Canada, Canada Centre for Remote Sensing

Significance of river ice

River ice constitutes a major component of the cryosphere that modulates natural processes and can either facilitate or jeopardize human activities. Consequently, the significance of river ice in northern countries such as Canada is substantial and multi-faceted.

Consider that river ice

- controls the winter flow regime of rivers and compromises the operation of hydrometric stations
- provides seasonal road access to locations that lack a regular land-based road network (e.g. communities, hunting/fishing grounds and mining operations)
- governs the water intake and discharge activities of municipalities and businesses (e.g. hydroelectric power and oil sands industries)
- is hazardous to shipping and, particularly during spring break-up, can create jams and floods that endanger infrastructure (e.g. locks, bridges, pipelines) and communities but may also nurture aquatic ecosystems
- affects the habitat of wildlife and represents an erosive force that can reshape fluvial landscapes
- influences weather patterns and, consequently, weather forecasting and climate modelling
- may be used as an indicator of climate change

Figure 1. Mackenzie River at Inuvik, N.W.T., May 26, 2008 (break-up)

Therefore, information on river ice cover supports various science, engineering and management activities, including hydraulic/hydrological modelling, break-up forecasting and decision making related to such issues as water intake and discharge, routing ice roads, wildlife management and emergency preparedness for ice jam flooding. Typical river ice variables of interest include the timing of freeze-up and break-up, the extent of ice coverage, ice type, ice thickness and ice condition (e.g. dry and solid versus wet and deteriorating).

Collecting data

Often, collecting information on river ice cover is complicated by

- unfavourable weather conditions
- the large extent and poor accessibility of the river of interest
- the dynamic nature of ice cover during the freeze-up and break-up seasons

The capability of remote sensing satellites to routinely image the Earth's surface in a systematic, synoptic and repetitive manner makes satellites potentially outstanding tools for collecting up-to-date information on river ice cover.

Using synthetic aperture radar (SAR) satellites rather than optical satellites offers certain advantages

- the radar's ability to penetrate dry ice cover and snow (see Figure 2)
- the radar's sensitivity to the presence of free water
- the capability of radar sensors to create images regardless of weather and daylight conditions

Research and development

Current research and development (R&D) activities regarding using SAR satellites to map and monitor river ice focus on the Mackenzie River near Inuvik, Northwest Territories. The work is part of an International Polar Year (IPY) project in collaboration with partners that include Environment Canada, the University of Alberta and Simon Fraser University. One particular objective of the IPY project is developing a hydraulic model for the Mackenzie River delta.

Types of information derived from radar images that feed into the development of the hydraulic model include

- channel network layout
- ice type distribution
- ice jam locations
- ice cover break-up sequence
- extent/location/duration of break-up flooding

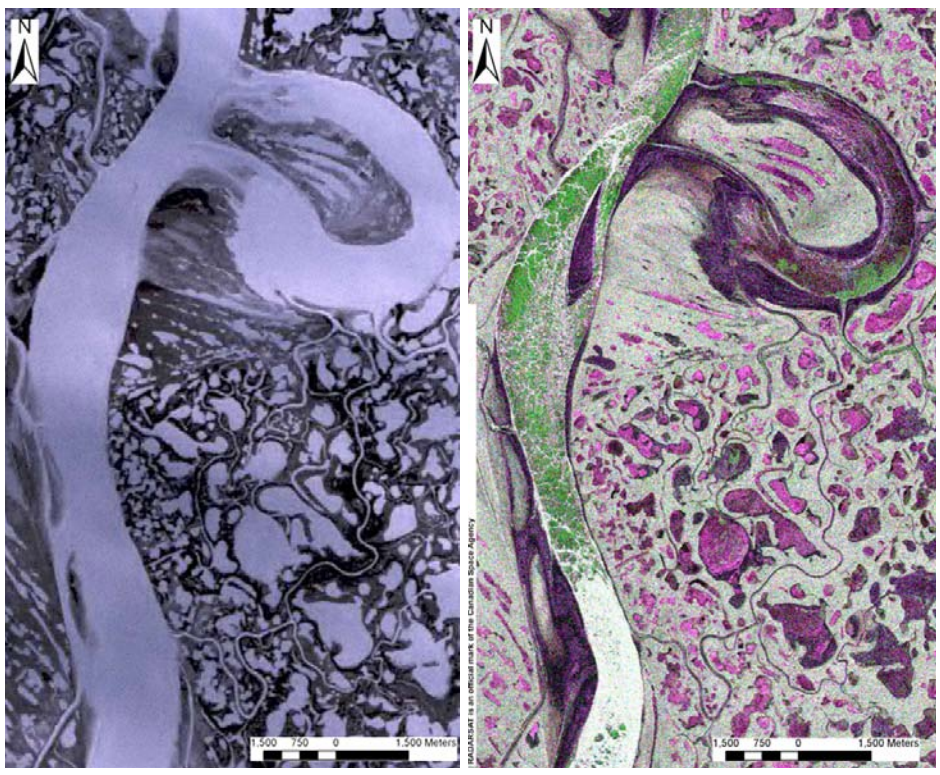
From the perspective of radar remote sensing, the research improves our understanding of the interaction process between river ice and radar waves, which translates into knowledge about the potential of SAR satellites to map and monitor certain river ice cover characteristics. The available radar data set comprises images acquired by RADARSAT-1, RADARSAT-2, Envisat ASAR, ALOS PALSAR and TerraSAR-X satellites.

Results

Results show that a SAR satellite is a good tool in support of mapping and monitoring river ice cover. Its potential for supporting the mapping of ice cover conditions during spring break-up is demonstrated in the RADARSAT-1 derived information product in Figure 3.

The product is also available in a geographic information system-ready format. It is 1 of 11 maps generated for the 2008 spring break-up season. The approach used to generate these maps is guided by expert knowledge about the breakup process and exploits the information contained in both the strength and the spatial variability of the radar return signal.

The ability of second generation SAR satellites (e.g. RADARSAT-2, ALOS PALSAR, TerraSAR-X) to simultaneously acquire images in multiple polarizations considerably improves their potential to map winter ice cover, in particular. The interpretation of polarimetric radar images is complicated by the challenges associated with the collection of ground reference data. R&D in this particular field is ongoing.



(a) **(b)**

Figures 2(a-b). Image subsets showing the Mackenzie River near Inuvik, NWT, Canada:

(a) Landsat TM true color image composite acquired March 25, 2009

(b) RADARSAT-2 multi-polarization image composite acquired March 8, 2009. The RADARSAT-2 image can be seen to show many ice cover details that are not visible in the Landsat TM image nor to the human eye.

NOTE: RADARSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd. 2009 - All Rights Reserved; RADARSAT is an official mark of the Canadian Space Agency

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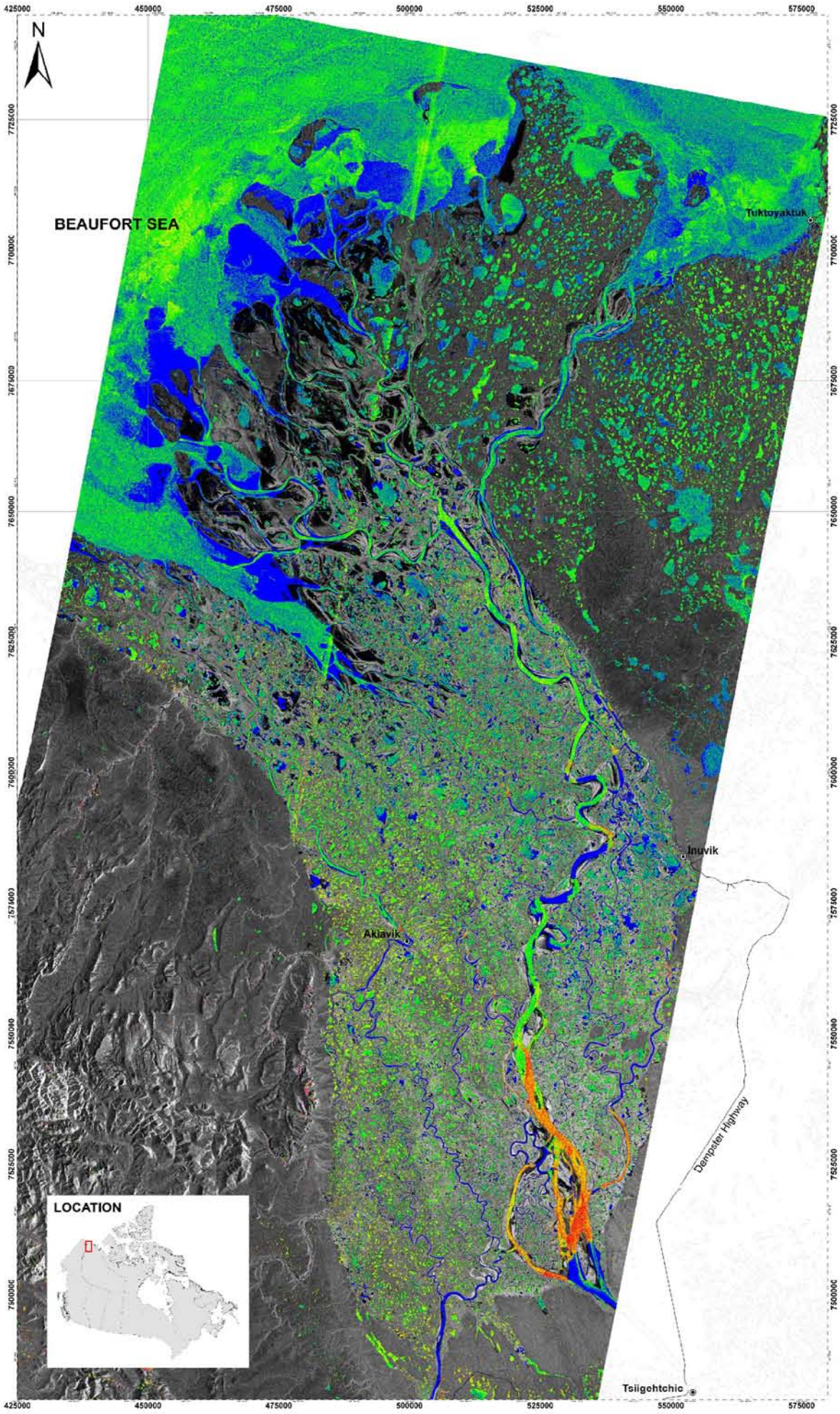
Mackenzie River Delta, Northwest Territories, Canada

Ice Cover Condition for 26 May 2008, 09:27 MDT (UTC- 6)

Map 5 of 11



LEGEND

WATER

SHEET ICE
- Smoother Smooth Texture (mm scale)
- Smooth Texture (mm - cm scale)
- Rougher Smooth Texture (cm scale)

RUBBLE ICE
- Smoother Rough Texture (cm - dm scale)
- Rough Texture (dm - m scale)
- Rougher Rough Texture (m scale)

- Radar Image (land surface area)
- Water Body
- Town
- Road

DESCRIPTIVE NOTES

During the 2008 spring ice breakup season, three radar satellites were tasked to image the Mackenzie River Delta at time intervals ranging from 1 to 3 days. The images acquired enabled the development and production of a series of maps, including the map shown here, that provide information regarding the change in the condition of freshwater ice cover as a function of time and space. This map series is intended to facilitate the development of a hydraulic model for the area of interest.

The potential of radar satellites in support of the mapping of decaying and therefore wet ice can be explained from their sensitivity to differences in the surface roughness or, in ice cover terminology, the texture of the covers observed. As shown in the legend, the maps discriminate between 'water' and three classes each for ice cover conditions identified as 'sheet ice' or 'rubble ice'. Sheet ice covers are characterized by smooth textures whereas rubble ice covers have rough textures. It should be noted that radar observations of ice covers overlain by wet snow, a common situation at the onset of breakup, will represent the roughness of the snow cover.

The photographs and image subsets below exemplify the legend adopted and facilitate the interpretation of the maps produced. Assignment of image pixels to classes was based on an analysis of the strength and spatial variability of the radar return signal as well as on rules derived from knowledge about the breakup process.

Ground reference information in the form of visual observations, photographs and videos obtained by means aerial surveys was used as much as possible to validate the ice cover condition maps produced. The validation efforts focused on the confirmation of the information with respect to river ice cover conditions. Given the similarities between river ice and lake ice, the information about lake ice conditions is also expected to be reliable. However, the conditions mapped for ice covers found in brackish or salt water environments, e.g. the Beaufort Sea, should be interpreted with care.

ICE COVER CONDITION; FIELD OBSERVATIONS AND MAP REPRESENTATIONS

Sheet Ice

Rubble Ice

Sheet Ice and Rubble Ice mixture

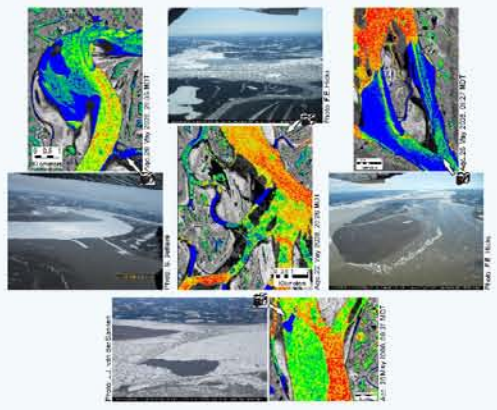


Figure 3. Mackenzie River delta, N.W.T. ice cover conditions May 26, 2008 09:27 MDT (UTC-06)

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