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Mapping and monitoring lake ice by using SAR satellites

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Lake ice

Many thousands of freshwater lakes cover the northern Canadian landscape. Lake ice is thus an important part of the cryosphere, and its phenology affects a wide variety of natural and human activities. Lake ice controls the biological productivity of lake ecosystems and the migration of species that depend on ice or open water. Lake ice determines the extraction of winter water for human use (shallow lakes can freeze to the bottom), and it is a component of ice roads that provide winter road access to remote locations. Lake ice also influences weather patterns and, thus, weather forecasting and climate modelling. The sensitivity of lake ice to air temperature makes it an effective indicator of climate change.

Ice characteristics

Lake ice phenology encompasses three key ice events:

- freeze-up in the fall
- bottom freezing in the winter
- break-up in the spring

Mapping and monitoring the intra-annual and inter-annual dates of these three ice events is a primary objective. The timing of these ice events relies mainly on air temperature, although wind, snow cover and lake size (area and depth) also play a role. In winter, most ice is floating; however, bottom freezing (grounding) may occur in shallow lakes that are less than two metres (m) deep.

Ice characteristics of interest are

- lake ice coverage (percent ice versus open water)
- ice type
- ice thickness (usually less than 2 m)
- surface condition (snow cover, stage of melting, crystal structure)

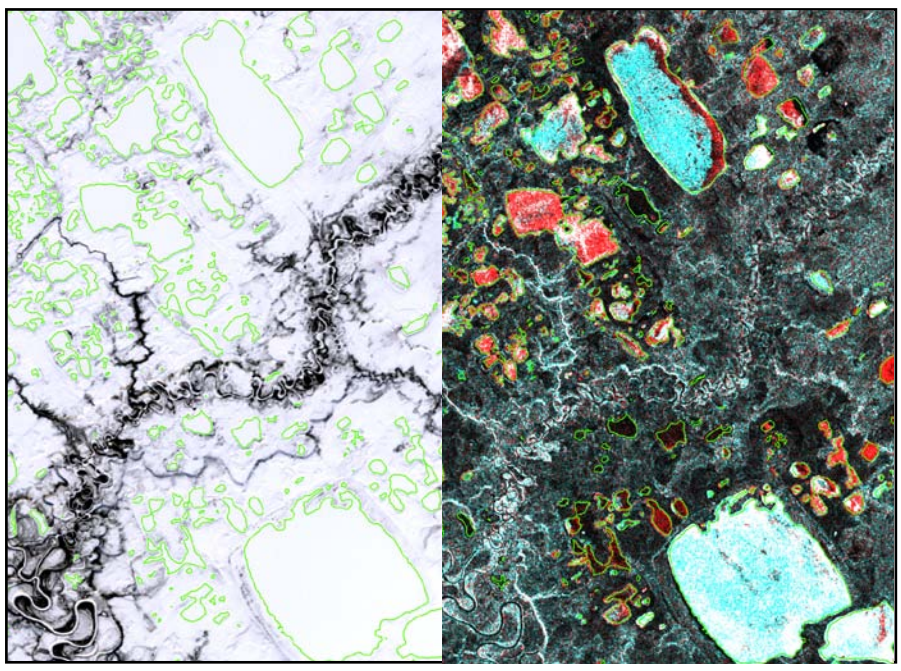

Figure 1. Ice- and snow-covered lakes in Vuntut National Park, Yukon, late March 2009

In Figure 1, the lakes are outlined in green. The left image is from the optical Landsat satellite. The right image is from the RADARSAT-2 SAR satellite with both co- and cross-polarizations. The dark lakes are grounded ice; the red, blue and white areas on the lakes are three different types of floating ice.

SAR satellites

In Canada's north, mapping and monitoring lake ice is especially challenging, because the geographical areas are vast and remote and they experience winter darkness and/or persistent cloud cover. Measurements at frequent intervals are required to map precise dates for ice events. Remote sensing satellites that use synthetic aperture radar (SAR) are ideally suited to this task.

SAR satellites send and receive microwave radar signals and can image the Earth's surface during total darkness and through cloud cover (unlike optical satellites). SAR satellites record the received microwave signal as backscatter. The strength and character (e.g. polarization) of the backscatter is used to infer surface conditions. Microwave signals can penetrate ice and snow cover to varying degrees, enabling detection of water beneath the ice or within the snow cover.

Methods

Current research and development (R&D) is done in collaboration with Parks Canada and focuses on lakes in three of Canada's most northerly national parks (NPS): Vuntut NP, Yukon; Tuktut Nogait NP, Northwest Territories; and Ukkusiksalik NP, Nunavut.

This R&D involves four steps:

1. Observe the SAR backscatter from lake ice in fall, winter and spring.
2. Relate the backscatter to the geophysical properties of lake ice to understand how microwaves interact with snow, ice and water.
3. Develop methods to consistently discriminate lake ice from open water and grounded ice from floating ice.
4. Apply these methods operationally for automated mapping and monitoring of ice events.

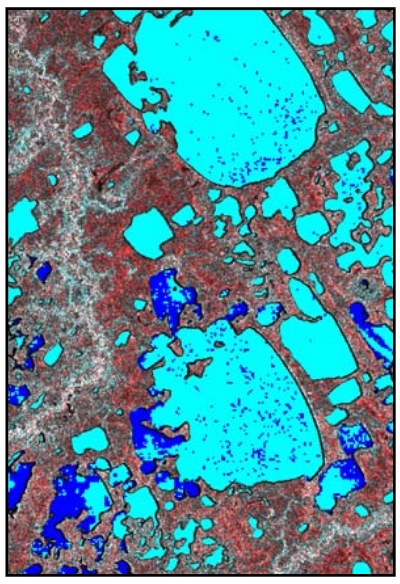

Figure 2. Lake ice classification based on SAR backscatter

In Figure 2, the ice is light blue and open water is dark blue. This is a RADARSAT-2 image of Vuntut NP, Yukon, taken in late May 2008.

Results

Results thus far show that SAR satellites are excellent tools for mapping and monitoring lake ice because they provide both co-polarized (co-pol) and cross-polarized (cross-pol) images simultaneously. Such imagery is available from second-generation SAR satellites (RADARSAT-2, ALOS PALSAR and TerraSAR-X).

In winter, grounded ice and floating ice are identified by either low or high co-pol backscatter, respectively. Differentiation among floating ice types is possible with the addition of cross-pol imagery (see Figure 1).

In spring, lake ice and open water are classified by their co- and cross-pol backscatter (see Figure 2). During the early melt period, co-pol imagery is used because cross-pol backscatter imagery has a lower signal-to-noise ratio, that is, it contains less useful information. However, during final ice break-up, cross-pol imagery is used when large areas of open water are present and wind-induced waves create co-pol backscatter very similar to that of ice.

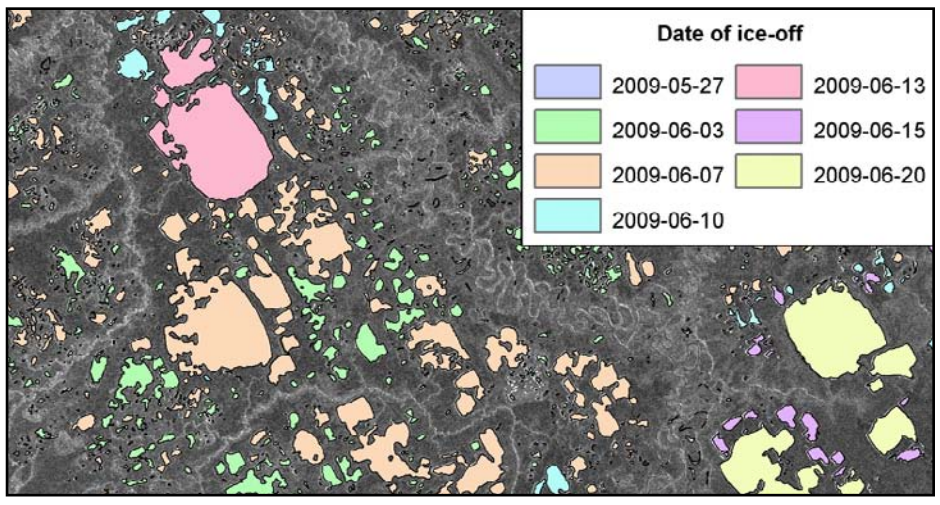

Figure 3. Lake ice break-up (ice-off) map for 2009, Vuntut National Park, Yukon

In winter, bottom freezing occurs quite slowly and can be monitored by using weekly or monthly SAR imagery. However, rapid changes during both fall freeze-up and spring break-up require SAR imagery every three to four days to accurately map and monitor these ice events (see Figure 3).

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