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Monitoring ice cover characteristics and behaviour along the Slave River

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Abstract
For communities along the Slave River, ice is an important component of the traditional way of life. During the winter, a stable ice cover provides local residents with safe access to traditional hunting, trapping, and fishing areas along the river. In recent years, however, local communities have observed changes in ice cover characteristics (e.g. air pocket formation, double layer ice), that have increased the risks associated with travel on the ice. Research to date has focused in the impact of flow regulations, but very little is known about the Slave River ice cover characteristics and behaviour. Remote sensing and field surveys were used to gain an understanding of the ice cover progression along the river during the 2013 – 2014 and 2014 – 2015 winters. RADARSAT-2 satellite imagery captured changes in the ice cover and identified different types of ice during the entire course of each winter season. The results show that flow regime and meteorological conditions are the main parameters influencing the ice regime along the Slave River.

Introduction

Since the construction of the W.A.C. Bennett hydroelectric dam on the upper Peace River, the Slave River flow has become modulated, with increased flow in the winter and lower flows in spring and summer (AANDC and NWT 2012; Dubé and Wilson 2013; Prowse et al. 2002). Communities along the Slave River have indicated that the changes in the flow regime are altering the ice regime of the river. Air pocket formations along the ice cover and thinner river ice pose a great risk to persons crossing the river, thus impeding traditional and subsistence winter activities. A few studies have assessed the impacts of flow regulation on Slave River ice conditions during the winter (AANDC and NWT 2012; Prowse et al. 2002). Most of them have provided very limited information about the ice regime. High water levels in the winter can produce a double layer of ice along the Slave River. Additionally, high winter flows keep the ice cover thin, resulting in open water sections forming along the river. High flows can also produce a significant amount of frazil ice on the Slave River, which can be deposited downstream and lead to increase thickness of the ice cover.

Documentation on different types of ice during freeze-up, ice cover development and its progression, and patterns of the spring ice cover breakup along the river, is sparse. Such information is, however, essential for the communities along the river. It is used to make decisions about safe access to the river in the winter and also to understand the river's ecological structure and functioning. The forest industry has also expressed interest in such knowledge to help them decide which locations along the river are the safest and most economical, for the creation of ice bridges to access and harvest remote forest stands. Additionally, detailed reporting about the different types of ice and their formation mechanisms is required, in order to improve predictability of the behaviour of the ice cover impacted by regulation. This research attempts to fill some of the knowledge gaps on the Slave River's ice regime.

Data and Methods

Study sites

The Slave River (Fig. 1) is a Canadian transboundary river, originating at the Peace-Athabasca Delta (PAD) in Alberta. It flows north about 434 km and drains into Great Slave Lake in the Northwest Territories (NWT). The river has a series of four rapids – Cassette, Pelican, Mountain and Rapids of the Drowned – along an approximately 23 km long stretch, where the river bed drops approximately 35 m from Fitzgerald to Fort Smith. The river forms the Slave River Delta (SRD) at its confluence with Great Slave Lake, near Fort Resolution in the NWT. The Delta has several active channels – Nagle, Steamboat, Middle, East and Resdelta Channel – through which the river water flows to maintain the delta's ecosystem. The Jean River diverts water from the river around the SRD to the lake.

The Peace River is the major inflow to the Slave River, contributing 60% of the Slave River's total volume flow (AANDC and NWT 2012). The other 40% stem from the Lake Athabasca/Athabasca River system. Therefore, the hydrological regime of the Peace River basin has a strong influence on the Slave River's hydraulic regime.

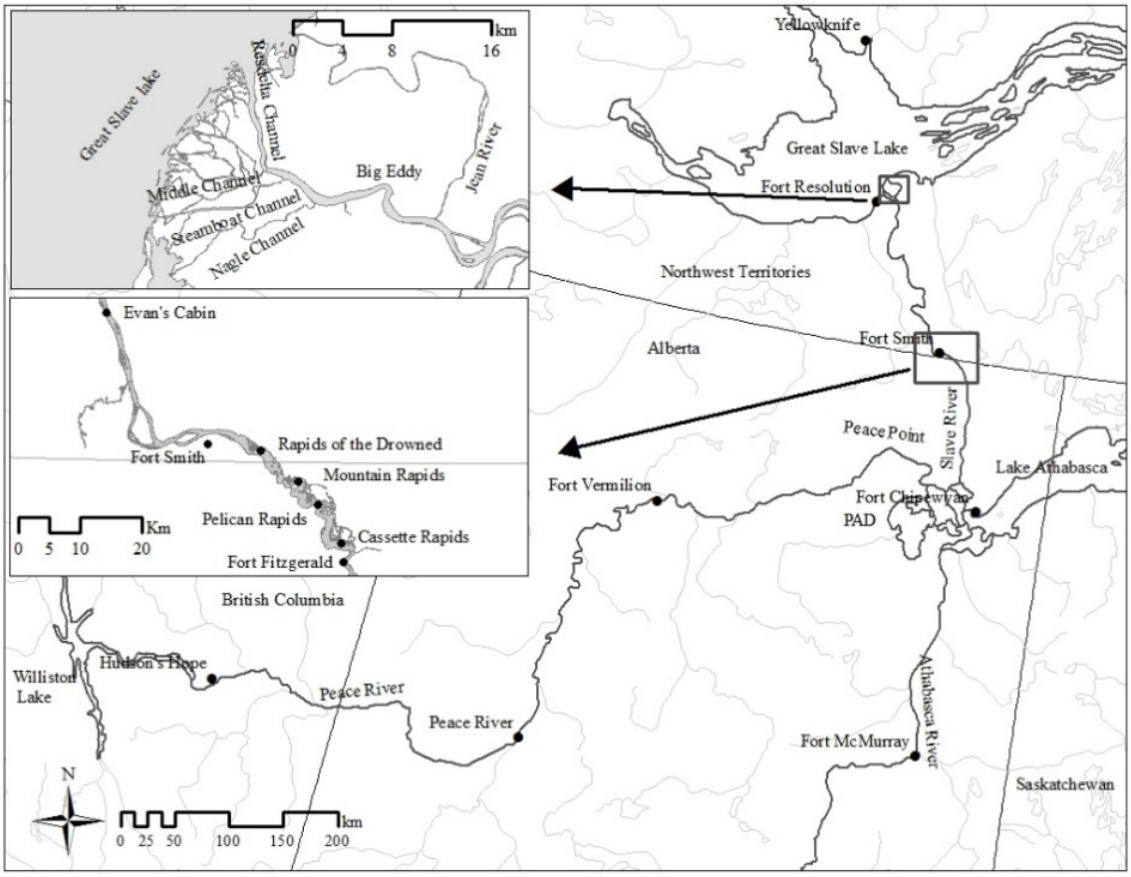

Figure 1. The Slave River network and its important locations.

Satellite Imagery and Field Surveys

RADARSAT-2 satellite imagery has been used in this study to describe the ice cover formation along the river for both winters, 2013 – 2014 and 2014 – 2015. The unsupervised fuzzy k-means method was applied to the images to classify different types of river ice. Backscattering values of the images were also extracted in order to understand the nature of ice cover progression during both winters (Lindenschmidt et al. (2010) for methodology).

Ice surveys were conducted during both winters at several locations: (i) Evan's Cabin near Fort Smith, (ii) at the inlet to the Jean River and (iii) between Nagle and Steamboat channels in the SRD. Surveys included ice thickness and snow depth measurements and observations of the characteristics of air pockets along the river ice cover.

Meteorological and hydrometric data

Air temperature data was retrieved from the Environment Canada (EC) weather station at Fort Smith in order to calculate the accumulated degree days (ADDF) along the river for both winters. Water flow data was obtained from the real-time gauge station at Fitzgerald, operated by Water Survey Canada (WSC).

Results

Ice regime in the Slave River Delta

There are three main ice types that constitute the river's ice cover during the winter - thermal, juxtaposed and consolidated ice (Fig. 2). At freeze-up, a long stretch of thermal ice cover typically forms from the mouth of Great Slave Lake to Big Eddy. A juxtaposed ice cover extends from Big Eddy to further upstream along the river. Additional ice deposition and shoving can transform the juxtaposed ice cover into a consolidated ice cover, which remains stable during the entire course of winter. At the beginning of the 2013 – 2014 winter, the thermal ice cover extended for a long stretch in the lower portion of the river. However, after December 2013, due to high turbulence and prolonged open water conditions at Big Eddy, slush ice was deposited and air pockets formed downstream of Big Eddy. This phenomenon was observed as a successive brightening of the area in a series of satellite images taken at regular intervals during the course of winter. During the following 2014 – 2015 winter, the ice cover was dominated by thermal ice with interspersed areas of juxtaposed and consolidated ice.

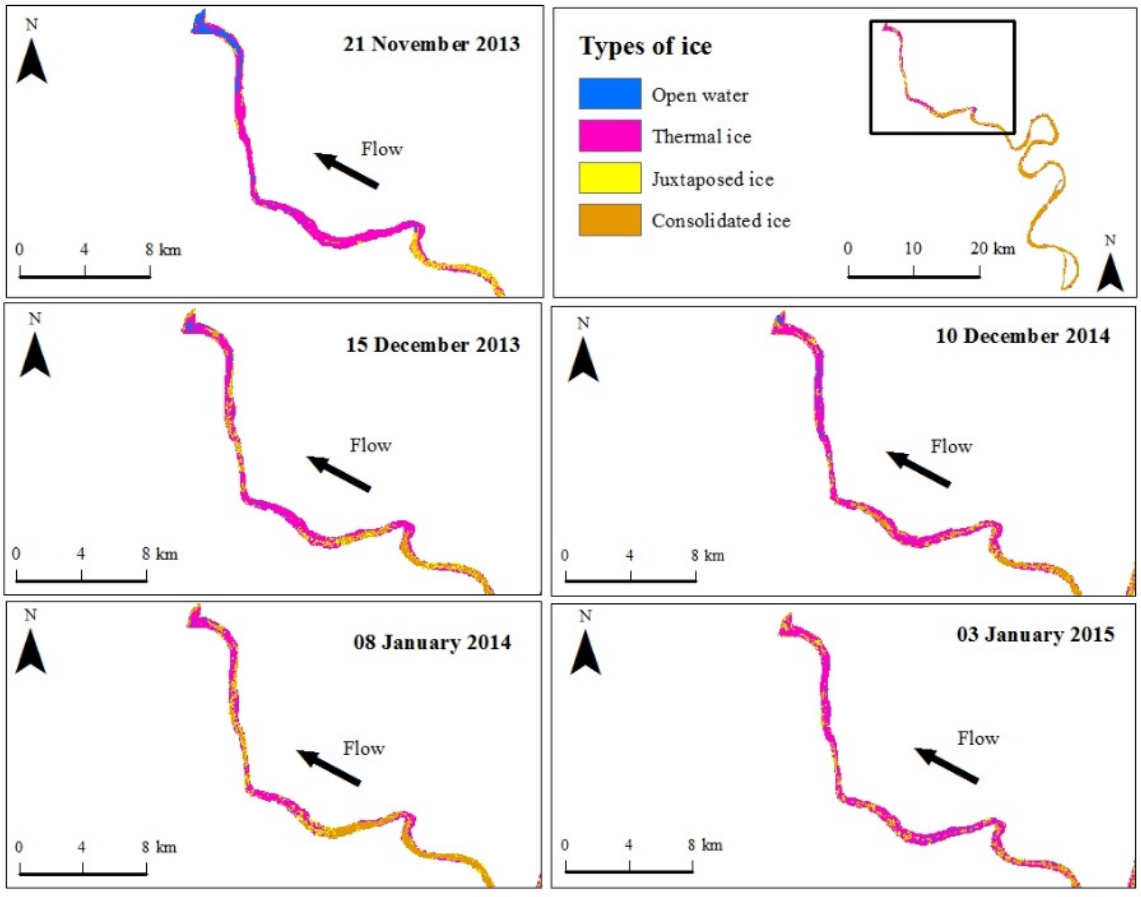

Figure 2. Different types of ice cover along the Slave River Delta during the winters of 2013 – 2014 (left panel) and 2014 – 2015 (right panel).

Figure 3 shows the longitudinal profiles of the backscatter values from satellite imagery acquired during the 2013 – 2014 and 2014 – 2015 winters. Significantly higher backscatter values in the

first winter reveal a high volume of consolidated ice cover along the river. Only one area of the river, approximately 15 km upstream of Great Slave Lake, had backscatter values less than -20 dB. However, significantly lower backscatter values in the second winter indicate that the river was mostly dominated by thermal or very thin layers of ice cover. On 10 December 2014, the river was covered by a very thin ice cover with open sections, which yielded very low backscatter values ranging between -20 and -39 dB. Although the backscatter values increased by 03 January 2015, they were far lower than the backscatter values on 08 January 2014 from the previous winter. The changes in backscatter values from the consolidated ice cover from 15 December 2013 to 08 January 2014 were minimal, however, the changes in backscatter values from the thermal ice cover from 10 December 2014 to 03 January 2015 were greater. After consolidation, the ice cover become relatively stable and changes in the backscattering values were small. However, in the 2014 – 2015 winter, the ice cover changed to an incomplete thermal ice cover from a complete thermal ice cover, which resulted in a greater difference in backscattering values between December 2014 and January 2015.

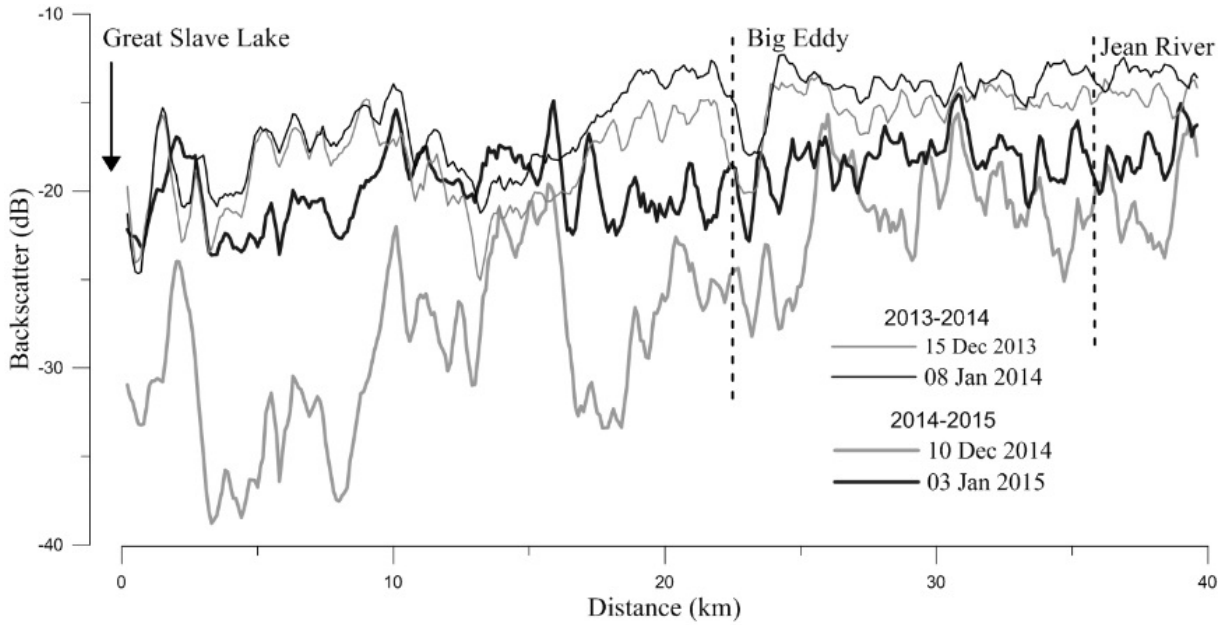

Figure 3. Longitudinal profiles of the RADARSAT-2 satellite images backscattering returns along the Slave River.

According to the field surveys, the ice cover was thinner by the end of the 2014 – 2015 winter than the ice cover of the preceding winter. The maximum ice thickness along the Slave River Delta measured 0.66 m on 24 March 2015, while the maximum ice thicknesses measured 0.87 m on 01 March 2014.

Air Pocket formation along the Slave River at Evan's Cabin

Two years of field surveys suggest that air pocket formation along the ice cover was greater in the first winter than the second winter. Lower flows at freeze-up resulted in a smoother extended ice cover during the second winter and decreased air pocket formation along the river's ice cover. Several air pockets were observed during the field surveys. Air pockets usually look white through

the transparent top layer of the ice cover (Fig. 4). They can be more than 1 m in length and extend vertically and horizontally in the ice cover. Air pockets were most often observed along the main channel, where the turbulence of the water was much stronger than other sections of the river. Several open water sections may be major sources of air entrainment into the river water. Air, dissolved in the water, is transported downstream under the ice cover until it is trapped to form pockets along the ice underside.

Figure 4. Air pockets observed along the Slave River at Evans Cabin near Fort Smith.

Discussion

Relatively high flow conditions (Fig. 5) during the first winter maintained high flow velocities for frazil ice and fragmented ice pieces to submerge under the ice cover, subsequently, producing a consolidated ice cover upstream of the SRD. Submerged ice floes were randomly transported under the ice cover to thicken and produce a rough ice cover that also increased the backscattering values in the satellite image. However, relatively low flow conditions in the second winter were unable to produce sufficient water velocity to transport ice floes under the ice cover, which reduced the chances of the formation of a consolidate ice cover along the river. Therefore, most of the sections of the river in the second winter were covered with a thermal ice cover. As the ice cover thickens thermally downward, the reduced cross-sectional flow area constricts and funnels the water to the main channel, where the flow velocity and turbulence increase. High velocity and turbulence of the water creates more air bubbles, which become trapped in the ice cover, particularly when ice thermally thickens.

At the freeze-up during the second winter, the ADDF progressed at relatively the same rate as the previous winter. However, by the end of the second week in December 2014, the temperature was relatively warm, which kept the ADDF values consistently lower than those of the previous winter (Fig. 5). By 25 March 2014, the total ADDF along the river was calculated to be 3034.4 °C while by 25 March 2015, the total ADDF was 2655 °C. High rates of freezing along the river quickly thickened the ice cover and also contributed to increase in backscattering values recorded by the satellite receiver.

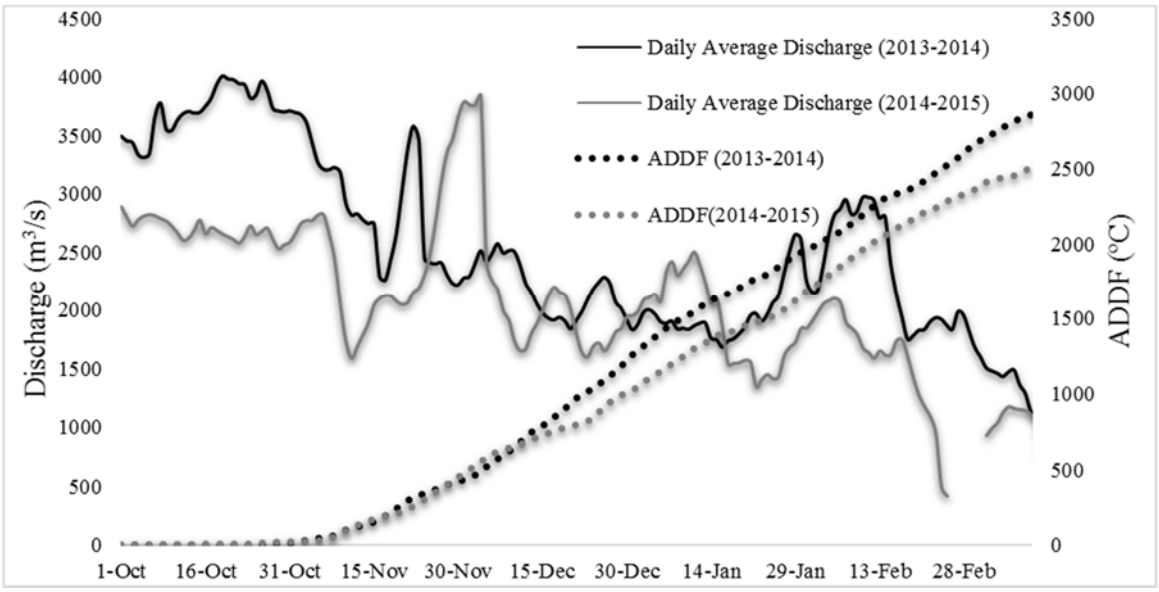

Figure 5. Daily Average Discharge and Accumulated Degree Days of Freezing along the Slave River at Fitzgerald Gauge Station (Data Source: WSC and EC).

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