Monitoring the ice cover evolution of a medium size river from RADARSAT-1 : preliminary results

Y. Gauthier, T. B.M.J. Ouarda, M. Bernier and A. El Battay

INRS-Eau, 2800 Einstein, C.P. 7500, Ste-Foy (Qc) G1V 4C7
gautyves@inrs-eau.uquebec.ca

Summary Until the launch of RADARSAT-1, no satellite could offer sufficient spatial resolution or repeat coverage so that remote sensing could play a significant role in river ice monitoring, for small to medium size rivers. The objective of this study is therefore to evaluate this recent remote sensing technology for gathering temporal and spatially distributed information on river ice cover and river ice jams. Under this framework, thirteen RADARSAT Fine mode images were acquired over a stretch of the Saint-François river (Quebec), from November 24, 2000 to April 19, 2001 (ice free to full ice cover). A temporal analysis of the backscattering coefficients shows that open water, a thin smooth ice cover and a wet and smooth snow cover all have a similar low backscattering. However, significant variations of the radar signal are visible during a fall break-up event, during spring meltdown and under complete ice cover conditions. Furthermore, specific features such as shear walls, ice roads and rapids present distinct radar signatures.

1. Introduction

Most operational river ice surveillance programs generally depend on field measurements for ice data. However, traditional methods of data collection are often too difficult, too dangerous or too expensive and they rely on a long term engagement from the field observer. Alternatively, remote sensing can play an important role, as long as it can provide the temporal and spatial coverage needed for research on freeze-up and breakup processes and for research on variations in the state of river ice cover due to thermal and hydraulic conditions.

RADARSAT-1 is the first satellite to respond to three of the essential conditions for the monitoring of river ice: a fine spatial resolution (9m), a frequent repeat coverage (2 to 3 days in Canada) and the independence from clouds and illumination. Moreover, RADARSAT-2, scheduled for launch in 2003, will offer a finer spatial resolution of 3 meters. A fourth condition essential for the monitoring of river ice is obviously the capacity of the sensor to “see” the ice characteristics. Prior to the launch of RADARSAT, some work done with airborne radar data (Leconte and Klassen, 1991; Leconte and Pultz, 1991; Pultz *et al.*, 1991) indicated that ice features could be detected with this technology. Moreover, after a detailed analysis of data needs for the study of river ice processes, Petryk and *al.* (1996) concluded that synthetic aperture radar (SAR) was the remote sensing sensor with the most promising future in this field of research. Some preliminary work was done with RADARSAT-1 data (Leconte and *al*., 1998; Thibault and *al*., 1997) but much work still needs to be done to further investigate the potential of this sensor.

The specific objective of this study is therefore to evaluate the effectiveness of RADARSAT-1 to characterize and monitor ice cover related processes on a medium size river (width <500 m), over the whole winter season. It is part of a larger river ice study going on at *INRS-Eau* and aimed at improving the quantity and the quality of river ice related data. The long term objectives are to develop new remotely sensed products, to acquire information concerning river ice cover and to help in the development, calibration and validation of numerical river ice models, climate-cryosphere interaction models or early warning systems for ice jam events.

2. Study site

The study site is located on a stretch of the Saint-François river, in southern Quebec (Canada) (Figure 1). The area covered by a RADARSAT Fine mode image (50 km X 50 km) comprises the towns of Drummondville in the North-West and Windsor, in the South-East. This is a 70 km long section where the width of the river vary from approximately 100m to 400m. The river flows SE-NW and discharges into the Saint-Lawrence river. It is mostly an agricultural area, with three dams, eight bridges and an history of ice jams and flooding. The natural flow of the river being disturbed by man made structures, it provides a variability of ice conditions ideal for this kind of research.

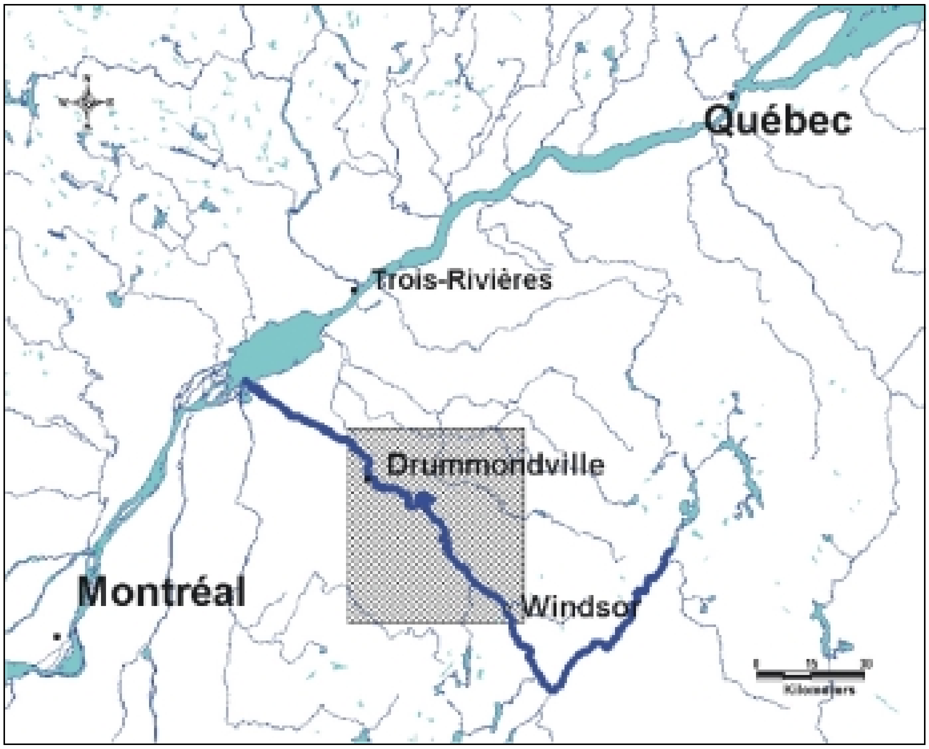

Figure 1 : Study site on the Saint-François river

3. Dataset

As part of the ADRO-2 program of the Canadian Space Agency, we obtained 13 RADARSAT-1 Fine mode images over the study area, from November 24, 2000 to April 19, 2001 (Table 1). Fine mode images cover a 50 km X 50 km area, with a spatial resolution of approximately 8m. Incidence angles vary from 37º-40º (F1 mode) to 45º-47.5º (F5 mode). The acquisition timeframe covers ice-free water to full ice cover conditions, as well as break-up events.

The preliminary results presented in this paper will focus on the six F5-Descending mode images plus the F3-Descending mode image from April 10. On all images, we applied the standard procedure to retrieve the backscattering coefficients: reversing of the look-up table, determination of incidence angles, transformation of digital numbers into amplitude. Amplitudes were chosen because of their greater dynamic range. The images were also geocoded with the provincial 1:20 000 cartographic database.

Table 1 : Characteristics of acquired images

Date	Local time	Mode	Conditions
24 Nov. 2000	5 :48	F5-Descending	Partial ice cover
26 Nov. 2000	17 :50	F5-Ascending	Partial ice cover
18 Dec. 2000	5 :48	F5-Descending	Ice jams and floating ice
11 Jan. 2001	5 :48	F5-Descending	Complete ice cover
28 Feb. 2001	5 :48	F5-Descending	Complete ice cover
16 March 2001	17 :42	F1-Ascending	Complete ice cover
17 March 2001	5 :52	F3-Descending	Complete ice cover
24 March 2001	5 :48	F5-Descending	Partial ice cover
26 March 2001	17 :50	F5-Ascending	Partial ice cover
9 April 2001	17 :42	F1-Ascending	Partial ice cover
10 April 2001	5 :42	F3-Descending	Partial ice cover
17 April 2001	5 :42	F5-Descending	Ice free
19 April 2001	17 :50	F5-Ascending	Ice free

Some general field observations, weather data (hourly or daily air temperature and precipitation) and hydrological data (streamflow, water level) are available for the area. From this information we can determine the conditions prevailing on the river for each image acquisition date (Table 2).

Table 2 : Conditions prevailing on the river for the seven processed images

Date	State of the river
November 24	Thin ice cover under dry snow downstream and open water upstream;
December 18	Sudden breakup after heavy rain and strong winds, floating ice, ice jams;
January 11	Complete ice cover with dry snow;
February 28	Complete ice cover with dry snow;
March 24	Complete ice cover with wet snow;
April 10	Melting ice cover downstream, open water upstream;
April 17	Open water

4. Temporal analysis of the radar signal

To look at the temporal variation of the backscattering coefficients coming from the river, we have extracted the signal amplitude along a mid-channel vector going from Drummondville to Windsor. Figure 2 shows the backscattering amplitude along that vector, for the seven processed images. The river channel is only added for a better understanding of where the action is taking place. The curve from April 17 (open water) shows the lowest backscattering because the smooth water surface reflects the radar signal away from the sensor. The November 24 image also shows a low backscattering because it is open water for most part. The thin ice cover under dry snow downstream presents a smooth surface that has the same effect as open water. A third image (March 24) shows low backscattering. But this time, a couple of warmer days have started the melting process and wet snow covering the ice is responsible for the low signal return. When the snow cover is moderately wet and pretty smooth, high signal losses occur because of the liquid water content of the snow, resulting in low backscattering (Ulaby, 1986). From these preliminary observations, the discrimination of smooth open water, thin ice with dry snow and ice covered by smooth wet snow is expected to be rather difficult. However, when a very wet snow is combined with a rough surface, surface scattering is enhanced and the backscattering increases. This can be seen on the April 10 curve, in the downstream section. On this 20 km stretch, the ice cover is still present but rapidly transforming. There is a very wet and rough snow cover as can be expected after ten days of above 0ºC temperatures. Consequently, the backscattering is higher than in the case of the upstream ice free water.

On December 18, after a sudden heavy rain and wind event, we have confirmed reports of break-ups, ice jams and floating ice in the upstream section of the river, which causes higher backscattering. This image presents a mixture of ice conditions and therefore, a greater variability of the signal. More field information are however needed to conduct a detailed analysis. On January 11, temperatures have been well under 0ºC for three weeks and the ice cover is complete and solid. The December events have left a rough and heterogeneous ice cover, which produces a very strong backscattering, two to three times higher than for open water. Through February 28, the air temperature remains low, but the signal decreases significantly in some sectors. This could be related to dam operations or changes in the ice thickness and indicates that RADARSAT is sensitive to some changes in the ice condition.

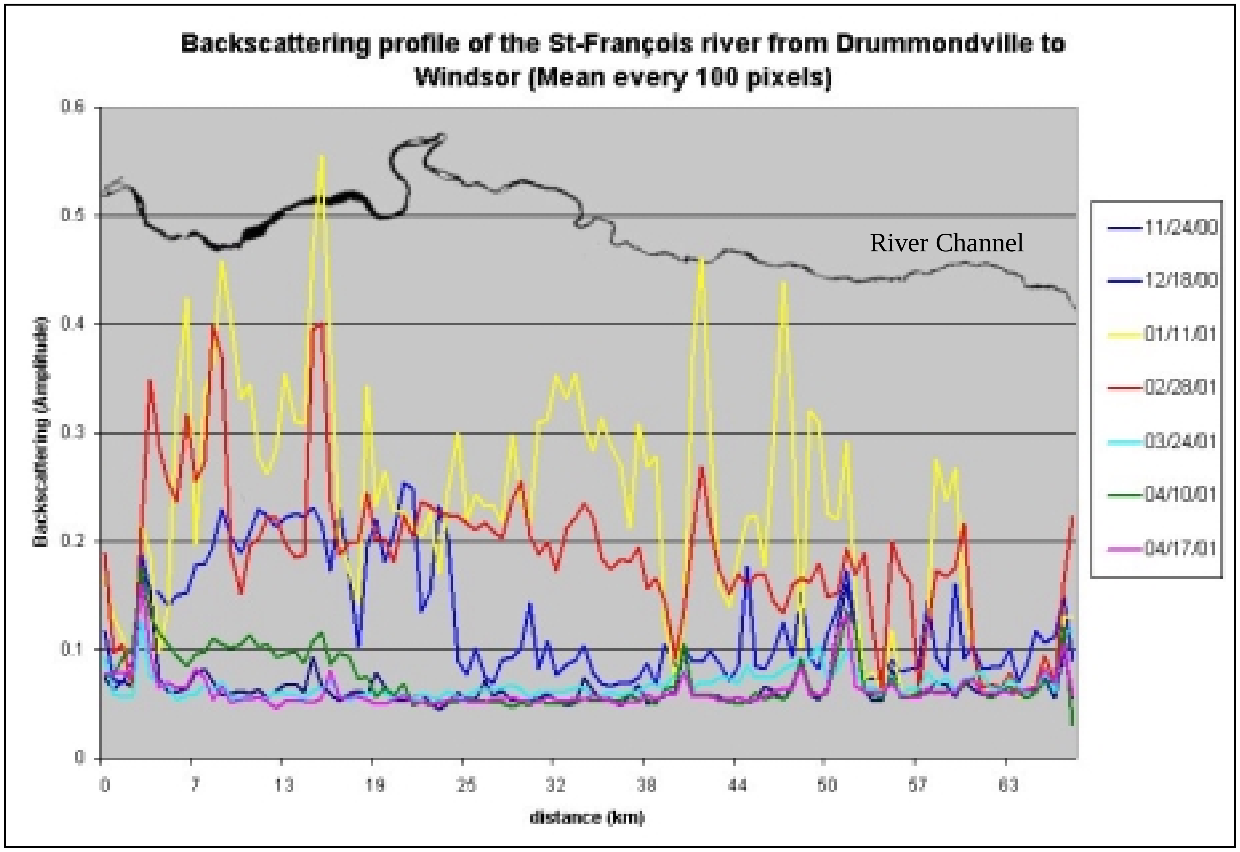

Figure 2 : Temporal variation of the backscatterings along a mid-channel vector

To confirm the preliminary observations from Figure 2, Figure 3 shows how a downstream sector of the river looks on the six F5-mode radar images. We can clearly see the low backscattering of November, 24, March 24 and April 17. The mixed backscattering of floating ice is apparent on December 18. Finally, the high backscattering of the January 11 complete ice cover and the lower backscattering of February 28 are also visible. The April 10 (F3-mode) image is presented in Figure 4, and zooming on a larger sector just 1 km upstream, where we can see the transition from open water in the mid channel to melting ice on the sides and downstream. The signal is relatively low and some special enhancement was required. We have first created a texture image from the original image, using the Mean parameter and a 5 X 5 window. We have then applied an equalization enhancement to sufficiently contrast the image.

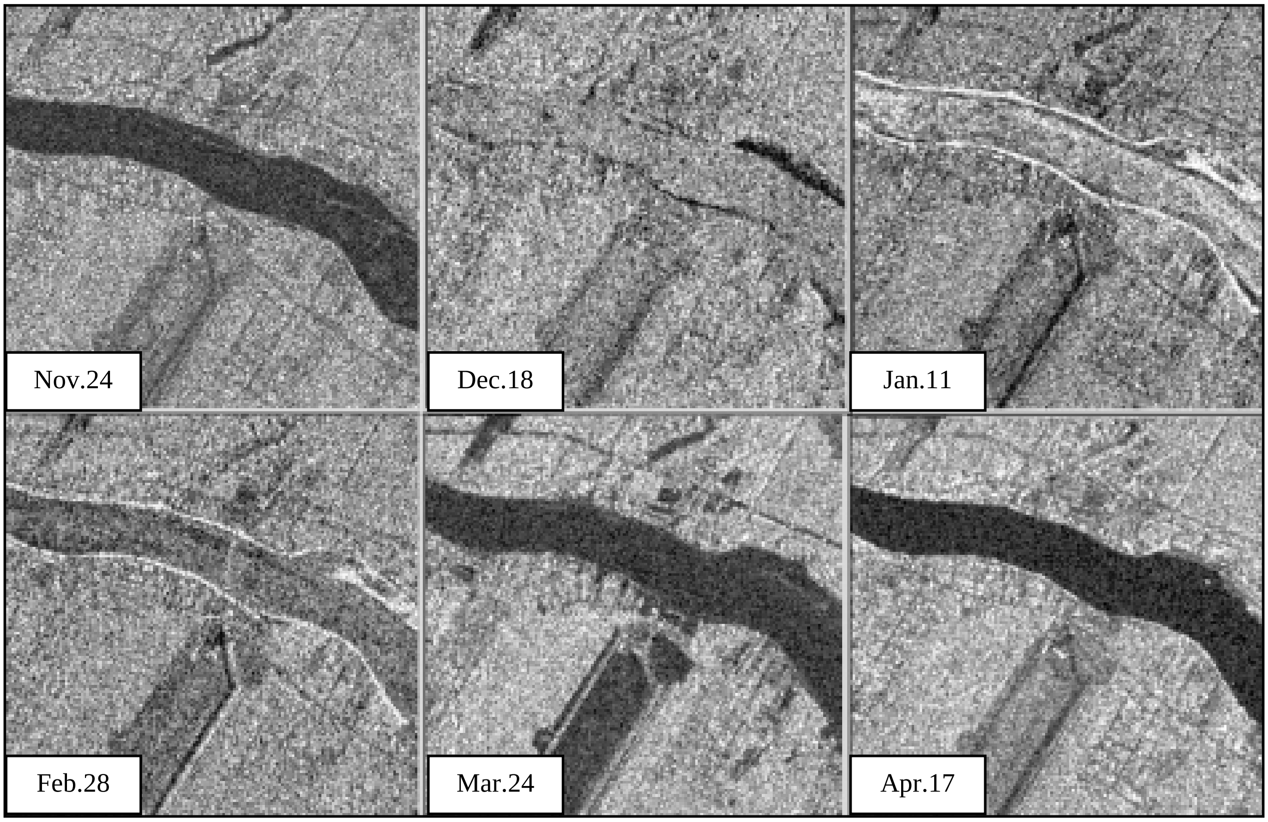

Figure 3 : Subset of six RADARSAT F5-mode images on a downstream sector of the Saint-François river

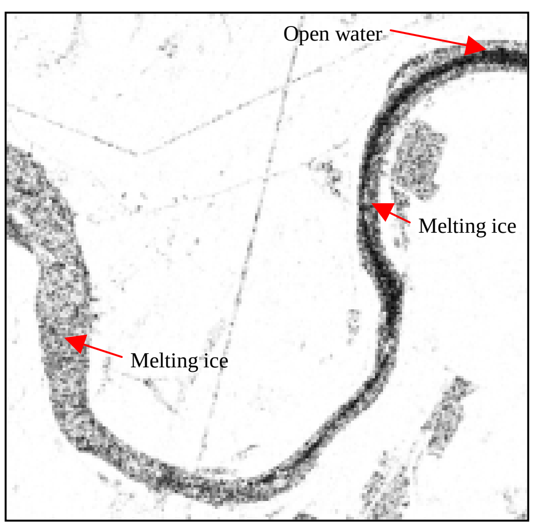

Figure 4 : Transition from open water to melting ice on April 10.

5. Interesting features

During this preliminary analysis, some other interesting ice features were observed on the radar images. The first one is the very high backscattering of January 11, along the river banks (Figure 5). The values there are almost twice higher than those measured in the channel. From field observations in the spring (see picture in Figure 5), it is believed to be the signal coming from the shear walls left on the banks, after the surge of December 18.

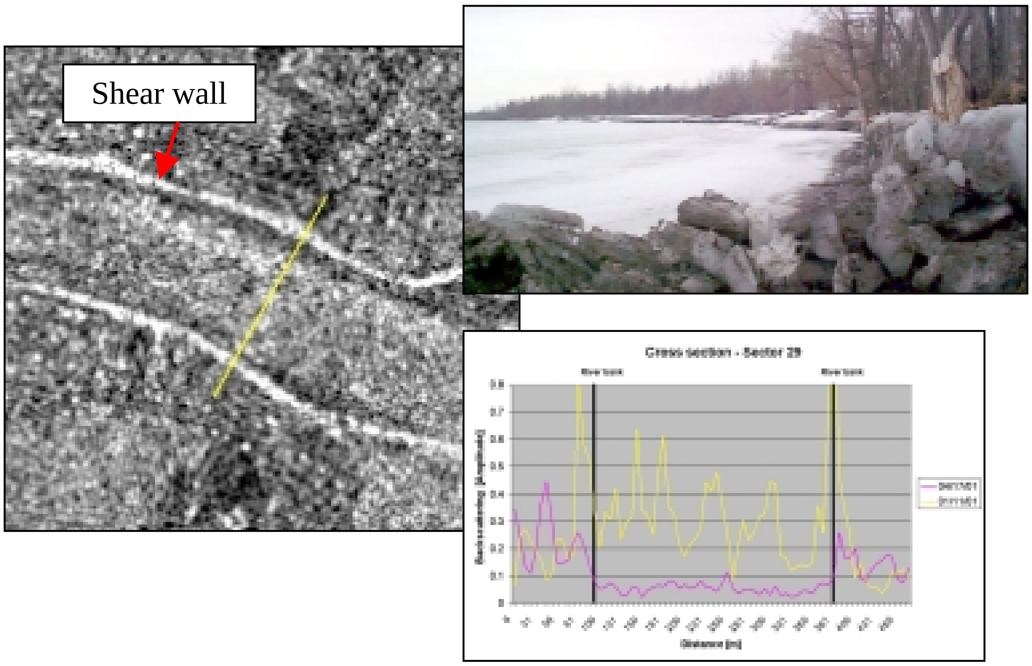

Figure 5 : Evidence of shear walls

The second feature is another unusually high backscattering phenomena observed across the river this time, in the February 18 image (Figure 6). The values there are again twice higher than the neighborhood pixels and they correspond to the location of an ice road. A third feature is the influence of a dam over the ice formation, in the town of Drummondville (Figure 7). Upstream from the dam, the river flow is slow, allowing an early formation of a thin smooth ice cover (low backscattering). Downstream from the dam and near bridges, rapids are creating a very high backscattering.

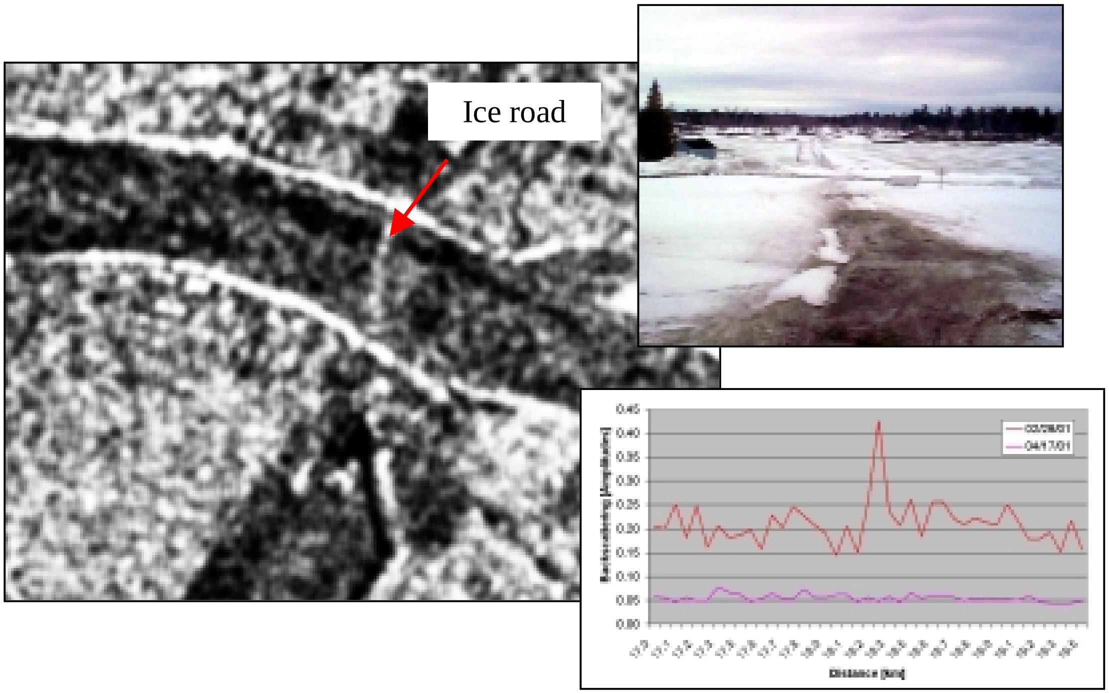

Figure 6: Evidence of an ice road

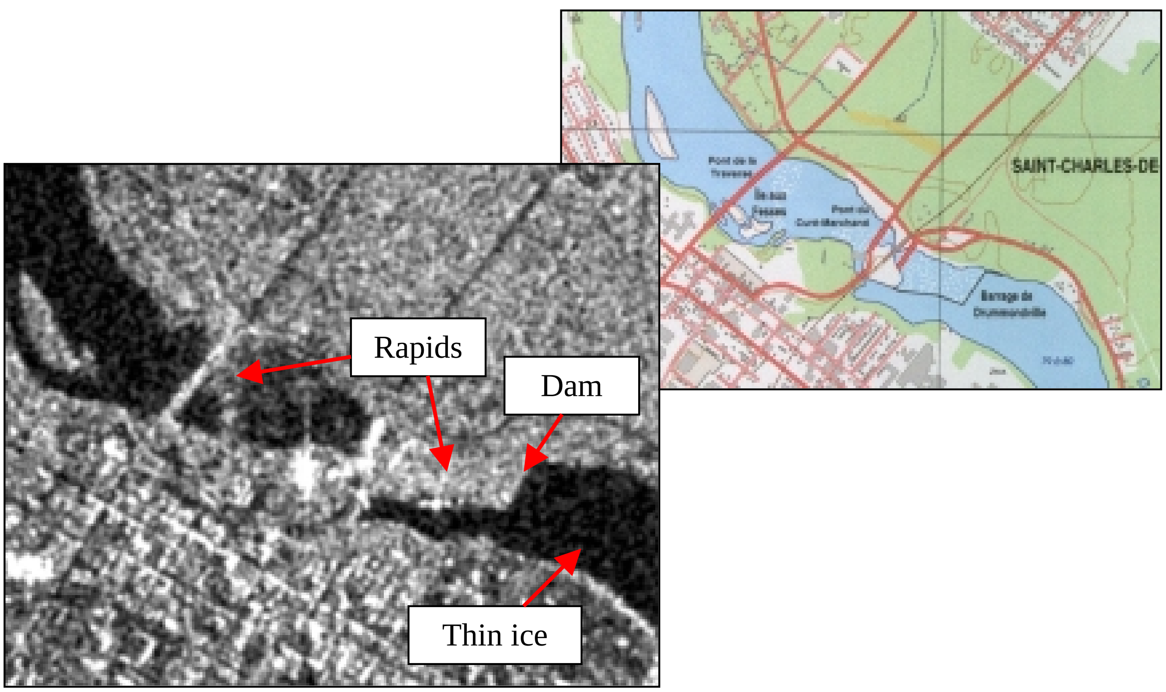

Figure 7 : Influence of a dam over ice formation

6. Conclusion

The work described here is preliminary. It has nonetheless demonstrated that changes in the Saint-François river ice cover can be detected by RADARSAT-1 SAR and that some particular ice features can create specific radar signatures. The next step is now to process the other acquired images and compare the signal coming from ascending mode and descending mode images. We will also compare the signal coming from images with different incidence angles (F1, F3, F5). This analysis will be based on homogeneous river segments determined using slopes from a DEM and meandering coefficients. We will then proceed to a detailed interpretation of the images with river ice experts and determine specific signatures and patterns for ice characteristics.

Acknowledgements

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