CGU HS Committee on River Ice Processes and the Environment
18th Workshop on the Hydraulics of Ice Covered Rivers
Quebec City, QC, Canada, August 18-20, 2015

IceFRONT: Integration of radar and optical images for operational river freeze-up monitoring

Yves Gauthier[1], Stéphane Hardy[2], Catalina Gutiérrez[2], Antoine Padel[1], Jonathan Gaudreau[2], Jimmy Poulin[1], Martin Jasek[3], Monique Bernier[1], Hellen Gomez[2], Achim Roth[4]

[1] *INRS Centre Eau Terre Environnement, Quebec City, Qc, yves.gauthier@ete.inrs.ca*
[2] *Dromadaire Géo-Innovations inc., Montreal, Qc, shardy@dromadaire-geo.com*
[3] *BC Hydro, Burnaby, BC, martin.jasek@bchydro.com*
[4] *German Aerospace Center (DLR), Earth Observation Center, Achim.Roth@dlr.de*

The objectives of the IceFRONT project are 1) to help hydropower companies to gather from satellite images, the timely information needed for operational river freeze-up monitoring and 2) to speed up and simplify the process of analyzing the satellite images and extracting the required information. The study is conducted on the Peace River (Alberta). The project has succeeded in developing an integrated automated approach to provide ice information from various sources of satellite data, based entirely on open source software. IceFRONT integrates optical (MODIS and LANDSAT-8) and radar (RADARSAT-2 and TERRASAR-X) images. The various approaches are described.

1. Introduction

Hydropower companies that are operating on northern latitude rivers have to adapt to winter conditions. One particular challenge that they are facing is to minimize the impacts of dam operation on the ice cover. If weakened, the ice cover can break prematurely and cause ice jams and flooding downstream. So there is always a need for a detailed and updated knowledge of the ice processes occurring on the river. This is why BC Hydro and Alberta Environment have been monitoring the ice cover of the Peace River for decades. Extensive field measurements, on-site cameras, air surveys, modeling and radar satellite images are used to monitor a 1 300km long stretch of the river. A recent study (Jasek, 2013) has shown that combining SAR and optical imagery could help to determine the location of initial ice lodgement and the ice front progression on the Peace River, hence providing information at the spatial and temporal scale needed. Managing multiple sources of satellite data could however become a complex task.

Therefore, the IceFRONT project was initiated to 1) help hydropower companies gather from satellite images, the timely information needed for operational river freeze-up monitoring, 2) speed up and simplify the process of analyzing the satellite images and extracting the required information and 3) develop an integrated service using complementary satellite imagery sources and open source software.

2. The IceFRONT application

The IceFRONT application is based on several image sources in order to increase information availability. The first component deals with optical images. Namely, free MODIS and Landsat-8 images. The objective of this module is to access, download, visualize and classify both types of images, with a minimum of user intervention.

MODIS images

MODIS images are free and acquired twice daily. Here, we only use the 250m red band. From this we can infer the presence or absence of ice over the river, provided that the channel is wide enough. Because MODIS is an optical sensor, it is subject to frequent cloud cover. The MODIS processing approach is adapted from Chaouch et al (2012). It simply applies reflectance thresholds on band 2, in order to discriminate ice from water (Figure 1). But prior to that, because of the resolution and the probability of getting mixed pixels, we have to first select what are called “pure pixels”, which are totally included within the river channel. This is done with a frequency analysis of summer images and selecting pixels that are steadily showing the lowest values. Then, to eliminate pixels that could show low values because of shadows caused by the steep banks, we use a series of images with a complete ice cover. Combining the two provides the application mask. For each image, we also use the cloud mask from MODIS. Finally, we apply thresholds between values of the pure water pixels and the values of the pure ice pixels. A probability function can alternatively be used to classify between the water and ice thresholds.

Estimation of accuracy is done through a visual “ground truthing”. The channel is divided into 1 km sections. For each section, a visual analysis determines if there is the presence of water or only ice. The same information is extracted from the ice map. When both sources agree, we have a match. Over 8 images of the 2013-2014 winter season and 2700 sections, concordance was 80%. Errors are mainly due to uncertainties in the cloud mask.

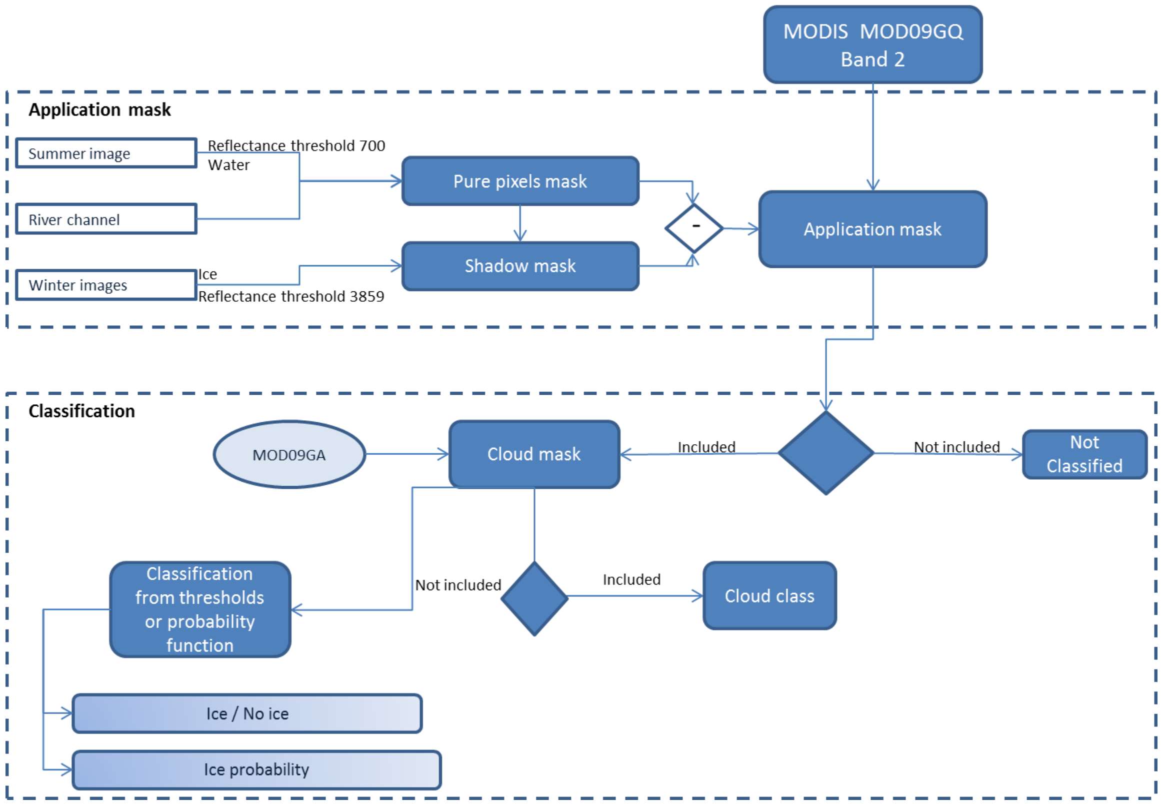

Figure 1: MODIS processing approach in IceFRONT.

<u>LANDSAT-8 images</u>

The Peace River is covered by six Landsat-8 orbits every 16 days (Figure 2). The overlaps enable a weekly coverage of many sections. And a 750km stretch, flowing northerly, can be covered on a single orbit. From Landsat images (30m resolution), we can detect the presence of ice and of floating frazil pans. It is however also affected by cloud cover and by the snow cover, which can mask some ice information that could otherwise be detectable at this resolution.

LANDSAT-8 images are first retrieved from the USGS Earth Explorer site. Bands 3 (green) to 6 (mid-infrared) are downloaded and radiances are calculated. Again, we use the cloud mask provided with the imagery. A band ratio is used for classification of the pixels as ice or water. With the band ratio, we are trying to get an optimal discrimination between water and ice. We have tested the usual NDVI or Normalized Difference Vegetation Index, then the NDSI or Normalized Difference Snow Index (Hall et al, 1995), then the NDSII or Normalized Difference Snow and Ice index (Xiao et al, 2001) and finally, the NDSII-2 (Keshri et al, 2009). Presently, we have implemented the NDVI only (**Figure 3**). The NDSII-2 will be implemented soon as it gives better results. As for the classification, thresholds between water and ice are determined through a frequency analysis and with a clustering analysis (Ward's method).

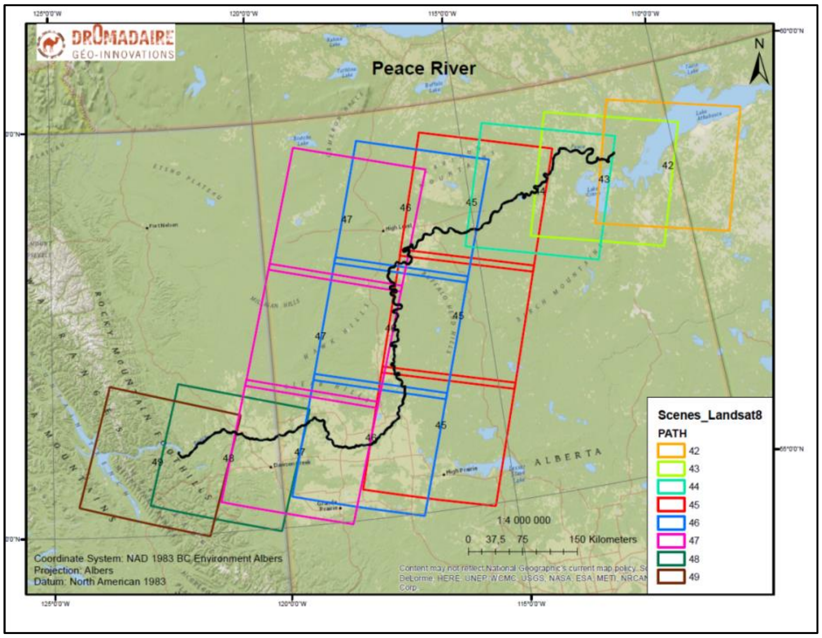

Figure 2: Landsat-8 coverage.

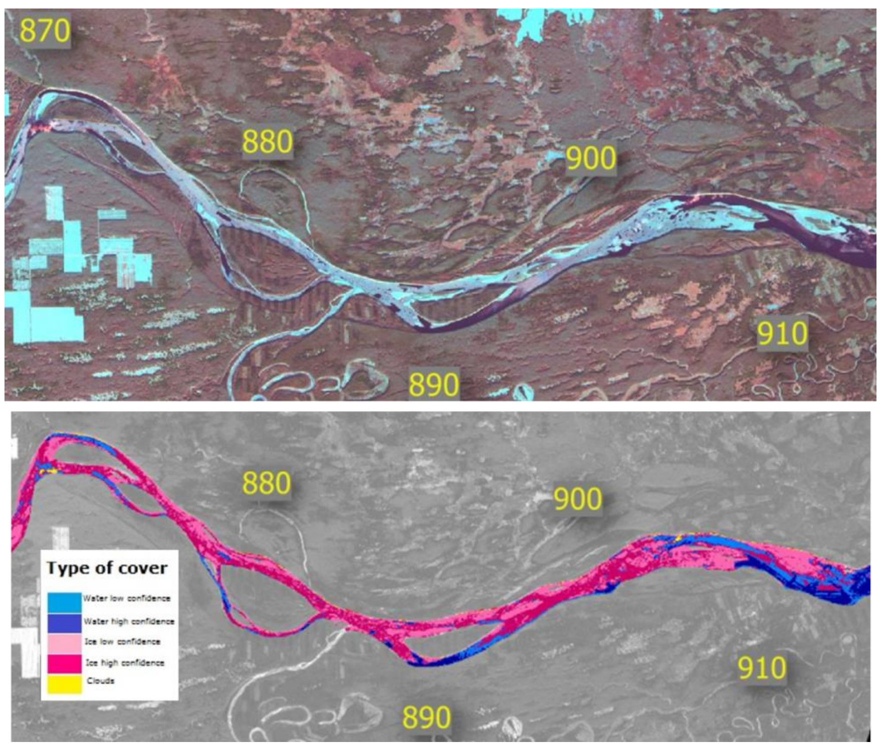

Figure 3: Top: RGB composite of a section of the Landsat-8 image of November 11th, 2014.
Bottom: Classification resulting from IceFRONT.

Quantitative accuracy of this approach has yet to be performed. Overall, the main challenges working with optical imagery are: spatial resolution, shadow of steep banks and trees, clouds, floating frazil, turbid spring water.

Radar images

The goal of the second component of the IceFRONT application is to integrate various sources of radar imagery. The work is being done with Radarsat-2 (Canada) and TerraSAR-X imagery (Germany), provided respectively by MDA and DLR. Here we have compared different approaches, including the use of polarimetric images, to achieve optimal ice/no ice classification and the identification of dominant ice types. At northern latitudes, radar coverage of a single satellite is 1 week or better. With two sources ot tandem satellites, coverage increases. Advantages of radar imagery are: all weather acquisition, good spatial resolution for rivers and getting information through snow. Disadvantages are about cost and complexity of interpreting the radar signal of a river ice cover. However, free radar data are starting to appear (Sentinel 1 satellite, European Space Agency).

In the radar work package, we have compared three processing approaches. In this workpackage of the project we are looking at three processing approaches. The first one was the IceMAP-R approach (Gauthier et al, 2010), which uses intensity data and texture elements within a fuzzy K-Mean classification. The second one was a polarimetric approach, from Dromadaire Geo-Innovation, using alpha and entropy, with thresholds for discriminating ice types. These thresholds are based on training sites for different ice conditions (Figure 4).

The third approach, developed at DLR, uses Kennaugh elements with polarimetric data (Schmitt and Brisco, 2013). Resulting ice maps are presented in **Figure 5**. On a preliminary validation analysis on one Radarsat-2 image, the DLR approach yielded the best overall accuracy and Kappa coefficient (88%/90%).

3. Conclusion

To date, several modules are automated in the IceFRONT application, using only open source software: Retrieving of MODIS and Landsat images; Quick visualization of the RGB composites; Classification of MODIS and LANDSAT images; Classification of RS-2 images. Therefore, the IceFRONT project has succeeded in developing an integrated automated approach to provide ice information from various sources of satellite data, based entirely on open source software. Some of the products have been tested in operational mode with BC Hydro in the 2015 breakup of the Peace River. The next steps of this project include accuracy assessment for all classification modules, improvement of the MODIS and LANDSAT-8 classification schemes, integration of TerraSAR-X data and Sentinel-1 data; as well as improvements and add-on to the interface.

4. Conclusion

To date, several modules are automated in the IceFRONT application, using only open source software: Retrieving of MODIS and Landsat images; Quick visualization of the RGB composites; Classification of MODIS and LANDSAT images; Classification of RS-2 images. Therefore, the IceFRONT project has succeeded in developing an integrated automated approach to provide ice information from various sources of satellite data, based entirely on open source software. Some of the products have been tested in operational mode with BC Hydro in the 2015 breakup of the Peace River. The next steps of this project include accuracy assessment for all classification modules, improvement of the MODIS and LANDSAT-8 classification schemes, integration of TerraSAR-X data and Sentinel-1 data; as well as improvements and add-on to the interface.

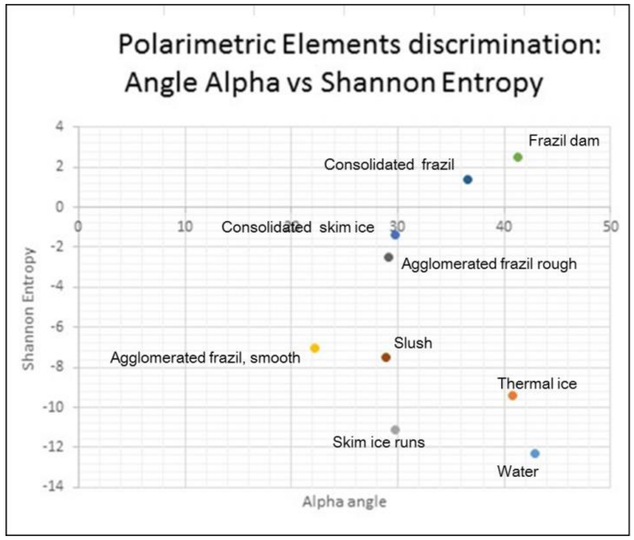

Figure 4: Defining thresholds for classification of ice types from polarimetric parameters.

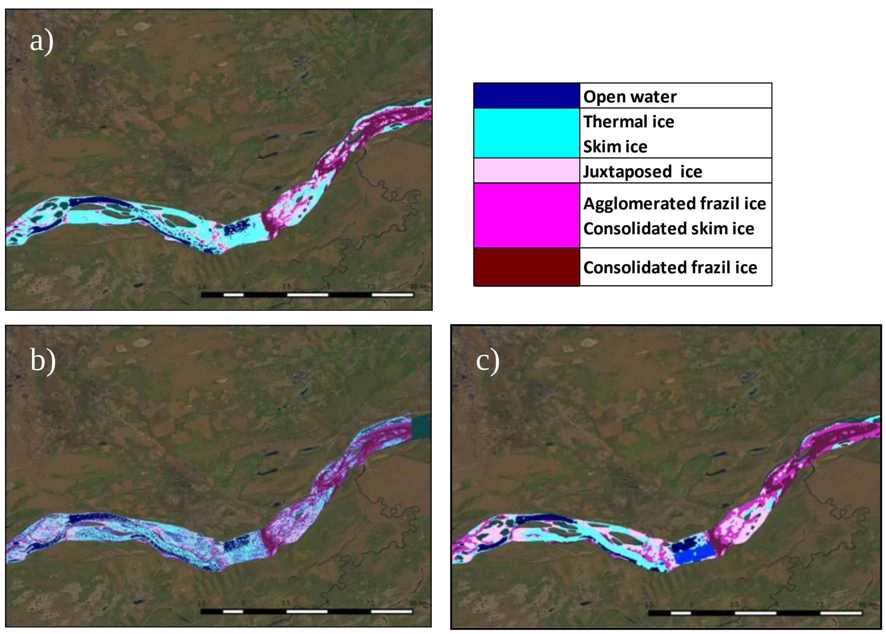

Figure 5: Classification of ice types from three methods a) IceMAP-R; b) Alpha/Entropy; c) Kennaugh elements.

Acknowledgments

The IceFRONT project was funded by the Canadian Space Agency, with contributions from Dromadaire Geo-Innovations inc., BC Hydro, DLR and INRS.

References

Chaouch, N., Temimi, M., Romanov, P., Cabrera, R., Mckillop, G., & Khanbilvardi, R., 2014. An automated algorithm for river ice monitoring over the Susquehanna River using the MODIS data. Hydrological Processes, 28, 62–73.

Gauthier, Y, Tremblay, M., Bernier, M. And C. Furgal, 2010. Adaptation of a Radar-Based River ice Mapping Technology to the Nunavik Context. *Canadian Journal of Remote Sensing*, 36: (S1), 168-185.

Hall, D. K., Riggs, G. A., And Salomonson, V. V., 1995. Development of methods for mapping global snow cover using moderate resolution imaging spectroradiometer data. *Remote Sensing of Environment*, 54, 27–140. Xiao et al, 2001

Jasek, M., Gauthier, Y., Poulin, J., & Bernier, M., 2013. Monitoring of Freeze-up on the Peace River at the Vermilion Rapids using RADARSAT-2 SAR data. In: Proceedings of the 17th Workshop on the Hydraulics of Ice Covered Rivers, Edmonton, Alberta, July 2013.

Keshri, A.K., Shukla, A. And Gupta, R.P., 2009. ASTER ratio indices for supraglacial terrain mapping. *Int. J. Remote Sensing*, vol 30, no. 2, 519-524.

Schmitt, A. And Brisco, B., 2013. Wetland Monitoring Using the Curvelet-Based Change Detection Method on Polarimetric SAR Imagery. *Water* **2013**, *5*(3), 1036-1051

Xiao, X., Shen, Z. And Qin, X., 2001. Assessing the potential of VEGETATION sensor data for mapping snow and ice cover: a Normalized Difference Snow and Ice Index. *Int. J. Remote Sensing*, 2001, vol. 22, no. 13, 2479–2487.