A geospatial model to determine patterns in river ice cover breakup and jamming behaviour

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A geospatial model to determine patterns in river ice cover breakup and jamming behaviour

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In the past, both empirical and process-based attempts have been made to predict river ice behaviour, in particular ice cover breakup and ice jamming occurrences. These methods perform with varying and limited success and tend to be site specific. A method is required which can simply estimate the predisposition of river reaches to ice breakup and jamming events. This paper introduces a geospatial modelling approach which can fulfil that task and improve the predictive power of ice cover breakup and ice jamming behaviour. The geospatial model can determine the most vulnerable sections along the studied reaches to such behaviour, which are phenomena entailing hydraulic, ice morphology and fluvial geomorphology. A geospatial model clusters hydraulic characteristics (e.g. discharge or stage), ice characteristics (e.g. ice thickness and ice type) and river geomorphological characteristics (e.g. sinuosity, slope, width, etc.) into common river features called Geomorphic Response Units (GRU). A statistical clustering technique such as principle component analysis (PCA) is used to derive these GRUs. It is assumed that certain GRUs will be more susceptible to certain ice cover behaviour, such as breakup and jamming of river ice. Data acquired along the Slave River and its delta in Canada is used to test the geospatial model. The main data sources are space-borne remote sensing MODIS imagery and traditional and local knowledge from members of the communities alongside the river, in particular Fort Resolution and Fort Smith.

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1. Introduction

The Slave River is the largest transboundary river in the Northwest Territories (NWT) and the Slave River Delta (SRD) is one of the most productive fresh water ecosystems in the NWT. The large population of waterfowl, the large extent of animals and their habitats, and the highly productive ecosystem in the SRD makes its ecosystems particularly sensitive to hydrologic regime changes along the Slave River. Seasonal flooding is one of the key requirements to replenish the delta region for maintaining a healthy and balanced ecosystem. Since the construction of the Bennett Dam on the upper Peace River in 1968, significant changes in the annual flow regime of the Slave River have resulted. Due to flow regulation the annual hydrograph has been modulated with winter discharges in the Slave River being increased significantly, while spring discharges have been reduced dramatically. This seasonal variation in flow changes may impact spatial and temporal patterns of the ice cover breakup during the spring on the Slave River, the focus of this study, which can lead to changes in the hydrology of the SRD.

2. Study site

The Slave River (see Figure 1) begins at the confluence of the Peace River and Athabasca Lake/River system in northern Alberta and flows northward for 434 km to empty into Great Slave Lake in the Northwest Territories. The outlet is the recipient of water draining a catchment area of 616,400 km^2. A large portion of the river's flow is regulated by the Bennet Dam situated in the headwater region of the Peace River. Mining activities in both the Peace and Athabasca River catchment areas are also impacting both downstream water quantity and quality.

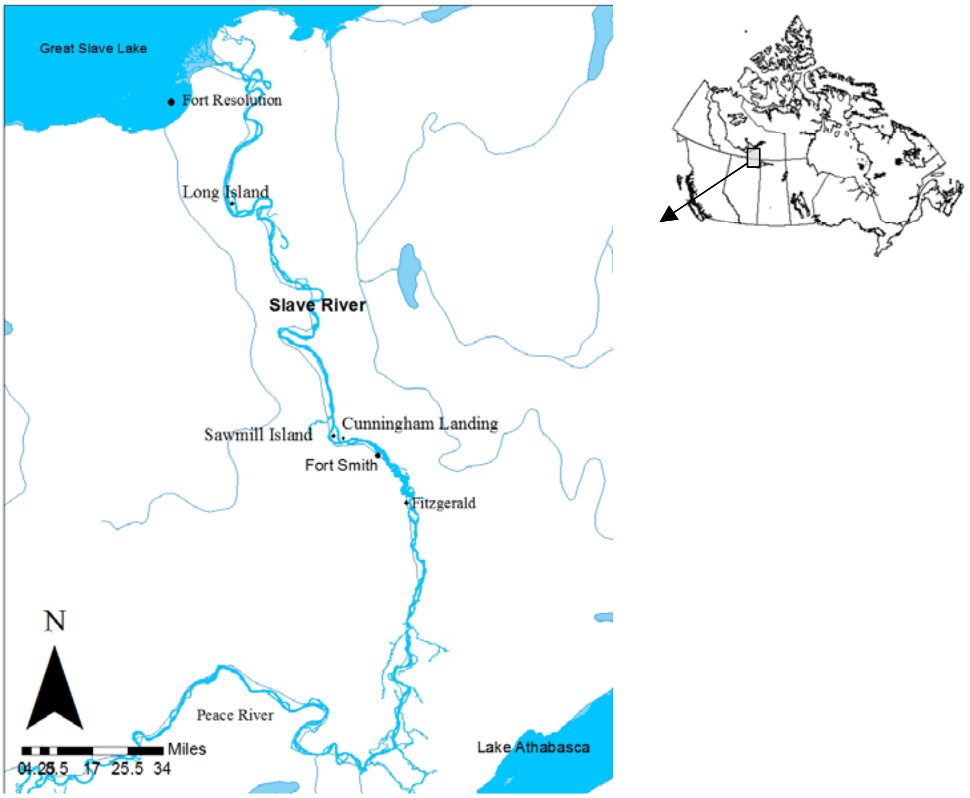

Figure 1: Slave River

3. Development of a geospatial model

The geospatial modelling approach (Lindenschmidt & Long, 2013; Lindenschmidt & Chun, in press) may be a more reliable method to predict the predisposition of river reaches to ice breakup and jamming events. In addition, this modelling technique has the potential to forecast ice jamming events on a large scale. Ice jamming events not only depend on meteorological and hydrological parameters but also on the geomorphology of the channel (Lindenschmidt and Chun 2013a). Some research has been carried out to forecast ice breakups and jamming events by applying similar methods. For instance, Kalinin (2008) defined six factors such as the presence of islands, bridges, bends, loops, tributaries and narrowing riverbeds which may be responsible for ice jam formation and occurrences. A simplified geospatial model could help to predict the location of certain ice cover behaviours on the basis of the morphological characteristics of the channel (De Munck et al., 2011). They identified different geomorphological factors such as islands, channel geometry, bridges and slope and applied a geospatial model to determine the potential location of ice jams along the Chaudiere River, Quebec. Lindenschmidt and Chun (in press) successfully applied a geospatial modelling methodogy to examine the process of ice cover formation along the Dauphin River, Manitoba. In this research they clustered geomorphological parameters such as sinuosity, river width, and slope into typologies using principle component analysis. Certain typologies describe the position of ice bridging and non-bridging locations along the river.

A geospatial model has been developed to help identify patterns of ice cover breakup along the Slave River and possibly reaches with the highest potential to ice jamming. Ice breakup and ice jamming are hydraulic, ice morphology and fluvial geomorphology phenomena and a geospatial model can help to predict locations with the highest probability to ice jamming. The geospatial model assumes that a river's geomorphological characteristics and ice characteristics are responsible for the occurrence of ice jamming in certain locations along a river. A geospatial model discretizes a river into sections called Geomorphic Response Units (GRUs) which cluster common hydraulic characteristics (e.g. discharge or stage), ice characteristics (e.g. ice thickness) and river geomorphological characteristics (e.g. sinuosity, slope, width, etc.). A multi-variant statistical clustering technique such as the principle component analysis (PCA) is used to derive these GRUs.

Methodologically, the geospatial model was constructed from the river's geomorphological characteristics derived from spatial data that can be extracted using a Geographic Information System (GIS). First, a centreline of the river was constructed from river polygons provided by the GeoGratis database (http://geogratis.cgdi.gc.ca). Points were inserted along the centreline at 50 metre intervals. At each point, a perpendicular transect was inserted which intersected each river bank, represented by the edge of the river polygon. The length between the bank intersections represents the river width at that point. A digital elevation model (DEM) was overlain to obtain the elevations at the bank intersections. Due to the low resolution of the DEM, some running-average smoothing was necessary to obtain a longitudinal profile of the river banks. From these profiles, slopes at each centreline point were calculated. An area of 8 sq. km was used to calculate fractal dimension which represents how much of the river length fits into an 8 sq. km Euclidian space. A moving box was run along the centreline to calculate the fractal dimension for each point, the point always being at the most-upstream part of the box. The box was rotated to encompass the maximum amount of river length within the box. These three variables, width, slope and fractal dimension, were then grouped using the multivariate Principal Component Analysis (PCA). Different combinations of negative and positive signed values of the principle components represent different typologies that can be colour coded for each centreline point along the river. Clusters of single typologies or patterns of two or three typologies along certain segments of the river are then grouped into units called geomorphic response units (GRU). Correlations were then found between these units and river ice characteristics and breakup behaviour.

4. MODIS satellite imagery

The MODIS instruments are part of the National Aeronautics and Space Administration's (NASA's) earth observing system (EOS). MODIS sensors are mounted on the Terra and Aqua satellites which capture data in 36 spectral bands in the visible, near-infrared, and infrared bands. The spatial resolution of the data ranges from 250 meters to 1 km. This study considered some criteria to acquire appropriate MODIS imagery that can track the ice cover along the entire river. First, MODIS images (Fig. 2) should be cloud free, and spatial resolution should be sufficiently high to detect the presence and absence of ice along the channel. The finest resolution spatial available in MODIS imagery, 250 m, was sufficient to track the ice cover dynamics along the Slave River.

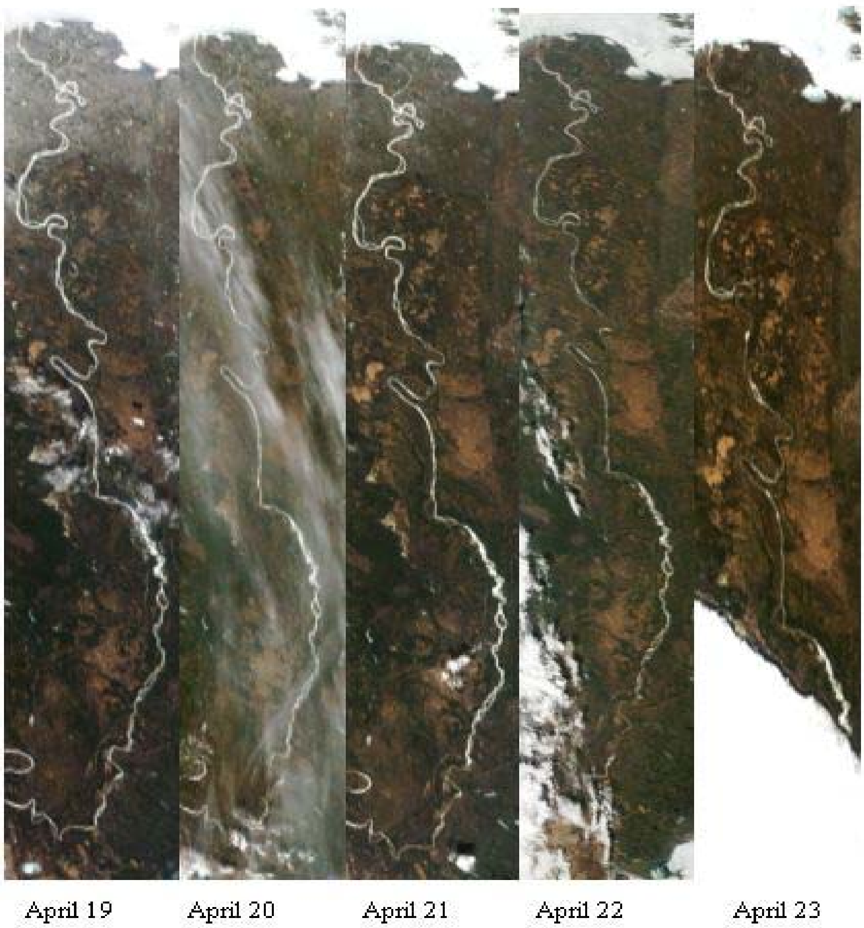

Figure 2. Time-series of MODIS imagery acquired of the Slave River during the break-up of its ice cover in the spring of 2010.

5. Results and discussion

A series of MODIS images have been used to document the patterns of ice cover breakup along the entire course of the Slave River between the years 2008 to 2011. Breakup of the ice cover along the Slave River begins near Cunningham Landing at Sawmill Island, below the Rapids of the Drowned near Fort Smith, and then moves downstream. As an example for the lower Slave River, downstream from Fort Smith, in the spring of 2010, MODIS images show the first open water sections occurred on 19 April at Sawmill Island. On 23 April 2010, MODIS imagery reveals that some ice dislodgement areas along the Slave River coinciding with GRU III of the geospatial model (Fig.3).

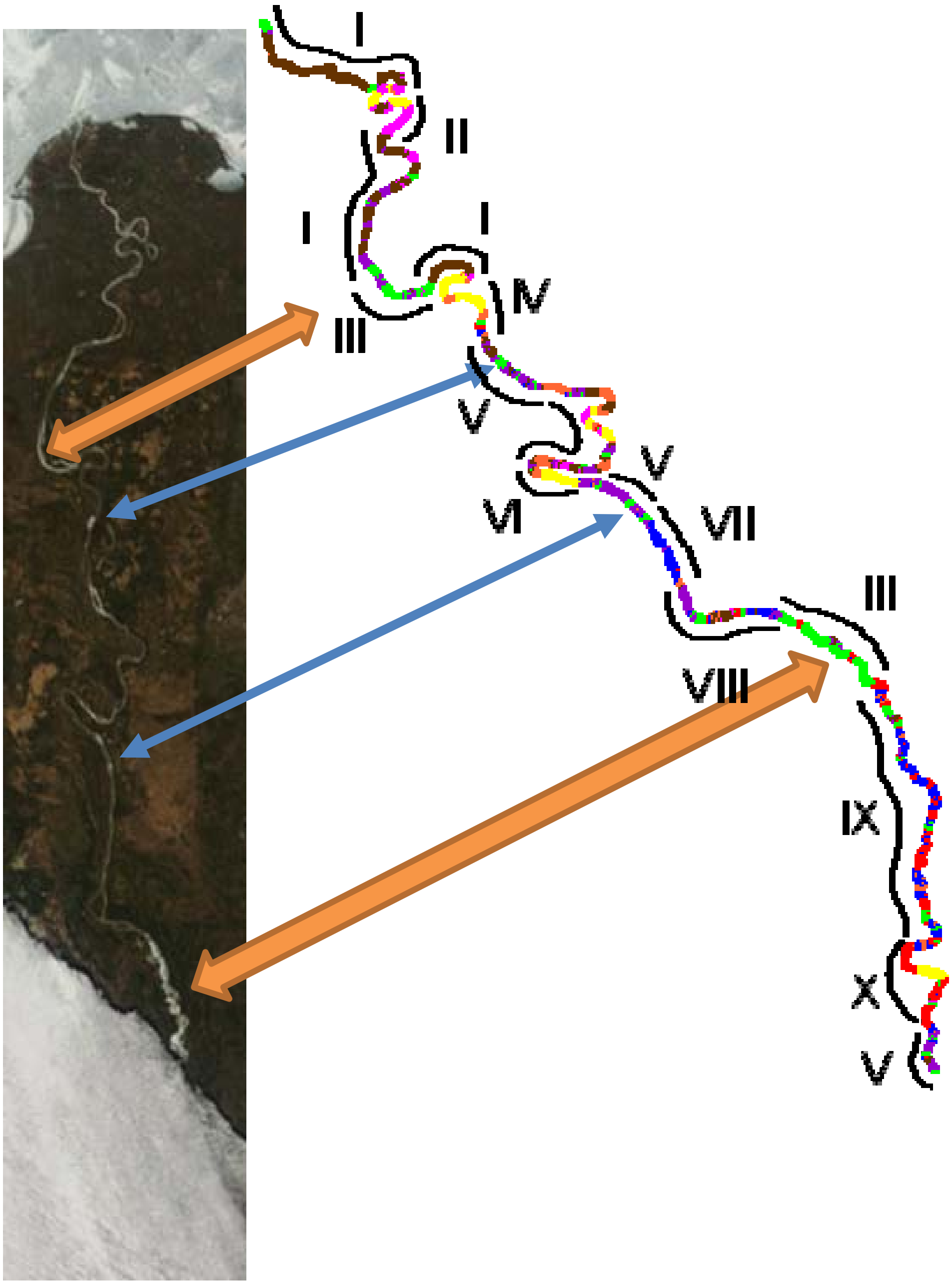

Figure 3. Remnants of ice and ice cover along the lower Slave River evident in the MODIS image taken 23 April 2010 and coinciding with GRU III in the geospatial model.

Clusters of each typology or clusters of two or three typology combinations are found at different locations along the river course. Each clustering constitutes a Geomorphic Response Unit (GRU). GRU III along the Slave River is relatively steep with many small and large islands dividing the main flow into two or more smaller flows. Flow conditions during the breakup may also be affected by ice cover conditions along the Slave River. In 2010 comparatively low flows were recorded between April and May and a medium freshet occurred on 19 April.

6. Conclusions

This geospatial model provides guidance in monitoring river ice behaviour and predisposition of ice jamming along a river. The results may provide valuable information about ice quality and ice characteristics along the Slave River to help determine the effect of dam operation on water flows and levels and asses the river health. Future work will concentrate on incorporating ice type into the geospatial modelling setup.

Acknowledgement

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