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Measurements and analysis of ice breakup and jamming characteristics in the Mackenzie Delta, Canada

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ABSTRACT

Ice breakup is a controlling factor in the hydrology of arctic deltas, including the Mackenzie River Delta, which is characterized by a flat front and numerous channels and lakes. Ice-jam flooding replenishes delta lakes with essential water, sediment and nutrients. The present study, carried out under the auspices of the International Polar Year, aims to gather essential quantitative information for improving understanding of delta ice processes and associated prediction capability. Comprehensive observations and measurements, which were carried out during the 2007 and 2008 breakups, are described along with relevant analysis and data interpretation. The spacing of pre-breakup transverse cracks in delta channels is similar to that of rivers, typically ranging from 2 to 5 ice cover widths. Ice jamming in the delta is driven by major ice runs originating in the Mackenzie River and stalling in the upper reaches of Middle Channel. The data collected during the mechanical breakup event of 2008 permitted crude, but first-ever, quantification of flow re-distribution resulting from the formation of a Middle Channel jam. This jam also generated jams in East Channel and smaller distributaries. Examination of threshold velocity for ice block submergence indicated that, with notable exceptions, the expected kind of jam in delta channels is a surface accumulation of ice blocks and plates. This prediction is in accord with observations and hydrometric data at the Inuvik and Aklavik gauges. The use of portable loggers to record water level variations at selected sites proved to be a robust and effective technique for obtaining key hydraulic data.

1. Introduction

The Mackenzie Delta, one of the world's largest Arctic deltas, contains over 49,000 lakes and covers 13,135 km^2 (Emmerton et al., 2007). This lake-rich environment is one of the most productive ecosystems in northern Canada (Squires et al., 2009), supporting large populations of birds, fish and mammals. River ice breakup is a controlling factor in the hydroecology of the Mackenzie Delta (Marsh et al., 1994). Breakup ice jams can raise water levels to much higher elevations than do open-water floods. The resulting replenishment of delta lakes with river water, sediment, and nutrients, plays a key role in the maintenance of their aquatic ecosystems. The main concerns addressed by the present study relate to the hydroecology of the Mackenzie Delta ecosystem (Marsh and Lesack, 1996; Prowse et al., 2006) and to potentially growing development resulting from oil and gas exploration and the proposed Mackenzie Valley pipeline. Ice jamming also modifies the temporal and spatial distribution of the flow entering the delta (Mackenzie, Peel, and Arctic Red Rivers) and therefore has an effect on the fluxes of freshwater, sediment, and nutrients to the Arctic Ocean (Emmerton et al., 2008).

Delta ice processes in general, and breakup processes in particular, have been qualitatively documented in some detail (e.g. Terroux et al., 1981), but there is little quantitative information. However, quantitative data are essential for advancing current understanding of hydrologic processes, and for developing mathematical models for use in environmental impact assessments and predictions of climate impacts on the long-term stability of delta ecology. Under the auspices of the International Polar Year (IPY), and as a part of SCARF (Study of Canadian Arctic River Delta Fluxes; http://www.sfu.ca/ipy/), this gap is now being addressed via detailed field observations and measurements, specifically designed to collect quantitative data on delta ice breakup and jamming processes.

The objectives of this paper are to introduce the ice jam research component of IPY–SCARF and to report on measured and deduced properties and effects of ice jams in delta channels. Following background information and description of the main components of the ice jam study, brief chronologies of the 2007 and 2008 breakup events are presented. Emphasis is placed on the 2008 event, which resulted in significant jamming and flooding, unlike the thermal breakup of 2007. Data analysis and interpretation, which are presented next, pertain to the spacing of pre-breakup transverse cracks, ice jam

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water levels and approximate thickness profiles, effects of jamming on flow distribution among delta channels, and a comparison to findings in "normal rivers" [as opposed to delta channels; for brevity, the word "rivers" will, in the following text, imply normal rivers]. Jamming potential in channels of different sizes is then explored, based on ice block submergence criteria. This is followed by a discussion of various aspects of the results and a concluding summary section.

2. Background information

Breakup in the delta usually starts in the second half of May and ends in the first half of June. It is generally driven by the rising flows of the Mackenzie and Peel Rivers (Fig. 1). The Peel and west-side tributaries rise earlier, and thus breakup develops more rapidly in the southwestern sector of the delta. However, the breakup in the central and eastern sectors is driven by the much larger flow of the Mackenzie (e.g. Terroux et al., 1981).

Ice jams often form in Middle Channel between the entrance to the delta at Point Separation and Horseshoe Bend (Bigras, 1988), diverting backwater and Mackenzie River ice into the Aklavik and Peel Channels (Fig. 1; see also review and extensive bibliography in Goulding, 2008). The community of Aklavik has a history of ice-related flooding, most recently during the 2006 breakup, one of the most dynamic breakup events on record.

Relative to rivers, the Mackenzie Delta channels have very mild slopes (~0.02 m/km or less in late summer — based on data provided by Hill et al., 2001), which translates to low water speeds and hydrodynamic forces. Coupled with the relatively large ice thickness, this feature is conducive to thermal breakup, unless the hydrodynamic forces are amplified by "javes", short for waves generated by releases of upstream ice jams. This pattern has been identified and quantified in the Peace–Athabasca Delta, another major freshwater delta of northern Canada that is also a part of the Mackenzie River basin (Beltaos, 2007; Beltaos and Carter, 2009).

The lack of quantitative measurements and data on delta ice jams is exacerbated by recently-detected uncertainties in estimates of

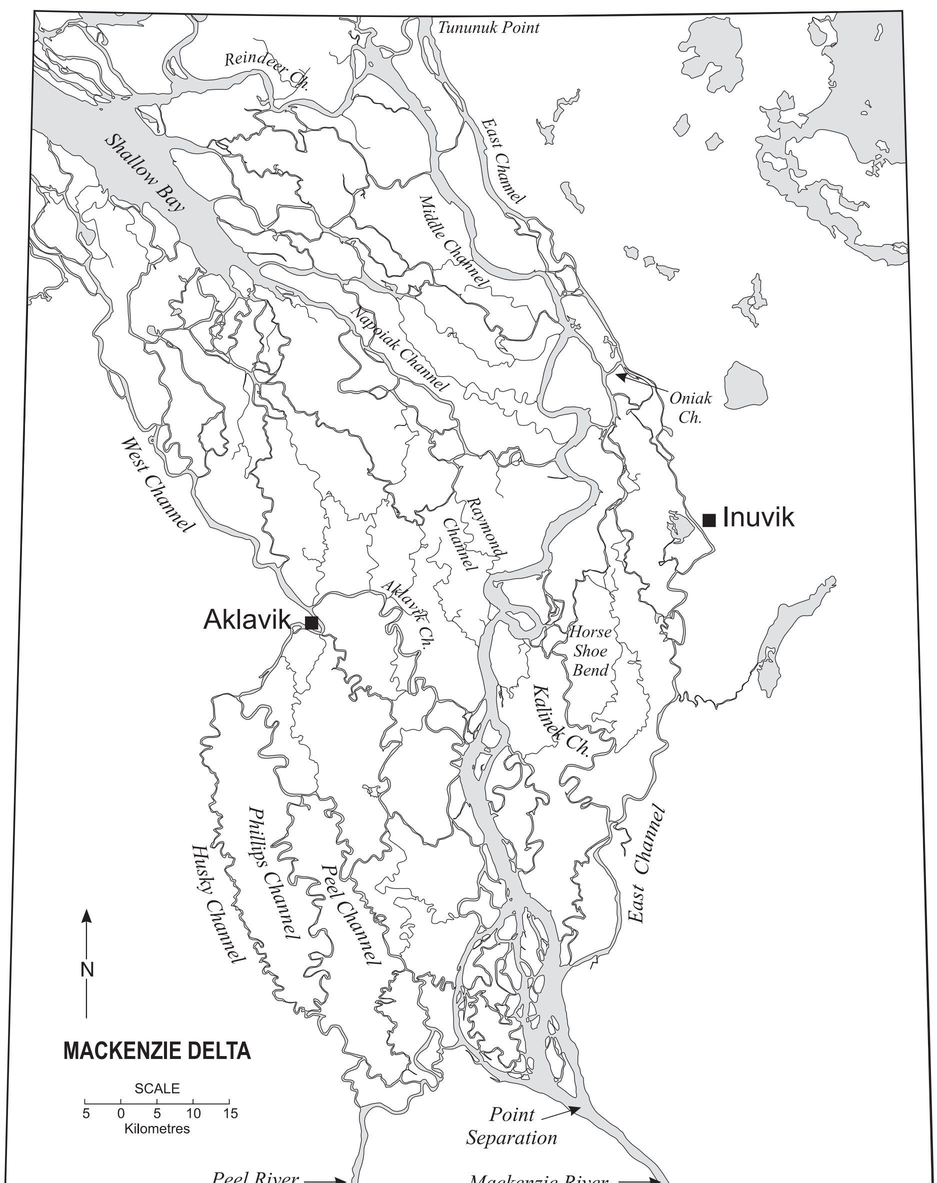

Fig. 1. Plan view of Mackenzie River Delta and of main delta channels. The multi-branch reach of Middle Channel within the first 30 km below Point Separation is herein denoted as the "Turtle".