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Editorial: Advances in monitoring and modelling of river ice processes

Significant advances in field monitoring, laboratory experiments and computational modelling of river ice processes have been made in the past few decades. Different ice processes, such as frazil ice evolution, ice-cover formation, ice-cover break-up and ice jamming, have been studied, as well as linkages of ice regime with water quality and sediment transport. There has also been extensive research on understanding hydro-climatic drivers and controls of river ice processes along with assessments of climatic effects on river ice hydrology. Recent studies have focused on evaluating the impact of future climate on more complex ice processes, such as ice jamming and ice-jam flooding. These efforts have not only improved process understanding but have also led to innovations in tools, methods and models. This Special Issue acknowledges these recent advances and highlights some of the novel contributions.

The major advance is reported in the modelling of the complex break-up process and subsequent ice jams and ice-jam floods. Moving away from the traditional approach of deterministic hydraulic river ice modelling, recent studies have incorporated a stochastic approach to capture the uncertainty related to different input datasets and generate probabilistic outputs. Lindenschmidt (2023) presents an extension and refinement to one such stochastic ice-jam flood modelling framework, which includes establishing a dependency between the volume of ice accumulating in ice jams and upstream discharge, constraining ice-jam toe locations to ice-jam prone areas and including historical data in the frequency analyses for improved ice-jam flood modelling. The utility of these advances was demonstrated by modelling an ice-jam flood event of 2020 that occurred at the town of Fort McMurray along the Athabasca River in western Canada. Das *et al.* (2023) use the same stochastic modelling framework for forecasting mid-winter break-up. With recent changes in climatic patterns, modelling mid-winter break-up has been identified as one of the major challenges in the coming years. While forecasting of spring break-up events has been reported in the past, predicting the severity of mid-winter break-up is a new advancement. For this work, the authors loosely coupled a land-surface hydrology model with a hydraulic model and applied the framework to the Saint John River, a transboundary river shared by Canada and the United States. Their results show that mid-winter break-up severity can be successfully simulated, paving a way for developing a real-time operational model, a much-needed tool in managing ice-jam flood risk in cold-region environments.

Similar modelling advances are reported by Ladouceur *et al.* (2023). They present a comprehensive method to estimate ice-jam-induced flood water levels. The authors employ a stochastic modelling approach, where they performed thousands of HEC-RAS simulations within a Monte-Carlo framework to generate an ensemble of backwater-level profiles. This assessment was aided by a global sensitivity analysis which helped to determine ice-jam parameters that are most sensitive to simulated backwater levels. The authors were able to demonstrate why certain ice-jam-prone locations have much higher 1:100 Annual Exceedance Probability (AEP) water levels compared to open-water scenarios owing to geomorphological and hydrological factors. In another modelling study, Xu *et al.* (2023) apply a numeric model to study different emergency measures that could help reduce ice-jam flood risk in a large water diversion project in China. From the evaluation of different management options, including gate group scheduling, electric heating and de-icing, the authors were able to identify an emergency intervention mode that could increase efficiency and result in safer water transfers during the ice period. The findings of this study have an important operational utility for the South-to-North Water Diversion Project in China and elsewhere in the world.

The second group of manuscripts submitted to this special issue investigates complex ice-cover break-up and ice-jam events. Ghobrial *et al.* (2023) carried out an extensive field campaign during the 2018–2019 and 2019–2020 winter seasons to quantify the spatio-temporal characteristics of the break-up processes along the Chaudière River in Quebec province in Canada. Their results show that the break-up process is highly dynamic and very localized. The authors were able to document 51 local ice jams from their field campaign. The findings of this study, including insights on break-up patterns, hydro-meteorological thresholds for ice mobilization and identification of ice-jam-prone locations, will pave a way for developing an ice-jam flood warning system. Duguay *et al.* (2023) take advantage of recent developments in aerial photogrammetry to document a 2.05 km long ice-jam event that had formed on the Aux Saumons River in southern Quebec in February of 2022. Their findings show that information on ice-jam conditions and its formation process can be accurately generated by using remotely piloted aircraft photogrammetry. The authors were also able to extract continuous longitudinal elevation profiles of the ice-jam's surface, allowing a numerical model's simulated ice profile to be validated. This study provides compelling evidence that remotely piloted aircraft photogrammetry could be a reliable source of information to supplement traditional in-situ measurements that can aid in development, calibration and validation of river ice-jam models.

The final paper of this special issue reviews the impact of future climate on frazil ice events. Frazil ice is an important phase of ice-cover formation but also poses a significant challenge for shoreline infrastructure and may also promote freeze-up jams. Barrette & Lindenschmidt (2023) provide an overview on frazil ice generation processes and their dynamics. Previous modelling endeavours that aimed at predicting frazil ice generation in rivers are summarized, and both short-term and long-term assessments of frazil ice events are discussed. This review suggests that winter break-up will likely be more frequent in the future, which implies that clogging risks at water intakes from frazil ice generation could extend well into the winter months. However, the authors note that a careful prediction of such events will require climate model output to adequately capture month-to-month variability.

We are grateful to the Editorial team for the opportunity to organize this special issue. Our much appreciation goes to all the reviewers for their time, effort and constructive comments, without which this special issue would not have been possible. We are also thankful to all the authors for opting to submit their valuable research to this special issue. We sincerely hope that the rejection of any submitted manuscript will not discourage the authors from carrying out research in this exciting field and submitting the results to this journal.

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