Detecting trends and geospatial patterns of river ice navigability with remote sensing

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Introduction

Many people living at high latitudes rely on ice-covered rivers for winter travel and access to subsistence resources. Climate-driven changes in ice regimes, such as shorter ice duration, persistent open water, and thinner ice, present new challenges and risks to river users.

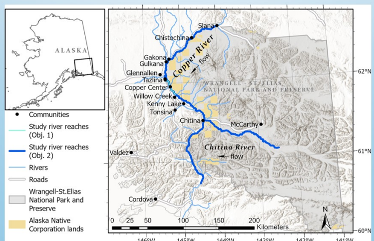
This study focused on the Copper River basin of southcentral Alaska, an area where residents have expressed concern about major changes in river ice. We used satellite remote sensing (optical and synthetic aperture radar, SAR), validated with community observations, to achieve two main objectives:

(1) to document the historic changes in local river ice phenology (i.e., seasonality);

(2) to characterize the geospatial patterns and drivers of open water hazards along rivers.

Our goals were to understand how river ice navigability has changed and to foster safe access to traditional lands and resources.

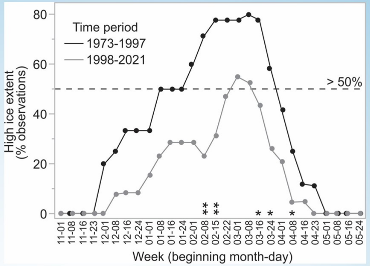
Data, map products, and code from this project are freely available (Brown et al 2023), and a manuscript is currently in press.

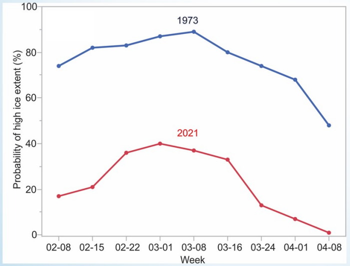


Obj. 1: Changes in river ice phenology

We determined ice extent of a 30-km reach of the Copper River by date through visual interpretation of Landsat images from water years (WY) 1973-2021 . 'High ice extent' was defined as < 25% of the length of the river reach affected by water, and indicates widespread opportunities for ice travel and river crossing.

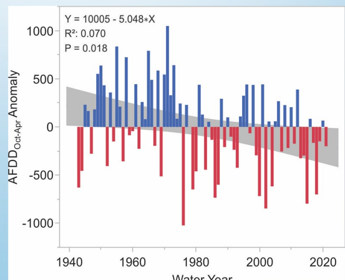
A lower proportion of high ice extents occurred in WY 1998-2021 than WY 1973-1997 for the full freeze-up through break-up cycle. Years without the development of an extensive ice cover have become more common.





The probability of weekly high ice extent occurrence from late winter through spring declined by an average of 53.3 (± 6.6) percentage points between WY 1973 and 2021.

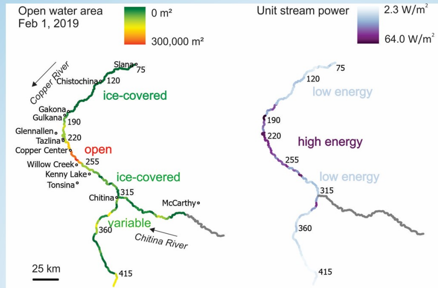
Ice extent was related to local accumulated freezing degree days (AFDD). Seasonal AFDD (October – April) have declined by 15% since the 1940s, indicating a long-term winter warming trend that has affected ice extent and navigability.



Obj. 2: Geospatial patterns of river ice cover

We estimated reach-level (5-km) open water area by digitizing Sentinel-2 multispectral imagery at late-winter anniversary dates, and compared these with hydrologic and geomorphic characteristics of the Copper and Chitina rivers.

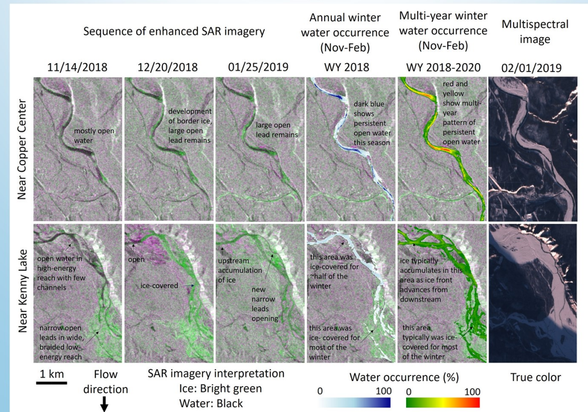
Stream flow energy and river morphology affected the development of the ice cover and navigability. Hazardous areas with large open water leads occurred in high energy and single-channeled reaches, whereas predominantly ice-covered areas occurred in low energy and braided reaches.



$$\omega = \frac{\rho g Q S}{b}$$

ω: unit stream power (W/m2)
ρ: density of water (1000 kg/m3)
g: acceleration from gravity (9.8 m/s2)
Q: discharge (m3/s)
S: channel slope (m/m)
b: channel width (m)

We enhanced Sentinel-1 SAR imagery (by combining autumn and winter scenes) and mapped water occurrence throughout winter (by compositing threshold-based water classifications) to examine the progression of freeze-up. Below are examples from a high-energy reach near Copper Center that tends to remain open through much of winter, and near Kenny Lake, where ice develops in low-energy braided reaches and then accumulates upstream. Distance from downstream jamming points influences the timing of freeze-up.



Conclusions

This study suggests a striking decline in the duration of the season for river ice travel on the Copper River due to increased air temperatures, including delayed or incomplete freeze-up and early break-up. This finding echoes the experiences of local residents who can no longer predictably access land across the river from their communities (Miller 2023). With projected increases in air temperature, precipitation, and river discharge over the next century (Valentin et al. 2018), we expect the duration of river ice cover to continue to decline.

Our study also showed reach-level variation in freeze-up and open water occurrence, patterns that appear to be driven by flow energy, channel form, and the bi-directional effects of ice flow and accumulation. We identified potential winter river crossing areas and areas prone to open water hazards to support travel safety and access.

We are currently developing automated methods of detecting trends in ice phenology with Landsat imagery to characterize the regional variation in changing ice seasonality throughout the state of Alaska.

Acknowledgements

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