Climatology and potential predictability of fast ice breakoff events in Admiralty Inlet, Nunavut

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Introduction and Motivation

The community of Ikpiarjuk (Arctic Bay) in Nunavut relies on immobile landfast sea ice in Admiralty Inlet for travel north to the floe edge where the landfast ice meets the open ocean [1,2]. Over the last few decades there have been incidents where people have become stranded on sea ice floes that have broken-off of landfast ice (aka. breakoff events) and local hunters are observing a spring sea ice cover that is increasingly more unpredictable and dangerous for travel [2,3]. The ability to anticipate these events is critical for safe travel on the ice. This study seeks to determine how breakoff is changing over time using satellite imagery and to determine the association between breakoff events and environmental variables, with the goal of creating predictive tools for local ice users.

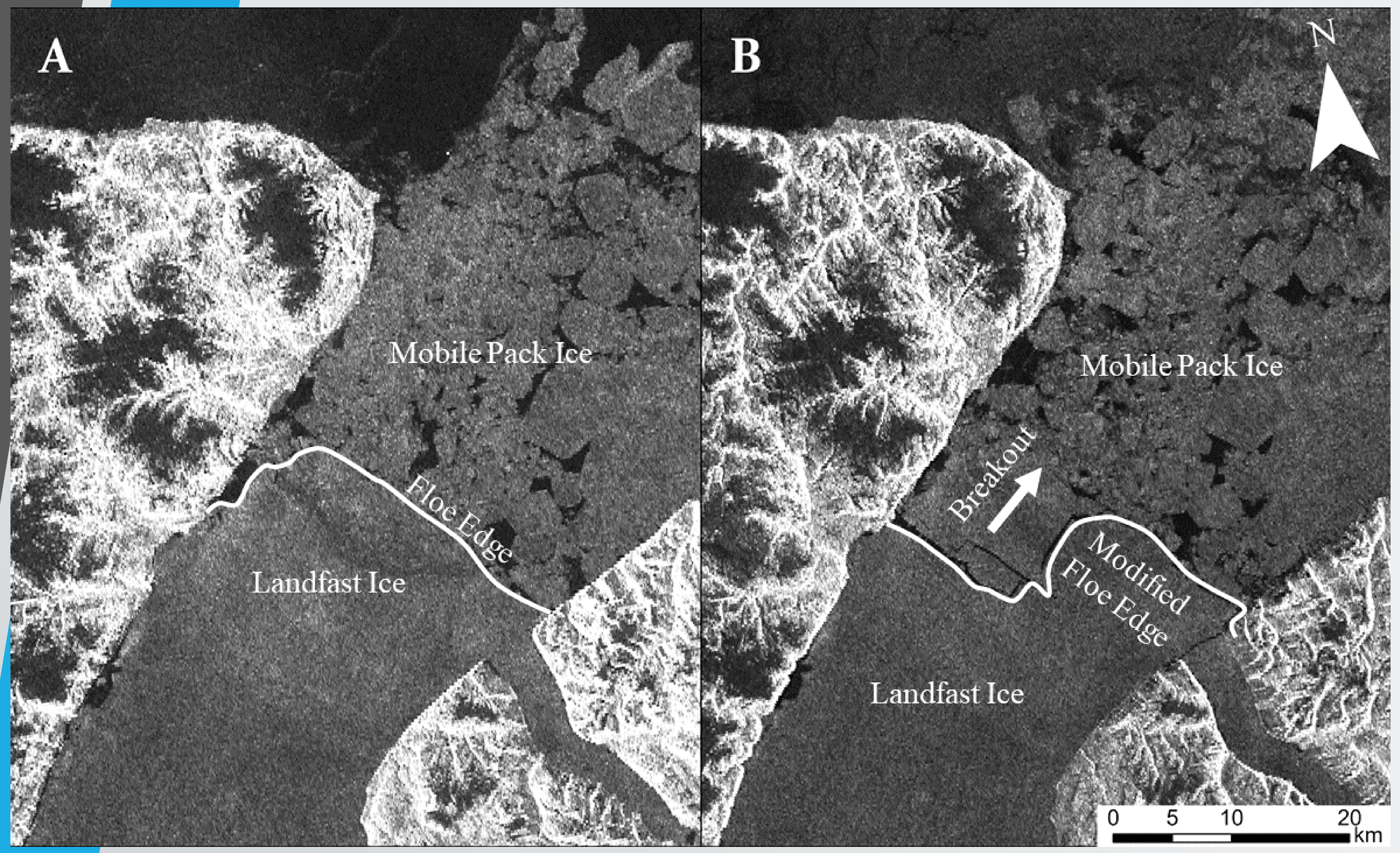

Figure 1. Breakoff event in Admiralty Inlet, captured by RADARSAT-2 images in July of 2013. Pre-breakoff imagery on July 7, 2013 (A) and post-breakoff imagery on July 8, 2013 (B). The broken-off ice floe along the western floe edge joins the mobile ice floes that occupy the northern end of Admiralty Inlet. RADARSAT-2 Data and Products © MDA Geospatial Services Inc. (2021) – All Rights Reserved. RADARSAT is an official mark of the Canadian Space Agency.

Methods

Satellite Imagery Analysis

A climatology of breakoff events (BOE) from 2000 to 2020 was generated from RADARSAT-1/-2 and MODIS imagery.

- Two images taken 24 hours apart were compared (Figure 1A and 1B),
- If a BOE occurred, the floe edge receded southward (Figures 1 and 3),
- Size and location along the floe edge of BOEs were also recorded.

Relational Statistics

A binary BOE variable was produced from the climatology and compared to 21-day leads and averages calculated from 105 environmental variables from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis data set. 21-day leads are produced by shifting observations from previous days forward, and averages are produced by averaging previous days' observations.

- The point-biserial (PB) correlation coefficient was calculated to measure the strength of association between the BOE variable and each ERA5 variable,
- PB correlations with p-values <0.10 were considered significant after accounting for temporal autocorrelation,
- A Pearson correlation matrix was used to identify multicollinearity between significant variables,
- Non-collinear, significant environmental variables were implemented as predictors in logistic regression models to predict the timing of BOEs.

Climatology

A total of 122 BEOs were identified from 2000 to 2020. The number of BOEs varies from 2 to 10 per year and sizes range from 7 to 1463 km^2. The number of BOEs increased over the study period and are also occurring earlier in the season.

- In the early 2000s, the first BOE did not occur until early to mid-June, but by the late 2010s they occurred as early as mid-April (Figure 2),
- The average number of BOEs that occur each year increased from 5 to 10,
- Onset of the complete mobilization of the sea ice (defined here a general breakup) has advanced by 4.6 days per decade (Figure 2),
- BOEs occurred most frequently on at the eastern end of the floe edge.

These results mirror observations of local ice users who have stated that sea ice is becoming more unpredictable and hazardous to travel on during the spring season [1,2].

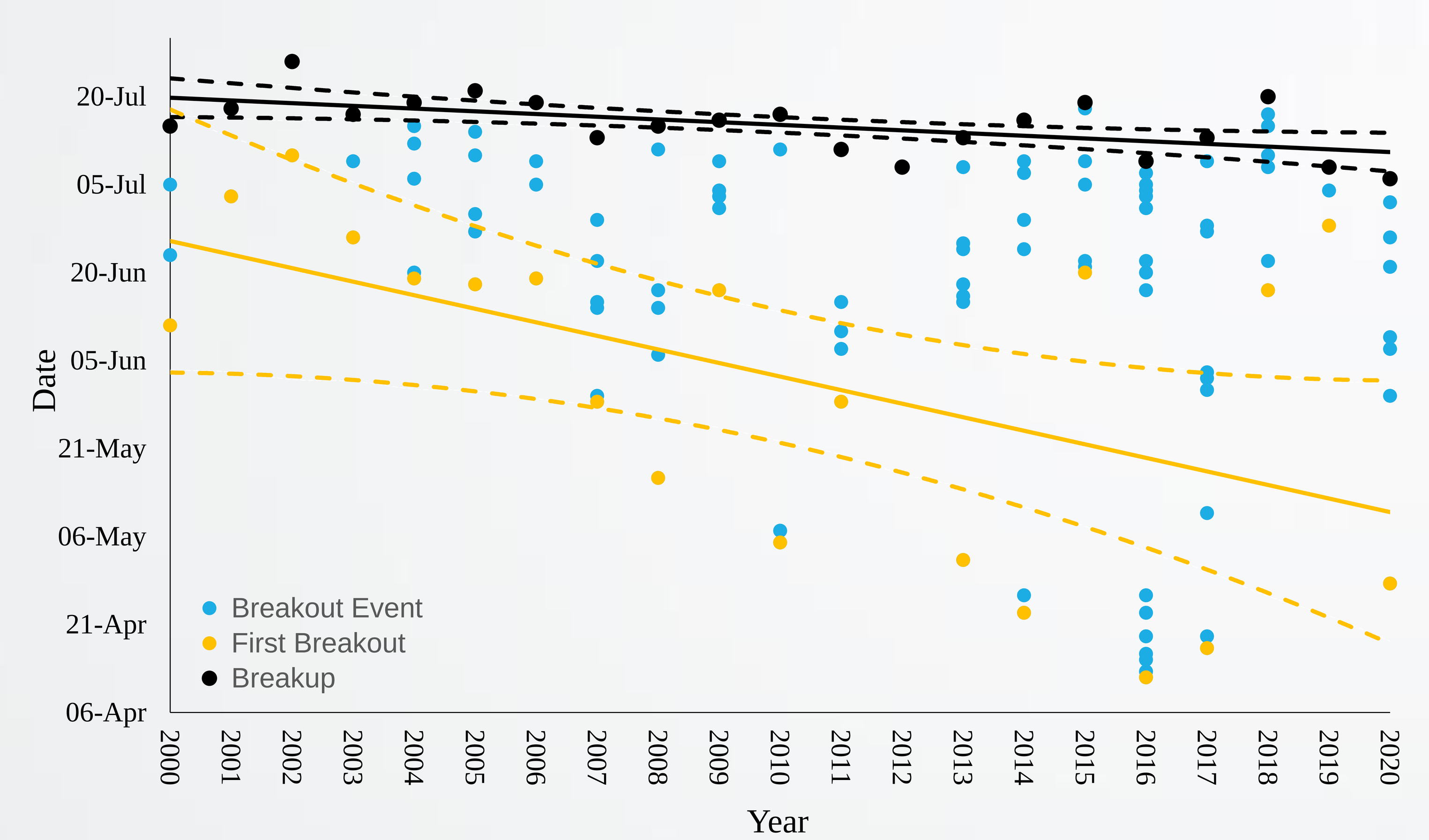

Figure 2. Timing of breakoff events identified in satellite imagery. Linear trends of the onset of breakup (black line) and the first breakoff event (orange line) each year are also plotted with their respective 95% confidence intervals (dashed lines). The linear trend for the first breakoff event indicates an earlier occurrence of ~23 days per decade (R^2 = 0.25, p = 0.02). The linear trend for the onset of breakup indicates an earlier occurrence of ~4.6 days per decade (R^2 = 0.34, p = 0.004).

Significant Environmental Variables

The statistical relationships between breakoff events and many environmental variables (e.g., winds, snowfall, rainfall, heat fluxes, and radiation fluxes), are weak (<|0.12|) but significant.

1 to 7 days ahead of a BOE, offshore winds are positively correlated with BOEs,

- Strong winds may push floes away from the landfast ice and away from the shore, ungrounding the floes,
- Strong winds may result from synoptic low-pressure systems (i.e., storms) [4], associated with low downwelling solar radiation and high downwelling thermal radiation (due to cloud cover) [5], low air pressure and high precipitation.

7 to 18 days ahead of a BOE, rainfall is positively correlated with BOEs,

- Precipitation falling as rain can transfer heat to the sea ice, enhancing melting [6].
- Rainfall occurs under cloud cover, associated with low downwelling solar radiation and high downwelling thermal radiation.

>18 days ahead of a BOE, snowfall is negatively correlated with BOEs,

- Precipitation falling as snowfall insulates the ice from warm air, inhibiting the exchange of heat and the thermal decay of the landfast ice [6,7].
- The snowfall is precluded by the absence of cloud cover, associated with high downwelling solar radiation and low downwelling thermal radiation.

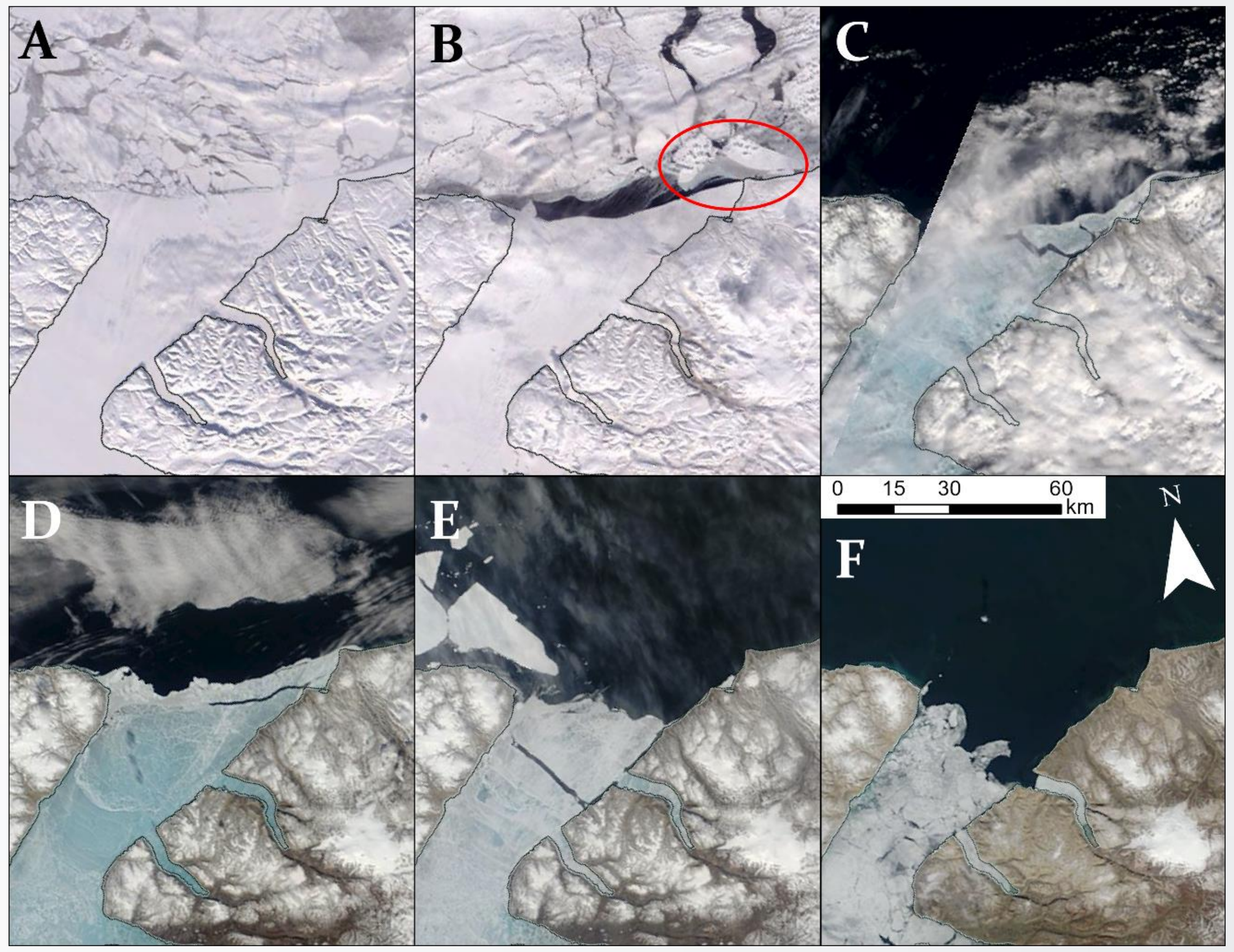

Figure 3. MODIS imagery of the 2013 spring season landfast ice deterioration in Admiralty Inlet. (A) April 1st: ice in Lancaster Sound is completely mobile (fully mobilized in mid-March) but the northern floe edge is stable, so no breakoff events had occurred yet (i.e., pre-breakoff season). (B) May 2nd: the first breakoff event of the year, marking the beginning of the breakoff season. The northern floe edge is recessed compared to image A, and the ice floe that broke out can be seen to the east of the mouth of the inlet (circled in red). (C) June 15th and (D) June 18th: two breakoff events contributing to the gradual recession of the northern floe edge. Flaw leads are observable as a darker strip of open water between the remaining landfast ice and the escaping mobile floe. (E) June 24th: a "plug failure" that stranded hunters and tourists (Learn, 2016). (F) July 18th: ice in the inlet is fully mobile, complete breakup occurred on July 13th but was partially obscured by cloud in the MODIS imagery. We acknowledge the use of imagery from the NASA Worldview application (https://worldview.earthdata.nasa.gov), part of the NASA Earth Observing System Data and Information System (EOSDIS).

Prediction Potential

Logistic regression models had better skill than random chance in predicting the timing of BOEs, but the skill of the models was not high enough for operational implementation. The environmental variables used in this thesis are not ideal for use in predictive modelling because they are generated by a reanalysis model, rather than from in situ observations. A lack of in situ observations in the Arctic limits the accuracy of reanalysis data for modelling local processes [8]. A long-term record of local on-ice observations is expected to improve predictive skill. Observations should include:

- Weather stations equipped with anemometers, radiation and precipitation sensors,
- Ice sensors for thickness, snow depth, and ice temperature profiles,
- Ocean buoys or moorings to measure currents and tides.

Additionally, the launch of the RADARSAT Constellation Mission in 2019 now provides imaging of the Arctic up to four times each day [9]. This frequency of images will contribute significantly to improving observations of breakoff events in the inlet.

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