Characterizing Deformation and Ridging in Shorefast Ice using Remote Sensing Techniques

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Abstract

Sea ice ridges are an important morphological feature that stabilize shorefast ice across the Northern Alaskan coastline. This stability is important to local communities and ecosystems that rely on this habitat for food security and safety. Investigating the development of shorefast ice around Utqiagvik, AK, we describe an approach to identify grounded ridges throughout the winter season. To do this, we utilize high resolution altimetry data from NASA's ICESat-2 satellite which provides unprecedented along-track detail that allows, for the first time, the detection of individual pressure ridges. We apply the University of Maryland Ridge Detection Algorithm (Duncan and Farrell, 2022) using ICESat-2 elevation data to identify and calculate ridge sail heights along each satellite track. From these heights, we estimate the depth of the ridge using sail/keel height ratios described in the literature. The calculated ridge depths are compared with high-resolution bathymetric data (NCEI Digital Elevation Model Mosaic) to classify potentially grounded ridges. This methodology for identifying and quantifying grounded ridges in shorefast ice will improve our understanding of coastal ice processes in a changing environment.

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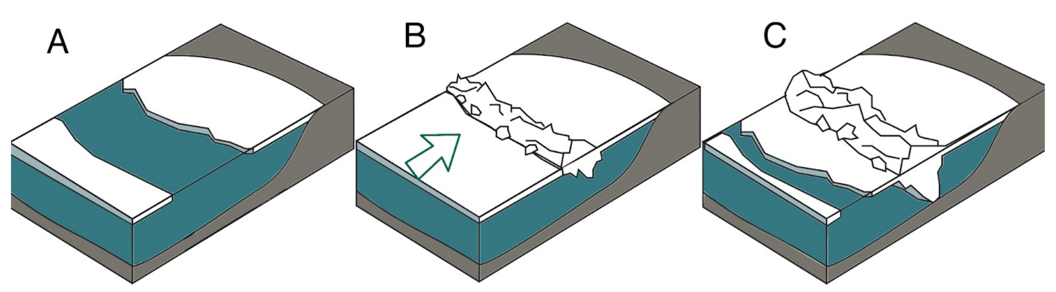
Introduction

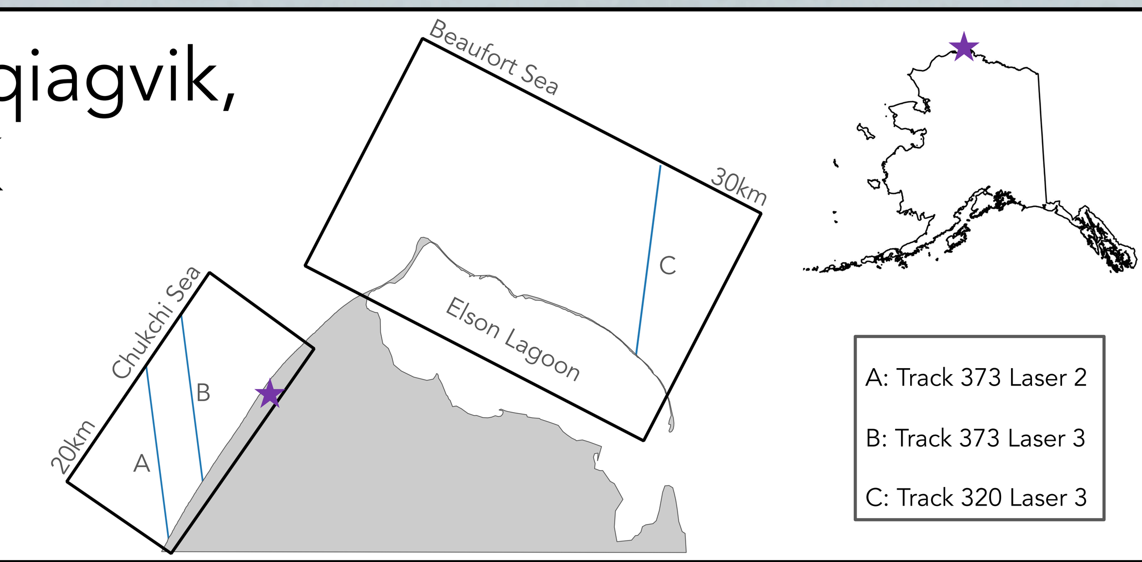


Wind, ocean currents, and other forces cause drift ice in the Arctic ocean to collide with shore ice to form sea ice ridges (B). These ridges become grounded when the keel (the portion of the ridge under the water) extends deep enough to anchor the ice in the seafloor. This process forms stable shorefast ice between the grounded ridge and the shoreline (C).

Why are Grounded Ridges Important?

- Stabilize shorefast ice for transportation
- Food security for local communities
- Habitat and hunting ground for Arctic mammals
- Protect coastline from wave-driven erosion and winter storms

Utqiagvik, AK



Data

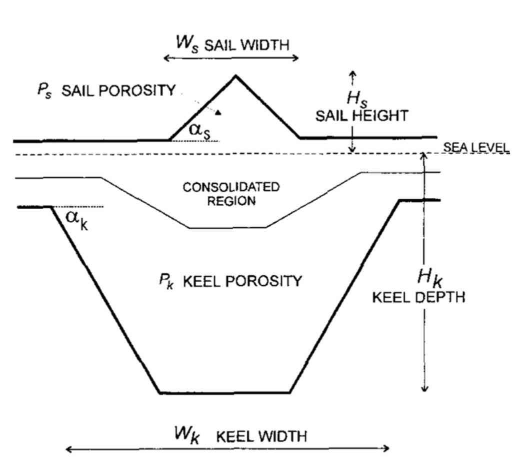
ICESat-2: We utilize altimetry data from NASA's ICESat-2 satellite which provides unprecedented along-track resolution and enables the detection of individual pressure ridges. We apply the University of Maryland Ridge Detection Algorithm (Duncan and Farrell, 2022) using ICESat-2 photon data to identify and calculate ridge sail heights along each satellite track (heights greater than 0.6m are considered ridges).

Bathymetry: We use the Digital Elevation Model Global Mosaic data product with a resolution of 10m to extract depth data along ICESat-2 tracks.

Sentinel-1: We use Synthetic Aperture Radar (Ground Range Detected) data from Sentinel-1 to investigate changes in ice between the ICESat-2 tracks.

Ridge Morphology

We use a dataset of previously surveyed ridges in the Beaufort, Chukchi, and Bering Seas to estimate the relationship between sail height(H_s) and keel depth(H_k) (Strub-Klein and Sudom, 2012; figure 1). With the heights retrieved from the ICESat-2 tracks, we can use relationships based on ridge dimension statistics to estimate how deep each feature extends below the surface.



Components of a first-year ridge (Timco and Burden, 1997)

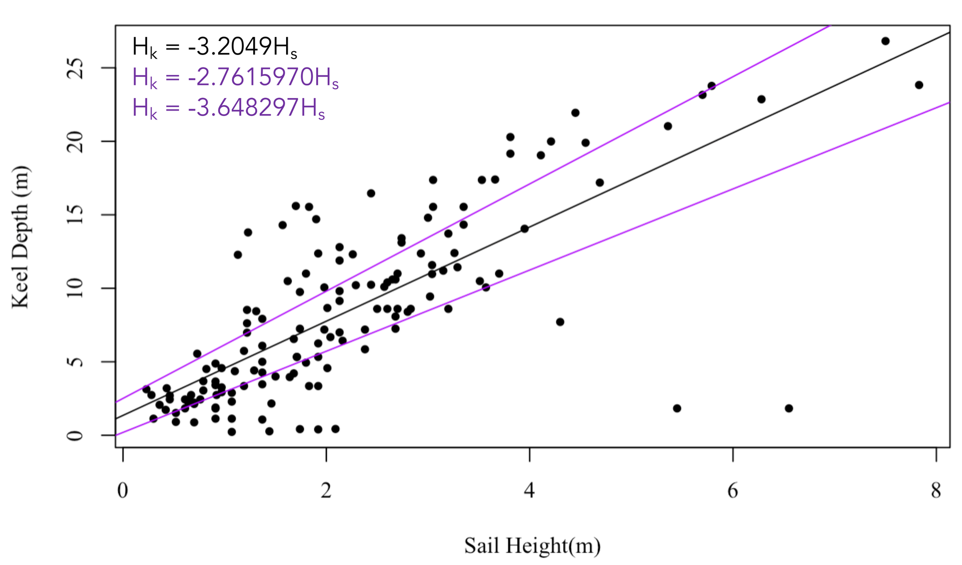


Figure 1: A comparison of sail heights and keel depths for surveyed ridges in the Chukchi, Beaufort, and Bering Seas, including the 95% confidence interval of the ratio

Preliminary Conclusions

- We identified grounded ridges from individual ICESat-2 tracks, and confirmed them using repeat tracks and SAR imagery
- SAR imagery provides higher time resolution, allowing us to identify when these ridges formed and how long they persist

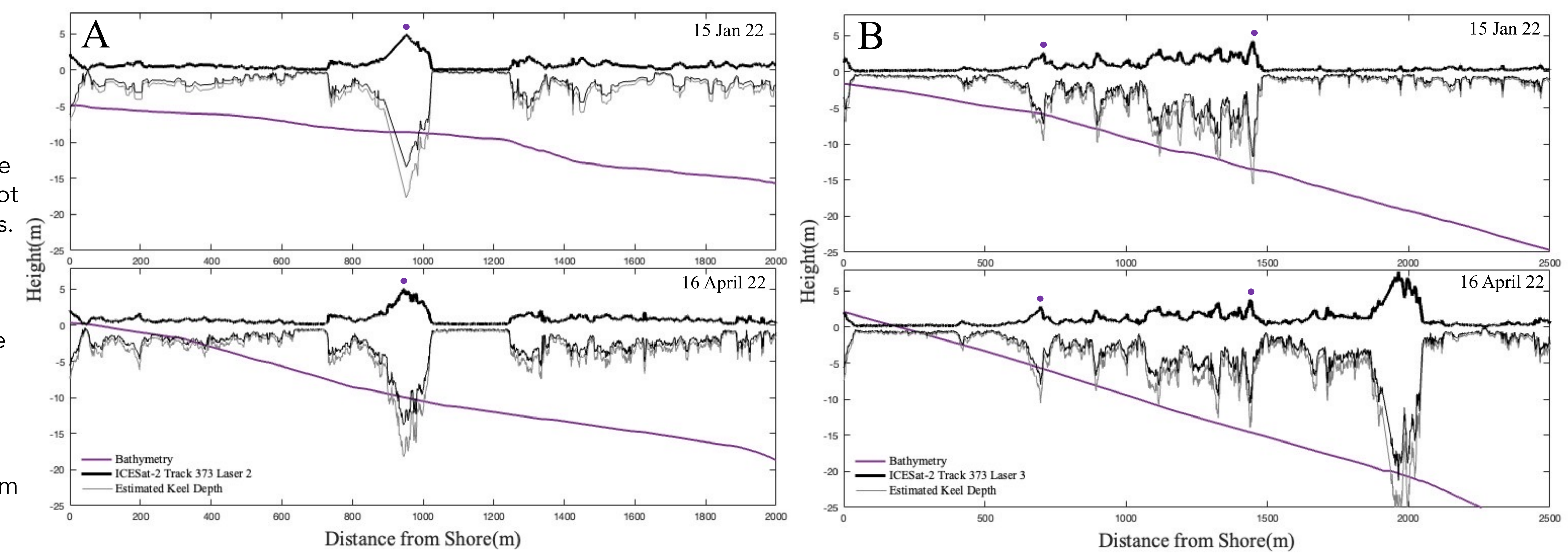
Next Steps

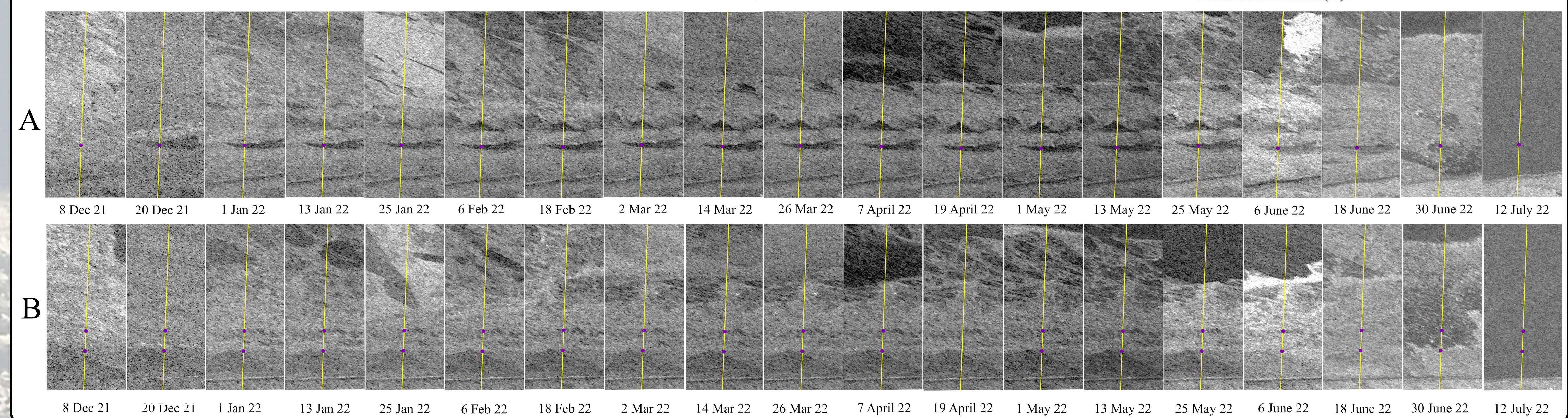
- Use interferometric SAR products to analyze height profiles from phase data
- Compare results with local radar data
- What climatic factors influence the date of grounding, and how does this change across different years?

Duncan, K., & Farrell, S. L. (2022). Determining variability in Arctic sea ice pressure ridge topography with ICESat-2. Geophysical Research Letters, 49, e2022GL100272
NOAA National Centers for Environmental Information (2023), Digital Elevation Model Global Mosaic 10m resolution [Dataset]. Bathymetric Data Viewer Gridded Extract.
Earth Data ASF Data Search Vertex (2023), Sentinel-1 [Dataset], Ground Range Detected

Chukchi Sea Results

To the right are ICESat-2 surface heights and corresponding estimated keel depths for two repeat tracks during the 2022 winter. These depths are based only on the max sail height: keel depth ratio and do not factor for freeboard buoyancy assumptions. Based on the bathymetric data, we find a series of roughly 5 ridges that are deep enough to be grounded and persist between January and April in track A while only one meets the grounding threshold and persists in track B. Below, corresponding SAR imagery (ridges noted in purple on the yellow ICESat-2 track) show persistent features in the ice that form early in December and break-up in June.





Beaufort Sea Results

This figure uses the same methods as deployed on the Chukchi tracks with differences in the local bathymetry and ice dynamics apparent: shallower sea floor extends farther from shore, and different prevailing currents and wind patterns relative to shore. We find many persistent ridges between these two repeat tracks, including a potentially grounded feature around 4km distance from shore. We see several persistent features in SAR imagery from January through June.