Characterization of Sticky Spots in Rutford Ice Stream, West Antarctica with High-Granularity Microseismicity

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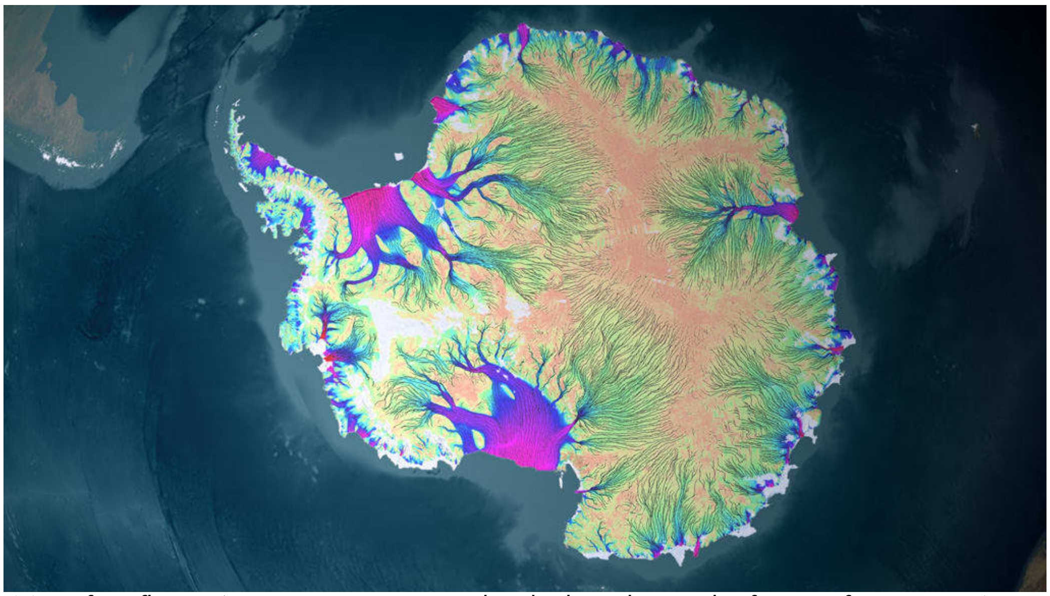
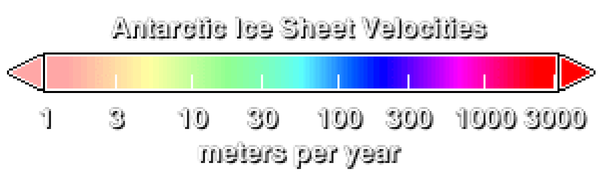
THE PROBLEM

- The Antarctic Ice Sheet contains a massive amount of ice and is losing it at an increasing rate.
- Most of this ice is discharged via ice streams.
- Ice stream velocity is strongly controlled by the glacier bed, which we lack detailed information on.
- Basal sliding is a critical component in ice-flow models.



Map of ice flow in Antarctica, representing hundreds to thousands of years of ice motion. Note that the slower ice flow velocities have been scaled up to make them more visible, and help show how majority of the ice is transported from the interior of the continent to the ocean by ice streams. Image credits: NASA/Goddard Space Flight Center Scientific Visualization Studio (image released 2011, updated 2023).



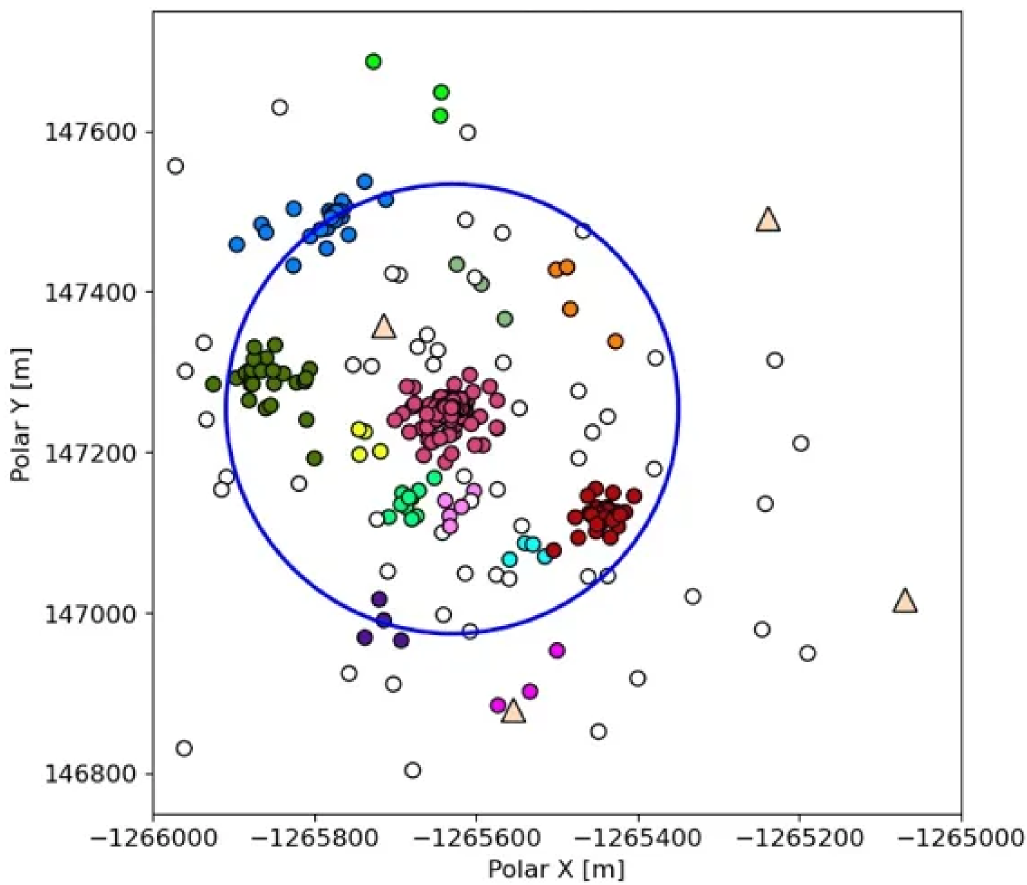
CRYOSEISMOLOGY @ RUTFORD ICE STREAM (AUSTRAL SUMMER 18/19)

- Icequakes are generated by the glacier sliding over its bed.
- Icequakes offer a high-volume, data-rich method to investigate the bed.
- Focus on regions of high basal drag or "sticky spots" that contain bountiful icequakes.
- Icequake occurrences help inform bed properties and processes.

Location of Rutford Ice Stream, which flows into the Ronne Ice Shelf and drains a significant portion of the West Antarctic Ice Sheet.

FINDING STICKY SPOTS

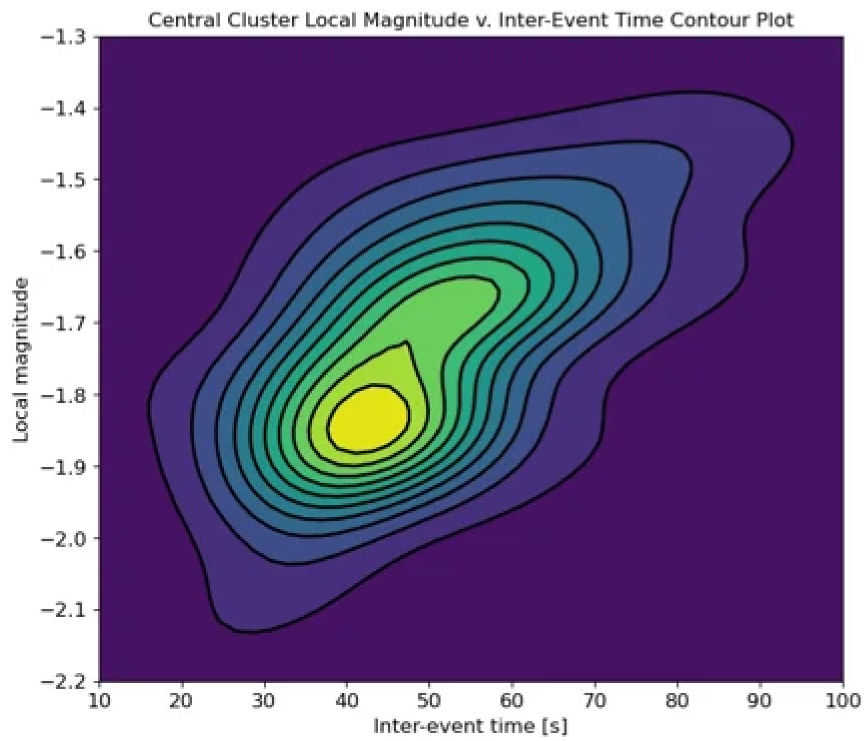
- Processed seismic data using QuakeMigrate, GrowClust, DBSCAN, and HDBSCAN.
- Large sticky spots can generate 1,000+ highly repeating icequakes a day.
- Icequakes originating from the same sticky spot have similar waveforms.
- Icequakes surrounding the larger sticky spots could be smaller sticky spots or icequakes triggered by icequake activity from the main sticky spot.



A small subset of icequakes at the Rutford grounding line seismic array, relocated using GrowClust. The large central icequake cluster/sticky spot (in dark pink) is surrounded by several smaller icequake clusters. Triangles are seismic stations while the blue circle indicates the original coverage of icequakes used in the GrowClust relocation.

RESULTS AND FUTURE WORK

- Positive slope for local magnitude vs. inter-event time is consistent with a scaling build-up/release of stress and fault-plane healing in the interseismic period.
- The slope and shape of the contour plots may provide hints about the source mechanisms of the clusters.
- Weak tidal forcing on icequakes; further investigations into relation of these icequakes to surface ice velocities are ongoing.
- Test of independence between icequakes from different sticky spots (counting statistics) and determination of icequakes relations are ongoing.



Local magnitude vs. inter-event time contour plot of the dark pink icequake cluster/sticky spot from the previous figure, with lighter colors on this plot indicating higher event density.

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TRANSCRIPT

ABSTRACT

Glacier sliding or slipping over its underlying bed is the dominant mechanism controlling the transport of massive quantities of ice from the interior of the ice sheets to the oceans, yet the sliding component remains poorly understood and poorly modeled in ice-flow models. This problem is largely attributed to the dearth of information about the bottom of glaciers due to the difficulty of acquiring data; this observational void leads to increased uncertainty in ice-flow models. As a glacier slides over its bedrock, strain is continuously built up and suddenly released, generating micro-earthquakes or icequakes – we utilized this spatially and temporally dense form of microseismicity to address the observational void and obtain detailed information about the bed. Here we use passive seismic observations to monitor the natural source seismicity near the grounding line of Rutford Ice Stream in West Antarctica, by installing a seismic array in the region to collect data for ~1 month as part of the BEAMISH project. We processed the seismic data using QuakeMigrate to detect and locate the icequakes, and used GrowClust to refine the icequake locations. Our icequake analysis focused on the characterization of sticky spots, which are localized regions of the glacier bed that support high basal shear stress surrounded by a generally low-shear stress bed. In our medium-sized 10 km x 10 km study site near the grounding line we located on average ~30,000 basal events/day. Many of the icequakes nucleate in highly repetitive clusters (i.e., sticky spots) which are indicative of stick-slip sliding, and we use the DBSCAN algorithm to find distinct clusters. We made use of the high density of icequakes within each cluster to perform even finer clustering within each cluster to investigate sub-clusters. We observed that even within a cluster not all events had similar waveforms, and this high-granularity microseismicity allows us to characterize sticky spots in unprecedented detail. We present results from this investigation and also investigate the relation of events to tides and ice surface velocity. Through the rich microseismicity we can better understand how Rutford flows over its bed, and ultimately better project global mean sea-level rise over the coming years to decades.

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