An Ice Sheet Aseismic Zone Inferred from the Absence of Icequakes in the Deep Interior of the Antarctic Ice Sheet

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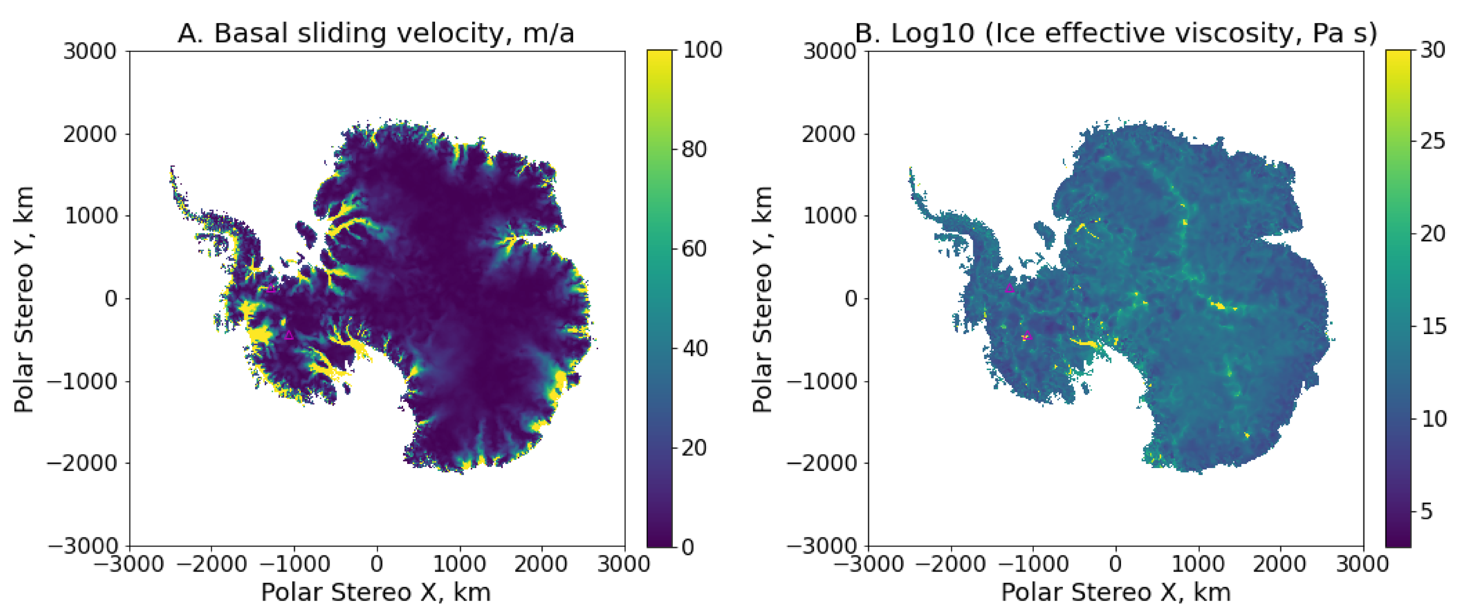
environmental geophysics and computation

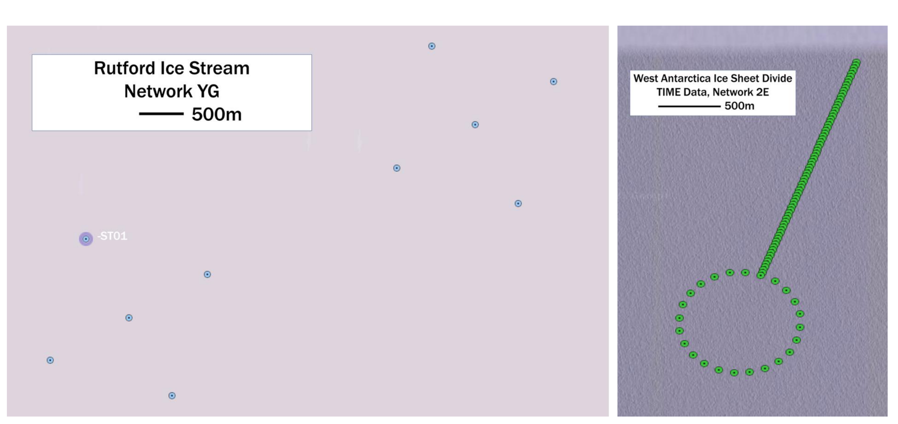
Introduction

There are two main types of ice movement: viscous flow, and basal sliding. We expect to find icequakes where basal sliding occurs due to the motion being similar to a normal fault. Here, we seek to falsify the hypothesis that basal shearing-mode icequakes indicate basal sliding. This is done by comparing passive seismic datasets from areas with and without basal sliding: the West Antarctic Ice Sheet (WAIS) Divide and the Rutford Ice Stream (RIS).



Modeled velocity and viscosity fields from the ISSM ISMIP 6 5km run. Magenta triangles mark the two field sites.

Data

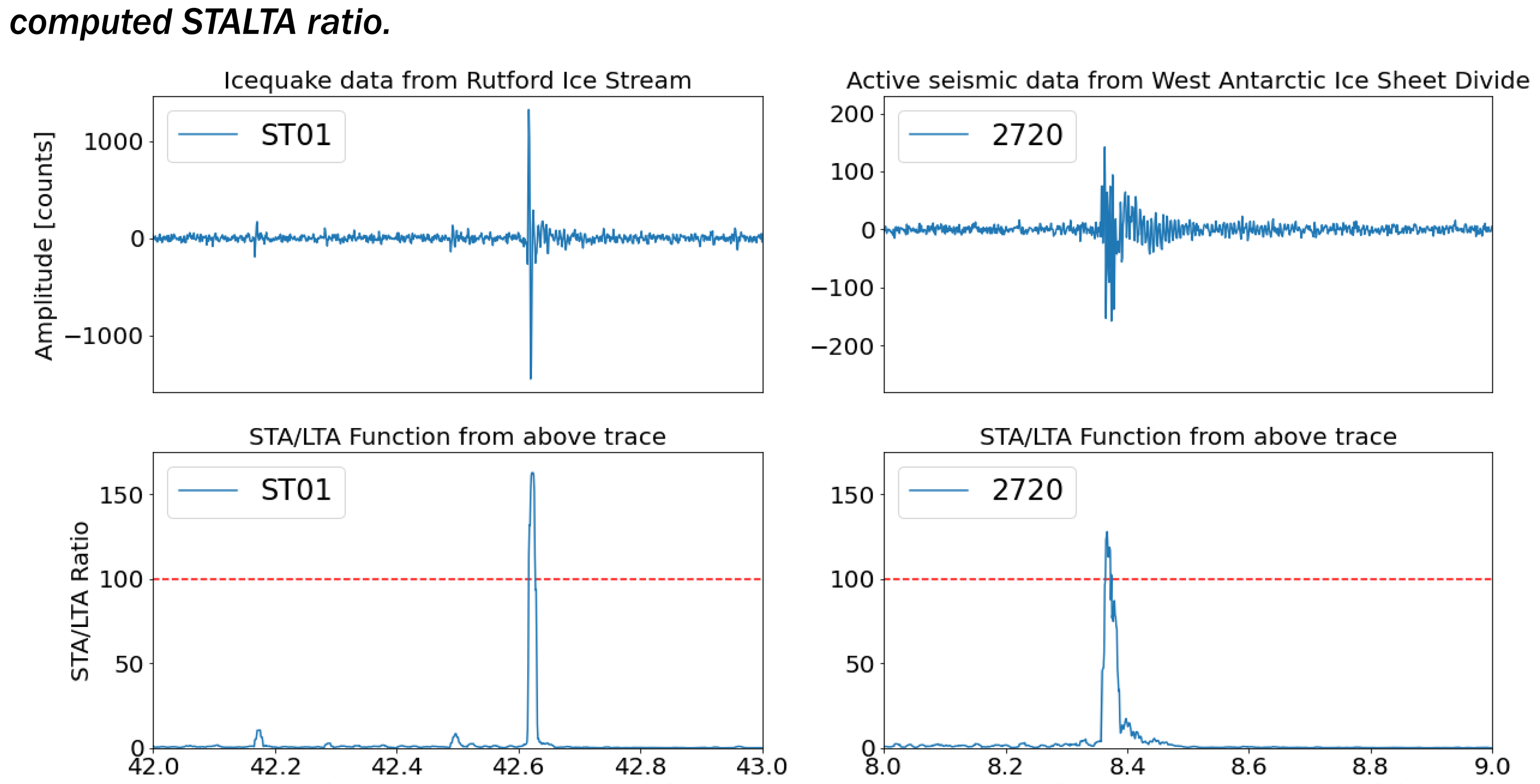


The **Rutford deployment** (left) was described by Smith et al. (2017) and consisted of 10 4.5 Hz geophones and was deployed from 2009-01-01 to 2009-02-03 with approximately 500m spacing.

The **WAIS Divide deployment** (right) consisted of 99 three–component nodes deployed from 2019-01-07 through 2019-11-15. The array had 1m and 30m station separations

Method

We detect events with the short time average-long time average method (STA/LTA), which identifies events by comparing the ratio of amplitudes between a short duration window and long duration window. We apply this method to both the RIS and WAIS divide arrays to compare seismic activity at the two sites. *Figure below: Demonstration of the STALTA detection scheme on real data. Top panel shows recorded waveform. Bottom panel shows computed STALTA ratio.*



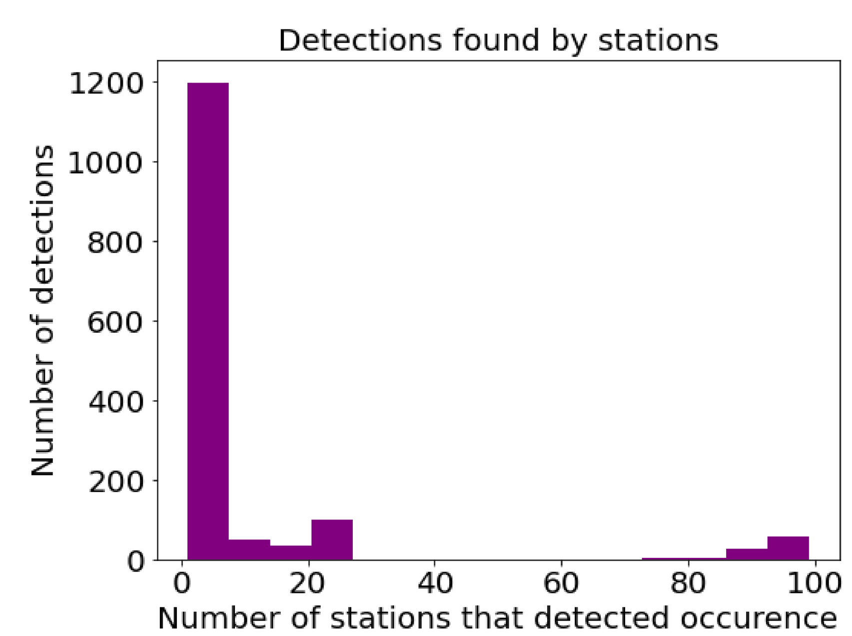
Results

Our method resulted in 194 detections at RIS and 1465 detections at the WAIS Divide.

The RIS detections have the characteristics of basal shear slip icequakes noted by Smith et al. (2017): they have mixed polarity arrivals, have clear body wave arrivals, and are extremely impulse with characteristic durations just longer than the sampling rate.

The WAIS Divide detections lack these characteristics. Specifically, most of the detections at the WAIS divide site contain mostly emergent surface waves that are not indicative of basal shear slip seismicity.

The highest quality impulsive detections at the WAIS site consisted of a series of active seismic shots (figure below, right). Of all of the detections, There were 89 occurrences that were detected by at least 60 stations that were all identified to be the deployed shots, with the remaining 2 being detected by at least 40 stations (figure below, left). This finding confirms that our STA/LTA approach is able to detect impulsive events, yet did not detect any events indicative of basal sliding.



Reported Shot Times		Recorded Shot Times		Reported Shot Times		Recorded Shot Times	
Day	Time	Day	Time	Day	Time	Day	Time
2019-01-10	23:55:00.017	2019-01-10	23:55:00.187	2019-01-13	02:09:00.017	2019-01-13	02:35:00.190
2019-01-11	00:22:00.017	2019-01-11	00:22:00.191	2019-01-13	02:35:00.017	2019-01-13	02:52:00.187
2019-01-11	00:37:00.017	2019-01-11	00:37:00.191	2019-01-13	02:52:00.017	2019-01-13	03:16:00.186
2019-01-11	00:56:00.017	2019-01-11	00:56:00.190	2019-01-13	03:16:00.017	2019-01-13	22:36:00.182
2019-01-11	01:53:00.017	2019-01-11	01:53:00.190	2019-01-13	22:36:00.017	2019-01-13	22:46:00.012
2019-01-11	02:39:00.017	2019-01-11	02:39:00.190	2019-01-13	22:46:00.017	2019-01-13	22:52:00.006
2019-01-11	02:51:00.017	2019-01-11	02:51:00.190	2019-01-13	22:52:00.017	2019-01-13	22:58:00.008
2019-01-11	03:01:00.017	2019-01-11	03:01:00.188	2019-01-13	22:58:00.017	2019-01-13	23:03:00.006
2019-01-11	03:21:00.017	2019-01-11	03:21:00.188	2019-01-13	23:03:00.017	2019-01-13	23:08:00.009
2019-01-11	03:45:00.017	2019-01-11	03:45:00.188	2019-01-13	23:08:00.017	2019-01-13	23:13:00.008
2019-01-11	03:58:00.017	2019-01-11	03:58:00.186	2019-01-13	23:13:00.017	2019-01-13	23:19:00.008
2019-01-11	04:19:00.017	2019-01-11	04:19:00.189	2019-01-13	23:19:00.017	2019-01-13	23:24:00.006
2019-01-11	04:40:00.017	2019-01-11	04:40:00.188	2019-01-13	23:24:00.017	2019-01-13	23:29:00.007
2019-01-11	05:02:00.170	2019-01-11	05:02:00.189	2019-01-13	23:29:00.017	2019-01-13	23:34:00.008
2019-01-11	05:17:00.017	2019-01-11	05:17:00.188	2019-01-13	23:34:00.017	2019-01-13	23:39:00.008
2019-01-11	05:32:00.017	2019-01-11	05:32:00.188	2019-01-13	23:39:00.017	2019-01-13	23:44:00.008
2019-01-11	05:46:00.017	2019-01-11	05:46:00.188	2019-01-13	23:44:00.017	2019-01-13	23:49:00.008
2019-01-11	06:00:00.017	2019-01-11	06:00:00.188	2019-01-13	23:49:00.017	2019-01-13	23:54:00.008
2019-01-11	06:15:00.017	2019-01-11	06:15:00.188	2019-01-14	23:54:00.017	2019-01-14	00:04:00.008
2019-01-11	06:35:00.017	2019-01-11	06:35:00.183	2019-01-14	00:04:00.017	2019-01-14	00:09:00.008
2019-01-11	06:52:00.017	2019-01-11	06:52:00.188	2019-01-14	00:09:00.017	2019-01-14	00:14:00.008
2019-01-11	07:03:00.017	2019-01-11	07:03:00.188	2019-01-14	00:14:00.017	2019-01-14	00:21:00.007
2019-01-11	07:25:00.017	2019-01-11	07:25:00.188	2019-01-14	00:21:00.017	2019-01-14	01:06:00.009
2019-01-11	07:40:00.017	2019-01-11	07:40:00.185	2019-01-14	00:56:00.017	2019-01-14	01:16:00.009
2019-01-11	08:02:00.017	2019-01-11	08:02:00.184	2019-01-14	01:06:00.017	2019-01-14	01:21:00.007
2019-01-12	08:20:00.017	2019-01-11	08:20:00.188	2019-01-14	01:16:00.017	2019-01-14	01:28:00.008
2019-01-12	00:24:00.000	2019-01-12	00:24:00.009	2019-01-14	01:21:00.017	2019-01-14	01:35:00.008
2019-01-12	00:56:00.000	2019-01-12	00:56:00.012	2019-01-14	01:28:00.000	2019-01-14	01:40:00.008
2019-01-12	01:09:00.017	2019-01-12	01:09:00.014	2019-01-14	01:35:00.000	2019-01-14	01:45:00.008
2019-01-12	01:26:00.017	2019-01-12	01:26:00.011	2019-01-14	01:40:00.017	2019-01-14	01:52:00.008
2019-01-12	03:27:00.017	2019-01-12	03:27:00.005	2019-01-14	01:45:00.017	2019-01-14	01:58:00.008
2019-01-12	03:39:00.017	2019-01-12	03:39:00.012	2019-01-14	01:52:00.017	2019-01-14	02:04:00.007
2019-01-12	03:53:00.017	2019-01-12	03:53:00.015	2019-01-14	01:58:00.017	2019-01-14	02:09:00.008
2019-01-12	04:08:00.017	2019-01-12	04:08:00.014	2019-01-14	02:04:00.017	2019-01-14	02:14:00.009
2019-01-12	04:24:00.017	2019-01-12	04:24:00.013	2019-01-14	02:09:00.017	2019-01-14	02:18:00.010
2019-01-12	04:38:00.017	2019-01-12	04:38:00.011	2019-01-14	02:14:00.017	2019-01-14	02:23:00.008
2019-01-12	04:57:00.017	2019-01-12	04:57:00.014	2019-01-14	02:18:00.017	2019-01-14	02:27:00.007
2019-01-12	05:19:00.017	2019-01-12	05:19:00.012	2019-01-14	02:23:00.017	2019-01-14	02:32:00.009
2019-01-12	05:30:00.017	2019-01-12	05:30:00.010	2019-01-14	02:27:00.017	2019-01-14	02:36:00.005
2019-01-12	05:42:00.017	2019-01-12	05:41:56.696	2019-01-14	02:32:00.000	2019-01-14	02:41:00.011
2019-01-12	05:55:00.017	2019-01-12	05:55:00.007	2019-01-14	02:36:00.017	2019-01-14	03:23:00.008
2019-01-13	00:31:00.017	2019-01-13	00:31:00.191	2019-01-14	02:41:00.017	2019-01-14	03:33:00.182
2019-01-13	00:52:00.017	2019-01-13	00:52:00.192	2019-01-14	03:33:00.017	2019-01-14	04:17:00.181
2019-01-13	00:59:00.017	2019-01-13	00:59:00.192	2019-01-14	06:01:00.017	2019-01-14	06:01:00.107
2019-01-13	01:06:00.017	2019-01-13	01:06:00.192	2019-01-14	07:48:00.017	2019-01-14	07:48:00.114
2019-01-13	01:30:00.017	2019-01-13	01:30:00.184				

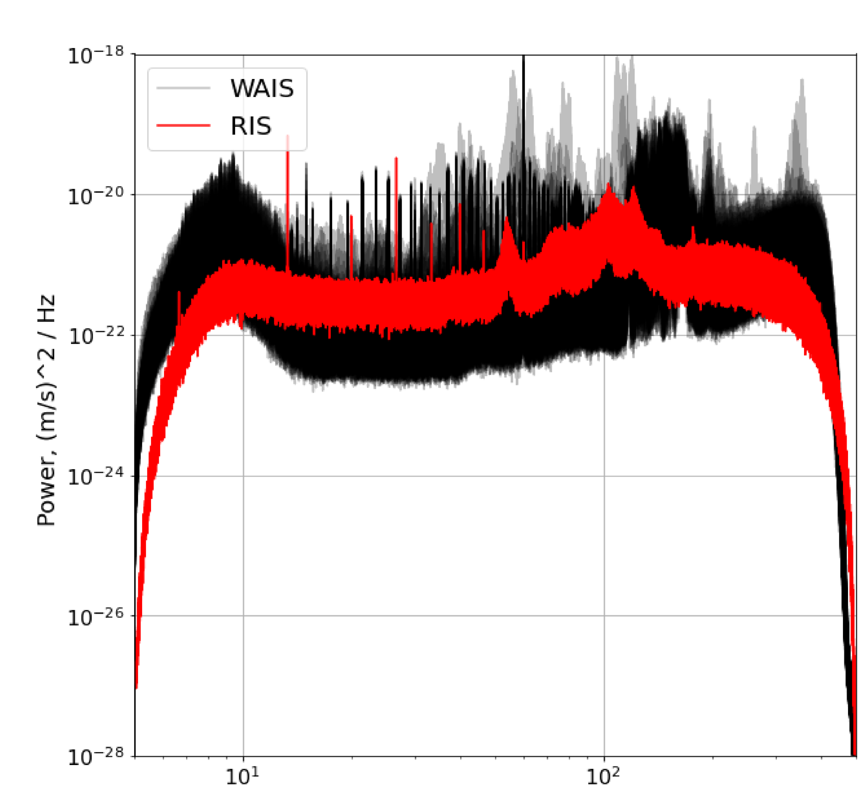
(Left) Histogram of number of stations per detection for the WAIS Divide site. Most events were only detected on one station, which suggests extremely local sources given the close station spacing. (Right) Our detection scheme successfully detected all reported active seismic survey shots at WAIS. No additional icequakes were detected at WAIS divide.

We examine whether the lack of basal icequakes at the WAIS Divide site was due to higher noise levels there. We compute probabilistic power spectral densities (PPSD) to compare noise levels at RIS and WAIS divide.

We find significantly higher noise levels at WAIS, where stations were deployed at the surface, than at RIS, where stations were buried at 1m depth. Computed PPSD for both sites show that WAIS divide experiences a higher noise level.

Despite the generally higher noise levels at WAIS versus the RIS, we do find **quiet intervals at WAIS** where the noise levels are comparable to the RIS.

We note that even during these quiet interval, we detected zero basal icequakes at the WAIS divide site.



Computed PPSD for WAIS divide and RIS. Black curves show average power on 2019-01-08 at all WAIS seismometer locations. Red curves show average power on 2009-01-03 at RIS location.

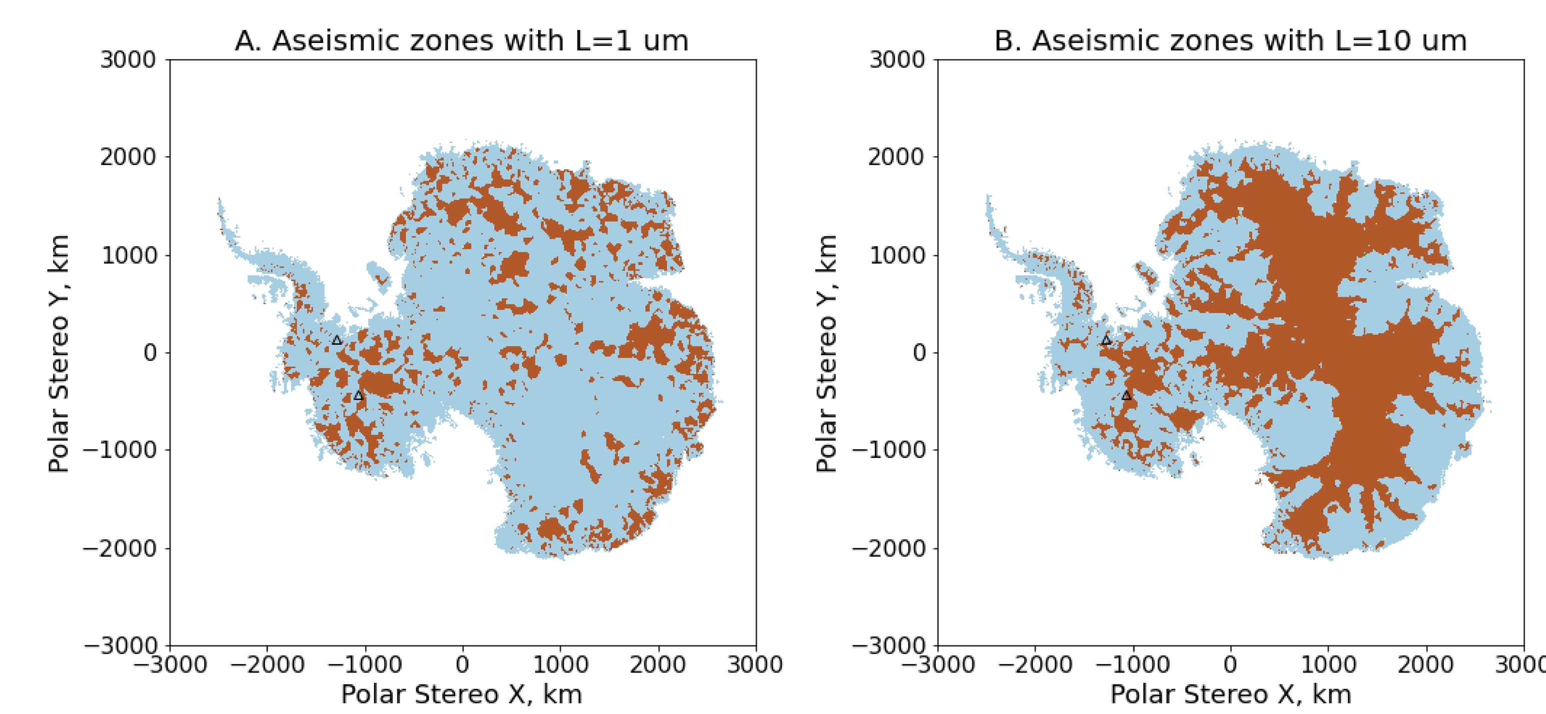
Discussion

We did not detect icequakes at the WAIS Divide site. <u>What can the absence of basal icequakes tell us about the ice sheet?</u>

The literatures suggests three reasons why basal seismicity may be absent:

1. Sliding is too slow – essentially a viscoelastic effect (Lipovsky et al., 2019)
2. Water pressure is too high – Ruina and Rice (1983)
3. Slip surfaces don't have the rate-weakening friction – either due to low sediment content (Lipovsky et al., 2019) or temperature effects (Saltiel et al., 2021)

We test hypothesis #1 (sliding is too slow) using a viscoelastic icequake model (Lipovsky et al., 2019) parameterized with data from the ISSM ISMIP6 5km model run (see maps at far left of poster). We find that (unrealistically?) large frictional weakening length scales L are needed to explain the lack of seismicity at the WAIS Divide site:



Conclusions

- We detected icequakes on the Rutford Ice Stream but not at the WAIS Divide.
- This result is consistent with the hypothesis that basal icequakes indicate basal sliding, *however, this result is not currently explained by a coupled ice flow – icequake model.*
- <u>This line of thinking suggests that basal icequakes could be used as a new type of constraint in ice flow models.</u>

References

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