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Abstract:1424

Cluster Analysis of Thermal Icequakes Using the Seismometer to Investigate Ice and Ocean Structure (SIIOS): Implications for Ocean World Seismology

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Introduction

Icy-ocean worlds have thick icy shells covering subsurface oceans (1,2). Due to the potential habitability of the subsurface ocean, Europa has become a target for a potential lander mission (3,4). Seismology is the preeminent method for constraining the thickness of an icy shell. The Seismometer to Investigate Ice and Ocean Structure (SIIOS) uses flight-candidate instrumentation to develop approaches for seismic studies of icy bodies. **Here we discuss how we used two analog sites to characterize seismicity of the local ice structure.**

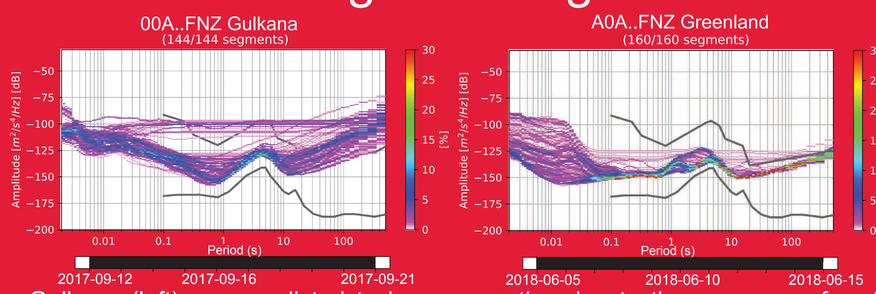
Image Credit: NASA/JPL

Experimental Setup

SIIOS was deployed on Gulkana Glacier in September 2017 (top). Gulkana is classified as a "benchmark" glacier by the USGS (5) and has ice ~100 meters thick (6). Gulkana's seismic signals include regional and teleseismic earthquakes, icequakes, rockfalls, and water drainage events from a nearby moulin. It experiences diurnal changes in seismicity.

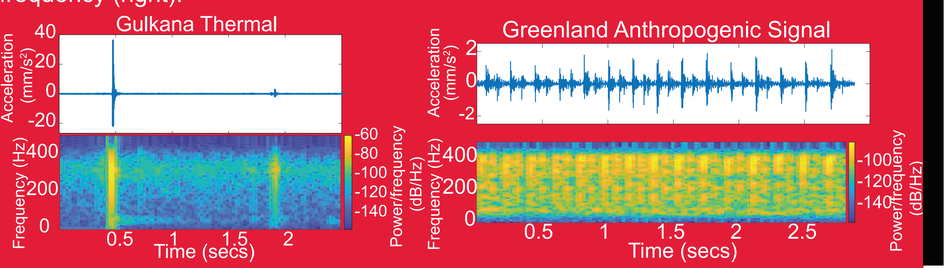
SIIOS was then deployed in Northwest Greenland in June 2018 (bottom). This site has ice ~850 m thick (7), and sits above a sub-glacial lake (8,9) . Greenland is a quieter site due to low-temperatures, isolation, and the enclosure around the instruments.

Background Signals



Gulkana (left) was predicted to be more active due to the presence of surface runoff, moulins, and potential for rockfalls. Greenland (right) had thicker ice and a subglacial lake which helped insulate it from basal icequakes.

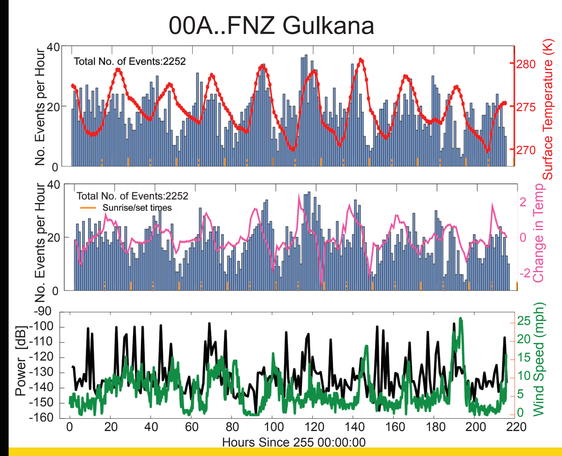
At each site we expected to record small local events such as thermally induced icequakes or wind events. Each event has characteristic durations and range of dominating frequencies. For thermal events we used a bandpass filter of 5-20 Hz, and a minimum signal to noise ratio of 15 (10). At the Greenland site, we noticed an anthropogenic signal with a fairly consistent recurring interval and characteristic frequency (right).

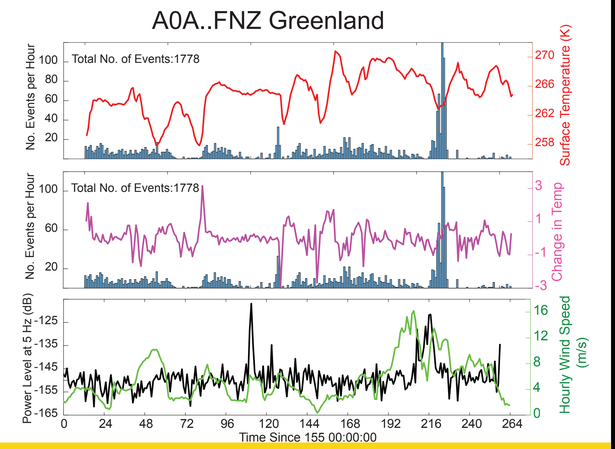


Signal Detection

We can use these characteristics to detect events in passively recorded data. Events are detected using a short-term average/long-term average approach (10,11). We can then compare the results with weather data. For Greenland, we recorded temperature and wind measurements with our own weather station. Gulkana wind data was provided by a nearby USGS weather station (12). Temperature data was collected by the MERRA weather satellites (13).

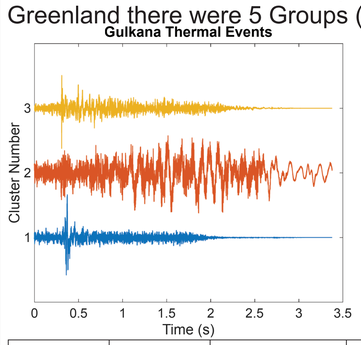
The detection rate at Gulkana Glacier has a clear periodicity. The detection rate is correlated with temperature (top) but more so with the change in temperature (middle). We found a lack of detections could be related to periods of high wind (bottom) which caused background noise to increase, thus increasing long-term average values. Greenland does not show the same strong correlation with temperature and wind speeds.





Cluster Analysis- Thermal Icequakes

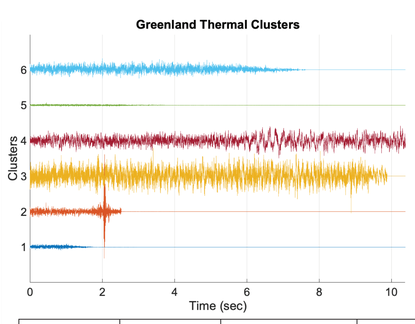
For the thermal events at both sites we performed a cluster analysis on the detected events. This analysis allows us to find similar waveforms that may have similar origins or other characteristics. For Gulkana there were 3 Group (left) for Greenland there were 5 Groups (right).



Cluster 1 had lower frequency content, but no strong time preference.

Cluster 3 preferentially occurred during daylight.

Cluster	# of Events	Dom. Freq (Hz)	Time Preference	Event Length (s)
1	1713	4-8, 15-21	None	1.45
2	7	4-11	No events 8am-3pm	2.45
3	532	11-20	4am-6pm	1.45



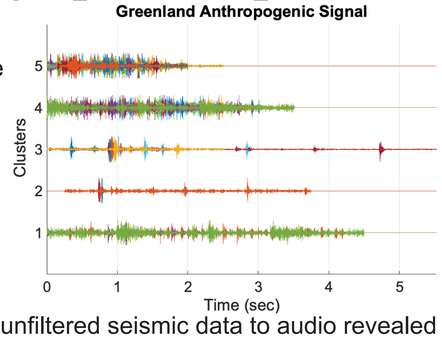
Cluster 1 were shorter events. Cluster 2 were high quality events. Cluster 5 were most similar to Gulkana events, albeit with lower frequencies. Cluster 6 had longer durations.

Cluster	# of Events	Dom. Freq (Hz)	Time Preference	Event Length (s)
1	325	5-15	None	0.3
2	3	20-60	--	1.5
3	4	2-7	--	8.4
4	1	3-7	--	10.5
5	1413	1-9	12pm-6pm	1.5
6	32	2-11	8am-8pm	5

Cluster Analysis- Greenland Anthropogenic Signal

A template was used to locate the Greenland anomaly signal. The series was found in passively recorded data 100 times. A cluster analysis found they fell into 5 groups. Unlike the thermal events which tended to peak in the afternoon. Very few of these events occurred between 5:30 PM and 10 PM. All of the events originated between 340-360°, suggesting they originate form the same source.

Cluster	# of Events	Dom. Freq (Hz)	Pattern	Event Length (s)
1	5	230-340	Repeats every 0.1 second	2
2	2	220-320	Repeats every second	1
3	15	320-390	Repeats every 0.1 second	1
4	30	220-330	Varied by amp, 0.1 for small, 0.3 for large	1.5
5	46	230-380	Repeats every 0.1 second	0.5



Converting the unfiltered seismic data to audio revealed the likely cause of this signal were flags attached to bamboo poles so the array could be spotted from air. The 1 meter long poles buried at one end would have a resonant frequency of 320 Hz, matching the signals.

Summary

- Analogs allow us to search for local seismicity. Gulkana was a more active site, Greenland was quieter
- Gulkana's thermal events were strongly tied to temperature and changes in temperature
- Greenland's thermal events coincident with temperature variations
- Cluster analysis allows for more in-depth analysis of events. Reveals variations among categories
- An anthropogenic signal in Greenland was recorded
- Cluster analysis revealed the events all originated from the same location
- Variations in detections revealed more about the driving force behind the signals (wind)
- We identified the source of the signal as bamboo poles with flags. Audio conversion of the seismic signal and analysis of dominant frequencies confirmed the hypothesis

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