Wind-driven effects on spectral amplitudes and seismic detection thresholds in a polar glacier setting

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Abstract

Temporally variable environmental microseismicity and narrowband signals are both demonstrated to reduce the detectability of small seismic events. We investigate the influence of winter wind events on detection thresholds for a 3-sensor seismic network at the terminus of Taylor Glacier, Antarctica. As wind speeds increase, we observe higher spectral amplitudes across the frequency spectrum; however, some frequency bands are preferentially excited. Surprisingly, these spectral peaks shift frequencies through time. To determine detection thresholds, we implement a waveform injection routine wherein we add scaled waveforms to the datastream, and track changes in the size of the smallest scaled event that we can reliably detect. We thereby demonstrate a capability to quantify the size of the smallest detectable event in temporally variable signal environments. Lastly, we propose a method to forecast our ability to detect sources of a threshold size in measured noise conditions.

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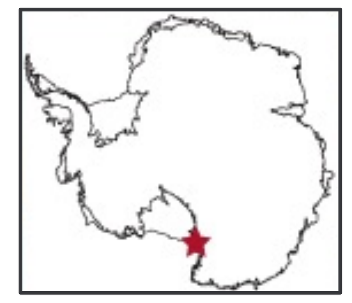

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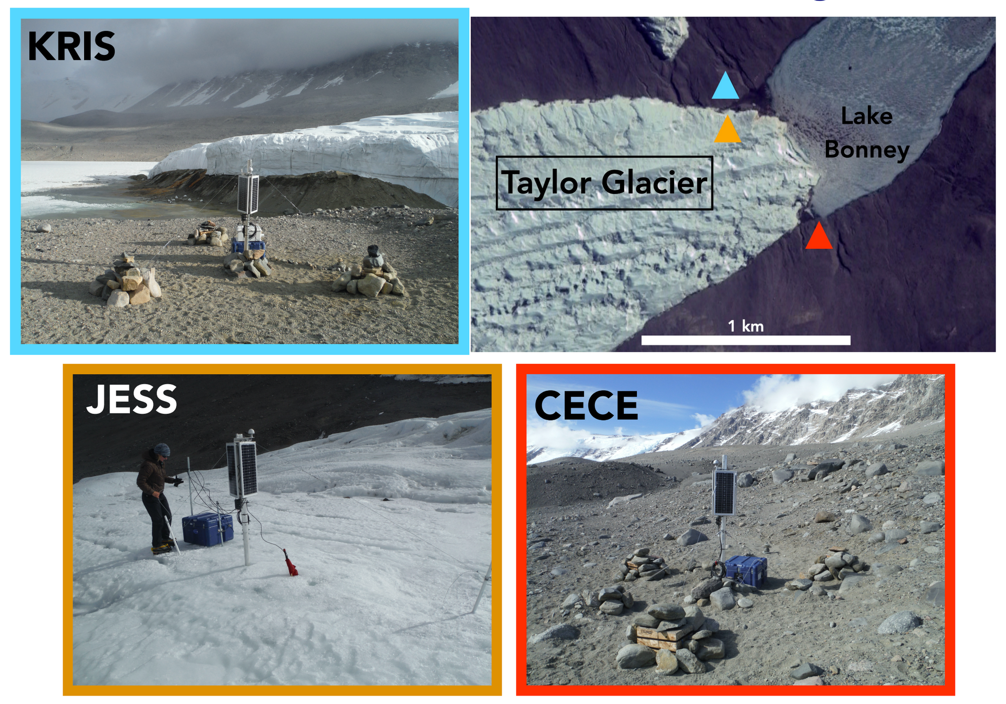
Seismic network at Taylor Glacier, Antarctica



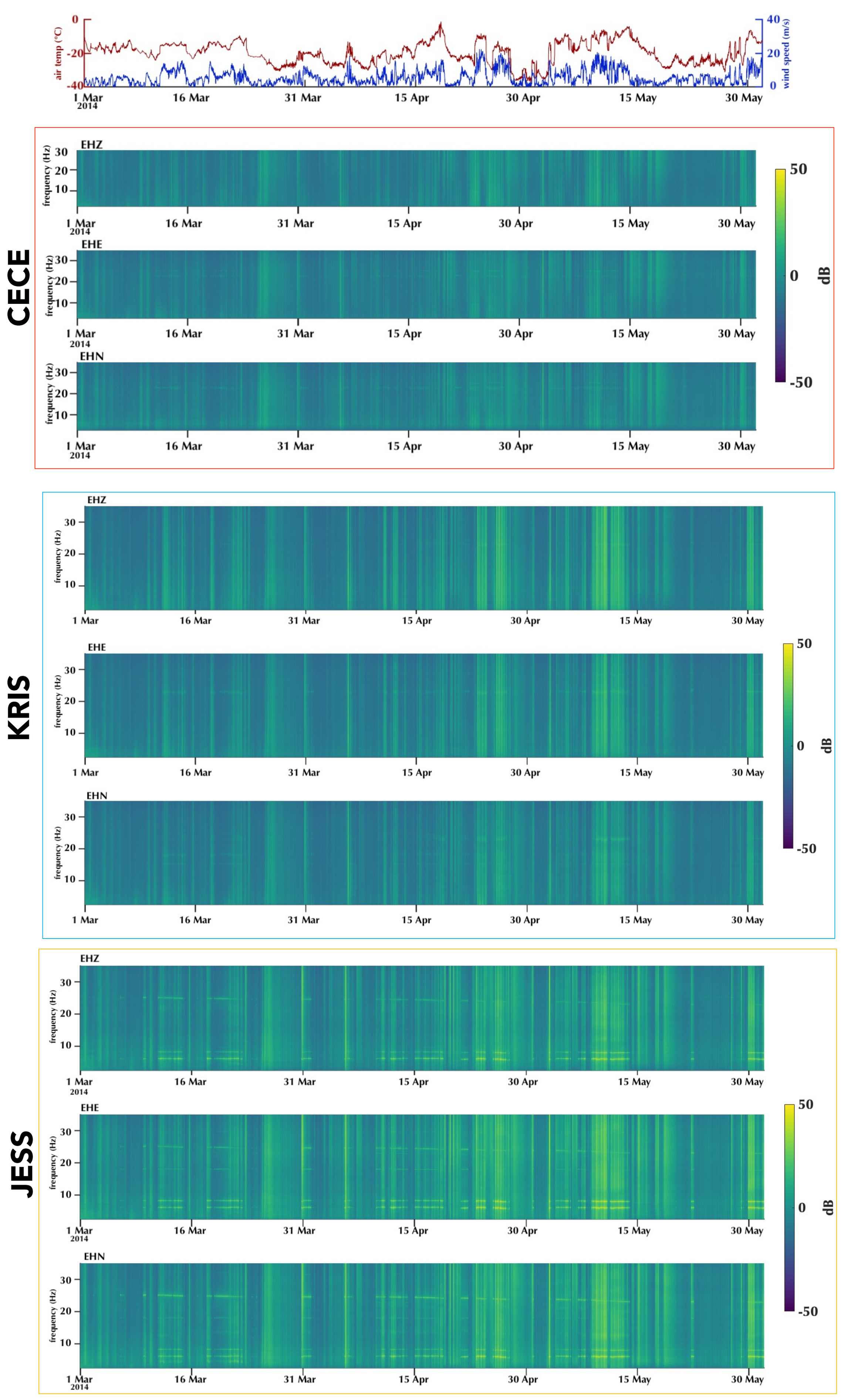
Photos: CGC, Map base image: Google, Maxar Technologies, image date: 5 Dec 2008

[NOV 2013 – JAN 2015]

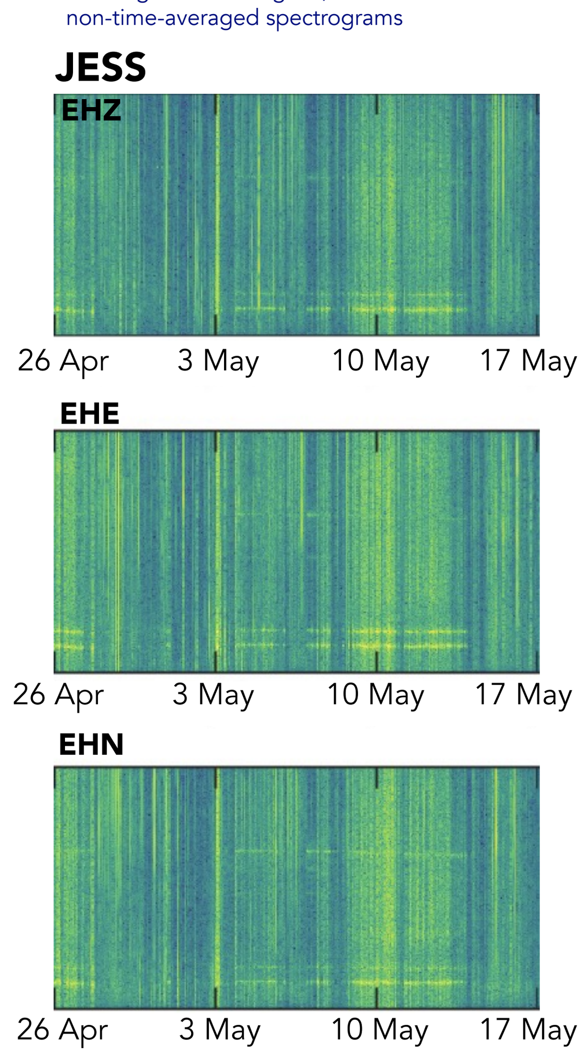
- Three Sercel L-22 seismometers
- 2 in sediment, 1 on glacier
- 3 different seismic detectors (2 STA/LTA and 1 Rayleigh wave correlation) all show temporally variable detector performance in terms of the minimum source size required to detect events
- Wind speed seems to be associated with some of the variability in detector performance
- Could wind-driven excitation of particular spectral bands explain these observations?
- Seismic data available: Pettit (2013)
- Wind speed & air temp: Doran & Fountain (2019)

PROCESSING STEPS

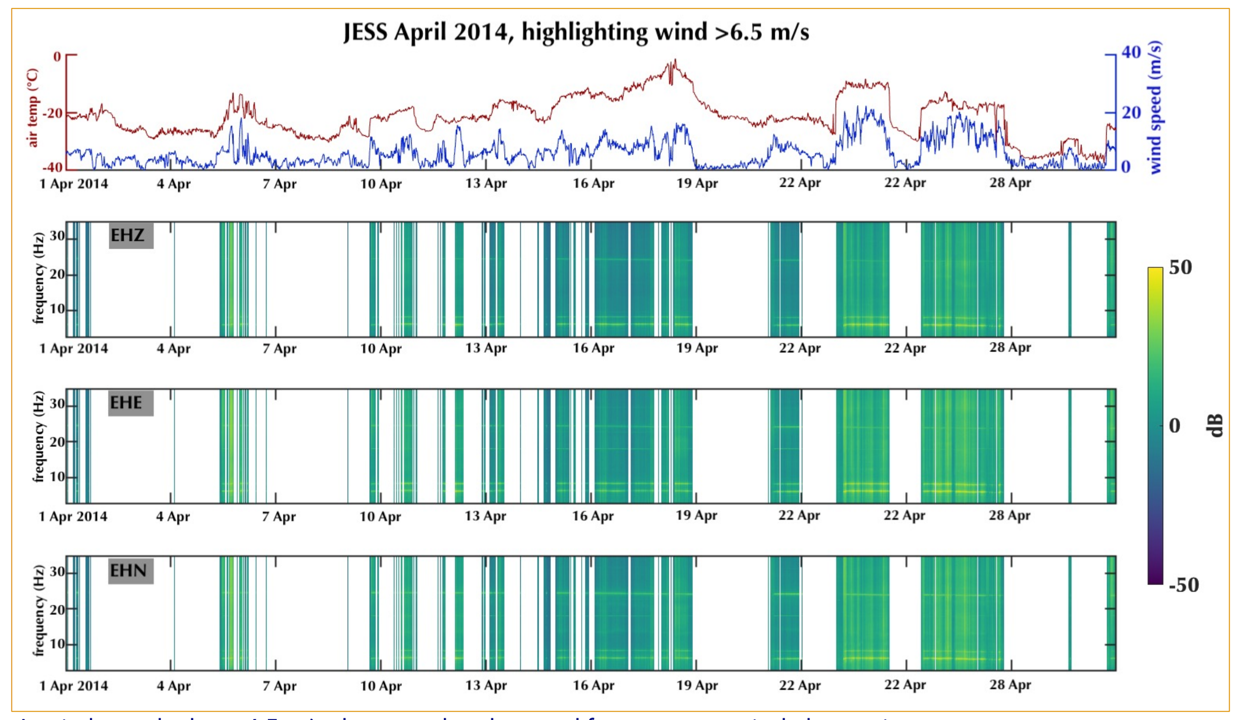
- 8 second window with 5 second overlap
- Frequency band [2.5,35]Hz, Butterworth bandpass filter
- Instrument response is not removed, but instrument response is flat in this frequency range
- Bin into same 15-minute windows at meteorological data



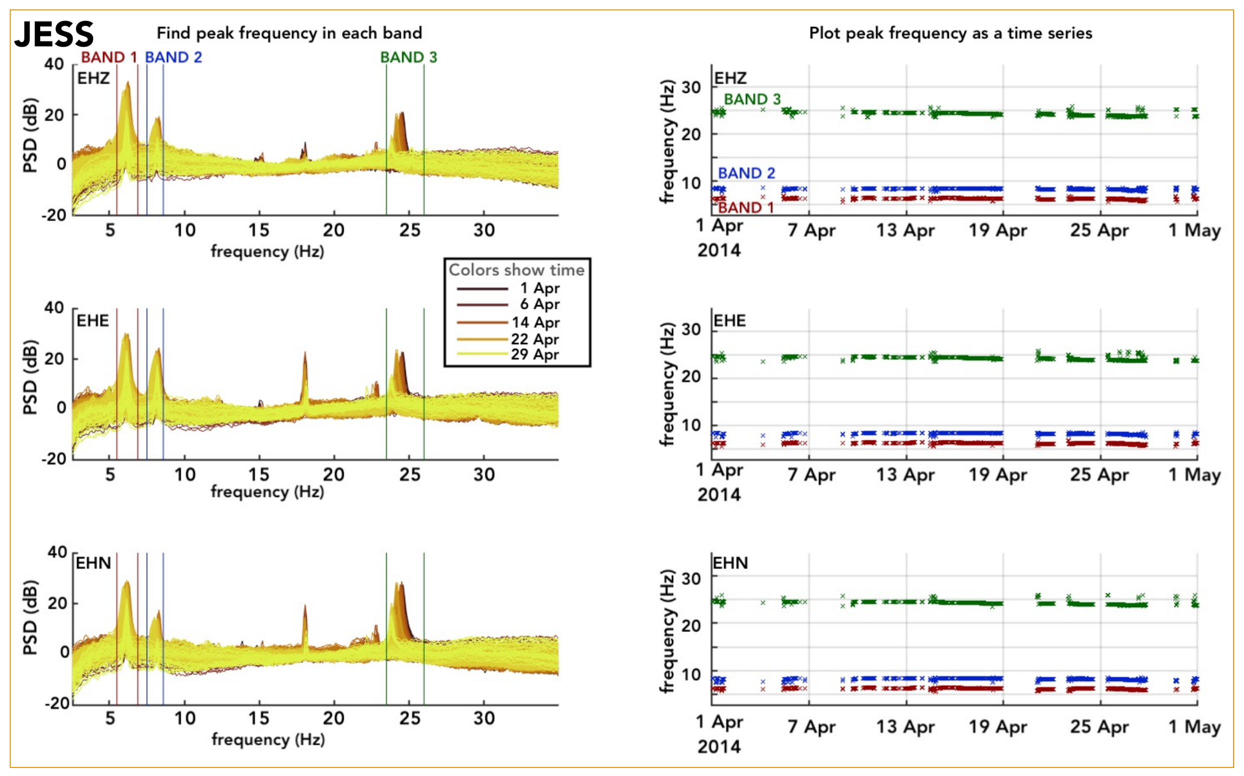
3 weeks of data from the on-glacier station, showing detail of original, non-time-averaged spectrograms



Bin by wind speed



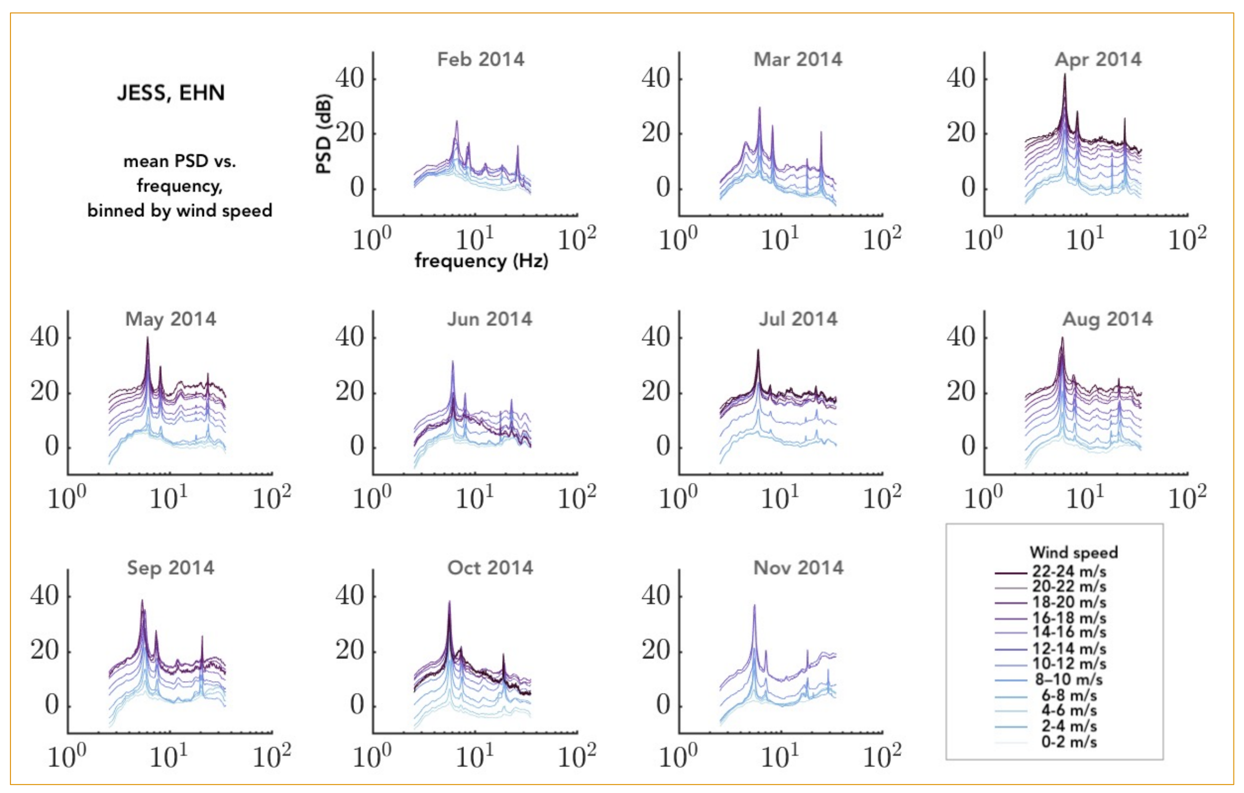
At wind speeds above 6.5 m/s, the narrowband spectral features are particularly prominent



Frequency peaks shift downwards through time. In this figure, the shift in peaks in "Band 3" (green) around 25Hz is particularly prominent on the left panels. Here, the mean PSD, averaged over 15 minutes windows when wind speeds are >6.5 m/s, are plotted as a function of frequency at left, and the peak frequency in each of three visually identified bands (Band 1: red, Band 2: blue, and Band 3: green) are plotted as a function of time at right.

Spectral peaks shift frequency through time

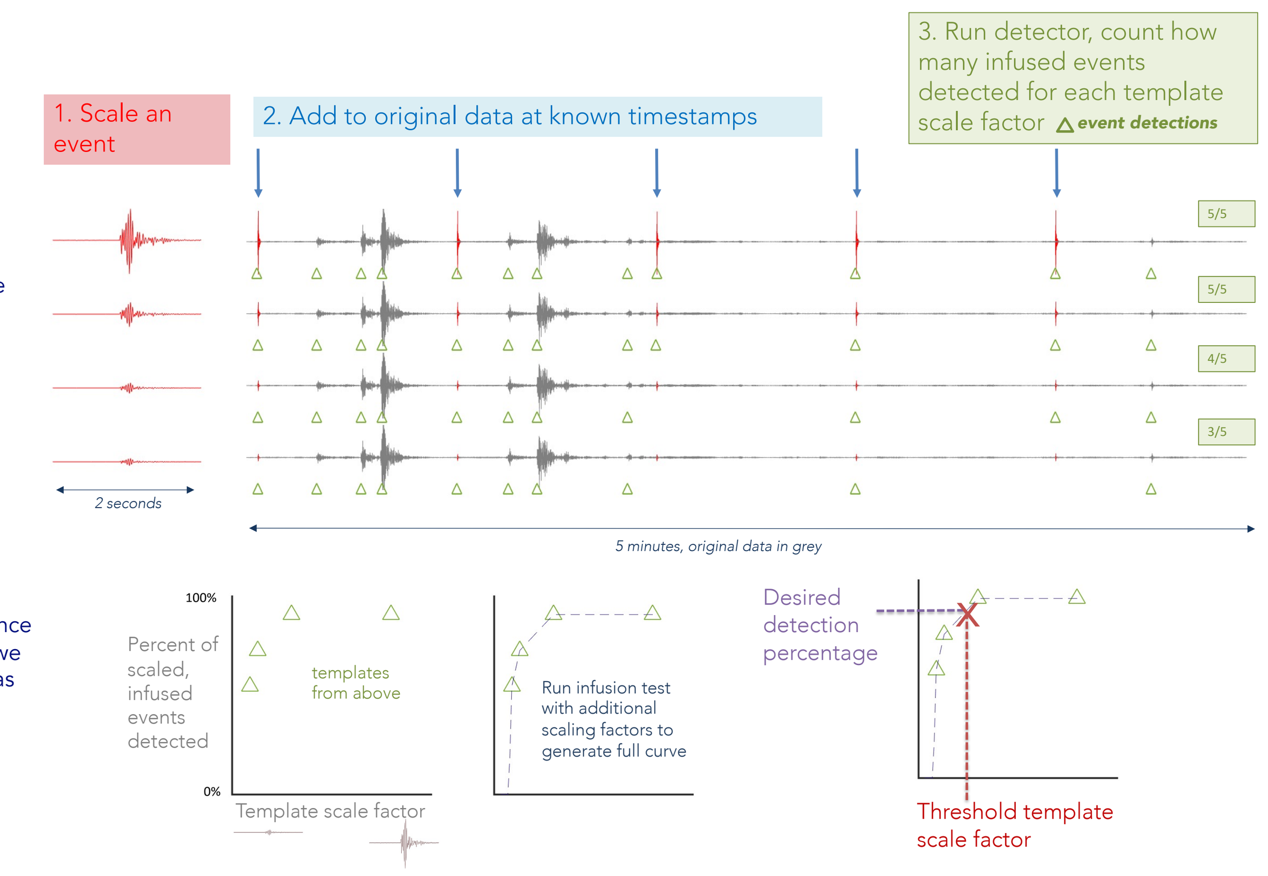
Higher wind speeds cause increased power across all frequencies, but particularly excite specific frequency bands



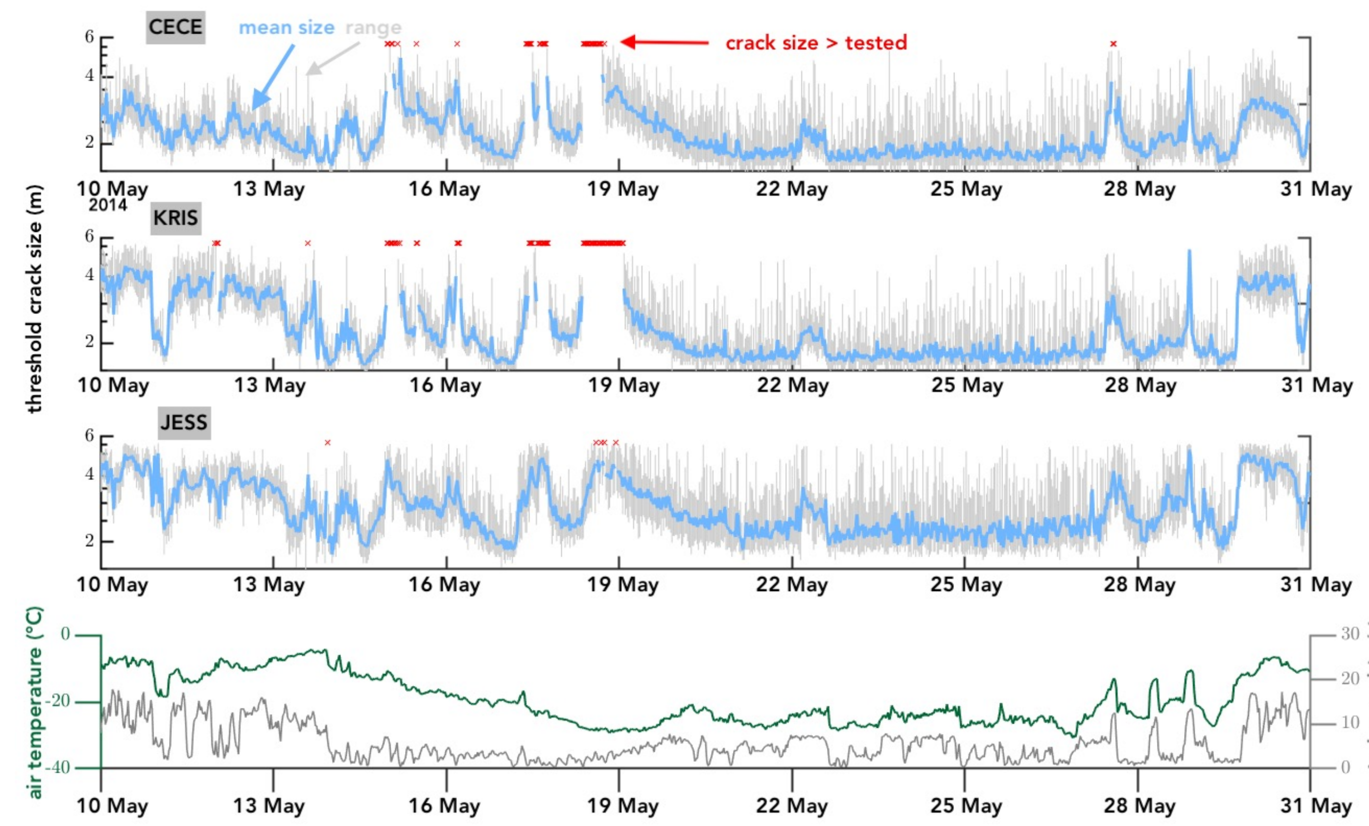
As wind speeds increase, power increases across all frequencies, but certain bands are particularly excited. Some exceptions occur – for instance, in June, the highest wind speeds do not correspond to the highest observed powers.

Event detection & minimum source sizes

Minimum source size analysis: We infuse waveforms into the original data stream, run the detector, and count how many of the added events are successfully identified. We scale the template amplitude, and repeat the process for a range of scaled amplitudes.



Threshold scale factor: By generating empirical performance curves from the infusion process, we define the threshold scale factor as the amplitude scale required to successfully identify the infused events at the desired detection percentage.



Some increases in threshold crack size correspond to increases in wind speed. Here, we used a model to convert amplitude scale factors to an equivalent volumetric crack opening. We convert volumetric opening to linear crack dimensions, for an idealized crack opening 1 cm, and with crack length = crack depth (see Carr et al., *accepted*)

How does wind impact event detection?

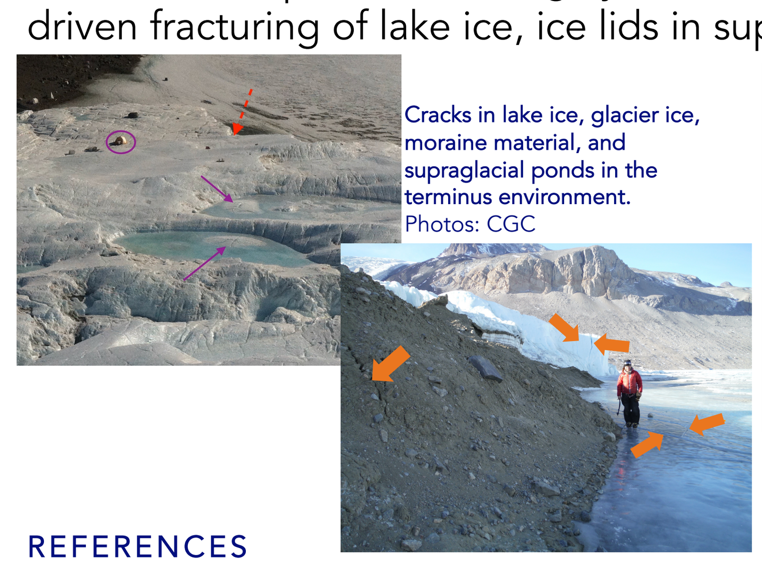
POSSIBLE MECHANISMS:

1) CHANGES TO STATISTICAL DISTRIBUTIONS IF PERSISTENT SOURCE IS EXCITED

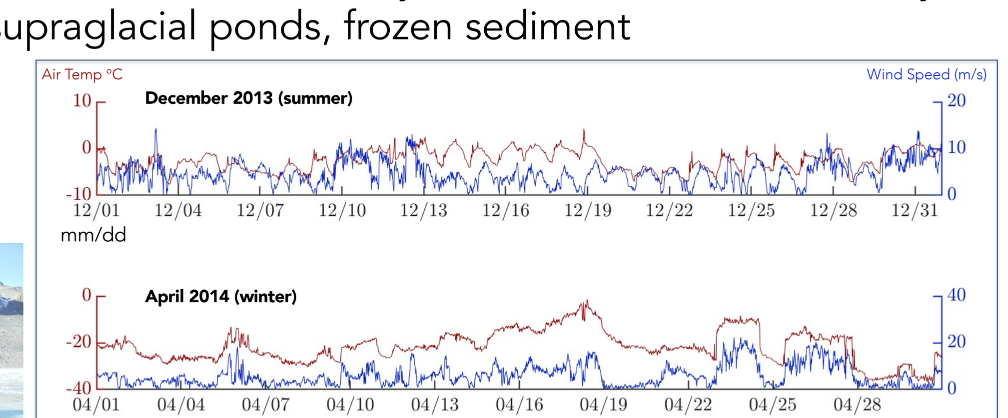
Increasing standard deviation of correlation distributions→ increasing thresholds, fewer events

2) INCREASED NATURAL FRACTURING EVENTS DUE TO THERMAL CHANGES

Wind and temperature are highly correlated; wind events may be associated with thermally-driven fracturing of lake ice, ice lids in supraglacial ponds, frozen sediment



Cracks in lake ice, glacier ice, moraine material, and supraglacial ponds in the terminus environment. Photos: CGC



Wind speed and air temperature are often highly correlated. We observe diurnal patterns in the summer, and multi-day weather systems in the winter.

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