UNIVERSITY OF MARYLAND

NS43B-0838: Microseismic Remote Sensing of Sea Ice: Exploratory Study on the Potential Uses of the EarthScope Transportable Array in the Detection of Sea Ice Dynamics

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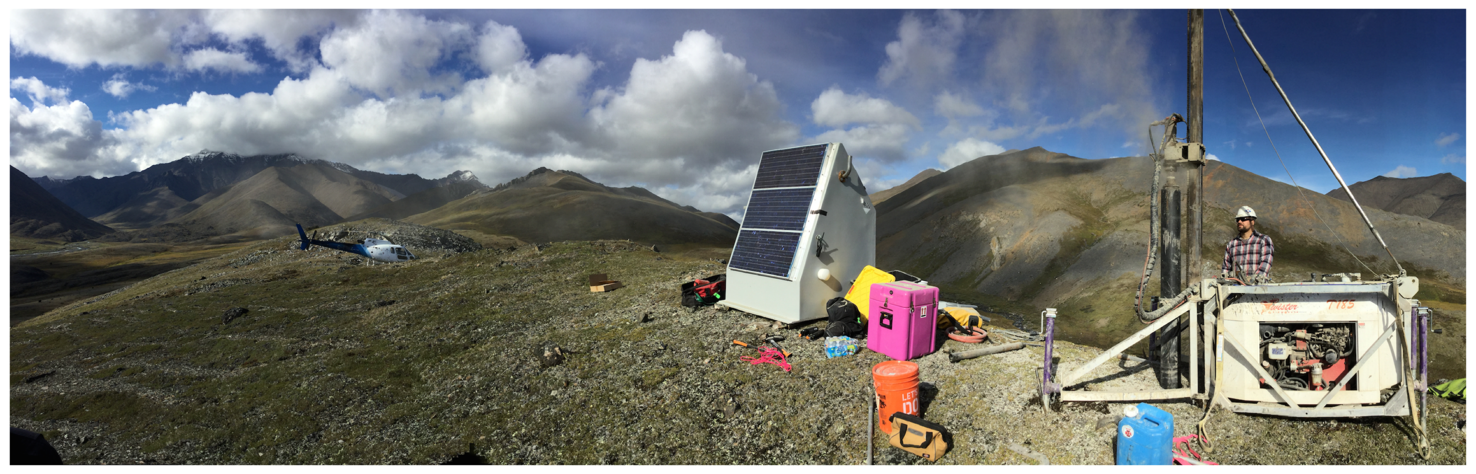


Motivations and Project Goals

Over recent decades, remote sensing of sea ice has advanced at a rapid pace. However, there are inherent limitations in the ability of existing space and airborne sensors to observe changes in the properties of near-shore sea ice, especially over short (hourly) time scales. This information is of critical importance to the livelihood of local communities and to meteorologists who depend on accurate knowledge of near-shore ice conditions for weather prediction.

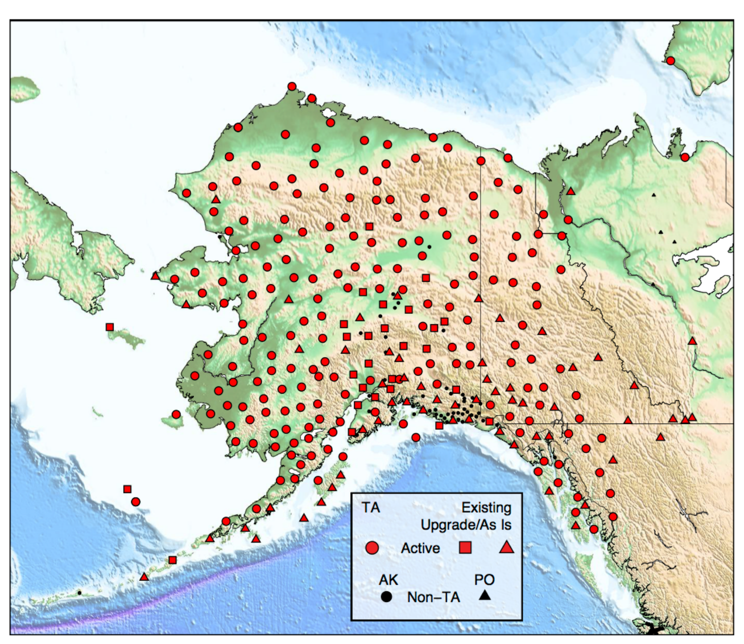
The use of near-real-time data from coastal seismic arrays promises to advance coastal ice observations by measuring the amplitude of background seismic noise, known as microseism.

Microseism is generated by interactions between oceanic waves, the ocean floor, and the shoreline. Previous studies have shown that along polar coastlines the microseism is modulated by the presence of sea ice.

In this feasibility study, we explore the use of power spectral density (PSD) measurements from the Utqutgvik station of the EarthScope Alaska Transportable Array (TA) to provide information about sea ice conditions off the northern coast of Alaska and other Arctic shorelines.

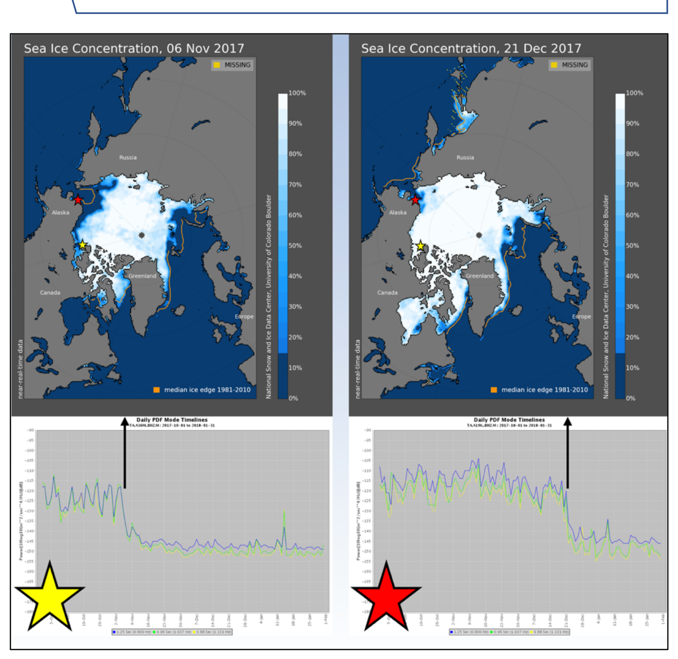
PSD signals are compared with daily estimates of near-shore ice extent and concentration within the Beaufort and Chukchi seas. These are derived from satellite passive microwave radiometer data. The amplitude of microseism at a frequency near 1 Hz is compared with ice coverage on both an intra-daily and long term basis to determine if microseismic signals from a coastal station can be used to identify particular ice events, such as fast-ice breakup and formation or the onset of summer melt.

Alaska Transportable Array Network



The Alaska Transportable Array (Alaska TA) is a network of 280 autonomous, telemetered seismic stations installed at a dense grid spacing of ~85 km across Alaska and western Canada. Supported by the National Science Foundation as part of the EarthScope Program, the network was installed primarily over three field seasons beginning in 2015 in order to record earthquakes and map Earth's structure beneath the North American plate. The high-quality observations have also led to additional research including this investigation into sea ice.

- High levels of noise around the 1Hz period recorded on coastal seismometers correlate with high frequency ocean waves in open water. Low noise correlate with intact, continuous sea ice.
- Note the much earlier drop in noise at A36M (yellow star) on 6 November 2017 that corresponds with local fast sea ice on the satellite obtained sea ice concentration, and the much later drop in noise on 21 December 2017 at A19K (red star), which is much further southwest and freezes up later. Both channels show a ~25 dB drop in amplitude at these frequencies.



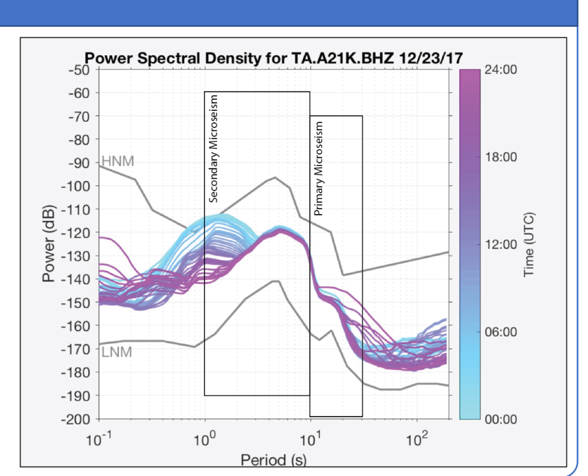
Microseism : Background and Intra-daily Variations

Broadband seismometers around the world have peaks in the 1-20 second period band. These peaks are caused by ocean gravity wave interactions that generate seismic Rayleigh waves on the seafloor.

The primary microseism is at 10-20 seconds period and energy is generated by the breaking or shoaling of ocean gravity waves nearer the coast.

The secondary microseism is at 1-10 seconds period and energy is generated by waves that are standing or colliding, either coastal or deep ocean.

Microseism energy varies with seasonal storms and local ice conditions.



Methodology

Long Term Correlation with Daily Ice Concentration: Daily values of near-shore sea ice concentration and microseism amplitude are compared at two TA stations near the Arctic coast over the period January 2016 to December 2017. Ice concentration data is obtained from the OSISAF-401b product, and spatially averaged values are calculated for regions roughly parallel to the coastlines nearest each array (Figure 1.) Regional concentration values are then combined with corresponding daily values of ~1Hz vertical (BHZ) channel microseism power in dB, and a Pearson correlation coefficient is calculated using the Generic Mapping Tools (GMT) math module.

Power Spectral Density of Discrete Concentration Intervals: The relationship between discrete ranges of ice concentration and microseism power is explored by binning days with concentrations that fall within 10% range intervals, starting from those between 0 and 10%, and continuing to those between 90 and 100% . The median and standard deviation are then found for associated microseism amplitudes over a range of frequencies for each bin, and used to generate an average PSD for each interval with error bars of +- 1 SD.

Station	Utqutgvik	Sachs Harbour
TA station name	TA.A21K	TA.A36M
Adjacent Selection Regions (as shown in Fig. 1)	Beaufort Sea (red), Chukchi Sea (blue)	Beaufort Sea (purple), Amundsen Gulf (yellow)

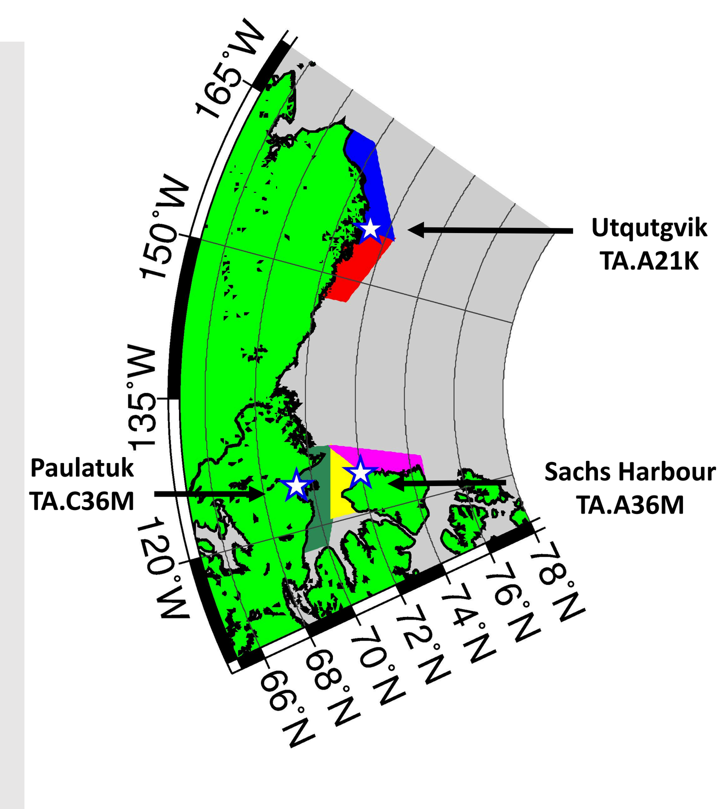


Figure 1. Regions used in the calculation of sea ice concentration near TA stations. Polygons extend ~110km outwards from a line approximating the mean coastline. Divisions reflect regional variation in the distribution and motion of sea ice. Regions shown are Beaufort Sea near TA.A21K (red), Chukchi Sea near TA.A21K (blue), Beaufort sea near TA.A36M (purple), Amundsen Gulf near TA.A36M (yellow), and Amundsen Gulf near TA.C36M (green).

Sea Ice Phenomena Along Arctic Coasts

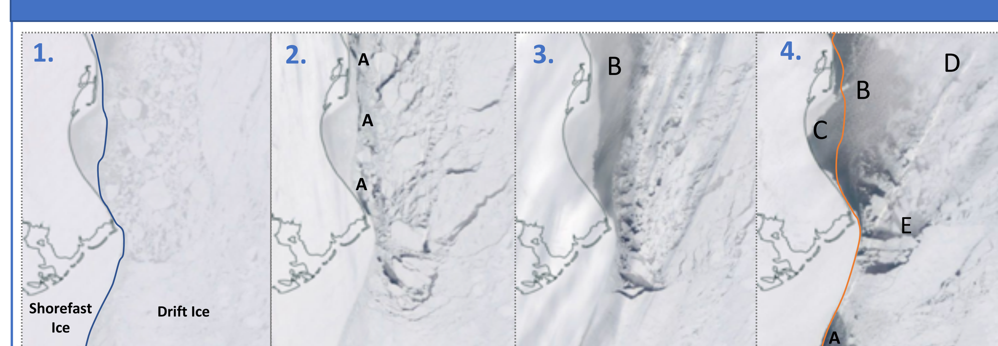


Figure 2. MODIS imagery of sea Ice near Utqiagvik, AK on March 31st, April 1st , April 3rd, and April 5th 2016. Coast is shown with thin solid line. Fast Ice edge before breakup outlined with thick Blue (1st panel) and after breakup with thick orange (4th panel) Images from EOSDIS worldview

A. Development of flaw lead along fast ice boundary
B. Widening of flaw lead into larger polyna
C. Breakup of shorefast ice
D. Downwind weather impacted by exposure of sea surface (may cause increased cloud-cover and precipitation)
E. Re-freezing of ocean surface within leads

The behavior of sea ice near shorelines and in littoral areas can be highly dynamic. Ice adjacent to certain shorelines may be grounded to the seafloor or otherwise immobilized (***fast ice***). Openings in the ice pack known as ***flaw leads*** occur directly adjacent to the fast ice boundary as offshore winds or currents push mobile ice (***drift ice***) away from the coast. These leads may then expand into large expanses of open water (***polynyas***) which can significantly impact local weather conditions.

The formation and breakup of fast ice is particularly important to coastal communities for a wide variety of reasons, especially transportation and resource accessibility. Fast ice in Alaska typically forms from October into the Winter months, and breaks up entirely by mid Summer. However, partial breakup of fast ice can occur at anytime, particularly under strong external stress or when the ice is mechanically weak, often in the early stages of growth.

Ice floes near Utqiatgvik, AK. Photo by Ken Graham , Accent Alaska

Measuring Sea Ice: Passive Microwave Derived Concentration and Other Remote Sensing Products

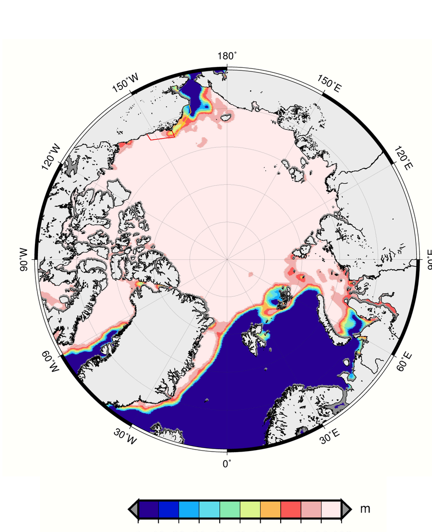


Figure X. OSISAF-401b Sea Ice concentration for December 23rd 2017. Derived from SSMIS passive microwave data.

Due to the harsh environmental conditions and remoteness of Arctic waters, satellite measurements provide most of the information necessary for near real time sea ice data products. Available derived products include: sea ice extent, sea ice concentration, ice surface temperature, ice drift, and ice thickness.

Operational concentration and extent products have traditionally relied on *passive microwave observation* which measures the EM emissivity of the surface below. Two currently used instruments are the **Special Sensor Microwave Imager/Sounder (SSMIS)** and the **Advanced Microwave Scanning Radiometer 2** (**AMSR-2**). Passive observation of shorter wavelengths , and active sensing using synthetic aperture radar (SAR) systems may be used to derive higher resolution products, some of which have reached operational status in recent years. Better resolution of ice coverage in areas immediately adjacent to shore might help to further clarify the connection between sea-ice and microseism.

Results

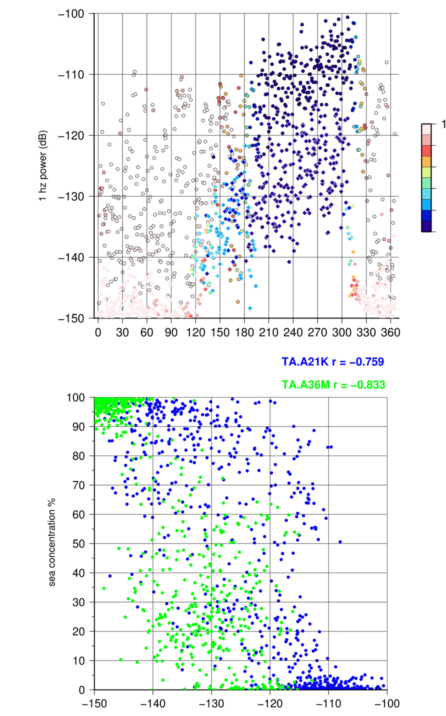


Figure 3. (top) Scatterplot of daily average microseism power at 1Hz vs day of year for two TA stations over years 2016-2017. Data points from TA.A21k (Utqutgvik) are circles outlined in black. Data points from TA.A36M (Sachs Harbour) are diamonds outlined in white. Ice concentration for day of measurement indicated by color scale. Concentration date is found for Chukchi coastal region (blue Fig. 1) for TA.A21K and for the Beaufort coastal region (purple Fig. 1) for TA.A36M

Figure 4. (bottom). Scatterplot of daily ice concentration vs microseism power at 1Hz for two TA stations. Data points and correlation value for TA.A21K in blue. Data points and correlation value for TA.A36M in green.

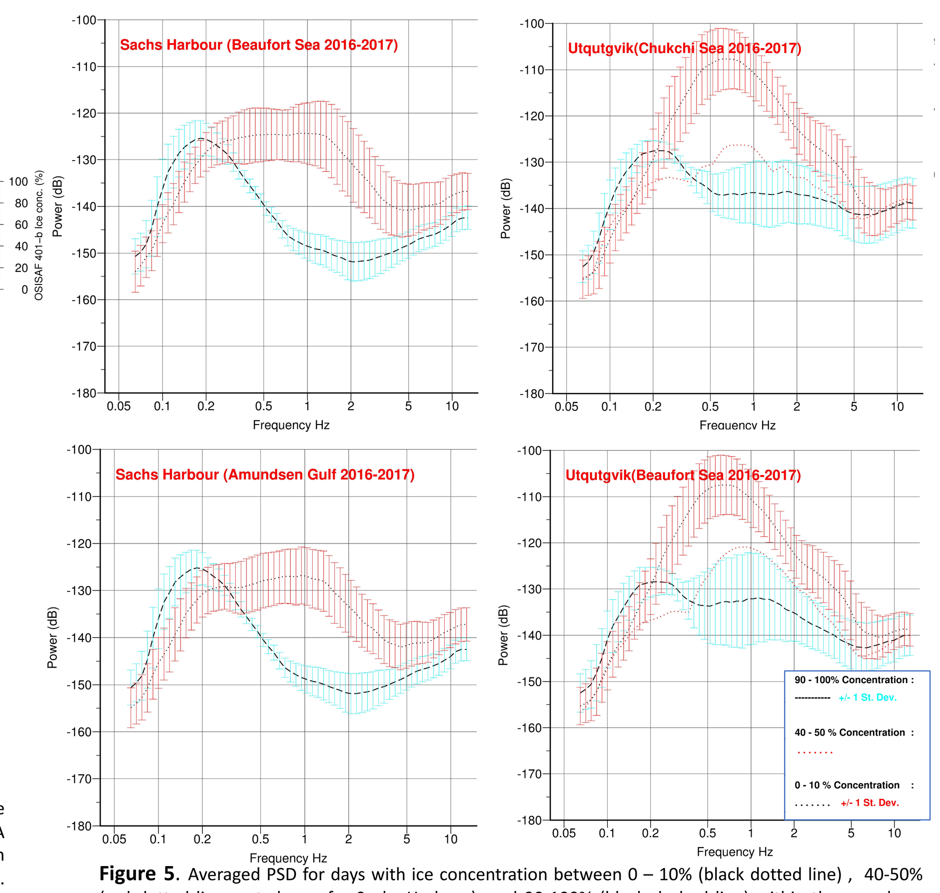


Figure 5. Averaged PSD for days with ice concentration between 0 – 10% (black dotted line) , 40-50% (red dotted line, not shown for Sachs Harbour), and 90-100% (black dashed line) within the nearshore regions indicated to the right of TA station location. Error bars corresponding to one standard deviation shown for the 90-100% concentration PSD (red) and for the 0-10% PSD (light blue).

- **Both TA stations show a strong negative correlation between microseism amplitude at 1Hz and near shore sea ice concentration (Fig. 4). This correlation is -0.718 at the Utqutgvik array (TA.A21K) and -0.896 at the Sachs Harbour array (TA.A36M)**
- **The frequency range between ~0.3Hz and ~4Hz shows reduced median microseism amplitude for days of 90-100% sea ice concentration (Fig 5). Frequencies below ~0.2Hz show a slight increase in median amplitude on the same days although with a greater variance**

Conclusions

Our results show that there is a significant correlation between nearshore sea ice concentration and the microseism amplitude near 1 Hz at coastal TA stations. This correlation holds across multiple stations within the TA network. We also find that the intra-daily trends of microseism power spectral density on days of suspected ice formation occur over a similar range and intensity as that shown over the long term between ice free and fully ice covered days, suggesting that the moderating effects of sea ice on microseism can become detectable on a short (hourly) timescale.

Image: SAR image of the Bering Strait. From University of Alaska Fairbanks Alaska Satellite Facility

Open Questions

- Can we demonstrate an empirical diagnostic relationship between microseism amplitude and specific values of near shore ice concentration ?
- Can fast ice breakup and formation be detected, specifically on an intra-daily timescale?
- Can microseism tell us about properties of the icepack other than concentration?
- Does sea ice concentration have a significant correlation with the amplitude of microseism at frequencies lower than 1Hz and if so is there a different physical mechanism?

Possible Directions

- Use higher resolution datasets to identify near-shore ice concentration
- Obtain intra-daily validation datasets of sea-ice concentration, perhaps through SAR imagery or in-situ observation

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