SIIOS in Alaska – Testing an 'In-Vault' Option for a Europa Lander Seismometer Experiment

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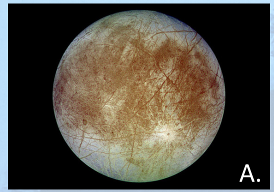
Introduction

The icy moons of Europa (Fig. A.) and Enceladus are thought to have global subsurface oceans in contact with mineral-rich silicate interiors, likely providing the three ingredients needed for life as we know it: liquid water, essential chemicals, and a source of energy [Siegel et al., 1979; Marion et al., 2003 Thomas et al., 2016; Hsu et al., 2015]. The possibility of life forming in their subsurface oceans relies in part on transfer of oxidants from the irradiated ice surface to the sheltered ocean below. Constraining the mechanisms and location of material exchange between the ice surface, the ice shell, and the subsurface ocean, however, is not possible without knowledge of ice thickness and liquid water depths.

In a future lander-based experiment seismic measurements will be a key geophysical tool for obtaining this critical knowledge. The **Seismometer to Investigate Ice and Ocean Structure (SIIOS)** field-tests flight-ready technologies and develops the analytical methods necessary to make a seismic study of Europa and Enceladus a reality. We have been performing small-array seismology with a flight-candidate sensor in analog environments (Fig. B) that exploit passive sources. Determining the depth to a subsurface ocean and any intermediate bodies of water is a priority for Ocean Worlds missions as it allows assessment of the habitability of these worlds and provides vital information for evaluating the spacecraft technologies required to access their oceans.

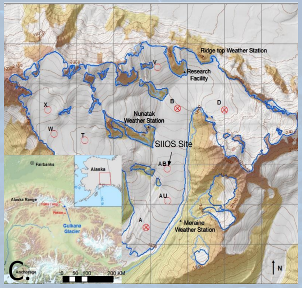


A.

B.

Field Site #1: Gulkana Glacier, Alaska

Our first field study took place in Fall of 2017 at Gulkana Glacier, Alaska . Gulkana is located in the cold, dry continental climate of the eastern Alaska Range and is a USGS "benchmark" glacier, where consistent measurements of mass balance, streamflow and meteorology have been recorded since 1966 [Josberger et al., 2007]. Ice thickness is on the order of tens to hundreds of meters [O'Neel et al., 2014]. Figure 4. Gulkana Glacier is located about 200 km by helicopter from Fairbanks and is also accessible by road to trailheads leading to the field site. Site equipment and accompanying personnel was flown to the site and the remainder of the campaign party took transit by truck and foot for a nominal three-week field campaign.



C.

Despite the relevant differences between this terrestrial and European settings, Gulkana Glacier provides an analog for this experiment in several key ways: ice is present at scales hundreds of meters thick (compared to tens of kilometers on Europa); the motion of the glacier is influenced by diurnal signals; and during the melt season the glacier provides a kilometer-scale region of coexisting ice, water, and silicate material, thereby providing areas with the desired analog seismic contrasts.

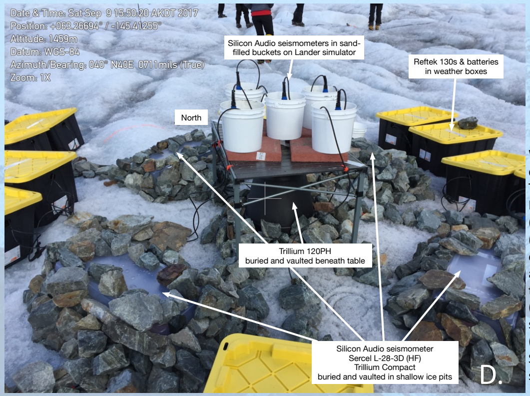
Figure C (*left*) provides a plan view of the glacier and the field-site.

Field Experiment

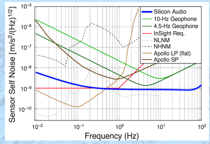
The Gulkana Glacier field campaign generated a 3 week seismic time series of passive and active events acquired by a lander-deployed short aperture array and a conventional short aperture array. From this datasets we will begin developing the flight requirements for a:

(1) Flight-like array geometry, outside of and "within" a mock lander.
(2) Sampling rate, sensitivity and bandwidth.
(3) Lander storage, data processing, and preliminary flight downlink data rate.

This first field-test provides data from a hard-ice surface with a rock-ice interface and mm-scale sub-glacial water. Data from this fieldwork will be used to develop data processing algorithms and estimate realistic data downlink for data ahead of a more intensive field-test in Greenland.



D.

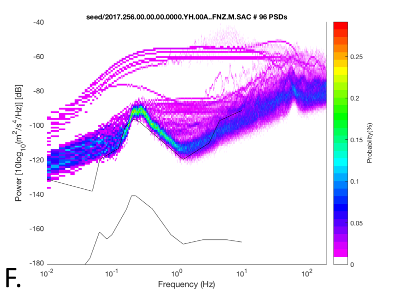


E.

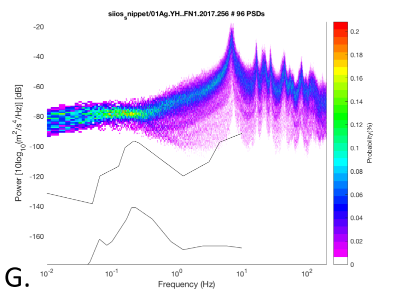
We deployed Silicon Audio seismometers and conventional Sercel L28-3D Short Period and Trillium Compact instruments provided by the IRIS-PASSCAL Instrument Center. Our deployment (Fig. D, *left*) was designed to:

(1) Mimic the orientation of instruments placed on the legs (e.g. in direct contact with the surface) and within the vault of a lander spacecraft, similar to the deployment expected on an Ocean World.
(2) Determine the effective resolution of different sized array geometries.
(3) Evaluate the performance of flight candidate Silicon Audio sensors (Figure E) to traditional seismic instruments in an analog environment.

Preliminary Analysis



F.



G.

The above plots illustrate the seismic spectral analysis based on the calculation of Power Spectral Density (PSD) distribution using a Probability Density Function (PDF) (McNamara and Boaz, 2006) for an on-ground instrument (Fig. F, *left*) vs. an on-lander instrument (Fig. G, *right*). Data were analyzed in 15 minutes over a 24 hour period beginning at midnight on September 13th, 2017. Black lines indicate low noise model (LNM) and high noise model (HNM) of Peterson, (1993). The highest probability of ground motion (greens and reds on the head map) indicate approximately where most of the signal sits. The HNM and LNM are estimates for a noisy global seismic network site and quiet global seismic network site, respectively. The active setting of Gulkana Glacier at the end of the summer melt season clearly is more noisy than the average, however the on-lander instrument is significantly more noisy. The lander structure may act as noise amplifier, and "spikes" seen at frequencies $\geq$10 Hz are most likely resonances with the mock-lander and wind. Any landed spacecraft deploying an in-vault seismometer should be designed so that the spacecraft's peak resonances are outside of the frequencies of interest.

Future Work

Subglacial Lakes in Greenland Ice Sheet

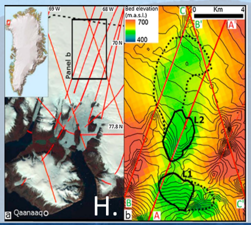
Subglacial lakes are an established and important component of the basal hydrological system of the Antarctic ice sheets, but none had never been reported from Greenland until recently. In summer of 2017 we will investigate a subglacial lake discovered via airborne radio echo sounder (RES) measurements in Northeast Greenland. These unique circumstances make it an ideal field site for the next SIIOS trial.

The primary objectives of a Greenland field campaign is to:

(1) Determine ice and ocean structure of a compelling Ocean World analog site using seismic instrumentation.
(2) Prototype lander-based data reduction methods and the resulting direct to Earth data rate.
(3) Determine lander buffer storage size required to retain time-series for either downlink or reanalysis with updated lander algorithms.
(4) Obtain measurements from the flight-candidate Silicon Audio seismic sensor, as compared to conventional seismic instrumentation.

The active source and passive data from our field seasons in the Greenland will be analyzed using a combination of single station techniques [e.g., Panning et al., 2015] and array processing methods [Rost & Thomas, 2009]. The goal of these methods is to enhance the signal coherence of the data to generate high resolution images of internal structure and to retrieve the location, magnitude, and depth of seismicity. Similar to our first field experiment, in Greenland we intend to demonstrate in situ the advantages and disadvantages of a small aperture seismometer array over a single seismometer and develop requirements for the sampling rate, data reduction methodologies, and operational requirements of such arrays. The algorithms and software developed for our data analysis will be automated to produce data products that simulate those retrieved from onboard processing techniques. Our data reduction objectives are to determine the internal structure and seismicity of icy features at our field sites, determine how the geometry of the field deployment affected our retrieval of these features, and to compare and contrast the performance of a collocated single station and short aperture array in Ocean World analog environments.

Flight-line map and derived bed elevation from northwest Greenland. (a) Regional context of the study area shown on a Landsat image acquired on 1 August 2002, showing radar flightlines (red lines), the ice divide (dashed black line), and the settlement of Qaanaaq (white circle). (b) Subglacial bed elevations (color) derived from airborne ice thickness measurements along flightlines. Black lines delineate contours of basal hydraulic potential; thick black lines show the inferred extent of observed subglacial lakes; and dashed black lines show possible previous larger extent. Radargrams for the labeled flightlines are shown in Fig. H, *right*.



H.

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