ON-LANDER SEISMOLOGY AT AN OCEAN WORLDS ANALOG SITE IN NORTHWEST GREENLAND.
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Introduction: The Seismometer to Investigate Ice and Ocean Structure (SIIOS) project has conducted a series of seismic analog missions funded by NASA's Planetary Science Through Analog Research (PSTAR) program. Analog studies are vital for maturing the experimental concepts that are needed prior to including a seismometer on a landed mission to an icy planetary body. To date, SIIOS experiments have been completed on a mountain glacier in the Alaska range [1] and a subglacial lake on the Greenland ice sheet.

In Summer 2018, the SIIOS project conducted an Ocean Worlds analog mission in Northwest Greenland (Fig. 1) above a subglacial lake located nearly 830 m below the surface of the Greenland ice sheet [2]. The experimental objectives of this study included: 1) Quantify the difference in scientific return between what can be recovered with an array vs. a single sensor. 2) Examine the efficacy of different geometrical configurations of the seismometers within an array. 3) Quantify the difference in scientific return between a seismometer coupled directly to the ice vs. on the lander instrument 'deck'. 4) Compare the performance of a 3-axis flight-candidate Silicon Audio seismometer with traditional seismic instrumentation. And 5) verify the depth and conditions of the lake from independent techniques to validate experimental results. Here we present the analysis that has been performed to achieve Objective #3.

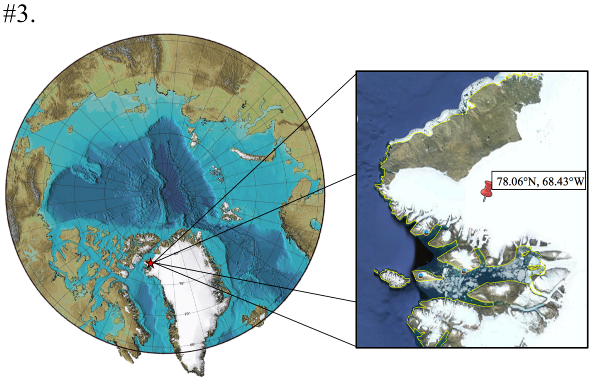

Figure 1: Location the SIIOS field site (78.06° N, 68.43° W) in Northwest Greenland.

On-Lander Seismology Experiment: In terrestrial seismology, the Apollo seismic experiments [3], and the InSight Mars SEIS investigation [4], the sensor is coupled directly to the ground. In contrast, the Viking Mars missions hosted seismometers on a lander spacecraft, which resulted in compromised seismology, mostly from wind noise but also masking noise from the motion of sample arms and diurnal thermal effects [5]. The Viking experiments illustrate the types of risks associated with a lander-hosted seismometer.

Our team has conducted a field experiment to better understand these risks and identify mitigation measures for a lander-mounted seismic experiment. To achieve this, we designed a small mock spacecraft lander for our field experiment. The weight of the lander (~25 kg) under Earth's gravitational acceleration (9.8 m/s^2) generates a normal force comparable to that produced by the proposed Europa lander spacecraft (250 kg) in the lower gravity field of an icy satellite such as Europa or Titan (~1.3 m/s^2). This ensures that the gravitational coupling between the lander and the ground is analogous to a landed spacecraft at one of our planetary targets of interest.

Finite Element Modeling: Prior to our field campaign we performed finite element modeling (FEM) to identify the most critical mechanical interfaces between our lander simulator and the ground (Fig. 2). A lander-mounted seismometer will be coupled to the planetary surface through three major interfaces: 1) Surface to Lander feet. This interface creates an impedance mismatch that might reflect some seismic energy; 2) Lander feet to deck. The lander legs, joints, and attachments combine with the mounting of the deck to the lander presenting a transmission path, which may attenuate or amplify the signal as a function of incoming seismic wave frequency; 3) Deck to sensor mount. Flexure of the deck can amplify seismicity while improper coupling between the instrument and deck will attenuate seismicity.

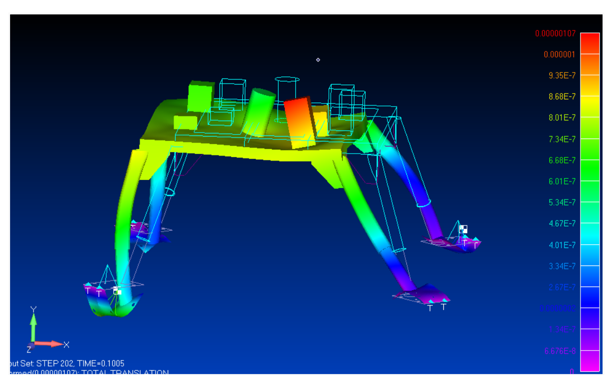

Figure 2: Finite element model of mock lander as it accelerates in response to simulated seismic shaking.

Deploying sensors such that they preserve seismic signals at frequencies of interest and accurately represent ground motion will be critical for on-lander seismology. To that end, we also employed FEM to study the effect of lander design and seismometer placement on the fidelity of acquired seismic signals. The study includes consideration of the lander deck-leg-ground interfaces and the resonant frequency of the lander itself. Our results indicate that mounting a seismic sensor to the stiffest section of a lander deck will minimize amplification caused by deck flexure. The details of the lander design are important for preserving the amplitude, frequency, and polarization of the seismic waveforms. These findings suggest that a cooperative engineering effort is required between the lander structural design and the seismic experiment to enhance the science return. It also suggests that carefully-designed tests of the flight hardware would be useful to validate modeling efforts.

Preliminary Results: Our lander simulator was deployed above the subglacial lake at our field site on the Greenland ice sheet for 10 days from late-May until early June, 2018. Four Silicon Audio seismometers were mounted to the lander—two at different locations on the deck, and two on the "feet". A reference seismometer was buried approximately 30 cm below the lander, providing a baseline against which we could examine seismicity recorded by the on-lander sensors (Fig. 3). The experiment was conducted inside of a 1-m deep buried and enclosed vault, intended to keep the experiment isothermal and minimize noise caused by wind and precipitation.

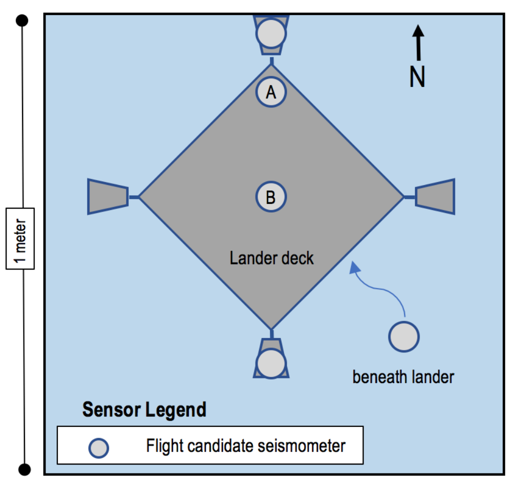

Figure 3. Plan view schematic that illustrates the instrument set-up for our on-lander experiment. Grey circles are the flight-candidate seismometers

Here we show results from one of the four teleseismic events observed during field study. We recorded 4.5mb earthquake which occurred in Western Greenland approximately 1000 km from the SIIOS lander experiment (64.96° N, 51.75° W) on 6/04/2018 at 22:49:26 UTC. We calculate the coherence of the z-component sesimograms between each on-lander sensor and the in-ground reference sensor (Fig. 4). Results show the preservation of seismic signals from the on-lander instruments up to the lowest resonance frequency of the lander. These results are consistent with prior experiments which demonstrate the scientific viability of on-lander seismology for planetary exploration [6]. They also confirm results from FEM—that is, in the vertical channel we see better coherence between the in-ground reference sensor and the on-lander seismometer mounted at the stiffer corner of the deck.

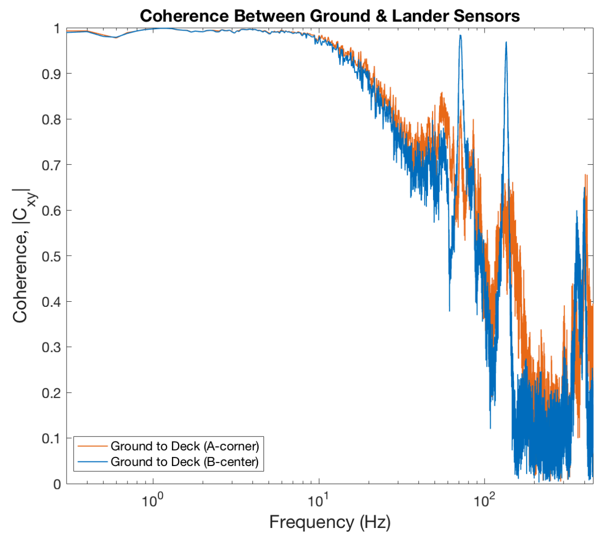

Figure 4. Coherence of both seismometers mounted to the deck with the in-ground reference instrument during the first 3 seconds of the 4.5mb event that occurred at 64.96° N, 51.75° W on 6/04/2018 at 22:49:26 UTC. Both on-lander sensors demonstrate high-coherence with the reference in-ground sensor across frequencies of interest.

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References: [1] Marusiak et al., This Meeting. [2] Palmer, S. J., et al., Geophysical Research Letters 40.23 (2013): 6154-6159. [3] Nakamura, Y. et al Journal of Geophysical Research: Solid Earth 87.S01 (1982): A117-A123. [4] Panning, M. P., Icarus 248 (2015): 230-242. [5] Lorenz, R. D., et al. Earth and Space Science 4.11 (2017): 681-688. [6] Panning, M. P. and Kedar, S. (2019). Icarus, 317, 373-378.