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Spacecraft Seismology at an Ocean Worlds Analog Site

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Abstract

Recently proposed landed missions to outer solar system ocean worlds have included seismic sensor payloads [1][2]. Seismometers are uniquely suited to determine the depth to a subsurface ocean and any intermediate bodies of water. Here we present results from a seismology experiment at an ocean worlds analog site in Northwest Greenland. In particular, we focus on the efficacy of lander-mounted seismic payloads to recover teleseismic signals and subsequently constrain the depth to an ice-water interface.

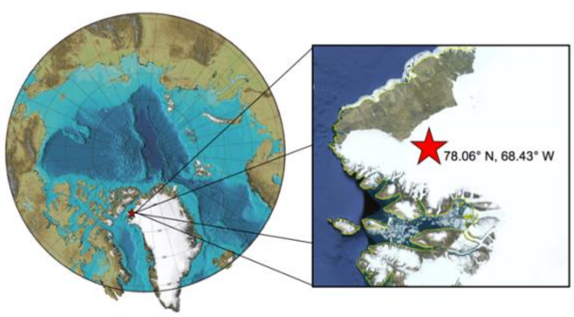

Figure 1. Location the SIIOS field site in Northwest Greenland.

1. Introduction

The Seismometer to Investigate Ice and Ocean Structure (SIIOS) project is conducting a series of seismic analog missions funded by NASA's Planetary Science Through Analog Research (PSTAR) program. To date, we have completed experiments on a mountain glacier in the Alaska range [3] and a sub-glacial lake on the Greenland ice sheet (Fig. 1). Analog studies are vital for maturing the instrument and experimental designs that will be needed prior to including a seismometer on a landed mission to an icy planetary body.

In Summer 2018, we conducted an ocean worlds analog mission in Northwest Greenland above a sub-glacial lake located nearly 830 m below the surface of the Greenland ice sheet [4]. One experimental objective of this study included quantifying the difference in scientific return between a seismometer coupled directly to the ice through burial, versus sensors mounted to the lander deck and feet. Here we present early analysis that has been performed to achieve that objective.

2. Motivation

In terrestrial seismology, the Apollo seismic experiments [5], and the InSight Mars SEIS investigation [6], the sensor is coupled directly to the ground. Recent mission concepts such as the Europa Lander and Dragonfly have proposed including seismic payloads mounted to a spacecraft, either on the feet or within the spacecraft itself [1][2]. Like these mission concepts, the Viking Mars missions hosted seismometers on a lander spacecraft, which resulted in a high degree of environmental noise on the instruments, mostly from wind exciting spacecraft resonances, but also noise from the motion of sample arms and diurnal thermal effects [8]. The Viking experiments illustrate the types of risks associated with a lander-mounted seismometer.

Our team has conducted a field experiment and finite element analysis (FEA) 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 in Northwest Greenland. 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. Prior to our field campaign we also performed FEA to identify the most critical mechanical interfaces between our lander and the ground.

3. Results

The FEA shows that our spacecraft-hosted seismometers will be coupled to a planetary surface through three interfaces: 1) Surface to lander feet; 2) Lander feet to deck; 3) Deck to sensor mount. We considered these interfaces when identifying how best to deploy the seismic sensors.

Our spacecraft lander 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 flight-candidate 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. 2 inset). The lander experiment was deployed inside of a buried and enclosed vault (depth 1 m), intended to keep the experiment isothermal and minimize noise caused by wind and precipitation.

Here we show results from one of the four teleseismic events observed. We recorded 4.5mb earthquake which occurred in Western Greenland ~1000 km from the field experiment (64.9643° N, 51.7498° W) on 6/04/2018 at 22:49:26 UTC. For this event, we compare the seismograms between one of the foot-mounted sensors, two on-deck sensors mounted in different locations, and the buried in-ice reference sensor. Results show the preservation of seismic signals from all three of the spacecraft-hosted instruments up to the lowest resonance frequency of the lander (Fig. 2, 3). This is consistent with prior experiments that demonstrate the scientific viability of spacecraft-hosted seismology for planetary exploration [6]. Intriguingly, the performance of the seismic sensor mounted on the foot and in contact with the ice is nearly equivalent to the sensors mounted above the foot on the spacecraft deck. This indicates that direct contact with the ground is not necessary for on-lander seismometer to recover teleseismic signals, and that optimal sensor placement may vary per a spacecraft's mechanical design.

Acknowledgements

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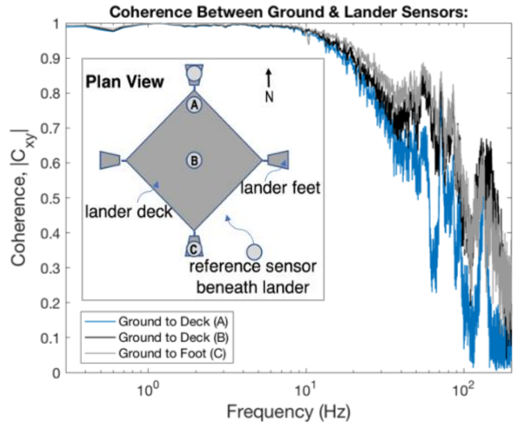

Figure 2. Coherence of each lander-mounted sensor (z-axis) with the buried reference sensor during 30 sec of the 4.5mb event on 6/04/2018 22:49:26 UTC. All sensors demonstrate high-coherence with the buried reference sensor at frequencies of interest. A plan view of the experimental setup is shown in the inset.

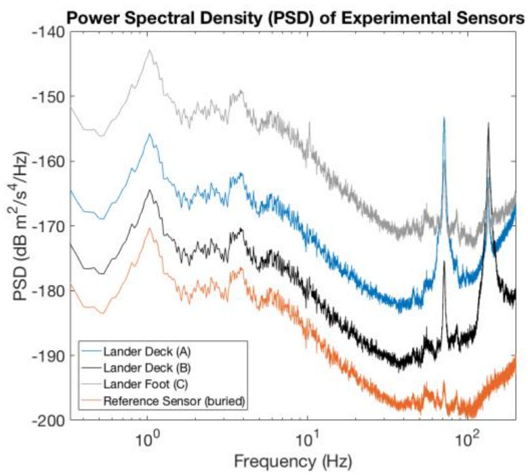

Figure 3. PSD function of each sensor (z-axis) during the 4.5mb event on 6/04/2018 22:49:26 UTC. The offset between each curve shows the amplifying effect of the lander. Otherwise, lander-mounted sensors only differ significantly from the reference sensor at the spacecraft resonant frequencies.

References

[1] Hand et al., JPL D-97667, 2017. [2] Turtle et al., LPSC 2017, 1958. [3] Marusiak et al., LPSC 2019, 1546. [4] Palmer et al., GRL 40.23, 2013: 6154-6159. [5] Nakamura et al JGR, 87.S01, 1982: A117-A123. [6] Panning et al., Icarus 248, 2015: 230-242. [7] Lorenz et al., ESS 4.11, 2017: 681-688. [8] Panning & Kedar, Icarus, 317, 2019: 373-378.