INSIGHT LESSONS ON SCIENCE POTENTIAL FROM ON-DECK OPERATION OF A BROADBAND SEISMOMETER.

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Introduction: The InSight mission to Mars is now returning seismic data from another planetary body for the first time since Apollo lunar data and Viking Mars data from the 1970's but with broadband measurements (see e.g. [1, 2] for a review of planetary seismic applications and [3] for the SEIS instrument). Part of the reason for the lack of planetary seismic deployments is a perceived complexity of seismic instrumentation in order to have extremely sensitive instruments well-coupled with ground motion. A large reason for this perception is the lack of clear identification of Marsquakes in the Viking data [4], and the final report of the Viking seismology project [5], which identified direct coupling to the ground as an important future consideration to move beyond the Viking seismometer. However, as discussed in [6], there were other features of the Viking seismology project that hampered its ability to detect internal events, primarily the relatively low sensitivity of the instrument strongly peaked near a resonant frequency of 3 Hz [4], as well as the fact that much of the data was sent back in a compressed event mode consisting of an envelope amplitude sent back at approximately 1 Hz and a count of positive-going zero crossings [7], which prohibits modern digital waveform processing.

Given the significant deployment complexity of surface instrument placement, though, it's important to better constrain the science potential of high-quality seismometers mounted on a spacecraft to achieve science objectives. While InSight has now deployed its seismic instrument package (Seismic Experiment for Internal Stucture, or SEIS) on the surface, the short period instrument (SP) successfully operated on the deck, providing an excellent test for determining science potential for future landed missions.

On deck InSight SP instrument operation: Because the SP seismometers of the SEIS instrument package have tilt tolerance up to 15° [3], they were able to run on the deck of the lander without leveling while sites for surface placement were selected. While temperature limitations and other operational concerns prevented continuous operation, over 47 hours of data was recorded over a 3-week period on the deck. While this data does not cover all portions of the diurnal cycle, it includes periods both before and after sunset and covering a range of atmospheric noise conditions. This dataset is powerful for understanding the noise characteristics of deck-deployed seismometers and can be used to better understand the science potential of future seismic deployments on landed assets on Mars and other planetary bodies, including for airless bodies when the calmest periods recorded by InSight are considered.

Test deployment on Mars Science Laboratory engineering model: While InSight will allow us to compare deck and surface operation of seismic instrumentations, it does not allow for simultaneous operation on both the ground and deck. This prevents a direct understanding of the transfer function of ground motion to a deck-deployed seismometer. However, we performed a similar test on Earth on the engineering model of the Mars Science Laboratory (MSL) "Curiosity" rover ([6] and figure 1).

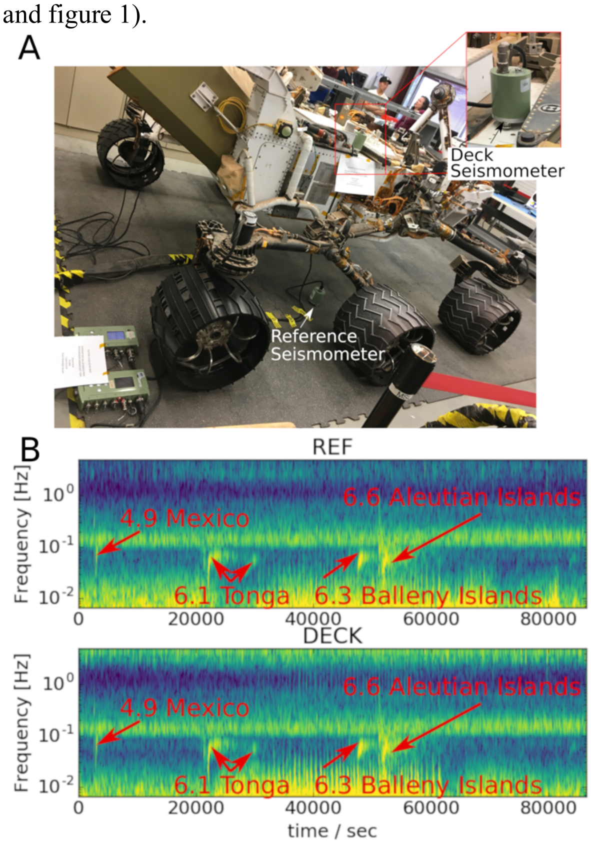

Figure 1: Test deployment of Trillium compacts on the deck of the MSL engineering model and immediately below (A). Spectrograms of both show clear correlation of ground signals through seismic band (B). Figure adapted from [6].

Comparison of the deck-deployed seismometer with one immediately below the rover showed nearly identical recordings of earthquake signals (figure 1). In fact, the transfer function is near 1 for much of the seismic band of interest between a period of 30 seconds up to the beginning of resonant frequencies near 3 Hz (figure 2). There are important differences, however, between day and night observations due to air motion from climate control in the hangar where the engineering model is kept (figure 2), providing an interesting analogue to how wind and pressure noise on Mars may impact the measurement of ground motion.

While the design of the surface assets for MSL and InSight are obviously quite different, observed noise characteristics of on-deck data from Mars suggest similar reduction in power spectral density below resonant frequencies. This suggests excellent coupling with ground motion below the resonant frequencies of the lander itself, emphasizing the potential for a deck seismometer to record potential marsquake signals.

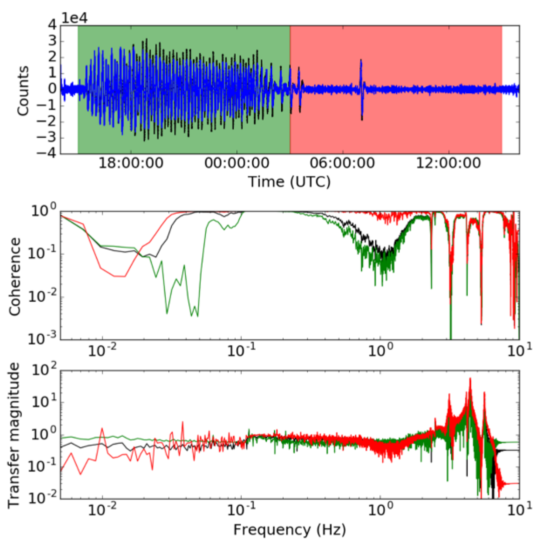

Figure 2: Deck and reference seismograms from [6] for one 24 hour cycle (top) including a noisier daytime (green) and quieter night (red). Coherence between the seismograms (middle) suggests strong consistency between the 2 signals at all times between 30 and 3 second period, although coherence is reduced near 1 Hz during the day. The transfer function amplitude (bottom) is near 1 through this band of high coherence.

Comparison with anticipated seismic signals and evaluation of science potential: While the total duration of on-deck recording during the InSight mission was relatively short, the noise statistics derived from this data can be compared with expected amplitudes of seismic signals (e.g. [3]) and seismicity rates (e.g. [8, 9, 10]), and eventually with measured rates of seismicity derived from InSight surface operations. This will permit prediction of event detection rates for a deck-deployed seismometer, allowing for quantitative assessment of the science potential of such a seismometer in future missions as a function of measurement timing and duration. We can also better establish instrument sensitivity requirements in order to record seismically relevant signals in the quietest frequency bands and times of day.

Signals will also be correlated with simultaneous recordings from the pressure sensor and other meteorological instrumentation of the InSight mission, which will allow for better understanding of the best times for seismic observation relative to the atmospheric dynamics of Mars.

Other planetary applications: While this data only directly constrains the science potential of deck seismometers on Mars, the basic conclusions of good recovery of ground motion below lander resonances apply to any landed mission. In fact, deployment on airless bodies, such as the icy moons Europa or Enceladus or Earth's moon may be able to achieve much lower noise levels, while a deployment on Titan or Venus with much thicker atmospheres may be more challenging.

Summary:

Sitting on the deck
Planet shakes lander and me
Science can be done

References: [1] Lognonné, P. and Johnson, C.L (2015) *Treatise on Geophysics*, 65–120. [2] Lognonné, P. and Pike, W.T, (2016) *Extraterrestrial Seismology*, 36–48. [3] Lognonné, P. et al (2019) *Space Sci. Rev.*, in press. [4] Anderson, D.L. et al. (1977) *JGR, 82*, 4524–4546. [5] Lazarewicz, A.R. et al. (1981) *NASA Contractor Report 3408*. [6] Panning, M.P. and Kedar, S. (2019) Icarus, 317, 373–378. [7] Lorenz, R.D. et al. (2017) *Earth Space Sci., 4*, 681–688. [8] Golombek, M.P et al. (1992) *Science, 258*, 979–981. [9] Knapmeyer, M. et al. (2006) *JGR, 111*, E11006. [10] Panning, M.P. et al. (2015) *Icarus, 248*, 230–242.

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