IMPACT DETECTION WITH INSIGHT: UPDATED ESTIMATES USING MEASURED SEISMIC NOISE ON MARS.

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Introduction: The InSight spacecraft successfully landed on Mars on 26th November 2018 in the Elysium Planitia region. InSight is the first geophysics focused mission to Mars and deployed sensitive seismometers directly onto the surface: the Seismic Experiment for Interior Structure (SEIS) package [1]. SEIS comprises dual three-component seismometers: a very broad band (SEIS-VBB) instrument for long and intermediate seismic periods; and a short period (SEIS-SP) instrument for short and intermediate seismic periods. The primary science goals of InSight are to determine Mars' internal structure, measure the current seismic moment release rate, and improve estimates of the present day impactor rate [1,2].

Positive identification of seismic signals generated by meteorite impacts are of key importance to the mission science goals for a number of reasons: 1) they will improve our knowledge of the present-day meteoroid flux, which is critical for dating recently geologically active surfaces via the crater counting method [2,3]; 2) the impact-generated seismograms will improve our knowledge of the crater forming process and inform numerical models [4,5]; and 3) if an impact event can be detected in both a seismic recording and in orbital imaging, the accurate source location can be used to more accurately constrain Mars' interior structure and physical properties of the subsurface.

A critical unknown in determining the likely number of impacts that InSight will detect is the ambient seismic noise. This noise is expected to be dominated by atmospheric wind and pressure variations, and a wind and thermal shield (WTS) will be deployed over the SEIS instruments to minimize this noise [1]. The SEIS-VBB and SEIS-SP were designed to have noise floors of 10^{-9}-10^{-8} $ms^{-2}/Hz^{-1/2}$, which are expected to be lower than the nominal ambient noise floor on Mars once the WTS is deployed, so that the instrument sensitivity would not limit the science return. However, predictions of Mars' noise environment are challenging due to many unknowns and so contain at least an order of magnitude error. Noise is also expected to be highly variable and is expected to be highest during the daytime when the atmosphere is more turbulent and winds are stronger.

On 18th December 2018 the SEIS instruments were successfully deployed onto the surface (Figure 1). Once the WTS is installed in January 2019 we will be able to measure the environmental noise directly as a function of local solar time. This will allow us to more accurately predict the number of impacts that InSight is likely to detect over the mission and will aid efforts to identify impact-generated seismic signals in the data. Here, we update our impact detection rate estimates for the actual noise levels on Mars and consider how we might identify these signals from tectonic and other events in the recorded waveforms.

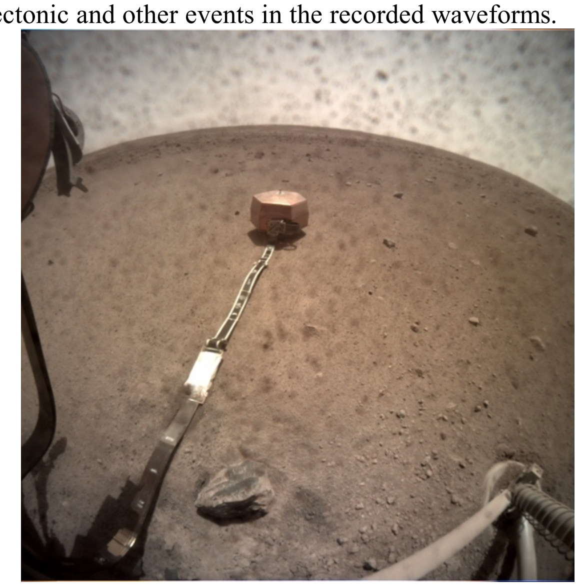

Figure 1: SEIS instrument package deployed onto Mars' surface. SEIS is clear of the lander, so lander related noise should be minimized. Further noise reduction will be achieved using the WTS, to be deployed Jan 2019. [Image credit: NASA, JPL-Caltech.]

Current Impact Rate: Present-day impact rates can be estimated using before-and-after orbital imagery [6]. Impacts into dust covered surfaces produce short-lifetime dark areas that can be identified in 6m resolution MRO-CTX data for example, with more accurate crater diameters determined using follow-up 0.25m resolution MRO-HiRISE images. This technique includes some detection bias as it requires dusty surfaces and smaller craters are more difficult to identify [6]. However, this method successfully determines a lower limit on current impact rates that is within a factor of three of previous lunar impact rate extrapolations [3,6,7].

Existing Impact Detection Rate Estimates: Converting the present-day impactor rate into a detection rate by the InSight seismometers introduces additional uncertainty from two main sources: 1) the unknown environmental noise levels; and 2) the amplitude of generated seismic waves for a given impact crater. Pre-landing estimates of the seismic noise of 10^{-9}-10^{-8} $ms^{-2}/Hz^{-1/2}$ were used by [7] and [8] to independently determine the seismic detection range of a given crater using different methods. [7] uses empirical scaling laws based on lunar/terrestrial impacts, missile tests, and explosions to determine a relation between impact energy and seismic amplitude as a function of distance, whereas [8] use amplitude estimates based on Apollo impact observations, corrected for differences between Mars and the Moon [9]. These two independent methods give comparable predictions (Figure 2), but have large uncertainties due to the unknown noise levels. The methods predict ~1 large globally detectable impact and ~10 small regionally detectable impacts per year, with an order of magnitude uncertainty [2].

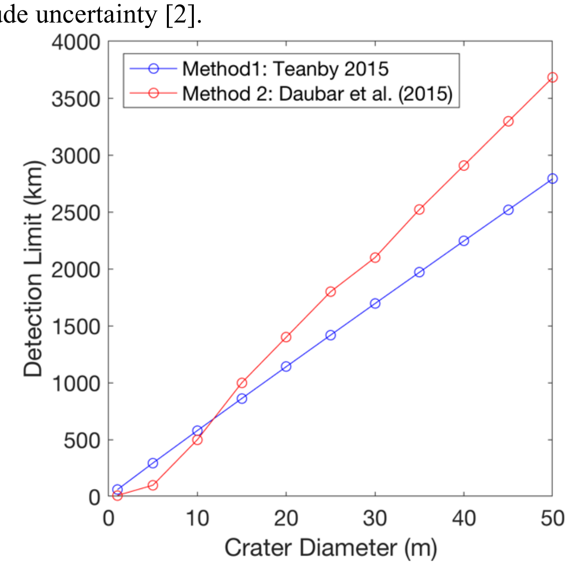

Figure 2: Estimated prediction of crater seismic detection range with SEIS using two independent methods [7,8]. Methods are generally consistent and show that small (~10m diameter) craters should be detectable at regional scales (<1000km), whereas a large impact event (>50m) will be required for a global scale detection. [Redrawn from [2].]

Updated Impact Detection Rate Estimates: Following the WTS deployment in January 2019 the ambient seismic noise level will be characterized as a function of time of day. This will allow existing predictions to be updated using realistic deployment conditions. We will present these updates and consider the implications for the InSight mission science goals.

Impact Identification: The measured noise level will tell us if a particular event will be detectable above the noise. However, there are likely to be many other types of seismic signals including marsquakes, atmospheric events, and lander generated signals. Therefore, it will be challenging to positively identify impacts events in the seismic record. Our approach to impact identification will be to consider a set of “impact discriminators”, drawing on terrestrial work for test ban treaty monitoring [2]. These discriminators will include: 1) First motion. The positive pressure pulse from an impact should result in a positive first motion (away from the source). 2) S-wave energy. Impacts should produce less shear wave energy than marsquakes due to the lack of double-couple source. 3) Surface wave to body wave magnitude ratio. A marsquake should produce more surface wave energy than an impact event. 4) Frequency content. Impacts and marsquakes will have very different source mechanisms and a resulting difference in the frequency content. In general distant recordings of impacts are expected to have a lower corner frequency than tectonic events [10]. 5) Depth phases. Marsquakes are likely to have non-zero depth, whereas impacts occur at the surface, which should result in secondary reflections for marsquakes but not for impacts. It is important to note that these conditions are individually non-unique and will depend on the source mechanism and event orientation with respect to InSight. Therefore, all discriminators must be considered together to form an impact metric. The final definitive identification of an impact must thus rely on identification of a new crater in before and after orbital imagery.

Summary: We will present updated impact detection predictions using the measured noise from InSight’s SEIS instrument package (SEIS-SP and SEIS-VBB). These will be more accurate than the pre-landing predictions [7,8], which included significant error margin for the uncertain noise levels. We will also consider perspectives for impact event detection and discrimination in the InSight seismic data.

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