BUILDING MARTIAN SEISMOGRAMS FROM CALIFORNIA AND NEVADA SEISMIC EVENTS: inversion of the Californian crust using InSight Mars Structure Service routines.

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Introduction: On Mars, contrary to the Earth, the interior is poorly constrained. Based on terrestrial experience, a few geophysical data (k_2, mass, moment of inertia) and geochemical analysis of Martian meteorites, allowed to establish the existence of the main discontinuities of the crust, the mantle and the core [1]. However, the chemical state of the core, either liquid or solid, is uncertain and its size has a 200 km uncertainty range. The crustal thickness is still under debate considering different visco-elastic models.

Successfully landed on Mars on past November 26th 2018, the NASA's Discovery Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission is dedicated to the study of the Martian interior. The main instrument, the Seismic Experiment for Interior Structure (SEIS) seismometer is designed to record the Martian seismic activity from different seismic sources : atmospheric turbulences, meteorite impacts and tectonics/thermal contraction.

The understanding of the seismic source characteristics is mandatory to constrain the deep interior of the planet. Since SEIS will be the lonely seismometer at the surface of Mars, the inversion approaches are different from what is performed on Earth, where the large seismic networks allow robust triangulation methods. Therefore, the greater uncertainties on Mars, and the non linearity of the problem (single station), imply the use of probabilistic inversion process such as Markov chains Monte Carlo (McMC) methods. In order to efficiently process the incoming SEIS data, the InSight collaborators (MSS and MQS teams) are developing tools to compute the seismic properties, *i.e.* the source distance, depth and initial time and the seismic velocities ([2], [3] and [4]).

Pending for the first Martian seismic records, we propose to use transformed Earth data, such as California large earthquakes and Nevada nuclear events. The dataset stands for faulting activity and meteorite impacts sources respectively. To mimic real Martian record, three processing are made on the raw data. The arrival times of body waves and surface waves are then extracted from the "Martian seismograms" and implemented in the MSS inversions algorithms. We finally compare the resulting inverted crustal model to the previously published regional models of California.

Data selection: Only 1-2 large marsquakes of M_w > 3.5 and about 10 quakes of M_w > 4 are expected to occur during the nominal mission [2], the small quakes with lower magnitudes are likely most detected.

For this reason, we focus on medium-sized marsquakes (M_w 3-4) resulting from the faulting activity (*i.e.* Cerberus Fossae graben system). We also consider the seismic contribution of the meteorite impacts, as they are easier to localize and possibly more frequent (M_w 1-3). Due to the high energy of the oceanic noise of the Earth, the direct use of a noisy M_w 1-4 terrestrial event to obtain an equivalent medium marsquake is not realistic. Thus, higher magnitude events are chosen to avoid this loss of signal:

1. Marsquakes induced by fault seismicity are modeled from 8 large Californian earthquakes of M_w > 6. California is indeed the region with one of the largest seismic network and is characterized by a constant and intense seismic activity. Moreover, the crust has been modeled by tomography and field observations [5].
2. In Nevada, on the 1951-1992 period, dozens of nuclear tests per year were performed, with large range of intensities. The resulting craters are very similar to Martian ones. We select 15 nuclear tests larger than 100 kt (or an equivalent M_w > 4) to model meteorite impacts.

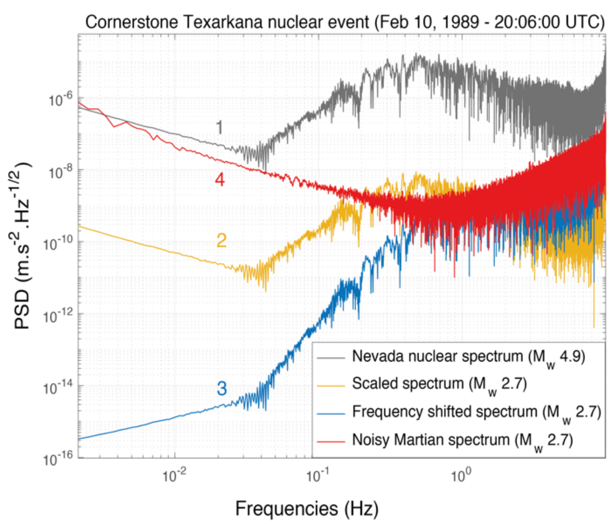

Figure 1. Power spectral density representations of the different transformation steps for the M_w 4.9 Cornerstone Texarkana nuclear event (Feb 10, 1989). The initial signal is in black and the final one is in red.

We select the seismic station PAS (34.14°N, 118.17°W), which recorded our 23 events and acts as our single station detecting the data to be inverted. The station is located on Quaternary deposits to reduce the possible seismic site effects.

Data transformation: The figure 1 displays the following transformation steps: (1) → (2) First, Martian seismograms are computed by scaling the original terrestrial spectrum with the magnitudes difference between the earthquake/nuclear event and the target marsquake /impact. (2) → (3) The second transformation is a frequency shift towards higher frequencies using the Brune Model (1970) of the source spectrum, and based on the cutoff frequencies of the initial Earth and the target Martian quake. (3) → (4) Finally, the Martian noise calculated by [6] is summed to the signal. The noise is taken during the night where it is minimal.

Source inversion: In order to retrieve the source location Δ and the seismic model, we use the probabilistic inversion method developed by the MSS team, based on the Bayesian inference and McMC algorithm [2], [3]. The difference of body waves/surface waves arrival times controls the misfit calculation of the model. 3 to 4 seismic events are inverted at the same time, with 1 marsquake and 2 to 3 impacts.

Inversion inputs: From the Martian seismograms we generated, we extract the arrival times of body waves, and that of the Rayleigh waves train (R1) at 5 and 10 seconds. Body waves arrival times (first P, first S and pP waves) are picked manually on the filtered signals and with the help of spectrograms visualization. R1 arrival times are also picked on filtered seismograms. The epicentral distance Δ is known in the case of nuclear events/meteorite impacts and allow to impose another constraint in the misfit calculation. In fact, the meteorite craters are expected to be easily located during the InSight mission thanks to MRO HiRISE remote sensing detections.

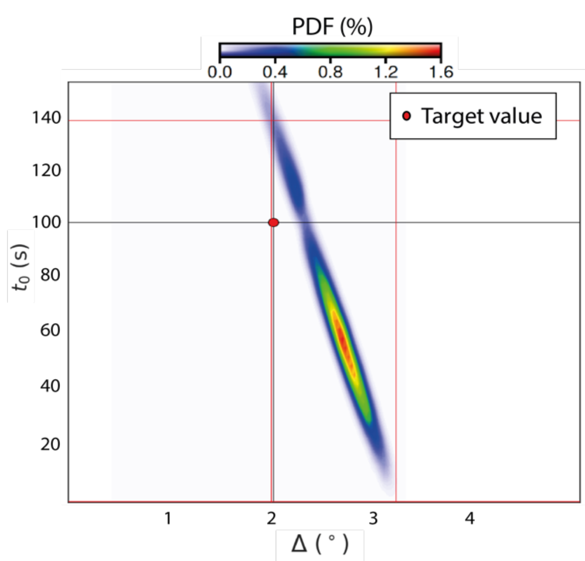

Figure 2. Correlation graph of Δ and t_0 calculated for a single meteorite impact M_w 2.3 event Sculpin Bexar (April 4, 1991). The probability density function (PDF) is the colored area describing the most probable resulting configuration. The red dot is the target source parameters (Δ^{obs} = 2.02° and t_0^{obs} = 104 seconds). Red lines represent the standard deviation 2σ. Figure is not to scale.

Preliminary results and discussion: The figure 2 displays the preliminary results obtained on Δ, with a single near-field nuclear event example and a fixed internal model (1D California crustal model from averaged SCEC 3D model [5], on top of PREM **[7]**). The boundaries on Δ and t_0 domains were set wide on purpose (0 to 90° and 0 to 500 seconds) to verify the convergence of the model. Note that Δ and t_0 are highly dependent of this preliminary model. We plan to directly invert the seismic model in the near future.

The inversion ended with an error of less than 5% in the evaluation of Δ which is a good estimation for a single station-event approach. The addition of 2 or 3 events is expected to greatly enhance the accuracy of the source parameters calculation, especially with known Δ^{obs} as inputs for meteorite impacts. California and Nevada are subjected to large site effects with San Andreas, Basin and Range or Coast range structures, which certainly impact the seismic waves propagation behavior (low-velocity zones in desert lands and denser materials in mountains). The use of a fixed PREM model in the inversion is not consistent with these local seismic variations.

We will present new results by varying the model in the inversion process, in order to constrain both the location of the seismic event and the seismic model of the Californian crust.

References:

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