NESF2020-059

Obtaining Robust Seismic Constraints in Planetary Exploration: The Full Waveform Perspective

D. Kim, V. Lekic, N. Schmerr
University of Maryland, College Park, MD

OVERVIEW

Our overarching goal of this research is to develop and evaluate an active seismic imaging approach that can maximize the utility of seismic waveform data while quantifying uncertainties of inferred subsurface properties. The successful implementation of this method and its validation in a planetary analog environment will inform future geophysical exploration of the SSERVI target bodies.

PLANETARY ANALOG EXPERIMENTS

Planetary analog studies allow assessment and refinement of geophysical methods for planetary exploration. The Geophysical Exploration of the Dynamics and Evolution of the Solar Systems (GEODES) SSERVI is focusing on the San Francisco Volcanic Field (SFVF), Flagstaff, AZ as an analog environment (Fig. 1) appropriate for developing geophysical exploration strategies for upcoming lunar science missions.

Figure 1. ASTER image of SP Crater lava flows interacting with graben in the SFVF, Flagstaff, AZ.

OFF-EARTH SEISMIC EXPLORATION

Seismic studies have been carried out on the Moon by the *Apollo* missions and on Mars by the *InSight* mission (Fig. 2). Shallow subsurface properties of both bodies have been probed by identifying the arrival times of artificially generated seismic waves. While this approach allows a straightforward processing scheme and can map out discontinuities in the shallow subsurface, much more information about subsurface structures can be extracted from the complete waveforms. When interpreting seismic images of the subsurface in terms of physical properties and processes, it is crucial to adequately quantify uncertainty; however, this can be extremely challenging due to trade-offs and non-uniqueness inherent to seisimc inversion.

Figure 2. Active seismic surveys from Apollo (top) and InSight missions (bottom).

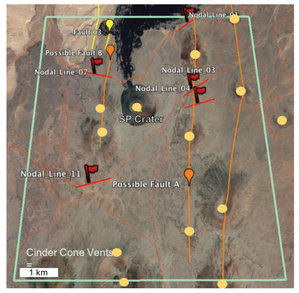
THE FULLWAVEFORM PERSPECTIVE

Full waveform simulation is very time consuming. However, it is also a very powerful way of extracting information from seismic waveforms. Interesting target structures, such as voids, fracture networks, and volatile deposits, are particularly challenging to image and require the exploitation of waveform information and not just first-arriving traveltimes.

Figure 3. The Deepthought High-Performance Computing (HPC) cluster at University of Maryland

METHOD DESCRIPTION: EPICYCLE WAVEFORM INFORMATION EXTRACTION (EWIE)

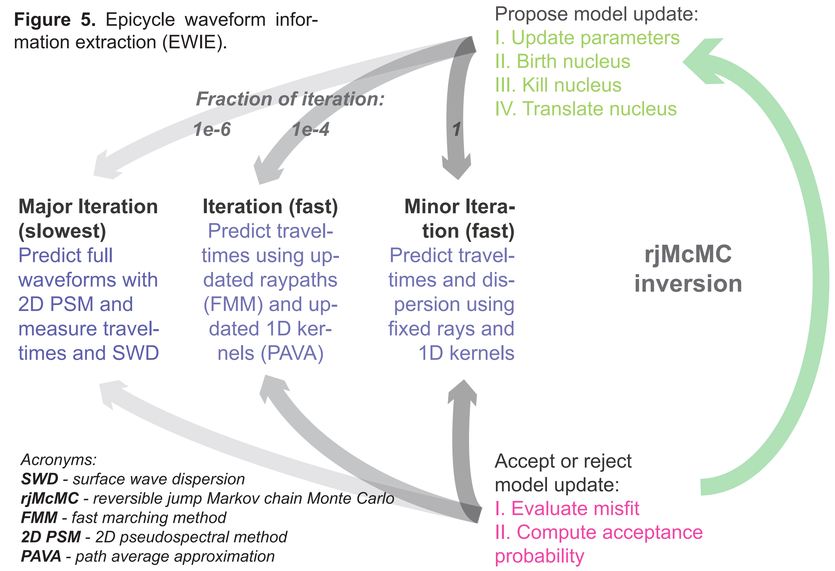
We present a hybrid, full wave inversion (FWI) approach that leverages multiple levels of approximation to carry out **epicycle waveform information extraction (EWIE)** using a transdimensional, Bayesian inversion (TBI) technique (Fig. 5). TBI enables uncertainty quantification and non-uniqueness assessment that is not possible with traditional optimization-based approaches. The Voronoi-cell parameterization adapts in complexity and geometry during the inversion, and allows for straightforward extension to other geophysical observables (e.g. gravity).



We focus on active-source seismic data acquired on linear arrays of 51 3-component 5Hz geophones deployed in 1-km transects across several target structures in the SFVF.

Figure 4. SFVF active source survey (Bell et al., 2019, LPSC abstract). Known and possible faults are shown by yellow and orange lines, respectively. Yellow circles indicate volcanic vents. 1-km seismic arrays are shown in red lines.

Figure 5. Epicycle waveform information extraction (EWIE).



SYNTHETIC TEST WITH TARGET SFVF MODEL

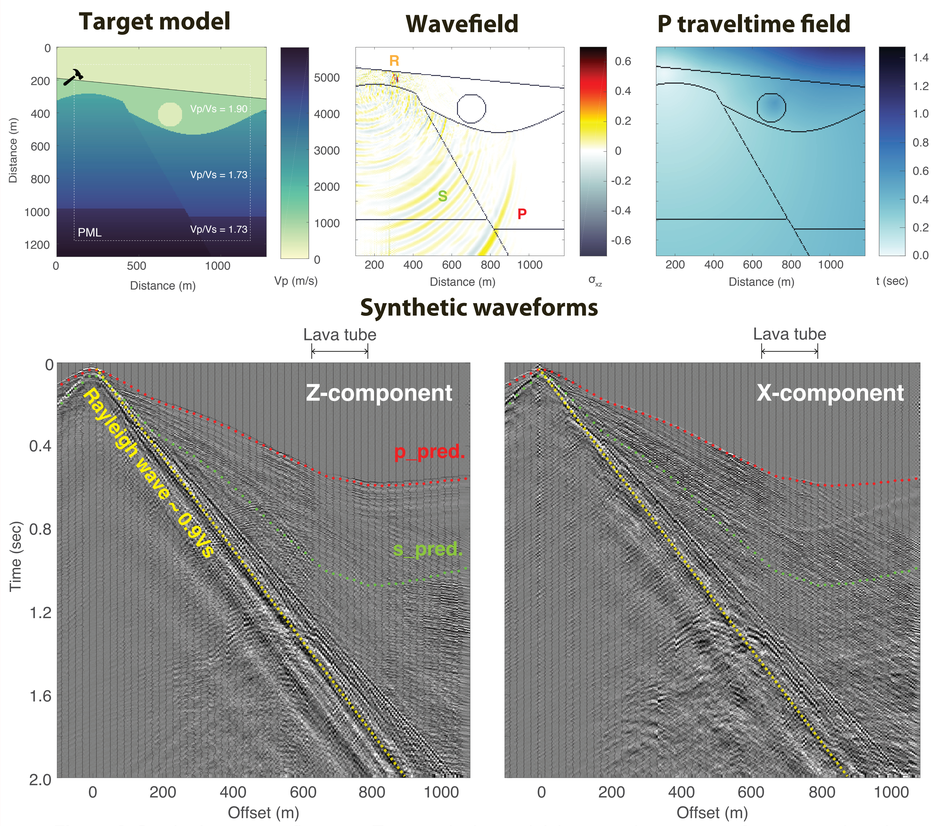


Figure 6. Synthetic test as a first step. Target velocity model that contains a range of structures thought to be relevant for the SFVF (e.g., topography, faults, lava tubes, deep reflector etc.) while retaining the geometry of the active seismic experiment (Fig. 4). Synthetic waveforms are generated using the pseudospectral method in 2D (kWave).

INITIALIZING MODEL

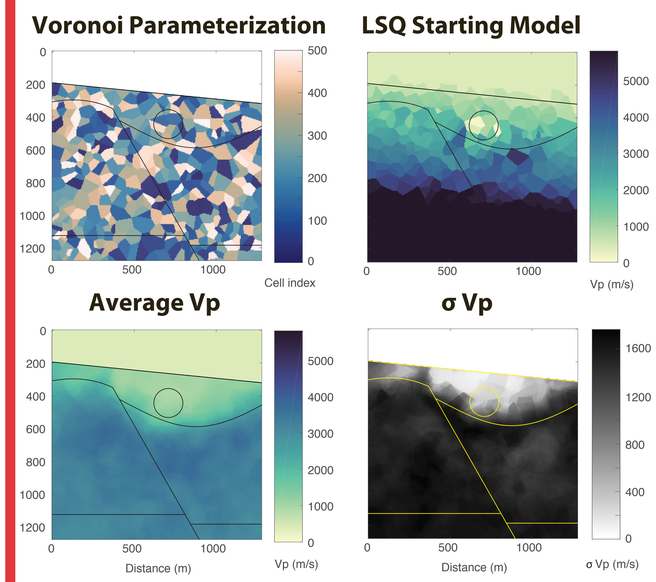


Figure 7. Parameterization with Voronoi cells (top left) is flexible and adapts in complexity and geometry during the inversion. Input and output models from rjMCMC inversions using just P arrival times as a constraint. EWIE enables uncertainty quantification, such as estimating the standard deviation of the Vp estimates (bottom right).

WORK IN PROGRESS

I. Refinement of EWIE by implementing both S-wave and SWD measurements.
II. Application to data collected by the SFVF experiment (Fig. 4).
III. Extension to joint inversion with other available geophysical measurements (e.g., gravity, GPR, etc.).