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Determining crust and upper mantle structure by Bayesian joint inversion of receiver function and surface wave dispersion at a single station: preparation for data from the InSight mission

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1. Abstract

The InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission will deploy a geophysical station on Mars in 2018. Using seismology to explore the interior structure of the Mars is one of the main targets, and as part of the mission, we will use 3-component seismic data to constrain the crust and upper mantle structure including P and S wave velocities and densities underneath the station. We will apply a reversible jump Markov chain Monte Carlo algorithm in the transdimensional hierarchical Bayesian inversion framework, in which the number of parameters in the model space and the noise level of the observed data are also treated as unknowns in the inversion process (Panning et.al., 2017). Bayesian-based methods produce an ensemble of models which can be analyzed to quantify uncertainties and trade-offs of the model parameters (e.g. Bodin, et.al., 2012; Kolb and Lekic, 2014). In order to get better resolution, we will simultaneously invert three different types of seismic data: receiver functions (RF), surface wave dispersion (SWD), and ZH ratios (ZH). Because the InSight mission will only deliver a single seismic station to Mars, and both the source location and the interior structure will be unknown, we will jointly invert the ray parameter in our approach.

2. Theory & Method

2.1 Bayesian Inversion

$p(m|obs) \sim p(m) \bullet p(obs|m) \quad posterior \sim likelihood \bullet prior$

2.2 Data Space

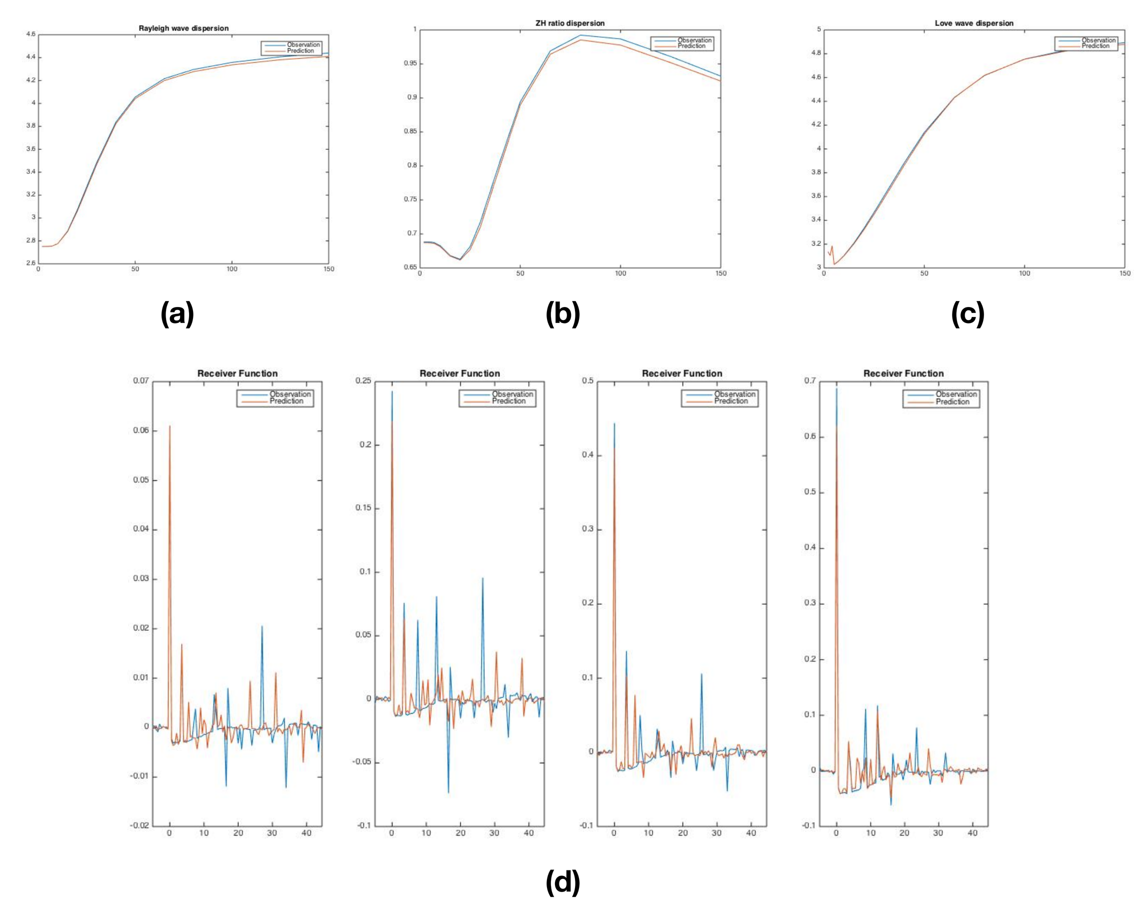


Figure.1 (above): Different data used in the Bayesian inversion: (a) Rayleigh wave dispersions, (b) ZH ratios, (c) Love wave dispersions, (d) Receiver functions with different ray parameter value. Blue line: observation, red line: prediction by inverted results.

2.3 Model Space

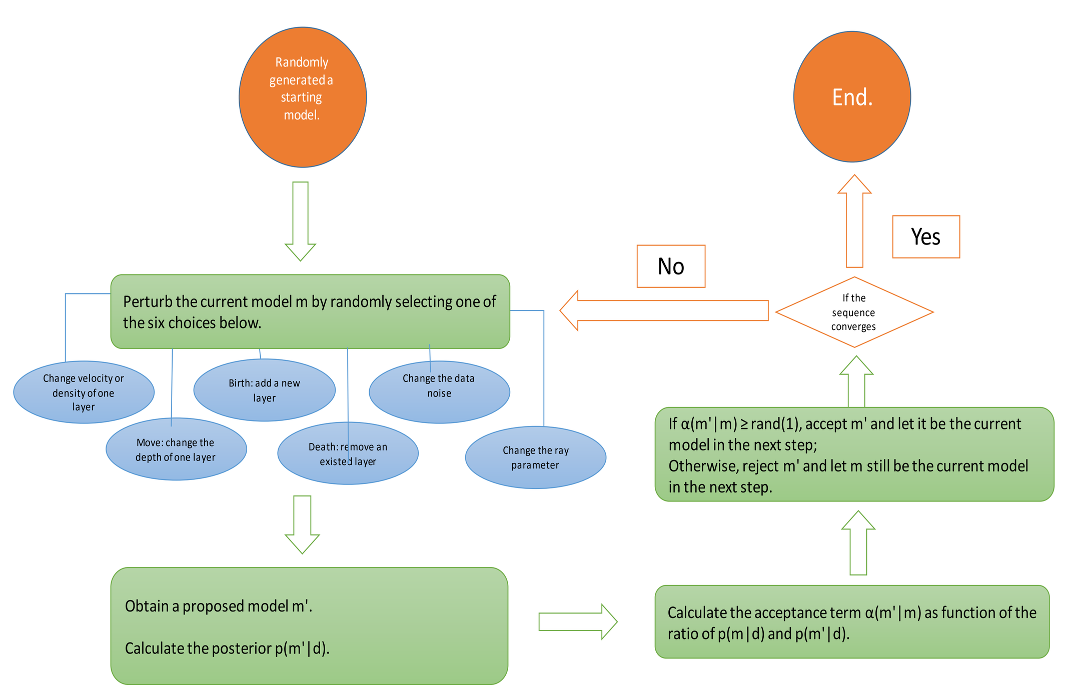
- Structure Parameters: number of layers, depth, Vs, Vp/Vs, density.
- Noise Parameter: noise amplitudes in RF, SWD and ZH; noise cross correlation coefficient of RF (that of SWD and ZH are fixed as 0).

2.4 Markov Chain Monte Carlo Algorithm (MCMC)

MCMC iteratively generates new point which only depends on the current point, and the generated model distribution is proportional to the posterior probability distribution function (PDF).

2.5 Work Flow Chart

Figure.2 (below): An overview of the transdimensional hierarchical MCMC method in our research.



3. Inversion of Synthetic Data

First we tested our method on a simple three-layer model (red line in Figure.3) along with 4 different events characterized by different parameter values. We run 40 independent chains with random starting point and each chain includes 100,000 models.

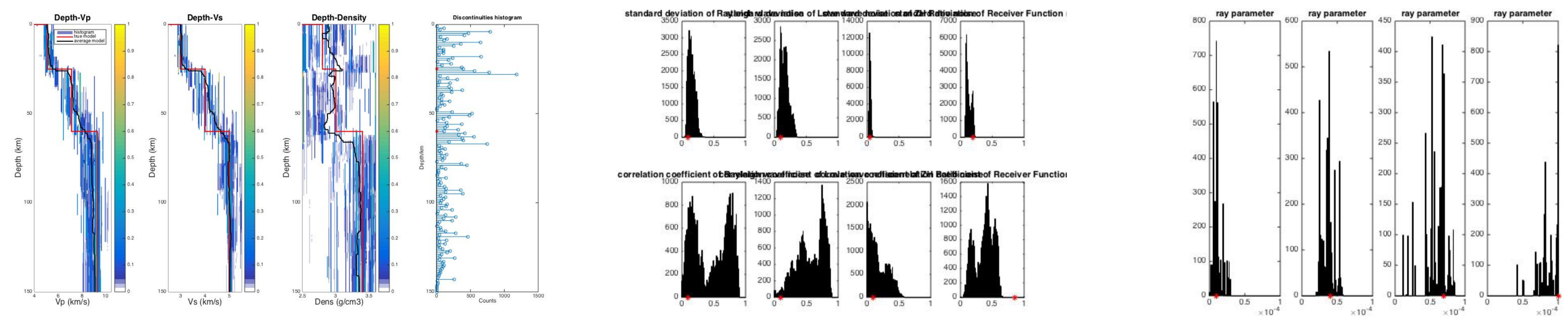


Figure.3:
Left: Interior structure under the station including P velocity, S velocity, density and the histogram of discontinuity depth (from left to right). Red line: true model; black line: average model; green line: most frequent model.
Middle: Distributions of noise parameters. Upper row is noise amplitude, lower row is cross correlation coefficient. Columns are, from left to right, Rayleigh wave dispersion, Love wave dispersion, ZH ratio and receiver function. Red star: true model.
Right: Distributions of ray parameter. Red star: true model.

4. Inversion of Real Earth Data

Then, we tested our method on real Earth data recorded at the Global Seismic Network station BFO, located at the Black Forest Observatory in Germany. We selected 3 events above 7.0Mb in magnitude with significantly different azimuths with respect to the station. We run 40 independent chains with random starting models and each chain includes 200,000 models. The inversion used receiver functions only. The Moho depth is well-constrained by RF alone and the results are consistent with other related studies (Kind et.al., 1995; Lombardi et.al., 2008). To improve the velocity resolution, SWD will be incorporated in future tests.

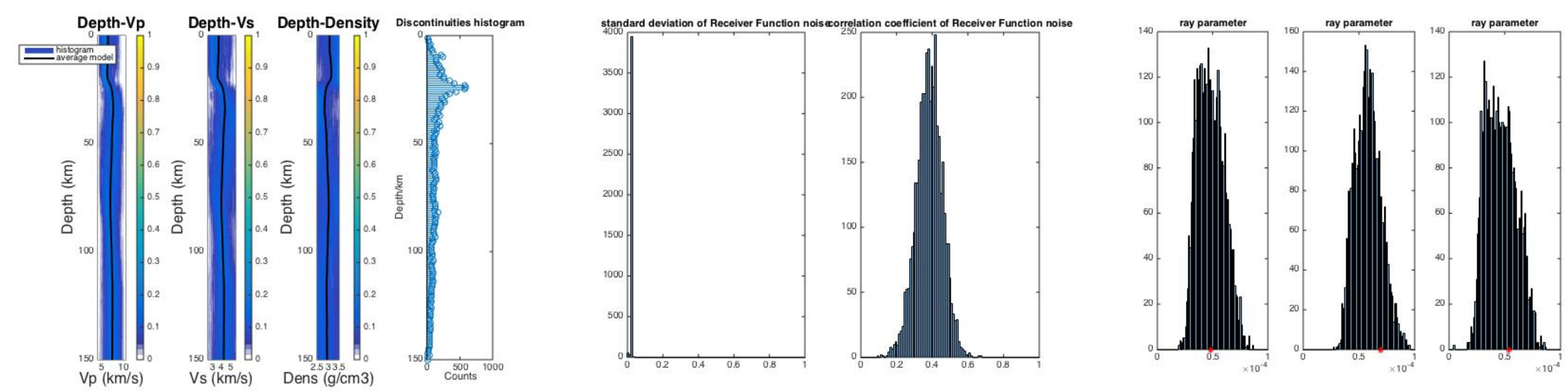


Figure.4: Left and Right: same as Figure.3. Middle: Only noise parameters of receiver functions.

5. Conclusion & Continuing Work

- Our hierarchical joint inversion method in Bayesian framework was well-tested with synthetic data as well as with well-determined real RF measurements from large events.
- This method will be further tested with smaller events which are comparable with expected Mars seismicity, and surface wave observations from local events will be incorporated to improve velocity resolution.

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