Monte Carlo Inversion of the 1D isotropic and anisotropic velocity model in the Juan de Fuca Plate

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Introduction

In this study, we demonstrate the advantage of the Monte Carlo method in solving 1D velocity models. In order to obtain accurate models, both velocity and anisotropy need to be accounted for in the inversion. However, the unknown number of layers of isotropic and anisotropic velocity separated by discontinuities makes it challenging to set up the model parameters. The number of parameters could also alter during the Monte Carlo search process, which controls the speed and resolution of inversion.

Inversion Method

The core of Markov Chain Monte Calro (MCMC) Inversion Method is Bayesian Law:

posterior∝likelihood×prior

p(m|d)=p(d|m)×p(m)

The probability will be used in making decisions:

1) set an initial model and perturb one random parameter (including adding or removing parameters).

2) In each iteration, If the new model provides a better fit to the data than the previous one, the new model is accepted. Otherwise, the probability to accept depends on the ratio of P1 (m|d)/ P0 (m|d).

3) Integrate all collected models and draw the probability distribution of parameters after the search converges.

Theory

The Rayleigh waves are dispersive. In general, the longer period is sensitive to deeper structures. The sensitivity kernels of different modes acted as a bridge to connect the period and depth.

The following equation is used to perform the traditional 1D velocity inversion:

$$\frac{\delta C}{C} = \int_0^a M(\omega, z) * \frac{dv}{v(z)} dz$$

δC /C (ω) is dispersion curve (dataset), M (ω,z) is the sensitivity kernel at frequency f and depth z, dv/v(z) shear velocity structure (model).

When anisotropy is considered:

$$C(w,m) = C_0(w,m) + dC_1(w,m) * cos2\theta + dC_2(w,m) * sin2\theta$$
$$C(w,m) = C_0(w,m) + G(w,m) * cos(2(\theta - \Phi(w,m)))$$

Where C0 (w,m) is isotropic component, dC1 (w,m) and dC2 (w,m) describe the velocity anisotropy. The anisotropy can also be described with another two parameters amplitude G (w,m) and azimuth Φ (w,m) .

Synthetic Test

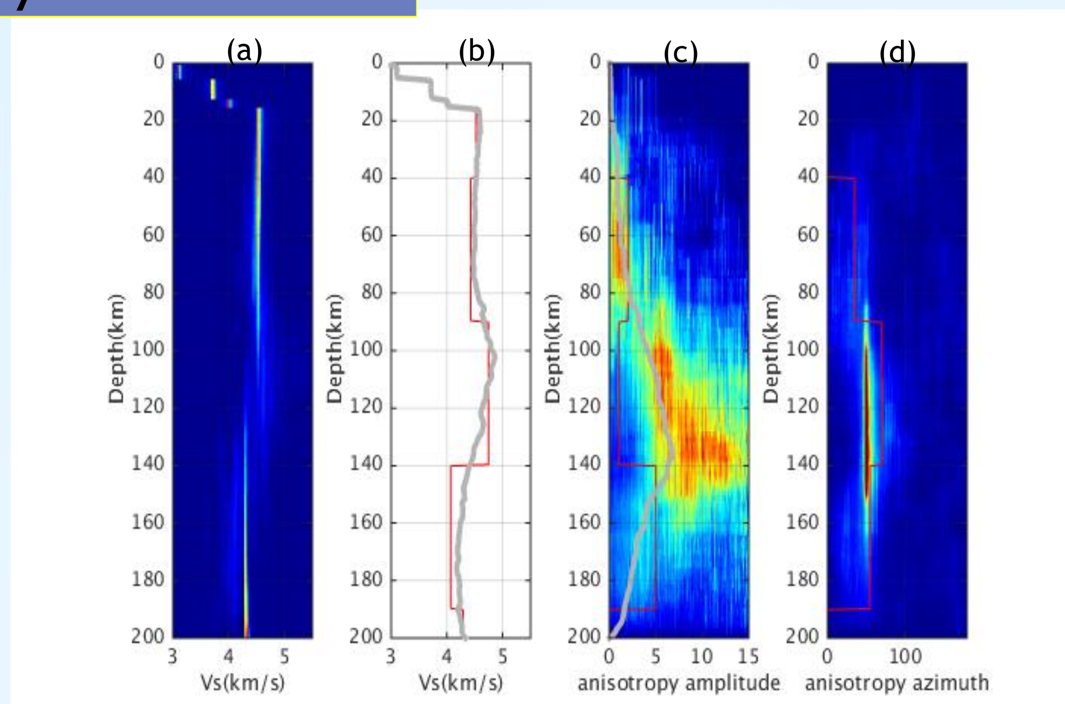

Figure 1 shows the synthetic test of MCMC Inversion. a) the probability distribution of shear wave velocity (Vs), b) the mean isotropic 1D velocity model derived from MCMC inversion (gray solid line) and the model (red solid line), c) Percentage of anisotropic component. d) azimuth of fast axis.

In this work, we derive the 1D isotropic and anisotropic velocity models based on the Rayleigh wave dispersion curves using the MCMC method. We conducted synthetic tests and verified the accuracy of this method (Figure 1).

Juan de Fuca Plate

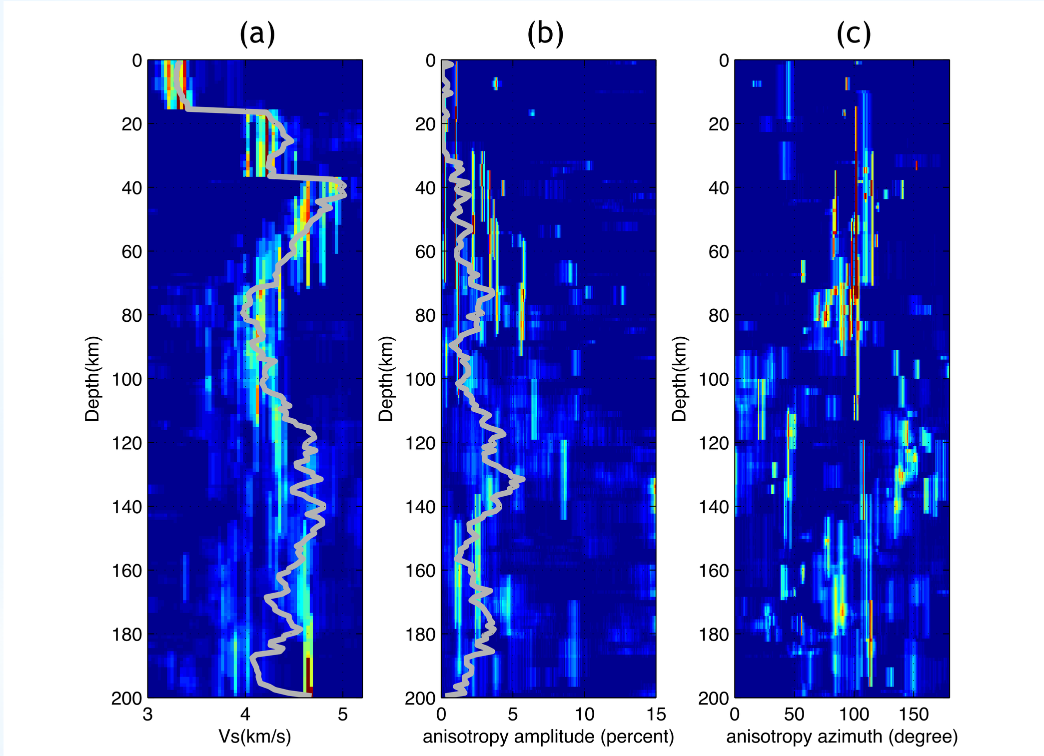

Figure 2 shows the isotropic and anisotropic velocity model of Juan de Fuca Plate based on MAMC Inversion. a) the probability distribution of shear wave velocity (Vs) and mean value of it (gray solid line), b) Percentage of anisotropic component, c) azimuth of fast axis.

In comparison with SKS splitting observations (figure 4), the overall mean splitting times predicted by our 1D model based on Rayleigh waves are smaller.

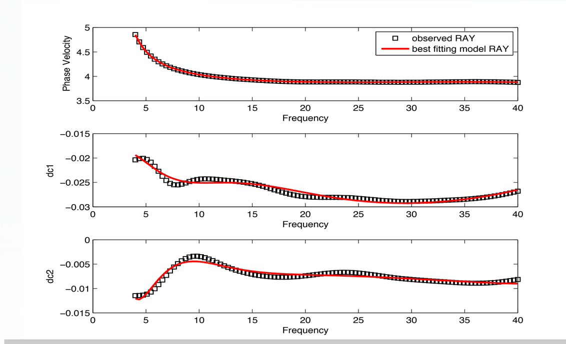

Figure 3 Comparison between dispersion curve dataset (empty square) and dispersion curve created by best fit 1D velocity model (red solid line)

This phenomenon can be explained by the difference of path effects between the SKS waves and Rayleigh waves: SKS phases samples the whole depth range from the core-mantle boundary to the receiver station. On the other hand, Rayleigh waves are mainly sensitive to the crustal and upper mantle structures beneath the receiver station. We then extend similar analysis to other regions to separate the contribution of shallow and deep anisotropy in SKS splitting observations.

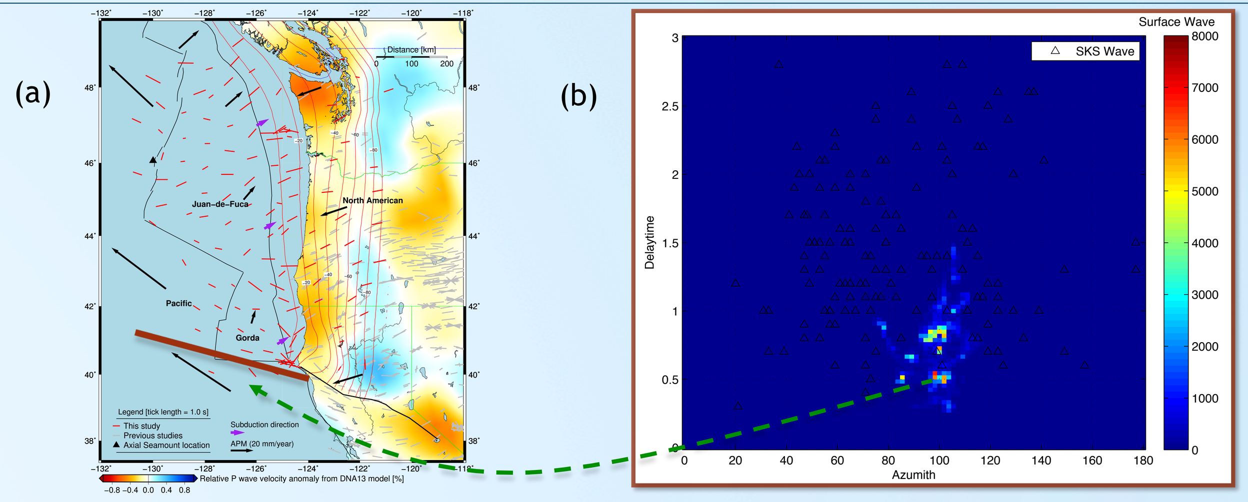

Figure 4. (a) The seismic anisotropy inferred from SKS splitting [Martin-Short et al. 2015]: the lengths of small bars indicate the delay times, the directions of bars indicate fast axis azimuths, the big red bar shows the mean azimuth of Rayleigh wave result; (b) Comparison of seismic anisotropy derived from SKS splitting (empty triangle) and 1D Rayleigh wave inversion (background color).

SKS Wave VS. Rayleigh Wave

We hypothesize that the splitting times predicted by 1D velocity models based on Rayleigh wave inversion are smaller than SKS splitting times. To test this hypothesis, we compare the anisotropy derived from Rayleigh wave dispersion curves and SKS splittings in different tectonic regions.

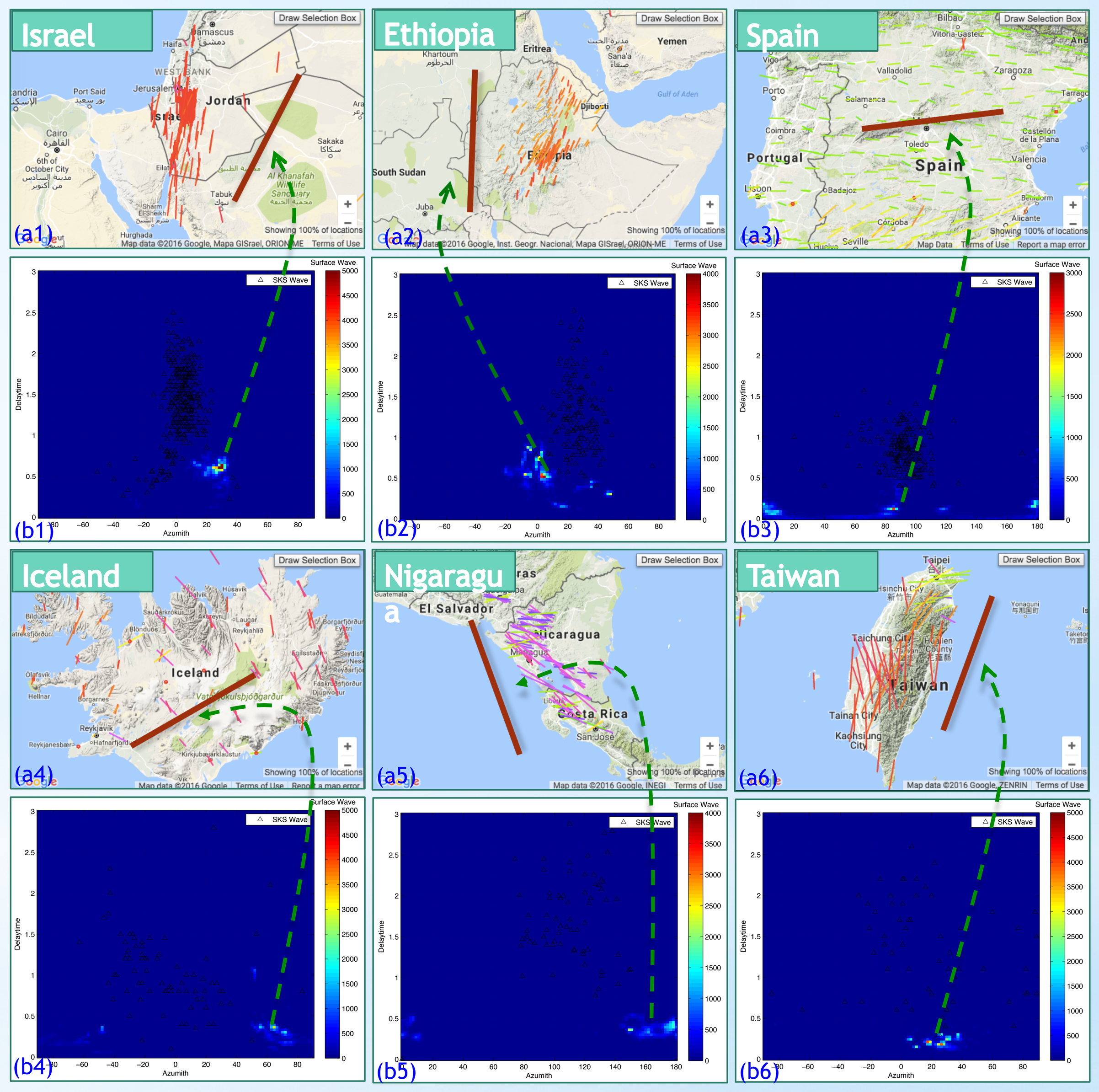

Figure 5. (a1~a6) The seismic anisotropy inferred from SKS splitting (from IRIS dataset): the lengths of small bars indicate the delay times, the directions and colors of bars indicate fast axis azimuths, the big red bar shows the mean azimuth of Rayleigh wave result; (b1~b6) Comparison of seismic anisotropy derived from SKS splitting (empty triangle) and 1D Rayleigh wave inversion (background color).

We find the delay times in different tectonic regions inferred from SKS splitting are systematically larger than those inferred from 1D Rayleigh wave inversions. These phenomenon is similar with the case study of Juan de Fuca Plate, which supports our hypothesis. Since the delay times inferred from Rayleigh wave inversions are smaller and the azimuth of fast axis more concentrated, delay times inferred from Rayleigh wave inversions may represent only the anisotropy of the crust and uppermost mantle (depth < 200km). We can therefore potentially remove this shallow component from the SKS observation and isolate the deep anisotropy. In the future, we hope to build a global anisotropy model of shallow depth to provide corrections for SKS splitting observations.

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