10 Joint Inversion of Receiver Functions and SKS Data: An Application to the Canadian Craton

Julie Leiva, Thomas Bodin, Barbara Romanowicz

Introduction

In order to improve layered structure models of the upper mantle beneath individual seismic stations, a new method involving a two step joint inversion of core refracted shear wave (SKS) splitting and receiver function (RF) data is currently being explored. This combination of seismic data results in a more robust structure model of the Canadian craton, and produces a probabilistic shear velocity (Vs) model acquired from RF data that incorporates azimuthal anisotropy from SKS splitting measurements. Our main focus involves resolving structure to a depth of up to 350 km beneath each seismic station, with an emphasis on layering around the lithosphere-asthenosphere boundary (LAB) and within the lithosphere itself. Knowledge of the structure around the LAB in cratonic regions will help improve the understanding of the formation of cratons and continents.

Methodology

Our inversion process utilizes a transdimensional Bayesian method that incorporates a Markov Chain Monte Carlo (MCMC) scheme to create probabilistic models, where the degree of layering, anisotropic strength and anisotropic direction are treated as unknowns.

Initially, our methodology involved a joint inversion of RF, surface wave dispersion (SWD) and SKS data that produced models of shear velocity and anisotropic parameters (strength and fast axis direction) in a single step. However, this proved to be a computationally expensive technique; the computation time was heavily improved by separating the process into two separate steps where the Vs model was first obtained by inverting RF and SWD data, and then performing a subsequent inversion for anisotropy. The latter step uses the acquired Vs model as a heavily constrained reference model, effectively limiting the second part of the inversion to solve for anisotropic parameters. A joint inversion of RF, SWD and SKS data has proven to be advantageous; by combining different sets of data that are sensitive to sharp changes in shear velocity and anisotropy, we are able resolve finer structure with depth and distinguish both isotropic and anisotropic boundaries. Receiver functions are used to detect interfaces where seismic conversions occur (Ps and Sp), and thus expose sharp velocity changes which are necessary in constructing Vs models. SKS splitting data account for azimuthal anisotropic effects integrated over the mantle on the receiver side. Seismic anisotropy in the upper mantle is a product of past and present tectonic and mantle processes and their resultant deformation, and thus provides additional structural information. However, since SKS data relies on integration over the entire upper mantle, depth resolution for SKS data is poor. SWD data are included to improve resolution in the upper 250 km, where the LAB and the focus of our research are contained.

Results and Future Work

The full two step process has been applied to synthetic data, and the full joint inversion was able to be applied in a single step due to the relatively low computational cost. The final results of Vs, strength of anisotropy, and fast axis direction by layer are shown in Figure 2.10.1. This inversion combined three Ps RF traces and seven SKS traces, as well as SWD with periods of up to 250s. The true structural model contains five isotropic and two anisotropic layers, with anisotropic strength equal to 4% and 6%, and the fast axis direction 45° and 60°, respectively. Figure 2.10.1 shows well resolved layering, shear velocities, and anisotropic parameters.

The first step of the inversion process has been applied to the permanent seismic station YKW3 from the Canadian National Seismograph Network (CN). YKW3 is located in Yellowknife, Northwest Territories and at the northern edge of the craton and provides archived seismic data through Incorporated Research Institutions of Seismology (IRIS) from as early as 1994. Results from the first step of the inversion process are shown in Figure 2.10.2, where RF and SWD data were inverted to find the Vs model. In this case, one Ps RF trace and nine SKS traces were used, as well as SWD with periods of up to 150 s. The resultant Vs model is currently being modified to use as a reference model in the second step of the joint inversion for real data.

Future work involves finishing the second part of the inversion for data from YKW3. Steps will be taken to improve computation time for real data and to further enhance our methods prior to applying this technique to other CN stations within the Canadian craton. Subsequent work can then be done in other cratonic regions across the world in order to better understand craton and continent formation on a global scale.

Acknowledgements

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References


Figure 2.10.1: Results of synthetic data for the full joint inversion, where red lines indicate the true models. From left to right: a) a probabilistic solution for a shear velocity structure model down to 250 km; b) strength of anisotropy with depth, where the white line indicates the mean of the data; c) fast axis direction with depth; d) the probability of anisotropy within each layer. Note that the Vs model was allowed to be inverted for in this step, due to the relatively low computational cost.

Figure 2.10.2: Results from the first step of the two step process for real data from station YKW3. From left to right: a) a probabilistic solution of the shear velocity structure model down to 350 km beneath the station, where white coloration indicates higher probability; b) a comparison of the single layer reference model to the average and maximum models; and c) the probability of the existence of a discontinuity.