# Global seismic wave propagation simulation

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## 1. Introduction

The origin and structure of the Earth's inner core has been studied extensively [1-6]. Seismology has provided effective data to pursue this study. When the seismic waves are recorded at the antipodal point of an earthquake (Δ ≃ 180°), these seismic waves, such as PKIIKP, are focused near the antipodal point where the seismic energy is amplified. The wave fields of PKIIKP that are amplified at the antipodal point cover the inner core boundary in an annular region around the circumference between the epicenter and the antipodal point. Various studies have been conducted on the Earth's inner core structure using these characteristic properties [7–15] at the antipode of earthquakes. Since antipodal PKIIKP wave is not a ray, but rather comprises a ray sheet sampling the whole path, it should be necessary to use full waveform theory to model the waveform at the antipodal observation. We have shown in Butler and Tsuboi (2010) [11] that there are earthquake doublets in the Tonga Islands, antipodal to TAM, Tamanrasset, Algeria—one in 1992 and the other 2001—which show consistent arrivals of the PKIIKP phase in both seismograms. We have modeled these antipodal seismograms by using the Spectral-Element Method (SEM) [16-19], which is a high-degree version of the finite-element method that is accurate for linear hyperbolic problems such as wave propagation. We showed that we may include the full complexity of the 3-D Earth in our simulations, i.e., a three-dimensional (3-D) wave speed and density structure, a 3-D crustal model, and ellipticity and could model antipodal PKIIKP phase because SEM is based on the full waveform theory. We discussed that the observed PKIIKP phase may be explained by the low P-wave velocity layer at the base of the outer core by using the synthetic seismograms calculated by SEM. We also discussed the existence of a S-wave discontinuity just below the inner core boundary by using the SEM synthetics in Butler and Tsuboi (2021) [7]. One of the advantages in using SEM to discuss the inner core structure is that the Spectral Element Method is implemented with the adjoint simulations to generate finite-frequency sensitivity kernels, which can be used to perform tomographic inversions for 3-D Earth structure. Here, we use our recent antipodal observations for PKIIKP and its precursors to compute the finite-frequency sensitivity kernels for a shear wave velocity structure on the inner core by using the Spectral Element Method. We discuss the spatial distribution of the sensitivity kernel to locate the possible fluid region at the surface of the inner core.

## 2. Sensitivity kernels by adjoint method

We calculated the sensitivity kernel of shear wave velocity for the amplitude of PKIIKP and its precursor phases to be used in the waveform inversion using a liquid/solid boundary of S wave velocity 100 km below the surface of the inner core as an initial model, and tried to identify the position of the fluid region on the surface of the inner core. Although the number of earthquakes used is not large, the raypaths of the PKIIKP phase cover an annular surface within the upper inner core. Each of the earthquake-receiver pairs used in this study covers a ray surface encompassing nearly 60% of the inner core surface and the orthogonal, antipodal propagation surfaces — in total—encompass the whole of the top of the inner core [11].

## 3. Results

Figure 1 shows the amount of modification of the shear wave velocity structure in the upper 150 km of the inner core [20]. The figure shows that the vicinities of South America and Indonesia need to be modified to slow down the shear wave velocity structure near the inner core surface by up to 1% from the initial model. Since the shear wave velocity of the initial model is 0.5 km/s, these locations can be considered as regions of fluid where the shear wave velocity is close to zero. In addition, it has been shown that surrounding these regions construed as fluid there are alterations increasing the shear wave velocity.

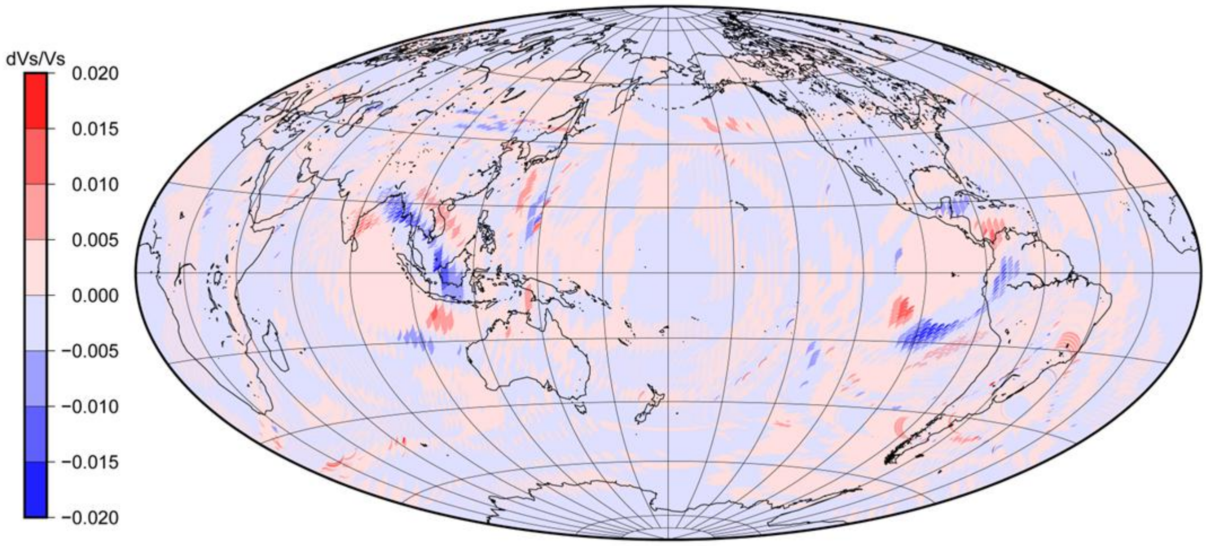


Fig. 1 Map of percentage of shear velocity modification to be made to the initial model. This corresponds to the modification to the model from a depth of 100km to the surface of the inner core. The red (faster) region corresponds freezing/solid areas and the blue corresponding (slower) melting/liquid areas.

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