Full-waveform analysis of core-mantle boundary structure using adjoint methods

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This study presents a new approach for investigating the structure of the core-mantle boundary (CMB) topography based on full-waveforms and adjoint methods. We compute intermediate period (10-20 seconds) spectral-element seismograms using existing models of core-mantle boundary topography and we analyse the sensitivity of relevant seismic phases. Our study adds new information about effects of CMB structure on exact synthetics and observable traveltimes of seismic body waves by means of sensitivity kernels. It also highlights the difficulty of imaging the boundary due to the strong trade-off between velocity and topography variations, addressed by many previous investigators.

Given the significance of CMB and its importance for many disciplines in geophysical research, there have been many studies trying to understand and geographically map the variations of topography and velocity above this boundary. However, the vast mantle area wherein seismic waves travel before and after they
interact with the CMB makes the identification of desired seismic phases somehow difficult. In addition, the observable traveltimes can be hard to interpret as a result of the boundary's topography only, due to the approximate inverse methods and limited modelling methodologies. Despite considerable progress made the past years, there is still a necessity for improving the understanding of effects of core-mantle boundary and D" structure on recorded waveforms.

For our analyses, we perform comparisons between time shifts due to topography made on full-waveform synthetics to ray theoretical predictions in order to assess methods usually deployed for imaging CMB. Then, we calculate the corresponding sensitivity kernel for time windows around the theoretical arrival of each phase. We focus on diffracted, core reflected and refracted P and S waves. The sensitivity kernels depict the finite-frequency nature of these waves and possible contributions from other phases unpredictable by ray theory. Results show that for most phases ray theory performs acceptably with some accuracy loss, however comparisons of the effect of velocity variations to topography on traveltimes are discouraging due to the low sensitivity to the latter.

The conclusions drawn by our traveltime and sensitivity analyses are twofold. Firstly, using spectral-element waveforms, the seismic phases which are frequently found in literature can be thoroughly investigated and better understood, since their traveltime sensitivity through mantle and core is explicitly shown. The
full-waveform analysis allows us to assess the usability of phases which are informative for core-mantle boundary structure and its topography. Secondly, we propose that using the analysed phases simultaneously in a full-waveform inversion scheme will improve imaging of the CMB, while also allowing to jointly invert for velocity variations along the D" layer, which is generally poorly understood. From this study, we want to promote advanced techniques of full-waveform inversion for improving CMB and lower mantle models.