# Global Elastic Response Simulation

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We conduct waveform inversion to obtain detailed whole mantle seismic velocity model using the direct solution method. The results show that there are strong low-velocity anomalies horizontally long and narrow in the vicinity of the core-mantle boundary below the western Pacific region. We also pursue accurate numerical techniques to obtain theoretical seismic waves for realistic three dimensional (3-D) Earth models using Spectral-Element Method. We calculate synthetic seismic waveform for 2010 Chile earthquake (Mw8.7) using fully 3-D Earth model. Our results indicate that the earthquake rupture model we have used for this simulation is fairly accurate to grasp the rupture propagation along the earthquake fault.

**Keywords**: Synthetic seismograms, 3-D velocity structure of the Earth, Spectral Element Method

## 1. Waveform tomography for the whole mantle

Waveform tomography for the whole mantle SH velocity structures is conducted using approximately 3.5 times the data used for obtaining the previous model, SH18CE (Takeuchi, 2007[1]). The resultant new model, SH18CEX, shows a cluster of ridge-like low-velocity anomalies in the western part of the Pacific Large Low-Shear-Velocity Province (LLSVP) (Fig. 1). The detailed features in the western Pacific region (Fig. 1a, top) indicate that the strong low-velocity anomalies are horizontally long and narrow in the vicinity of the core-mantle boundary (CMB). These ridge-like anomalies surround the relatively high-velocity region (represented by the green dot in Fig. 1a), suggesting that the observed strong low-velocity anomalies are associated with the return flow of the downwelling at the center. These features were not well observed in SH18CE (Fig. 1a, bottom) or other representative models (see Fig. 11 of Ritsema et al., 2011 [2]). The most prominent anomalies (intersected by the line A-A' in Fig. 1a) extend to the shallower region. The vertical cross sections (Fig. 1b) show that the extent of the anomalies is wide in the NW-SE direction, narrow in the NE-SW direction, and high upwards. These features are similar to those observed in the African LLSVP (e.g., Ni and Helmberger, 2003 [3]; Wang and Wen, 2007 [4]).

The obtained low-velocity structures have good correlations to the D'' topography observed by Takeuchi and Obara (2010) [5] who analyzed ScS-SdS times for the Fiji-Tonga events. The sampling region is across the ridge-like structure (Fig. 2a). The ScS-S residuals observed by Takeuchi and Obara (2010) [5] were indeed large at the center of the ridge-like structure and linearly decreased as the distance from the center increases (Fig. 2b, left). The D'' discontinuity was deep at the center, became slightly shallower at the side, and abruptly became very shallow beyond the side of the ridge-like structure (Fig. 2b, right). The abrupt jump in the discontinuity suggests that the ridge-like structure is probably associated with a chemically distinct pile (Fig. 2c), suggesting that the LLSVP is associated with a cluster of chemically distinct ridge-like-piles rather than a single large pile spreading over the entire region.

## 2. Source process of 2010 Chilean earthquake inferred from waveform modeling

We have calculated synthetic seismograms for February 27, 2010 Chilean earthquake using the fault rupture model obtained by teleseismic P waveform and the Spectral-Element Method on the Earth Simulator. Fault rupture model was obtained by the same procedure described in Nakamura et al (2010) [6] using 14 teleseismic stations of IRIS GSN. The result of the analysis is shown in the following web site.
(http://www.jamstec.go.jp/jamstec-j/maritec/donet/chile1002/index.html)
The fault parameters we obtained are: seismic moment; $1.6\times10^{**}22$ Nm (Mw8.7), the fault dimension ; 140 km × 510 km, depth; 35 km, duration of rupture; 100 s, and maximum slip; 15.0 m. Using this rupture model, we calculate synthetic seismograms for realistic Earth model using the Spectral-Element method (Komatitsch and Tromp, 2002 [7]) and the Earth Simulator. We used SPECFEM3D for SEM computation and P-wave velocity 3D mantle model of GAP-P2 (Obayashi

et al., 2006 [8]) and P and S-wave velocity 3D mantle model S20RTS and P12 (Ritsema et al., 1999 [9]). Simulation was done with 91nodes (726CPU) of the Earth Simulator with the accuracy of about 5 sec. We show comparisons of vertical ground velocity with the observation for IRIS GSN stations, HRV, SNZO and SUR with tomographic P-wave velocity model in Fig. 3. Synthetic P-waveform reproduces the observed waveform fairly well, which suggests that the rupture model is correct. The misfits of the synthetics may reflect the incompleteness of the mantle model but the differences between models are not significant.

Recently, Butler and Tsuboi (2010) [10] have reported that those waveforms recorded at the antipodes show anomalous phases which cannot be explained by PKIIP or PKP-Cdiff, especially at Algeria station for Tonga earthquake. They also reported that the antipodal station in China for Chilean earthquake does not show those anomalous arrivals. For 2010 Chilean earthquake, since station XAN in China locates at epicentral distance 177 degree, we have compared synthetic seismogram with observation for station XAN and shown in Fig. 4. The observed record can be reproduced by synthetics with spherically symmetric core structure and confirmed the observation of Butler and Tsuboi (2010) [10].

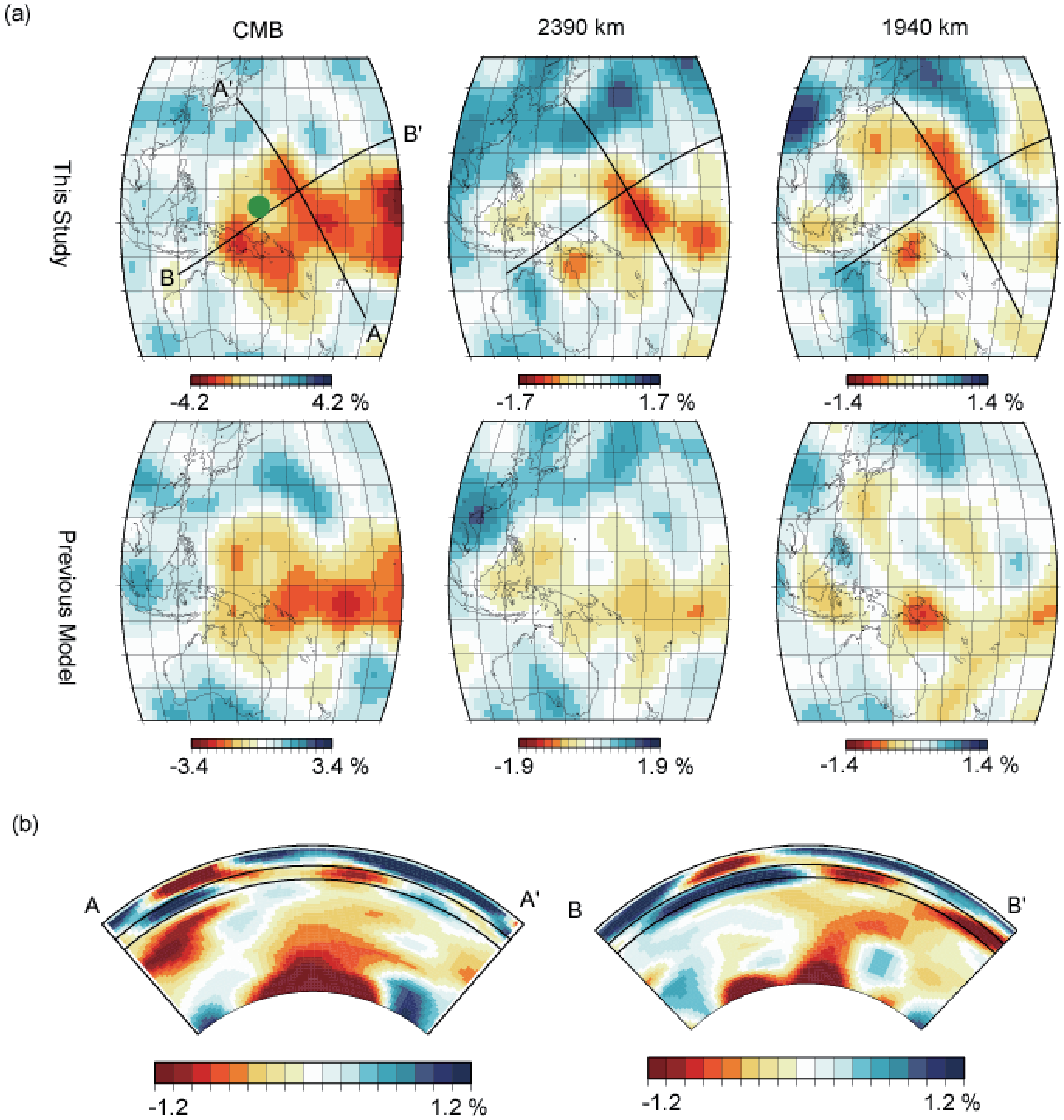


Fig. 1 (a) Comparison between the model obtained in this study, SH18CEX (upper figures), and the previous model, SH18CE (lower figures), in the western Pacific region. The lines A-A' and B-B' denote the location of the vertical sections shown in (b). The green dot denotes the relatively high-velocity region discussed in the text. (b) The vertical cross sections of the model SH18CEX at the locations indicated by the lines in (a).

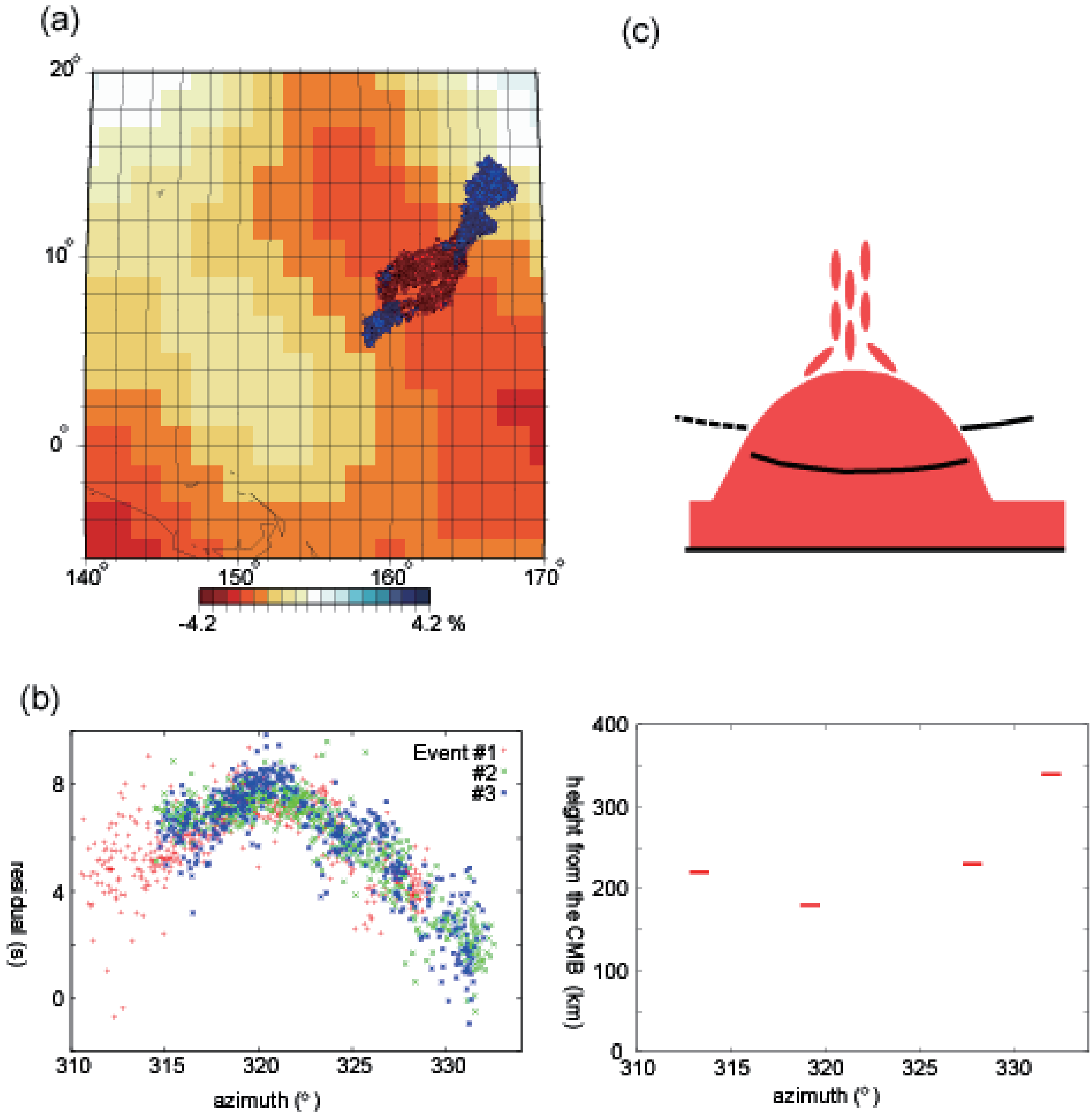


Fig. 2 (a) The model SH18CEX at the CMB overplotted by the ScS-S residuals previously reported by Takeuchi and Obara (2010). (b) The ScS-S residuals shown in (a), plotted as a function of the azimuth. The azimuth is measured from the centroid of the events analyzed by Takeuchi and Obara (2010) [5] (left). The height of the D" discontinuity as a function of the azimuth reported by Takeuchi and Obara (2010) [5]. (c) The schematic picture of the structures of the region studied by Takeuchi and Obara (2010) [5]. The red part denotes the chemically distinct region and the solid black lines denote the D" discontinuity.

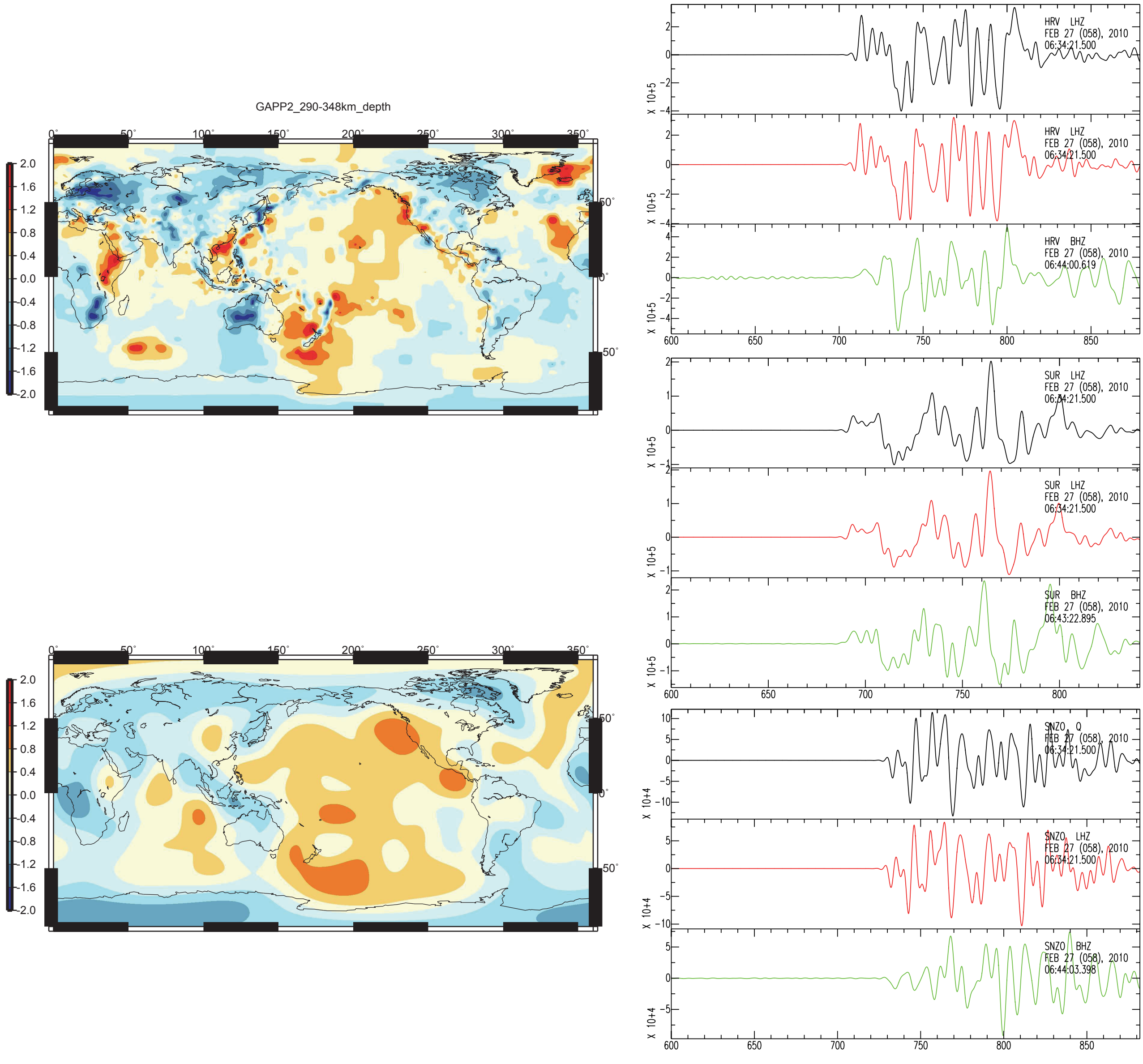


Fig. 3 P-wave velocity at depth 300km of tomography model GAP-P2 (upper left) and P12 of S20RTS (lower left). Comparison of synthetics and observation for HRV (upper right), SUR (middle right) and SNZO (lower right) are shown. Synthetic seismograms for GAP-P2 is shown in black, for P12 is in red and the observation is shown in green. 3 minutes vertical component velocity seismograms are shown respectively. Each seismogram is bandpass filtered between 500 sec and 5 sec. Vertical axis of seismograms are digital count.

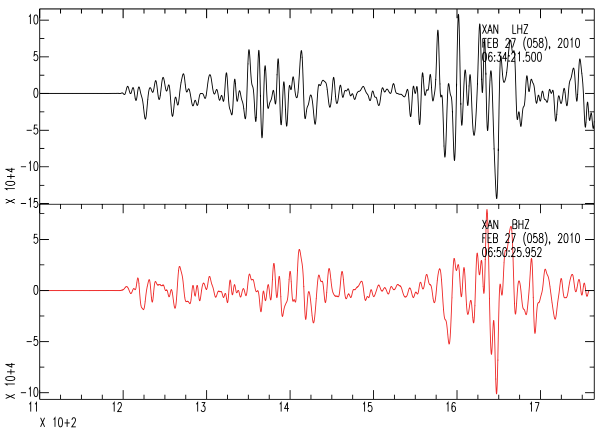


Fig. 4 Comparison of vertical velocity synthetics (black) and observation (red) for XAN. Both traces are bandpass filtered between 500 sec and 5 sec. 11 minutes seismograms are shown. Vertical axis of seismograms are digital count.

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# 全地球弾性応答シミュレーション

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Direct Solution 法を用いた波形インバージョンにより、地球内部マントル 3 次元地震波速度構造モデルを改善した。これまでより、およそ 3.5 倍のデータを用いることにより、より高精度の地球内部構造モデルを得ることが出来た。得られたモデルには、西太平洋下の核マントル境界に局所的な速度異常を示す構造が示されている。

スペクトル要素法により現実的な 3 次元地球モデルに対する理論地震波形記録を 2010 年チリ地震（Mw8.7）に対して計算した。計算は地球シミュレータの 91 ノードを用いて、周期約 5 秒の精度で行った。計算した理論地震波形は観測波形をよく説明しており、用いた地震断層モデルがよく断層における破壊過程をモデル化していることを示している。2010 年チリ地震に対しては中国大陸の観測点 XAN が震央距離 177 度と対蹠点に近いところに位置している。XAN の理論地震記録は、観測をよく説明しており、計算に用いた球対称内核構造モデルがこの観測点と地震の組み合わせに対しては適用可能であることを示している。

キーワード : 理論地震波形記録, 3 次元地球内部構造, スペクトル要素法