Flat and Sharp Earth's Inner Core Boundary Beneath Mid-Eastern China Determined by PKiKP Spectrum Fitting

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Abstract

The properties of the inner core boundary (ICB) carry important information about the growth of the solid inner core and solidification of the liquid outer core. In this presentation, we study the ICB by analyzing the spectrum difference of PKiKP (a compressional wave reflected from the ICB) and PcP (a compressional wave reflected from the core-mantle boundary) phase pair. Our dataset includes the seismic data recorded by the Hi-net in Japan for two earthquakes occurring in Myanmar on 4th September 2009 and 4th February 2011, with their PKiKP waves sampling the ICB beneath mid-eastern China. Little waveform and spectrum differences are observed between PKiKP and PcP waves in the seismic data. By comparing spectrum shapes of the seismic data and the synthetics of models with various topographic fluctuations and transitional thicknesses of ICB, we conclude that the studied ICB region is flat and sharp. Within the resolvability of the seismic data, the ICB topographic fluctuation of the region is less than 200 m in height and the transition of the boundary is thinner than 100 m in thickness.

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1. Introduction

The properties of the inner core boundary (ICB) carry important information about the growth of the solid inner core and solidification of the liquid outer core. The use of the phase pair **PKiKP** (a compressional wave reflected from the ICB, plotted by red lines in Fig. 1a) and **PcP** (a compressional wave reflected from the core-mantle boundary, plotted by blue lines in Fig. 1a) are often used in learning the ICB to eliminate the effects from the source location and travel time determination, and also in reducing the influence of shallow structures. Approaches like relative travel time residuals, amplitude ratios and waveform fitting have already revealed a complex ICB with topography, transition zones and even mushy zones. But spectrum contents have little studied yet.

2. Event doublets

Our dataset includes the seismic data recorded by the Hi-net in Japan for two earthquakes (more details shown in table 1) occurring in Myanmar on 4th September 2009 and 4th February 2011, whose PKiKP waves sampling the ICB beneath mid-eastern China. *Tian and Wen* [2017] have selected the event doublet and proposed a flat and sharp ICB structure of the region using PKiKP-PcP travel time residuals and waveform fitting[1].

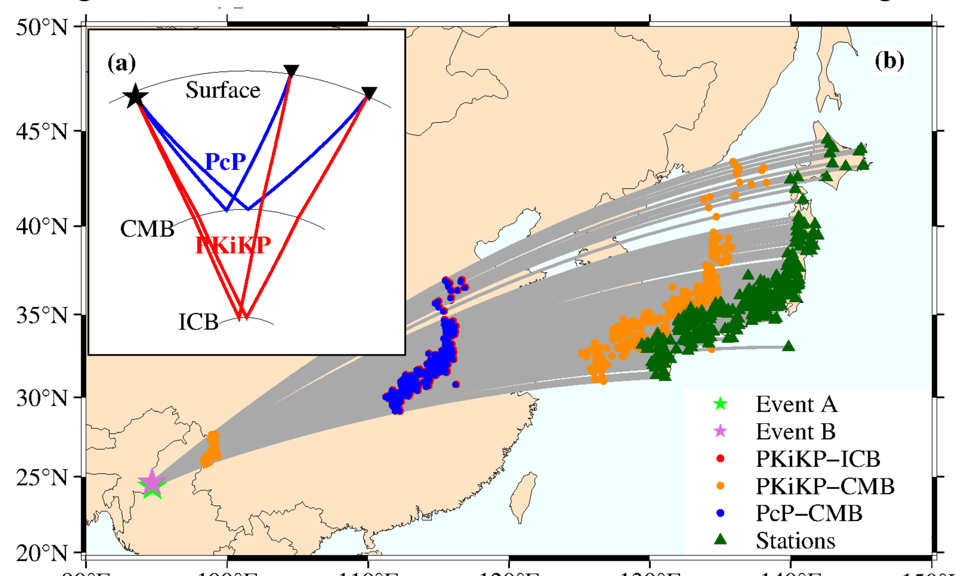

Figure 1 Dataset used in this study. (a) Ray path of PKiKP (red) and PcP (blue) at distance of 30° and 45°. (b) Distribution of the event doublet, stations recording phase pairs of the Hi-net in Japan and bouncing points of PKiKP and PcP.

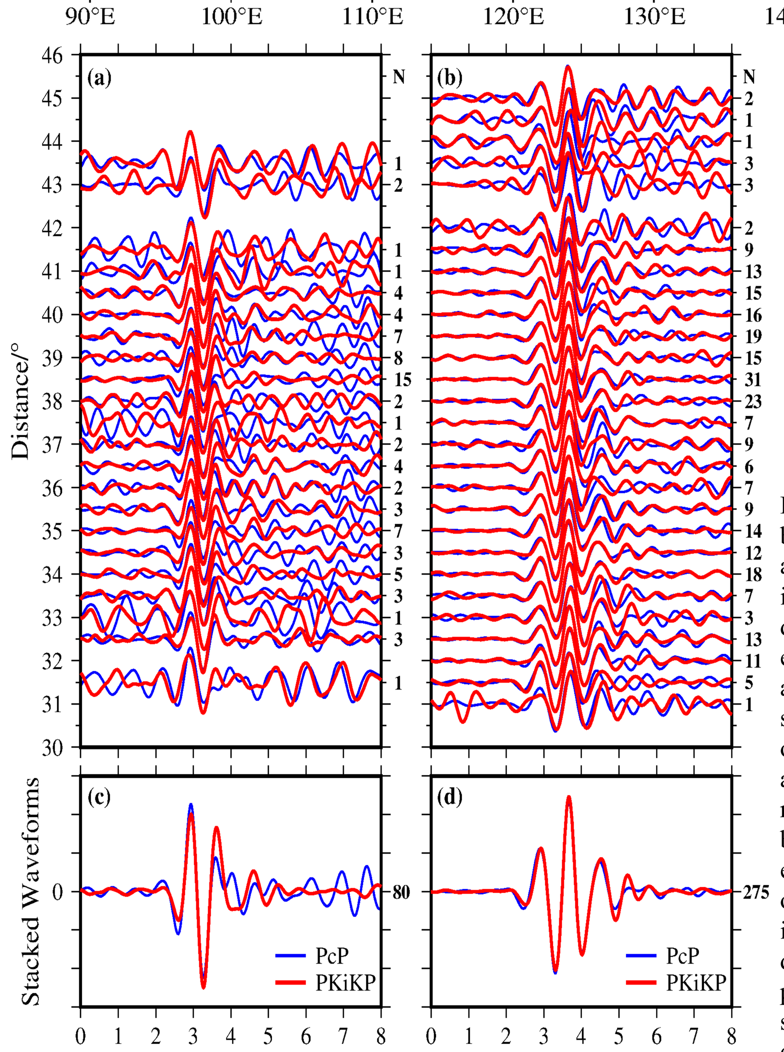

Figure 2. Waveform comparison between PKiKP and PcP. (a) PKiKP and PcP waveforms stacked as 0.5° in distance of event A. (c) All-distance stacked waveforms of event A. (b) and (d) are same as (a) and (c) but for event B. Numbers of stacked waveforms are all marked on the right margin. All waveforms are bandpass filtered in a frequency range of 1~2 Hz. Little differences between PKiKP and PcP of each event as the distance changes are observed, indicating little variation in the studied ICB region. All-distance stacked waveforms of the phase pair are also similar in shape, suggesting a simple ICB structure of the studied region.

Table 1. Information of the event doublet

ID	Time (yyyymmddhhmmss)	Location (°E, °N)	Depth (km)	Mw	Number of Selected PKiKP-PcP Pairs
A	20090904045107	94.702, 24.355	104	5.9	80
B	20110204225346	94.680, 26.910	85	6.2	275

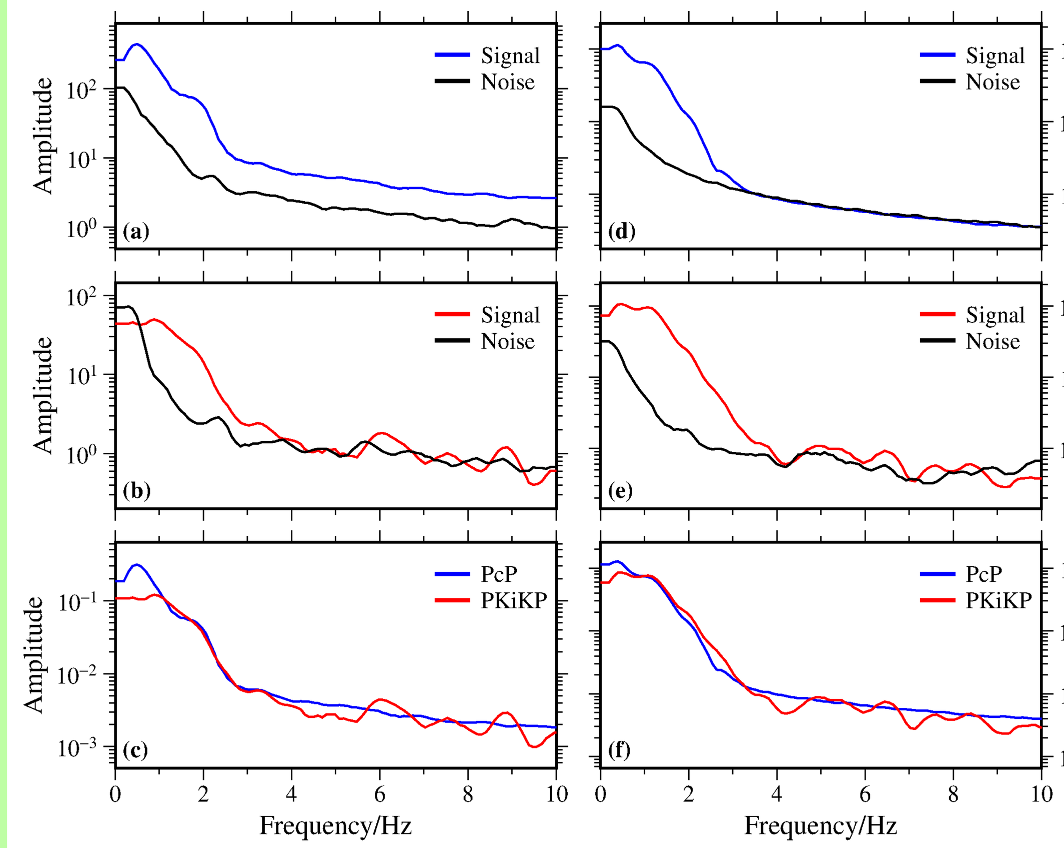

Figure 3. Spectra of observed PKiKP and PcP. (a) Spectra of PcP and its noise observed in event A. (b) Spectra of PKiKP and its noise of event A. (c) Normalized spectra of PKiKP and PcP by the integral of each amplitude in the frequency range of 1~4Hz of event A. (d)~(f) Same as (a)~(c) but normalized by the integral of 0.5~3.5Hz. High similarity of spectra between PKiKP and PcP also implies a simple ICB structure of the region.

3. Synthetics from P-SV hybrid method

Based on analysis of observation above, we modeled ICB structure with three types: a) **the flat and sharp model** (exactly the PREM model), b) **topographic and sharp models** (with various height and width of topographic fluctuations at ICB modified from the PREM model) and c) **flat and transitional models** (with various thickness of transition layers at ICB modified from the PREM model). We use **P-SV hybrid method** to calculate PKiKP synthetics, which is a 2D method developed by *Wen and Helmberger*[2] in 1998 to calculate synthetic seismograms involving 2D localized heterogeneous structures by applying finite difference in heterogeneous regions and general ray theory in homogeneous regions. In this study, we use Gaussian time function as the source time function. height of topography and thickness transitional layers.

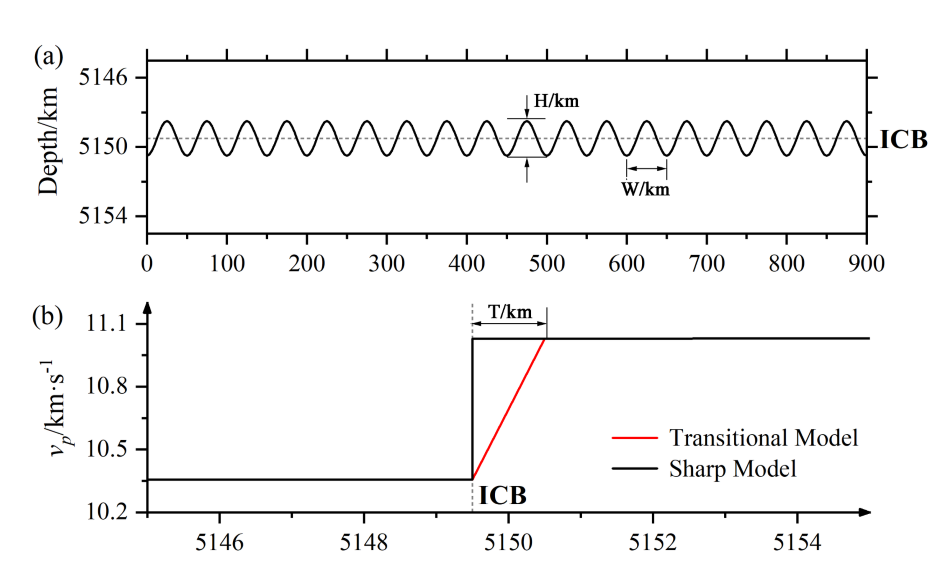

Figure 4. Theoretical models for PKiKP synthetics. (a) Topographic models which are consist of continuous sine functions with various amplitude (H/2, km) and wavelength (W, km). (b) Transitional models with thickness of transition layer T (km). In this study, we select H as 0.1, 0.2, 0.4, 0.6, 0.8 and 1km, W as 1, 2, 6, 10, 20 and 90km and T as 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1, 2 and 3km.

4. PKiKP Spectrum fitting between observation and synthetics

Spectrum fitting is to compare the shape of spectrum, namely the energy distributions in frequency domain. To compare spectra of observations and synthetics of three types of theoretical models, we firstly normalize all three types of synthetic spectra with the integral of 1~4Hz for event A and 0.5~3.5Hz for event B, which are frequency domains with positive SNR for phase pairs. Then to make synthetic spectra comparable to observations, we multiple every normalized synthetic spectrum by the observed spectrum of PcP and divide it by the spectrum of PKiKP of PREM model (which is exactly the flat and sharp model as Formula (*) shows. Then we can compare shapes of spectra in all frequency domains with positive SNR of both PKiKP and PcP as fig. 3 shows.

$$\mathbf{PKiKP}_{Synthetics} \cdot \frac{\mathbf{PcP}_{Observation}}{\mathbf{PKiKP}_{PREM}} \quad (*)$$

By comparing spectrum shapes within frequency ranges with positive SNR of both PKiKP and PcP, we can see that among synthetics of models with various topographic fluctuations and transitional thicknesses of ICB, the flat and sharp model fits best to the observed PKiKP spectrum. Then we can conclude that the studied ICB region is flat and sharp.

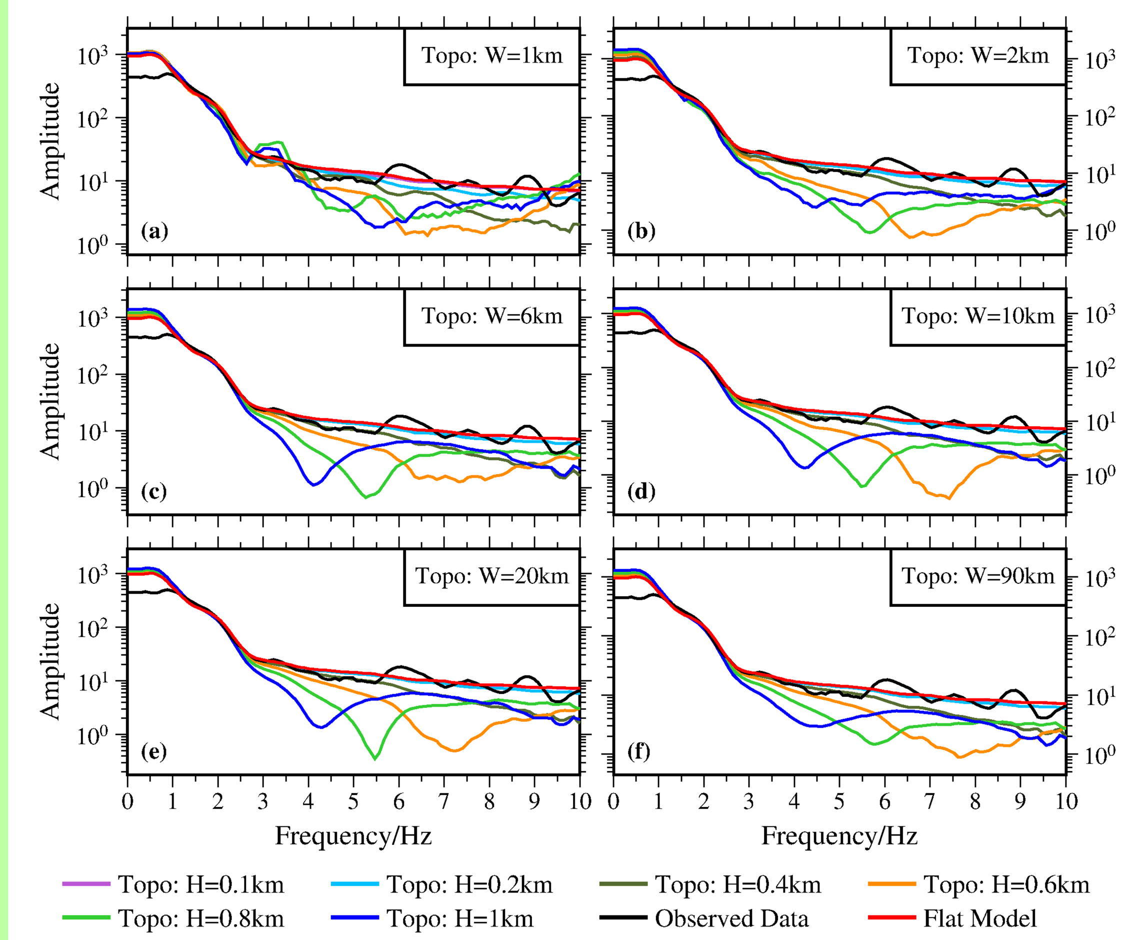

Figure 5. Spectrum fitting results from flat and topographic models to the observed stacked PKiKP spectrum of event A. We design topographic models as continuous sine functions with the amplitude being half of the height H and the wavelength being the width of one fluctuation W, which indicates the intensity of topographic fluctuations. The shape of spectra can change a lot for different topography models, where the height of topographic fluctuations take a more important part in influencing the shape of PKiKP spectra than the intensity of fluctuations. Spectra of models with fluctuations no more than 0.2 km in height always fit the observation well no matter how wide fluctuations are.

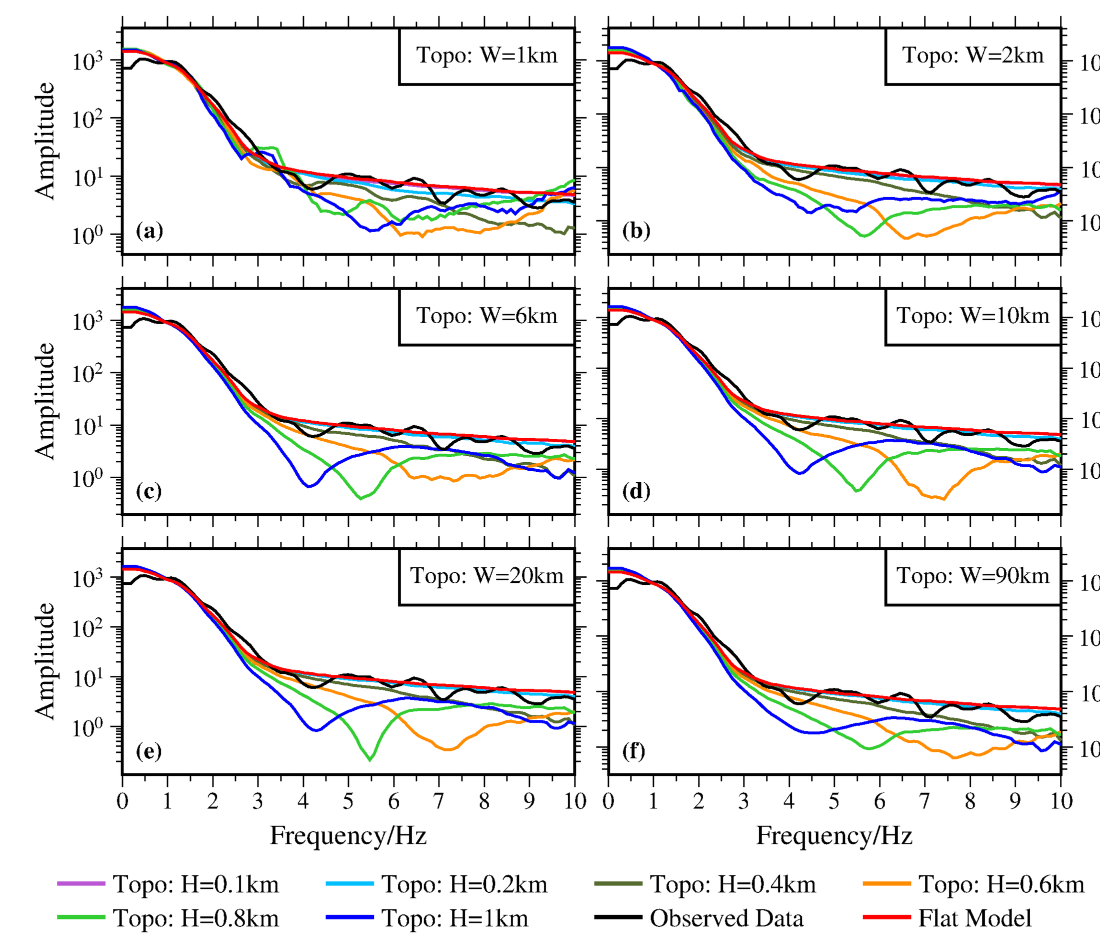

Figure 6. Same as figure 5 but for event B.

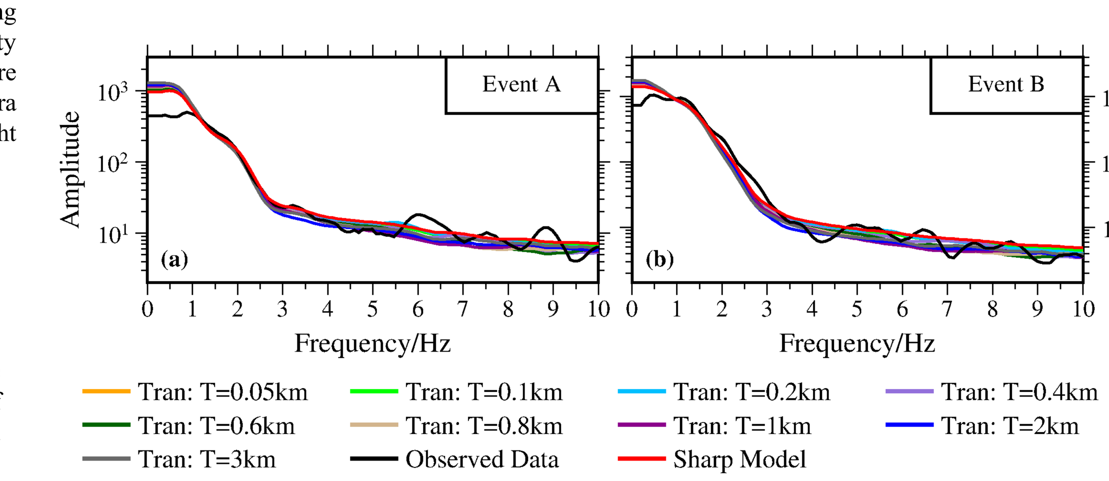

Figure 7. Spectrum fitting results from sharp and transitional models to the observed PKiKP spectra of the event doublet. The influence of transition layers on shape of PKiKP's spectra is much less than that of topographic fluctuations. Within the resolution of observed data, transition layers less than 0.1 km in thickness have nearly the same responses on PKiKP spectrum as the sharp model does.

5. Conclusions

1) Spectrum properties of PKiKP is sensitive to both the topographic fluctuation and the thickness of transition zone of ICB structure.

2) Within the resolvability of the seismic data, the ICB beneath mid-eastern China is flat and sharp, with topographic fluctuations less than 200 m in height and transition zones thinner than 100 m in thickness.

6. References

[1] Tian D, Wen L. Seismological evidence for a localized mushy zone at the Earth's inner core boundary[J]. Nature communications, 2017, 8(1): 165.

[2] Wen L, Helmberger D V. A two-dimensional P-SV hybrid method and its application to modeling localized structures near the core-mantle boundary[J]. Journal of Geophysical Research: Solid Earth, 1998, 103(B8): 17901-17918.