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Global P-wave tomography: On the effect of various mantle and core phases

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Abstract

In this work, many global tomographic inversions and resolution tests are carried out to investigate the influence of various mantle and core phase data from the International Seismological Center (ISC) data set on the determination of 3D velocity structure of the Earth's interior. Our results show that, when only the direct P data are used, the resolution is good for most of the mantle except for the oceanic regions down to about 1000 km depth and for most of the D″ layer, and PP rays can provide a better constraint on the structure down to the middle mantle, in particular for the upper mantle under the oceans. PcP can enhance the ray sampling of the middle and lower mantle around the Pacific rim and Europe, while Pdiff can help improve the spatial resolution in the lowermost mantle. The outer core phases (PKP, PKiKP and PKKP) can improve the resolution in the lowermost mantle of the southern hemisphere and under oceanic regions. When finer blocks or grid nodes are adopted to determine a high-resolution model, pP data are very useful for improving the upper mantle structure. The resulting model inferred from all phases not only displays the general features contained in the previous global tomographic models, but also reveals some new features. For example, the image of the Hawaiian mantle plume is improved notably over the previous studies. It is imaged as a continuous low velocity anomaly beneath the Hawaiian hotspot from the core-mantle boundary (CMB) to the surface, implying that the Hawaiian mantle plume indeed originates from the CMB. Low-velocity anomalies along some mid-oceanic ridges extend down to about 600 km depth. Our results suggested that later seismic phases are of great importance in better understanding the structure and dynamics of the Earth's interior.

Keywords: Mantle and core phases; ISC data; Global tomography; Hotspot; Mantle plume; Subducting slab

1. Introduction

In the past two decades, seismic tomography has become the most powerful tool to explore the heterogeneous structure of the Earth's interior and has provided vital information for understanding the global tectonics and dynamic evolution of our planet. Although a few researchers measured the arrival times carefully in their work (e.g., Woodward and Master, 1991; Su et al., 1994; Grand et al., 1997), most seismologists are still using the data set from the International Seismological Center (ISC) to study the mantle and core structures because the ISC bulletins represent the largest collection of arrival time information available worldwide. The ISC data set has been reprocessed and now its data quality has been improved much better than before (Engdahl et al., 1998). With the remarkable advances in computer technology, it becomes feasible to improve the spatial resolution of global tomography by using a great number of travel

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time data. However, if only direct P wave data are used in the tomographic inversion, it is still hard to improve the resolution in the southern hemisphere and oceanic regions where few seismic stations exist. Later phases of reflected and converted waves can sample the Earth's structure that is not ordinarily sampled by the direct P rays. Therefore, adding later phases is an effective way to improve the tomographic images of the Earth.

In the global tomographic inversions, different researchers have used different ISC data sets. In an earlier work, Inoue et al. (1990) used only the direct P data to invert for the 3D mantle structure. Vasco et al. (1995) added PP phases in their tomographic inversion, van der Hilst et al. (1997) and Bijwaard et al. (1998) used P and pP phases. Widiyantoro et al. (1998) added the core phase (SKS) for improving the lowermost mantle structure. Vasco and Johnson (1998) used P, PP, PcP, PKPab, PKPbc and PKPdf phases to invert for both the mantle and core structures. Later Boschi and Dziewonski (2000) also determined the 3D mantle and core structures but used P, PcP, PKPbc and PKPdf phases. Gorbatov et al. (2001) used P, PP and Pdiff phases. Karason and van der Hilst (2001) investigated the effects of PKP and Pdiff on the lowermost mantle structure. Zhao (2001, 2004) used the mantle phases of P, pP, PP, PcP and Pdiff. A few recent researchers carried out global tomographic inversions by using only P and PP waves (e.g., Fukao et al., 2003; Montelli et al., 2004).

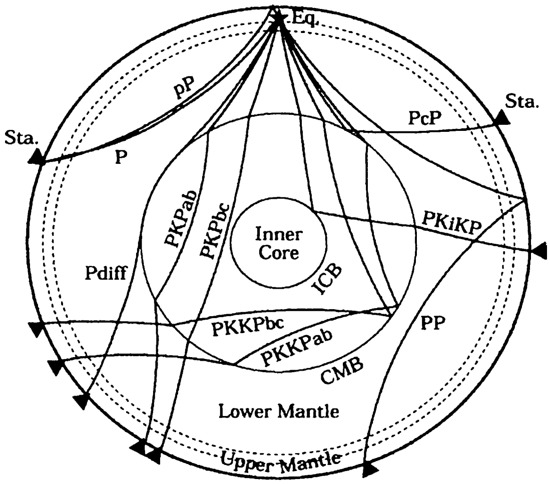

Fig. 1. Sketch illustration of ray paths used in this study. The rays are direct P wave, depth phase (pP), surface reflected wave (PP), CMB reflected wave (PcP), outer core diffracted wave (Pdiff), outer core transmitted waves (PKPab and PKPbc), inner core reflected wave (PKiKP), and CMB underside reflected waves (PKKPab and PKKPbc). Star and inverted triangles denote earthquake and seismic stations. Two dashed lines denote the 410 and 660 km discontinuities, respectively.

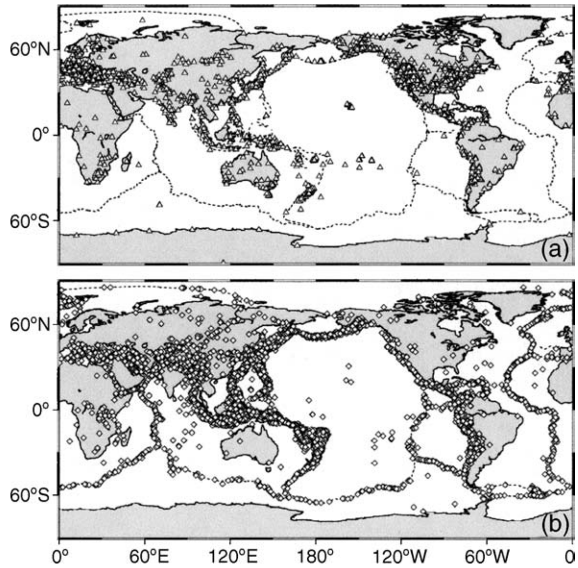

Fig. 2. Distribution of seismic stations (a) and earthquakes (b) used in this work. The hypocentral parameters were redetermined by Engdahl et al. (1998).

In this work, we attempt to fully investigate the influence of various mantle and core phases, including P, pP, PP, PcP, Pdiff, PKPab, PKPbc, PKiKP, PKKPab and PKKPbc (Fig. 1), on the determination of the 3D Earth structure. PKPdf and PKKPdf are not taken into account in this study because they pass through the inner core where strong anisotropy is considered to exist (e.g., Morelli et al., 1986; Tromp, 2001).

2. Data and method

In this work, 3D grid nodes were set up in the model to express the mantle and outer core structure. The grid

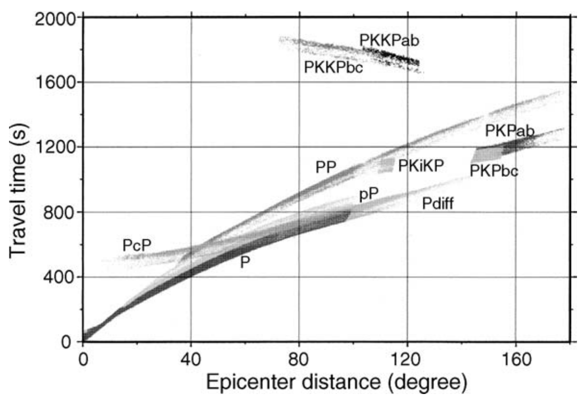

Fig. 3. Travel time curves of the observed travel times versus epicentral distances for P, pP, PP, PcP, Pdiff, PKPab, PKPbc, PKiKP, PKKPab and PKKPbc. This data set was extracted from the reprocessed ISC bulletins (Engdahl et al., 1998).