Tomographic Imaging of Central Java, Indonesia: Preliminary Result of Joint Inversion of the MERAMEX and MCGA Earthquake Data

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Abstract. The realization of local earthquake tomography is usually conducted by removing distant events outside the study region, because these events may increase errors. In this study, tomographic inversion has been conducted using the travel time data of local and regional events in order to improve the structural resolution, especially for deep structures. We used the local MERapi Amphibious EXperiments (MERAMEX) data catalog that consists of 292 events from May to October 2004. The additional new data of regional events in the Java region were taken from the Meteorological, Climatological, and Geophysical Agency (MCGA) of Indonesia, which consist of 882 events, having at least 10 recording phases at each seismographic station from April 2009 to February 2011. We have conducted joint inversions of the combined data sets using double-difference tomography to invert for velocity structures and to conduct hypocenter relocation simultaneously. The checkerboard test results of Vp and Vs structures demonstrate a significantly improved spatial resolution from the shallow crust down to a depth of 165 km. Our tomographic inversions reveal a low velocity anomaly beneath the Lawu - Merapi zone, which is consistent with the results from previous studies. A strong velocity anomaly zone with low Vp, low Vs and low Vp/Vs is also identified between Cilacap and Banyumas. We interpret this anomaly as a fluid content material with large aspect ratio or sediment layer. This anomaly zone is in a good agreement with the existence of a large dome containing sediment in this area as proposed by previous geological studies. A low velocity anomaly zone is also detected in Kebumen, where it may be related to the extensional oceanic basin toward the land.

Keywords: Central Java, P- and S-wave velocities, tomo-DD.
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INTRODUCTION

Several local tomography studies by previous investigators were performed by removing the distant events outside the study region in order to prevent increase in residual travel time error [1- 6]. In contrast, the previous study of Koulakov [7] concluded that the out-of-network events may not cause a problem in local tomography, but at the same time it could improve the spatial resolution of the resulting velocity model. The previous study of regional tomography conducted by Widiyantoro and van der Hilst [8] concluded that the area below Java shows a continuous form of the lithospheric slab from the Earth's surface to the lower mantle. Whereas, the previous local tomography studies in central Java by Wagner et al. [9] and Koulakov *et al*., [10] have not mapped the detailed structure of the western part of central Java. This study follows the suggestion by Koulakov [7] i.e. by incorporating regional data into the local MERAMEX data.

DATA

In this study we used a combination of the MERAMEX and MCGA earthquake data catalogs (Fig. 1). In total, the numbers of arrival time data from the MERAMEX and MCGA catalogs are 15,364 for P wave and 8,298 for S wave.

METHOD

We used a double-difference tomography method (tomo-DD) that has been developed by Zhang and Thurber [11]. A double-difference is the difference between observed and calculated differential arrival times for the two events [12].

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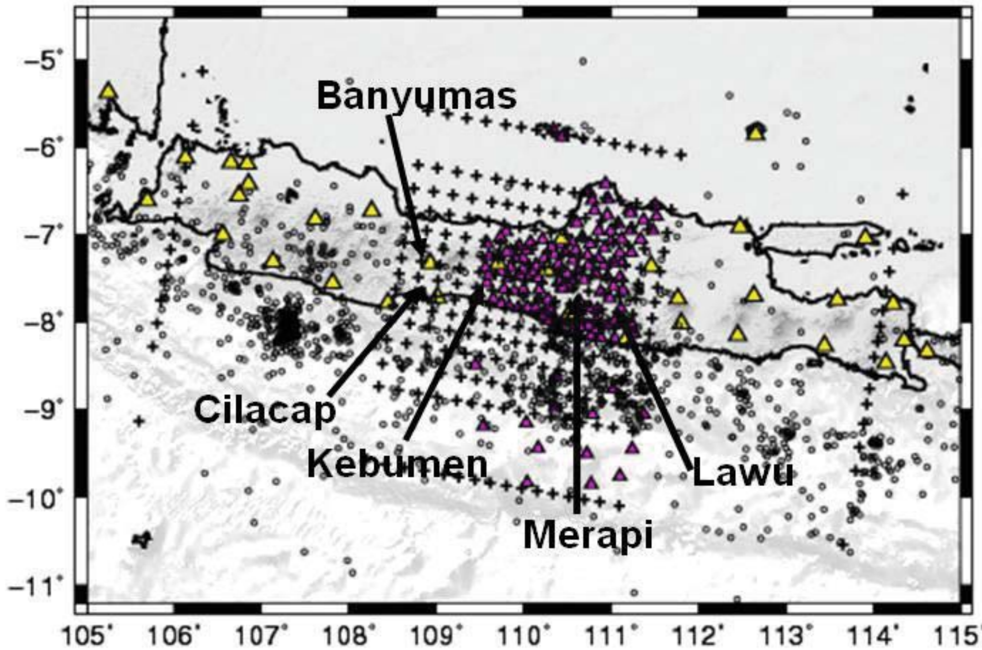

FIGURE 1. Map of study area (central Java). Symbols: black pluses, black circles, yellow and magenta triangles depict grid nodes, epicenters distribution, MCGA and MERAMEX stations, respectively.

The double-difference equation (dr_k^{ij}) of two events i and j recorded by station k is

$$dr_k^{ij} = \left(T_k^i - T_k^j\right)^{obs} - \left(T_k^i - T_k^j\right)^{cal} \quad (1)$$

The matrix form of double-difference tomography is

$$Q_{DD}A\Delta X + Q_{DD}C\Delta M = Q_{DD}\Delta T \quad (2)$$

Q_{DD} is a difference operator, A is the partial derivative matrix corresponding to the hypocenter and origin time, ΔX is the perturbation vector for earthquake location and origin time, C is the model derivative (path length) matrix corresponding to the slowness model, ΔM is the vector of slowness perturbations, and ΔT is the vector of arrival time residuals.

The calculation of the theoretical travel time from the source to the receiver via a reference velocity structure model was computed through ray tracing using a pseudo-bending method [13]. Inversion was solved by using LSQR techniques [14]. The reliability of our tomographic inversion was examined by applying a checkerboard test.

RESULTS

Our tomographic inversion results (Fig. 2) reveal a low velocity anomaly zone beneath Lawu-Merapi zone which is consistent with previous studies [9,10]. Our results also demonstrate some important features of the obtained velocity model which are not identified in the previous studies [9,10], such as: low velocity anomalies beneath Cilacap-Banyumas and beneath Kebumen (Karang Sambung).

The prominent low Vp and low Vp/Vs (< 1.65) are observed between Cilacap and Banyumas. We interpreted these features to be associated with a fluid content material with large aspect ratio or sediment layer. This anomalous zone agrees well with the existence of a large dome containing sediments in this area [15]. The low Vp, low Vs, and low Vp/Vs features in the upper crust suggest the existence of H_2O with a large aspect ratio (rather than melt) beneath active volcanoes [16-18]. The Vp/Vs ratio also increases when fluid-filled cracks exist within a rock [19]. Another previous study showed that the Vp/Vs ratio of a rock containing cracks saturated with water was not significantly different from that of the intact rock, but the Vp/Vs ratio of a rock containing cracks saturated with melt was much higher than that of the intact rock [20]. This is the case when the aspect ratio of cracks is the same for water and melt.

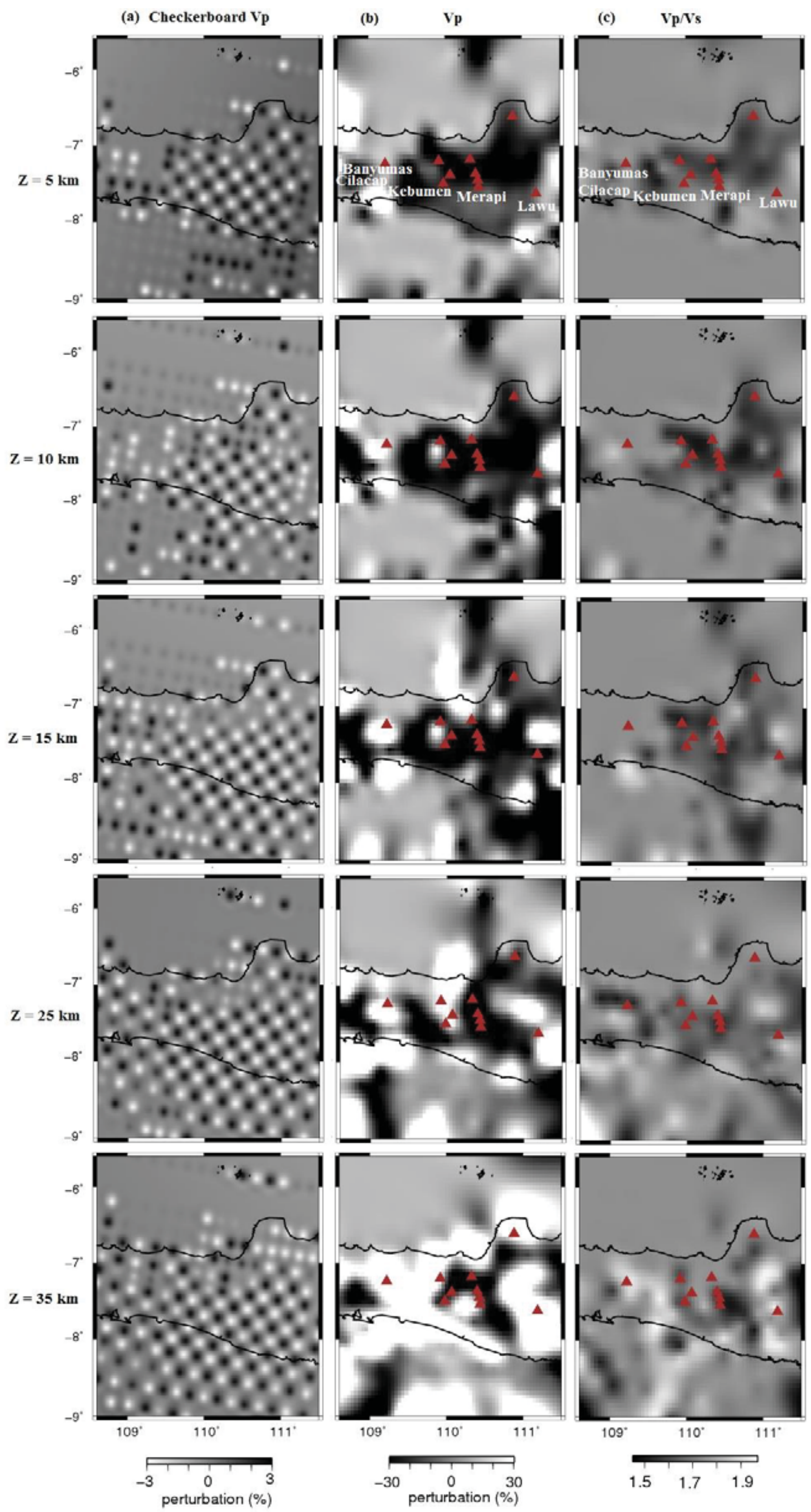

FIGURE 2. (a) The horizontal map views of the P- wave checkerboard test results at depths of 5, 10, 15, 25, and 35 km that can be used to evaluate the resolution of the resulting model. (b)The horizontal map views of the double-difference P-wave velocity (Vp) resulting from tomographic inversion in the central Java region. (c) As in (b), but for the Vp/Vs structure. The Vp structure is plotted as perturbations relative to an initial 1-D velocity model. Vp/Vs is plotted as absolute values. Dark and light gray colors represent high and low values for Vp and Vp/Vs structures. Brown triangles depict volcanoes.

CONCLUSIONS

The resulting tomographic images show 3-D structures of Vp and Vp/Vs in detail. The images reveal low velocity anomaly zones beneath Lawu - Merapi, Cilacap -Banyumas and Kebumen (Karang Sambung). We interpreted these anomalies are related to the existence of sediments. The low Vp/Vs features in the upper crust suggest the existence of H_2O with a large aspect ratio. The areas with contrast velocity anomalies are related to weakened fracture zones, which may be of importance for earthquake mitigation.

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