Updating Hypocenter Relocation in Indonesia using 3D Seismic Velocity Model: Period of April 2009-March 2018

Andri Dian Nugraha, Shindy Rosalia, Sri Widiyantoro, Pepen Supendi, Samsul Wiyono, Daryono

Global Geophysical Research Group, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung
Graduate Program of Geophysical Engineering, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung
Meteorological, Climatological, and Geophysical Agency of Indonesia, Jakarta

E-mail: nugraha@gf.itb.ac.id

Abstract. In the past 2 years, we have been conducting routine hypocenter relocation in Indonesia. We compiled and conducted hypocenter relocation of ~50,000 events from a magnitude of 1.4 to 8.5 recorded by 451 stations around and outside Indonesia region. We used local, regional, and teleseismic arrival time data from Indonesian Agency of Meteorology, Climatology, and Geophysics (BMKG) catalog from April 2009 to March 2018. We performed teleseismic double-difference relocation inversion using our previous study of 3D seismic velocity model beneath the Indonesian region with grid size 1° by 1° for inside Indonesia region and 1D global seismic velocity model from AK135 for outside Indonesia region. This method improved limitation from BMKG earthquake data catalog in which events were recorded from scattered seismic station array and insufficient azimuthal gap around Indonesia. Our results show that travel-time RMS residuals were greatly reduced compared to those of the BMKG catalog and the hypocenter location shows significant improvement, refining to the geological structure, especially trench and major faults. These hypocenter relocation results can be helpful for another seismic study in Indonesia region that required a precise hypocenter location e.g. body wave tomography and probability seismic hazard analysis.

1. Introduction
Indonesia is a region with a complex tectonic system, characterized by junctions of Eurasian, Indo-Australia, Pacific, and Philippine plates. The dynamic interaction between those tectonic plates produces high seismicity in Indonesia region. Studying the seismicity of Indonesia is important to get a better understanding of tectonic system in Indonesia. To conduct seismicity analysis in this region, we need more precise hypocentre location. Since 2016 we have been performing routine hypocenter relocation in Indonesia to do the seismicity analysis and to support updating hazard map of Indonesia programme. We used a double-difference relocation teleseismic (teletomoDD) method to relocate hypocenter location in Indonesia. This method was successfully relocated hypocenter along the Sunda Arc, Indonesia for the time of period of April 2009 to May 2015 [1]. In this study, we present the results of the relocation using more recent data catalogue from April 2009 to March 2018.
Figure 1. Seismicity map of Indonesia after telestomoDD hypocenter relocation applied to the BMKG data (M ≥ 3. Black boxes indicate vertical cross sections passing through (A) Northern Sumatra (B) Southern Sumatra (C) Java (D) Nusa Tenggara (E) Banda Sea (F) Papua (G) Molucca Sea from west to east, and (H) Molucca Sea from south to north. Plate motion movement from Nuvel 1.0 [2]. The circle is the epicenter and the color show the depth of the hypocenter.

2. Data and Method
We compiled ~50,000 events of BMKG catalogue from magnitude 1.4 to 8.5 from period April 2009 until March 2018. The data were recorded from 451 stations at local, regional, and teleseismic stations. The BMKG catalogue then selected with criteria have at least 8 arrival times, have an azimuthal gap of less than 210° [3]. After the selection, a total of ~40,000 events were used as an input for the relocation process.

We performed teleseismic double-difference relocation inversion which is a modification of double difference method [4] to teleseismic cases [5]. For velocity model, we used our previous study of 3D seismic velocity model beneath the Indonesian region [6,7] with grid size 1° by 1° for inside Indonesia region and 1D global seismic velocity model from AK135 [8] for outside Indonesia region.

3. Result and discussion
Hypocenter relocation result in ~34,000 events (Figure 1). The travel-time residual of the telestomoDD result shows significant reduction (Figure 2). Comparison between the BMKG catalogue and the telestomoDD results in vertical cross-section are shown in Figure 3. The relocation results show more clustered earthquakes distribution to the geological features e.g. in the major fault and Wadati-Benioff Zone (WBZ).

Based on the hypocenter relocation results (Figure 3), in the Western Sunda Arc, Wadati-Benioff Zone extent to 300 km and has gently dipping slab, meanwhile in the Eastern Sunda Arc, the Wadati-Benioff Zone is extent deeper to 500 km and has steeper slab geometry. This result is in a good agreement with previous study [1]. At Sunda-Banda transition zone, low seismicity is shown beneath the oceanic-continental transition region. In Molucca collision zone, two-slab of Halmahera sea plate are dipping into east and west. In Papua region, the earthquake distribution more concentrated around the active faults.
Figure 2. Histogram of travel-time residuals for the BMKG catalog (left) and teletomoDD relocation results (right). The travel time residual of the teletomoDD result show significant reduction.

Figure 3. Vertical cross-section of hypocenters before relocation (BMKG catalog) and after relocation (DD Relocation) through the box in Figure 1: (A) North Sumatra (B) South Sumatra (C) Java (D) Nusa Tenggara (E) Banda Sea (F) Papua (G) Molluca Sea from west to east and (H) Molluca Sea from south to north.
4. Conclusions
We had conducted hypocenter relocation using teletoDD methods to BMKG catalogue and relocated ~34,000 earthquakes in Indonesia for the April 2009-March 2018 periods. The relocation results show improvement of travel time residual and better clustering earthquake related to the geological feature. These hypocenter relocation results can be helpful for seismic hazard study in Indonesia region that required a precise hypocenter location.

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