Seismicity around Sunda strait and its surroundings based on hypocenter relocation using 3-D velocity: a preliminary result of relocated hypocenter database construction from the BMKG catalog

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Abstract. The relocated hypocenters are very important to study advanced tectonic in one area. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) provides a complete earthquake catalog consisting of hypocenter parameter and seismic wave arrival times of P and S phases or only P phase in every seismic station. This study uses the BMKG earthquake catalog from April 2009 to December 2018, in which the earthquakes were recorded by BMKG and international seismic networks. The hypocenters from the BMKG catalog are relocated using a 3-D regional velocity model and applying the teletomoDD method for hypocenter relocation. The results succeed in detecting many tectonic features in Indonesia. The study result will be useful to provide a precise hypocenter for earth scientists around the world who is interesting in a tectonic study in Indonesia. Some tectonic features which are interesting exist in Sunda Strait and its surrounding. The complex structure in Sunda Strait causes the area having high seismic activities. The results show seismic activities in three regions are delineated well. The first seismic region relates to the subduction zone. There is low seismic activity in the Wadati-Benioff zone from 70-120 km. This result is a little different from the previous study. The different result is most likely caused by the use of data and methods that are not the same. The second seismic region associates with graben fault. The last or third seismic region exists beneath Anak Krakatau Volcano relating to the magmatic activity. The last two seismic regions are detected clearly because there are no more fix depths at a depth 10 km after hypocenter relocation.

1. Introduction

The Sunda Strait is an area with complex tectonic structures. This area is an oblique subduction transition zone between the Australian Plate and the Southeast Asian Plate along Sumatra Island and perpendicular subduction along Java Island [1]. In addition to subduction affected, the Sunda Strait region is also located in the southernmost Sumatran fault zone [2]. In this area, there is Gunung Anak Krakatau which has high eruption activities. Local faults related to graben structures also exist in this area with high seismicity [1].

Complex tectonic systems cause the area has potential disasters. One of the large disasters that ever occurred was the Krakatau Volcano eruption caused a tsunami in 1883. The tsunami struck the coast around the Sunda strait as high as 35-40 m and caused 36416 fatalities [3]. The latest tsunami occurred on December 23, 2018, with 437 fatalities [4], the tsunami was caused by a flank collapse of Anak Krakatau Volcano [5]. The potential of the megathrust earthquake with a magnitude of 8.8 Mw is also one of the disasters threats in the area [6]. If the earthquake occurs in that area it can cause a big tsunami, so massive infrastructure damage and casualties will be difficult to avoid.
A disaster mitigation preparedness has to be done to minimize casualties and infrastructure damages. The availability of a precise earthquake catalog is one of the efforts to mitigate the area striking a disaster. The catalog can be used for tsunami source and ground motion modelings. Both of these models can be used in preparing earthquake-resistant buildings and mapping areas prone to tsunami impacts in the area.

2. Data and Methods
We relocated hypocenter parameters applying the teletomoDD method [7] with the regional 3-D velocity model in Indonesia [8,9] and the global 1-D velocity model [10]. The BMKG catalog time duration was from April 2009 to December 2018 at coordinates 90°-160°E and 15°S-15°N with 60186 earthquake events. The horizontal grid size used is 1°x1°. All these parameters were used in the previous study that relocated the hypocenter parameters of the BMKG catalog in the Sunda Arc area [11]. Each earthquake event used in this study consists of at least six phases of P and S or P seismic phases. We used different parameters with the previous study for residual time criteria in every seismic station [11]. The residual time range for P wave is between -3 to 3 seconds and for S waves of -5 to 5 seconds. This study utilized 320 seismic stations (174 BMKG and Global 146). Figure 1 shows the seismic station used in this study in the Indonesian area and its surroundings.

![Figure 1](image-url)

**Figure 1.** Seismic stations (blue reverse triangles) in the Indonesia region and its surroundings. The study area is in the black box.

3. Results and Discussions
There are 60186 earthquakes from the BMKG catalog recorded by the BMKG and international seismic networks. After hypocenter relocation, we end up with 48584 events. There are some earthquakes that could not be relocated because the data were not fit. The total relocated events in the study area are 4420. A comparison between epicenter distributions before and after the relocation is shown in figure 2. Epicenter shifts after hypocenter relocation and a rose diagram depicting the number of relocation for 5° azimuth bins are showed in figure 3. The average epicenter shift is 7.8 km and the maximum shift is 50.8 km. Rose diagrams at figure 3(b) show the epicenter majority moves towards NNE. The description shows that a station seismic configuration is an important thing because it will affect the quality of an epicenter. In addition to the accuracy of arrival time picking, an earthquake event covered by seismic stations will produce a high-quality hypocenter.
Figure 2. Seismicity before (a) and after (b) hypocenter relocation in the study area.

Figure 3. a). Epicenter shifts from the catalog events to relocated events. The blue rectangle depicts the location of vertical cross-sections A-A’ shown in Figure 4. Width of the rectangle is 100 km b). Rose diagrams showing azimuth and magnitude shifting. The maximum value in the rose diagram is 1.0, i.e., a normalized value. 0.2 is the increment scale in the radial direction.

Figure 4 shows the A-A’ cross-section before 4 (a) and after hypocenter relocation 4 (b). In the cross-section, it appears that earthquakes at a depth of 10 km are well relocated to produce earthquake clusters. The results of hypocenter relocation indicate the presence of three seismic systems in the Sunda Strait area and its surroundings. The first system was related to a subduction zone where the earthquake is in the Wadati-Benioff zone. In this zone, there is a low seismicity zone at a depth of 70-120 km and a distance of 220-280 km. This result is a little different from the previous study which showed the existence of the aseismic zone at a depth of 100-150 km [12]. Low seismicity in the zone may be related to the presence of an upwelling mantle in the vertical direction beneath the slab. The increase in hot material towards the slab causes a change in the chemical composition of the slab. As a result, the rigidity of the slab material is reduced so
that there are not many earthquakes in the area. The hypothesis must be proven by the latest regional or global seismic tomography studies in the area.

Seismicity in the southwest of Anak Krakatau Volcano relates to the pull-apart graben conventional system that developed in the area. In the cross-section of figure 4 (b), it appears that the earthquake clusters are almost vertically directed at a distance of 100-200 km and depths between 0-20 km. The previous study showed earthquakes in the area had a normal fault mechanism [1]. The Normal fault activities caused by the transitional force of the rotation movement of Sumatra Island clockwise which is axis in the Sunda Strait and the shift of Java Island to the east [13].

Earthquakes that are beneath Anak Krakatau Volcano at a distance of 300-350 km and depths of 20-70 km are likely related to the magmatic activity under the volcano. In this zone, seismicity is not as high as on the southwest of Anak Krakatau Volcano. This zone is connected to the low seismicity zone at a depth of 70-120 km as discussed above. Seismicity beneath the volcano is caused by an increase in magma towards the surface. The increase in magma is associated with the extension force so as to produce earthquakes that have a normal fault mechanism [1]. The tsunami that occurred in the Sunda Strait last year was caused by the activity of the volcano.

Figure 4. Vertical cross-sections A-A’ showing the hypocenter distribution before (a) and after (b) relocation. The blue line shows the slab 1.0 model [14]

4. Concluding Remarks
The hypocenter relocation study successfully detects three seismic zones around the Sunda Strait. The first seismic zone relates to the subduction zone. There is a low seismicity area at the depth 70-120 km which is connected to a low seismicity zone beneath Anak Krakatau Volcano at the depth 20-70 km. The second seismic zone associates with the local fault zone (transtensional graben) having a very high level of seismicity compared to its surroundings. The last seismic zone relates to magmatic activity beneath the volcano. The study results are very useful for advanced tectonic study in this area that is used for earthquake disaster mitigation.
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