Hypocenter Determination Using a Non-Linear Method for Events in West Java, Indonesia: A Preliminary Result

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Abstract. West Java, part of the Sunda Arc, has relatively high seismicity due to subduction activity and faulting. The first step of tomography study in order to infer the geometry of the structure beneath West Java is to conduct precise earthquake hypocenter determination. In this study, we used earthquake waveform data taken from the regional Meteorological, Climatological, Geophysical Agency (BMKG) network from South Sumatra to central Java. We have repicked P and S arrival times from about 800 events in the period from April 2009 to December 2015. We selected the events which have azimuthal gap < 210° and phase more than 8. The non-linear method employed in this study used the oct-tree sampling algorithm from NonLinLoc program to determine the earthquake hypocenters. The hypocenter location results give better clustering earthquakes which are correlated well with geological structure in the study region. We also compared our results with BMKG catalog data and found that the average hypocenter location difference is about 12 km in latitude direction, 9.5 km in longitude direction, and the average focal depth difference is about 19.5 km. For future studies, we will conduct tomographic imaging to invert 3-D seismic velocity structure beneath the western part of Java.

1. Introduction

West Java is located in the central Sunda Arc, i.e. an active plate boundary zone between oblique subduction of the Indo-Australian plate beneath Sumatra and perpendicular subduction along Java [1]. This tectonic activity has formed fault structure in the western part of Java, such as Cimandiri Fault [1]. Historical seismicity of West Java before 1921 has been studied and revealed that West Java has 2 major earthquake events with magnitude greater than 7.5, i.e. in 1903 and 1921 [2]. Meanwhile for the last decade, there were also two major earthquakes occurring in this area. On 17 July 2006, a thrust faulting earthquake with Mw 7.7 occurred on the boundary between the Indo-Australian and Sunda plates producing tsunami in Pangandaran [3]; and on 2 September 2009 a reverse faulting earthquake with Mw 7 hit south of West Java and caused a landslide in Cikangkareng [4]. Due to its high seismicity level, it is important to have a better knowledge of the geometrical structure beneath West
Java, for example by employing a tomographic method, which requires accurate earthquake hypocenters as input.

Figure 1. Map showing the location of seismographic stations (inverted triangles) used in this study. Colours depict the number of phases picked for each station.

Previous studies related to seismicity and tomography in West Java and its surroundings were conducted by using a global data set beneath the Sunda Arc [5], regional and local earthquake data catalogue [6, 7, 8], volcano-tectonic earthquake [9, 10, 11], employing non-linear tomography for eastern Sunda Arc [12], and relocating hypocenters with a 3D velocity structure of West Java [13, 14]. In this study, we used different data set and method to determine earthquake hypocenters.

2. Data and Method

We repicked P and S-wave arrival time data taken from BMKG waveforms for 891 events in West Java and its surrounding area from April 2009 to December 2015. We used 33 BMKG stations from South Sumatra to central Java (Figure 1). We selected the events which have azimuthal gap < 210° and phase more than 8 in order to have a good constraint and quality of location result. We also conducted a quality control of the repicking process by plotting Wadati diagram.

After the repicking process, we applied a hypocenter determination technique using the non-linear NLLoc program [14, 15]. This program contains a probabilistic, direct search method which employs the algorithm developed by Tarantola and Valette [16]. Unlike a linearized approach that can give convergent problems, e.g. the solution can be trapped in a local minimum, the non-linear approach can overcome such a convergent problem and can identify irregular volumetric, probability density function better. This method has been applied successfully in Yellowstone [17] and Southwest Iberia [18]. For this study, we used the global package from NLLoc with AK135 spherical velocity model [19] and oct-tree importance sampling algorithm [20] to determine the hypocenter.

3. Result and Discussion

Hypocenter determination result consists of 829 events located using ~12,000 P and ~4,900 S arrival times. The NLLoc result shows a significant improvement in epicentre locations (Figure 2a) by refining more clustered earthquakes related to geological features. The epicentre shifting vectors and rose diagram show that the direction of the shifting is trending to Northeast-Southwest, perpendicular to the trench (Figure 2b). Histogram of NLLoc residual travel times also shows a better data fit compared to those of BMKG (Figure 2c). The average hypocenter location difference between NLLoc and BMKG is 12 km in latitude direction with maximum shifting 136 km, 9.5 km in longitude...
direction with maximum shifting 142 km, and 19.5 km in depth with maximum shifting 157 km. The improvement may be due to the repicking process so that arrival times are more accurate and/or because of the velocity model used and station distribution, in which most of the stations are located in the Java Island.

**Figure 2.** a) Comparison of West Java seismicity from BMKG catalog (left) and NLLoc result (right). Colours indicate earthquake depths and the size of dots depicts event magnitudes. Boxes represent
areas used to plot the cross sections shown in Figure 3. The NLLoc result gives a better event clustering compared to BMKG. b) Map representing epicenter shifting from BMKG location to NLLoc location (left). Rose diagram showing the major direction of the shifting that is perpendicular to the trench. c) Histograms of residual times of BMKG (left) and NLLoc result (right).

Seismic activity in West Java is dominantly distributed to the south of the island, i.e. near the trench, and in the fore-arc owing to the subduction of the Indo-Australian plate. Shallow clustered earthquakes on land are probably related to faulting, e.g. Cimandiri Fault. We also observed some interesting earthquake clusters (Figure 2a). For instance: an earthquake cluster in the south of Sumatra which is related to Mentawai Fault; an earthquake cluster that shows a lineation in the south of the Sunda Strait that is probably the continuation of Sumatra Fault; and an earthquake cluster in the south of Garut. However, we still need further studies in order to confirm these intriguing event clusters.

![Figure 3](image)

**Figure 3.** Cross sections of West Java: (A) through the Sunda Strait, (B) Pelabuhan Ratu and Cimandiri Fault, (C) earthquake cluster in the south of Garut, and (D) earthquake cluster near the trench. Colours represent earthquake depths and blue line depicts the slab 1.0 model [15]. In general the NLLoc result gives stepper earthquake distributions compared to those inferred from BMKG hypocenters and slab 1.0.

Based on the cross sections in Figure 3, the NLLoc result shows a better earthquake clustering that is in good agreement with geological features, especially in shallow part. One of the problems if we use the BMKG catalog as input to a tomographic study is the 10 km fixed depth (see Figure 3a, b, c). We can see that below the mountain and its surrounding area, there are lineations of events of 10 km depth in the BMKG location. Our NLLoc result improves the fixed depth and produces earthquake clusters below the mountain, e.g. beneath Mt. Anak Krakatau (Figure 3a). We also observed that there is an earthquake sequence trending from the slab surface upwards, close to the 2 September 2009 Mw 7 earthquake, indicating a back-thrust fault in the area of the 2009 event. From the NLLoc result, we infer a slab in the eastern part of the study area (Figure 3d), which is steeper than those inferred from the BMKG location and the slab model 1.0 [21].
4. Conclusions
We have conducted hypocenter determination using a non-linear method for events in West Java. The new hypocenter locations can improve the location of 10 km fixed depth from the BMKG catalog. Furthermore, the new locations also give better clustered earthquakes which are correlated with geological structures from previous studies. This hypocenter location data set will be used as input in our near future works which will include an application of a double-difference tomography to obtain a 3D velocity structure beneath West Java.

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