Early Results of P Wave Regional Tomography Study at Sunda-Banda Arc using BMKG Seismic Network

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Abstract. The plate movement, geological structure, magmatism, and seismic activity in the area of Bali to East Nusa Tenggara are mainly related with the subducting of Indo-Australian Plate underneath the Eurasian plate. The complexity is added with the recent collision of Australian continent lithosphere with the western Banda arc, along the islands of Flores, Sumba and Timor island. Our study area is known as the Sunda-Banda arc transition. With the aim of imaging subsurface structure, we perform seismic tomography inversion using regional events. We collected 5 years of earthquake data (January 2015 – December 2019) from the Indonesian Agency of Meteorology, Climatology, and Geophysics (BMKG). The output of our data processing is not limited to only P wave velocity model, but also relocated seismicity pattern in the region. In general, seismicity pattern shows dominant shallow events in the south that progressively shift into deeper events in the north down to a few 500 km, marking a dipping subduction zone in this region. A group of shallow events down to a depth of 50 km is also seen at the norther region that may relate to back-arc thrust activity. P wave tomogram model show a lower velocity perturbation at a depth of 30 km that could be associated with magmatic activity along the volcanic front line. Higher P wave perturbation model are spotted at two different zones, the first one is marking a dipping Indo-Australian plate down to depth of 400 km. We noticed that the angle of dipping is steeper in the Eastern part compared to the Western part. The second a relatively flat at shallow depth at the northern region from the island of Lombok to Nusa Tenggara Timur that may mark the back-arc thrust region.
1. Introduction
The area of Bali to East Nusa Tenggara is located on the ring of fire route which has high earthquake activity due to the subduction zone between the Indo-Australian plate and the Eurasian plate. The Indo-Australian plate is moving at a rate of 6 - 7.3 cm/year to the north [1]. A study by [2] proposed a microcontinental fragments generation when the Indo-Australian plate is moving to the north (Figure 1).

[3] estimated that the age of the plates in the southern part of the island of Java to Flores or the eastern part of the Sunda Arc has an age of 100 - 120.4 Ma. The difference in plate age from the subduction zone affects the deformation and seismicity in the Sunda Arc [4]. Interestingly, a series of shallow earthquakes is seen at north of Bali to East Nusa Tenggara [5] and [6] that was interpreted as the back arc thrust events. Tomographic studies have been conducted previously by [7] and [6] to determine the tectonic patterns that developed in the area, which focus on the subduction zone of the eastern Sunda Arc. Tomogram model by [7] displayed a high-velocity zone extending northward interpreted the down-going oceanic plate and also a high velocity between the two low-velocity anomalies, interpreted as forearc sliver from the continent. This study was conducted to image the tectonic structures that developed in this area of Bali to East Nusa Tenggara, by displaying the results of the P wave tomogram in that area. The objective is to better image the structure and understand more about complex tectonic in this region.

2. Data
The data used in this study taken from the BMKG earthquake catalogue for Bali to East Nusa Tenggara with coordinates 112o to 125o E and -5o to -13o S at the period 2015-2018. It has 8875 events with depth 0-700 km and magnitude from ≥3 SR. Majority of events have shallow depth around 1-100 km, particularly to the southern of regions although a dipping down to the north is also seen. A region of shallow events is also spotted in the northern part of the station network (Figure 2). In total, we used 27 stations distributed from east to the west of regions, mainly around Bali to Nusa Tenggara, and a few in the East Java.

3. Method
We performed our processing data in this study by using simulps12 software [8]. This software uses a simultaneous inversion algorithm to relocate earthquake and determine the P-wave velocity structure each layer. For parameterization, we set the center of grid at 9°S and 118.5°E where the x-axis has a 60 km interval in the inner grid and a 110 km interval for the for outer grids. Meanwhile, the y-axis has a 30 km interval in the inner grid and 70 km interval for the outer grids, yet the z-axis has 10 km, 30 km, 60 km, and 100 km intervals. The velocity model used is 1-D global velocity model AK-135 by [9] with depth over 720 km divided into 4 layers.

The simultaneous tomography inversion uses a pseudo-bending method for ray tracing. The purpose of ray tracing is to estimate the ray path and calculate travel times between hypocenter and station based...
on the velocity model. The software will also invert the optimum velocity and sources location based on the kernel matrix and different between travel time and observation time.

The tomography inversion is a non-linear problem that is linearized where the amount of data is not enough to cover all unknown variable parameters so that the matrix becomes under-determined. To avoid the inversion problem, regularization with damping is generally used. The value of damping is acquired from a trade-off curve between data variance and model variance by empirical iteration. Optimum damping value is expected to increase model variance and decreasing data variance. In this study, the optimum damping value is 70 based on the trade-off curve from various damping around 10 until 80. The optimum damping value pointed out variance model value is 0.03739173 and the variance data value is 0.28614.

**Figure 2.** Seismicity map of Bali to East Nusa Tenggara at the period 2015-2018 and distribution of the recording stations used. Black lines indicate the position of the vertical cross sections displayed in Figures 3.

4. Result and Discussion

To validate the results of the tomographic inversion that has been done, a resolution test is required. The resolution test conducted is the checkerboard resolution test, where the resolution test is carried out by alternating positive and negative anomalies such as a chessboard both horizontally and vertically, where each positive and negative anomaly is ±6% of the initial velocity model. On the results of the checkerboard resolution test, the depth limit of the resolution is 240km, the area that has a good resolution to this depth is the northern area of Sumbawa. East Nusa Tenggara, Lombok and the western areas of the study area were only well resolved to a depth of 150km (Figure 3).

Figure 3 also show the results from P wave tomography in horizontal dan vertical slices. The perturbation value is expressed in colour, blue and red. Positive perturbation with a wave velocity value that is higher than the initial velocity model is expressed in blue. Faster velocity can be associate with higher density and colder temperature. Meanwhile, negative perturbation with a lower wave velocity
value than the initial velocity model is expressed in red that be seen an area with lower density, weaker structure or higher temperature region. A band of lower velocity is seen a depth of 30 km not too far from the volcanoes line. We also observed a pattern of fast velocities that dip down to the north although this is not as continuous as we expected.

Figure 3. Plot a checkerboard resolution test based on depth (left), Horizontal P wave tomogram plot based on depth (right) and vertically in the study area (bottom). The black line represents the subduction zone modelling in the study area. Bottom figure is the location of cross sections

The fast velocities band may represent the oceanic plate that subducting the continental plate. We see a pattern of low angle dip at shallow depth that turn into steep angle at a depth of 60 km. We have confidence of our resolution down to a depth of 300 km. Below this depth, we have not seen good resolution on our checkerboard model so that it would be difficult to interpret where there is a break in the subducting slab as previous claim by [10]. One interesting feature that is previously targeted in this study is the features of back arc thrust previous imaged as a dipping positive velocity model to the south at shallow depth. We might have seen this on cross section E in our model, however, we see the tomogram model is not convincing.

5. Conclusions
We have conducted tomographic imaging of subduction zones in the area of Bali to East Nusa Tenggara using regional data. A dipping fast velocity to the North is seen to the north that is interpreted as the oceanic plate subducting the Eurasian plate. This model is supported by previous geophysical studies. We see a pattern of lower angle of subduction at shallow depth that increase its angle into around 55°
at lower depth. A pattern of lower velocity is also seen beneath volcano that might explain the origin of magmatism in the region. Further analysis from the checker-board model and seismicity suggest several improvements to improve the image. We suggest lowering down the standard during event relocation to capture more events since we see too many events removal. Next, we also think of adding more data set and damping tests to improve the resolution at deeper depth.

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