Comparison of P-Wave Tomography Model in Sunda-Banda Arc by Using Data from BMKG and ISC

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Abstract. The tectonic setting of our study area is located between the Island of Java and Timor Leste. The complexity of this region is started with two different plates, The Indo-Australian plate and the Eurasian plate that move with different orientations and convergence rate. This area also shows active seismic activity and has a series of active volcanoes as a product of subduction and collision. To deepen understand this area, we perform delay time tomography using FMTOMO package that includes 3-D finite-difference based ray tracing and sub-space inversion procedure. We used two different sets of data, the first one is 4 years data catalog from the Indonesian Agency of Meteorology, Climatology and Geophysics, and the second one is 47 years of data from the International Seismological Centre. Data from the local Indonesian show agency shows a fewer number of events but more focus clusters. Meanwhile, the data from ISC catalog has more events and evenly distributed data. However, we also noticed that data from ISC has cluster events located at the same depth that can be improved with events relocation for better depth estimation. The Checkerboard models from both data set show a comparable result, though data from ISC show a better recovered model at a deeper depth and shallow part in the eastern area. The checkerboard from the local Agency shows slightly better results in the shallow part. Next, we invert delay time for each data set using we optimized damping and smoothing parameters. Final tomogram models show that data from the local Agency show a more continuous fast velocity band representing a downgoing subducting slab and possible back-arc thrust while results from the ISC data show a more detached fast velocity band that could be contributed from fixed depth problem in the data set. However, we noticed that data from ISC show a higher amplitude low-velocity anomaly especially in the shallow depth.

Keywords: Sunda-Banda Arc, Back Arc Thrust, FMTOMO
1. Introduction
The movement of the Indo-Australian plate to the north, subducting the Eurasian plate, has a substantial impact on the tectonic setting of the Sunda-Banda Arc. The Indo-Australian plate is moving northward at a rate of 7.7 mm/year relative to the Eurasian Plate [1]. Based on the modeling of ocean floor age and spreading rate [2], shows that Bali Island to Nusa Tenggara Timur has a variety of subduction ages that the age of the oceanic floor in the East is older than the West. As an additional, back-arc thrust structure formed for the slab's pressure continually made the accumulation of energy in northeast Bali Island to Flores is known as Flores Back-Arc Thrust. This thrust estimate has a depth of up to 60 km and a dip of 30° [3]. Sunda-Banda Arc has various seismic activities. [4] showed that seismicity in Bali to Nusa Tenggara Timur is dominated by the earthquake mechanism of a normal fault with shallow depth. The earthquake that occurred in this area was recorded as a large and destructive earthquake. The objective of this study is to better image geological features in this region using delay time P wave tomography and arrival time recorded by permanent station. We used two different data set, the first ones 4 years data from the Indonesian Agency of Meteorology, Climatology and Geophysics and the second one from the International Seismological Centre (ISC) with 30 years recorded data. The result of the study is expected to better understand the tectonic systems in Bali up to Nusa Tenggara Timur by comparing results from different data set.

2. Data and Method
This study is a collaboration project between Department of Geophysical Engineering, Universitas Pertamina and the Indonesian Agency of Meteorology, Climatology and Geophysics (BMKG). The BMKG data collection period is for 4 years (January 2015-December 2018) with number of 3186 earthquakes. The ISC data collection is for 47 years (November 1969-October 2016) with the number of earthquake events is 8234. Both data set have events with magnitude higher than 3 and a 20-400 km depth range. The station that is used in the study area is 29 for BMKG stations and 37 for ISC stations. Figure 1 shows data distribution in the region for both data set. ISC data set distribution shows a more distributed events especially in the shallow section in the South and deep events in the North. ISC also shows shallow data set di North close to the area where back-arc thrust events located.

![Figure 1](image1.png)

**Figure 1.** Map of distribution of seismicity and station in the study area with (a) BMKG data and (b) ISC data. The seismic stations are represented by magenta inverted triangles. The epicenters of earthquakes are represented by red to blue circles as a function of depth. Volcanoes are represented by black triangles.

This study applied delay time seismic tomography to illuminate sub surface structure. We used the fast-marching method to construct ray path between sources and receivers [5]. For parameterization, we set the interval grid size of 56.61 km in latitude direction, 45 km in longitude direction and 40.5 km in
vertical direction. The subspace inversion is applied to solve the inversion problem. The damping and smoothing values are chosen based on the trade-off between data and model variance, with the goal of minimizing data variance while maintaining as little model variance as possible.

3. The result, Discussion, and Conclusion

3.1. Checkerboard Resolution Test

We used the checker-board resolution by adding a pattern of positive and negative anomaly next to each other as the velocity model. By using the same combination of source and receiver, we tried to invert synthetic data set and compared with the input velocity model. This technique is performed to check how deep our resolution target, size of geological features, and which area has higher degree of confidence for modeling. We set the input velocity anomaly into ± 0.2 km/s to the 1-D reference ak135 velocity model. The input model also uses the same interval grid as the final model mentioned before. The results of the checkerboard test can be seen in on Figure 2 for horizontal slices and Figure 3 for vertical slices. In general, although the number of events from BMKG catalog are much less than the data from ISC, the pattern and quality of checkboard does not differ a lot. However, better resolutions are seen at deeper depth especially at western part of the model.

Figure 2. (a) On the left side is the result of the checkerboard resolution test for the horizontal slice in various depths using BMKG data. (b) On the right side is the result of the checkerboard resolution test for the horizontal slice in various depth using ISC data.
Figure 3. (a) Map of the cross-section in the study area. Lines A-A’, B-B’, C-C’, and D-D’ depict the locations of the vertical section. (b) Vp synthetic input model with perturbation of ±0.2 km/s for a vertical slice. (c) On the left side is the result of the checkerboard resolution test for the vertical slice in BMKG data. (d) On the right side is the result of the checkerboard resolution test for the vertical slice in ISC data.

The results of the checkerboard test for the vertical slice on both data show the same pattern. The Vp model for the vertical slice at the latitude of −8° to −9.5° and the depth of 20-200 km can be recovered well. However, we noticed a stronger amplitude recovery for ISC data set from a depth of 100 km.

3.2. Vp Tomography Model

The travel time residual is plotted as a histogram and is associated with the initial and final models. The value of the initial model residual on BMKG data is 12.9659 ms while on ISC data is 30.03759 ms. The value of the final model residual on BMKG data is worth 8.8201 ms while on ISC data is worth 20.39058 ms. The data from ISC show more numbers due to a higher number of events. Figure 4 show horizontal P wave tomogram at different depth for both data set. The red color is a negative velocity that can interpreted as lower density or higher temperature model and blue color is positive velocity model that can seen as higher density or colder temperature model.

Figure 4. (a) On the left side is the Vp model of a horizontal slice for BMKG data. (b) While on the left side is the Vp model of a horizontal slice for ISC data. Models are plotted in ±4 km/s of Vp perturbation. Positive and negative anomalies are marked by blue and red colors.

The P wave tomograms show different results for both data set. At a depth of 20 km, the BMKG model shows a presence of low anomaly in a few places such as beneath Bali, Lombok, Sumbawa, central of Flores Island, and Sumba, strong amplitude beneath west of Flores and south of Sumba. The ISC model shows a negative velocity with stronger amplitude with bigger area, such as in Selayar Island, Maluku, Sumba, East Nusa Tenggara, East Java, Bali, Lombok, Sumbawa, and Timor. At deeper depth, results from ISC data set show a domination of positive amplitude compared with model the BMKG. Positive amplitude model is also seen a deeper depth with much thinner area at the BMKG set.
Figure 5. (a) On the left side is the Vp model of a horizontal slice for BMKG data. While on the left side (b) is the Vp model of the horizontal slice for ISC data. Models are plotted in ± 4 km/s of Vp perturbation. Positive and negative anomalies are marked by blue and red colors.

Figure 5 show cross section profiles from south (right) to north (left) for both data set. The subduction slab is clear seen in the BMKG data set as a steep dipping fast velocity model to the north. However, results from the ISC data set, although show a dipping pattern, the fast velocity seem to be oversized and dominated. The fast velocity also seems not as continuous as the model from the BMKG model.

3.3. Conclusion
This study used earthquake event arrival data input and station networks from two different agencies, The BMKG and ISC. Although the ISC data set has more events and arrivals, the hypocenter information may need to be relocated for better modeling and interpretation. A positive amplitude anomaly is clearly seen on the BMKG data set that dipping in northward direction at steep angle. A negative amplitude is seen in some area that coincides with volcanic line. We would like to thank the Agency of the Indonesian Agency of Meteorology, Climatology and Geophysics, and also the International Seismological Centre for providing the data set.

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