ITB Graduate School Conference (IGSC)
December 21, 2021
ISSN: 2963-718X

Preliminary Results: Tomographic Imaging of P-Wave Velocity Structure Beneath Kalimantan, Makassar Strait, and Sulawesi using Fast Marching Tomography Method

Harmita Lestari[1] , Pepen Supendi[2], Andri Dian Nugraha[3], Nova Heryandoko[2]

[1]Master Program of Geophysical Engineering, Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology
[2]Agency for Meteorology, Climatology, and Geophysics (BMKG), Indonesia
[3]Global Geophysics Research Group, Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology

Email: harmitalestarymvd@gmail.com

Abstract. Sulawesi has significantly higher rate of seismicity than Kalimantan. Furthermore, the Makassar Strait exists, and it has a relationship with the tectonic setting of Kalimantan and Sulawesi. This study employs seismic tomography to imaging sub-surface structures beneath the Kalimantan, Makassar Strait, and Sulawesi region. The data used are earthquake arrival-times data from the Meteorology, Climatology, and Geophysics Agency (BMKG), Indonesia, from January 2017 to January 2021, containing 7.481 earthquakes and 78.610 P-wave phases. FMTOMO employs the fast-marching ray tracing method, a grid-based numerical method that employs a finite–difference algorithm. The results of the checkerboard resolution test will be displayed in this paper using a variety of grids. Then we will look at how the checkerboard resolution of each depth slice, as well as the vertical north-south, changes. The checkerboard resolution test looks for areas with high resolution that can be interpreted further using the inversion tomography method. The preliminary results show that grids with smaller spaces relatively have better recovery checkerboard, with the checkerboard model able to recover the resolution from areas with high seismicity and traversed by many ray paths. As an example, consider North Sulawesi, Central and South Sulawesi, and Southeast Sulawesi.

Keywords: *P-Wave, Seismic Tomography, Tectonic, Sulawesi, Makassar Strait.*

1 Introduction

Makassar Strait is the site of extension, block-faulting and subsidence, leading to the severing of land links between Kalimantan and Sulawesi [1]. The Makassar Strait is covered by quite complex active faults, namely the Paternoster Fault, the complex of the Mamuju Fault and the Palu-Koro Fault. The Palu-Koro Fault Zone is connected to the North Sulawesi Basin, and separates the Sulawesi Sea from the Makassar Basin [2]. Most of the earthquake activity in Sulawesi is related to subduction in North Sulawesi, Palu-Koro Fault, Matano Fault and in Maluku subduction zone in eastern Indonesia (Figure 1). Earthquakes in northern Sulawesi are related to subduction in the North Sulawesi basin. Shallow earthquakes in Sulawesi generally occur around the Palu-Koro Fault and the Matano Fault [3].

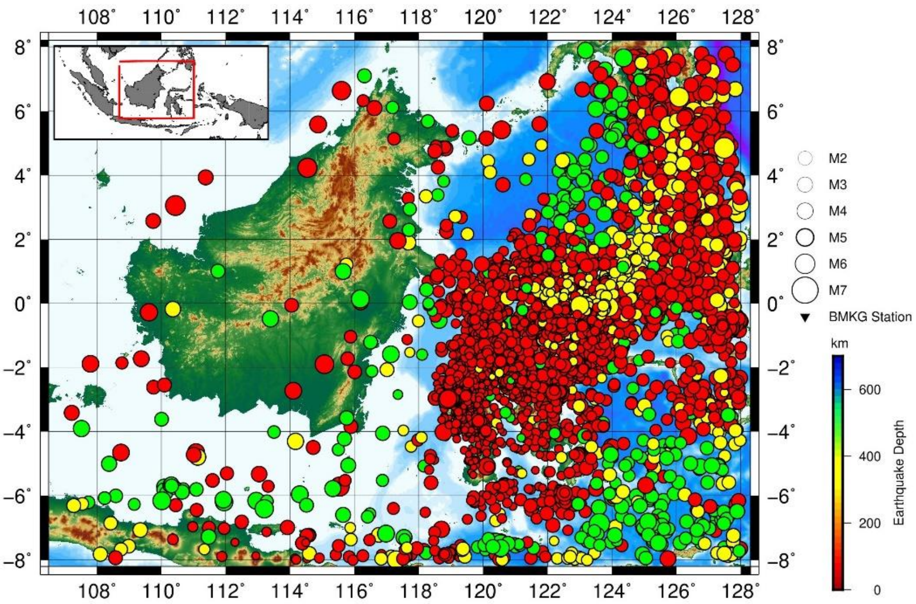

Figure 1 Location of study area and earthquake epicenters from January 2017 to January 2021. The figure shows that Sulawesi has a high of seismicity compared to Kalimantan. This is due to the large number of active faults in Sulawesi and the presence of the Subduction zone in the north of Sulawesi. The inverted black triangles are the BMKG seismic stations that recorded these earthquakes. The thin black line on the map represents the fault and the thick black line represents the trench.

The previous study of seismic tomography has been successful imaging the seismic velocity structure of subducting slabs in Southeast Asia using global [4] and regional [5] body wave arrival times. In [6] described the seismic velocity of a material depends on its elastic properties and density, which in turn are influenced by variations in temperature, pressure, and composition [7].

Regional-scale studies of upper mantle in SE Asia, seismic structure have largely used P wave dan S wave velocity models and focused on subduction zone include subduction zone in North Sulawesi [6]. Global tomography models demonstrate that subducted slabs are characterized by anomaly high velocities, which likely have a dominantly thermal origin [4].

This study uses P-Wave velocity to create a seismic wave velocity model based on travel time tomography, that can explain the tectonic conditions of the study area. Vp variations used FMTOMO software for detailed description of the subsurface structure [6]. This study will later be used as further study the potential seismicity beneath Kalimantan, Sulawesi Strait, and Sulawesi.

2 Materials and Method

The data used in this study are the arrival-times earthquakes from 85 BMKG seismic stations for earthquakes in Kalimantan, Makassar Strait, and Sulawesi. for the time period from January 2017 to January 2021. The number of earthquakes are 7.481 consist of 78.610 P-wave phases, with depth range of 5 and 750 km and a magnitude of Mw 2 to 7.2. In addition, AK135 [8] velocity model is also used as the initial 1D velocity model. In this study, seismic tomography calculation of travel time was carried out using FMTOMO software [9] and [10] and resulted in variations in the value of the P wave velocity (Vp) to explain important structures in the study area. FMTOMO uses the fast-marching method (FMM) [11] and [12], a grid-based electronic solver for the forward step of tomography inversion using traveltime prediction [6].

Tomographic inversion stage that will be shown in this paper is the checkerboard resolution test, this method will test the entire model space by compiling the positive and negative velocity values from the initial velocity values in the checkerboard model. Determination of grid size and spacing depends on the number of stations, the number of events, ray path assessment, and the distance between stations. The results of the checkerboard relocation test will provide an overview and information of areas and depths that can be used in tomography inversion. Damping and smoothing values were 5.0 respectively to solve variations in deep structure. If the recovered model is close to the initial input, it can be interpreted further. The anomalous pattern and the quality of the checkerboard resolution are determined by the number of ray paths that pass through the area both horizontally and vertically depend on depth.

3 Result and Discussion

To determine the size and spacing of the grids that will be applied to the tomographic inversion, 3 different grid inputs are used to compare the robustness of the resulting checkerboard model. Where the smaller the grid used, the resolution of the resulting tomogram should also be better and can explain the research area well, but the computation time will be increase [6]. In addition, the grid size must also consider the number of that pass through the study area. This study used 3 different grid input schemes.

The first sceme using the input of velocity grid in grid3dg with number of grid points in depth, latitude, and longitude 10, 12, 25, respectively. Velocity grid input produced a large grid size, X in longitude: 111 km, Y in latitude: 185 km, Z in depth: 75 km. The second sceme using the input of velocity grid in grid3dg with number of grid points in depth, latitude, and longitude 20, 25, 25, respectively. Produced a large grid size, X: 111 km, Y: 88.8 km, Z: 37.5 km. The third sceme using the input of velocity grid in grid3dg with number of grid points in depth, latitude, and longitude 35, 35, 42, respectively. Produced a large grid size, X: 66.07 km, Y: 76.11 km, Z: 24.28 km. The checkerboard resolution test was performed using the standard deviation of Gaussian noise 0.7 s for the P wave travel time in the synthesis data. The aim is to simulate the P wave arrival time by selecting the uncertainty from the observational data set [6]. The results of checkerboard resolution test are shown in Figure 2-7.

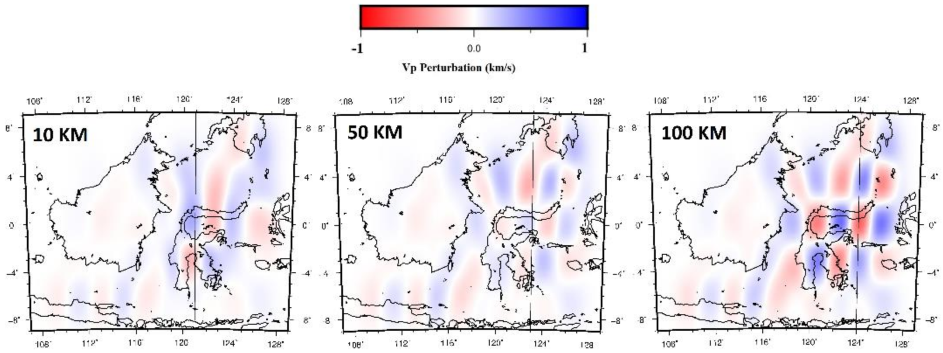

Figure 2 Horizontal cross section of checkerboard resolution test result with a large grid size, X: 111 km, Y: 185 km, Z: 75 km.

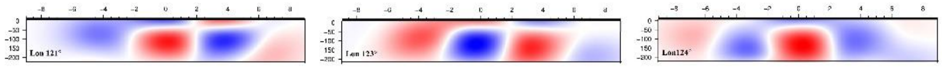

Figure 3 Vertical cross section (North-South) of checkerboard resolution test result. Longitude slice is 121°, 123° and124° consist with depth 5-200 km. The area sliced is shown by a black line on figure 2.

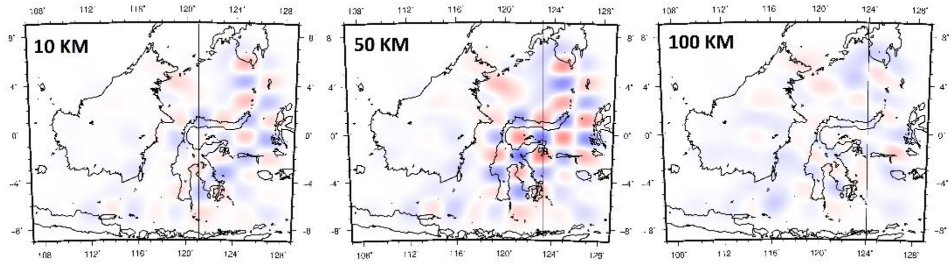

Figure 4 Horizontal cross section of checkerboard resolution test result with a large grid size X: 111 km, Y: 88.8 km, Z: 37.5 km.

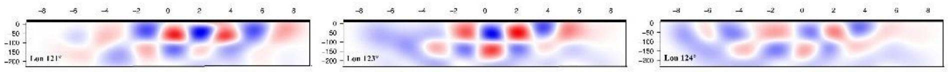

Figure 5 Vertical cross section (North-South) of checkerboard resolution test result. Longitude slice is 121°, 123° and124° consist with depth 5-200 km. The area sliced is shown by a black line on figure 4.

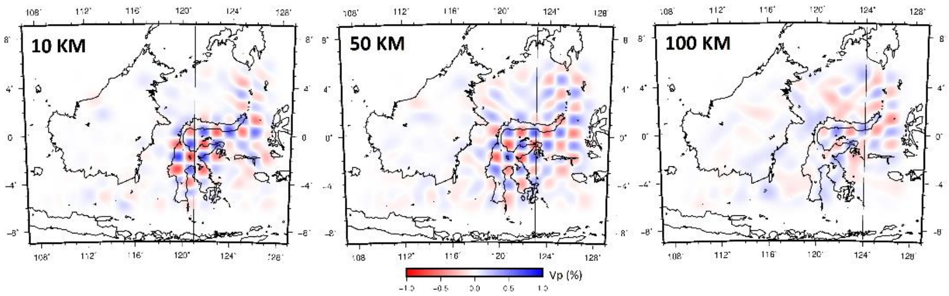

Figure 6 Horizontal cross section of checkerboard resolution test result with a large grid size, X: 66.07 km, Y: 76.11 km, Z: 24.28 km.

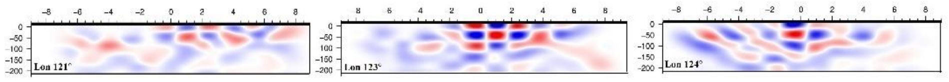

Figure 7 Vertical cross section (North-South) of checkerboard resolution test result. Longitude slice is 121°, 123° and124° consist with depth 5-200 km. The area sliced is shown by a black line on Figure 6.

The positive and negative anomalies in the checkerboard model are defined by two grid points in each dimension. From three schemes of grid size, the third scheme with grid size X: 66.07 km, Y: 76.11 km, Z: 24.28 km can provide a better recovered model. This can be seen in the figure 6 where at a depth of 10 km, 50 km, and 100 km the checkerboard input can recovered model in almost all areas of Sulawesi, especially in the North Sulawesi, Central Sulawesi and Southeast Sulawesi regions. Around the Makassar Strait, the checkerboard model is still visible even though the resolution is not good. This is in accordance with the initial assumption that the checkerboard resolution will depend mainly on the number of earthquake events and stations which result in the number of ray paths that pass through the study area.

The second scheme with grid size X: 111 km, Y: 88.8 km, Z: 37.5 km, it is also quite good in the recovered checkerboard model in depth 50 km. But the resolution is not good at a depth of 10 km and 100 km as shown in figure 4. The recovered checkerboard model looks similar in all research areas so that it does not meet the basic assumptions and theories of the principles of seismic tomography.

Meanwhile, the third scheme grid size that is larger than other grid sizes as shown in figure 2, which is X: 111 km, Y: 185 km, Z: 75 km, the model resolution can recovered the input model only at a depth of 100 km. This is the same as the north-south vertical slice, indicates that a grid size that is too large will make the inversion result less accurate.

In general, from the three grid sizes used by the Kalimantan area, the recovery of the checkerboard resolution test is not good with a low resolution. Relatively good resolution of checkerboard recovered model are in eastern Kalimantan near Palu-Koro fault and Makassar Strait. Where in the area there are also three fault structures of the earthquake source, there are Maratua Fault, Sangkulirang Fault, and Paternoster Fault, which are the sources of earthquake generators in the region even though the earthquake frequency and strength is low. So that from the results obtained the areas that will be further interpreted are only eastern Kalimantan, Makassar Strait, and the entire Sulawesi region. The inversion step based on the recovered model from the applied checkerboard resolution test.

4 Concluding Remarks

By looking at the recovered model of checkerboard resolution test from the three grid sizes, when sliced at a certain latitude as shown in the Figure 3, Figure 5, and Figure 7, tomographic inversion and further interpretation can be performed down to a depth of 200 km. Cross section of checkerboard resolution test using 3 different grid sizes, it can be seen that the grid with the smaller size in the third scheme X: 66.07 km, Y: 76.11 km, Z: 24.28 km, has better model resolution as well as can be recovered model input well. So that the tomographic inversion will be carried out using the input model and the grid size in East Kalimantan to the entire of Sulawesi, at longitude of 116°-127° and at latitude of 8° to -6.2° from depth 5 km until 200 km.

5 Acknowledgement

We thank for Meteorology, Climatology, and Geophysics Agency (BMKG) Region IV Makassar, Indonesia which provides the catalog data. We thank to Rawlinson for FMTOMO software [13] that we used in this study. This study also supported by LPDP Scholarships 2020 from the Ministry of Finance of the Republic of Indonesia awarded to Harmita Lestari. All map figures in this study were made using Generic Mapping Tools (GMT) [14].

6 References

[1] Moss, S. J. & Wilson, M. E., (1999). Cenozoic palaeogeographic evolution of Sulawesi and Borneo. Palaeogeography, Palaeoclimatology, Palaeoecology,145, 303–337.

[2] Katili, J. A. (1978). Past and present geotectonic position of Sulawesi, Indonesia, Tectonophysics, 45, 289–322.

[3] Supendi, P., Nugraha, A. D., Widiyantoro, S., Pesicek, J., Clifford, T., Chalid, A., Daryono, Wiyono, S., Shiddiqi, H., Rosalia, S., 2020. Relocated aftershocks and background seismicity in eastern Indonesia shed light on the 2018 Lombok and Palu earthquake sequences, Geophysical Journal International, 221, 1845–1855.

[4] Hall, R., & Spakman, W. (2015). Mantle structure and tectonic history of SE Asia. Tectonophysics, 658, 14–45. https://doi.org/10.1016/j. tecto.2015.07.003.

[5] Zenonos, A., De Siena, L., Widiyantoro, S., & Rawlinson, N. (2019). P and S wave travel time tomography of the SE Asia-Australia collision zone. Physics of the Earth and Planetary Interiors, 293(1), 106267. https://doi.org/10.1016/j.pepi.2019.05.010

[6] Zenonos, A., DeSiena, L., Widiyantoro, S., Rawlinson, N. (2020). Direct inversion of S-P differential arrival times for Vp/Vs ratio in SE Asia. Journal of Geophysical Research: Solid Earth, 125, e2019JB019152. https://doi.org/10.1029/2019JB019152

[7] Cammarano, F., Goes, S., Vacher, P., & Giardini, D. (2003). Inferring upper-mantle temperatures from seismic velocities. Physics of the Earth and Planetary Interiors, 138(3), 197–222.

[8] Kennett, B.L.N. Engdahl, E.R. & Buland R., 1995. Constraints on seismic velocities in the Earth from travel times, *Geophys J Int*, **122**, 108-124.

[9] de Kool, M., Rawlinson, N., & Sambridge, M. (2006). A practical grid-based method for tracking multiple refraction and reflection phases in three-dimensional heterogeneous media. *Geophysical Journal International*, *167*(1), 253–270.

[10] Rawlinson, N., & Sambridge, M. (2004a). Multiple reflection and transmission phases in complex layered media using a multistage fast-marching method. Geophysics, 69(5), 1338–1350. http://library.seg.org/doi/10.1190/1.1801950
[11] Sethian, J. A. (1996). A fast-marching level set method for monotonically advancing fronts. Proceedings of the National Academy of Sciences, 93(4), 1591–1595. http://www.pnas.org/cgi/doi/10.1073/pnas.93.4.1591
[12] Sethian, J. A., & Popovici, A. M. (1999). 3-D traveltime computation using the fast-marching method. *Geophysics*, *64*(2), 516–523. http://library.seg.org/doi/10.1190/1.1444558
[13] Rawlinson, N., de Kool, M., & Sambridge, M (2006). Seismic wavefront tracking in 3D heterogeneous media: applications with multiple data classes. Exploration Geophysics (2006) 37, 322–330
[14] Wessel P, Smith W H F, Scharroo R, Luis J and Wobbe F 2013 Generic mapping tools: Improved version released *Eos (Washington. DC).* 94 409–10