Preliminary Results of Regional P and S Wave Tomography at Seram, Indonesia

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Abstract. The Seram Trough is located in the northern part of Indonesia and has a complex tectonic setting. The uniqueness of these regions lies in the U-shape subduction system. Several models have been proposed in this region, such as one subduction system that has been rotated 90° or 180°, two subduction systems, and one subduction that has a slab rollback that causes extension systems. In this study, we try to invert velocity and seismicity using double-difference tomography with the target of better imaging the sub-surface structure in the region. We use data catalogue collection from the Indonesian Agency of Meteorology, Climatology, and Geophysics. The length of data is 4 years from January 2015 to December 2019 from 16 permanent stations. Earthquake relocations show a focused hypocenter distribution at shallow depth, and we interpreted some of these shallow depth events are related to the magmatic activity. Event distribution also displays a steep angle of seismicity pattern that represents the dipping subduction slab. Inverted Tomography models show a band of faster velocity models that dip from North to South, suggesting a subduction slab. We also observe a possibility of a tear in the slab from the seismicity pattern and tomogram model. The slower velocity perturbation is seen at shallow depth that may associate with magmatic and frequent shallow seismicity. A possibility of partial melting is also seen with low-velocity zone at a depth of 70 km next to the fast dipping velocity.

Keywords: P-wave tomography, S-wave tomography, Double Difference Tomography, Seram
1. Introduction
Seram is one of the areas in the Maluku archipelago. The tectonic setting of this area is affected by 3 main plates, namely the Australian Plate, the Pacific plate and the Eurasian plate. This area is known for having a pattern of curved subduction (Figure 1).

![Figure 1. Study area (grey colour) and a pattern of curved subduction (red line)](image)

To the present, there are several models to explain the interesting pattern of curved subduction. Spakman & Hall [1] proposed a one slab system that rolled back. Sri Widiyantoro et al. [2] also found that seismic tomography successfully depicts Banda Slab as a single system that twisted and forming spoon-shaped structure towards Banda Sea as well as conforming the slab rollback scenario. In the other hand, Cardwell, R. K. et al [3] with seismicity and fault plane study proposing Banda Slab constructed by two different system. The first one is the Timor – Aru Trough system from south and the second one is the Seram Trough system in the north that joined the Banda Slab because New Guinea Tarera – Aiduna Fault Zone extension. The objective of this study is to image subsurface feature in this region especially at Seram Trough using regional data set and double difference tomography method. We are interested in knowing the seismicity pattern and understand the geodynamic of Seram Trough.

2. Data and Method
This research used data on the arrival times of P and S waves from the Agency of Meteorology, Climatology and Geophysics Agency (BMKG), Indonesia. The data consists of 1238 earthquake events and 16 observation stations from 2015 to 2019. Note that we used velocity model data from previous research of Madlazim [4] as the starting model. The number data before being relocated was...
1238 earthquake events and after being relocated the number of data was reduced to 1225 earthquake events. We do not see a significant difference in hypocenter location between before and after inversion although some improvements in fixed depth events (Figure 2). The data is distributed evenly at shallow depth and some events dipping to south-west direction that can reach a depth of 500 km.

Figure 2. Seismisity map before relocation (left) and after relocation (right)

We used double difference tomography method known widely as TomoDD [5]. The double difference method minimizes the remaining time from the calculated travel time and the observed travel time on two earthquake events that are interconnected with the same number of earthquakes recording stations [5,6,7]. Note the travel time and ray path is estimated using the pseudo bending method. For model parameterization, we set the grid into 40 km cube in all directions. To validate the results of the inversion, a resolution test was performed using the Derivative Weight Sum (DWS) method. DWS is carried out to test the results of the tomogram and the results of the tomographic inversion by weighting the total length of the rays through a node in the inversion grid.

3. Results and Discussion

One indication of having good inversion model is calculating the residual value before and after relocation. The residual value is obtained from the difference in travel time between the travel time of observation and the travel time of calculation. Figure 3 shows that majority of time residual has been removed closer to zeros.

Figure 3. Histogram residual (left), rose diagram (centre), and compass diagram (right)

In Figure 3 shows a diagram of a rose and a compass resulting from a hypocenter relocation. The direction of the hypocenter spacing is indicated by an arrow on the compass diagram and rose diagram to the hypocenter shift in km. Overall, we do not see any relocation weigh in one direction. The wave velocity structure model is obtained by the tomographic inversion process using tomoDD software with 20 iterations. Damping parameter is added in regularization process to solve underdetermined problem with value of 150 estimated from trade off curve between model variance and data variance.
Figure 4. Horizontal tomogram $V_p$ (left), $V_s$ (centre), and $V_p/V_s$ (right)
Figure 4 shows the results of the tomogram model for horizontal P and S wave velocity at each depth. The results of the tomogram show the difference in red and blue, where the blue colour is a positive perturbation with a higher wave velocity value than the initial velocity model and the red colour is a negative perturbation with a lower wave velocity value than the initial velocity model. Positive anomaly shows the density of the structure in the area is denser or colder which is associated with subduction slabs. Negative anomaly shows the density of the structure in the area is more fragile or hotter which could be associated with the local fault zone or partial melt zone. The horizontal plotting of perturbation values obtained an anomaly pattern at shallow depths <20 km dominated low velocity, then a high velocity is seen that is stifling from north to south from a depth of 40 km and follows a slab pattern. Some area at the point of volcanic area show velocity model of Vp with low velocity, Vs with high velocity, and Vp/Vs with high velocity indicated there are partial melting in this area.

![Subduction slab model tomogram Vp and Vs. Volcano is pictured in red triangle.](image-url)
Figure 5 shows different cross section profiles at different longitude from north to south direction. Note that our red dash line interpretation as subduction slab is mainly based on seismicity depth. Cross section L is a good representation of subduction slab that coincides with seismicity. Some sections also display a relationship between low velocity and beneath volcano.

4. Conclusions
Based on the results of relocation earthquake data recorded from the January 2015 - December 2019 period in the study area, the earthquake distribution pattern shows a slab pattern from north to south and east to west. A deep earthquake can be caused by several sources, including the subduction slab plunging to a depth of more than >450 km. Then shallow earthquakes can be caused by local faults close to the surface. The relocation results show good results where the residual travel time histogram data, the residual value of the earthquake after relocation, has increased close to the value of 0 and the value has decreased away from 0.

The tomographic inversion results have succeeded in providing a new 3D velocity model from the initial 1D velocity model. Some sections show convincing down-going fast velocity coincides with seismicity. A low velocity is also found on beneath volcano. Next works would like to include more data set for better interpretation in this area.

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