Analysis of the mentawai region fault field based on earthquake relocation data using the modified joint hypocenter determination (MJHD) method

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Abstract. Tectonic conditions in an area are very important to know, one of them is the Mentawai region. Mentawai is an area prone to earthquake disasters, this is because the Mentawai is located between the subduction zone between the Eurasian Plate and the Indo-Australian Plate. One of the earthquake parameters that is needed in analyzing tectonic conditions is the hypocenter. Accurate hypocenter determination can be done by relocating earthquakes using the Modified Joint Hypocenter Determination (MJHD) method. The MJHD method is carried out by inversion of the main earthquake and aftershocks with correction of the station at the earthquake event. The earthquake data in this study began on September 1, 2017, until December 31, 2018, with 1 main earthquake and 104 aftershocks in the format of arrival time. The main earthquake before the relocation is at longitude coordinates 99.85o latitude -2.6o with a depth of 12 km. After being relocated it is at coordinates 99.5413o latitude 2.5779o with a depth of 29 km. The results after the relocation were identified were fault fields occurring in the B-B cross-section 'nodal plane 2 with a strike of 141o 66o slip 92o. Earthquake relocation using the Modified Joint Hypocenter Determination (MJHD) shows a change in the Root Mean Square (RMS) value <1. This suggests that the earthquake hypocenter after relocation using the Modified Joint Hypocenter Determination (MJHD) method is more accurate.

1. Introduction
Sumatra Island is an earthquake-prone area, especially the Mentawai region [1]. This is because the Mentawai tectonic conditions are at the Eurasian Plate meeting with the Indo-Australian Plate. The Indo-Australian Plate which continually subducts the Eurasian Plate results in the formation of a shallow subduction zone called "megathrust" [2]. This subduction effect causes the Mentawai to have very high seismic activity and the potential for tectonic earthquakes.

One of the parameters of the earthquake that needs to be known is the hypocenter. The hypocenter is an earthquake center located on the surface of the earth [3]. The accuracy of determining the location of the earthquake hypocenter point has a different error rate, this is caused by several factors including seismic station network, earthquake data distribution, earthquake arrival time reading and speed structure model [4]. Determination of the location of the hypocenter of earthquakes accurately and accurately is very important to do in analyzing tectonic structures, including identification of fault zones.
and subduction zones. The Meteorology and Geophysics Agency (BMKG) in determining hypocenter parameters has several weaknesses and strengths.

The advantages include the InaTEWS sensor network, which is around 65 sensors spread across the Sumatra region and beyond, so that observations of earthquake events can cover a very wide area, the use of broadband sensors that allow wider frequency reception, data transmission from sensors to data processing centers using satellites so that it's easier to place sensors in any region [5][6]. The disadvantage is the position of the sensor is less tight so it is often constrained if there is a local earthquake that is only recorded in one sensor. Besides this data inaccuracies are also caused in the hypocenter determination process using an isotropic homogeneous earth velocity model.

The subsurface layer of the earth passed by the earthquake wave is heterogeneous. Lateral heterogeneity is what causes the difference in reading a hypocenter location by a series of stations so that the hypocenter spreads and is read into several events. Based on this, further studies are needed to minimize errors due to errors in reading the system and speed models used to relocate the earthquake hypocenter parameters that have been produced previously so that the earthquake hypocenter is obtained more accurately by relocating earthquakes using the Modified Joint Hypocenter Determination method [4].

2. Data and Methods

The data used in this study were obtained from the BMKG Center in the format of arrival time P and S. Wave arrival time. The earthquake focal mechanism data was obtained from Global CMT. Earthquake data starts from September 1, 2017, to December 31, 2018. It is at coordinates longitude 98° until 99° degrees and latitude 1 degree until 2 degrees. The earthquake data includes 1 main earthquake and 104 aftershocks.

![Research Map in Mentawai](image)

Figure 1. Research Map in Mentawai

Figure 1 is the Mentawai research area. This study uses the Modified Joint Hypocenter Determination (MJHD) method in relocating earthquakes. The MJHD method is a renewal of the Joint Hypocenter Determination (JHD) method [7]. The principle of the MJHD method is to vary the travel time of a group of earthquakes simultaneously to get better results than the Single Event Determination (SED) method used by the Seiscomp3 BMKG system. Calculation of the difference in travel time observed by each station with the travel time of the calculation results can be determined in the equation:

\[ r_{ij} = T_{ij}^{obs} - (T_{cat}^{ij} + S_i) \]  

(1)

Category of depth:

- Shallow (0-70 km)
- Intermediate (71-300 km)
r$_ij$ is the residue of travel time data from observations on calculations. $T_{ij}^{obs}$ is the seismic wave time from the source to the recording station. $T_{ij}^{cal}$ travel time and Si is station correction. Using Taylor Series, equation (1) is broken down into:

$$dr_{ij} = \frac{\partial T_{ij}}{\partial x_j} dx_j + \frac{\partial T_{ij}}{\partial y_j} dy_j + \frac{\partial T_{ij}}{\partial z_j} dz_j + dT_{oj} + dS_i$$

where dx, dy, dz, and dToj are station corrections for the initial hypocenter estimate and origin time for the jth earthquake, while dSi is the correction for the i-station. Coefficient $\frac{\partial T_{ij}}{\partial x_j}, \frac{\partial T_{ij}}{\partial y_j}, \frac{\partial T_{ij}}{\partial z_j}$ calculated based on the speed model used. The values dx, dy, dz, dTo, and dSi are the parameters that you want to specify, in this case, they are collected in a vector m. The vector m is obtained using the Least Square (LSQ) method by minimizing an objective function in the form of a residual square value [8]:

$$f(m) = \sum (O - C)^2 \rightarrow \text{minimum}$$

In the LSQ method, an initial model is needed as an initial estimate, in this case, the results of the SED method are used. After obtaining the values dx, dy, dz, and dTo, the initial model value is updated to the new model parameter:

$$x_1 = x_0 + dx$$
$$y_1 = y_0 + dy$$
$$z_1 = z_0 + dz$$
$$t_1 = t_0 + dTo$$

This solution is done iteratively by assuming the new model is obtained as an initial model. This iterative process is carried out until the changes obtained are no longer significant or limited by the maximum number of iterations.

3. Results and Discussion
Earthquake data consists of 105 earthquake events. 1 main earthquake and 104 aftershocks. With a period of September 1, 2017, to December 31, 2018. The results of the hypocenter distribution before relocation using the Generic Mapping Tool (GMT) can be seen in Figure 2.
Figure 2. (a) Distribution of Previous Earthquake Hypocenter Relocation (b) cross section A-A’ (c) cross section B-B’

Figure 2 (a) shows the results of the hypocenter distribution before being relocated. The results of the hypocenter distribution before relocation show that the earthquake distribution is not evenly distributed, (b) cross-section A-A’ to the nodal plane 1 with strike 315° dip 24° slip 84° shows there is still a hypocenter earthquake with a depth of 10 km or also called fixed depth obtained from manual results by the operator when analyzing earthquakes on Seiscomp3 on BMKG. (c) B-B’ s cross-section of the nodal plane 2 with strike 141° 66° slip 92° dip shows that the distribution of the earthquake begins to gather but still 10 km deep. The purpose is given a cross-section to be able to see the concentration of the distribution of the location and depth of the hypocenter until it can be seen the fault field that occurred in this study area.
Figure 3. (a) Distribution of After Earthquake Hypocenter Relocation using MJHD (b) A-A cross section (c) B-B cross section

Figure 3 (a) shows the results after the relocation process. Judging from the location and depth of the hypocenter before and after relocation there is a difference in the hypocenter position of the main earthquake before the relocation is at a depth of 12 km but when it has been relocated the depth changes to 29 km. This also improved the location of the hypocenter on the subsequent earthquake. (b) A-A cross section there was an improvement from the hypocenter position in all earthquakes, both the main earthquake and aftershocks (c) cross section B-B have hypocenter changes and more earthquake group distribution.

The results of earthquake relocation obtained using the MJHD method, it can be said that the parameters of the relocated earthquake have been improved in terms of position and depth. The results of the improvements produced after the relocation process can be shown in the form of a graph with a comparison of the RMS values based on the earthquake event that occurred as shown in the following figure

Figure 4. (a) RMS Graph Before Relocation (b) RMS Graph After Relocation

Figure 4 is a Root Mean Square (RMS) graph in this study. RMS is the difference between the travel time calculation and the travel time of observation. The RMS value shows the accuracy level of earthquake data used, which has a value of less than 1 (<1) to get accurate and good results [1]. Because the smaller the RMS value, the result will be close to the actual hypocenter position (a) the RMS graph before relocation still has a value > 1, this indicates that there are still earthquake events that have not fulfilled the actual value (b) of the RMS graph after the relocation appears to change, with value <1. This proves that the earthquake hypocenter after relocation using the modified joint hypocenter determination method is more accurate.
The hypocenter relocation of earthquakes using the MJHD method provides a change in hypocenter location based on station correction recorded by each earthquake station used [5]. Hypocenter locations before relocation have poor accuracy due to the process of determining hypocenter errors due to model structures that are not modeled using 1D speed models can not be minimized. The location of the determined earthquake center will certainly contain errors related to the unmodified speed structure. The modified joint hypocenter determination algorithm can increase relative location accuracy by correcting stations in earthquake events. The velocity model that is used increasingly into the primary wave velocity is getting higher, it shows that the deeper the structure of the earth gets denser [9]

4. Conclusion
Based on the comparison of the RMS value from the results before relocation with after relocating the earthquake 1 September 2017 to 30 December 2018 it was obtained that most of the data had improved hypocenter position more accurately, with the initial position 12 km to 29 km. The results of the aftermath relocation of aftershocks can be identified as fault fields occurring in nodal plane 2 with strike 141° dip 66° slip 92°

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