Horizontal Displacement Vector Analysis in Ujong Muloh GPS Station (UMLH) Sumatra Island on March 27 – April 25, 2012

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Abstract. Sumatra Island is an area that has high tectonic activities. This is because the island of Sumatra is located in two major plates of the world, the Indo-Australian plate and the Eurasia plate. The subduction zone causes Sumatra to deform from time to time. The deformation of Sumatra Island can be observed by continuous recording coordinates using the GPS Station. Continuous-GPS (C-GPS) in Sumatra Island is named Sumatran GPS Array (SuGAr), one of them named UMLH. The UMLH GPS station used to observe the displacement in the Aceh City of Sumatra Island, is located in Ujong Muloh. The changes of GPS coordinate recording data can represent the deformation pattern that occurred in Sumatra. On April 11, 2012, according to USGS data, there had been an earthquake in the city of Aceh about 8.6 at coordinates of 2.433°N, 93.072°E. The purpose of this research is to analyze the horizontal displacement due to the occurrence of the earthquake. Data processing is carried out using software GAMIT/GLOBK. The magnitude of the displacement of Sumatra Island before the earthquake, during the earthquake, and after the quake on component X were respectively: 0.04 mm/day, 56.63 mm/day, and 8.28 mm/day; while on component Y were respectively: 0.03 mm/day, 23.78 mm/day, and 1.22 mm/day. The direction of displacement was 253.8° towards Southwest with the assumption that 0° was in the North.

1. Introduction

Sumatra Island is located near in subduction zone, which is a meeting zone of the Indo-Australian Plate and the Eurasian Plate. This is the cause of Sumatra has the potential to experience an earthquake [1]. A tectonic activity can be followed by a deformation. Deformation is a change in the shape of an object due to the transformation of the position of its constituent particles. Deformation can also be seen as position from point to point. So that when tectonic activity occurs, an island has a certain direction displacement.

In Sumatra, there is a permanently installed GPS station to record coordinates continuously. The GPS station is named Sumatran GPS Array (SuGAr). SuGAr Station is operated by LIPI and Tectonic Observatory Caltech (USA) [2]. GPS observation data are stored in the Script Orbit and Permanent Array Center (SOPAC) which can be used for geodynamic measurement studies in Sumatra. Vector analysis is one method to observe deformation on an island [3]. Observation of the displacement is done using continuous GPS recording data [4-7].

Previous research on the displacement in North Sumatra had been done after the Aceh earthquake in 2004. One of them was at UMLH SuGAR Station (Ujong Muloh) on Day of Year (DOY) 19.2005-
19.2006. The horizontal motion showed the direction of the southwest with a velocity of 41.0 ± 0.1 cm/year prior to the outbreak of SAE 2004. The displacement rate then decreased to 18.0 ± 0.1 cm/year during the period 2006.19-2007.19 [8].

Based on USGS data dated April 11, 2012, there had been a tectonic earthquake with a magnitude of 8.6 in North Sumatra at 2.433°N, 93.072°E with a depth of 25 km. This research was conducted to observe the characteristics of plate movement horizontally. The GPS station used was UMLH in the Aceh area because the quake was felt in the city and the GPS station is the only one in Aceh. Observations were made by analyzing the magnitude of the displacement before and after the earthquake events.

2. Data and Methods

The research used continuous GPS observation data (SuGAr) which can be accessed through http://sopac.ucsd.edu/dataBrowser.shtml page. The range of data used was 30 DOY (87.2012-118.2012) in the event of an earthquake that laid in the mid-range of the DOY. The selected station was UMLH as deformation observation station and 7 reference GPS stations were BAKO, COCO, DGAR, IISC, PTAG, LHAZ. All data had been downloaded in RINEX data format. Then the data was processed using GAMIT/GLOBK 10.61 software because it had a better correction [9]. The design of deformation observation in this study is described in figure 1.

![Figure 1. Design of deformation observation](image-url)

The selection of these stations was based on the configuration of the connective nets. The quality of the data in the reference GPS station, as well as the availability of reference GPS data on the DOY corresponding to the amount of GPS deformation station data used [9]. RINEX data processing scheme is shown in the following figure 2.
3. Results and Discussion

3.1. Results of Data Quality Checks

The quality of data received for processing with GAMIT has the criteria of MP1 and MP2 values below 0.5 m [9]. The Rinex data used as a whole has good criteria as shown in figure 3 and figure 4. The smallest value of MP1 is shown in DOY 90, 102, and 116 with value 0.29 m, while the largest value found in 110 is 0.33 m. The average value of MP1 as a whole is 0.31 m. Day of year (DOY) is the order of the day in one year. Then the average value of MP2 is 0.25 m, with the smallest value is 0.23 m and the highest value is 0.27.

IOD Slips stands for Ionosphere Observable Delay (IOD), is a parameter showing the delay of GPS signal due to ionosphere influence [10]. The IOD value criteria that meet the processing standard is

**Figure 2.** Processing scheme

**Figure 3.** Graph of MP1 versus DOY

**Figure 4.** Graph of MP2 versus DOY
below 100 [10]. The IOD value of the slips has an average of 75.6 with the lowest value is 25 and the highest value is 97. The result of IOD or MP slips in Figure 4 has an average of 61.5 with the lowest value is 25 and the highest value is 99.

3.2. Results of Gamit Processing

The fract value of the GAMIT processing result can be seen from the q-files generated in the respective DOY folder. Good fract value criterion is less than 10 [9].

The processing result shows that the fract value for the latitude component undergoes an average change after DOY 102 is 4.1; while the average value of fract before DOY 102 is 0.1. This significant change can be investigated further through GLOBK processing results. Because in general this fract value should not have a significant change in Figure 7 and Figure 8. This may indicate that there is an effect on the UMLH station so that the fract value undergoes significant changes in DOY 102. The fract value of the longitude component has a good quality for processing in which the lowest fract value is -2 at DOY 100 and the highest fract value is 6.3 at DOY 112. Overall fract value of the GAMIT processing result has fulfilled criterion with maximal value 10.

After looking at the quality of GAMIT processing using fract value, the quality test result of GAMIT process is done by analyzing the value of postfit nmrs. This value can be seen in q-file of each DOY after final process using GAMIT [9]. The result of this value is plotted in the relationship graph
of postfit nmrs to the DOY to see the change in the value of postfit nmrs. Postfit nmrs results are divided into 2 solutions namely biases free and biases fixed.

![Graph of relationship biases free postfit nmrs value versus DOY](image1)

**Figure 9.** Graph of relationship biases free postfit nmrs value versus DOY

![Graph of relationship biases fixed postfit nmrs value versus DOY](image2)

**Figure 10.** Graph of relationship biases fixed postfit nmrs value versus DOY

The postfit nmrs biases free value of 30 DOY fluctuated with the highest value of the DOY 104 of 0.22 m and the lowest value at the DOY 111 of 0.17 m. While for postfit nmrs biases fixed value also shows a pattern of postfit nmrs fluctuate value. The lowest postfit value in the fixed biases solution is on the DOY 103 of 0.178 m and the highest postfit value of nmrs at the DOY 104 of 0.224 m. Overall postfit nmrs value meets criteria with values below 0.5 m. This may indicate that in observation there is no effect of cycle slips that have not been removed.

### 3.3. Results of Processing GLOBK

The time series plot is the result of the evaluation process of GLOBK used to see the existence of outlier data in the range of data used as the observation [9]. Outlier data is data whose value is the most different from other values. The value may be caused by incomplete data recording, in which one of them can be caused by an instrument error.

![Plot time series before the quake](image3)

**Figure 11.** Plot time series before the quake

![Plot time series after the quake](image4)

**Figure 12.** Plot time series after the quake
Based on figure 11 and figure 12 there is no outlier data, where the existence of outlier data can be shown with high wrms value. The maximum limit of wrms that can be tolerated for GLOBK processing is below 100.

3.4. Displacement of Station UMLH

Figure 13 and figure 14 is a plot of coordinate points from DOY 85 to 120 for X and Y components, respectively. It is clearly seen that in DOY 102 for both graphs shows a significant displacement. This is indicated by the earthquake on April 11, 2012, because DOY 102 is the same as April 11, 2012.

![Figure 13. Displacement on component X](image)

![Figure 14. Displacement on component Y](image)

The analysis of the displacement before and after the tectonic earthquake on April 11, 2012, based on Figure 13 and Figure 14 is obtained in X and Y components. The magnitude of the displacement values is summarized in table 1.

| Event        | Displacement Average | X (mm/day) | Y (mm/day) |
|--------------|----------------------|------------|------------|
| Before       |                      | 0.04       | 0.03       |
| Earthquake   |                      | 56.63      | 23.78      |
| After        |                      | 8.28       | 1.22       |

Overall at DOY 87.2012 - 117.2012, the shift occurred at UMLH GPS Station leads to the Southwest with a speed at component X is 4.58 mm/day and on the Y component is 1.31 mm/day. The displacement vector at the station is illustrated in Figure 15. Azimuth shifts that occured are calculated using the equation:

\[
\text{displacement of azimuth} = \arctan \left( \frac{\Delta N}{\Delta E} \right)
\]

(1)

Where the shift that occured is 253.8° with a reference angle is 0° in North.
4. Conclusion
Analysis of the displacement caused by the earthquake on April 11, 2012, for 30 DOY with the observation of UMLH GPS station showed the direction of the displacement to the Southwest with Azimuth 253.8°. The magnitude of displacement before and after the earthquake as seen in table 1, shows that the displacement before the earthquake has a smaller value than after an earthquake. This shows that the tectonic movement forces in the magnitude of changes in the displacement of the island's plate.

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