The Utilization of Spatial Filtering for Tectonic Strain Study Based on SUGAR (Sumatran GPS Array) Data 2006-2008
Study Case : The September 2007 Bengkulu Earthquake

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Key words: The September 2007 Bengkulu Earthquake; Strain; Spatial Filtering; SuGAr; Velocity Displacement.

SUMMARY

The September 12th 2007 Earthquake (Mw8.4) followed by Mw7.8 earthquake in September 13th, furthermore aftershock with a strong magnitude also happened in Bengkulu. This earthquake was one of the earthquake that observed by GPS continuous station at Sumatera, SuGAr, since 2002. This SuGAr data allowed us to observe the strain with occured during interseismic dan postseismic process.

In this research, time-series analysis being done in spatial domain by using spatial filtering technique. This technique is useful to eliminate outlier data and describe seasonal variation in the region of study. Data in a good group has quality improvement about 0.2-5 mm in horizontal component and 1-7 mm in vertical component, data in a medium group has quality improvement about 2-8 mm in horizontal component and 3-6 mm in vertical component, then data in a bad group has quality improvement about 3-8 mm in horizontal component and 17-30 mm in vertical component.

Displacement average value in all station during interseismic are 0.029m±4mm for horizontal and 0.008m±8mm for vertical. The average displacement in coseismic are 0.640m±4mm for horizontal and 0.037m±11mm for vertical. Furthermore, the average displacement in postseismic are 0.084m±5mm for horizontal and 0.013m±10mm for vertical.

This research describe the strain tectonic during slip accumulation that observe in the region of The September 2007 Bengkulu earthquake on SuGAr measurement period 2006 until 2008. This research give us compression value -0.088 μstrain and extension value 0.282 μstrain.

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1. INTRODUCTION

GPS used in many research to study geodynamic, based on network continuously GPS. From the September 12th 2007 Earthquake (Mw8.4) to the Mw7.8 earthquake in September 13th, followed by aftershock and the data we got from Sumatran GPS Array. We can observe position from GPS stations near Bengkulu. These station got involved from Bengkulu September 12th 2007 Earthquake. This observation related to thrust displacement and tectonic crustal deformation (subduction). Displacement data from GPS give us information about strain cause by tectonic activity.

In this research we used observation time from 2006 until 2008. By time series data result we got surface displacement value. Then we could calculate strain value that influence zones near Bengkulu. We did Spatial filtering to enhance processing data quality.

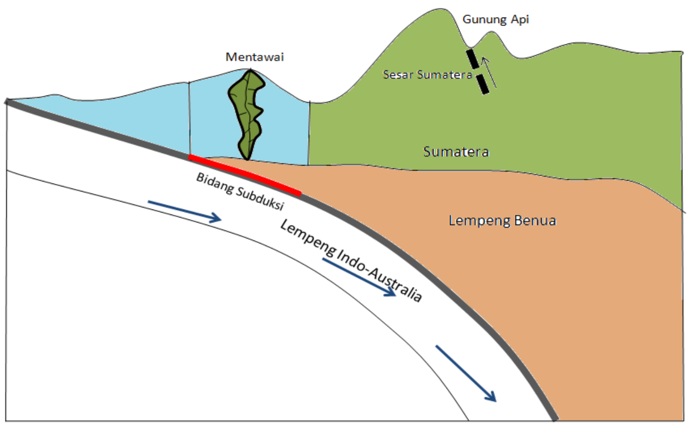

Figure 1.1. Interplate coupling in Sumatera

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High rate seismicity in Sumatera served as a basis for continuation study so we knew the illustration about tectonic activity in the future. This study was expected to give us a good tectonic strain pattern during those periods. Tectonic strain made by observing the accumulation of stress (compression) and distributing of stress (extension) in some area during those periods. It gave us the necessary information that related to disaster prevention activity such as Disaster Mitigation.

2. RESEARCH DESCRIPTION

2.1 Data and Location

We got the displacement data from 12 Continuous stations on SUGAR (LIPI, Bandung) in Bengkulu (Figure 2). Data can be download from this website *http://sopac.ucsd.edu/cgi-bin/dbDataBySite.cgi*.

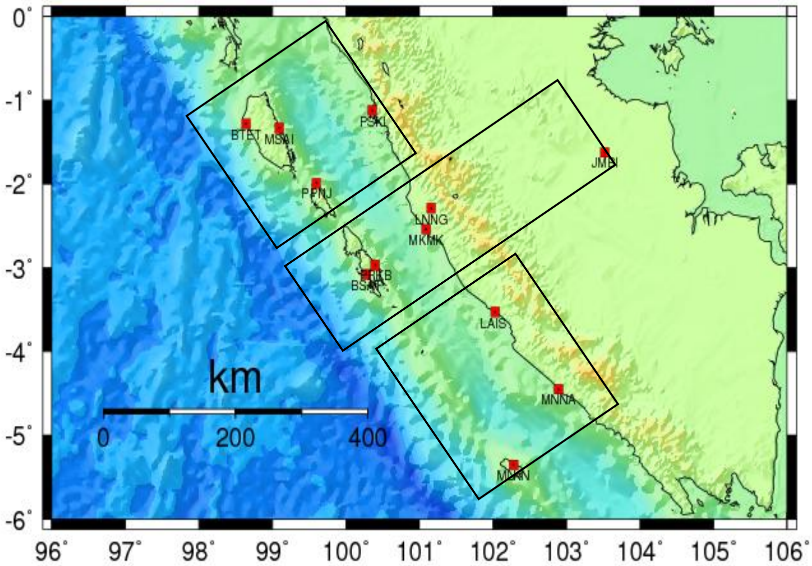

Figure 2.1. SUGAR Continuous Observation Network near Bengkulu

Observe location for this study is around those stations (BSAI, BTET, JMBI, LAIS, LNNG, MLKN, MKMK, MNNA, MSAI, PPNJ, PRKB, PSKI), the area about $0^0 – 6^0$ South Latitude and $98^0 – 105^0$ East Longitude. The figure 2.1 above explained about grouping area from the stations.

2.2 Research Methodology

Methodology in this research. First, we studied the literatures and references that related to tectonic strain in Bengkulu then we tried to make time series GPS from velocity displacement data. This step tried to eliminate outlier and seasonal effect by using spatial filtering method so we could enhanced data quality. Second, we made tectonic strain from enhanced velocity displacement pattern in first step. Third, we analyzed the displacement using spatial filtering method. And last we got the conclusion.

2.3 Process, Result, and Analysis

GPS data processed by using scientific software Bernesse 5.0. Coordinate. The result was transformated from geocentric to topocentric coordinate. In figure 2.3 gave us a description about raw data for time series GPS on BSAT station. This data needed to enhance to get good data quality from this process, so that we used spatial filtering method.

2.3.1 **Spatial Filtering**

In this step we analyze GPS Time series result with spatial filtering method. The main stages from spatial filtering are [*Shimon Wdowinski et al*, 1997]:

1. *Detrending*

This process purposed to detect and eliminate the outlier. Generally mathematics model for curve fitting from displacement data in interseismic phase was linier whereas in postseismic phase was logaritmic (*Marone,* 1991). *Logaritmic regression* assump that postseismic deformation happening was afterslip deformation (formula 2). That explain with below.

$y = ax + b$ 2.3.1)

Formula Marone :

$Up = \alpha.\log10[1+(\beta/\alpha)t] + U^s_c$ 2.3.2)

where α is lithosfer characteristic on subduction; β is average coseismic rate on subduction; Up are afterslip displacement; t is time of displacement (day of year); and U^s_c is a coseismic rupture on subduction.

Modelling with mathematics formula was purposed to calculate the residual between velocity observation and GPS velocity model. So from the residual we know the bias from observation. Example, observation in BSAT, from this station we clearly see interseismic, coseismic, and postseismic deformation. Coseismic displacement value descript with arrow from figure 2.2 (there is alteration value on this obeservation).

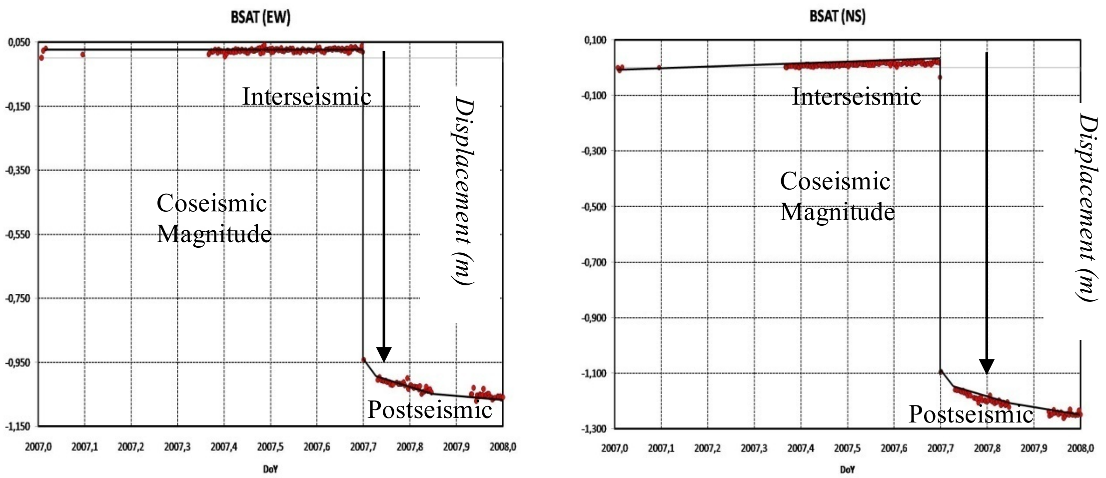

Figure 2.2. Displacemet East-West (EW) and North-South (NS) BSAT Station caused by Bengkulu 2007 Earthquake.

We use BSAT station to determine lithosfer characteristic α for another station that laid near Bengkulu. We get α value by using linear regression for interseismic and logaritmic regression for postseismic, 0.0587156797109187. This value use in formula Marone so we get displacement value for another station.

The residu between observation data value and prediction value, show in this below formula
$\varepsilon_s (h) = O_s (h) - C_s (h)$ 2.3.3)
where h is days of observation and s is observation stations. O is observation value and C is calculation value (prediction).

The difference between observation and prediction (fitting) value is a residual value (O – C), we calculate the average from this residual value in each days (day of year observations) and each stations. Then with this residuals we eliminate the outlier from observation data that unfulfill statistic testing. Level of confidence for residuals value in this statistic qualitative test is 95% (2xdeviation standard), with asumption the degree of freedom is unlimited because observation distance very excessively. Root mean square from observation based on displacement data consists of interseimic process (Si) and postseimic process (Sp), where :
$S = (Si^2 + Sp^2)^{1/2}$ 2.3.4)
so we get cleaned data for time series GPS (see figure 5).

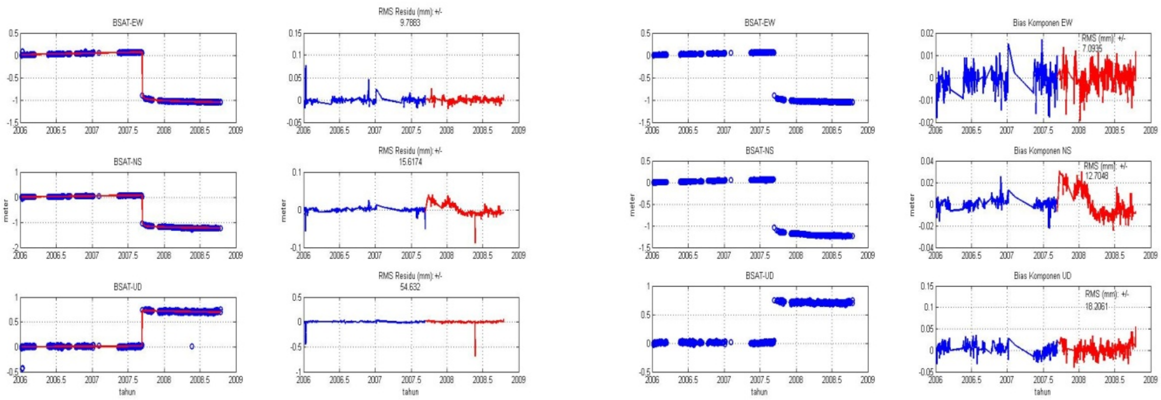

Figure 2.3. Raw data (left) and Cleaned data (right) from Time Series GPS

2. *Stacking*
This stage aim to re-calculate bias trend in each station after detrending. Bias value is residu and give us common-mode error that happen in stations, residual value devided to amount of observation station. This formula explain below :
$\varepsilon(h) = \sum_{s=1}^{S} \varepsilon_s (h) / S$ 2.3.5)
If S = 1, so points data for this station will be deleted from time series. Common-mode error will increase in series with the increment of observation station.
The residual value data. Which had cleaned out of outlier and bias, was stacking in every stations per day. It was reduced by the origin obeservation data. In this stage, all error from all station caused by bias effect summed and averaged. It assumed as common mode error in all observation stations.

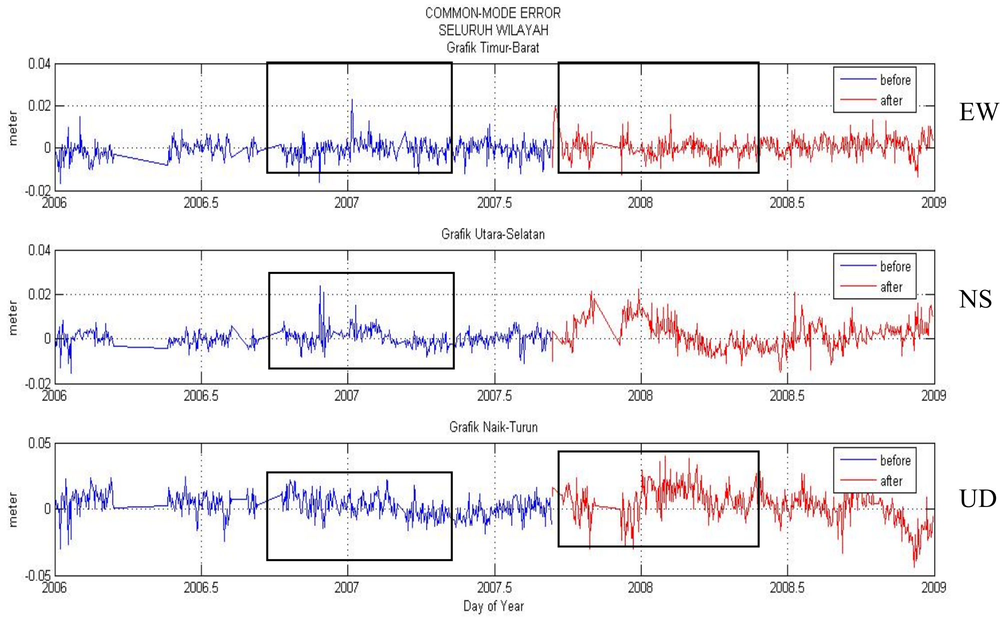

Figure 2.4. Common-mode Error, all component.

The average value of these bias values (*common-mode error*) is -0.2 mm on East-West component ; 1.1 mm on North-South component; and 3.1 mm on Up-Down component.

3. *Filtering*

Elimination the bias from every station on time series data was aimed to get a filtered data (free from bias) $\hat{o}_s(h)$.

$\hat{o}_s(h) = O_s(h) - \varepsilon(h)$ 2.3.6)

In this stage we get a better displacement data quality. The data after spatial filtering method gave a better root mean square than before. We can eliminated error cause by outlier and bias.

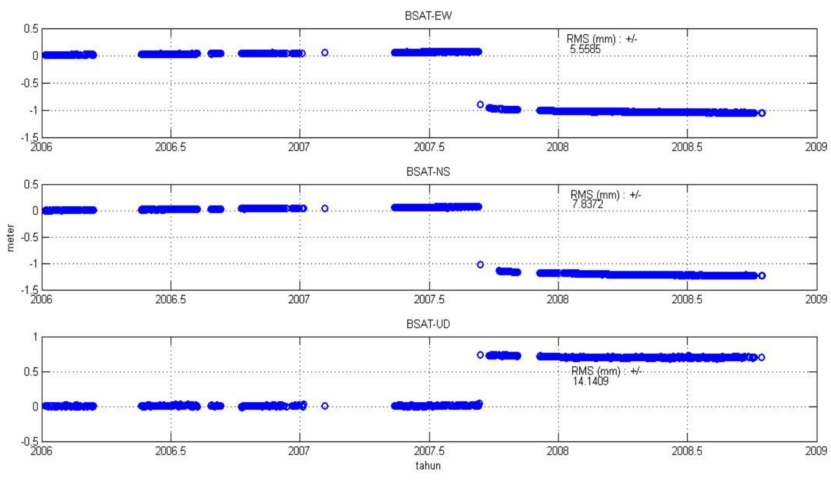

Figure 2.5. Filtered BSAT Station.

Fine Data, after *detrending,* RMS increased 1-12 mm for horizontal component, 36-43 mm for vertical component. After *filtering,* RMS increased 0.2-5 mm for horizontal component and 1-7 mm for vertical component.

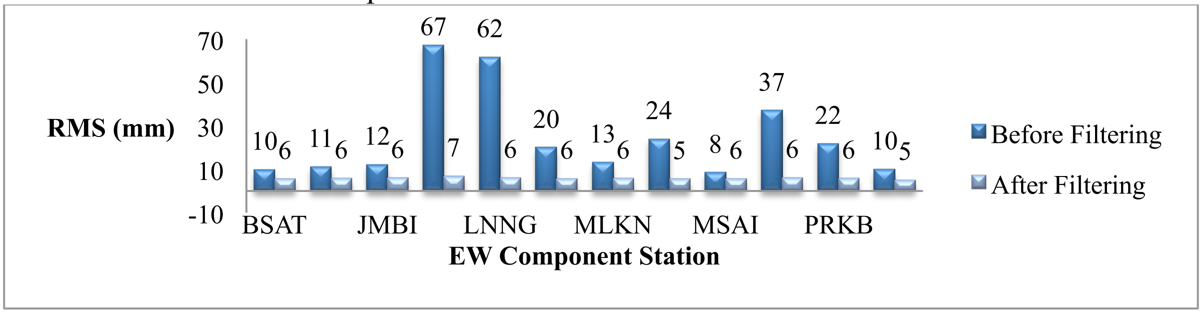

Figure 2.6. RMS of East-West component.

Moderate Data, after *detrending,* RMS increased 2-23 mm for horizontal component, 28-64 mm for vertical component. After *filtering,* RMS increased 2-8 mm for horizontal component and 3-6 mm for vertical component.

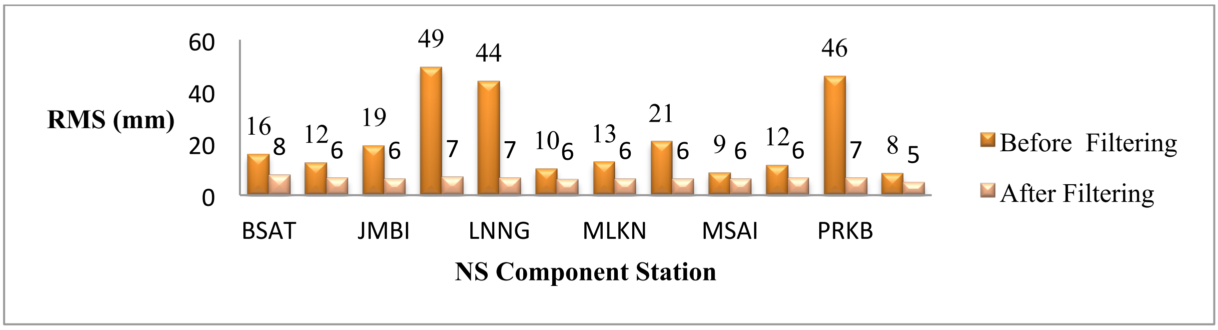

Figure 2.7. RMS of North-South component.

Poor Data, after *detrending,* RMS increased 13-54 mm for horizontal component, 95-154 mm for vertical component. After *filtering,* RMS increased 3-8 mm for horizontal component and 17-30 6 mm for vertical component.

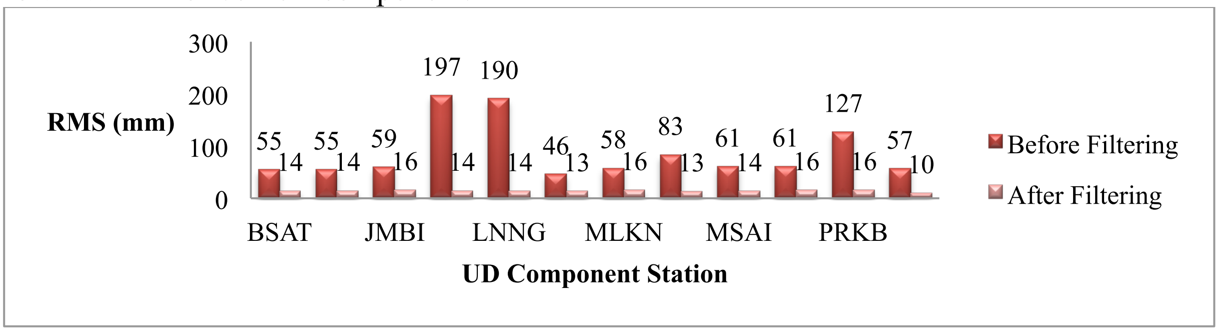

Figure 2.8. RMS of Up-Down component.

2.3.2 Velocity Displacement

Velocity displacement value need to be reduced with Sunda Block velocity. Sunda Block velocity was calculated by ITRF euler pole model. Center of rotation on -86.90 longitude and 38.90 latitude with rotation velocity 0.322 deg/Myr. [*Bock, et al, 2003*]. Velocity value for component ew dan ns after spatial filtering and minus Block sunda shown in table 2.1.

Table 2.1. Velocity Displacement after spatial *filtering*.

Station	Interseismic		Coseismic		Postseismic	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
BSAT	0.046	0.003	1.482	0.713	0.259	-0.027
BTET	0.044	0.003	0.034	-0.019	0.049	0.002
JMBI	0.005	0.011	0.099	-0.043	0.03	0.03
LAIS	0.019	0.007	0.842	-0.236	0.068	0.046
LNNG	0.025	0.008	0.705	-0.187	0.077	0.039
MKMK	0.027	0.012	0.814	-0.216	0.22	-0.01
MLKN	0.019	0.006	0.012	-0.036	0.014	0.016
MNNA	0.014	0.01	0.089	-0.026	0.022	0.029
MSAI	0.04	0.006	0.043	-0.023	0.033	0.006
PPNJ	0.036	0.006	0.73	0.251	0.024	0.029
PRKB	0.044	0.012	1.917	0.287	0.054	0.008
PSKI	0.026	0.01	0.279	-0.055	0.069	-0.027

Visualization for interseismic velocity displacement descript in Figure 2.6.

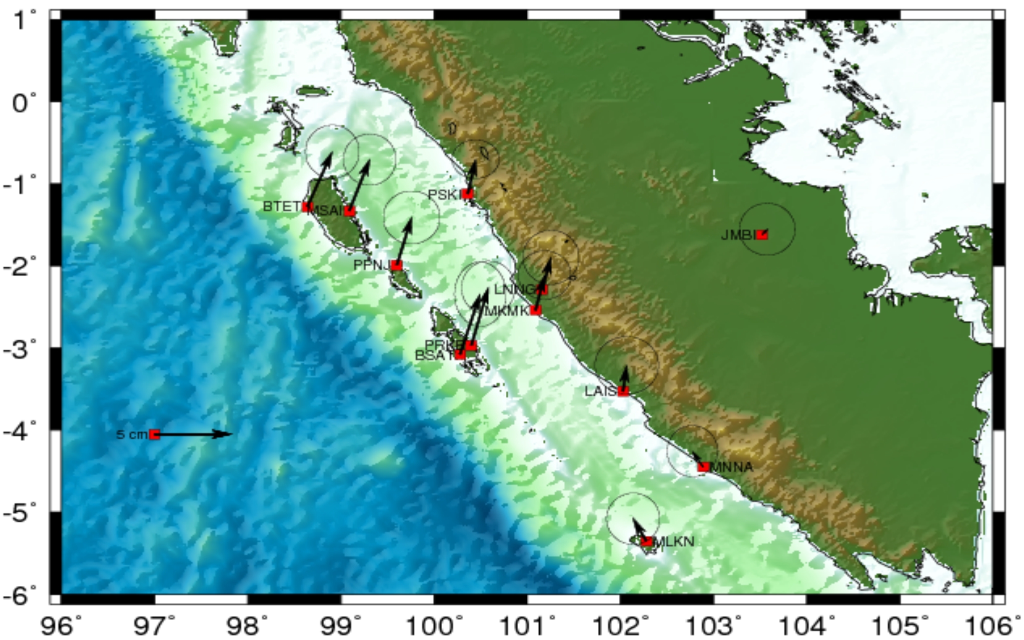

Figure 2.6. Interseismic Velocity Displacement before Bengkulu 2007 Earthquake.

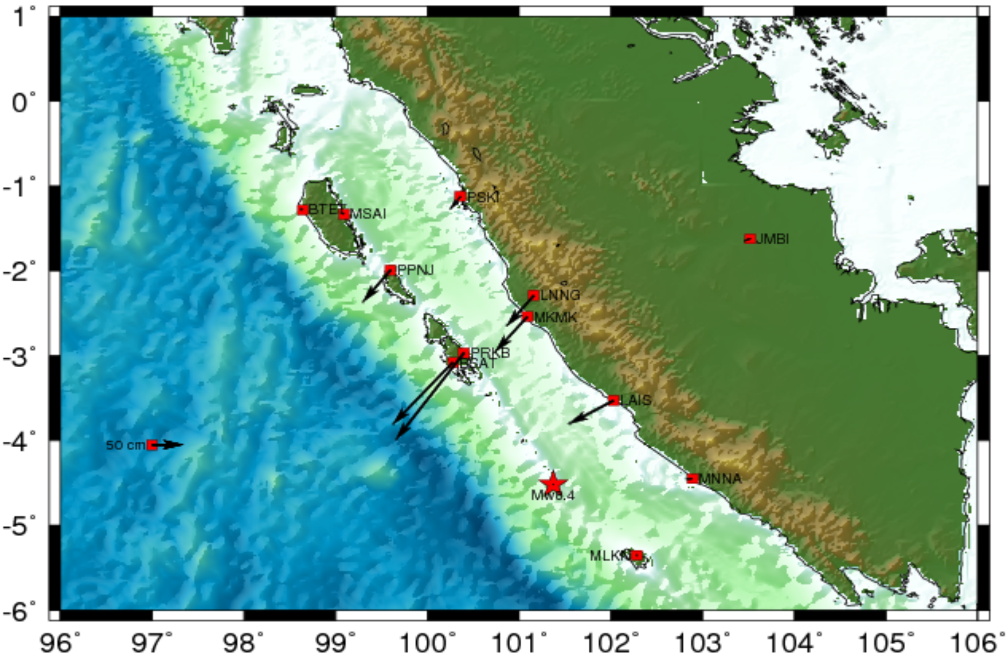

Figure 2.7. Coseismic Velocity Displacement before Bengkulu 2007 Earthquake.

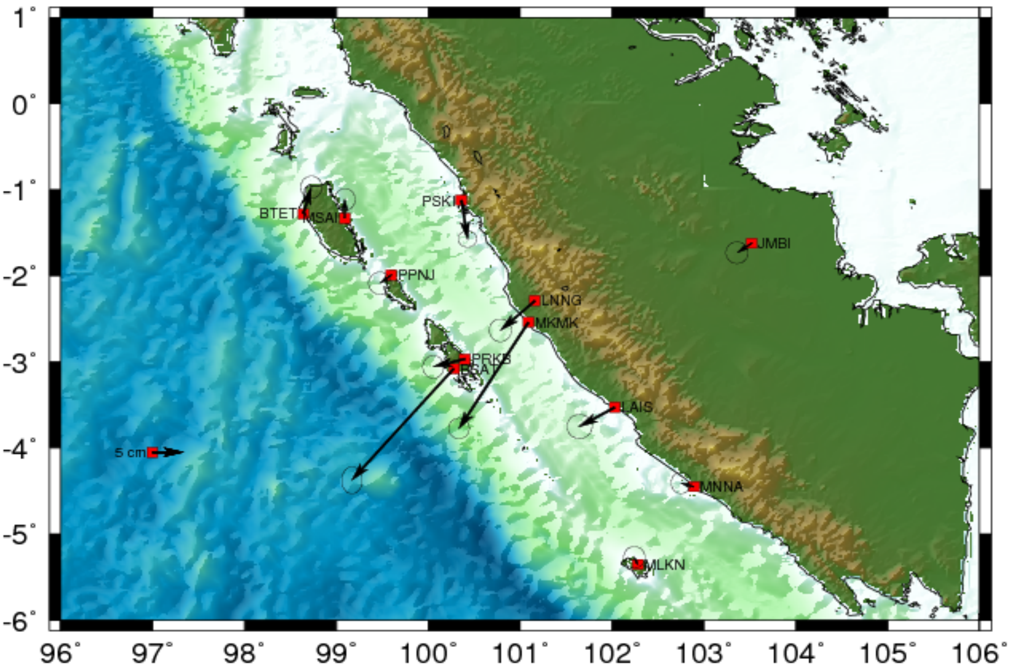

Figure 2.8. Postseismic Velocity Displacement before Bengkulu 2007 Earthquake.

2.3.3 Strain

Strain symbols (ε_1 and ε_2) represent shifting of length element towards origin length (mm/mm) with strain unit, θ is angle between ε_2 and north direction. Figure below is visualization of strain in Bengkulu, map scale 1:100. Strain pattern descript *compression* and *extension* fenomena in a region. We can see this fenomena clearly in study area (red : compression, blue : extension).

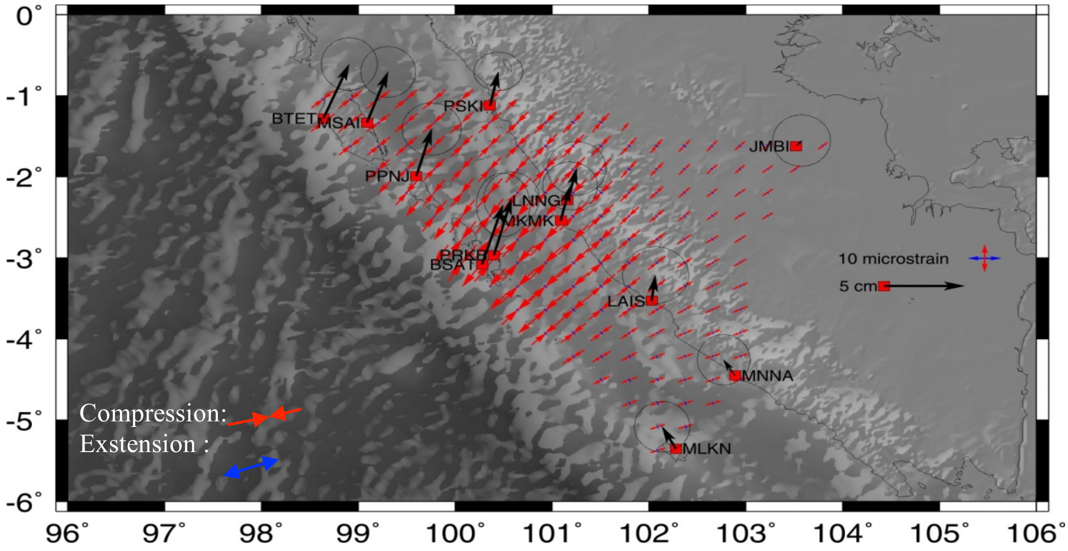

Figure 2.3.3.1. Interseismic Strain before Bengkulu 2007 Earthquake

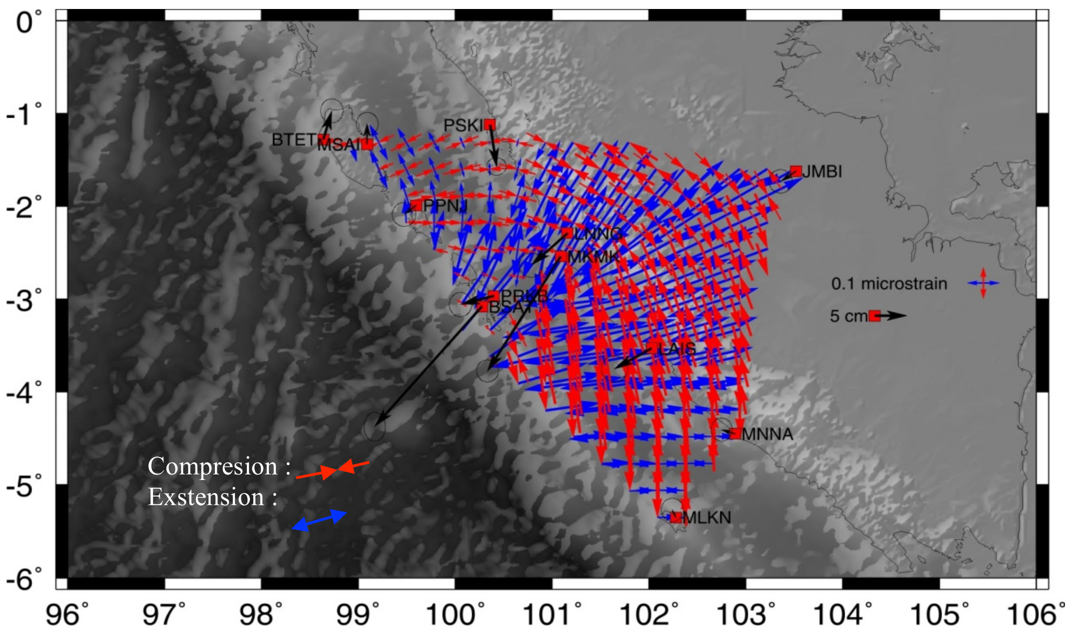

Figure 2.3.3.2.Postseismic Strain after Bengkulu 2007 Earthquake.

2.4 Conclusion

Through this research we concluded that time series RMS decreased based on each data grouping. Fine data group experienced increasing data quality about 0.2-5 mm on horizontal component and 1-7 mm on vertical component.Moderate data group experienced increasing data quality about 2-8 mm on horizontal component and 3-6 mm on vertical component. Whole poor data group experienced increasing data quality about 3-8 mm on horizontal component and 17-30 mm on vertical component. This declared that spatial filtering gave us different data quality enhancement for each GPS time series data grouping.

It was good to use this technique to analyze continuous stations in spatial, with expectation to get seasonal bias, that happen in obeservation area. However for poor data (empty after earthquake) this technique gave us enhance quality result over optimistic so it still needed reconsideration in usage.

This technique able to eliminate common mode error bias that happen in observation area spatially. This bias was caused by seasonal effect and strain on observation stations. Because of earth tidal effect, motion dynamics exclude subduction activity in region mentioned.

Displacement average value in all station during interseismic were 0.029m±4mm for horizontal and 0.008m±8mm for vertical. The average displacement in coseismic were 0.640m±4mm for horizontal and 0.037m±11mm for vertical. Furthermore, the average displacement in postseismic were 0.084m±5mm for horizontal and 0.013m±10mm for vertical.

During interseismic process, compression pattern dominantly occured in zone II, represented by BSAT, LNNG, MKMK, and PRKB stations with the compression value in the amount of -0.123 μstrain. Then this compression accumulated energy until released as Bengkulu 12 September 2007 earthquake. After earthquake occured extension pattern in south-west Bengkulu. Its represented by BSAT, LNNG, MKMK, PRKB obeservation stations. It also partially required in PPNJ with average extension value in the amount of 0.327 μstrain. Energy transfer occured with compression value 0.234 μstrain around JMBI, LAIS, MLKN and MNNA that potentially becoming earthquake in the future.

This research described tectonic strain that occur during slip accumulation. Observed on the area from September 2007 eartquake, in observation period of SUGAR for 2006 until 2008. The compression and extension value in the amount of -0.088 μstrain and 0.282 μstrain.

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BIOGRAPHICAL NOTES

Meiriska Yusfania was born in Bengkulu May, 10th 1985. She studied in Geodetic Engineering, Institute of Technology Bandung (ITB) for Bachelor (ST) and Master (MT) Degree in 2004 and 2008. She has to be an asistant when she studied master degree in Engineering, Institute of Technology Bandung (ITB) in 2008 until 2010. Now, She worked as lecturer in Nopember 10th Institute of Technology.

Dr. Irwan Meilano was born in Bandung-Indonesia, May 18th 1974. He was expertise in Tectonic Geodesy (Crustal deformation and modelling related with volcano eruption and earthquake recurrence). He was Associated Professor Faculty of Earth Science and Technology, Geodesy Research Division in Bandung Institute of Technology. He was Secretary of PPMB-ITB Disaster Mitigation Research Center in the same institution. He studied in Geodetic Engineering, Institute of Technology Bandung (ITB) 1997 for Bachelor (ST); in Earth Science, Nagoya University, Japan 2003 and 2006 for Master of Science (M.Sc) and Doctor of Science (Dr.); JSPS-Post doctoral (PD) Fellow in Earthquake process, Nagoya University, Japan 2008. He has done many researches, written some journals and articles.

Dr. Dina A. Sarsito was born in Semarang, May 12th 1985. She was lecturer in Bandung Institute of Technology (ITB) since 1995 until know. She studied in Geodetic Engineering, Institute of Technology Bandung (ITB) for Bachelor (ST) in 1992 ; Applied Geophysics, Institute of Technology Bandung (ITB) for Master (MT) in 1997 and , Institute of Technology Bandung (ITB) for Doctor (Dr) in 2010. She has done many researches and written some journals.

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