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Postseismic Deformation Parameters of the 2010 M7.8 Mentawai, Indonesia, Earthquake Inferred from Continuous GPS Observations

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ABSTRACT

The postseismic deformation parameters of the 2010 Mentawai earthquake using continuous Global Positioning System (GPS) data for period of 26 October, 2010 to 10 April, 2012 were investigated. Analytical solutions of logarithmic and exponential function to evaluate the postseismic deformation characteristics of the 2010 Mentawai earthquake are applied. The results indicate that the GPS time series data fitted well using logarithmic function with decay time of 5.2±0.1 days. The data fit using logarithmic function indicate a smaller misfit of 2.6 mm compare to data fit using exponential function. Our results clearly indicate deformation during long-term period after the 2010 Mentawai earthquake should considered other physical mechanisms.

Key words: The 2010 Mentawai earthquake, continuous GPS data, postseismic deformation

INTRODUCTION

The 25th October, 2010 M7.8 Mentawai earthquake that occurred in the western Sumatra along the Sunda trench was associated with the subduction process between Indo-Australian plate and Eurasia plate. In this particular region, previous study suggested that Southeast Asia behaves as an independent rigid plate with respect to Eurasia, named as Sundaland block (Bock *et al*., 2003). The relative motion between Indo-Australia and Sundaland varied with rate of ~5.6-6.2 cm year^{-1} (Chlieh *et al*., 2008). Inland of Sumatra, there exists a right lateral fault system named Great Sumatran Fault, which accommodates the trench parallel motion with slip rate increasing from 12 mm year^{-1} in the southern Sumatra to 20 mm year^{-1} in the northern Sumatra (Ito *et al*., 2012). Figure 1 shows the tectonic background of this region with after shock distribution 10 days after the 2010 Mentawai earthquake based on Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG) catalogue.

Previous study (Hill *et al*., 2012) suggests that the coseismic slip distribution of the 2010 Mentawai earthquake occurred along the shallow portion of the Sunda trench. Because its large slip concentrated on shallower region of the fault and slow rupture velocity of 1.25-1.5 km s^{-1}, then the 2010 Mentawai earthquake was classified as tsunami earthquake (Newman *et al*., 2011). It is important to note that not all of megathrust earthquakes which produce tsunami categorized as tsunami earthquake (Gusman *et al*., 2015).

Using Sumatran GPS Array (SuGAr) network, Feng *et al*. (2015) showed significant postseismic deformation information captured by Global Positioning System (GPS) data. They fit the data and

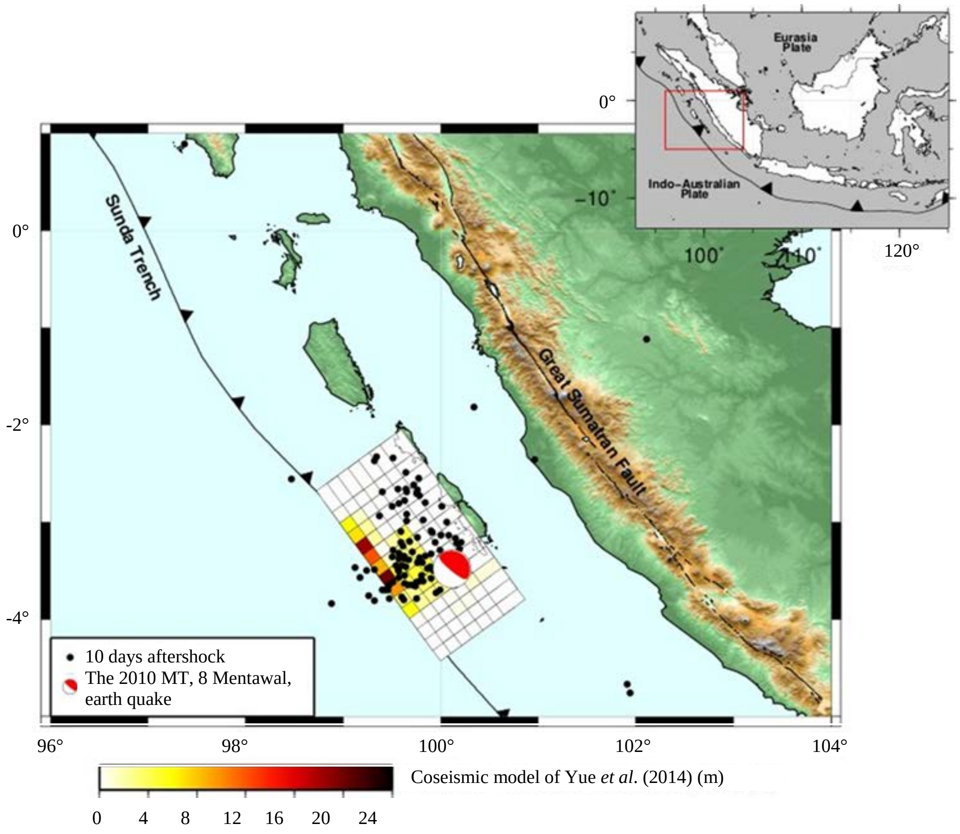

Fig. 1: Tectonic background in Mentawai Islands. Epicenter for the 2010 Mentawai earthquake obtained from United States Geological Survey (USGS) catalogue, while aftershocks are from Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG) catalogue

obtain parameters of each GPS sites associated to the deformation of the 2010 Mentawai earthquake. In this study, instead of data fit to each GPS sites only, we calculate the decay time associated to after slip of the 2010 earthquake. We reprocess these GPS data and use to analyze the postseismic deformation parameters of the GPS data time series using analytical solutions of logarithmic and exponential function. Our solutions generate postseismic deformation parameters in order for us to understand better the characteristics of postseismic deformation associated to the 2010 Mentawai earthquake.

MATERIALS AND METHODS

In this study, our first step is to collect and analyze all available continuous GPS data located around the rupture of the 2010 Mentawai earthquake. The data was obtained from SuGAr network. In total, there are 26 GPS sites available during time periods of 2010-2014; ABGS, BSAT, JMBI, KTET, LAIS, LBHU, LNNG, MKMK, MLKN, MNNA, MSAI, NGNG, PBJO, PKNB, PKRT, PPNJ, PRKB, PSKI, PSMK, PTLO, SLBU, SMGY, TIKU, TLLU, TNTI and TRTK. Figure 2 shows the location of these GPS sites.

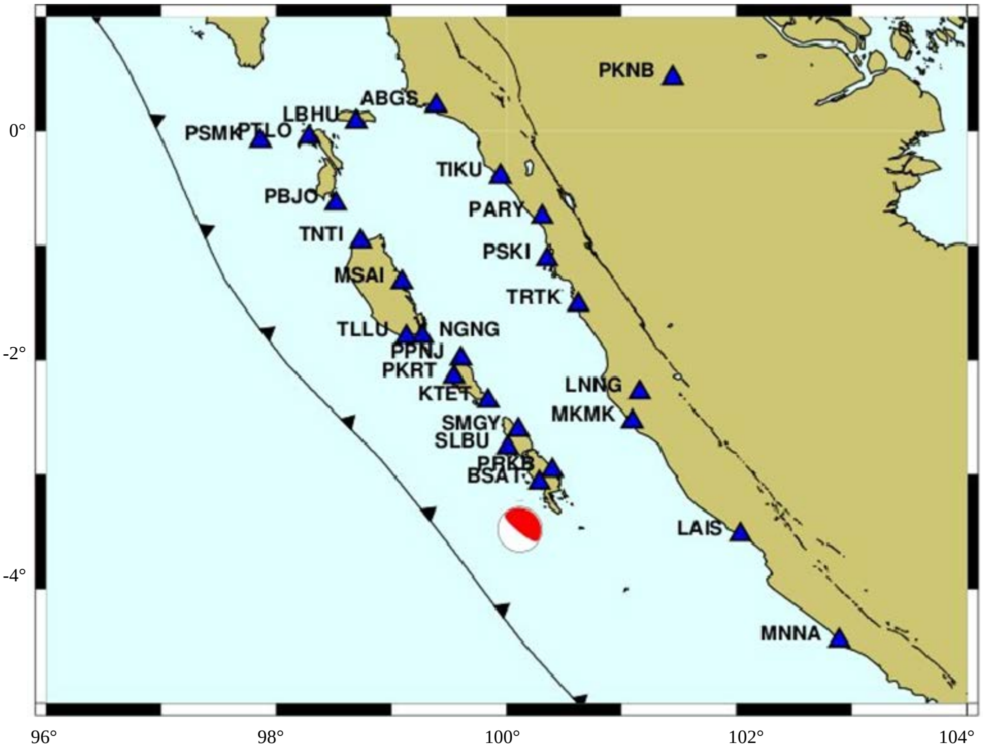

Fig. 2: Distribution of GPS sites used in this study show by blue triangle

We processed the GPS data using GAMIT 10.5 to obtained daily solutions for further analysis (Herring *et al*., 2010). In our processing strategy, we fix the preliminary coordinate result to International GNSS Service (IGS) sites of CNMR, COCO, CUSV, DARW, DGAR, HYDE, IISC, TNML, XMIS and YAR2 obtained daily solutions in International Reference Frame (ITRF) 2008 (Altamimi *et al*., 2011). Figure 3 shows the location of IGS sites used in our analysis.

In order to discuss crustal deformation in this region, we need to transform the time series reference frame into Sundaland block. Simons *et al*. (2007) proposed pole rotation parameters between Sundaland block and ITRF2000 as follows: 49.0°N, -94.2°E, 0.336°/Myr. In order to use these parameters, we need to transform our time series data from ITRF 2008 into ITRF 2000 first. Then we use the transformation parameters of Simons *et al*. (2007) to obtained data time series in the Sundaland block reference frame. Figure 4 show the data time series of sites use in this study. After obtaining daily solutions in the Sundaland block reference frame, we fit these data based on postseismic deformation characteristics associated to after slip using logarithmic function, defined as $u(t) = c+a \ln (1+t/\tau \log$ (Marone *et al*., 1991). In this study, we compare the results with another time series data fit using exponential function, defined as $u(t) = c+a (1-e^{-t/\tau \exp})$ (Savage and Prescott, 1978). In these logarithmic and exponential functions, u(t) was defined as displacement in the horizontal component, while c and a associated to displacement offset and amplitudes. The $\tau\log$ and $\tau\exp$ indicates decay time based on the calculation using logarithmic function and exponential function.

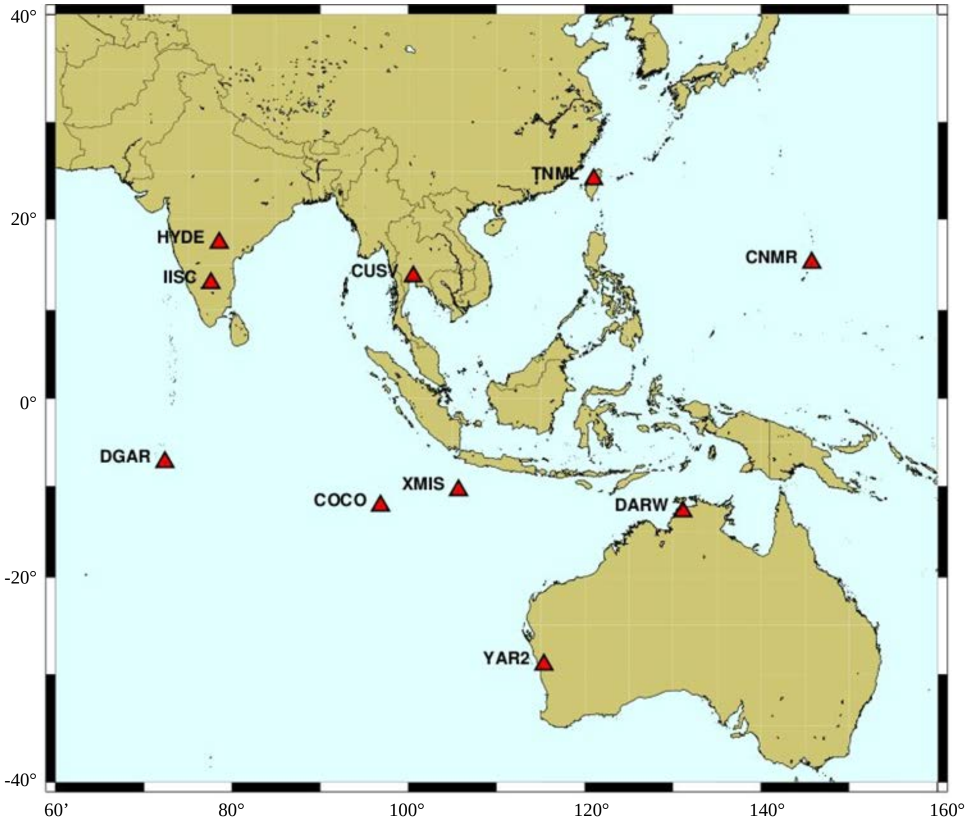

Fig. 3: Distribution of IGS sites used during GPS data processing

RESULT AND DISCUSSION

Data analysis: GPS data time series showed that coseismic displacement of the 2010 Mentawai earthquake for more than 1 cm significantly detects by 9 GPS sites in these region (Table 1). Our solutions are very similar to Hill *et al.* (2012) and Feng *et al.* (2015) that uses different GPS data processing strategy with ours. From these GPS sites, we find that postseismic deformation significant detected.

On 11 April, 2012 the M8.6 Indian Ocean earthquake occurred and affected crustal deformation across Southeast Asia (Yadav *et al.*, 2013). Coseismic displacements varied between 1-3 cm at GPS sites around Mentawai Islands (Feng *et al.*, 2015). For this reason, in our analysis, we exclude time series data after the 2012 earthquake and only focus on the postseismic deformation associated to the 2010 Mentawai earthquake.

We find that postseismic displacements for the period of 26 October, 2010 to 10 April, 2012 in 6 GPS sites were moving southwest direction towards rupture area of the 2010 Mentawai earthquake. These 6 sites are BSAT, KTET, LNNG, MKMK, PRKB and SLBU. On the other hand, 3 sites were moving southeast direction. These 3 sites are PKRT, PPNJ and TRTK. These results indicates that postseismic deformation clearly detected and influenced to these 6 GPS sites while on the other 3 GPS sites, the effect of postseismic deformation was minimum. For this reason, we exclude these 3 GPS sites (PKRT, PPNJ and TRTK) for our further analysis in this study.

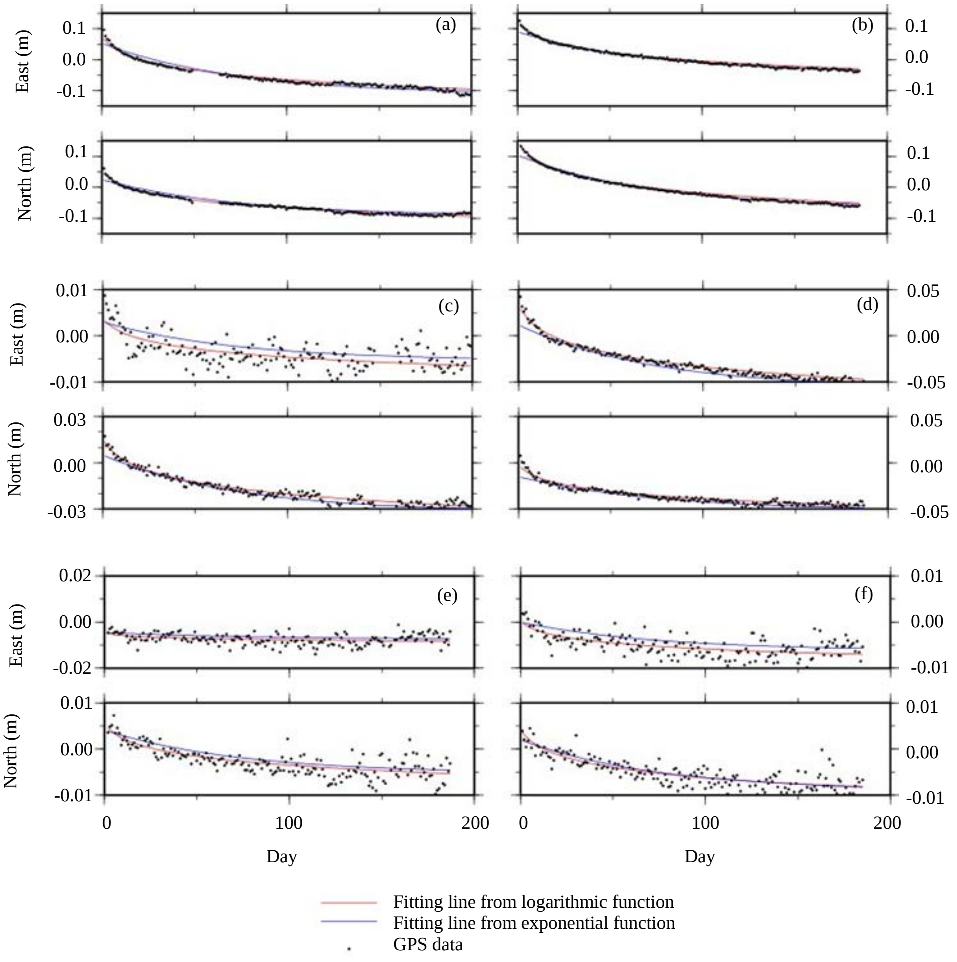

Fig. 4(a-f): GPS data time series with respect to Sundaland block, (a) BSAT (b) SLBU, (c) KTET, (d) PRKB, (e) LNNG and (f) MKMK

Postseismic deformation parameters: In our next procedure, we fit the GPS time series data of BSAT, KTET, LNNG, MKMK, PRKB and SLBU in the Sundaland block reference frame using logarithmic and exponential functions. In our analysis, we find that τlog is 5.2±0.1 days while τexp is 72.9.5±0.1 days. Our result indicate that smaller misfit was obtained in our data fit using logarithmic functions, that is 2.6 mm, than the exponential one, that is 4.4 mm. Table 2 and 3 show the result of GPS data fit in logarithmic and exponential functions.

This shows that postseismic deformation during 5.2 days before the 2010 earthquake was dominated by afterslip deformation. In order to explain long-term period time series data, other physical postseismic deformation should be taken into account. Similarly to other case of megathrust earthquakes, such as the 2004 Sumatra-Andaman earthquake (Gunawan *et al.*, 2014), the 2006 Java tsunami earthquake, combined physical mechanisms of viscoelastic relaxation and afterslip explain well the GPS time series data. In this study, we show that by an analytical solution of logarithmic function, we can capture and explain the ongoing physical mechanisms after earthquake occurrences.

Table 1: Coseismic displacement of the 2010 Mentawai earthquake for more than 1 cm

			This study		Feng *et al.* (2015)		Hill *et al.* (2012)	
Site	Long. (deg)	Lat. (deg)	E (cm)	N (cm)	E (cm)	N (cm)	E (cm)	N (cm)
BSAT	100.28	-3.08	-30.22	-22.30	-29.19	-21.35	-28.30	-21.00
KTET	99.84	-2.36	-3.53	-6.78	-3.54	-7.28	-3.50	-6.50
LNNG	101.16	-2.28	-1.35	-1.08	-1.25	-1.18	-1.40	-1.10
MKMK	101.09	-2.54	-1.72	-1.56	-1.68	-1.36	-1.80	-1.30
PKRT	99.54	-2.15	-0.70	-3.19	-0.70	-3.56	-0.90	-3.10
PPNJ	99.60	-1.99	-0.61	-2.30	-0.71	-2.67	-	-
PRKB	100.40	-2.97	-16.21	-11.58	-16.18	-12.85	-15.40	-11.10
SLBU	100.01	-2.77	-20.12	-26.05	-20.17	-25.75	-18.90	-24.30
TRTK	100.62	-1.52	-0.54	-1.13	-0.73	-1.20	-0.60	-1.10

Table 2: Postseismic parameters of logarithmic function

			Logarithmic				
Site	Long. (deg)	Lat. (deg)	c_{east} (mm)	c_{north} (mm)	a_{east} (mm)	a_{north} (mm)	RMS
BSAT	100.28	-3.08	75.30±0.09	-46.40±0.09	52.9±3.70	-39.9±3.70	4.3
KTET	99.84	-2.36	3.80±0.15	-2.80±0.15	15.8±2.40	-12.0±2.40	1.9
LNNG	101.16	-2.28	-4.80±0.05	-0.96±0.05	5.5±2.50	-3.0±2.50	1.6
MKMK	101.09	-2.54	0.19±0.05	-2.00±0.05	4.3±2.50	-3.5±2.50	1.5
PRKB	100.40	-2.97	33.70±0.17	-22.40±0.17	-2.2±4.10	-12.2±4.10	2.2
SLBU	100.01	-2.77	124.70±0.12	-42.90±0.12	149.0±2.80	-55.7±2.80	4.0
Average							2.6

Table 3: Postseismic parameters of exponential function

			Exponential				
Site	Long. (deg)	Lat. (deg)	c_{east} (mm)	c_{north} (mm)	a_{east} (mm)	a_{north} (mm)	RMS
BSAT	100.28	-3.08	101.7±0.90	-142.8±0.90	99.7±6.60	-123.8±6.6	8.2
KTET	99.84	-2.36	6.8±0.13	-8.4±0.13	30.3±3.80	-37.3±3.8	3.1
LNNG	101.16	-2.28	8.4±0.01	-3.0±0.01	6.1±3.00	-9.4±3.00	2.4
MKMK	101.09	-2.54	7.4±0.06	-6.2±0.06	9.2±3.00	-11.0±3.00	2.4
PRKB	100.40	-2.97	51.8±0.26	-69.0±0.26	48.8±3.10	-36.5±3.10	4.7
SLBU	100.01	-2.77	39.5±0.80	-133.1±0.80	63.8±15.50	-172.7±15.50	5.7
Average							4.4

CONCLUSIONS

GPS data around Mentawai Islands detect coseismic and postseismic deformation signal of the 2010 Mentawai earthquake. By using GPS data for the period of 26 October, 2010 to 10 April, 2012, we find that GPS time series data were very well fit using logarithmic function with decay time of 5.2±0.1 days. Our result of GPS time series data fit using logarithmic function indicate a smaller misfit of 2.6 mm compared to data fit using exponential function. We show that deformation during long-term period after the 2010 Mentawai earthquake should consider other physical mechanisms.

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