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Three Components Seismogram Analysis of Tasikmalaya, Indonesia on September 2nd 2009 Earthquake to Investigate the Coulomb Stress Change and Seismicity Rate Change

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Abstract

During the past decade remarkable progress has been made in studies related to fault interactions and how the occurrence of an earthquake perturbs the stress field in its neighbourhood, which may trigger aftershocks and seismicity rate change.

An earthquake event in Tasikmalaya, Indonesia on September 2nd, 2009 at 07:55:02.5 UTC (Universal Time Coordinate), has been investigated to estimate source parameters of the earthquake. Seismogram data was taken from five stations in the vicinity of the epicenter, which have distances less than 15°. All data analyzed are waveforms of three components. Method to estimate the source parameters is combination between iterative deconvolution and discrete wave number (DWN) for local data. The results show that variance reduction between the observed seismogram and the synthetic one and reduced variances for all stations is 61.66%. It indicates that results of the estimation (hypocenter, moment seismic, moment tensor and rupture direction) are suitable to describe source earthquake point. The source parameters of this event are hypocenter (-7.84°, 107.84°, 55 km), moment seismic is 4.001e+19 Nm, moment tensor and rupture direction that can describe the focal mechanism of the earthquake.

By trial and error we find that a rupture area of 27.20 km x 15.5 km having updip and downdip edges at depths of 0 and 11.7 km respectively, provides a good correlation between zone of increasing Coulomb stress, the three aftershocks hypocentres and zone of increasing seimicity rate.

Keywords: *Source parameters, Local data, Moment tensor, Waveforms, Coulomb stress change and seismicity rate change*

1. Introduction

During the past decade remarkable progress has been made in studies related to fault interactions and how the occurrence of an earthquake perturbs the stress field in its neighborhood, which may trigger aftershocks and seismicity rate changes. These studies have significant implications on the seismic hazard assessment of a region, as the change in stress and seismicity can cause either a delay or an advance in the occurrence of future earthquakes. Further, since the assessment of seismic hazard is dependent on the source parameters of past earthquakes, it is important to reliably estimate such parameters, source location, geometry, and extent of past earthquakes. Here, we report the constraints on some of the source parameters of Tasikmalaya earthquake on September 2nd 2009.

After Aceh earthquake in December 26th, 2004 with a very powerful magnitude (M_w = 9.3), several big earthquakes occurred in May 26th, 2006 at Bantul which has a magnitude M_w = 6.4, in July 17th, 2006 at South Java (M_w = 6,4) and August 8th, 2007 at Jakarta (M_w = 7.2), and on September 2nd 2009 at Tasikmalaya followed by aftershocks, mostly around the epicenter of South Java earthquake. Based on Global CMT Harvard catalog, from the four big earthquakes at Java, the post-South Java earthquake has the most aftershocks. Moreover, in September 2nd, 2009 there is another earthquake in the southern part of Java with a magnitude M_w = 5.6.

The earthquakes at Java and Sumatra happened because of a geodynamic implication of an active deformation around Java trench1). The length of the Java trench is about 5600 km, lied from Andaman-Nicobar Island until Banda archipelago. Sunda arc is caused by collision between ocean slab which is India-Australia that move 7 cm/year toward north direction with Eurasian slab. Slabs interaction around Southern Sunda arc create Java riverbed. Figure 1 illustrated Java trench which is an active deformation.

We investigated source parameters of the Tasikmalaya earthquake with a magnitude M_w =7,2 along with its aftershocks distribution, Coulomb stress change and seismicity rate change caused by the main earthquake. Stress change is considered using dislocation model obtained from waveform inversion for limited fault model. Coulomb stress change is used to observe aftershock distribution and earthquake risk around the main source fault. Catalog earthquake from Harvard CMT is used to calculated seismicity rate change.

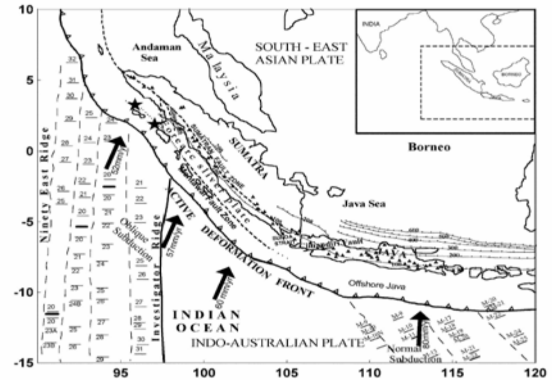


Figure 1. Tectonic map of Sumatra_Java trench[1)]

In this article, we present local waveform data analysis of Tasikmalaya earthquake on September 2nd, 2009 earthquake which is recorded by five stations (KOM, KSM, BTDF, UGM dan XMIS), to estimate the source parameters from the main earthquake. Mechanism and source parameters can be used to evaluate the next disaster around Java, an island with a very dense citizen and rapid development. Moreover, focal mechanism will be estimated to reveal the happening of fault, Coulomb stress change, aftershocks and seismicity rate change in this region.

2. Data Analysis and Method

The seismogram data analyzed in this research is used to obtain earthquake source parameters which occurred on September 2nd 2009 in Tasikmalaya. These seismograms was recorded at the five stations, in three components, with a good signal to noise ratio. The earthquake source position and observatory stations are illustrated in Figure 2.

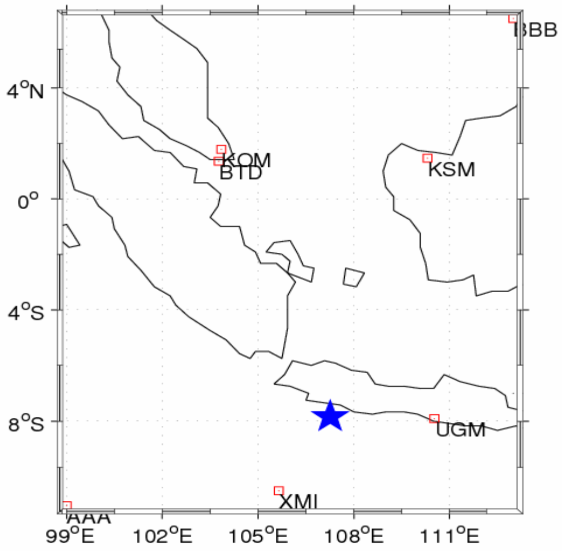


Figure 2. Stations and earthquake position

Waveform inversion method used to obtain earthquake source parameters is ISOLA_GUI[2)], where the earth model used to invert the waveform is obtained from a reference[3)], illustrated on table.1. The earthquake source area has a relatively shallow seismicity, similar with most of earthquake source which are recorded and analyzed by local seismic network BMKG, that happen along Java-Sumatra slab, therefore it can be included in Harvard CMT catalog. The occurrence of these earthquakes is important to acknowledge regional earthquake characterization, stress orientation, the aftershocks distribution and seismicity rate changes.

Table 1. Earth crust Models

Depth (km)	Vp (km/s)	Vs (km/s)	Rho (g/cm3)	Qp	Qs
0.0	2.31	1.300	2.500	300	150
1.0	4.27	2.400	2.900	300	150
2.0	5.52	3.100	3.000	300	150
5.0	6.23	3.500	3.300	300	150
16.0	6.41	3.600	3.400	300	150
33.0	6.70	4.700	3.400	300	150

Usually, waveform inversion is conducted on low frequency band, between 0.01 – 0.12 Hz. In this research, waveform inversion is conducted in a frequency range between 0.04 – 0.09 Hz and analyzed in three components.

Utilization of seismic waveforms in a longer period will improve the approximation of the earthquake source parameter because it relatively insensitive toward heterogeneity of lateral velocity and mass density[4)]. Regional waveform inversion usually gives good results for closer broadband station with a better signal to noise ratio. An observed event, which is recorded by seismological observatory stations in a range between 1.214 until 1.795 km, still considered a regional earthquake. Seismic record is used in this research to determine the mechanism and focal depth. Record picking is mainly based on its quality. Signal to noise spectral ratio is above 9. Instrument response is omitted and two horizontal components US and BT converted into radial (R) and transversal (T). One dimension earth model platform is used to calculate Green functions in this method[3)].

We used Coulomb 3.1 software[5,6)] to calculate Coulomb stress change, shear stress and normal stress changes on the source fault plane. Seismicity rate change and horizontal displacement was calculated with Zmap software[7)]. Catalog of earthquakes from Harvard CMT was used to calculate seismicity rate change. Earthquake parameters obtained from ISOLA_GUI method is used as an input for Coulomb 3.1 program. Coulomb stress changing distribution around the fault can be used to predict locations and magnitude of the aftershocks and its seismicity rate changes.

3. Momen Tensor Solution

We analyzed source parameters of Tasikmalaya earthquake on September 2nd, 2009. These studies have significant implications on the seismic hazard assessment of the region, as the change in stress and seismicity can cause either a delay or an advance in the occurrence of future earthquakes. Correlation between 3 components seismogram waveforms at five observational stations and the synthetic seismogram is presented in Figure 3 with a focal mechanism and parameters estimation of earthquake source is illustrated in Figure 4. Time series is taper-filtered between 0.025 to 0.06 Hz and it has 61.66% correlation. This fitting result also has the highest reduced variance 87% for Z components of BTDF station, where the reduced variance combination for all five stations is 61.66% that is also illustrated in Figure 3.

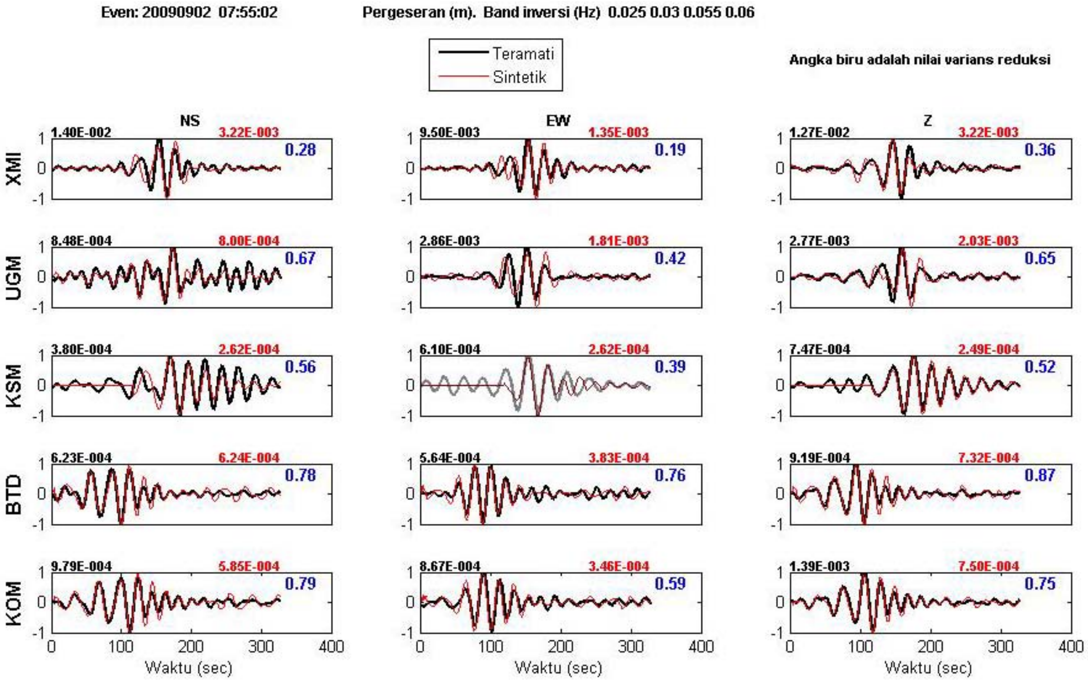
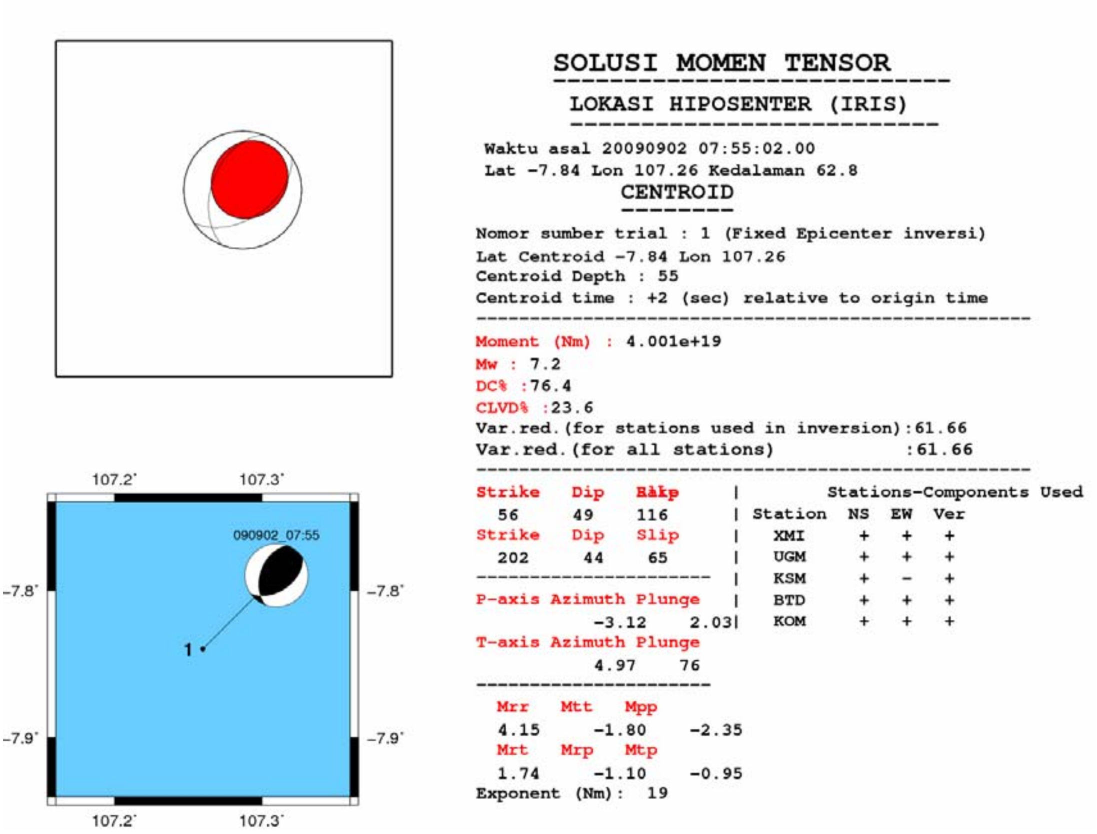


Figure. 3. Observed and synthetic seismogram data 3 components to all five stations



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SOLUSI MOMEN TENSOR
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 LOKASI HIPOSENTER (IRIS)
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 Waktu asal 20090902 07:55:02.00
 Lat -7.84 Lon 107.26 Kedalaman 62.8
             CENTROID
             --------
Nomor sumber trial : 1 (Fixed Epicenter inversi)
Lat Centroid -7.84 Lon 107.26
Centroid Depth : 55
Centroid time : +2 (sec) relative to origin time
---------------------------------------------------
Moment (Nm)  : 4.001e+19
Mw : 7.2
DC% :76.4
CLVD% :23.6
Var.red.(for stations used in inversion):61.66
Var.red.(for all stations)            :61.66
---------------------------------------------------
Strike   Dip   Bàkp      |        Stations-Components Used
  56      49    116      | Station  NS  EW  Ver
Strike   Dip   Slip      |   XMI     +   +   +
  202     44     65      |   UGM     +   +   +
----------------------   |   KSM     +   -   +
P-axis Azimuth Plunge    |   BTD     +   +   +
          -3.12    2.03|     KOM     +   +   +
T-axis Azimuth Plunge
          4.97    76
----------------------
  Mrr   Mtt   Mpp
  4.15      -1.80    -2.35
  Mrt   Mrp   Mtp
  1.74      -1.10    -0.95
Exponent (Nm):  19
```

Figure 4. Plot Solution of Moment Tensor

The convergence is determined by reduced variance value $(c^2) = 1 - (|d-u|/|d|)^2$ and correlation of observed and synthetic seismogram is root of variance reduction[8)], with d is observed data and u is synthetic seismogram obtained from. The greater reduced variance indicate a better fitting[9)].

Those values indicate the resulted seismogram fitting that in this research is appropriate to all five receiver stations. Therefore, the result of this research is appropriate to estimate earthquake source parameters (moment seismic, hypocenter, magnitude, tensor moment, strike, dip and rake) as indicated by Figure 4.

Seismogram comparison and fitting between the observed and synthetic seismogram is showed by Figure 3, where the stations epicentral distances are less than 15^0 (local/regional data). It is clear that excellent seismogram fitting is achieved. Because of small epicentral distance, the S and P wave amplitude is still interference with surface wave amplitude. Source parameters solution from the analysis result is also compared with the analysis from Harvard Global CMT, USGS, BMKG and IRIS which is illustrated at Table. 2 and 3.

4. Coulomb Stress Change and Seismicity Rate Change

In this research, Coulomb stress changes and seismicity rate change around the Tasikmalaya main shock source fault on September 2nd , 2009 with a 7.2 magnitude will be calculated, as illustrated in Figure 5. Figure 5 also contains earthquakes before the main shock. BMKG data of earthquakes before the main shock has been accessed by the author from Harvard University Catalog. While the Moment tensor solution of the main shock is the author analysis.

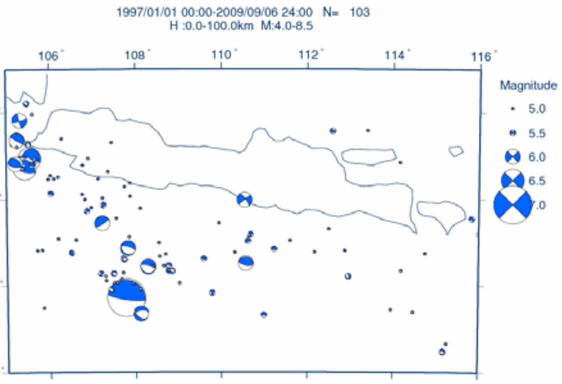

Figure 5. Focal mechanism of events around Tasikmalaya that occurred before main shock during 1997 until 2009

Chennery (1963) first showed that shear stress rises in more areas at about source fault. The importance of this discovery that aftershocks were seen to correspond to small calculated increases in Shae or Coulomb stress. The simplest expression of Coulomb stress change $\Delta\sigma_i$ is[10)]:

$$\Delta\sigma_i = \Delta\tau + \mu\sigma_n \qquad (1)$$

where $\Delta\tau$ is the shear stress change on the fault (reckoned positive in the direction of fault slip) and $\Delta\sigma_n$ is normal stress change (positive if the fault is unclamped/tention), and μ is the friction coefficient (with range 0-1).

Magnitude of the aftershock can be predicted based on this expression[11)]:

$$M_w = (1.32\pm0.122)\log(L)+(4.817\pm0.132) \qquad (2)$$

where M_w is magnitude moment, L is Rupture length (km), A is the rupture area (km^2) and D is a slip approximation (m). Figure 5 illustrate *mainshock* (black star), aftershocks (white circles), source fault and normal subduction at offshore Java. Red region around the fault indicate coulomb stress change increasing and blue region indicate coulomb stress change decreasing. Mainshock source parameters that are used as an input for coulomb 3.1 software to calculate Coulomb stress change are strike = 56, dip = 49 and slip = 116, $M_0 = 4.001 \times 10^{26}$ dyne-cm, magnitude moment = 7.2, depth = 5 km and friction = 0.4.

On an active plane of the mainshock, the highest (5 bar/ red) coulomb stress change occur around the mainshock and at an angle in front of the mainshocks in Figure 7. Aftershocks can be potentially occurred in this area.

The seismicity rate equation in simplest form is[12)]

$$R(t) = \frac{r}{\left[\exp\left(\frac{-\Delta\sigma_i}{A\sigma_n}\right) - 1\right]\exp\left(\frac{-t}{t_a}\right) + 1} \qquad (3)$$

in which R is the seismicity rate as a function of time, t, following a Coulomb stress change, $\Delta\sigma_i$. A is a constitutive parameter, σ_n is the total normal stress, t_a is the aftershock duration (equal to $A\sigma_n/\tau$), where τ is the stressing rate on the fault), and r is the seismicity rate before the stress perturbation. To evaluate equation (3), the Coulomb stress change is calculated and r, t_a and τ are estimated from observations data.

5. Discussion

Basic parameters of Tasikmalaya earthquake on September 2nd , 2009 have been resulted and reported by several agencies, like IRIS, BMKG and USGS. The analysis result from the agencies is used on this research as a comparison.

Table 2. Hypocenter comparison, magnitude and seimic moment for September 2nd ,2009 event

Agency	Lat. N (degree)	Lon. E (degree)	Depth (km)	Seismic Moment (10^{26} Nm)	Time event (UTC)	Magnitude
USGS	-7.887	107.341	53	3.9	07:55:04.15	7.0
HARVARD	-8.08	107.34	52.7	3.5	07:55:16.2	7.0
IRIS	-7.84	107.26	62.8	-	07:55:02	7.4
BMKG	-8.24	107.32	30	-	07:55:00	7.3
Author	**-7.84**	**107.26**	**55**	**4.001**	**07:55:04**	**7.2**

Table 3. Tensor moment comparison with 10^{26} Nm exponent

Agency	Strike1	Dip1	Rake1	Strike2	Dip2	Rake2
BMKG	Data is not available					
Harrvard	51	45	117	195	51	65
USGS	56	50	115	201	46	63
IRIS	Data is not available					
Author	**56**	**49**	**116**	**202**	**44**	**65**

Hypocenter, moment seismic, occurrence period and calculated magnitude of this research (table 2) do not significantly differ with the result from Harvard global CMT, EMSC and IRIS. Moreover, the magnitude value is exactly the same. And so do the moment tensor comparison in table. 3 show that the moment tensor obtained by Harvard global CMT and EMSC that does not significantly differ with this research.

All earthquakes magnitude in the red area (Figure 6) have a seismic magnitude predicted by eq. 2. In this research, we obtain the length L =27.2 km and the rupture width = 15.5 km. Equation (2) fits for Inland, Taiwan case but it does not fit to predict Tasikmalaya moment magnitude. Using aftershocks data from Harvard CMT catalog of mainshocks of Pangandaran, Indonesia that occurred on July 17th , 2006, we propose that from equation (2) we get maximum M_w of the aftershock around 7.26 and minimum M_w of the aftershock is 6.4 (event March 6 2007, lat=-0.65; lon=100.35). Whereas, the aftershock occur after South Java earthquake have a magnitude of 6,4 – 5,0 (event on Agustus 10 th2007, lat=-6.79;lon=105.25), while event at Jakarta on August 8th 2007 with M_w = 7,5 was not triggered by Coulomb stress from the mainshock at July 17th 2006, because the Jakarta event is outside of the red area Coulomb stress increased area). Therefore, equation (2) must be corrected. We suggested that the correction is in the form[13-17)]:

$$M_w = (1.34 \pm 0.345)\log(L) + (3.8 \pm 0.345).. \qquad (4)$$

Figure 6 clearly illustrates earthquakes that occur before the mainshock in the red area (Coulomb stress increased). In fact, a good correlation between zone of increasing Coulomb stress, the three aftershocks hypocentres and zone of increasing seimicity rate. two earthquakes occureed with 5.1 and 5.3 magnitude on September 2th 2009 and on September 4th, 2009 in that area. Base on equation (4), We can predict that aftershocks will occure at around Tasikmalaya mainshocks have maximum magnitude 6.5 and minimum magnitude 4.5.

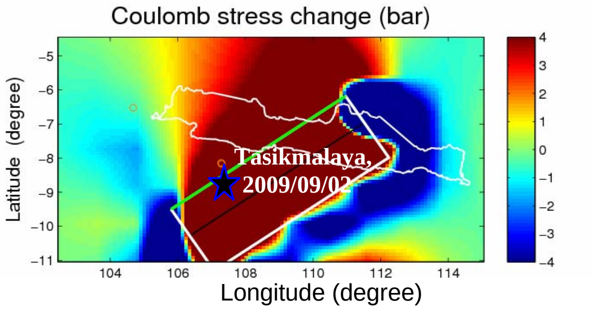

Figure 6. Coulomb stress zone (increased=red color), mainshock (black star), aftershocks (orange circles) and rupture area

Figure 7 clearly shows that correlation between the calculated increasing Coulomb stress zone and the increasing seismicity rate zone for the 2009 M=7.2 of the Tasikmalaya earthquake are very good. Both zones are situated in a rupture area.

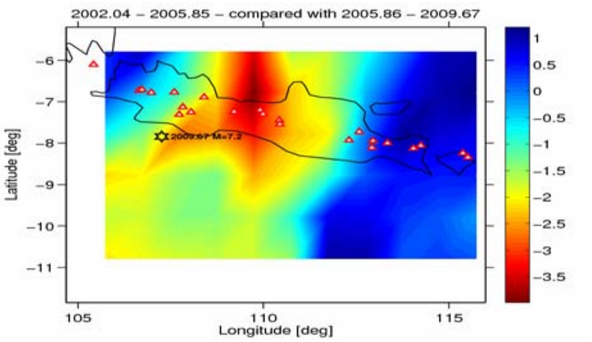

Figure 7. Comparison seismicity rate change before (r) to after (R) mainshock (r/R). Seismicity rate change increase for z negative value (red color)

Figure 8 shows ground horizontal displacements distribution around Tasikmalaya mainshock. The largest horizontal displacement is around epicenter. The further distance to the episenter, the smaller the horizontal displacement is.

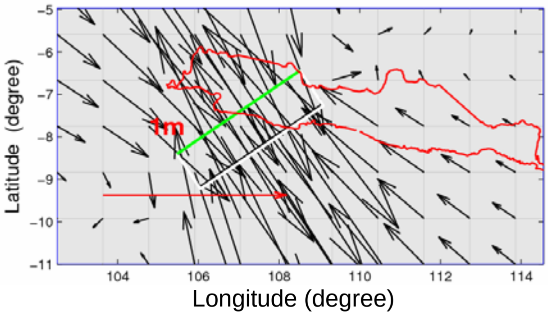

Figure 8. Horisontal displacements for ground around mainshock

6. Conclusion

Three aftershocks epicenter of Tasikmalaya September 2nd, 2009 mainshock is located in the area that has increasing Coulomb stress. This indicates that Coulomb stress changes can trigger aftershocks and there is positive correlation between Coulomb stress change and seismicity rate change.

Acknowledgments

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