Local Waveforms Analysis to Estimate the Fault Plane of May 2008 Sumatra Earthquakes

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Abstract

Five earthquakes source parameters in Sumatra have been estimated that occurred on May 3rd, 13th , 18-20th 2008, which earthquakes magnitude was over 5.4 Mw. To determine the earthquakes source parameters, we used three components local waveform. The seismogram data are inverted to achieve the earthquake source parameters. To investigate the depths of earthquakes, the determination used the highest value of variance reduction of waveform analysis. To identify the fault plane of the earthquakes, the H-C method is used. The research calculates also the length and width of the Fault planes.

KEYWORDS: Three components local waveform, earthquake source parameters, earthquake depth, width and displacement
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I. PENDAHULUAN

Earthquake is a natural phenomenon, in shape of natural shock from earth interior which earth ground movement propagates to the earth structure. The ground movement due earthquake is recorded as seismogram. The slab collision between ocean plate and continental plate in West Sumatra has close relation to fault formation which generate strong earthquake. If the earthquake has a magnitude more than 3.7 Richter scale, which seismogram still can be well recorded by local seismological stations.

The fault region is a weak zone that can be easily affected by tectonic earthquake. There are two zones where the earthquake strikes the most in Sumatra, which are: (1) slab subduction zone in West Sumatran ocean which has a potency of causing earthquake with a relatively big magnitude and has a good chance of causing tsunami, (2) Sumatra fault zone known as Semangko as long as Bukit Barisan mountains.

This research analyzes the three components seismogram of Sumatra Earthquakes: from Northern Sumatra until Bengkulu. Geodynamic implication of an active deformation around Sunda trench [2, 3] excites the earthquakes that occur in Sumatra. West coast of Sumatra island is the boundary between ocean slab and continental margin which consists of two faulting systems, which are strike-slip faulting system that rotate toward interface dip-slip subduction and right direction (dextral) [2]. Slope convergence that points toward north-west direction from Indian and Australian slabs is moving toward South East Asia with the velocity of 60 mm/yr [4]. Slab convergence is divided into a slip parallel to the trench accommodated by Sumatra fault and perpendicular slip which is accommodated by subduction zone interface [3] The Sumatra Island is partitioned by the oblique convergence into trench parallel to slip-mostly accommodated by Sumatra faulting zone and trench perpendicular to slip-mostly accommodated by subduction zone.

TABLE I: Hypocenter, Mw and origin/centroid time of events 2008/05/03, 2008/05/13 and 2008/05/18-20.

Source	Event	Time Origin (UTC)	Lat (°)	Lon (°)	Mw	Depth (Km)
WEBDC	2008/05/03	03:53:37	-3.00	101.10	5.7	64.0
	2008/05/13	10:29:22	4.80	95.10	5.4	44.0
	2008/05/18	12:17:25	-3.30	101.11	5.8	51.0
	2008/05/19	14:26:47	1.70	99.00	5.9	10.0
	2008/05/20	17:08:01	-3.20	101.30	6.9	50.0
IRIS	2008/05/03	03:53:35	-3.02	101.19	5.4	51.7
	2008/05/13	10:29:21	4.66	95.12	5.4	52.8
	2008/05/18	12:17:26	-3.21	101.32	5.7	51.8
	2008/05/19	14:26:46	1.68	99.05	6.0	14.8
	2008/05/20	17:08:01	-3.24	101.36	5.6	51.7
Global CMT	2008/05/03	03:53:37.8	-3.28	101.09	5.3	54.9
	2008/05/13	10:29:22.4	4.37	95.05	5.4	50.6
	2008/05/18	12:17:28.5	-3.52	101.11	5.7	50.1
	2008/05/19	14:26:48.9	1.64	99.14	6.0	16.1
	2008/05/20	17:08:04.1	-3.48	101.17	5.6	50.6

This research analyzes the three components seismogram of five earthquakes in Sumatra in May, 2008, which occurred in West Sumatra coast. The event on 2008/05/13 was occurred in the North Sumatra land and triggered by Semangko fault. The other events occurred in the Indian Ocean, triggered by the subduction zone. Hypocenter, depth and the origin time of these five events have been reported by IRIS [5] and Geophone [6] using travel time data, and also the centroid time of five earthquakes from www.globalcmt.org, using waveform analysis, as shown in Table I.

Hypocenter depth, magnitude moment and time origin of the earthquake that is provided by three seismological institutes have differences. Only one of these three institutes provides CMT (Centroid Moment Tensor) solution, which is Global CMT. The CMT solution from Global CMT will be compared to the CMT one of this research. This institute has

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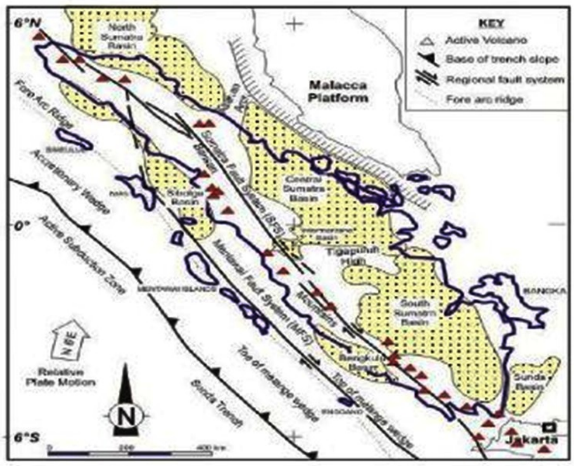


FIG. 1: The tectonic setting of Sumatera Island [1].

TABLE II: 1-D velocity model that is used in three components local waveform inversion.

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

analyzed the CMT of these events using teleseismic data (distance between epicenter and stations over 25°).

In this article, we present 3 components local waveform analysis of five earthquakes in May 3rd, 13th and 18th-20th, 2008, which were recorded by two IRIS network stations, stations are: PSI, IPM, KUM and KOM, with epicentral distances are less than 10° from the epicenter of the earthquakes. The ISOLA program is used to interpret the earthquake CMT solutions. The Hypocenter-Centroid (H-C)-plot software is then used to identify the fault plane of the earthquake sources.

II. EVENT LOCATIONS AND IRIS NETWORK STATIONS

By analysing earthquake seismogram data, then the earthquake source parameters can be obtained. Seismic wave that is originated from the earthquake source (hypocenter) is recorded by observatory stations installed in east of the earthquake region. To obtain seismic source of these earthquakes, the authors used three components waveform from the local data recorded by PS and MYnetwork stations (PSI, IPM, KUM, and KOM) as illustrated (Fig. 1). These stations are belong to IRIS Network stations. The epicentral distance of each station is less than 10.0°.

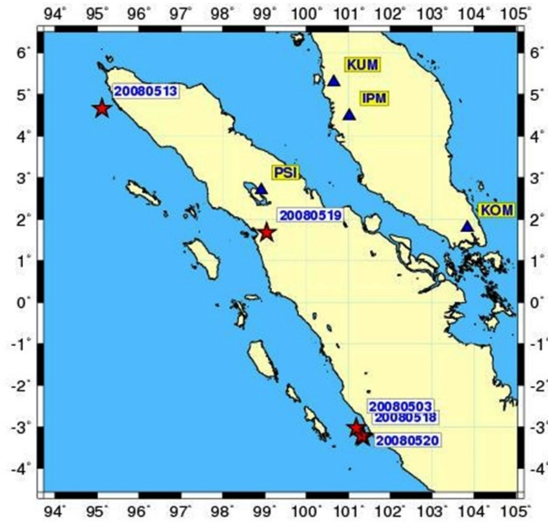


FIG. 2: Epicenter positions of 2008/05/03,2008/05/13 and 2008/05/18-19 (stars) events and 4 stations (PSI,IPM,KUM and KOM) (triangle).

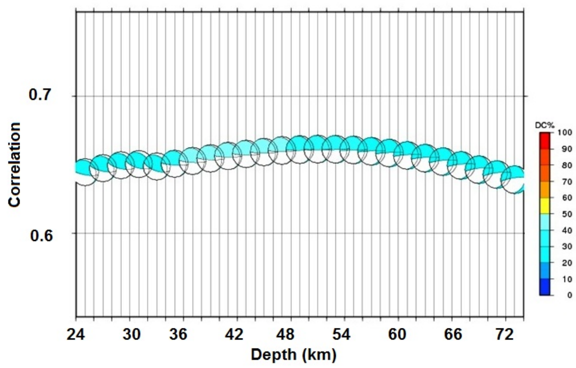
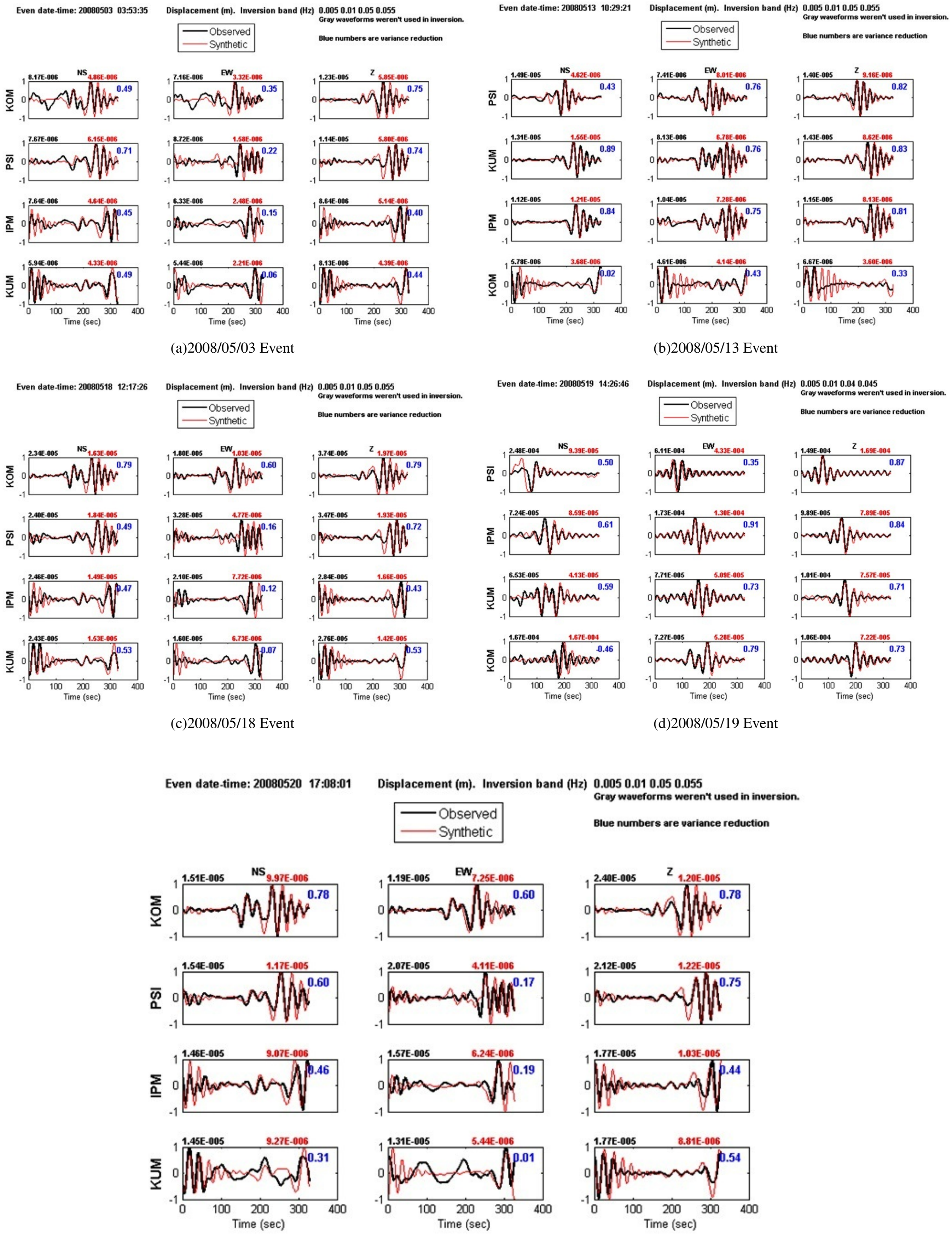


FIG. 3: Plot correlation depth for 2008/05/03 03:53 event.

III. FAULT PLANE DETERMINATION USING THREE COMPONENTS LOCAL WAVEFORM INVERSION

The Green function was used to calculate the synthetic seismogram, the observed seismogram is then compared to the synthetic ones in 3 components and same unit. The calculation of the Green function requires the complete described earth model. In order to calculate the synthetic seismogram calculation, we used the method based on *Wave Number Discretisation* method [8]. For the first, we used the hypocenter of five events obtained from IRIS and calculate the Green function using the 1-D velocity model (Table II). This velocity model is a research result [9, 10] which is verified and modified for Sumatra earth structure to analyze the seismogram of Sumatra earthquakes. The first two layer ofthe velocity model with its parameters is using the work of [8] and the modification of S wave velocity structure was based on Santosasearth model [9], which listed in the third and fourth columns, along



(a)2008/05/03 Event

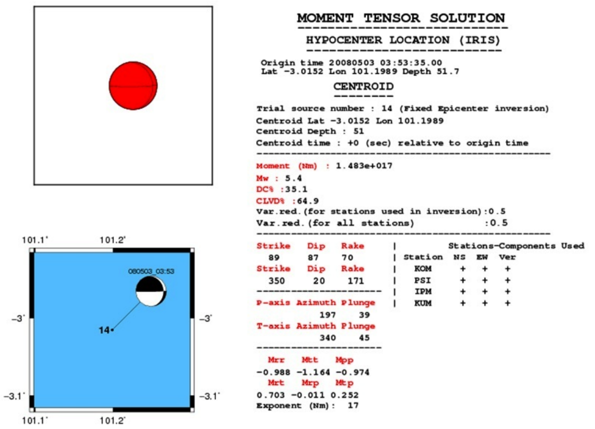
(b)2008/05/13 Event

(c)2008/05/18 Event

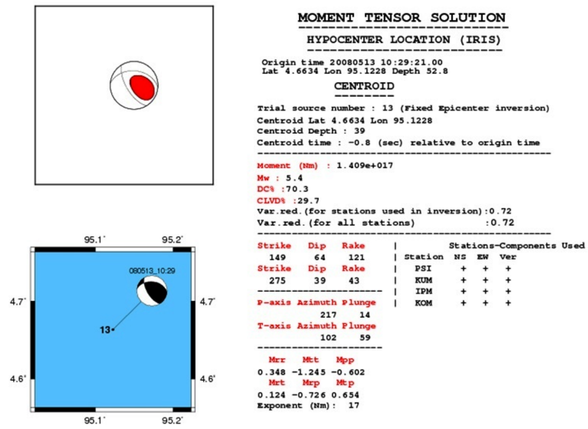
(d)2008/05/19 Event

(e)2008/05/20 Event

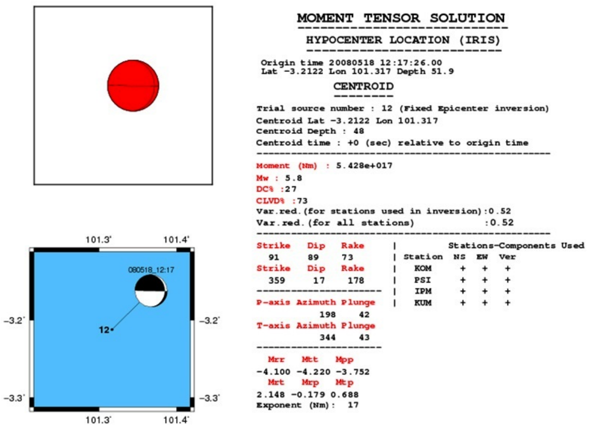
FIG. 4: Components Observed Local Waveform (black) and Synthetic (red)



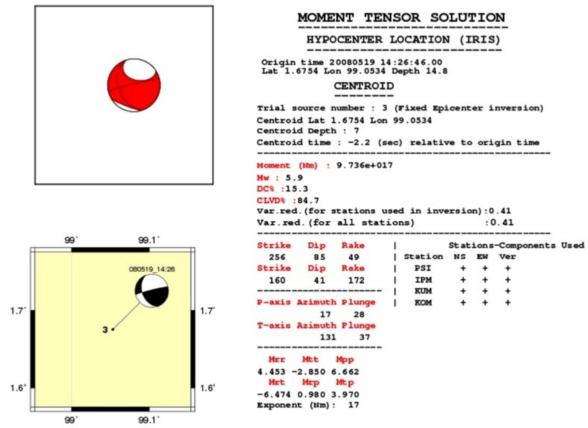
(a)2008/05/03 Event



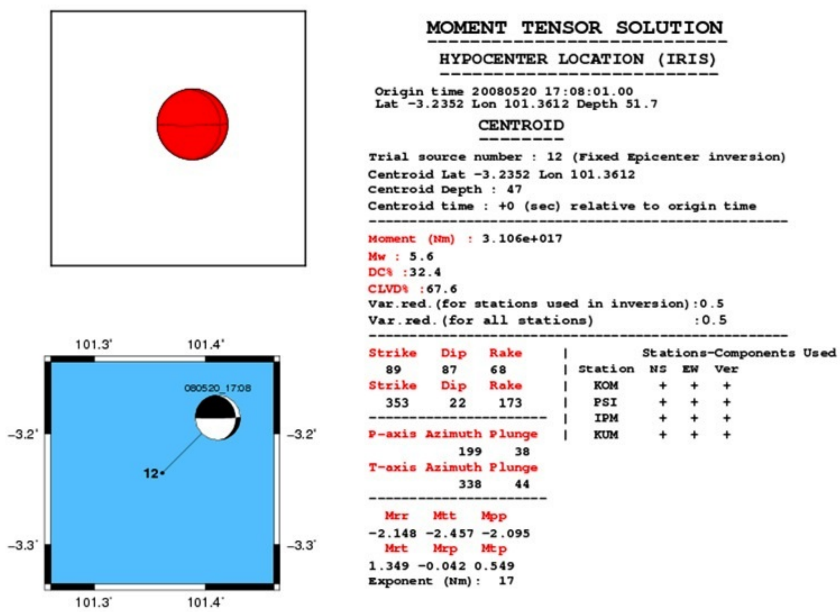
(b)2008/05/13 Event



(c)2008/05/18 Event



(d)2008/05/19 Event



(e)2008/05/20 Event

FIG. 5: Earthquake Source Parameters(CMT)

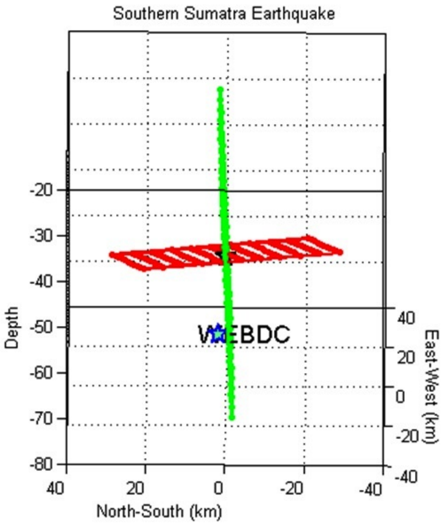


FIG. 6: The tectonic setting of Sumatera Island [1].

with all of its parameter are verified and modified result of the author. The available hypocenters from IRIS were used to calculate the Green function (Table I).

Next step is inverting three components waveform using iteration deconvolution method [10, 11] ISOLA software [12, 13] implemented all these methods, as a numerical simulation program development [14] to obtain earthquake source parameters. The inversion is using frequency band between 1 mHz and 50 mHz for all events. To determine real fault plane orientation, HC-plot method is used [13].

IV. EARTHQUAKE SOURCE PARAMETERS

Microzonation and seismic risk treatment [15] use the *Earthquake Source Parameters*, which are the seismic moment ($M_\circ$), magnitude moment (M_w), depth. The fault plane orientation are then determined for these five events. On this analysis, the authors used three components local waveform. First we try to achieve a good fitting between measured and synthetic seismogram. Reduction variant for these events are over 50%. Seismogram fitting, DC values and reduction variant are presented in Fig. 2, 3, and 4. Based on the analysis, earthquake source parameters for earthquakes event are obtained (Fig. 5).

In order to identify the actual fault plane of both faulting planes, HC-plot method is used. The centroid coordinate and the fault plane (strike = 89°; dip = 87° and depth = 51 km) for 2008/05/03 event is illustrated in Fig. 6, where its reduction variant for this event is 50%. The distance of webdc (http://webdc.eu/webdc3/) hypocenter approves that the correct fault plane is the green one. The rake of this fault plane shows that the fault plane movement is oblique reverse.

The other events parameters (strike, slip and fault plane movement) used in HC-plot were taken from source parameters of the inversion result on Figs. 5 are shown in Table III.

V. RESULTS AND DISCUSSION

In this research, we used three components local broadband that is recorded by IRIS/Malaysia MY network stations and IRIS/PS station [6] Station code (St), distance (Δ), centroid depth(d), $M_\circ$, M_w, time relative to origin time, strike(stk), dip, rake(rak) for each events is presented in Table III, and the results will be compared to the announced CMT by Global-CMT. The comparison consists of centroid points, magnitude and fault plane orientation. For event of $2008/05/03_0353$ earthquake shows the difference lattitude and longitude point, -3.0152 and -3.28, and 101.1989 and 101.09, respectivitely, and 2.1 km difference of the earthquake source depth (51 km and 54.9 km). Magnitude moment of this research is 5.4 (Mw), while from Global CMT is 5.3 (Mw). Detailed information of eartquake depth, moment magnitude and fault plane orientation for others events can be seen in Table III.

Earthquake source parameters obtained from this research shows good seismogram fitting on three components for all stations. The centroid depth, magnitude and the moments of these earthquakes and Global CMT have slightly different.

Displacement calculation

In order to calculate seismic moment $M_\circ$ from local earthquake magnitude 3 SR to 6.5 SR, [16] proposed to use the equation

$$logM_\circ = 1,5M_L + 16 \quad (1)$$

where M_L is local earthquake magnitude. In another hand, [16] employed

$$M_\circ = \mu\overline{D}LW \quad (2)$$

For calculating seismic moment, the constants μ, $\overline{D}$, L and W are describe the rock rigidity, displacement of fault, length of fault and width of fault respectively. Leonard [17] also shows that to determine seismic moment can be carried out by

$$logM_\circ = \frac{5}{2}log\ L + \frac{3}{2}loc\ C_1 + log\ C_2\mu \quad (3)$$

where C_1 and C_2 are 17.5 and 3.9 $\times 10^{-5}$ respectively, for reverse fault type. The combination of the equations above result quantity of L if W is submitted to the relation. One can find also W by occupying

$$W = C_1L^\beta, where\ \ \beta = \frac{3}{2} \quad (4)$$

Some results of displacement D taken from the data of magnitude of precise earthquake event in western Sumatra are presented in Table 4.

VI. CONCLUSIONS

Earthquake parameters of five events (seismic moment, magnitude moment and fault plane orientation) was extracted

TABLE III: Centroid Position, M0, Δt relative to origin time and Fault plane orientation from Author and Global CMT.

Event	D (km)	Lat	Lon	$M_\circ \times 10^{24}$	Mw	Δt (s)	Strike	Dip	Rake
2008-05-03	51	-3.0152	101.1989	1.483	5.4	0	89	87	70
	54.9	-3.28	101.09	1.33	5.3	2.9	121	63	109
2008/05/13	39	4.6634	95.1228	1.409	5.4	-0.8	149	64	121
	50.6	4.37	95.05	1.73	5.4	3.1	132	63	96
2008/05/18	48	-3.2122	101.317	5.428	5.8	0	91	89	73
	50.1	-3.52	101.11	4.44	5.7	4.7	124	62	82
2008/05/19	7	1.6754	99.0534	9.736	5.9	-2.2	256	85	49
	16.1	1.64	99.14	1.3	6.0	3.9	62	83	8
2008/05/20	47	-3.2352	101.362	3.106	5.6	0	89	87	68
	50.6	-3.48	101.17	2.89	5.6	3.9	122	64	79

TABLE IV: Fault length, width and displacement.

Event	M_L	L(Km)	W(km)	(D(m))
2008/05/03,03:53	5.7	843	156	141
2008/05/13,10:29	5.6	843	156	141
2008/05/18,12:17	5.8	1,275	206	200
2008/05/19,14:26	5.9	2,694	3,389	373
2008/05/20,17:08	5.8	1,111	188	178

after fitting between measured and synthetic seismogram is achieved with the reduction variants of all events are over 50%. Using H-Cplot method, we can identify the correct fault plane for these events. The fault type of all events is reverse oblique. The result of this research is different with Global CMT in which all components of moment tensor is compared. This reseach calculates also the length, width and displacement of the fault type.

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