

**ANALISA PULAU DI TERNATE DAN SEKITARNYA
BERDASARKAN KAJIAN TOPONIMI**

Yulius, H.W.L. Salim & Hariyanto Triwibowo

**ANALISIS PARAMETER BIOFISIK PERAIRAN DALAM
PENENTUAN ZONASI KAWASAN TERUMBU KARANG SELAT
LEMBEH, KOTA BITUNG, PROVINSI SULAWESI UTARA**

Taslim Arifin & Irma Shita Arlyza

**MODELING OF THE BENGKULU MINOR TSUNAMI EVENT,
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COMPARISON ON SINGLE- AND MULTI-SEGMENT OF
SOURCE GENERATION**

Widodo S. Pranowo & Widjo Kongko

**KONDISI HUTAN MANGROVE BERDASARKAN
INTERPRETASI CITRA SATELIT (Studi Kasus: Pulau
Pannikiang, Kabupaten Barru, Sulawesi Selatan)**

Syahrial Nur Amri

**STUDI INTRUSI AIR LAUT DI CIREBON DENGAN
MENGUNAKAN METODE GEOLISTRIK**

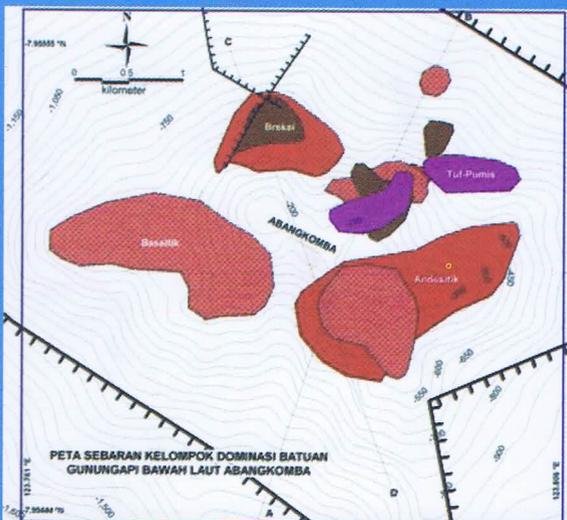
M. Hasanudin & Dino Gunawan Pryambodo

**KAJIAN SEBARAN SEDIMEN DI PERAIRAN PANTAI BANJIR
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**SEBARAN BATUAN DAN POTENSI MINERALISASI
HIDROTERMAL GUNUNGAPI BAWAH LAUT ABANGKOMBA,
PERAIRAN FLORES–WETAR, PROVINSI NUSA TENGGARA
TIMUR**

Rainer Arief Troa, Lili Sarmili & Eko Triarso



Peta penyebaran kelompok dominasi batuan gunungapi bawah laut Abangkomba

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Alamat : JL. Pasir Putih I Ancol Timur Jakarta Utara 14430

Telpon : 021 - 6471-1583

Faksimili : 021 - 6471-1654

E-mail : dewi_astika@yahoo.com dan herlina_ir@yahoo.com

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Di nomor kedua 2009, jurnal ini menampilkan 7 artikel ilmiah hasil penelitian tentang: Analisa Pulau di Ternate dan sekitarnya berdasarkan Kaidah Toponimi, Analisis Parameter Biofisik Perairan dalam Penentuan Zonasi Kawasan Terumbu Karang Selat Lembeh Kota Bitung Provinsi Sulawesi Utara, Modeling of The Bengkulu Minor Tsunami Event, September 12, 2007, West Sumatera, Indonesia: Comparison on Single- and Multi-Segment of Source Generation, Kondisi Hutan Mangrove berdasarkan Interpretasi Citra Satelit (Studi Kasus: Pulau Pannikiang, Kabupaten Barru, Sulawesi Selatan), Studi Intrusi Air Laut di Cirebon dengan Menggunakan Metode Geolistrik, Kajian Sebaran Sedimen di Perairan Pantai Banjir Kanal Timur Semarang (pada Kondisi Monsun Timur) dan Sebaran Batuan dan Potensi Mineralisasi Hidrotermal Gunungapi Bawah Laut Abangkomba, Perairan Flores – Wetar, Provinsi Nusa Tenggara Timur.

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MODELING OF THE BENGKULU MINOR TSUNAMI EVENT, SEPTEMBER 12, 2007, WEST SUMATERA, INDONESIA: COMPARISON ON SINGLE- AND MULTI-SEGMENT OF SOURCE GENERATION

Widodo S. Pranowo^{1) 3) 4)} & Widjo Kongko^{2) 3) 5)}

¹⁾ Peneliti pada Pusat Riset Wilayah Laut dan Sumberdaya Non Hayati, Badan Riset Kelautan dan Perikanan - DKP

²⁾ Peneliti pada Balai Pengkajian Dinamika Pantai, Badan Pengkajian dan Penerapan Teknologi - BPPT

³⁾ United Nations University – Institute for Environment and Human Security, Bonn, Germany

⁴⁾ Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

⁵⁾ Franzius Institut – Leibniz Universität Hannover, Germany

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ABSTRAK

Gempa berkekuatan Mw 7,9 – Mw 8,4 mengguncang Provinsi Bengkulu, Sumatera, Indonesia pada 12 September 2007, seperti yang telah dilaporkan oleh BMKG (Indonesia), USGS (USA), dan GFZ-Potsdam (Jerman). Makalah ini adalah dokumentasi riset sebagai tindakan respon cepat terhadap gempa Bengkulu berdasarkan hasil estimasi awal terhadap gempa berkekuatan Mw. 8,4 yang berpusat di 101,00°BT dan 3,78°LS, sebagaimana informasi yang diberikan oleh USGS (United States Geological Survey). Studi ini adalah melakukan perbandingan hasil simulasi antara model yang menggunakan pembangkitan tsunami oleh patahan dengan satu segmen dan patahan dengan multi segmen. Model tsunami menggunakan TUNAMI-N1 dengan resolusi grid 1852 meter dan dilakukan untuk 4 jam simulasi dengan langkah waktu sebesar 1 detik. Data batimetri (resolusi 1 menit) didapatkan dari GEBCO. Data muka air laut, diambil dari *on line real time* stasiun pasang surut di Padang (IODE-VLIZ, 2007), Pulau Cocos (BoM, 2007), dan stasiun DART Buoy No. 23401 (NOAA, 2007). Data tersebut kemudian digunakan untuk verifikasi model numerik. Hasil simulasi model numerik menunjukkan bahwa gelombang tsunami bergerak dari sumber pembangkitnya menghantam Pagai Selatan, Bengkulu dan sekitarnya, dan juga sebagian kecil Padang. Amplitudo gelombang tsunami hasil simulasi yang dibangkitkan oleh skenario satu segmen adalah lebih rendah dibandingkan dengan yang dibangkitkan oleh skenario multi segmen. Tinggi gelombang maksimum, yang dihasilkan oleh skenario multi segmen adalah lebih tinggi daripada skenario satu segmen, tetapi lebih rendah di Tanjung Bulan, dan juga mendekati kepada data hasil survei awal yang telah dilaksanakan oleh Borrero *et al.* (2007).

Kata kunci: tsunami kecil, model TUNAMI-N1, Bengkulu, patahan satu segmen, patahan multi segmen

ABSTRACT

Earthquake of magnitude Mw 7.9 – Mw 8.4 shocked the Province of Bengkulu in Sumatera, Indonesia on September 12, 2007, as reported by BMKG-Indonesia, USGS, and GFZ-Potsdam. This paper is based on research documentation, which is resulted from a quick response to the Bengkulu earthquake based on a preliminary estimation of earthquake magnitude (Mw. 8.4) and epicenter location (101.00°E, 3.78°S) provided by USGS (United States Geological Survey). This study is to compare the simulation model between single and multi-segment of source generation. TUNAMI-N1 used the domain model which has grid resolutions of 1,852 meters, and it was run in 4 hours simulation with time step of 1 second. Bathymetry data (1 minute-arc resolution) is derived from GEBCO. Water level data, also derived from real time tide gauge at the stations of Padang (IODE-VLIZ, 2007), Cocos Island (BoM, 2007), and DART Buoy No. 23401 (NOAA, 2007) for sea surface wave verification. Numerical modeling results show that tsunami waves propagated from its source location toward South Pagai, Bengkulu and its surroundings, and also the minor part of Padang. The wave amplitudes-series resulted from single-segment scenario is lesser than that of multi-segment scenario. The maximum wave height, resulted from multi-segment scenario is higher than the single-segment, but lesser in Tanjung Bulan, and also closer to the preliminary field survey results which were conducted by Borrero *et al.* (2007).

Key words: Minor tsunami, TUNAMI-N1 model, Bengkulu, single-segment, multi-segment

Korespondensi Penulis:

Jl. Pasir Putih I Ancol Timur, Jakarta Utara 14430. Email: widodosetioprano@yahoo.com

INTRODUCTION

Earthquake of magnitude Mw 7.9 – Mw 8.4 was shocking the Province of Bengkulu in Sumatera, Indonesia in September 12, 2007, as reported by BMKG (Badan Meteorologi Klimatologi dan Geofisika) Indonesia, USGS (United States Geological Survey), and GFZ (GeoForschung-Zentrum) Potsdam. At least 25 people were killed, 161 injured, 52,522 buildings were damaged or destroyed and some roads were damaged in Bengkulu and Sumatera Barat (USGS, 2007). Power and telephone outages occurred (ANTARA-NEWS, 2007). The earthquake was felt by people in high-rise buildings in Jakarta and also in Malaysia, Singapore and Thailand (USGS, 2007).

According to USGS, there were two main shocks of earthquake of Mw. 8.4 which was located at 101.00°E and 3.78°S (preliminary estimation) and or 101.382° E 4.514° S (after corrected) which have generated minor tsunami (Figure 1).

Even though the tsunami wave of 90 cm – 110 cm height was observed at Padang gauge (IODE-VLIZ, 2007),

there was no information about the tsunami (evidences) generated by this earthquake from BMKG Indonesia and other Indonesian's online-news, while according to historical data (ITDB, 2006) and some empirical formula (Iida, 1963) this Mw 8.4 earthquake could generate a tsunami. Tsunami expert from the Tsunami Research Center - University of Southern California in collaboration with researchers from the Tsunami Research Group of BPPT Indonesia were the first expert group who conducted field measurement and released evidence to the public about the tsunami at Bengkulu in September 12, 2007 (Borroro *et al.*, 2007).

In the 2nd International Tsunami Field Symposium (ITSF) 2008, the authors (2008: 113-114) presented the modeling of this event based on earthquake Mw 8.4 (USGS, 2007) and Mw. 8.2 (GFZ-Potsdam, 2007) using single-segment of source generation. Comparison of the two models reveals that Mw 8.4 is closer to the observation data. In this paper, as further study of the previous research, we compared the simulation model between single- and multi-segment of source generation from the earthquake Mw 8.4, and its comparison with observation and field survey data.

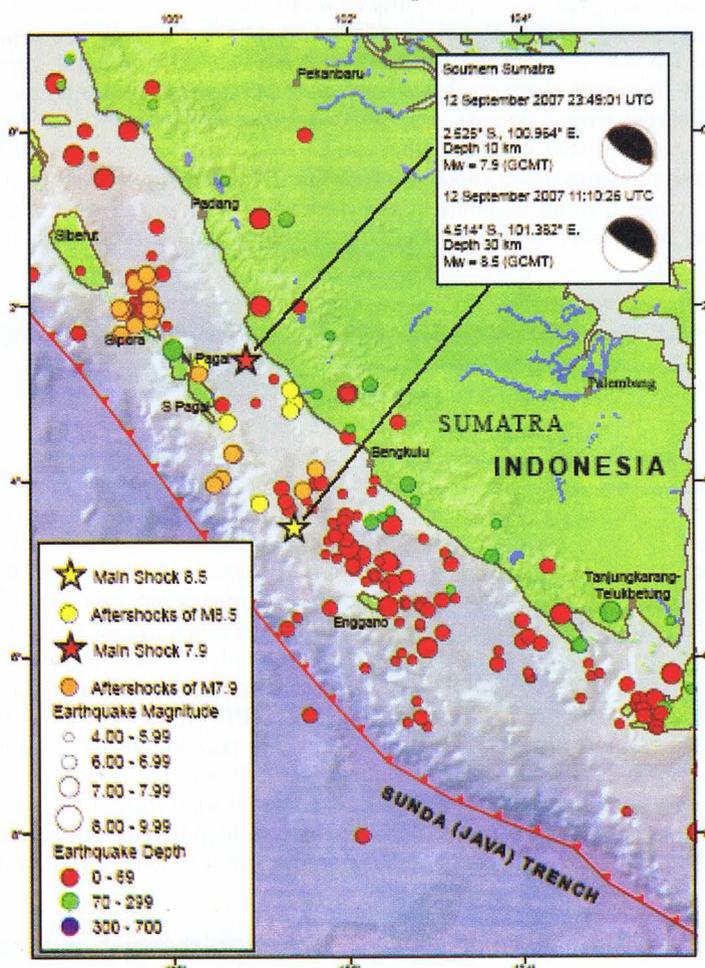


Figure 1. The main and aftershocks of the Bengkulu earthquake September 12, 2007 (USGS, 2007).

SOURCE PARAMETER

Two kind of tsunami sources have been used as scenarios to generate the excitation based on the fault displacement theory from Mansinha and Smylie (1971: 1433-1440); the first one is a single (fault) segment derived from USGS, and the second is the multi-segment derived from Lorito *et al.* (2008: L02310). The single segment source of earthquake Mw 8.4 epicenter is located at 101.00°E, 3.78°S with hypocenter depth of 23.3 km, fault dimension of 191 x 95.5 km², striking at 327°, dip angle of 12°, dislocation-slip values of 5.53 meters and 114° (Figure 2 left). Additionally, for the multi-segment (Table 1; Fig. 2 right) follows the model constructed by Lorito *et al.* (2008: L02310), with some modifications, using seismic moment of 4.2 x 10²¹ N.m. While Lorito *et al.* (2008: L02310) suggested shear modulus of rigidity $\mu = 2.0 \times 10^{10}$ N.m⁻² for the depth range of 10 - 20 kms. However, this paper use $\mu = 3.5 \times 10^{10}$ N.m⁻² for deriving the same seismic moment.

TSUNAMI MODELING

Tohoku University's Numerical Analysis Model for Investigation of near-field tsunamis Number 1, or known as TUNAMI-N1, will be used in this research. TUNAMI-N1 is a numerical simulation program based on finite difference method and structured grid, which uses linear theory in deep regions and shallow water theory in shallow regions and on land (Imamura *et al.* 2006). This model is employed for 4 hours simulation using 1 second time step, which satisfying the Courant-Friedrichs-Levy (CFL) criterion for the stability. The initial sea water wave is assumed equal to the vertical displacement of the sea bottom.

The model simulation uses bathymetry of 1 arc-minute resolution data from the General Bathymetry Chart for the Ocean (GEBCO). Domain model is 1021 x 1351 grids ("X = "Y = 1,852.00 meters), which is located in western

Sumatera waters, between 88 - 105°E and 9.5°N -13°S. The verification stations (Figure 2) were taken at Padang stations at 0.9 °S, 100.4 °E (IODE-VLIZ 2007); Cocos Island station at 21.1°S, 96.9°E (BoM, 2007); and DART No. 23401 at 8.9 N, 88.5 E (NOAA 2007). To compare the results with the preliminary field survey results (September 15 - 18, 2007) which conducted by Borrero *et al.* (2007), virtual gauge's values at grid-points near the coastline were taken.

RESULTS AND DISCUSSION

The wave form of excitation and amplitudes resulted from each scenario is very different because of the setting of segment faults (Figure 3), even though both models have the same seismic moment (4.2 x 10²¹ N.m) which represents Mw 8.4. Single-segment scenario produced a maximum uplift of 1.95 m and a maximum depression of 0.95 m, while the multi-segment scenario showed a maximum uplift of 3.59 m and a maximum depression of 1.75 m. In general, the wave amplitudes resulted from single-segment scenario is lesser than that of multi-segment scenario.

The interesting results from both scenarios are that the peaks of the first waves which were detected by gauges are more or less in the same form (Figure 4) compare to the observations, but are different at the rests. In general, the mean absolute error (Abramowitz & Stegun, 1972: 14) of multi-segment scenario is lower in the near-field station (Padang: single-segment of 29.72 % and multi-segment of 25.75 %) than the single-segment scenario, but little bit higher in the far-field stations (DART: single-segment of 0.89 % and multi-segment of 1.04 %; and Cocos: single-segment of 1.78 % and multi-segment of 1.81 %), see Table 2. In Padang gauge, the wave energy resulted from the single-segment model seems fast decreasing, while from the multi-segment still has

Table 1. Source Parameter of Multi-Segment

Segment No.	Coordinate		Depth (km)	Strike (°)	Dip (°)	Slip (°)	Length (km)	Width (km)	Dislocation (m)
	Lon	Lat							
1	101.864	-4.685	12	323	12	105	50	50	9
2	101.53	-4.92	12	323	12	105	50	50	6
3	101.243	-4.562	12	323	12	105	50	50	6
4	101.003	-4.233	12	323	12	105	50	50	6
5	101.069	-3.607	12	323	12	105	50	50	10
6	100.815	-3.258	12	323	12	105	50	50	8
7	100.546	-2.91	12	323	12	105	50	50	3

Note: Longitude (+) East, (-) West; Latitude (+) North, (-) South.

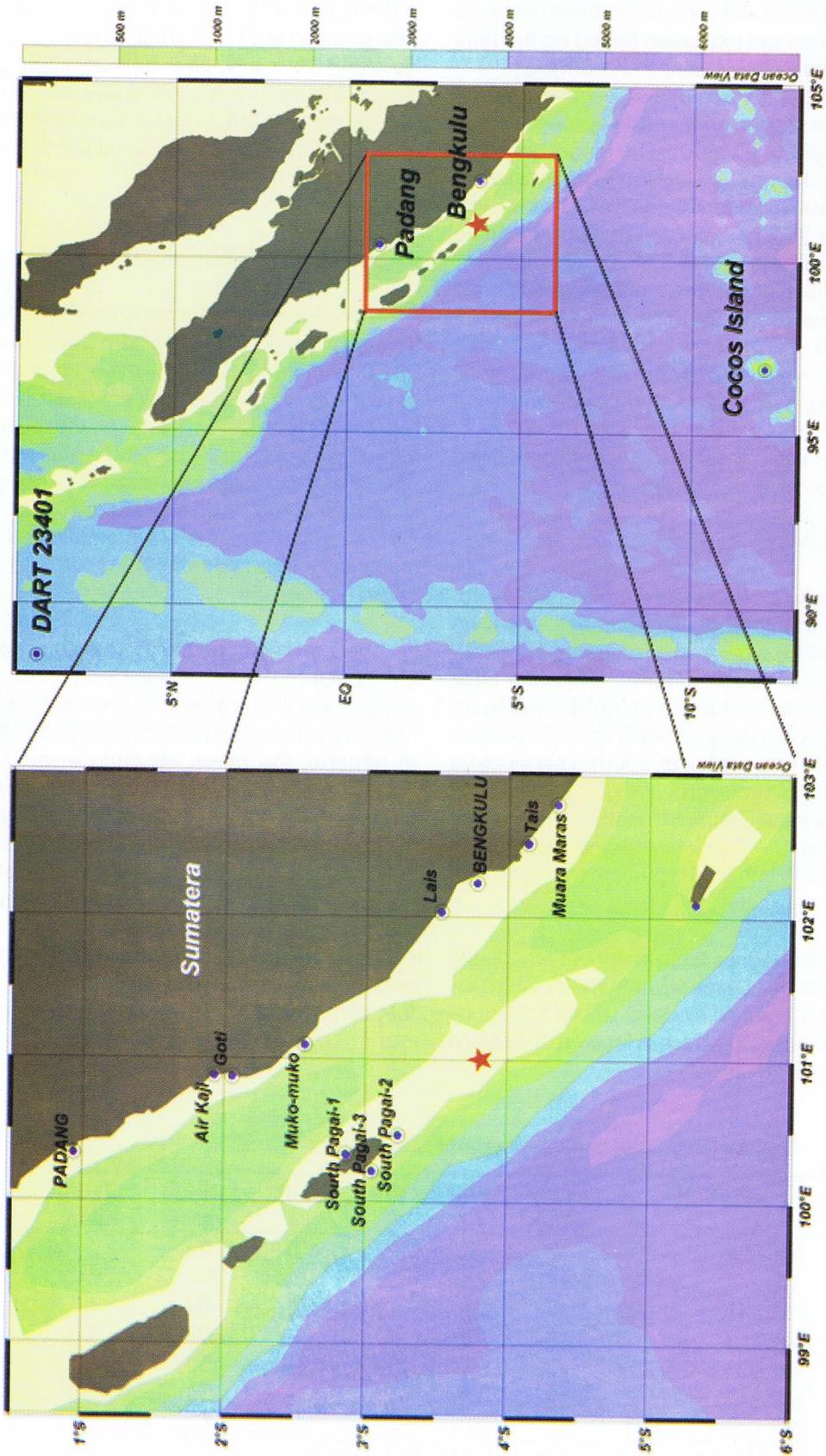


Figure 2. Domain area modeling and gauges location (right panel); and points location for the maximum wave height at the coast (left panel); the earthquake epicenter of Mw 8.4 (USGS, 2007) indicate by red star.

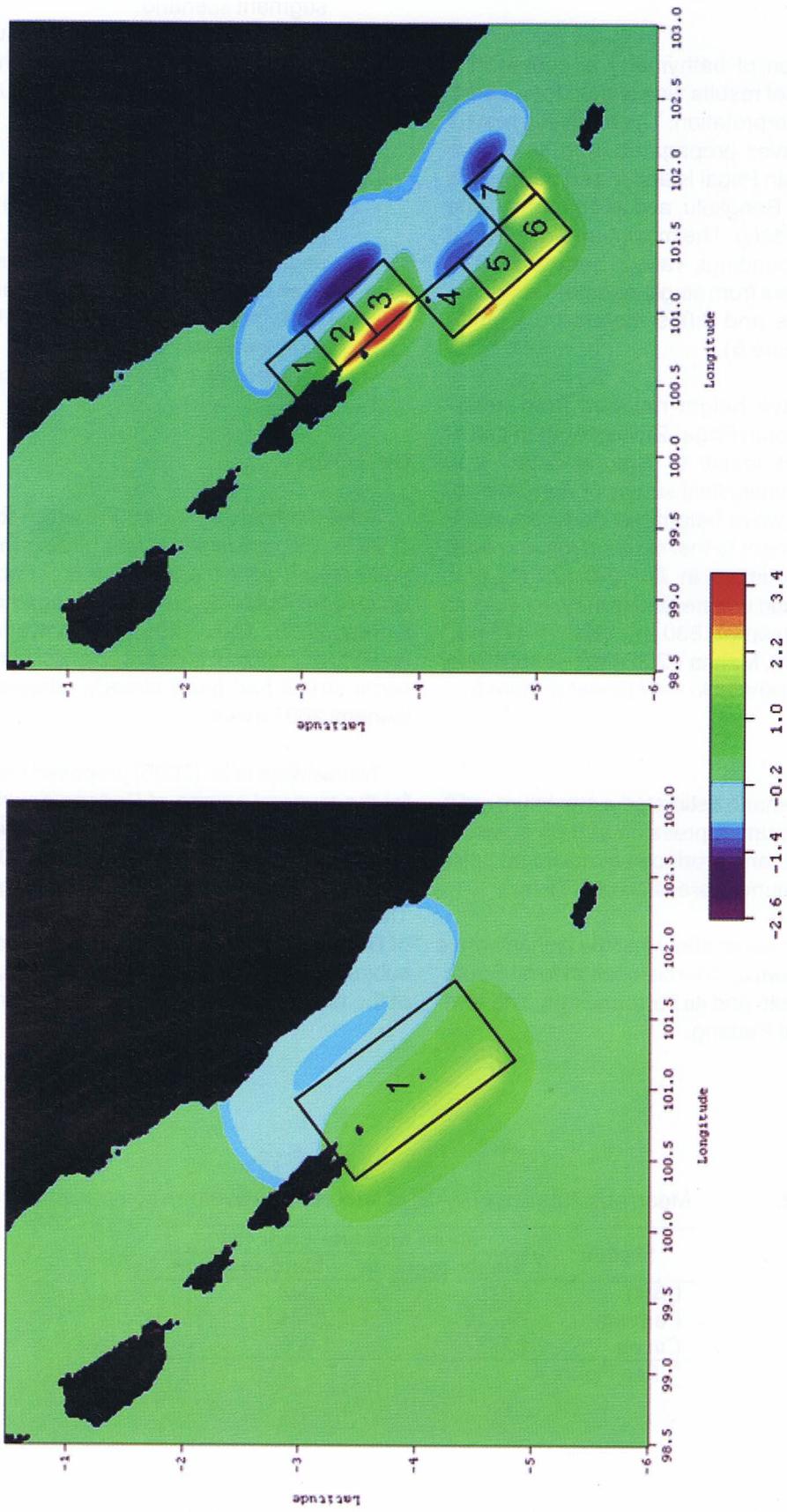


Figure 3. Setting single-segment (left panel) and multi-segment (right panel), including the results of sea level generated by models (colours shows the sea level in metres).

energy released after the first wave peak (Figure 4 middle-panel), as also shown in Cocos gauge (Figure 4 lower-panel).

Since the resolution of bathymetry is coarse, the arrival time of the model results was shifted for a better visualization during interpretation. The modeling results show that tsunami waves propagated from its source location, mainly hit South Pagai Island (no survey reports or evidence available), Bengkulu, and its surroundings, and also a minor part of Padang. The maximum wave height in Bengkulu and surroundings varied, between 0.321 meters and 4.145 meters from single-segment scenario, between 0.808 meters and 6.059 meters from multi-segment scenario (Figure 5).

The maximum wave height resulted from multi-segment scenario in South Pagai-2 is higher than that of single-segment, but is lesser in Tanjung Bulan. If it compared to the preliminary field survey of Borrero et al. (2007), the maximum wave height resulted from multi-segment scenario is closer to that of observations, even though slightly overestimate in Tais (+0.123 m) and Bengkulu (+0.445 m), and underestimate in Pasar Seluma (-0.381 m), Tanjung Bulan (-0.830 m), Lais (-1.474 m), Muara Maras (-1.758 m), Manna (-2.394 m), respectively from the smallest differences to the highest (Figure 5).

CONCLUSIONS

Single-segment scenario estimated a maximum uplift of 1.95 m and a maximum depression of 0.95 m, while the multi-segment scenario produced a maximum uplift of 3.59 m and a maximum depression of 1.75 m.

1. The modeling results show that the tsunami wave propagated from its source location to hit South Pagai, Bengkulu and its surroundings, and also a minor part of Padang.

2. The wave amplitudes-series resulted from single-segment scenario is lesser than that of multi-segment scenario.
3. The maximum wave height, resulting from multi-segment scenario is higher than the single-segment, but is lesser in Tanjung Bulan, and also closer to the preliminary field survey of Borrero *et al.* (2007).
4. The mean absolute error (MAE) of multi-segment scenario is lower in the near-field station (Padang: single-segment of 29.72 % and multi-segment of 25.75 %) than the single-segment scenario, but is a little bit higher in the far-field stations (DART: single-segment of 0.89 % and multi-segment of 1.04 %; and Cocos: single-segment of 1.78 % and multi-segment of 1.81 %).

OUTLOOK

After the Aceh tsunami 2004 which followed by Nias in 2005, the communities are girding for the next killer wave striking along the coastal area of Padang – Bengkulu, which contributed by the Sunda megathrust fault (Stone & Kerr, 2005: 1602-1605), but nowadays Padang is drawing attention of tsunami scientist communities since some stress had been already released by Bengkulu tsunami 2007 event.

Natawidjaja *et al.* (2008) proposed the slip distribution for the tsunami source of Padang next future, which is less than rupture area in 1883 tsunami event (Natawidjaja *et al.*, 2006: B06403; McCloskey *et al.* (2008) which could be still containing rupture area of the Bengkulu 2007 event. The slip distribution on the multi-segment in our simulation of Bengkulu 2007 events might be good to be used for subtracting their proposed model, to get closer estimation of the tsunami source of Padang in the next future.

Table 2. Mean absolute error (MAE) of time series waveform comparisons*)

Station	Mean Absolute Error (%)	
	Single-segment	Multi-segment
DART	0.890	1.043
Padang	29.718	25.747
Cocos	1.777	1.805

*) See Figure 4.

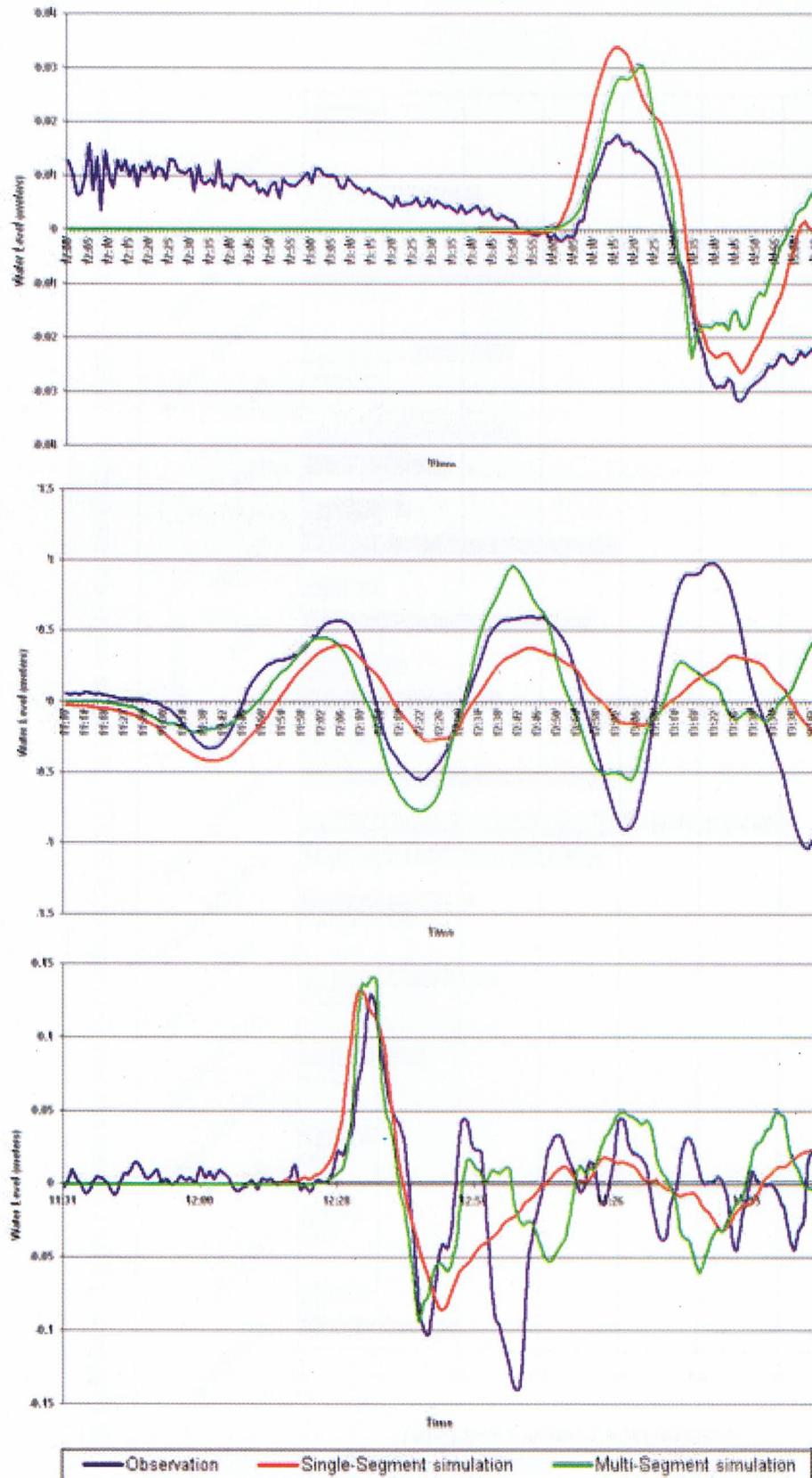


Figure 4. Comparison of the water levels at the gauges (upper: DART buoy; middle: Padang; lower: Cocos Island) from the simulation and the observations; Axis: X-axis is time, Y-axis is water level in meters.

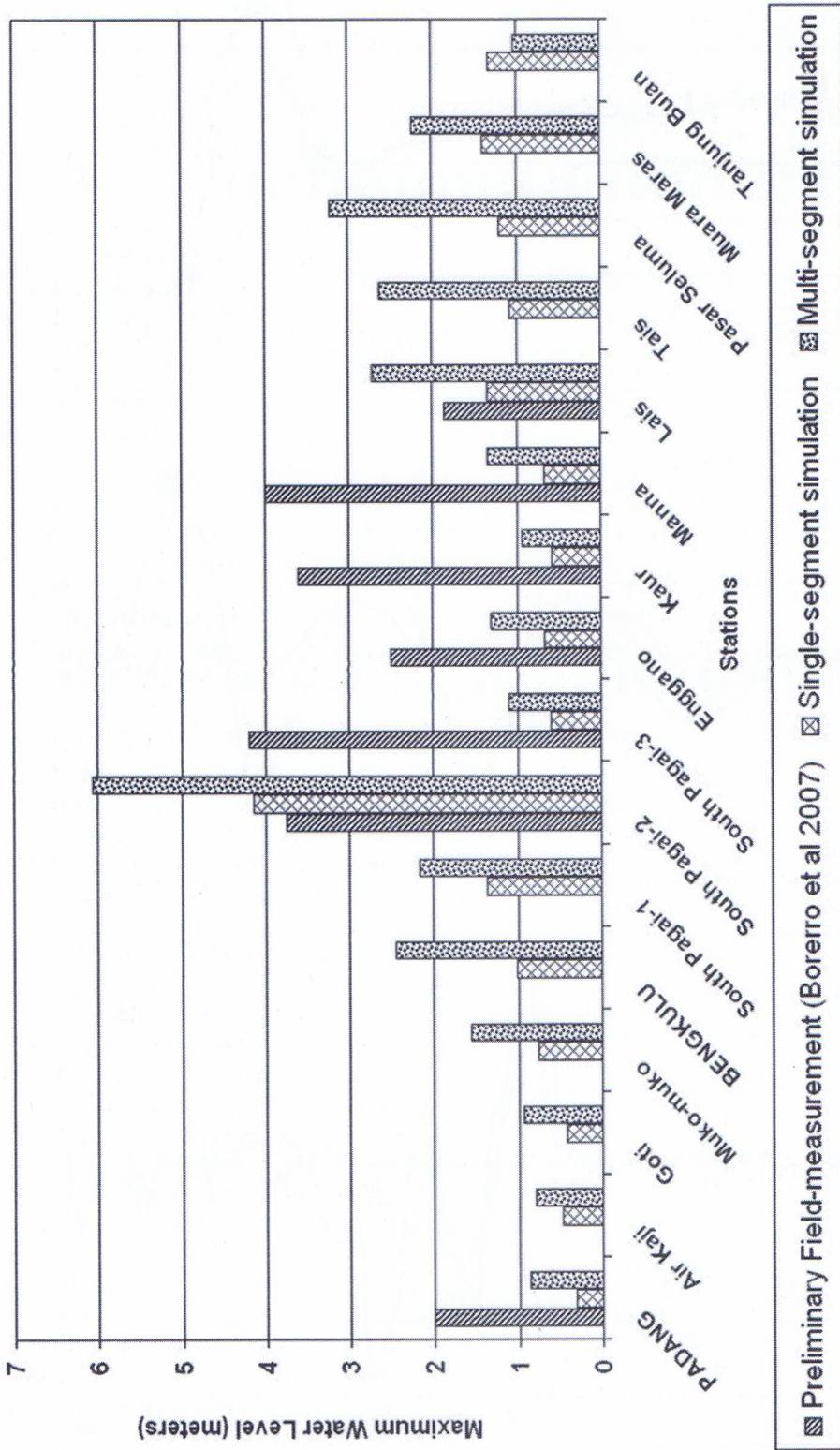


Figure 5. The maximum water levels at the coast produced by simulation in comparison to observations. The location of stations is shown in Figure 2 (left panel).

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