SUMMARY OF EARTHQUAKES

Occuring July-September 2006

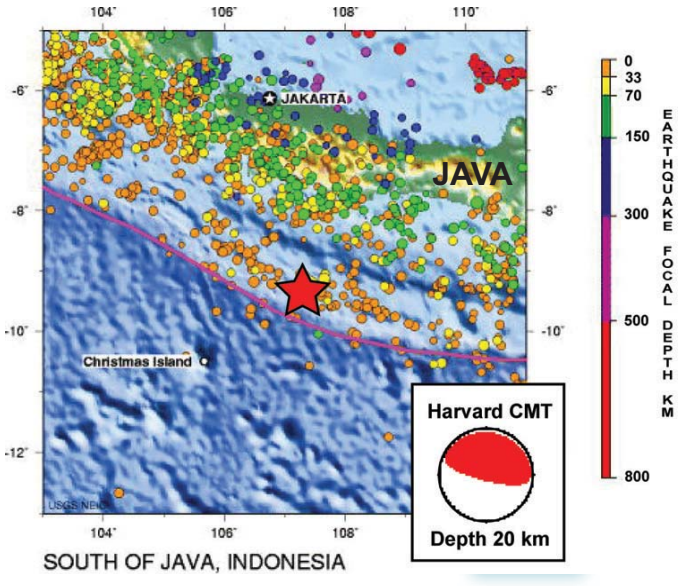
With surface wave or moment magnitude (Mw) greater than or equal to 6.5 and a depth no greater than 100 km, or an event for which a PTWC Tsunami Information Bulletin (TIB), PTWC Regional Watch Warning (RWW), and/or JMA Tsunami Watch Information (TWI) were issued. Epicenter, depth, and Mw from USGS National Earthquake Information Center (NEIC, G); Mw from Harvard (H); Mw from PTWC (P) at action time.

DATE	TIME (UTC)	LOCATION	EPICENTER	DEPTH (km)	M_w	PTWC (P), JMA (J) ACTION	ACTION TIME	TSUNAMI? DAMAGING?	Maximum height and place
17 July	08:19	South of Java, Indonesia	9.254° S 107.411° E	6	7.7 (H) 7.2 (G, P)	(P) TIB 001 (P) TIB 002 (J) TWI 001 (J) TWI 002 (J) TWI 003 (J) TWI 004	08:36 11:08 08:46 11:43 12:25 18:50	Yes Yes	4.6 m Widarapayung Java
7 Aug	22:19	Vanuatu	15.777° S 167.799° E	27	7.0 (P) 6.8 (G,H)	TIB	22:32	No	
20 Aug	03:42	Scotia Sea	61.029° S 34.365° W	27	7.1 (P) 7.0 (G,H)	TIB	03:59	No	
1 Sept	10:19	Bougainville Region, Papua New Guinea	6.759° S 155.512° E	38	6.9 (P) 6.8 (G) 6.7 (H)	TIB	10:35	No	
10 Sept	14:56	Gulf of Mexico	26.319° N 86.606° W	14	6.0 (P001) 5.8 (G,H, P002)	TIB 001 TIB 002	15:05 15:10	No	
28 Sept	06:22	Samoa Islands	16.613°S 172.035°W	28	7.0 (P002) 6.9 (H, P001) 6.7 (G)	TIB 001 TIB 002	06:38 07:19	Yes No	16 cm Pago Pago

SOUTH OF JAVA, 17 July 2006, 08:19 UTC, M_W=7.7

At 08:19 (15:19 local time) on 17 July 2006 an earthquake of magnitude 7.7 occured in the Indian Ocean, approximately 355 km south of Jakarta and about 200 km south of Java, Indonesia, triggering a local tsunami which hit a 300 km stretch of coast along southern Java. Summaries of surveys follow in the next section.

This was a 'slow earthquake', meaning that the rupture occurred more slowly and took longer than in a normal earthquake. Slow earthquakes usually occur at very shallow depths and produce greater displacements than normal earthquakes. As a consequence, they are more likely to significantly displace the seabed and generate tsunamis. In addition, the magnitude of slow earthquakes may be underestimated by traditional magnitude calculations because the energy they radiate is deficient in high frequencies due to the slower rupture speed. Further, the strongest energy release of the earthquake may occur minutes after the initial rupture and thus not be captured by the initial magnitude calculation. This event was also called a 'tsunami earthquake,' which is an earthquake that generates a tsunami much larger than expected given the earthquake magnitude. 'Tsunami earthquakes' are often caused by 'slow earthquakes'.



Historical seismicity (from 1990-present) of area south of Java from National Earthquake Information Center (NEIC). The pink line indicates the Java Trench. The red star indicates the present earthquake.

According to a ReliefWeb report, (*http://www.*

reliefweb.int/rw/dbc.nsf/doc108?OpenForm&emid=TS-2006-000087-IDN&rc=3) on 19 July, Indonesian Vice President Jusuf Kalla announced that the death toll had reached 525 with 273 people missing. Most damage centred on the town of Pangandaran. More than 50,000 people were evacuated.

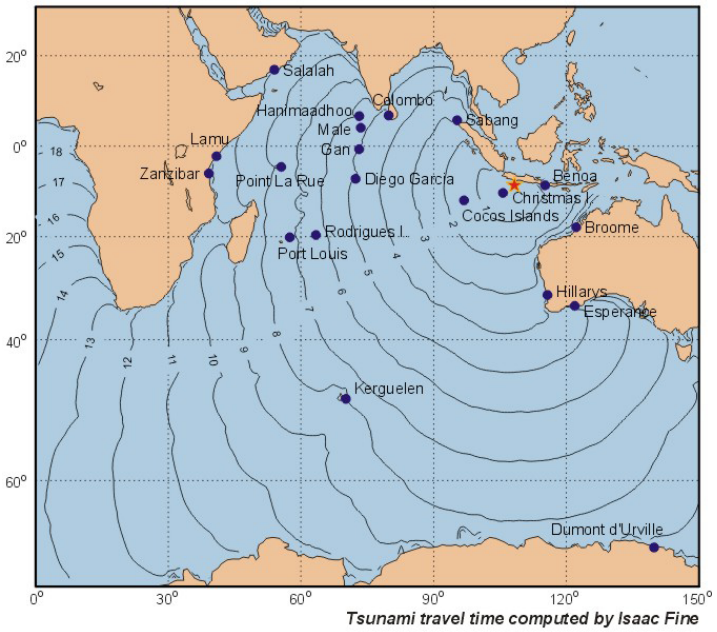
Timeline: 17 July 2006, Java, Indonesia Earthquake and Tsunami

Compiled by IOC ITIC

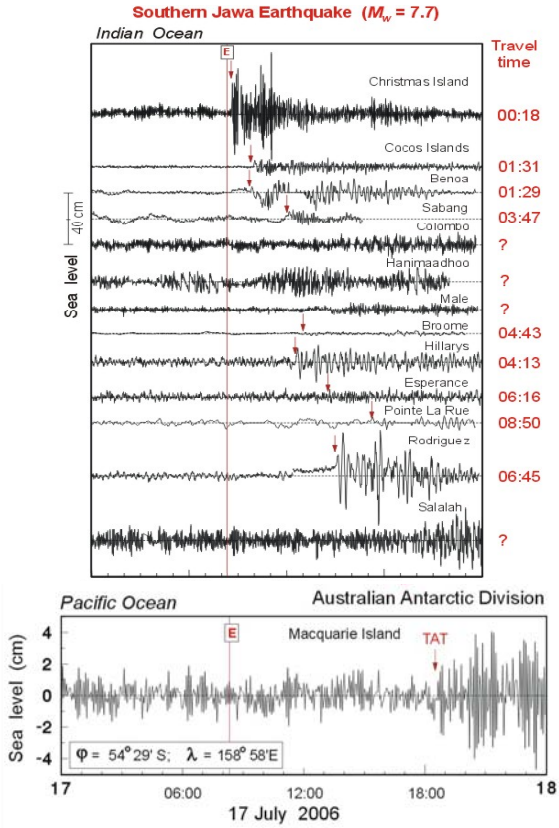
(http://ioc3.unesco.org/itic/contents.php?id=355)

UTC	Elapsed Time*	Action
0819		**Earthquake occurs** (USGS and Harvard CMT: 9.28S, 107.38E, 34 km, Mw7.7)
0821	0:02	**Indonesia Meteorological and Geophysical Agency (BMG) calls start being received.**
0824	0:05	**BMG SMS alert** reporting automatic solution using 8 stations, **ML6.8.**
0825	0:06	**BMG Mb5.5 =>** large difference in M implies non-typical earthquake **PTWC Seismic Alarm** triggers alerting PTWC staff.
0826	0:07	**BMG press inquiry on phone and issued to media - caution for tsunami** **Japan Meteorological Agency (JMA) Operations trigger for distant earthquake**
0827	0:08	BMG unsuccessful to contact local government official in the coastal area by telephone due to unavailability of communication contact points at the said areas. SMS message sent to list of about 400 available addresses, though list did not contain many Java coastal addresses.
0829	0:10	**NEIC Short Period Alarm**
0831	0:12	PTWC Observatory Message with preliminary epicenter (9.3°S, 107.3°E), magnitude (Mwp 7.3) and *P*-wave arrival times disseminated to other observatories (e.g., JMA, WC/ATWC)
0832	0:13	JMA receives PTWC Observatory Message.
0833	0:14	WC/ATWC calls to PTWC (determines that WC/ATWC does not need to issue a bulletin since the earthquake is not in the Pacific Ocean).
0836	0:17	**PTWC Bulletin #1** - Indian Ocean Local Tsunami Watch Message disseminated via GTS, email, fax, putting Indonesia and Australia in a watch, M 7.2; providing estimated tsunami arrival times for tsunami forecast points at Christmas Island, Australis (0836), Cilacap, Indonesia (0900). NEIC —Initial automatic solution, Mwp 7.2
0838	00:19	JMA receives PTWC Bulletin #1.
0839	00:20	PTWC confirms with Emergency Management Australia (EMA) by telephone.
0840	00.21	**Tsunami arrival, Pangandaran**, According to the witness accounts, the sea level went down at first due to the tsunami wave. The wave came twice: first wave was 3m, and second wave was 5m. According to witness accounts, in the whole Pangandran, the tsunami wave came into 500m inland from the shoreline. The earthquake continued for 3 minutes.
0841	00:22	NEIC Mw 7.2 from Body Wave Moment Tensor.

**All times are UTC. Italicized times are best estimates.*



Calculated Tsunami Travel Times for Indian Ocean Sea level stations (black dots) recording the tsunami of 17 July 2006. Epicenter shown by red star. Sea Level data are shown on the following page. Travel time plot and sea level data plots posted to the ITIC Tsunami Bulletin Board (TBB) by Dr. Alexander Rabinovich, Institute of Ocean Science, Sydney, Canada, 2 Aug 2006.



Courtesy Institute of Ocean Science, Canada; Bureau of Meteorology, Australia, and Pacific Tsunami Warning Center.

Java Timeline, *continued*

UTC	Elapsed Time*	Action
0843	00:24	PTWC attempts to confirm with Indonesia BMG by Telephone (no answer,10 attempts in 12 minutes to three phone numbers).
0846	00:27	**JMA Bulletin #1**– Indian Ocean Local Tsunami Watch disseminated via GTS and email, providing estimated tsunami travel times of 1 hour or less to Indonesia Indian Coast of Sumatra, Jawa, and south coasts of Lesser Sunda Islands, and Australia Cocos Islands.JMA receives NEIC Bulletin.
0849	00:30	JMA Fax Message of JMA Bulletin #1
0849-0859	*00:30-00:40*	**Tsunami arrival, Parang Endok DIY**: 3-4 waves, Receding wave 50-100m, No shaking, only heard explosions explosions before tsunami. Tsunami arrival, Suwuk–Kebumen: Receding wave >100m, 3 waves, 2nd biggest; Weak shaking, heard explosions before tsunami.
0900	00:31	BMG checks email from PTWC, JMA.
0904	00:45	**Tsunami arrival, Ayah – Kebumen**: 4-5 waves, first wave the biggest; No shaking or slight shaking; Explosions heard twice before wave coming.
0909	00:50	**Tsunami wave arrival, Bunton – Cilacap**: High waves (- 5m) but breaking into1-1.5m small waves, 2 waves, 1st biggest; Explosions not heard before arrival.
0914	00:55	**Tsunami wave arrival, Cikembulan 1 – Ciamis**: Some explosions before arrival.
0923	01:04	NEIC reviewed solution – took longer than usual because of recent staffing changes as well as complexity due to the 'slow' nature of the earthquake rupture. For most global earthquakes, reviewed solution available within 20-30 min (for May Tonga earthquake, it was about 20 min).
0930	01:11	**PTWC report** from Australia Bureau of Meteorology**, 0.6m amplitude tsunami on Christmas Island** gauge near epicenter.
0945	01:26	PTWC call from CNN – they report 6-ft tsunami in Indonesia.
1030	02:11	**PTWC and JMA receive first sea level readings from Benoa, Indonesia** (which were transmitting every 15 min) show 0.04m amplitude tsunami at 0951 (1:32 after earthquake).
1108	02:49	**PTWC Bulletin #2** - Local Tsunami Watch Follow-Up Message disseminated indicating media reports of a damaging tsunami in Indonesia and that a threat of a widespread tsunami was not probable; reported an observed 0.04m tsunami at Benoa.
1110	02:51	JMA receives PTWC Bulletin #2.
1143	03:24	**JMA Bulletin #2** – Indian Ocean Local Tsunami Watch, reporting Benoa, Indonesia observed maximum tsunami of 0.2m at 1944 JST.
1225	04:06	**JMA Bulletin #3** – Indian Ocean Local Tsunami Watch, correcting maximum tsunami arrival time
1432	06:13	Harvard CMT Mw 7.7.
1457	06:38	JMA receives USGS M7.7.
1850	10:31	**JMA Bulletin #4** – Final Bulletin, Indian Ocean Local Tsunami Watch, reporting Rodrigues Island, Mauritius maximum tsunami of 0.4m at 1750.

**All times are UTC. Italicized times are best estimates.*

EVENT NOTES:

1. By current protocols, PTWC and JMA are providing an interim service and only issue Tsunami Watch bulletins to the Indian Ocean Region. Warnings are issued by each national authority. Currently, only a single initial Watch bulletin is issued unless other information becomes available.
2. At the time, there was no dissemination system established from BMG to any local government or authorities other than the limited lists of SMS and email. In response to the event, BMG (as of 17 August 2006) made imporvements to its TWC operations including:

In response to the event, Indonesia BMG has made improvements to its TWC operations:

1. Additional telephone lines are now available
2. Dedicated communication links from BMG through:
   a. Police communication networks, from Police Headquarter to district level,
   b. Dept of Internal Affairs network to Governor offices to district level,
   c. Media centers of Radio and TV broadcasting services.

Points of Contact: BMG: Prih Harjadi, Fauzi, Suhardjono; PTWC: Charles McCreery; JMA: Osamu Kamigaichi; USGS: Stuart Sipkin; Germany: Joachim Saul; IOC: Laura Kong and Masahiro Yamamoto.

References:

BMG, Germany, JMA, PTWC, USGS NEIC, 29 July 2006, BMG Technical meeting, Bali.

BPDP–BPPT & ITS (Widjo Kongko, Suranto, Chaeroni, Aprijanto, Zikra, Sujantoko), Rapid Survey on Java Tsunami 17 July 2006, presented ICG/IOTWS-III, WG4, 29 July 2006.

BMG–ERI/UTokyo, Japan–Korea Institute of Earthquake Information, Field survey of the tsunami inundated heights due to the Java Tsunami

Java Timeline, *continued*

(2006/07/17) along the coast on the Indian Ocean in Java Island, http://www.eri.u-tokyo.ac.jp/tsunami/javasurvey/index_e.htm.

Fachrizal, Sugeng Pribadi, and Iwan Hermawan, 2006, Laporan Survey Gempabumidan Tsunami Selatan Jawa Barat 17 Juli 2006, Badan Meteorologidan Geofisika, p.77.

ITIC communications: Post-Tsunami Survey, Nusa Kambangan, ~August 5-10, 2006, University of Crete, Georgia Institute of Technology, personal communication by H. Fritz to L. Kong, 14 Aug 2006.

Tsunami Bulletin Board postings: Sea level data; posted by Dr. Alexander Rabinovich, Institute of Ocean Science, Sydney, Canada, 25 July, 2 Aug 2006; Post-Tsunami Survey 4-11 Aug 2006, BMG-U/Tokyo, Korea Institute of Earthquake Information, posted by Y. Namegaya, 13 Aug 2006; Post-Tsunami Survey 20-21 July 2006, Kyoto University, posted by J. Mori, 27 Jul 2006.

17 July 2006—Post-Tsunami Surveys

On the following pages, we report on the southern Java post tsunami surveys conducted in July and August 2006. Survey teams came from Australia, Crete, Indonesia, Japan, Korea, New Zealand and the United States of America. In general, people either did not feel, or only slightly felt the earthquake. It was also noted that walls perpendicular to wave direction are often knocked down, while walls parallel to wave direction remained intact.

NZ Post-Tsunami Survey 30 July-4 August, Institute of Geological and Nuclear Sciences, LTD, (GNS Science) New Zealand and others

A joint New Zealand reconnaissance team conducted a post-tsunami survey of the damaged areas of the port city of Cilacap and the resort town of Pandangaran to acquire data for calibrating models developed in New Zealand relating casualty rates to inundation and damage levels. The main tasks were to collect (a) run-up (water depth) and inundation (horizontal extent) along multiple transects, (b) building, infrastructure and vegetation damage levels for various water depths (run-ups), and (c) data on casualty rates. One of the aims of the study was to determine the rates of deaths and injuries as functions of water depth and type of building. Although it is known that: (a) people did not know exactly where they were at the time of tsunami; (b) most buildings were not uniform in type, and (c) water depths changed rapidly over small distances, it was nevertheless possible to obtain some conclusions by making reasonable assumptions based on the locations of people and rates of building occupancy. These assumptions included that:

1. *All deaths and injuries occurred in or near totally or badly damaged buildings;*
2. *Water depths could be assigned to the heavy-to-total damaged buildings based on the water depth ground profile transects;*
3. *Occupancy rates for a 4 pm Monday earthquake were according to Table 5-2 of the report (p. 31);*
4. *For every three persons indoors, there was one additional person outdoors and nearby.*

The resulting plot of death and injury rates a function of water depth (Figure 1) shows that death rate increases with observed water depth. Collection and comparison of the slope of the linear correlation with other tsunami studies will help to establish whether the results of this study are universal.

Village	Occupants*	Dead+ Missing	Injured	Death Rate	Injury Rate	Water Depth (m)
Ds. Pangandaran	792	41	5	0.05	0.006	2.75
Ds. Pananjung	709	32	19	0.05	0.03	4.0
Ds. Wonoharja	668	74	34	0.11	0.05	3.5
Ds. Cikembula	322	52	5	0.16	0.02	3.5
Ds. Ciliang	312	18	106	0.06	0.34	2.3
CIAMIS DISTRICT	4586	428	332	0.09	0.07	c.3

*in or around heavily damaged or destroyed buildings

Table 1. Data compiled in the study by village and district as a whole. The water depth for the Ciamis District is an assumed average. [p. 32 of the study].

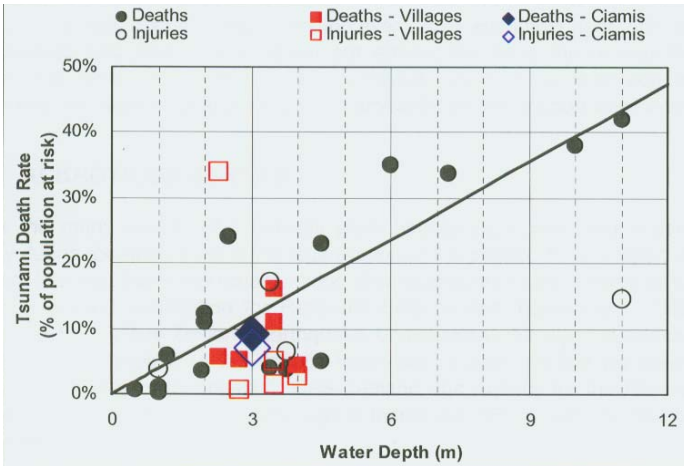


Figure 1. Effect of water depth on death rates (solid symbols) and injury rates (open symbols) due to tsunami. Squares are results for individual villages, trapezoids are approximate overall results for the Ciamis District (the assumed water depth average), and circles are data from other tsunami. The black line is a best fit to the pre-Java death rate data. [p. 32 of the study]

Reference:

Cousins, W. J.; Power, W.L.; Palmer, N.G.; Reese, S.; Tejakusuma, I.; Nugrahadi, S., South Java Tsunami of 17th July 2006, Reconnaissance Report, GNS Science Report 2006/33, 42 p.

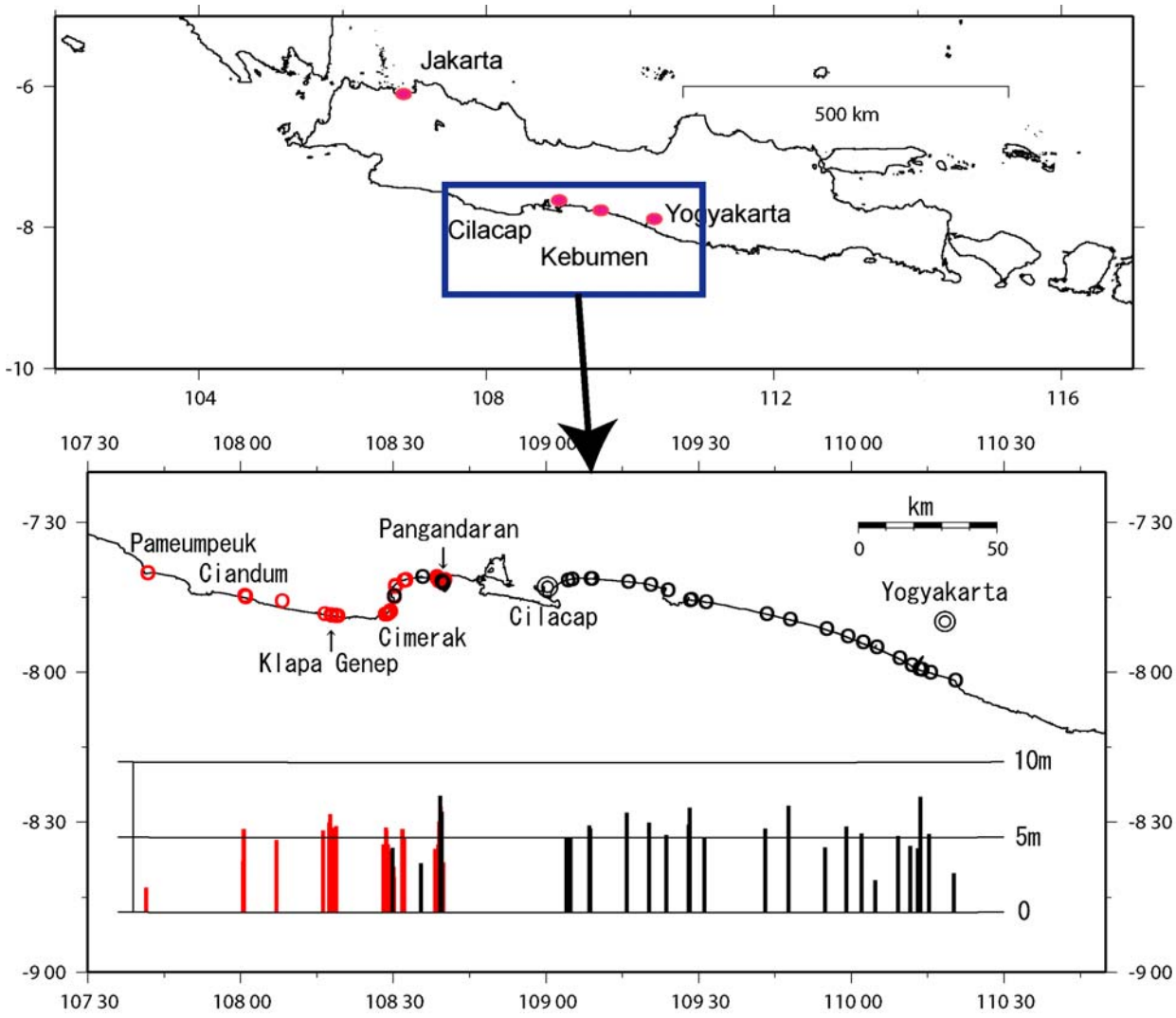
Java, *continued*

Post-Tsunami Survey, 4-11 August 2006, BMG, U/Tokyo, Kitvalley

A survey was conducted by Badan Meteorologi-dan Geofisika (BMG), Indonesia, Earthquake Research Institute-University of Tokyo (ERI), Japan, and Korea Institute of Earthquake Information, Korea. Tsunami run up measurements, following mean sea-level corrections, are depicted in the southern Java maps below. Detailed post-tsunami survey information can be accessed at: *http://www.eri.u-tokyo.ac.jp/tsunami/java-survey/index_e.htm*

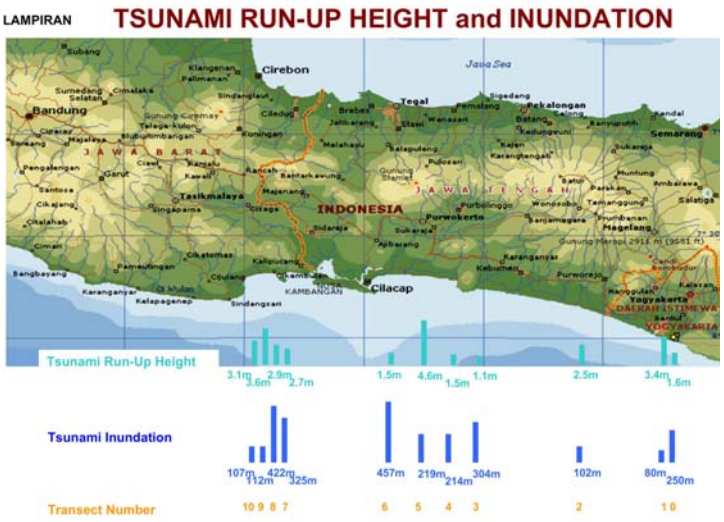
Reference:

Fachrizal, Sugeng Pribadi, and Iwan Hermawan, 2006, *Laporan Survey Gempabumidan Tsunami Selatan Jawa Barat 17 Juli 2006*, *Badan Meteorologidan Geofisika,* p.77.



Map of southern Java coast impacted by tsunami, showing area where post-tsunami survey was conducted. Red color indicates tsunami run up measured by BMG team, black color indicates tsunami run up measured by BMG team, ERI and Kitvalley.

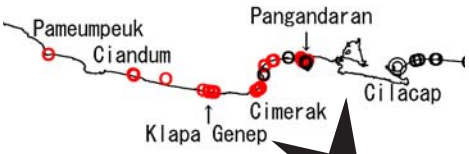
Java, *continued*



Two maps showing measurements taken in a post-tsunami survey led by Indonesian government agencies.

Post-Tsunami Survey, Nusa Kambangan, 5-10 August, 2006, University of Crete, and Georgia Institute of Technology, USA

An international team surveyed Nusa Kambangan and reported up to 20 m runups on this sparsely populated island.



Tsunami inundation in Nusa Kambangan Island, South Java. Note person in center right of photo (inside red circle) provides runup scale perspective.

Vegetative debris along uninhabited coast of Nusa Kambanga Island.

Batu Hiu damage in the Pangandaran area.

Marsawah village in the Pangandaran area. One building is left standing while all the rest in in this area have been completely destroyed. Seventy people were killed in this area.

Post-Tsunami Survey 20-21 July 2006, Kyoto University, posted by J. Mori

From the report on 24 July 2006:

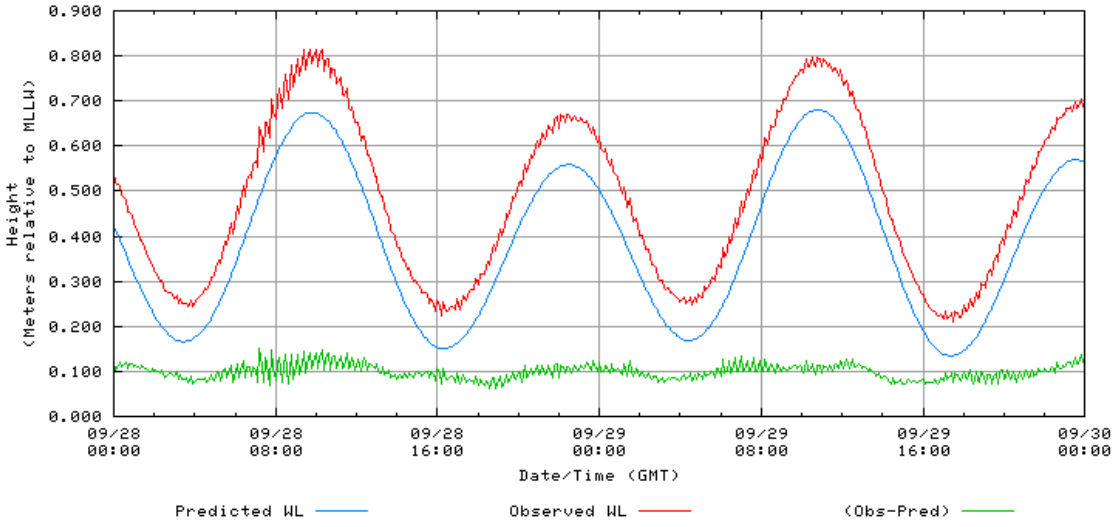
On 20-21 July, we inspected the damage area of the tsunami caused by the earthquake (M7.7) offshore of Java on 17 July. There was severe damage and over 200 people killed in the Pangandaran area. The largest tsunamis probably occurred in the Bulakbenda area about 20 km to the southwest of Pangandaran. Throughout the region, we saw no damage due to earthquake shaking, and people felt the earthquake only very slightly.

Reference: *http://www.eqh.dpri.kyoto-u.ac.jp/~mori/java/java-tsunami.html*

Damage in Pangandaran.

Samoa Islands, 28 September 2006, 06:22 UTC, M_W=6.9

An earthquake of magnitude 6.9 (Harvard) occurred on 27 September at 1922 local time (0622 UTC), 290 km southwest of Pago Pago with a location of 16.6° S and 172° W. There were no reports of damage. The largest local tsunami sea level measurement was made at Pago Pago harbour where a 16 cm wave height was recorded.



Tide gauge record from Pago Pago showing predicted and observed water levels for 28-29 September 2006. Courtesy of the U.S. National Ocean Service (NOS) website for tide records: http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=1770000%20Pago%20Pago,%20%20&type=Historic%20Tide%20Data