Online Training Course on
Disaster Risk Reduction and Climate Change Adaptation
for CARICOM and SICA Member Countries

Coastal Hazard in Indonesia due to Tsunami and Climate Change-induced Relative Sea-level Rise and their Mitigation

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Coastal Hazard in Indonesia due to Tsunami and Climate Change-induced Relative Sea-level Rise and their Mitigation

Outline:

1. **Introduction**
   - Indonesia
   - Coastal Condition in Indonesia
   - Coastal hazard
2. **Tsunami**
   - Tectonic Setting, History of Tsunami and level of tsunami hazard in Indonesia
   - Tsunami Modeling (Inundation model)
   - Tsunami Risk Assessment (hazard and vulnerability maps
   - Role of vegetation in reduce tsunami (hydraulics model and mathematical model
3. **SLR induced by Climate Change**
   - Ocean parameter induced by climate change
   - Oceanography Parameter and hazard cumulative scenarios
   - Coastal vulnerability index
   - Coastal Hazard maps, and several case studies
4. **Climate Changes Adaptation on the Coastal Sector**

Are the Topics relevant to **CARICOM** and **SICA?**

And then similar to Indonesia….. YES..

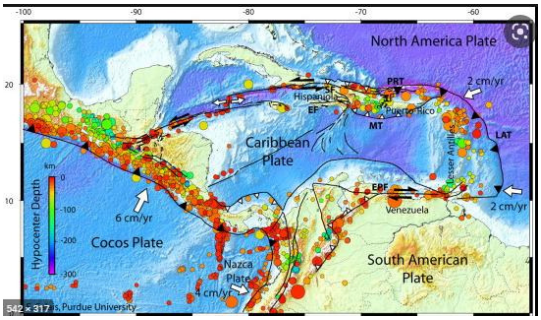
Let's See

- Tsunami
- Storm surge
- Global sea level rise and other Oceanography parameter (since CARICOM are archipelagos countries)

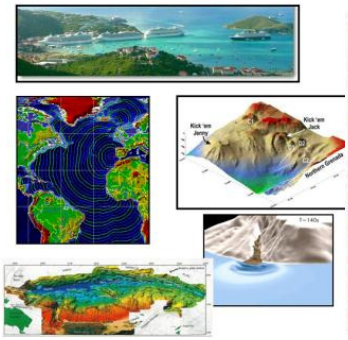
Historical of Caribbean Tsunamis

Hillebrandt-Andrade, and Dunbar, 2017

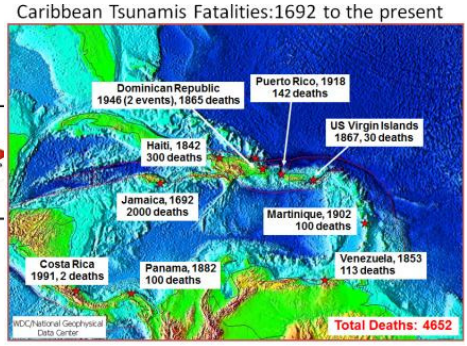
Caribbean Training Course in Seismology and Tsunami Warnings
St. Augustine, Trinidad & Tobago
June 25-30, 2007



- Local Caribbean Earthquakes = 71%
- Local Caribbean Submarine and Land Volcanoes = 18%
- Tele-tsunamis or distant sources (e.g. 1755 Lisbon, 1883 Krakatau, 2004 Indian Ocean) = 11%
- Submarine Landslides = 0%



Caribbean Tsunamis Fatalities:1692 to the present



Courtesy of Paula Dunbar, 2007

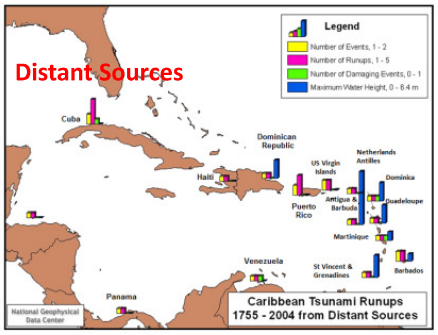
Historical Tsunami

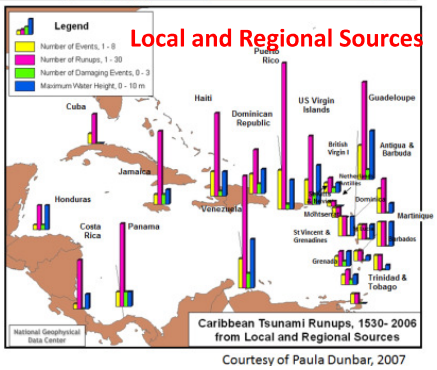
Historical Tsunamis which have Affected the Caribbean (http://www.ngdc.noaa.gov/seg/hazard)

Date					Earth-quake Mag	Vol-cano	Tsunami Source Location				Parameters		Effects	
											Max Water Height	Num. Runups	Deaths	
Year	Mo	Dy	Hr	Mn			Country	Name	Latitude	Longitude			Num	De
1530	9	1	14	30	*		VENEZUELA	CUMANA	10.7	-64.1	7.3	3		
1690	4	16			8		ANTIGUA AND BARBUDA	ANTIGUA; S	17.5	-61.5		3		
1692	6	7			7.7		JAMAICA	PORT ROYAL	17.8	-76.7	1.8	4	2000	3
1755	11	1			*		PORTUGAL	LISBON	36	-11	30	52		3
1761	3	31			*		PORTUGAL	LISBON	37	-10	2.4	11		
1767	4	24	6		*		MARTINIQUE	MARTINIQUE	14.4	-61		2		
1770	6	3			*		HAITI	PORT-AU-PR	18.5	-72.3		4		
1775	2	11			*		CUBA	SANTIAGO D	19.9	-76		2		
1802	8	15			*		VENEZUELA	CUMANA	10.48	-64.2		1		
1823	11	30			*		MARTINIQUE	SAINT PIERR	14.4	-61		1		
1842	5	7			7.7		HAITI	CAP-HAITIA	19.75	-72.2	5	8	300	3
1843	2	8	14	50	8.3		GUADELOUPE	POINTE-A-P	16.5	-62.2	1.2	1	12	1
1853	7	15			6.7		VENEZUELA	CUMANA	10.5	-64.2		4	113	3
1856	8	9			7.5		HONDURAS	OMOA	15.75	-88.17	5	5		
1860	4	8			7.5		HAITI	ANSE-A-VEA	18.52	-73.35		4		
1867	11	18	18	45	7.5		USA TERRITORY	VIRGIN ISLA	18.1	-65.1	10	33	30	1
1868	3	17	11	37	*		USA TERRITORY	VIRGIN ISLA	18.1	-65.1	1.5	5		
1882	9	7	7	50	7.9		PANAMA	SAN BLAS AI	9.5	-78.9	3	4	100	2
1887	9	23	12		*		HAITI	MOLE SAINT	19.7	-74.4		4		
1900	10	29			8.4		VENEZUELA	MANCUTO	11.2	-66.5	10	4		
1902	5	5					MARTINIQUE	MONT PELEE	14.82	-61.17	5	1		
1902	5	7				Vol	SAINT VINCENT AND TH	SOUFRIERE	13.33	-61.18		3	1565	3
1902	8	30					MARTINIQUE	MOUNT PEL	14.82	-61.17	1	1		

Tsunami Runups in the Caribbian

Country (year of first confirmed report)	# Events with any observed runup	# Events with measured max runup 0.01<0.5m	# Events with measured max runup 0.5<1.0m	# Events with measured max runup 1.0<3.0m	# Events with measured max runup >3.0m	Total # of observa-tions	# Reported Deaths
Caribbean							
Antigua & Barbuda (1755)	6	2		2	1	8	
Barbados (1755)	5	1	1	1		5	
British Virgin Islands (1867)	3	1	1	1		5	
Costa Rica (1991)	1			1		10	2
Cuba (1755)	3					7	
Dominica (1755)	4	1		1	1	4	
Dominican Republic (1755)	5		1	1	2	10	1865
Grenada (1867)	2		1	1		3	
Guadeloupe (1867)	7	2	3		1	21	
Haiti (1755)	6				1	18	300
Honduras (1856)	1				1	5	
Jamaica (1692)	2			2		14	2000
Martinique (1755)	7		1	1	1	7	100
Montserrat (1997)	4			2	1	4	
Netherlands Antilles (1755)	2				1	2	
Panama (1882)	4			3		18	100
Puerto Rico (1867)	9	3	2	2	1	33	142
Saint Kitts & Nevis (1690)	2					2	
Saint Lucia (1867)	2		2			2	
Saint Martin (1755)	1				1	1	
Saint Vincent & the Grenadines (1755)	3		1	1	1	4	
Trindad & Tobago (1911)	2					2	
US Virgin Islands (1690)	7	1	1	1	2	15	30
Venezuela (1530)	6				3	23	113
Caribbean Totals	94	11	14	20	18	224	4652

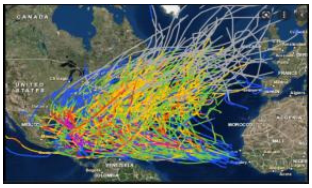




Courtesy of Paula Dunbar, 2007

Courtesy of Paula Dunbar, 2007

Historical Storm Surges (Huracane) in the Caribian



- GALVESTON 1900
- ATLANTIC-GULF 1919
- MIAMI 1926
- SAN FELIPE-OKEECHOBEE 1928
- FLORIDA KEYS LABOR DAY 1935
- NEW ENGLAND 1938
- GREAT ATLANTIC 1944
- CAROL AND EDNA 1954
- HAZEL 1954
- CONNIE AND DIANE 1955
- AUDREY 1957
- DONNA 1960
- CAMILLE 1969
- AGNES 1972
- TROPICAL STORM CLAUDETTE 1979
- ALICIA 1983
- GILBERT 1988
- HUGO 1989
- ANDREW 1992
- TROPICAL STORM ALBERTO 1994
- OPAL 1995
- MITCH 1998
- FLOYD 1999
- KEITH 2000
- TROPICAL STORM ALLISON 2001
- IRIS 2001
- ISABEL 2003
- CHARLEY 2004
- FRANCES 2004
- IVAN 2004
- JEANNE 2004
- DENNIS 2005
- KATRINA 2005
- RITA 2005
- WILMA 2005
- IKE 2008

1. Introduction

Indonesia is an archipelago:
Consist of 17,480 islands
- Inhabitant : 6000 islands
- 7.870 islands have a **name**,
- 9.634 island have not a **name**.

coastline length : 95,181 km
extends : N-S (6^0N-11^0S) = 4,400 km
W-E (97^0E-114^0E) = 7,700km

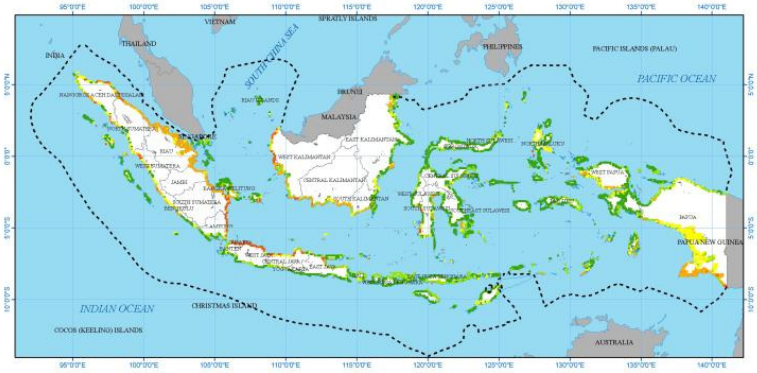
Wide scale:
5.8 million km² of marine area :
- 0.8 million km² of territorial sea,
- 2.3 million km² of archipelagic sea
- 2.7 million km² of the EEZ

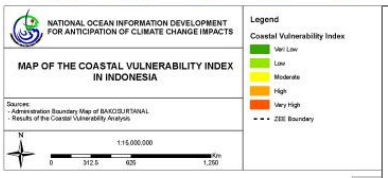
Three Time zone

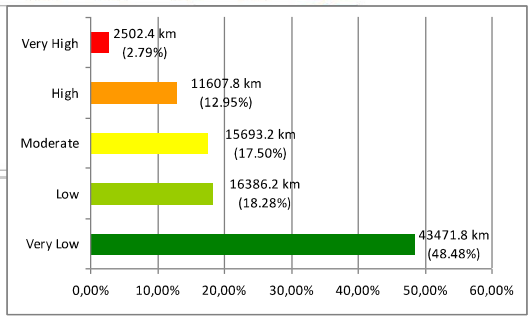
Population: 272.229.372 people,
- Male :137.521.557
- Female : 134.707.815
- 95.9% (0-100km from the coast
- productive age (15-64)=70.72%

Republic of Indonesia consist of :
- 35 provinces,
- 403 districts and 98 cities
- 6,493 sub-districts
- 76,655 villages

Coastal Vulnerability Index to SLR

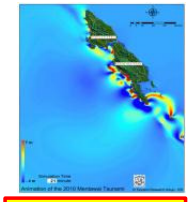




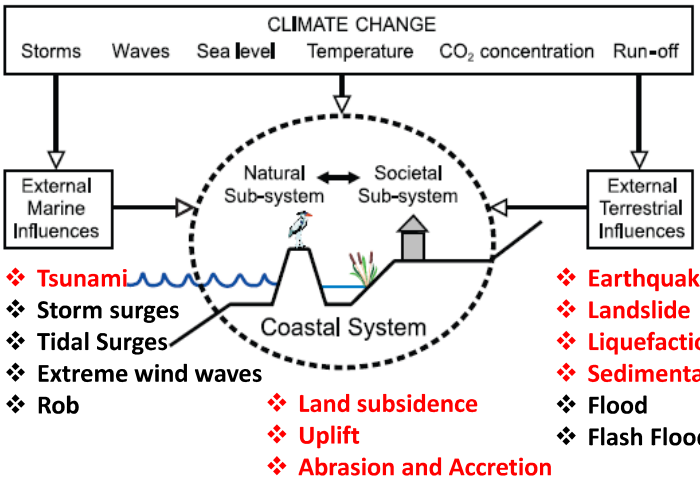


Percentage of Indonesian coastline condition for each vulnerability level

Coastal Area and Coastal hazards (multi hazards)



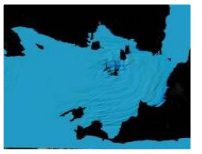
- Earthquake
- Volcano
- Landslide

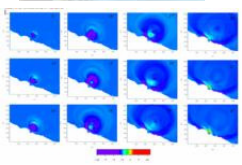


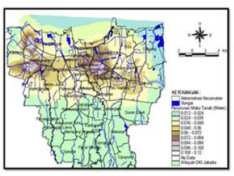
- Tsunami
- Storm surges
- Tidal Surges
- Extreme wind waves
- Rob

- Land subsidence
- Uplift
- Abrasion and Accretion

- Earthquake
- Landslide
- Liquefaction
- Sedimentation
- Flood
- Flash Flood







2. Tsunami : Developing Better Information for Tsunami Hazard Assessment in Indonesia

- **2. 1.** Tsunami Evidence
- 2.2. Tectonic Setting, History of Tsunami
- 2.3. level of tsunami hazard in Indonesia (DTHA,PTHA)
- 2.4. Tsunami Modeling
  - Modelling of The 2004 Aceh Tsunami
  - Role of vegetation to reduce tsunami
  - Modelling of tsunami inundation in Padang City by considering spatial variation of MANNING Roughness Coefficients
  - Landslide Tsunami Modeling : Krakatau 2018 and Palu 2018
  - Hypothetic Tsunami at MotoGP Mandalika Circuit
- 2.5. Risk Assessment and Mitigation

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2.1. Evidence of Tsunami Events and the Impact

- Tsunami marks on the ground/houses/trees will disappear after many years
- However, there is still some evidence that is existed and contains scientific information such as:
  - Sand sedimentation carried by the tsunami resulted in a tsunami layer
  - Rocks moved by tsunami
  - Uplift of live coral

Paleo-Tsunami Sediment deposit

Damaged due to the 1883 Krakatau Volcano Tsunami

Tsunami Blocks and tsunami swept the boat

Impact of Tsunami The 2004 Aceh, Indonesia

Gambar 2.13 Rumah pasangan bata di pantai yang rusak di Devanaanpattinam, India oleh Tsunami Aceh 2004 (FEMA P646, 2008).

Gambar 2.16 Contoh puing yang terbawa oleh air dari Tsunami Aceh 2004 (Foto: Antara).

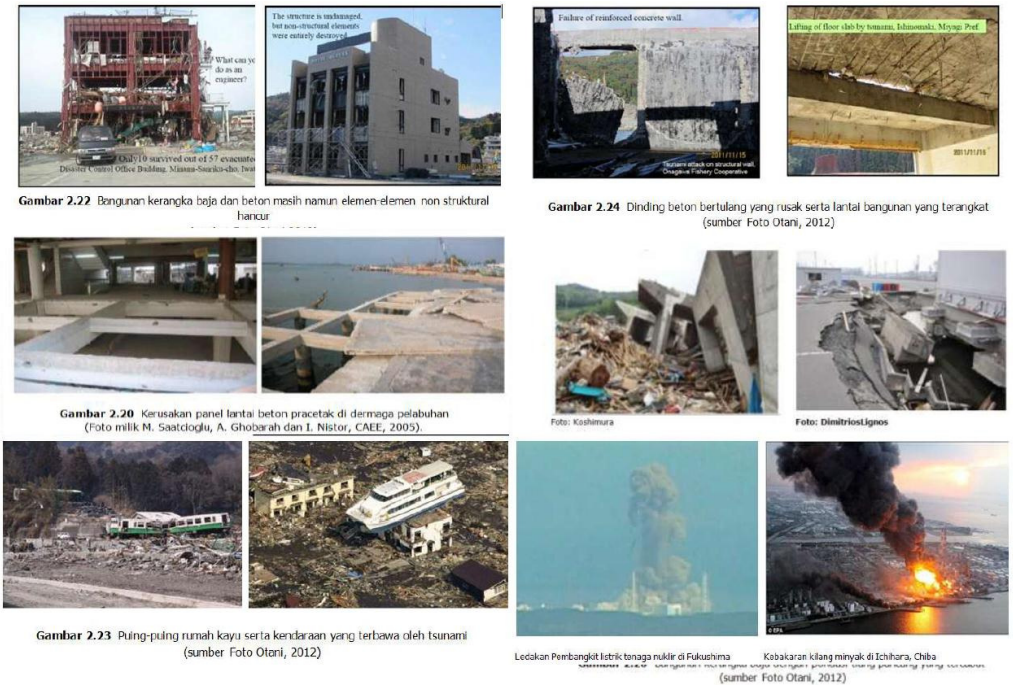
Gambar 2.14 Contoh bangunanbeton bertulang yang bertahan di Banda Aceh

Gambar 2.17 Kerusakan kolom beton yang tidak direkayasa dengan baik akibat hantaman puing-puing

Gambar 2.15 Contoh bangunan mesjid yang bertahan di Banda Aceh kerena dindingnya cukup terbuka

18 Kerusakan kolom sudut akibat pembendungan pui

Impact of Tsunami The 2011 Tohoku Tsunami, Japan



Gambar 2.22 Bangunan kerangka baja dan beton masih namun elemen-elemen non struktural hancur

Gambar 2.24 Dinding beton bertulang yang rusak serta lantai bangunan yang terangkat (sumber Foto Otani, 2012)

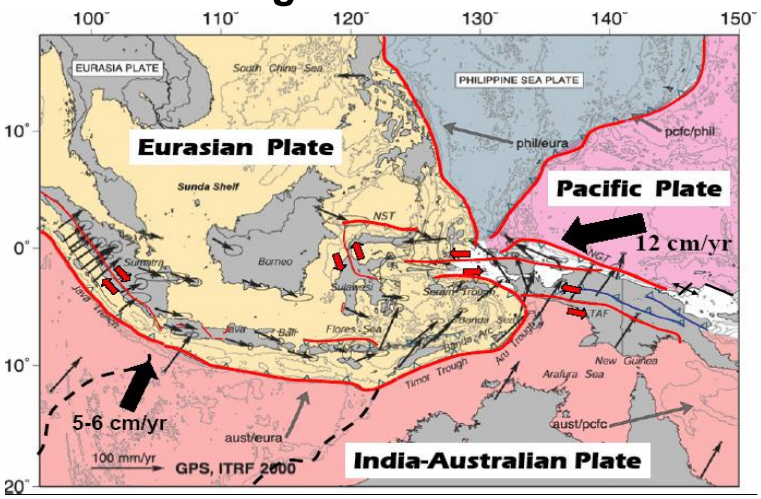
Gambar 2.20 Kerusakan panel lantai beton pracetak di dermaga pelabuhan (Foto milik M. Saatcioglu, A. Ghobarah dan I. Nistor, CAEE, 2005).

Gambar 2.23 Puing-puing rumah kayu serta kendaraan yang terbawa oleh tsunami (sumber Foto Otani, 2012)

(sumber Foto Otani, 2012)

2.2. Tectonic Setting, History of Tsunami and level of tsunami hazard in Indonesia (DTHA and PTHA)

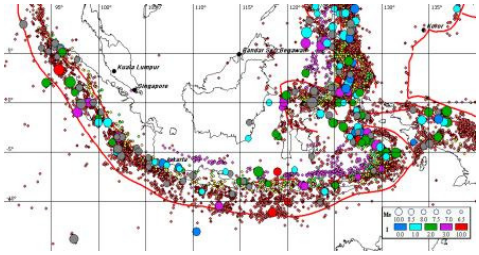
Tectonic Setting

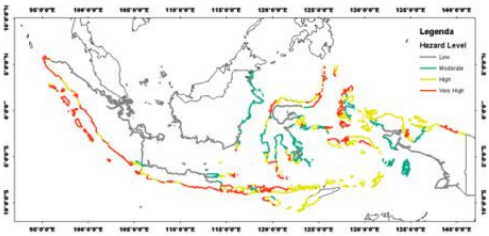


ACTIVE TECTONICS of INDONESIA: Crustal motions from GPS study (Bock et al, 2004)

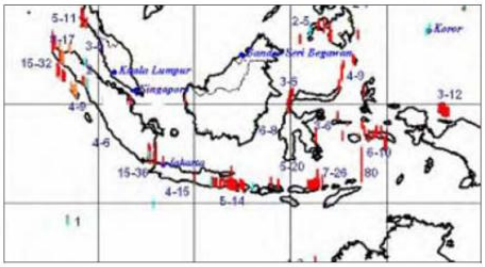
DHN,2007

History of Tsunami in Indonesia

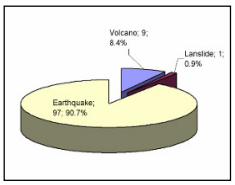




Gambar 2. 15 Level bahaya tsunami di sepanjang garis pantai berdasarkan basis data tsunami Indonesia (Latief dan Haris, 2009)



Gambar 2.14 Tinggi tsunami di sepanjang garis pantai berdasarkan data historis (Latief dan Hadi, 2007)



1600-2010,
128 tsunami

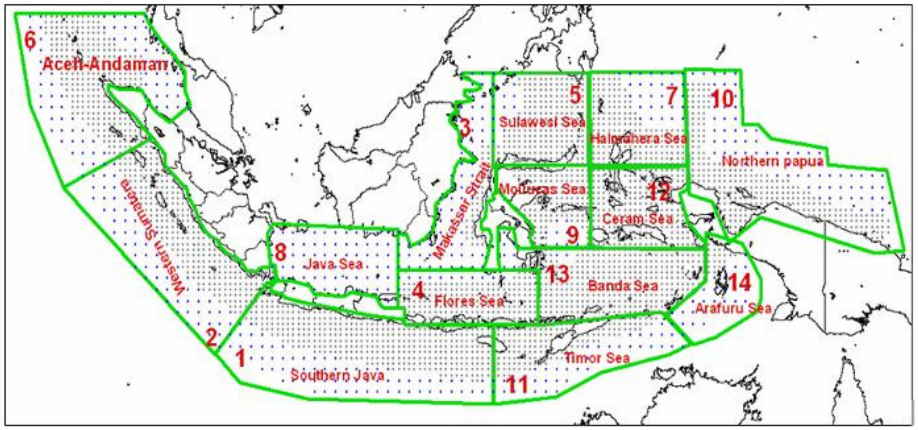
The recent large tsunamis in this area are:

- the 1992 Flores Tsunami (Indonesia) : 1,950 people,
- the 1994 East Java Tsunami (Indonesia) : 238 people,
- the 1994 Mindoro Tsunami (Philippine) : 78 people,
- the 1996 Irian Jaya Tsunami (Indonesia) : 110 people.
- the 1998 PNG Tsunami (PNG) : 3000 people
- the 2004 Indian Ocean Tsunami : 283.000 people
- the 2006 West Java Tsunami (Indonesia) : 600 people
- The 2010 Mentawai Tsunami (indonesia): 400 people

Deterministic Tsunami Hazard Assessment (DTHA)

Hypothetic tsunami sources distribution for whole Indonesian region (gray dot with interval 20 arc minutes and blue dot with interval 40 arc minutes) for pre-calculated tsunami data base in order to perform Indonesian TEWS

Total simulations = 220.000 sets



Latief dan Haris, 2009

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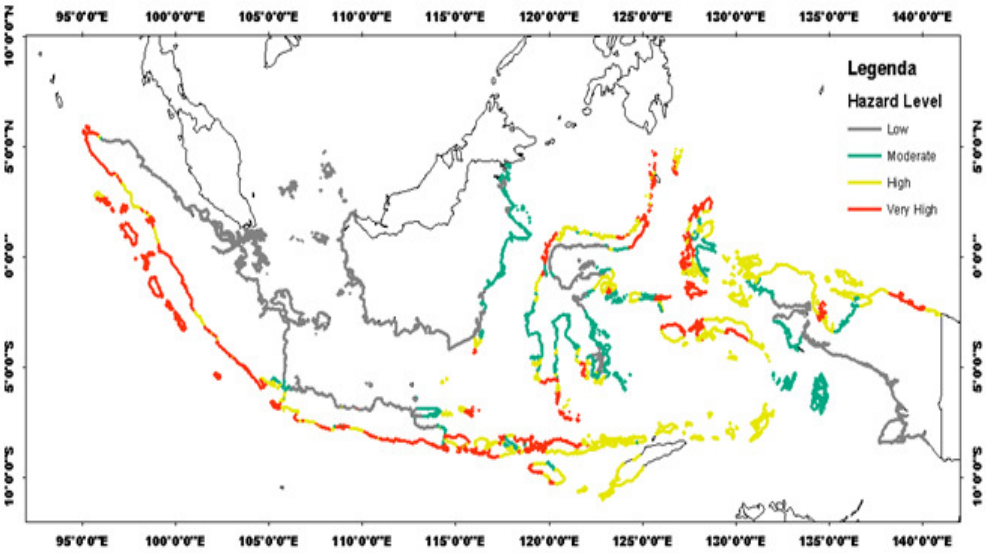
Map of level Tsunami Hazard along the coast in Indonesia from DTHA Results



(Latief dan Haris, 2009)

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Level of Potential Tsunami hazard at Coastal Cities

NO	KODE	NAMA	KABUPATEN/KOTA	PROVINSI	ORDE	BUJUR	LINTANG	HMAX (meter)	TMAX (menit)	LEVEL_RISK
1	1101	Sinabang	Simeuleu	NAD	2	96.365	2.483	13.8	15	VERY HIGH
2	1102	Singkil	Aceh Singkil	NAD	2	97.788	2.280	5.3	20	HIGH
3	1103	Tapaktuan	Aceh Selatan	NAD	2	97.180	3.258	7.6	20	HIGH
4	1107	Meulaboh	Aceh Barat	NAD	2	96.123	4.143	10.6	15	VERY HIGH
5	1109	Sigli	Pidie	NAD	2	95.960	5.385	4.4	15	HIGH
6	1109	Meureudu	Pidie Jaya	NAD	2	96.260	5.247	0.5	15	LOW
7	1110	Bireuen	Bireun	NAD	2	96.704	5.203	0.5	15	LOW
8	1111	Lhokseumawe	Aceh Utara	NAD	2	97.384	5.126	0.5	15	LOW
9	1112	Blangpidie	Aceh Barat Daya	NAD	2	96.835	3.739	7.4	15	HIGH
10	1116	Calang								
11	1171	Banda Aceh								
12	1172	Sabang								
13	1174	Lhokseumaw								
14	1201	Gunungsitol								
15	1204	Sibolga								
16	1214	Telukdalam								
17	1271	Sibolga								
18	1302	Painan								
19	1371	Padang								
20	1377	Pariaman								

NO	KODE	NAMA	KABUPATEN/KOTA	PROVINSI	ORDE	BUJUR	LINTANG	HMAX (meter)	TMAX (menit)	LEVEL_RISK
21	1701	Manna	Bengkulu Selatan	Bengkulu	2	102.906	-4.470	9.9	20	VERY HIGH
22	1704	Kaur	Kaur	Bengkulu	2	103.376	-4.793	11.0	13	VERY HIGH
23	1705	Seluma	Seluma	Bengkulu	2	102.520	-4.140	11.1	24	VERY HIGH
24	1706	Mukomuko	Muko-muko	Bengkulu	2	101.123	-2.582	7.2	15	HIGH
25	1771	Bengkulu	Kota Bengkulu	Bengkulu	1	102.263	-3.793	7.4	20	HIGH
26	1802	Kota Agung	Tanggamus	Lampung	2	104.603	-5.483	4.3	51	HIGH
27	1803	Kalianda	Lampung Selatan	Lampung	2	105.590	-5.743	3.7	56	MODERATE
28	1871	Bandar Lampung	Kota Bandar Lampung	Lampung	1	105.266	-5.429	1.5	91	MODERATE
29	3173	Jakarta	Kota Jakarta Pusat	DKI Jak	1	106.829	-6.173	0.1	164	LOW
30	3175	Kapuk	Kota Jakarta Utara	DKI Jak	2	106.761	-6.125	0.1	128	LOW
31	3175	Tanjungpriok	Kota Jakarta Utara	DKI Jak	2	106.870	-6.119	0.1	164	LOW
32	3202	Pelabuhanratu	Sukaburni	Jabar	2	106.547	-6.987	5.7	27	HIGH
33	3301	Cilacap	Cilacap	Jateng	2	109.004	-7.721	10.1	29	VERY HIGH
34	3501	Pacitan	Pacitan	Jatim	2	111.105	-8.201	10.3	29	VERY HIGH
35	3510	Banyuwangi	Banyuwangi	Jatim	2	114.369	-8.211	4.6	59	HIGH
36	3527	Sampang	Sampang	Jatim	2	113.250	-7.195	2.7	115	MODERATE
37	3528	Pamekasan	Pamekasan	Jatim	2	113.483	-7.162	2.4	99	MODERATE
38	3529	Sumenep	Sumenep	Jatim	2	113.860	-7.009	1.3	60	MODERATE
39	3672	Cilegon	Kota Cilegon	Banten	2	106.053	-6.015	4.4	141	MODERATE
40	5101	Negara	Jembrana	Bali	2	114.621	-8.359	5.5	37	HIGH
41	5102	Tabanan	Tabanan	Bali	2	115.125	-8.538	7.7	40	HIGH
42	5104	Gianyar	Gianyar	Bali	2	115.327	-8.542	9.5	41	VERY HIGH

58	5310	Maumere	Sikka	NTT	2	122.221	-8.625	6.4	5	HIGH
59	5311	Ende	Ende	NTT	2	121.643	-8.846	5.0	5	HIGH
60	5314	Baa	Rote Ndao	NTT	2	123.097	-10.684	5.6	48	HIGH
61	5315	Labuhan Bajo	Manggarai Barat	NTT	2	119.883	-8.488	18.7	12	VERY HIGH
62	5317	Bondowatu	Sumba Barat Daya	NTT	2	118.998	-9.596	9.2	22	VERY HIGH
63	5371	Kupang	Kota Kupang	NTT	1	123.584	-10.168	5.7	68	HIGH
64	6302	Kotabaru	Kota Baru	Kalsel	2	116.249	-3.217	0.8	60	LOW

HMAX (meter)	TMAX (menit)	LEVEL_RISK
5.4	38	HIGH
6.1	30	HIGH
8.1	20	VERY HIGH
9.3	37	VERY HIGH
6.6	20	HIGH
11.4	5	VERY HIGH
1.2	59	MODERATE
8.0	39	VERY HIGH
6.3	27	HIGH
1.2	59	MODERATE
3.8	69	MODERATE
5.4	82	HIGH
5.6	35	HIGH
4.4	18	HIGH
4.6	18	HIGH

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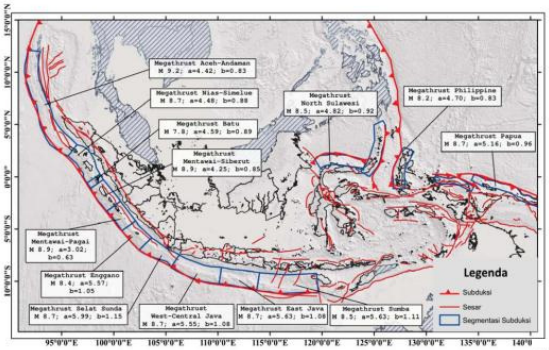
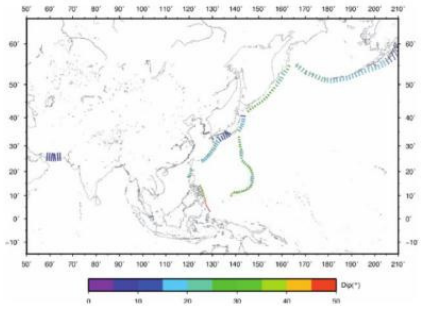
Bandung Institute of Technology, Tel/fax: 6 - 22 - 2504 - 4
Jalan Ganesha 10 Bandung 40

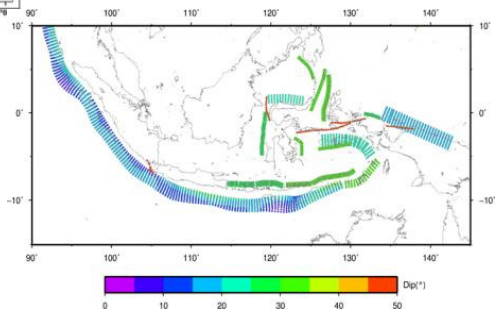
PTHA (Probabilistic Tsunami Hazard Assessment)

Segmentasi Megathrust Peta Gempa Nasional 2017





Location of far field faults that were used in the PTHA.

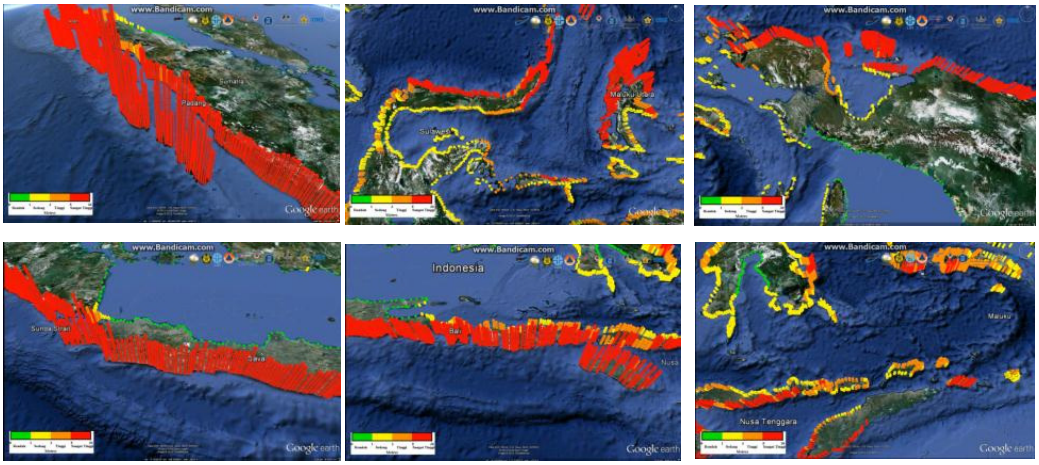


Location of local (near field) faults that were used in the PTHA.

A National Tsunami Hazard Assessment for Indonesia

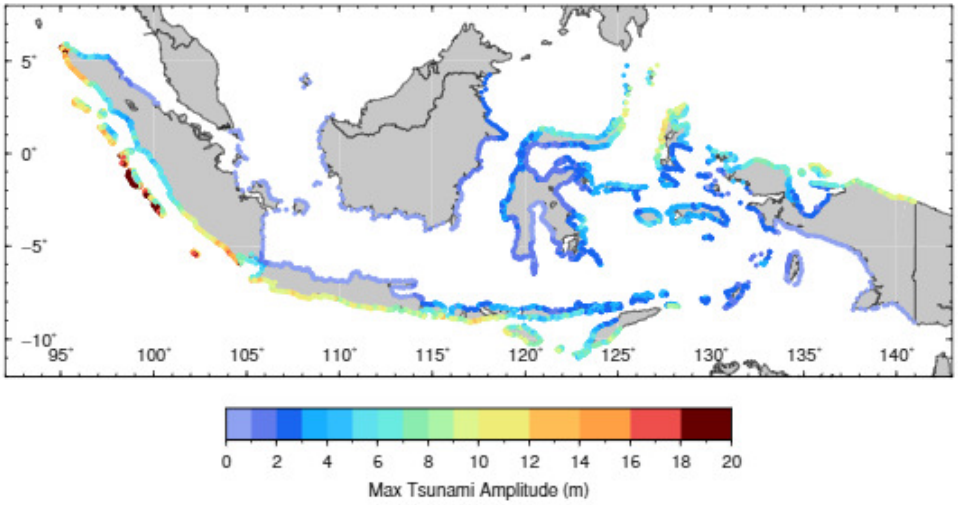
Nick Horspool[1#], Ignatius Ryan Pranantyo[2], Jonathan Griffin[3], Hamzah Latief[2], Danny Natawidjaja[4], Widjo Kongko[5], Athanasius Cipta[6], Bustamam[7], Suci Dewi Anugrah[8] and Hong Kie Thio[9]

PTHA with 500 year return periods

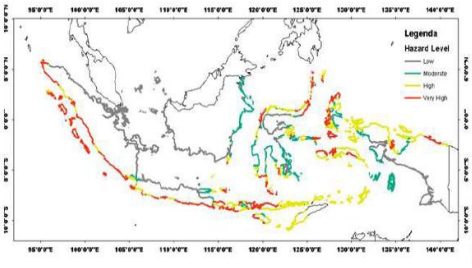


Horspool et al (2014)

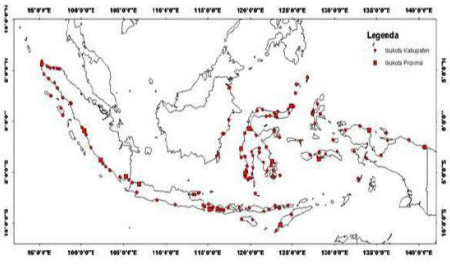
Tsunami Hazard Map showing maximum Tsunami Amplitude at the coast 500 year return period



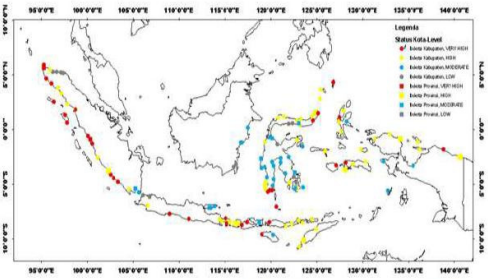
Cities and regions in Indonesia that Faced Tsunami Hazard



Level of tsunami hazard along the Indonesian shoreline base on Deterministic Tsunami Hazard Analysis (Latief and Haris, 2009)



Location of capital city of coastal districts in Indonesia (Latief and Haris, 2009)



Level of tsunami hazard of coastal districts in Indonesia (Latief and Haris, 2009)

146 Ditrict cities faced to tsunami hazard:

-Very high (H>8m) = 36 cities
- High (8m>H>4 m) = 57 cities
-Moderate (4m>H>1m) = 37 cities
- Low (H < 1m) = 16 cities

16 Provincial Cities faced to tsunami hazard:

-Very High: Banda Aceh, Padang, Denpasar, Ternate
-High : Mataram, Kupang, Manado, Ambon ,Manokwari and Jayapura
-Moderate: Lampung, Palu, Makassar, Kendari, and Mamuju
- Low: Jakarta

2.4. Tsunami Modeling:

- Modelling of The 2004 Aceh Tsunami
- Role of vegetation to reduce tsunami
- Modelling of tsunami inundation in Padang City by considering DEM
- Modeling of Tsunami Krakatau 2018 (Volc and LS)

4. The 2004 Indian Ocean Tsunami Model

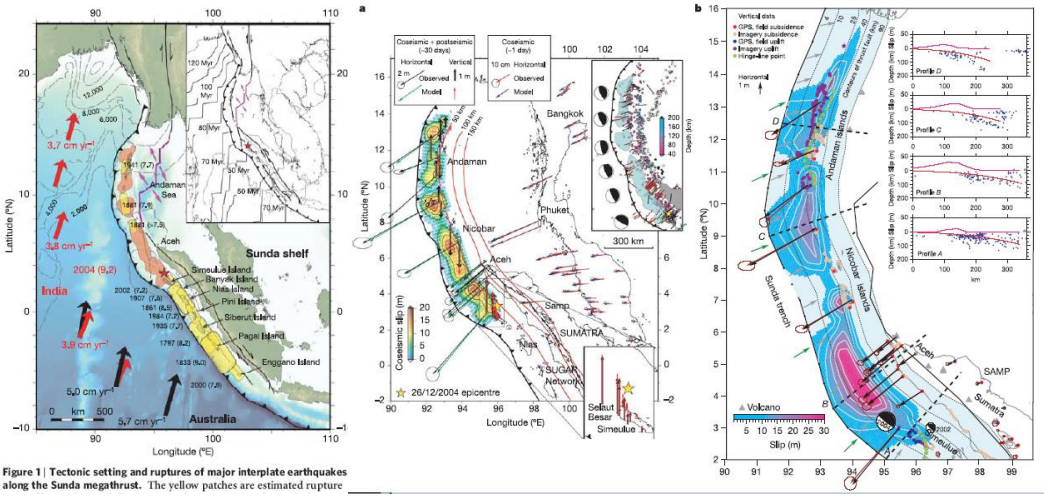
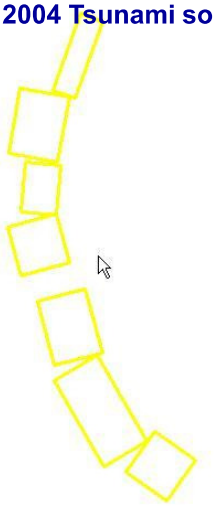


Figure 1 | Tectonic setting and ruptures of major interplate earthquakes along the Sunda megathrust. The yellow patches are estimated rupture

Fault slip distribution, sieh et, al, 2006

The 2004 Tsunami source



Slip distributions map, Subarya, et al, 2006

Scenario name aceh7

Subfault parameters from dany's GPS analysis

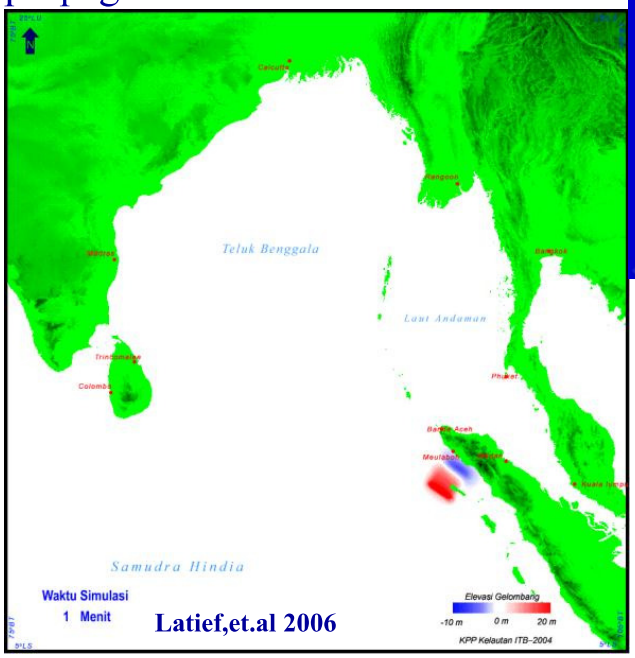
Subfault	Length (km)	Witdth (km)	Longitude	Latitude
F1	150	150	95.89	2.14
F2	300	150	94.17	3.07
F3	200	150	92.83	5.8
F4	150	150	91.92	8.25
F5	150	107	91.92	9.97
F6	200	150	91.58	11.54
F7	240	70	92.79	13.26

Depth (km)	Strike (deg)	Dip (deg)	Rake (deg)	Slip m	0.9 V=0.9km/S T=L/V SEG_TIME (s)
10	305	12	80	12	0
10	330	13	105	29	167
10	345	14	105	27	500
10	345	15	105	26	722
10	5	16	125	17	889
10	10	17	130	12	1056
10	20	17.5	135	8	1278

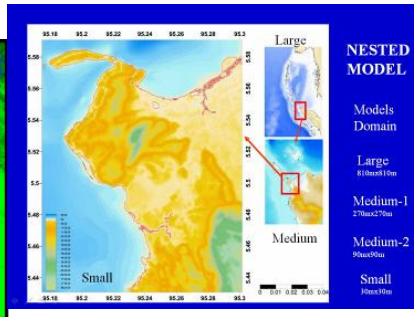
Latief,2006

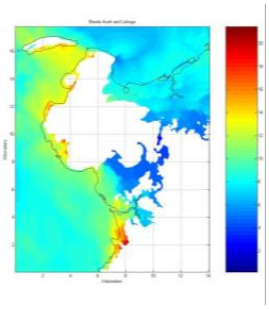
Slip Distribution and sub-faults design for tsunami sources

Tsunami animation including rupture propagation for tsunami source

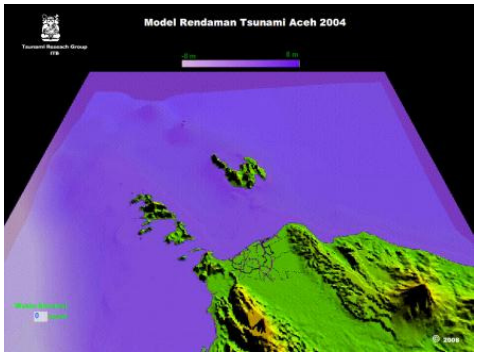


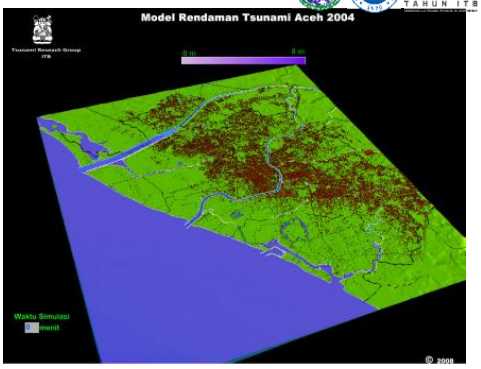
Latief,et.al 2006

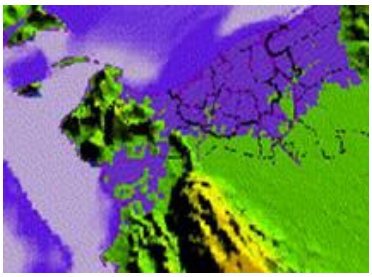


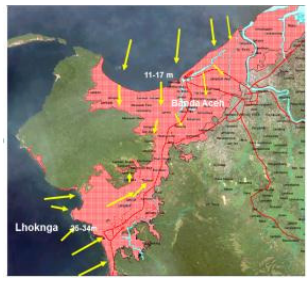


Tsunami inundation model at Banda Aceh and Loknga



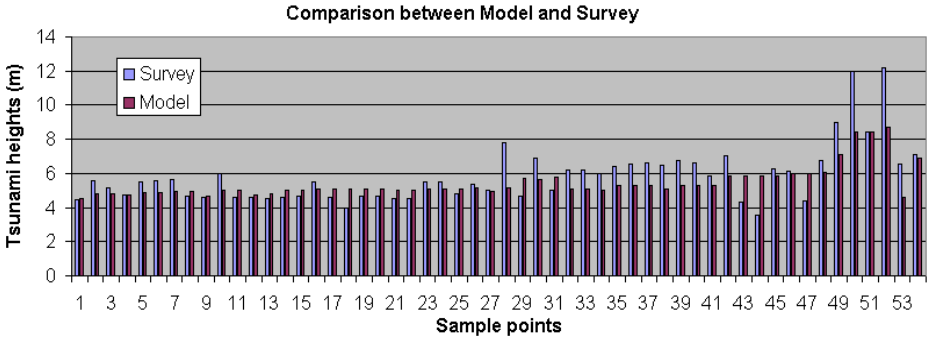






29

Field survey points measured of The 2004 Tsunami in Banda Aceh city by ITST (International Tsunami Survey Team-2005)



Role of Vegetation to reduce tsunami

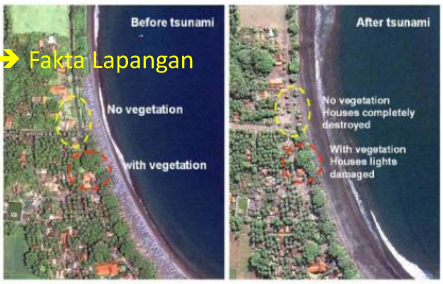


Plate 1.5 Ikonos imagery before and after the 2006 West Java tsunami shows how vegetation reduced tsunami impact at Pangandaran Beach (source: CRPS www.crips.nus.edu.sg)

Damaged houses struck by a 3–4-m-high tsunami; some of the houses behind the coastal forest were saved (Sirambu, West Nias)

Plate 1.4 Coastal forest (approximately 50 m wide) diminished a 6-m-high tsunami to 1.6 m in Cikalong, West Java

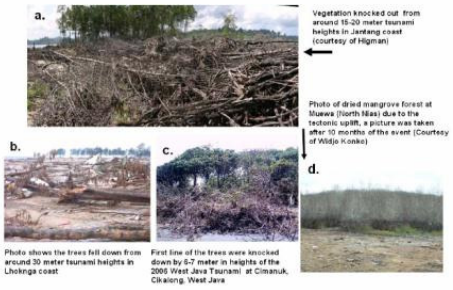


Plate 1.7a–d.Tsunami and earthquake impact on coastal vegetation

Effectiveness of Vegetation to Reduce Tsunamis

There are opinions about the effectiveness and ineffectiveness of forest → Shuto (1987):

- Effective because:
  - It stops driftwood and other floatages
  - It reduced water flow velocity and inundation water depth
  - It provides a live-saving means by catching persons carried out off by tsunami
  - It collect wind blown sands and rises dunes, which act as a natural barrier against tsunamis

- A represent negative opinion is that:
  - A forest may be ineffective against a huge tsunami, and at worst, tress themselves could become destructive forces to house, if cut down by tsunami

D= 10 cm → H=4.65m
D= 34.3 cm → H=7m
D =100 cm → 10 m

H = 3m → L =20m
H= 6 m → L 100 m

Tsunami with H = 8 meter
The vegetation do not effective to reduce tsunami

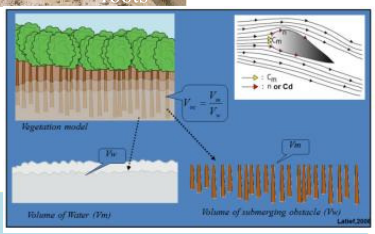
For detail → have to do hydraulics experiment

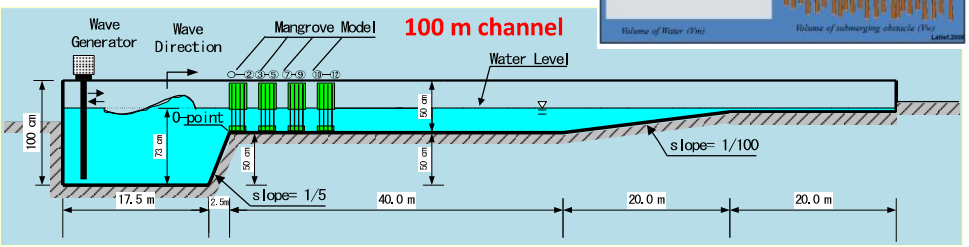
Hydraulics experiment

Latief (2000) : proposed formulas of Manning coefficient (*n*) and Impact force (Cm) as function of volumetric occupancy of flows trough vegetation

$$n = \begin{cases} 0.016 + 0.17V_{oc} & \text{If} \quad V_{oc} > 0.07 \\ 0.03 & \text{If} \quad V_{oc} < 0.07 \end{cases}$$

$$C_M V_{oc} = \begin{cases} 0.67 + 6.65V_{oc} & \text{If} \quad V_{oc} > 0.06 \\ 1 & \text{If} \quad V_{oc} < 0.06 \end{cases}$$





Set-up of hydraulics experiment in the open channel and location of models

Application of Greenbelt into the Numerical Model

Governing equation (include impact force)

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0$$

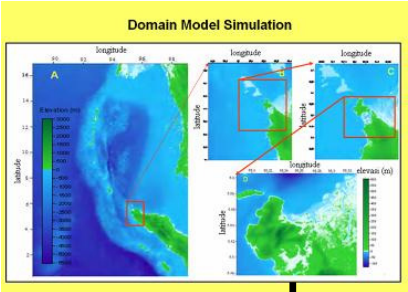
$$(1 + C_M V_{oc})\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}} M\sqrt{M^2 + N^2} = 0$$

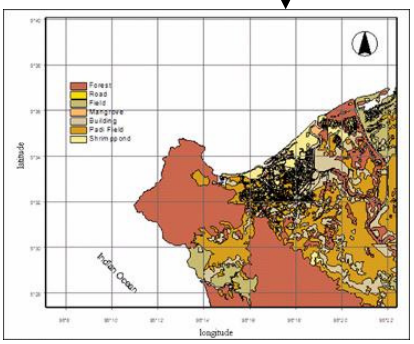
$$(1 + C_M V_{oc})\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} + \frac{gn^2}{D^{7/3}} N\sqrt{M^2 + N^2} = 0$$

Where:

$$V_{oc} = \frac{V_m}{V_w}$$

V_{oc} is volume occupied
V_m is the model volume
V_w is the water volume





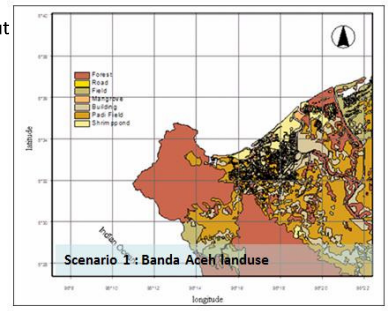
Manning and impact force coeff.

Class	Landuse	Manning Coefficient (n)	Impact Force(Cm)
0	sea	0.025	1
1	Forest	0.15	2.3
2	Mangrove	0.06	2.3
3	rice field	0.025	1
4	shrimp pond	0.025	1
5	road	0.016	1
6	field	0.035	1
7	building	0.15	3

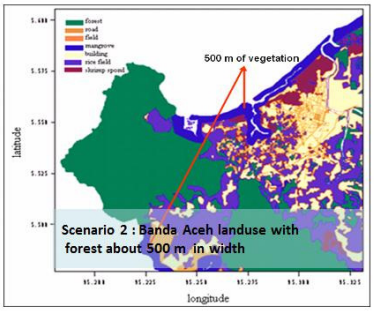
Online Training Course on
Disaster Risk Reduction and Climate Change Adaptation
for CARICOM and SICA Member Countries

Simulation Scenarios with Intervention by Coastal Forest, Rivergate, and Embankment

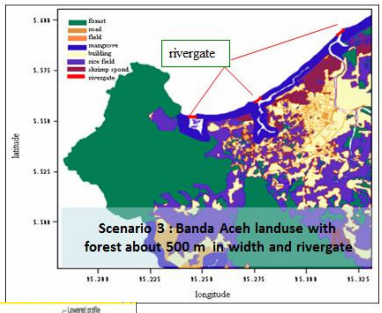
S-1 initial condition without intervention

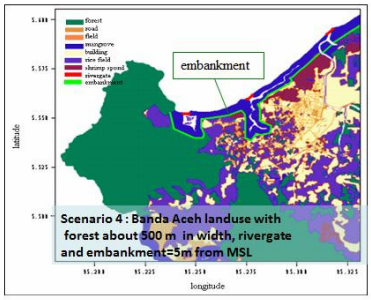


S-2 Coastal forest (500m)



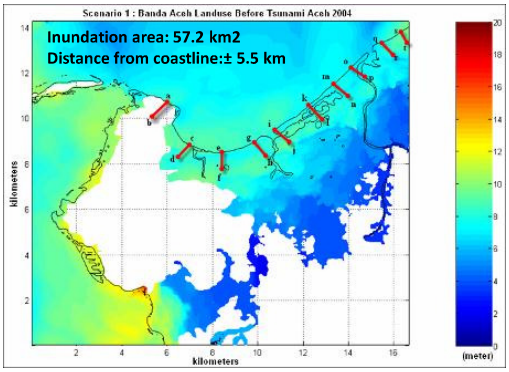
S-3 coastal forest (500m) with river-gate

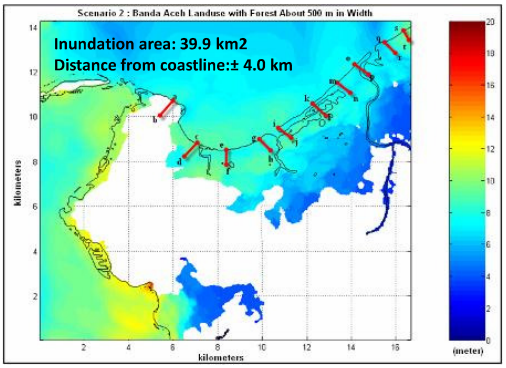


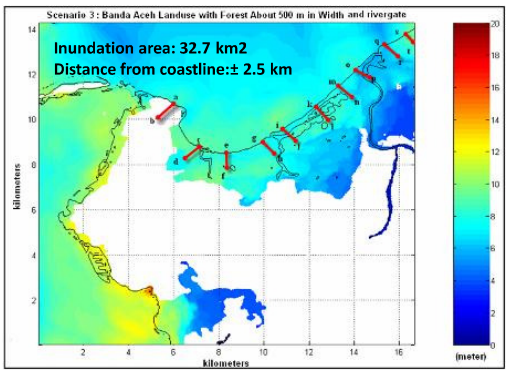


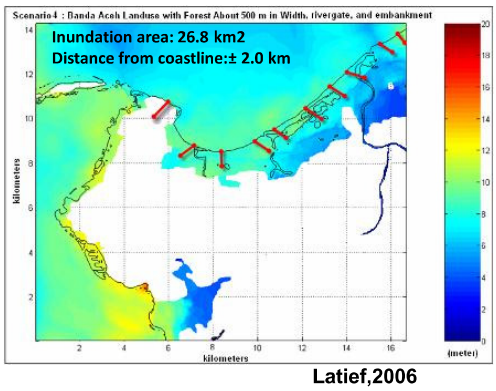
S- 4 coastal forest (500m) with river-gate and embankment (5 m)

Latief dkk (2006)





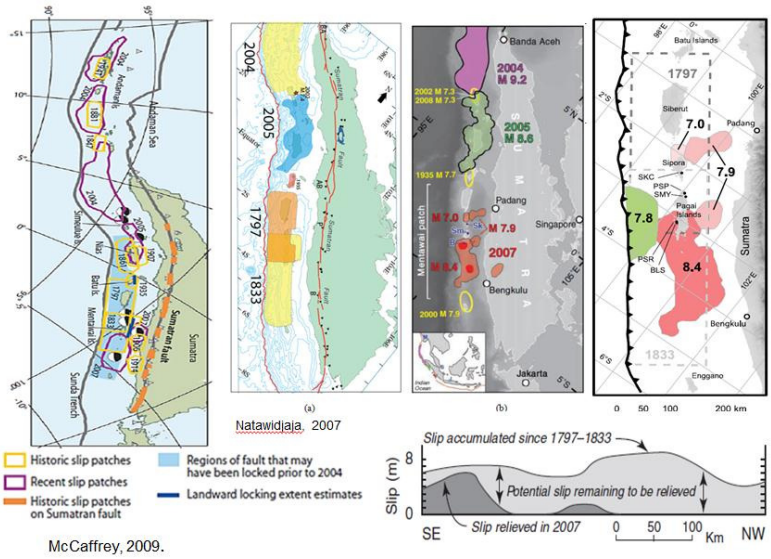




Latief,2006

Modelling of tsunami inundation in Padang City by considering spatial variation of MANNING Roughness Coefficients

Tsunami source at Padang City



Natawidjaja, 2007

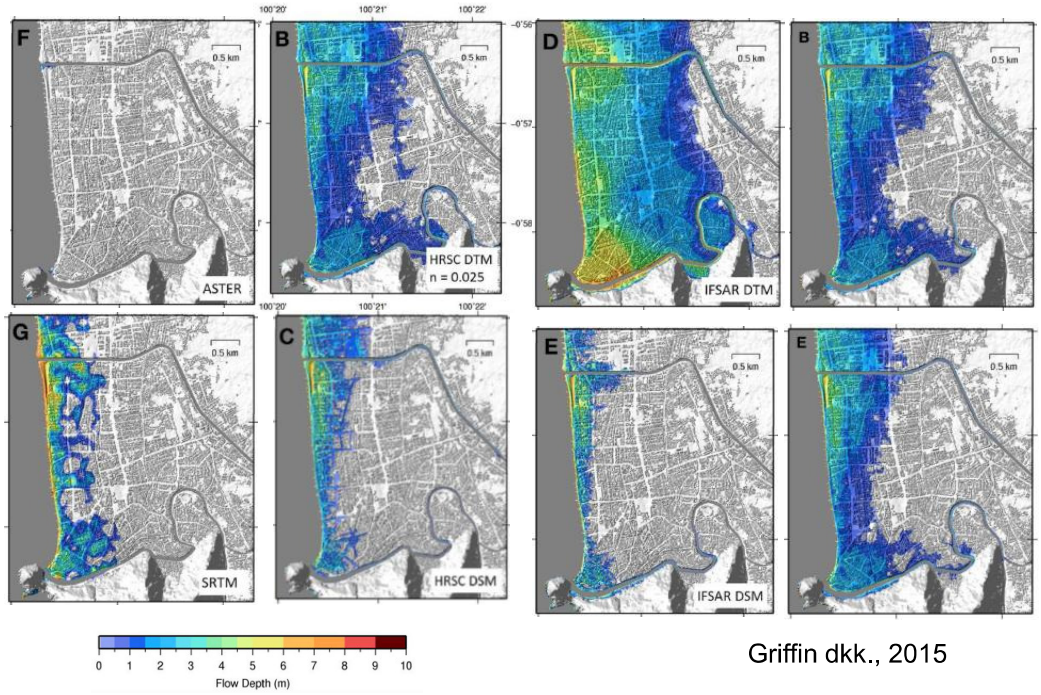
McCaffrey, 2009.

Evaluate DEM (DTM and DSM) data

	Method	Horizontal resolution	Vertical accuracy	Advantages	Disadvantages
LiDAR	Laser pulse	0.5–2 m	0.15 m	Most accurate DEM DTM and DSM	Expensive, can only fly in dry season Large data volumes provide challenges for storage and processing
High resolution stereoscopic camera	Stereocamera	0.3 m	0.5 m	High resolution and accuracy Cheaper than LiDAR DTM and DSM	Still expensive New technique without commerical providers in study regions
Airborne IFSAR	IFSAR	5 m	1–3 m	Reasonable vertical accuracy Lower cost than LiDAR DTM and DSM	Less accurate in steep and densely vegetated areas
SRTM 90 m	IFSAR	90 m	5.6–9.0 m (absolute) 4.7–9.8 m (relative)	Almost worldwide coverage Free	DSM only Low vertical accuracy
Aster	Stereocamera	30 m	6–15 m (absolute)	Covers 99% globe Free Accuracy less affected by steep topography than other methods	DSM only Cloud cover problems Low vertical accuracy

See text for references.

Inundation Maps with different DEM



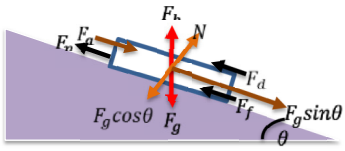
Griffin dkk., 2015

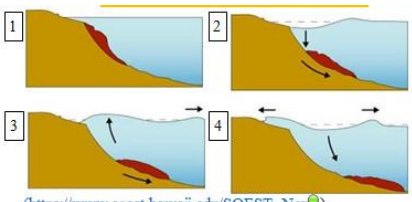
Conclusion and recommendation

- Airborne **IFSAR is sufficiently accurate to model the extent** of tsunami inundation compare to higher resolution of LiDAR datasets.
- The IFSAR dataset compares with historical run-up observations (in Maumere Case). This does not mean all inundation parameters are reproduced accurately and we do not recommend to use of this data for detailed engineering purposes.
- SRTM data do not represent the morphology of the coastline accurately and therefore should not be used to model tsunami inundation at all – results can be misleading and potentially more damaging than no information at all!
- Tsunami inundation models are less sensitive to mesh resolution and resolutions of 25 m are likely to be sufficient for calculating inundation extent, depending on the exact morphology of the coastline.
- Differences between DTMs and DSMs are large and further research is needed to identify which should be used, and how and at **what scale roughness should be parameterised.**

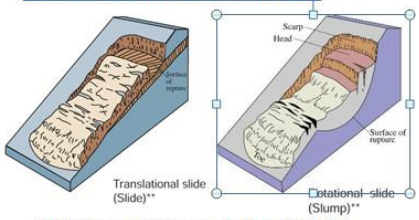
Landslide Tsunami Modelling

- Case study:
  - Tsunami Krakatau 2018
  - Tsunami Palu 2018





(https://www.soest.hawaii.edu/SOEST_News)



(https://www.thoughtco.com/geology-4133564)

Persamaan 1

$$m_b \frac{d^2s}{dt^2} = F_a + F_g + F_b + F_n + F_f + F_d$$

Persamaan 2

$$(m_b + C_m m_w)\frac{d^2s}{dt^2} = m_b g sin\theta - m_w g sin\theta - (m_b - m_w) g C_n cos\theta - \frac{C_f \mu_0 A}{h_0}\frac{ds}{dt} - 0.5\, C_d \rho_w A \left(\frac{ds}{dt}\right)^2$$

Persamaan 3

$$(m_b + C_m m_w)\frac{d^2s}{dt^2} = (m_b - m_w) g (sin\theta - C_n cos\theta) - \frac{C_f \mu_0 A}{h_0}\frac{ds}{dt} - 0.5\, C_d \rho_w A \left(\frac{ds}{dt}\right)^2$$

Panjang karakteristik gelombang

$$\lambda_o = t_o\sqrt{gd} \cong 3.87\sqrt{\frac{bd}{sin\theta}}$$

Jarak yang ditempuh longsoran

$$s(t) = s_o \ln\left[\cosh\left(\frac{t}{t_o}\right)\right]$$

m_w : massa air laut yg tertambahkan (kg)
C_m : koefisien penambahan massa
C_n : koefisien gesekan dasar
$A = Tw$: area tegak lurus arah longsor
μ_0 : viskositas dinamik air laut (kg/m s)
C_f : koefisien gesek air
C_n : koefisien lubrikasi
ρ_w : densitas air laut (kg/m³)
T : tebal longsoran (m)
w : lebar longsoran (m)

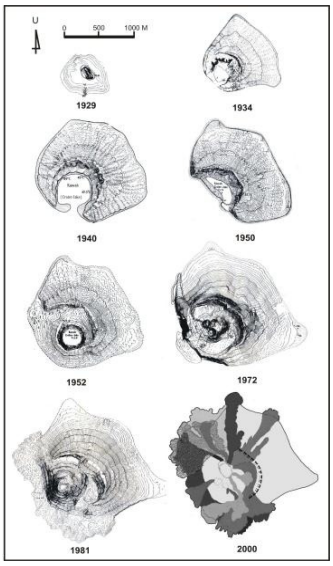
Amplitudo karakteristik gelombang

$$\eta_{2d} \cong 0.0654T(1 - 0.7548sin\theta + 0.1704sin^2\theta)\left(\frac{bsin\theta}{d}\right)^{1.25}$$

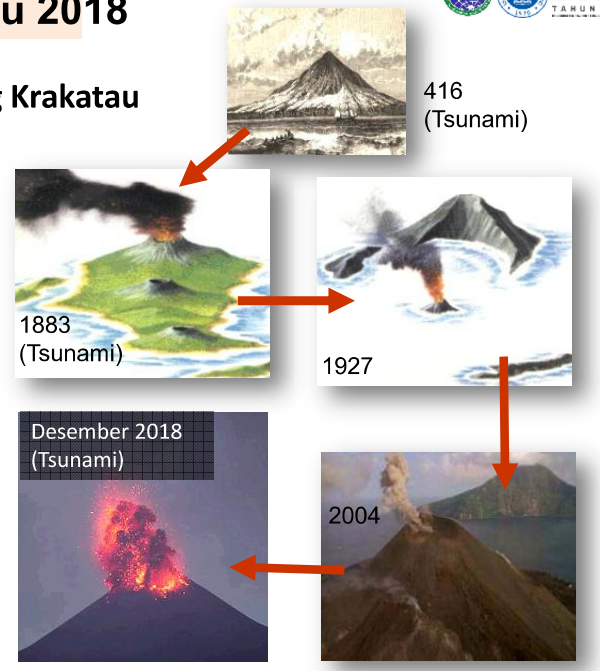
η_{2d} (m) : amplitudo karakteristik gelombang
s_o : jarak karakteristik gerakan
b : Panjang longsoran

Tsunami Krakatau 2018

Pertumbuhan Gunung Krakatau

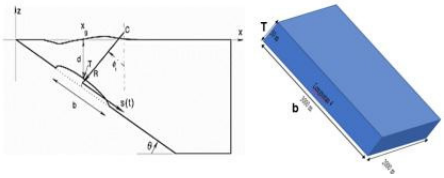


(Sutawidjaja, 2006)



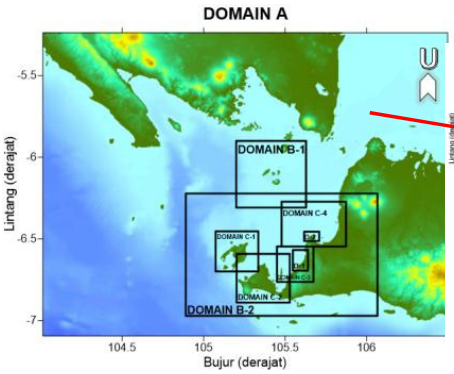
(https://meafterdeath.tumblr.com/post/181689621163, 2019)

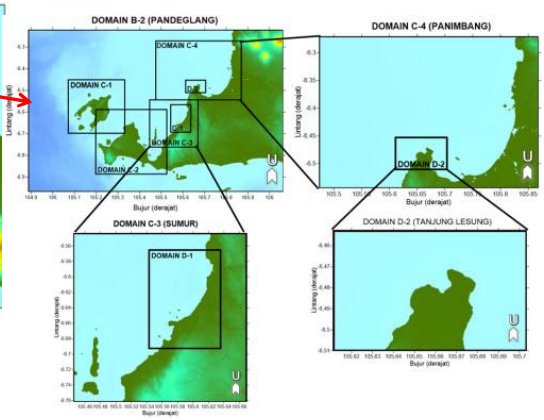
Domain Simulation



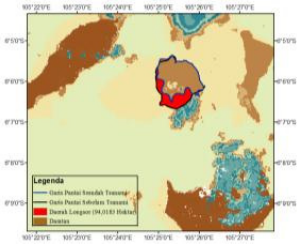
Developing Scenarios

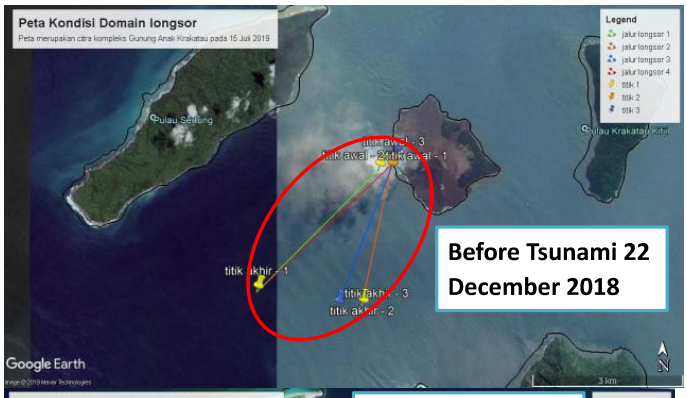
No	V (km³)	P (m)	L (m)	T (m)	Sudut (°)	Durasi (s)	Titik awal x	Titik awal y	Titik akhir x	Titik akhir y	Jarak (m)	Kecepatan (m/s)
1	0,28	2800	2000	50	15,25	132	105,416	-6,102	105,391	-6,125	3746	28,38
5	0,28	2800	2000	50	15,25	410	105,416	-6,102	105,391	-6,125	3746	9,14
2	0,27	2700	2000	50	15,25	410	105,416	-6,102	105,391	-6,125	3746	9,14
3	0,22	2200	2000	50	15,25	410	105,416	-6,102	105,391	-6,125	3746	9,14
4	0,3	3000	2000	50	15,25	410	105,416	-6,102	105,391	-6,125	3746	9,14
6	0,276	2450	1500	75	15,25	410	105,416	-6,102	105,391	-6,125	3746	9,14
7	0,171	1102,2	853	75	15,25	410	105,416	-6,102	105,391	-6,125	3746	9,14
8	0,27	2700	2000	50	8,2	410	105,413	-6,103	105,391	-6, 125	3435	8,38
10	0,276	2450	1500	75	8,2	410	105,413	-6,103	105,391	-6, 125	3435	8,38
9	0,3	3000	2000	50	8,2	410	105,413	-6,103	105,391	-6, 125	3435	8,38
11	0,3	3000	2000	50	12,46	410	105,413	-6,103	105,391	-6, 125	3435	8,38
13	0,27	2700	2000	50	15,25	410	105,416	-6,102	105,406	-6,128	3072	7,49
14	0,276	2450	1500	75	15,25	410	105,416	-6,102	105,406	-6,128	3072	7,49
12	0,27	2700	2000	50	16,01	410	105,415	-6,103	105,410	-6,127	2768	6,75

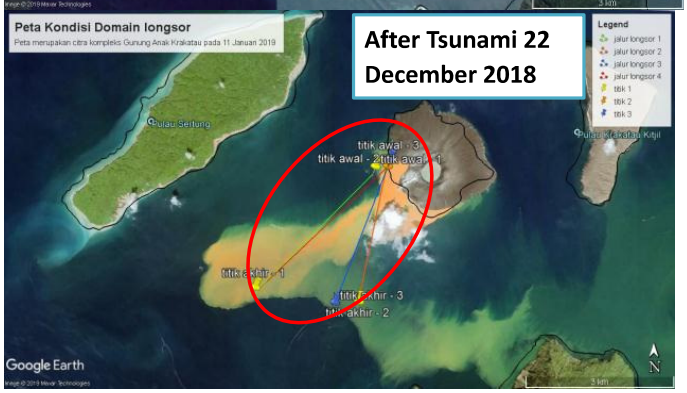




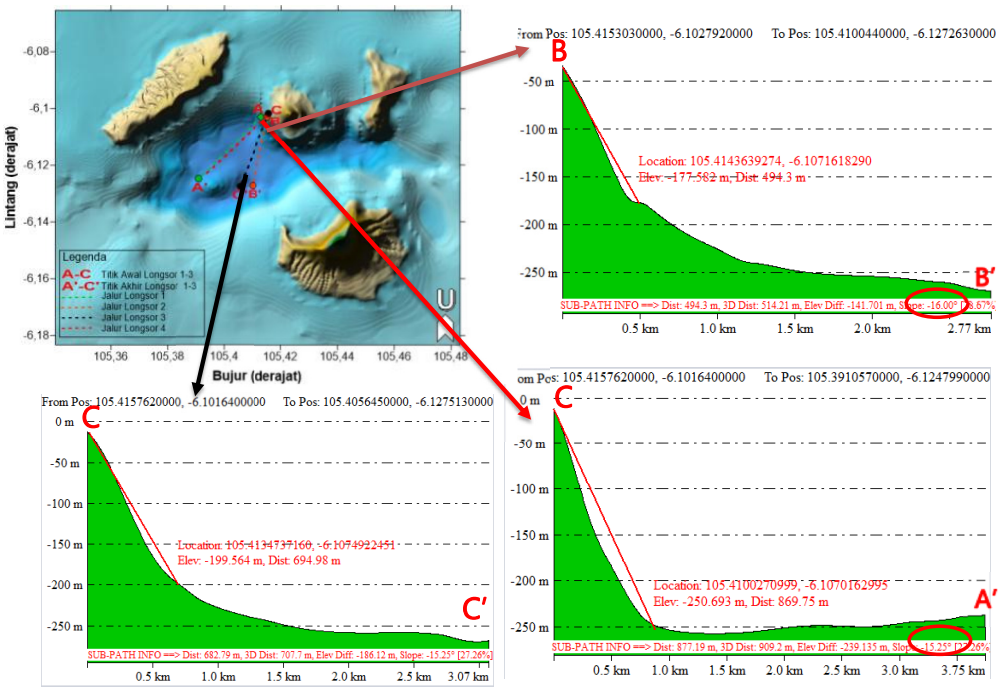
Landslide Scenario



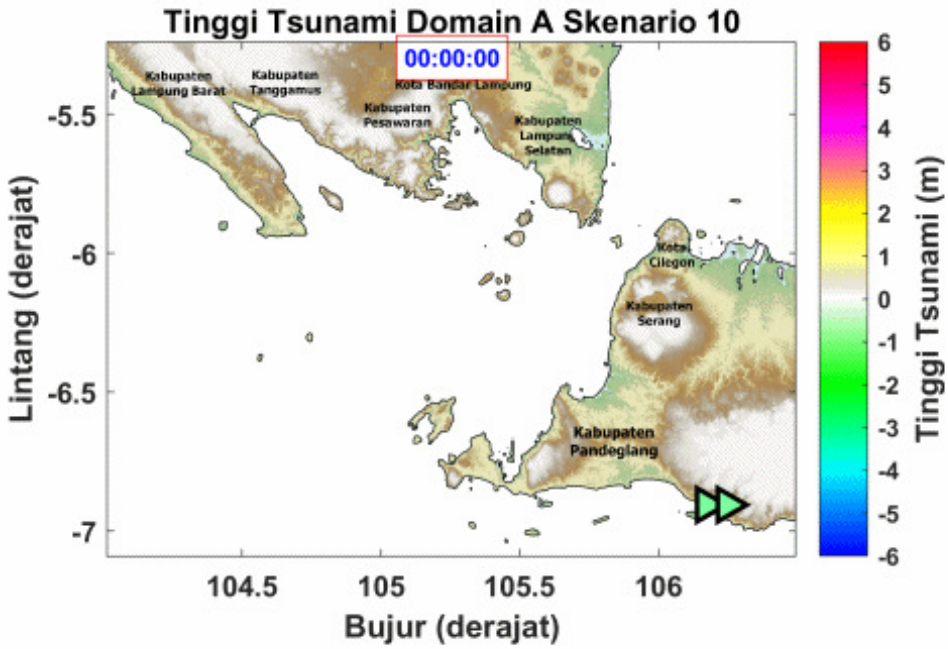




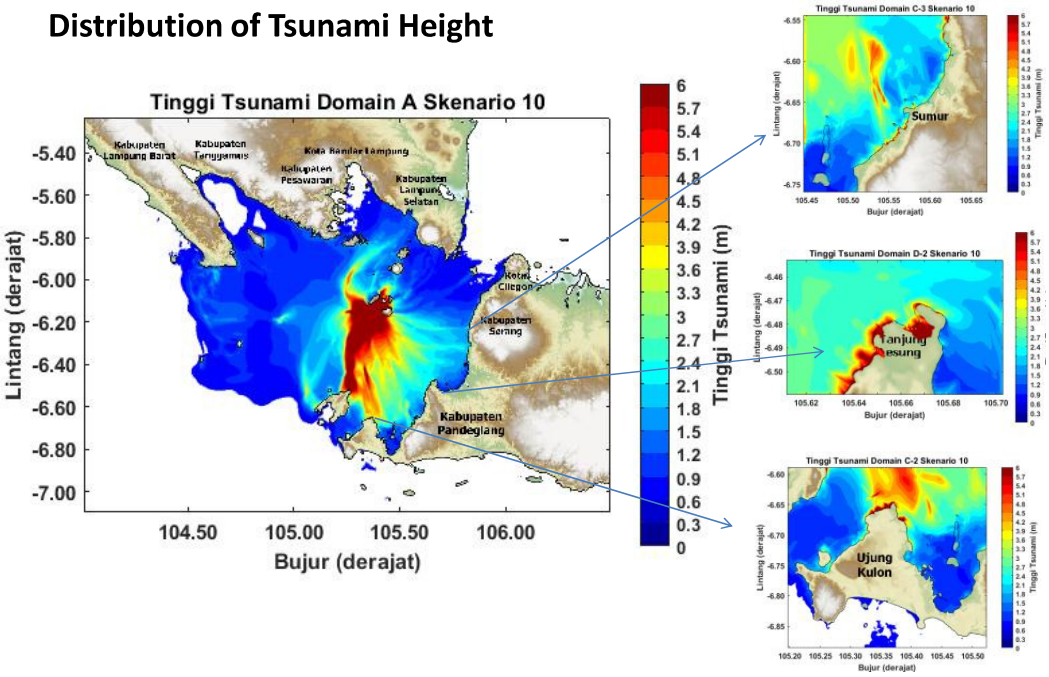
Landslide Angle Scenario



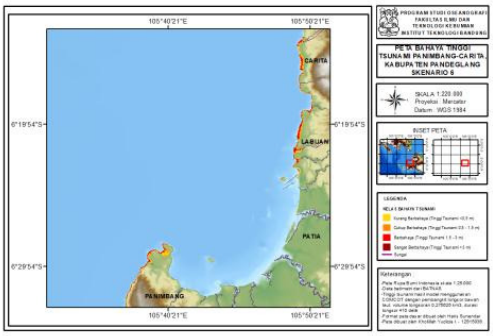
The 2018 Krakatau Landslide Tsunami Model

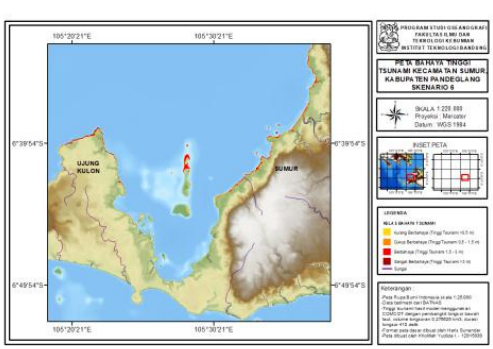


Distribution of Tsunami Height

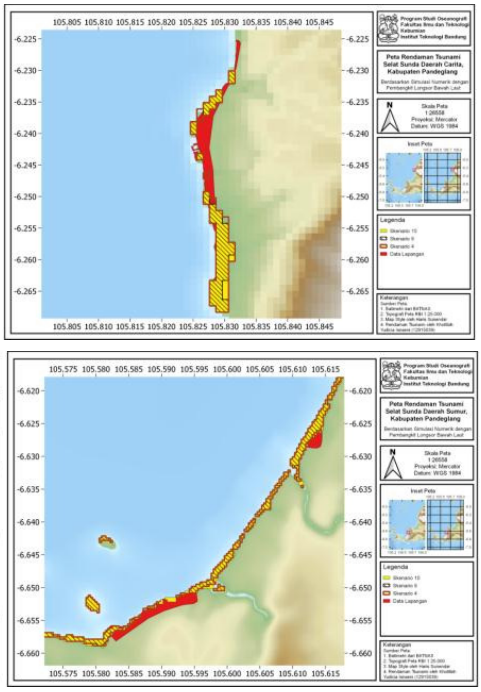


Peta Kajian Bahaya Tinggi Tsunami





Perbandingan Inundasi Hasil Model dan Data Lapangan



Risk Assessment

Resiko (*Risk*) **R** ↓ = (*Hazard*) **H** ↓ **X** (*Vulnerability*) **V** ↓ / (*Capacity*) **C** ↑

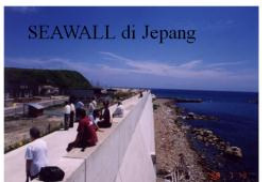
WHAT CAN WE DO TO REDUCE RISK IS:

- REDUCE HAZARD
- REDUCE VULNERABILITY
- INCREASE CAPACITY

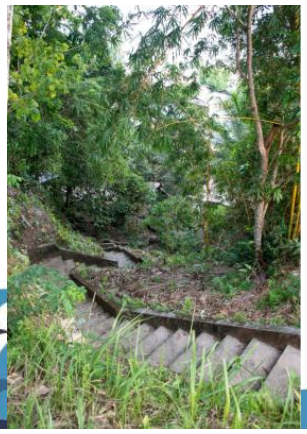
Mitigation of Tsunami Hazard

1. **Structural Measures** :
   a. Coastal protection (sea wall) → grey protection
   b. Vegetation → green protection
   c. TES (temporary Evacuation Shelter)

2. **Non-structural Measures**
   a. Hazards assessment (tsunami inundation map and ETA)
   b. Developing pre-calculated database tsunami, DSS for TEWS
   c. Real time monitoring and TEWS
   d. Land use planning
   e. building code
   f. Public education (Tsunami drill, awareness, public response)
   g. others



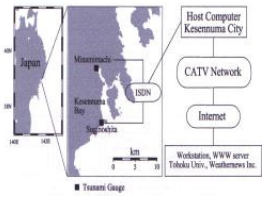
Several effort:
- Maintain of historical tsunami
- Socialization how to develop tsunami map
- Evacuation road
- Tsunami sign and tsunami board
- Tsunami drill
- Dissemination of tsunami information



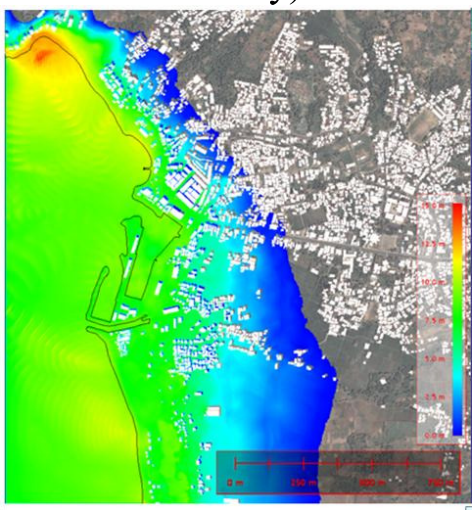
Nonstructural Measures

- Tsunami risk maps (Hazard and vulnerability)
- Tsunami database
- TEWS

Gambar 2.11 Tsunami gauge di Sanriku Jepang (**Sato, et. Al, 1992**)



Gambar 2.12 *Overview TIMING System* (Imamura, et.al., 2001)

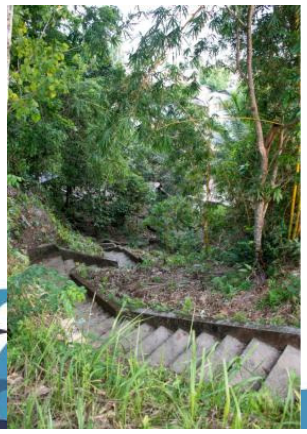


Latief, 2008

Online Training Course on
Disaster Risk Reduction and Climate Change Adaptation
for CARICOM and SICA Member Countries

Several attempts have been made:

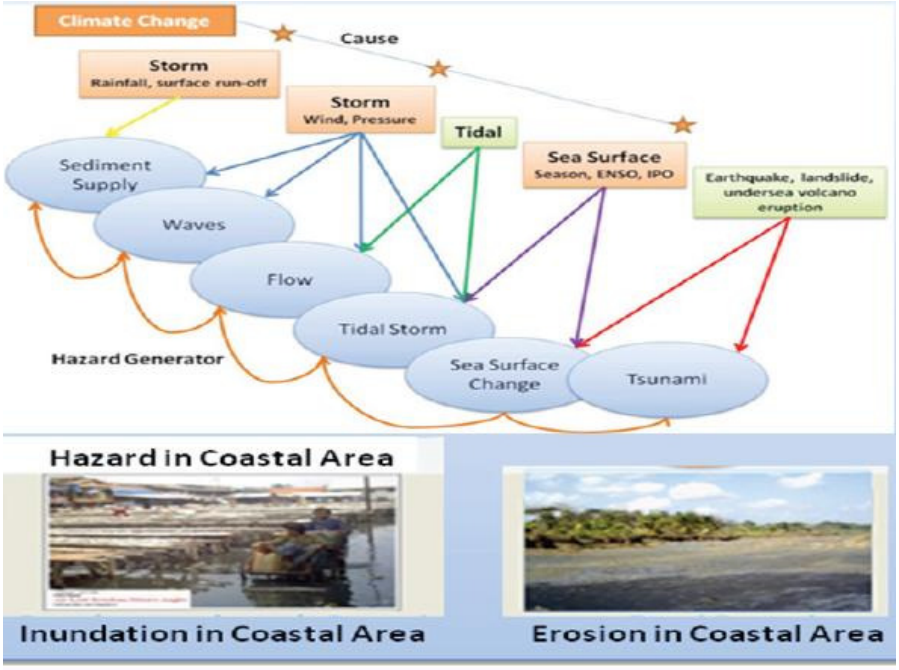
- Preservation of tsunami history
- Socialization of how to make a tsunami map
- Making a tsunami hazard map
- Determination of evacuation route
- Installation of evacuation signs
- Tsunami drill
- Tsunami socialization to schools



3. SLR induced by Climate Change

Facts of Coastal Inundation, Coastal Erosion and Land subsidence

- Ocean parameter induced by climate change



Oceanographic Condition in Indonesia

Parameter of relative SLR

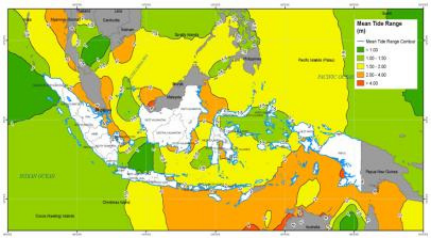
Periodic Factors

1. Sea Level Rise ➔ ocean tide,
2. Sea Level Rise ➔ storm surge,
3. Sea Level Rise ➔ Madden-Julian Oscillation (MJO),
4. Sea Level Rise ➔ El Niño–Southern Oscillation (ENSO), and
5. Sea Level Rise ➔ Indian Ocean Dipole (IOD).

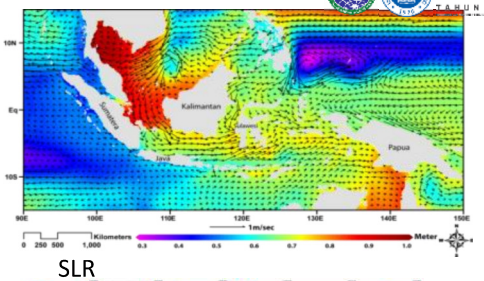
Non-Periodic Factor

1. Sea Level Rise due to climate change (global warming)
2. Flood
3. Tsunami
4. Land subsidence

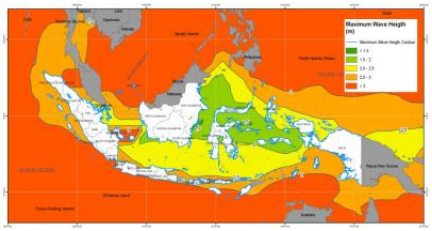
Ocean Tide



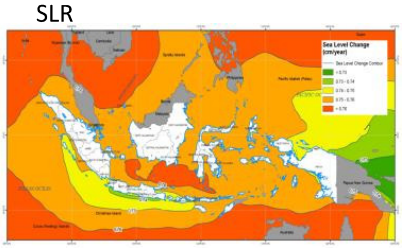
Ocean current

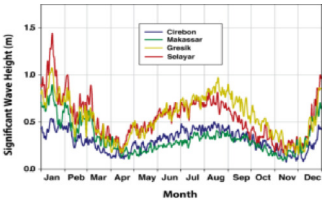


Ocean waves

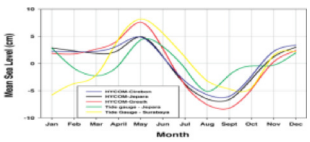


SLR

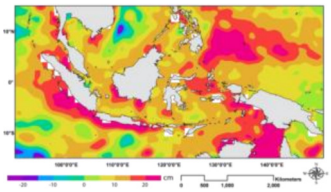




Monthly waves



Monthly MSL



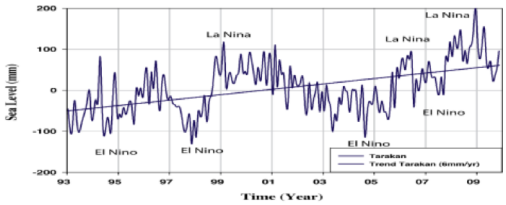
SLR during La Nina

(Sofyan, 2015).

- ENSO Projection

	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Agus	Sep	Okt	Nop	Des
2001	-1.04	-0.86	-0.81	-0.33	-0.55	-0.29	0.12	0.26	-0.34	-0.85	-0.85	-1.02
2002	-1.04	-0.77	-0.47	0.13	0.77	0.75	1.00	1.37	1.47	1.77	1.79	1.60
2003	1.13	0.83	0.09	-0.35	-0.56	-0.61	-1.16	-1.16	-1.05	-0.67	-0.69	-0.95
2004	-0.83	-1.20	-1.19	-0.86	-0.37	-0.78	0.30	0.42	0.77	0.93	0.89	1.13
2005	0.84	0.29	0.00	-0.25	-0.38	-0.75	-0.45	-0.68	-0.32	-0.77	-1.07	-0.99
2006	-0.89	-1.12	-1.19	-1.79	-1.68	-1.04	-0.53	-0.41	-0.36	-0.30	-0.28	-0.55
2007	-0.63	-0.93	-0.80	-0.73	-0.91	-0.29	0.10	0.23	0.43	0.72	0.76	0.69
2008	0.78	0.53	0.23	0.06	-0.90	-0.76	-0.86	-0.36	-0.67	-0.92	-0.75	-1.01
2009	-1.07	-0.78	-0.11	0.07	0.29	1.21	1.39	1.58	1.36	1.29	1.38	1.31
2010	0.98	0.56	-0.26	-1.18	-1.40	-1.23	-1.44	-1.74	-1.50	-1.36	-1.30	-1.11
2011	-0.95	-1.15	-1.47	-1.28	-0.10	1.53	2.21	2.95	2.24	2.40	2.71	3.06
2012	2.75	2.37	1.61	1.00	0.83	-0.06	-0.20	-0.01	-0.78	-1.02	-1.18	-1.59
2013	-1.45	-1.22	-0.54	-0.50	-0.42	-0.11	0.04	0.50	0.38	0.07	-0.08	0.12
2014	0.01	-0.20	-0.27	0.31	0.04	-0.24	-0.35	-0.46	-0.44	-0.14	-0.58	-0.54
2015	-0.70	-0.91	-0.50	-0.13	-0.04	-0.44	-0.15	-0.39	-0.05	-0.26	-0.52	-0.55
2016	-1.09	-0.91	-0.36	0.02	0.11	0.12	0.67	-0.03	-0.43	-0.45	-0.84	-0.97
2017	-1.09	-1.18	-1.30	-0.68	-0.95	-1.33	-1.09	-0.90	-0.90	-0.90	-0.96	-0.96
2018	-1.00	-1.07	-1.00	-0.38	-0.52	1.09	2.24	1.65	1.74	1.84	2.21	2.46
2019	2.50	2.25	1.85	1.39	1.19	0.73	0.50	0.73	0.45	0.17	-0.42	-0.78
2020	-0.82	-1.03	-0.85	-0.74	-1.26	-1.13	-1.41	-1.71	-1.52	-1.55	-1.55	-1.52
2021	-1.51	-1.54	-1.50	-1.09	-0.15	0.14	0.06	0.24	-0.21	-0.27	-0.08	-0.02
2022	-0.06	-0.18	-0.53	-0.56	-0.50	-0.83	-0.48	-0.40	-0.60	-0.71	-0.95	-1.49
2023	-1.49	-1.35	-0.98	-0.46	-0.03	1.05	0.63	1.13	1.04	0.92	0.73	0.25
2024	0.47	0.36	-0.28	-0.34	-1.33	-1.25	-1.31	-0.95	-0.85	-1.03	-0.90	-0.98
2025	-0.86	-0.97	-0.47	-0.66	-0.65	-0.48	-0.53	-0.36	0.29	0.53	0.70	0.50
2026	0.73	0.71	0.42	0.23	-0.56	-0.83	-0.85	-1.23	-1.87	-1.59	-1.80	-1.38
2027	-0.54	-0.26	0.09	0.00	-0.48	0.11	0.12	0.40	0.44	0.38	0.06	-0.38
2028	-0.54	-0.26	0.03	-0.20	-0.81	-0.64	-0.27	-0.44	-0.04	0.28	0.02	0.08
2029	0.26	0.39	0.18	-0.34	-0.65	-0.88	-1.37	-1.47	-0.94	-0.95	-0.92	-0.94
2030	-0.92	-0.80	-1.14	-0.89	-0.77	-0.79	-0.19	-0.12	0.51	0.45	0.56	0.37

La Nina El Nino
Weak
Moderate
Strong

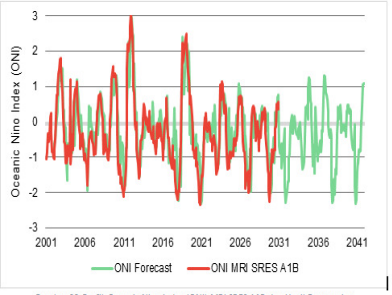


ENSO time table based on MRI model output for SRESA1B scenario

Tabel 15 Tabel Waktu ENSO Tahun 2031-2041 Berdasarkan Forecasting

	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Agu	Sep	Okt	Nov	Des
2031	-0,70	-0,86	-0,90	-0,63	-1,32	-1,08	-0,72	-0,50	-0,20	-1,86	-2,28	-2,10
2032	-1,94	-1,69	-1,69	-1,00	-0,94	-0,14	0,05	0,19	-0,22	-0,33	-0,06	0,17
2033	-0,06	-0,08	-0,29	-0,37	-0,39	-0,48	-0,19	-0,14	-0,01	-0,43	-0,84	-0,96
2034	-1,35	-1,29	-1,12	-0,49	-0,40	0,41	0,27	0,47	0,07	0,96	1,25	1,21
2035	0,59	0,51	0,14	-0,51	-1,25	-1,14	-0,65	-1,44	0,42	-0,17	-0,74	-1,11
2036	-0,87	-0,91	-0,71	-0,54	-0,86	-0,53	-0,25	-0,27	0,63	1,30	1,28	1,25
2037	0,81	0,76	0,63	0,28	-0,11	-0,37	-0,45	-0,21	-0,42	-1,82	-2,29	-2,24
2038	-1,64	-1,84	-2,05	-1,34	-1,47	-0,32	0,14	0,41	0,09	0,34	0,47	0,17
2039	-0,29	-0,24	-0,06	-0,11	-0,17	-0,25	-0,07	-0,42	0,30	0,37	0,47	0,46
2040	0,26	0,35	0,31	-0,13	-0,50	-0,70	-0,77	-0,53	-0,08	-1,85	-2,31	-2,20
2041	-1,39	-1,06	-1,19	-0,79	-0,86	-0,82	0,04	-0,06	0,45	1,04	1,08	1,09

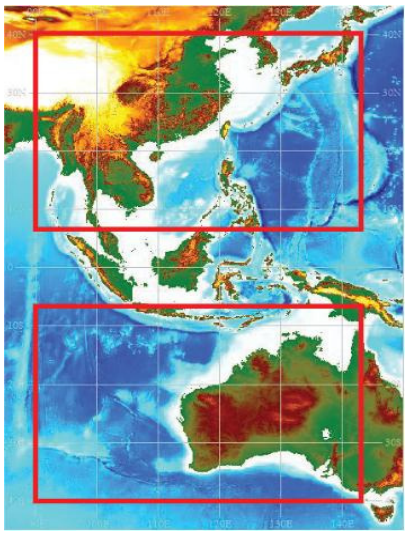
La Nina El Nino
Kuat
Sedang
Lemah



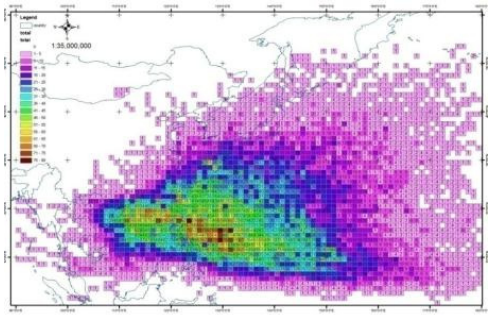
Gambar 39 Grafik Oceanic Nino Index (ONI) MRI SRES A1B dan Hasil Forecasting
Sumber: Hasil Analisis, 2022

- Storm Surges

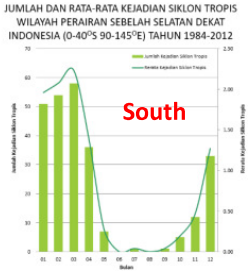
tropical cyclone at the west Pacific Ocean (the period of data is 1945 to 2009)



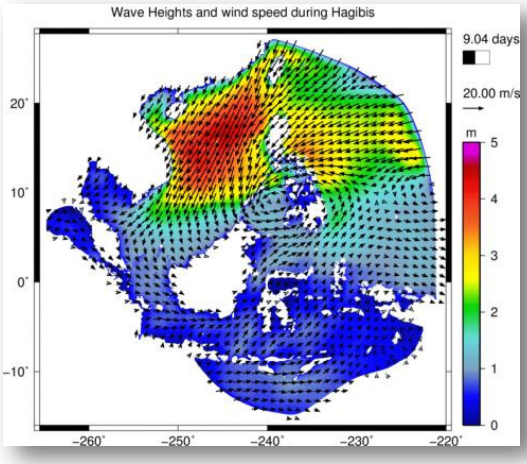
Tropical cyclone at the north of west Pacific Ocean (data period of 1984-2012).



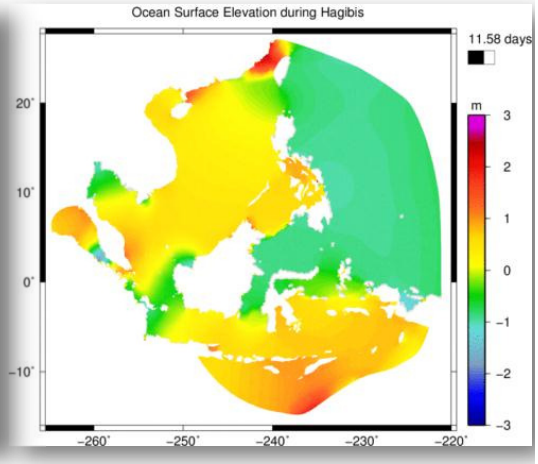
(source Latief, 2011)



Model of Hagibis Storm Surges, 14-7-2014



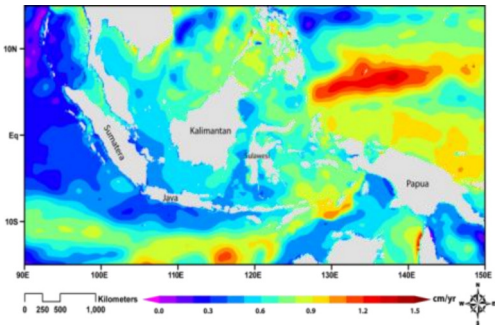
Significant Wave Height



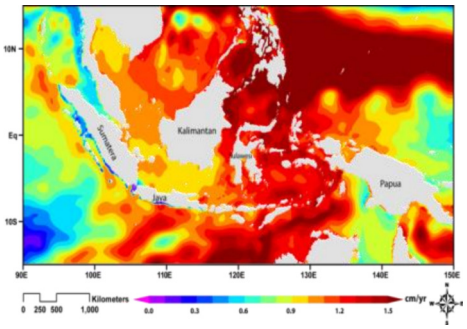
Ocean Surface Elevation

(Sofyan, Latief, Dika, 2014)

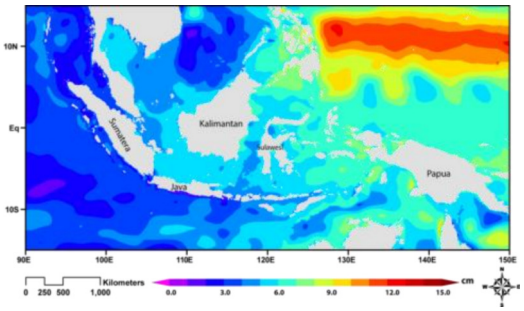
Sea Level Rise between 1993-2003 to 2003-2004



Assimilated HYCOM-altimetry estimated sea level rise rate from 1993 to 2003

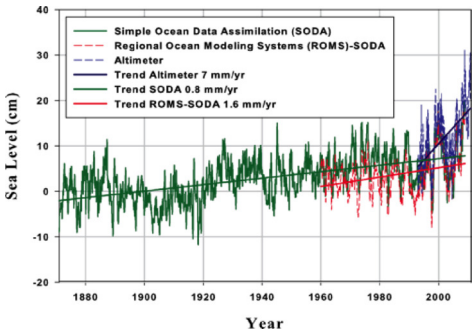


Assimilated HYCOM with altimetry estimated sea level rise rate from 2004 to 2013

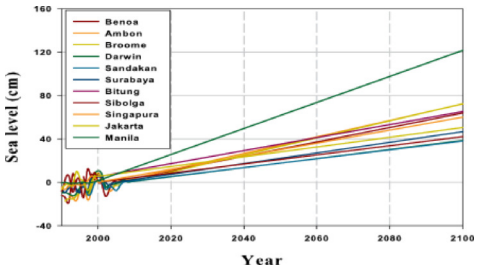


Sea level changes between mean sea level from 2004 to 2013 relative to the one from 1993 to 2003, with the maximum change of 15cm

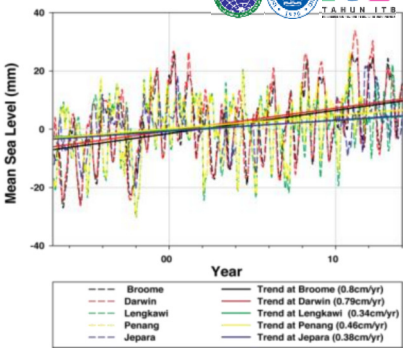
Global Sea level rise projection

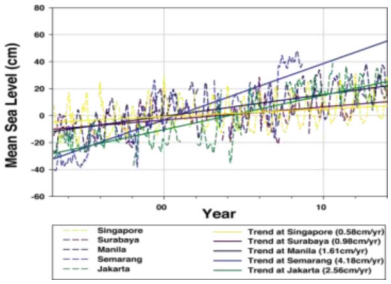


Long-term sea level change from 1860 to 2010 based on the SODA, ROMS and altimetry-estimated sea levels

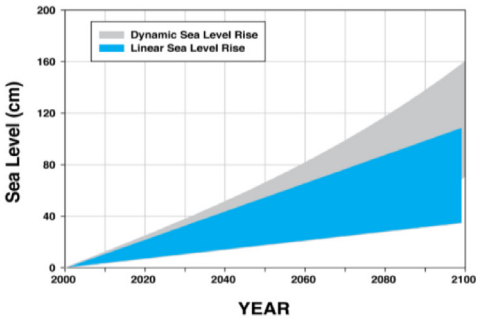


Approximation of sea level rise using a number of tidal data acquired from (UHSLC) *(Source : ICCSR, 2010)*

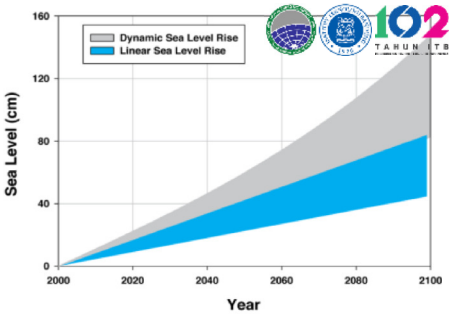




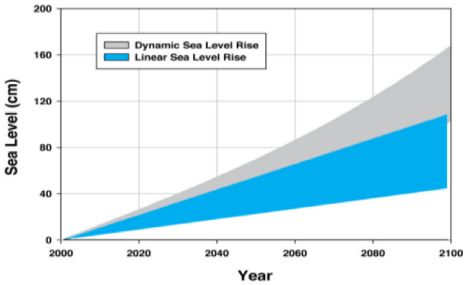
Sample of tide gauge estimated isostatic sea level change from 1993 to December 2014



Projection of eustatic sea level rise based on the tide gauges data



Projection of eustatic sea level rise based on the assimilated altimetry and HYCOM model



Projection of sea level rise based on CMIP5-RCP4.5 scenario

Year	Observation		Model	Unit	Level of Confident
	Tide Gauge	Altimeter	CMIP5-RCP 4.5		
2030	29±10cm	25±10cm	28±14cm	cm	High
2050	43±20cm	42±18cm	48±24cm	cm	High
2080	73±43cm	72±35cm	85±47cm	cm	High
2100	98±62cm	97±50cm	107±60cm	cm	Moderate to high

land subsidence

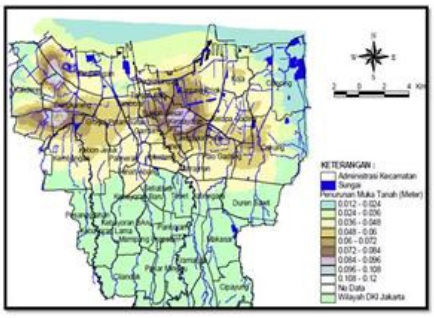


Figure 3-9 Subsidence in Jakarta
(http://meandmycoastallife.blogspot.jp/2010/12/coastal-problem.html)

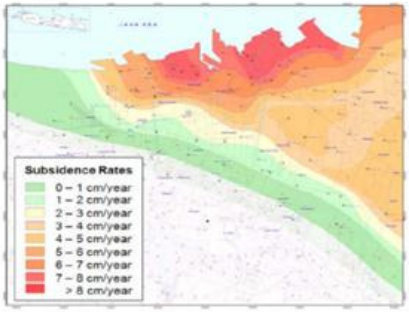
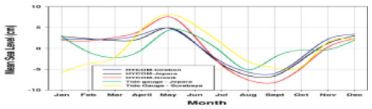
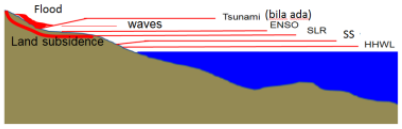


Figure 3-10 PS InSAR derived subsidence rates in Semarang
(Abidin et.al., 2010)

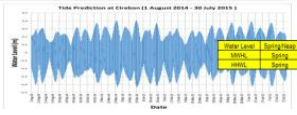
Cumulative Hazards

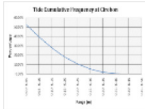
- MSL
- Tides
- SLR
- ENSO
- SS/Waves
- LS-Flood

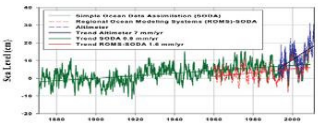


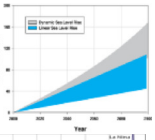


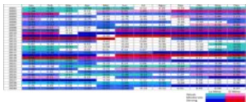
Elements of hazard induced by sea level change

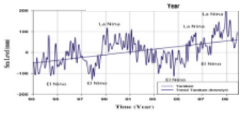


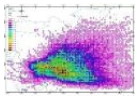


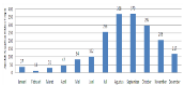


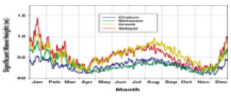


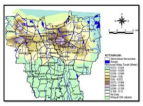












Cumulative Hazards Scenarios

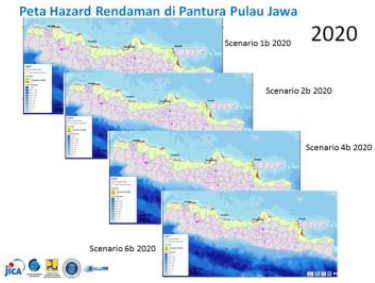
Hazard Code Number and Abbreviation

Hazard code number	Hazard code	Remark
0	reference	Mean Sea Level
1	MSL	Monthly Mean Sea Level
2	MHWL	Mean High Water Level
3	HHWL	Highest High Water Level
4	SLR	Sea Level Rise
5	SS	Storm Surges
6	LN	La Nina
7	FL	Flood

Scenario	Hazards Code Number	Hazards Code Abb.	Colors
Scenario-1b	0+1+3+4	MSL+MHWL+SLR	
Scenario-2b	0+1+3+4+5	MSL+MHWL+SLR+SS	
Scenario-3b	0+1+3+4+6	MSL+MHWL+SLR+LN	
Scenario-4b	0+1+3+4+7	MSL+MHWL+SLR+FL	
Scenario-5b	0+1+3+4+5+6	MSL+MHWL+SLR+SS+LN	
Scenario-6b	0+1+3+4+5+6+7	MSL+MHWL+SLR+LN+FL	

Sea level rise variation and their cumulative in North Java

Hazard Code No.	Hazards Component (cm)	Year of 2020											
		J	F	M	A	M	J	J	A	S	O	N	D
0	MSL	0	0	0	0	0	0	0	0	0	0	0	0
1	MSL monthly variant	2.3	2.2	2.3	3.3	4.9	1.3	-3.3	-5.7	-6.0	-2.3	2.2	3.4
2	Tide - MHWL	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52
3	Tide - HHWL	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27
4	SLR	14	14	14	14	14	14	14	14	14	14	14	14
5	Storm Surges (SS)							41	41	41	41	41	
6	La Nina (LN)	20	20										
7	Flood	100	100										100
8 = 0+1+2+4+5+6+7	Inundation Depth - MHWL	155.82	155.72	35.82	36.82	38.42	34.82	71.22	68.82	68.52	72.22	76.72	136.92
9 = 0+1+3+4+5+6+7	Inundation Depth - HHWL	176.57	176.47	56.57	57.57	59.17	55.57	91.97	89.57	89.27	92.97	97.47	157.67



Hazard Code No.	Hazards Component (cm)	Year of 2030											
		J	F	M	A	M	J	J	A	S	O	N	D
0	MSL	0	0	0	0	0	0	0	0	0	0	0	0
1	MSL monthly variant	2.3	2.2	2.3	3.3	4.9	1.3	-3.3	-5.7	-6.0	-2.3	2.2	3.4
2	Tide - MHWL	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52	19.52
3	Tide - HHWL	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27
4	SLR	21	21	21	21	21	21	21	21	21	21	21	21
5	Storm Surges (SS)							41	41	41	41	41	
6	La Nina (LN)												
7	Flood	100	100										100
8 = 0+1+2+4+5+6+7	Inundation Depth - MHWL	142.82	142.72	42.82	43.82	45.42	41.82	78.22	75.82	75.52	79.22	83.72	143.92
9 = 0+1+3+4+5+6+7	Inundation Depth - HHWL	163.57	163.47	63.57	64.57	66.17	62.57	98.97	96.57	96.27	99.97	104.47	164.67

Online Training Course on
Disaster Risk Reduction and Climate Change Adaptation
for CARICOM and SICA Member Countries

JAKARTA TENGGELAM

KUPAS TUNTAS *STATEMENT* PRESIDEN AMERIKA. BENARKAH JAKARTA AKAN TENGGELAM?

Flooding from in land in Jakarta (2013), (Photo from Internet)

Coastal Flooding from the sea in Jakarta (storm tide), (Photo from Internet)

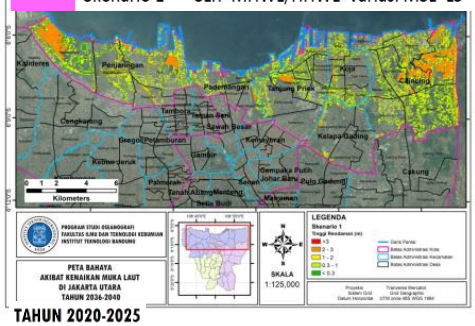
Muara Angke

JAKARTA TENGGELAM

KUPAS TUNTAS *STATEMENT* PRESIDEN AMERIKA. BENARKAH JAKARTA AKAN TENGGELAM?

Scenario	Hazards Code Number	Hazards Code Abb.	Colors
Scenario-1b	0+1+3+4	MSL+MHWL+SLR	
Scenario-2b	0+1+3+4+5	MSL+MHWL+SLR+SS	
Scenario-3b	0+1+3+4+6	MSL+MHWL+SLR+LN	
Scenario-4b	0+1+3+4+7	MSL+MHWL+SLR+FL	
Scenario-5b	0+1+3+4+5+6	MSL+MHWL+SLR+SS+LN	
Scenario-6b	0+1+3+4+5+6+7	MSL+MHWL+SLR+LN+FL	

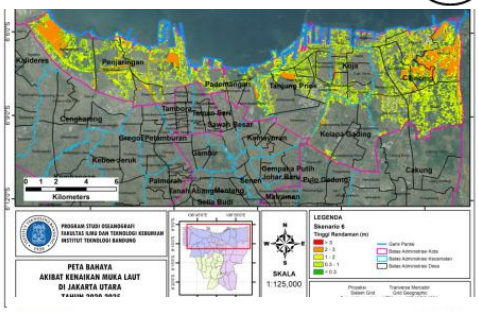
Skenario 1 SLR+MHWL/HHWL+variasi MSL+LS



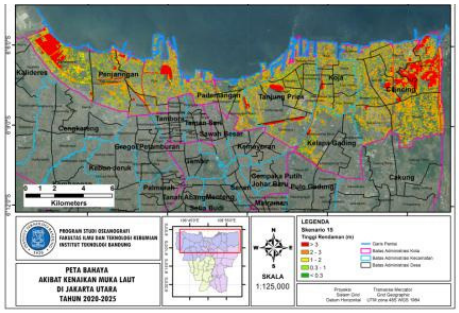
TAHUN 2020-2025

Scenario	Colors	2015-2019		2020-2024		2025-2029	
		freq	WL (cm)	freq	WL (cm)	freq	WL (cm)
Scenario-1b		16	55.67	14	59.17	16	62.67
Scenario-2b		18	93.97	19	97.47	16	100.97
Scenario-3b		4	76.37	6	80.57	4	160.77
Scenario-4b		14	154.17	10	157.67	9	161.17
Scenario-5b		7	109.17	6	118.87	9	121.67
Scenario-6b		1	176.97	5	179.07	6	181.87

Skenario 6 SLR+MHWL/HHWL+variasi MSL+LS+SG+LN

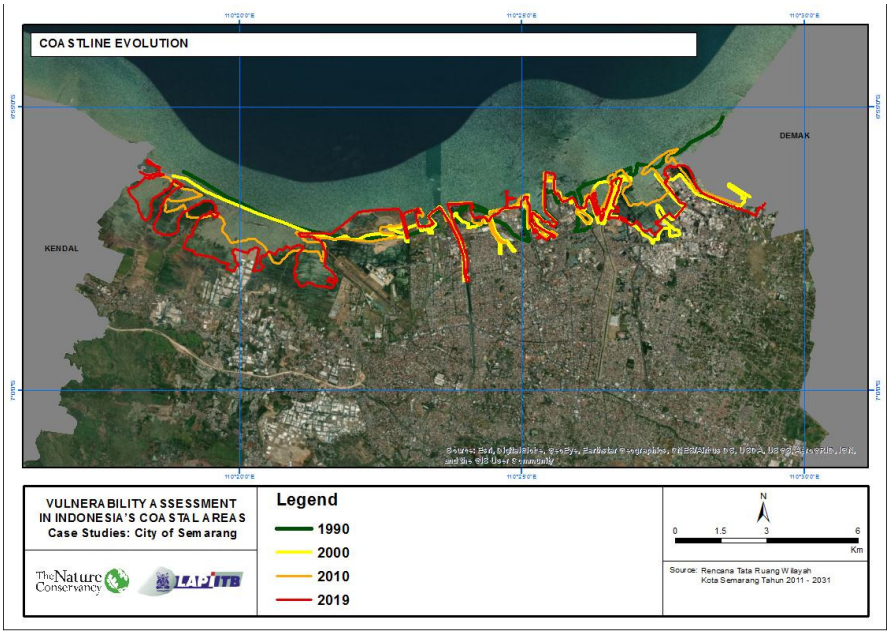


Skenario 15 SLR+MHWL/HHWL+variasi MSL+LS+B+MJO+LN

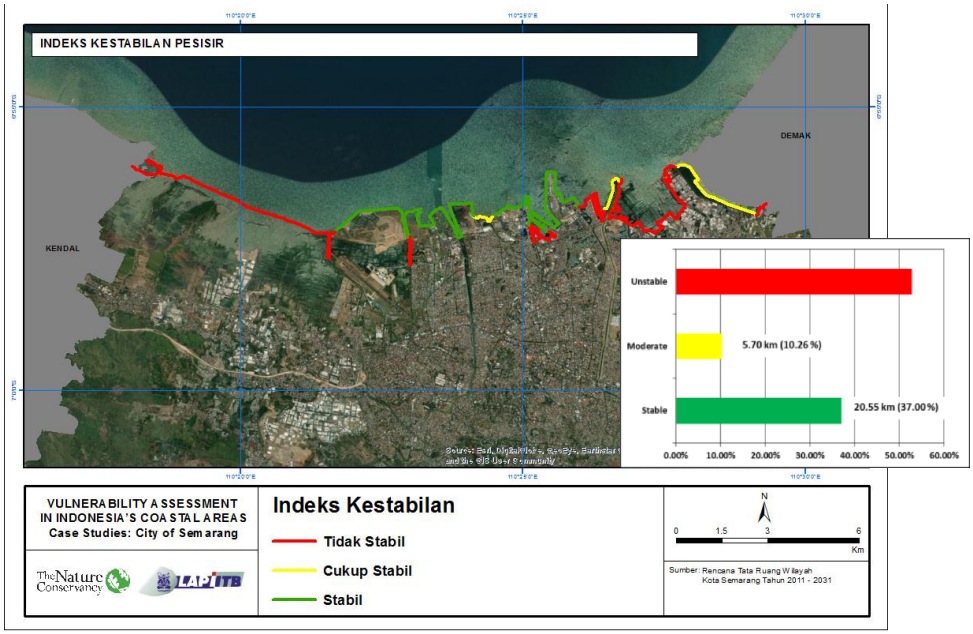


Housing Condition in Semarang

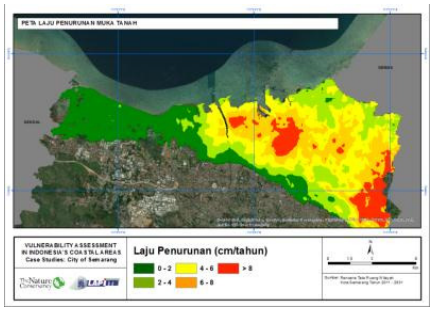
Coastline change in Semarang



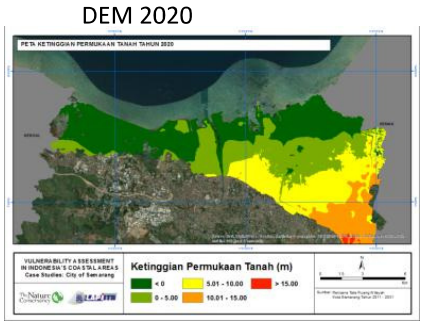
Coastal stability index in Semarang



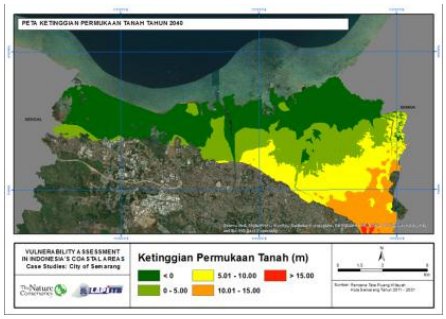
Land subsidence



DEM 2020



DEM 2040



Scenario

Skenario	Kode Angka Bahaya	Singkatan Kode Bahaya	Warna
Skenario-1a	0+1+2+4	MSL+MHWL+SLR+LS	
Skenario-2a	0+1+2+4+5	MSL+MHWL+SLR+SS+LS	
Skenario-3a	0+1+2+4+6	MSL+MHWL+SLR+LN+LS	
Skenario-4a	0+1+2+4+7	MSL+MHWL+SLR+FL+LS	
Skenario-5a	0+1+2+4+5+6	MSL+MHWL+SLR+SS+LN+LS	
Skenario-6a	0+1+2+4+5+6+7	MSL+MHWL+SLR+LN+FL+LS	

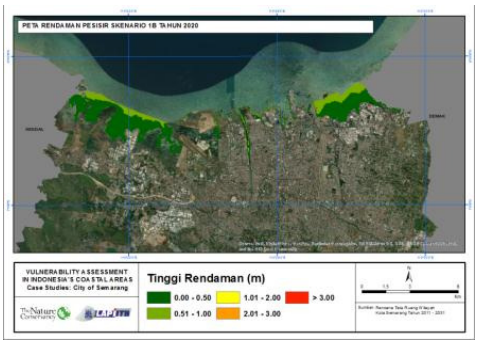
Keterangan:

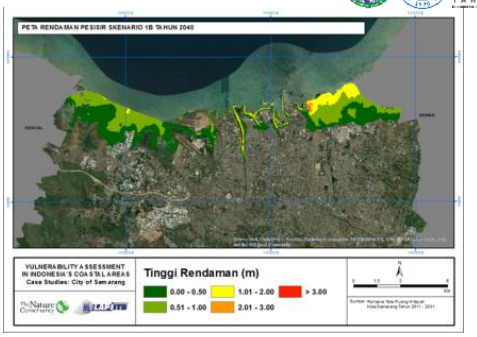
MSL : Mean Sea Level
SLR : Sea Level Rise
MHWL : Mean High Water Level
HHWL : Highest High Water Level
SS : Storm Surge
FL : Flood
LN : El Nino / La Nina

Skenario	Kode Angka Bahaya	Singkatan Kode Bahaya	Warna
Skenario-1b	0+1+3+4	MSL+HHWL+SLR+LS	
Skenario-2b	0+1+3+4+5	MSL+HHWL+SLR+SS+LS	
Skenario-3b	0+1+3+4+6	MSL+HHWL+SLR+LN+LS	
Skenario-4b	0+1+3+4+7	MSL+HHWL+SLR+FL+LS	
Skenario-5b	0+1+3+4+5+6	MSL+HHWL+SLR+SS+LN+LS	
Skenario-6b	0+1+3+4+5+6+7	MSL+HHWL+SLR+LN+FL+LS	

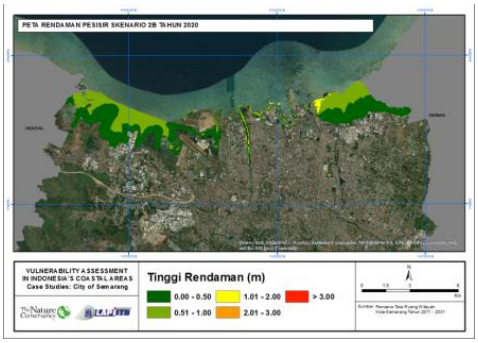
Kombinasi Skenario Muka Air Tinggi Tertinggi (HHWL) Dengan Komponen Bahaya Lain

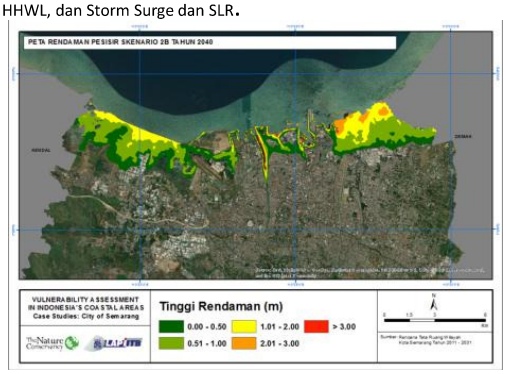
- Skenario 1b 2020 dan 2040 contributed by MSL Variation, HHWL, and Sea Level Rise.





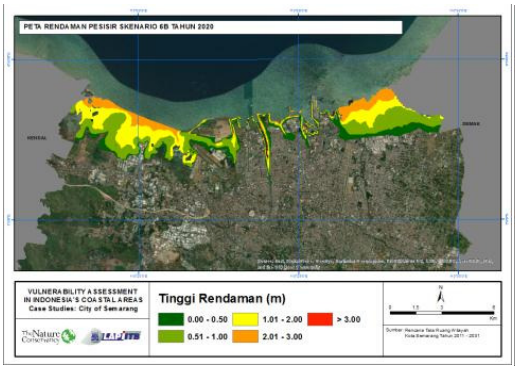
- Skenario 2b 2020 dan 2040 memasukkan kontribusi variasi MSL, HHWL, dan Storm Surge dan SLR.

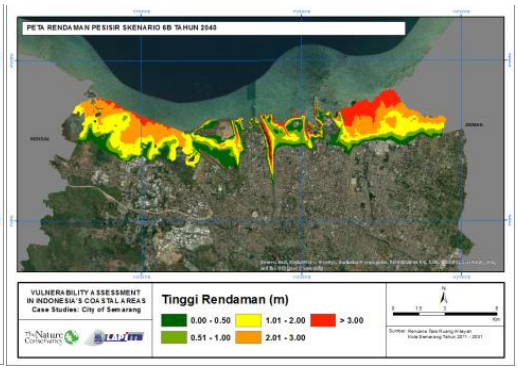




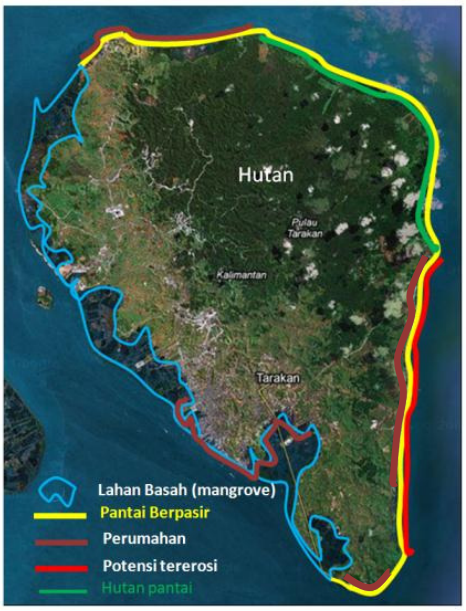
- Scenarios 6b 2020 and 2040 contribution by MSL, HHWL, Sea Level Rise, La Nina dan tidal flood.

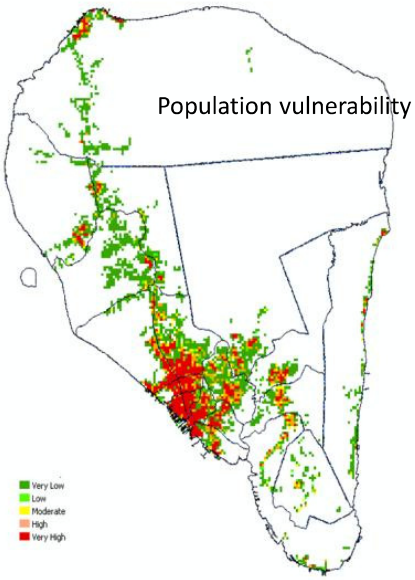
Hazard Code No.	Hazards Component (cm)	Year of 2040											
		J	F	M	A	M	J	J	A	S	O	N	D
0	MSL	0	0	0	0	0	0	0	0	0	0	0	0
1	MSL monthly variant	2.10	2.00	2.50	3.90	6.30	2.10	-3.70	-6.70	-7.10	-3.50	1.30	2.90
2	Tide - MHWL	36.00	36.00	36.00	36.00	36.00	36.00	36.00	36.00	36.00	36.00	36.00	36.00
3	Tide - HHWL	48.81	48.81	48.81	48.81	48.81	48.81	48.81	48.81	48.81	48.81	48.81	48.81
4	SLR	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3
5	Storm Surges (SS)							41	41	41	41	41	
6	La Nina (LN)	20	20	20					20	20	20	20	20
7	Flood	100	100										100
8 = 0+1+2+4+5+6+7	Inundation Depth - MHWL	190.40	190.30	90.80	72.20	74.60	70.40	105.60	122.60	122.20	125.80	130.60	191.20
9 = 0+1+3+4+5+6+7	Inundation Depth - HHWL	203.21	203.11	103.61	85.01	87.41	83.21	118.41	135.41	135.01	138.61	143.41	204.01

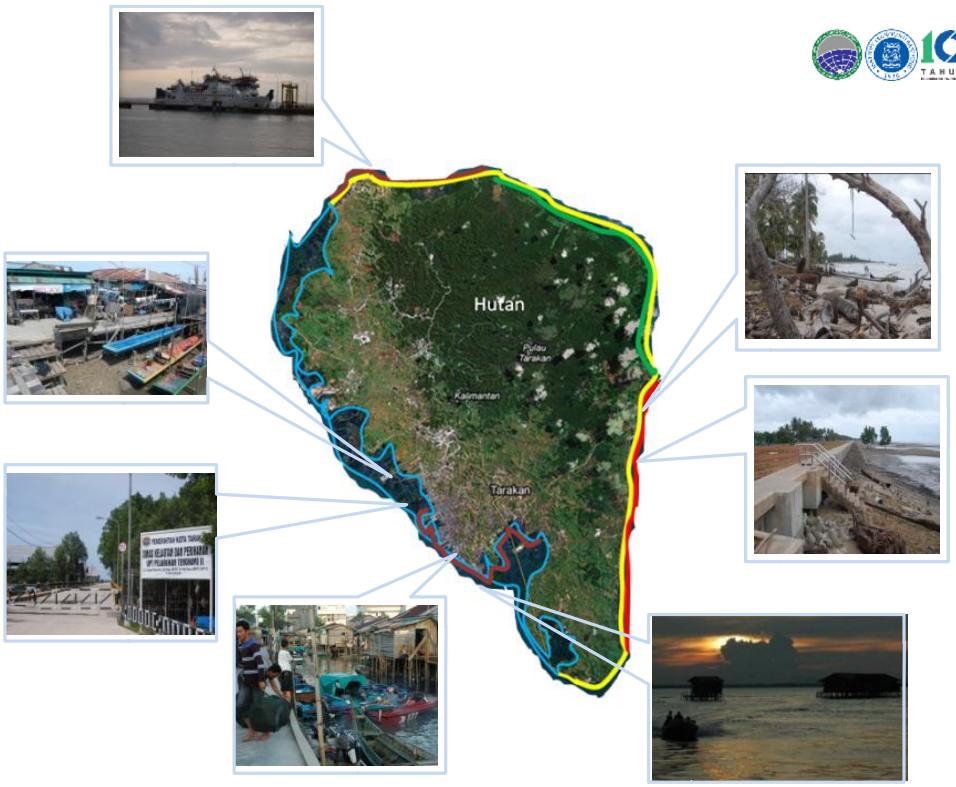




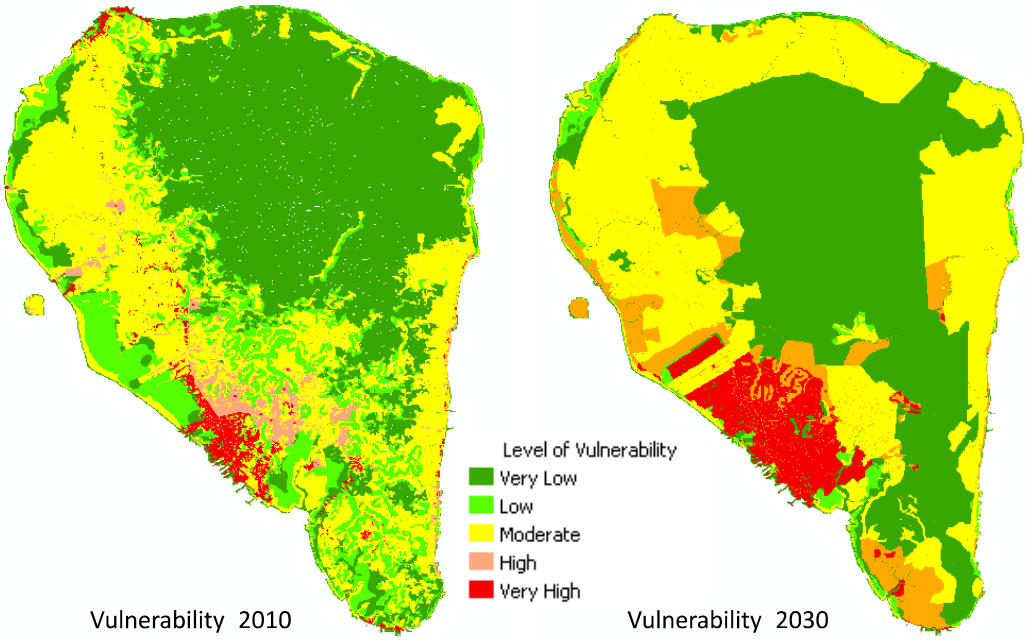
4. Climate Changes Adaptation at Tarakan Island (North Kalimantan)



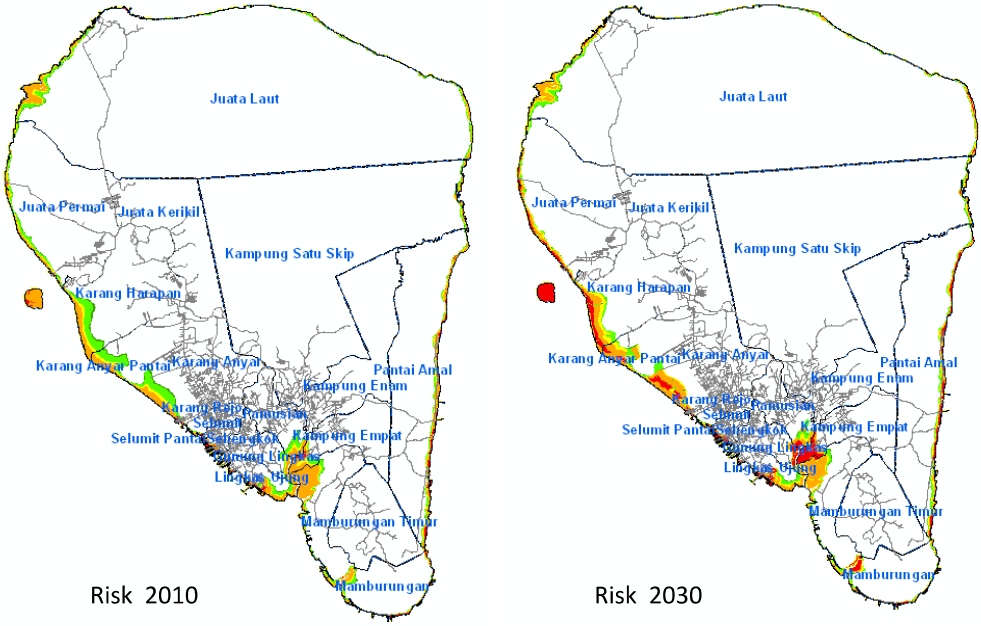




Vulnerability



Risk Scenario-3



Scenario-3 (Extreme+La Nina+ Surge)	1b+2b+4+5 + (3)	255.1 m	269.8 m	

Adaptation

Adaptation forces can be used to against sea level rise that potentially inundates the coastal system and low-lying areas. These adaptation measures are classified (IPCC-AR4) as:

to protect coastal areas,
to accommodate hazard, and
to retreat the coastal line

Technology Needs in Coastal Areas

Technologies are used to protect the coastal areas :

1. Hard Structures, ➔ coastal structures: sea wall, dike, breakwater, offshore break water, estuary closer, etc.
2. Soft Structures, which is protecting and increasing the ability of natural protector such as maintaining coral reef, dune, mangroves and coastal forests
3. Hybrid, ➔ combination of hard and soft protections

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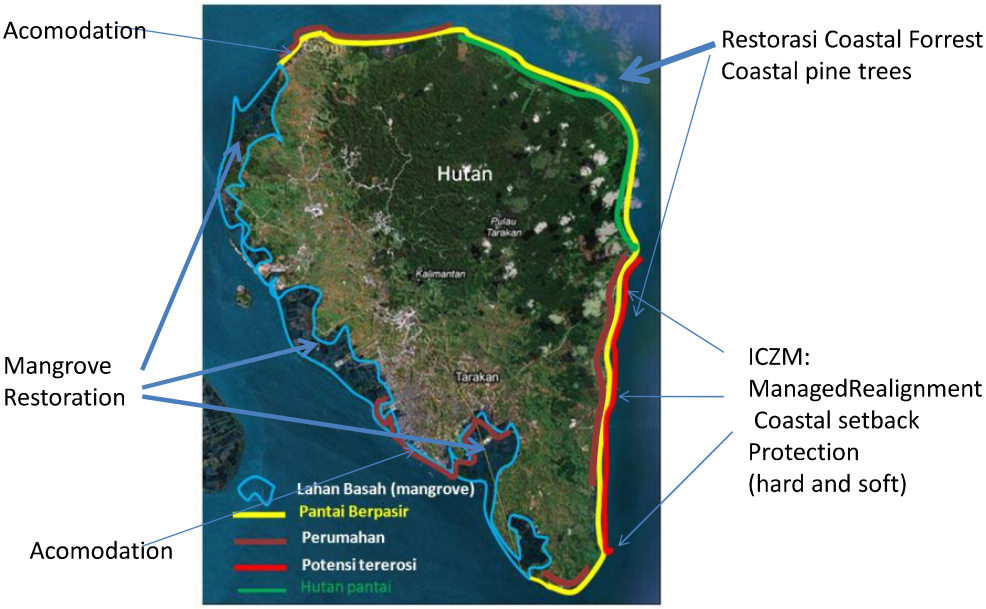
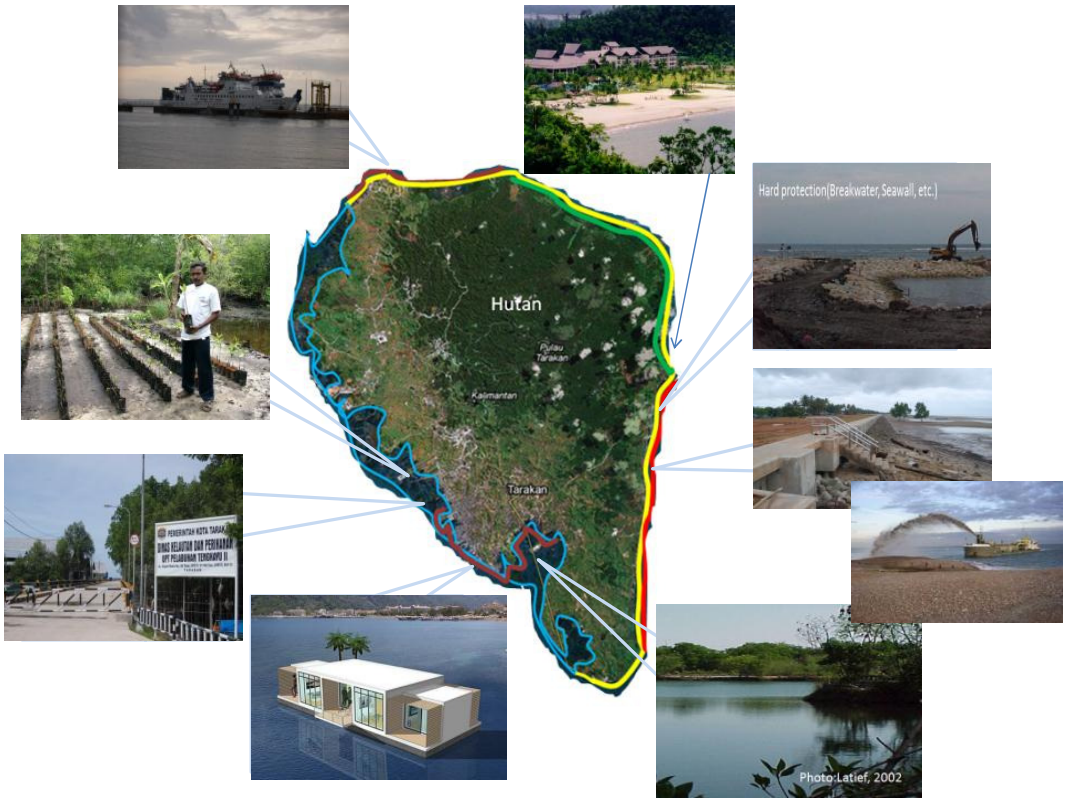
Recommendation for Tarakan





Gracias

Obrigado

Thank you

Terima Kasih