国際的な津波リスク評価
－これまでの研究と今後の課題－

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地震津波リスク研究部門（東京海上日動）

第6回　IRIDeS 金曜フォーラム
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研究部門の紹介　寄附研究部門
地震津波リスク研究部門（東京海上日動）

地震津波リスク研究部門（東京海上日動）

2012年4月、東京海上日動火災保険株式会社の寄附を受けて、東北大学災害科学国際研究所（IRIDeS）内に「地震・津波リスク研究分野」が開設されました。当研究部門では、東日本大震災の被害実態やこれまでの巨大地震における津波（波高分布や到達時間）を評価し、国内外における社会での脆弱性や防災力を考慮した被害推定や発生確率を加えた津波リスクの評価手法を研究します。また防災・減災に関するセミナー開催や防災教育ツールの開発等を通じて、得られた知見を広く社会に提供していきます。

メンバー

今村　文彦	教授
サッパシー・アナワット	准教授
安倍　祥	助手
福谷　陽	助手
保田　真理	助手

目的

地震津波リスクに関する研究を展開するため、国内外での地震による津波の評価（波高分布や到達時間）をベースに、社会での脆弱性や防災力を考慮した被害を推定し、さらには、発生確率を加えた総合的なリスクの評価手法について検討を行います。

研究活動と内容

- 地震津波リスクについて共同で研究を実施
- 国内外での津波リスクデータの収集と整理
- 東日本大震災での被害実態と復興関係の情報収集と整理
- 各種シンポジウム・啓発活動の実施

http://www.tsunami.civil.tohoku.ac.jp/hokusai3/J/irides_etrisk/index_j.html

Self Introduction

Birth place: Bangkok, Thailand (29)

Education background

- 2001 – 2005 B. Eng. (Civil Eng.) Chulalongkorn University
- 2005 – 2007 M. Eng. (Water Eng.) Asian Institute of Technology (AIT)
- 2007 – 2010 Ph. D. (Tsunami Eng.) Tohoku University

Working experience

- 2010 – 2012 Research Fellow, Willis Research Network (WRN)
- 2012 – present Associate Professor, IRIDeS, Tohoku university

Experienced two great disasters

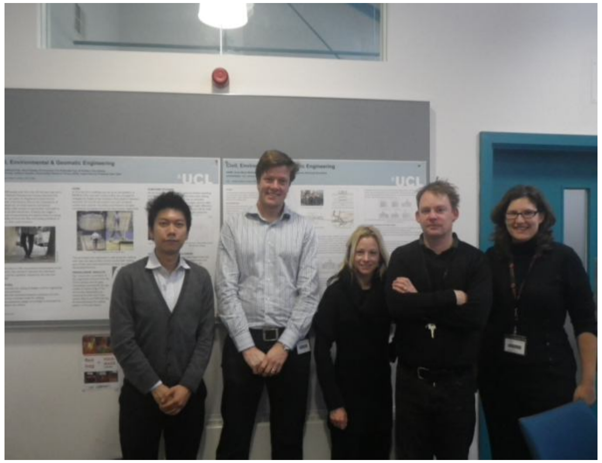
The Great East Japan tsunami in March 2011 and

The Great Thailand flood in October 2011

International collaboration: Tsunami survey guidance

Date	Organization	Location
3 October 2012	Profs from UK universities and UK Embassy in Japan	Onagawa, Ishinomaki and Sendai
21 September 2012	APRU Symposium participants	Onagawa, Ishinomaki and Sendai
23 August 2012	Ken Kornberg	Sendai area
23 August 2012	AIT Extensions (Disaster prevention training course)	Sendai area
25 July 2012	JICA training-Integrated disaster prevention in central Asia-Caucasus	Sendai area
2 July 2012	Thailand’s Minister of Information and Communication Technology	Sendai area
19 June 2012	Dr. Ingrid Charvet, UCL, the Royal Thai Embassy in Tokyo and Thai TV 9 channel	Sendai area
10 May 2012	Dr. Carl Harbitz (Norwegian Geotechnical Institute (NGI)	Sendai area
26 March 2012	Thai Flood experts	Onagawa, Ishinomaki and Sendai
16 March 2012	SATREPS (JST-JICA) tsunami project	Onagawa, Ishinomaki and Sendai
12 March 2012	Dr. Nick Wigginton (Science Editor)	Sendai
25 January 2012	Dr. Brain E. Tucker (GeoHazards International)	Sendai area
22 January 2012	KIP (Knowledge Investment Programs)	Sendai area
18 January 2012	Prof. Emile Okal (Northwestern University)	Sendai area
15 January 2012	Prof. Perwitt (University of Arizona) and Prof. Kirby (USGS)	Sendai area
21 November 2011	Prof. Iwata Shuichi (University of Tokyo)	Sendai area
9 November 2011	WRN	Miyako to Kuji
2 November 2011	JST National Innovation Coordinator Forum in Sendai	Ishinomaki city and Sendai city
22 October 2011	Dr. Veronica Cedillos (GeoHazards International)	Sendai area
19 October 2011	Alfred P. Sloan Foundation and Census of marine life	Sendai area
28-29 September 2011	Dr. James D. Goltz (California Emergency Management Agency) and Dr. Iuchi Kanako (The world bank)	Sendai area and Onagawa
7 September 2011	WRN	Onagawa to Watari
2-3 September 2011	Swiss Re	Minami-Sanriku to Sendai airport
25 July 2011	World Bank (GFDRR)-JICA	Ishinomaki to Sendai Port
30 May – 2 June 2011	Prof. Ahmet Yalciner team	Taro to Kesennuma
29 May 2011	JST-JICA and RISTEK Indonesia	Sendai airport to Sendai port

Visited University College London (UCL)



Key person
Dr. Tiziana Rossetto, Director (Earthquake Engineering)
Dr. Ian Eames (Civil Engineering)
Dr. Ingrid Charvet (Civil Engineering)
Dr. Tristan Robinson (Mathematics)
Dr. Ioanna Loannou (Earthquake Engineering)
Dr. Anna Mason (Earthquake Engineering)

EPICentre (Earthquake and People Interaction Centre)
http://www.epicentreonline.com/

The Leverhulme Trust – International network grant
http://www.leverhulme.ac.uk/

Quantification of uncertainties in tsunami models from sources to impacts

University College Dublin (Ireland), GNS Science (New Zealand), Durham University (UK), Tohoku University (Japan), University of New Mexico (USA) and University College London (UK)

Key person
Prof. Peter Sammonds, Director (Earth Science)
Dr. Rosanna Smith, Deputy Director (Earth Science)
Prof. David Alexander (Disaster Science)
Dr. Serge Guillas (Statistical Science)
Dr. Simon Day (Earth Science)
Dr. Joanna Faure Walker (Earth Science)

IRDR (Institute for Disaster Risk Reduction)
http://www.ucl.ac.uk/rdr/

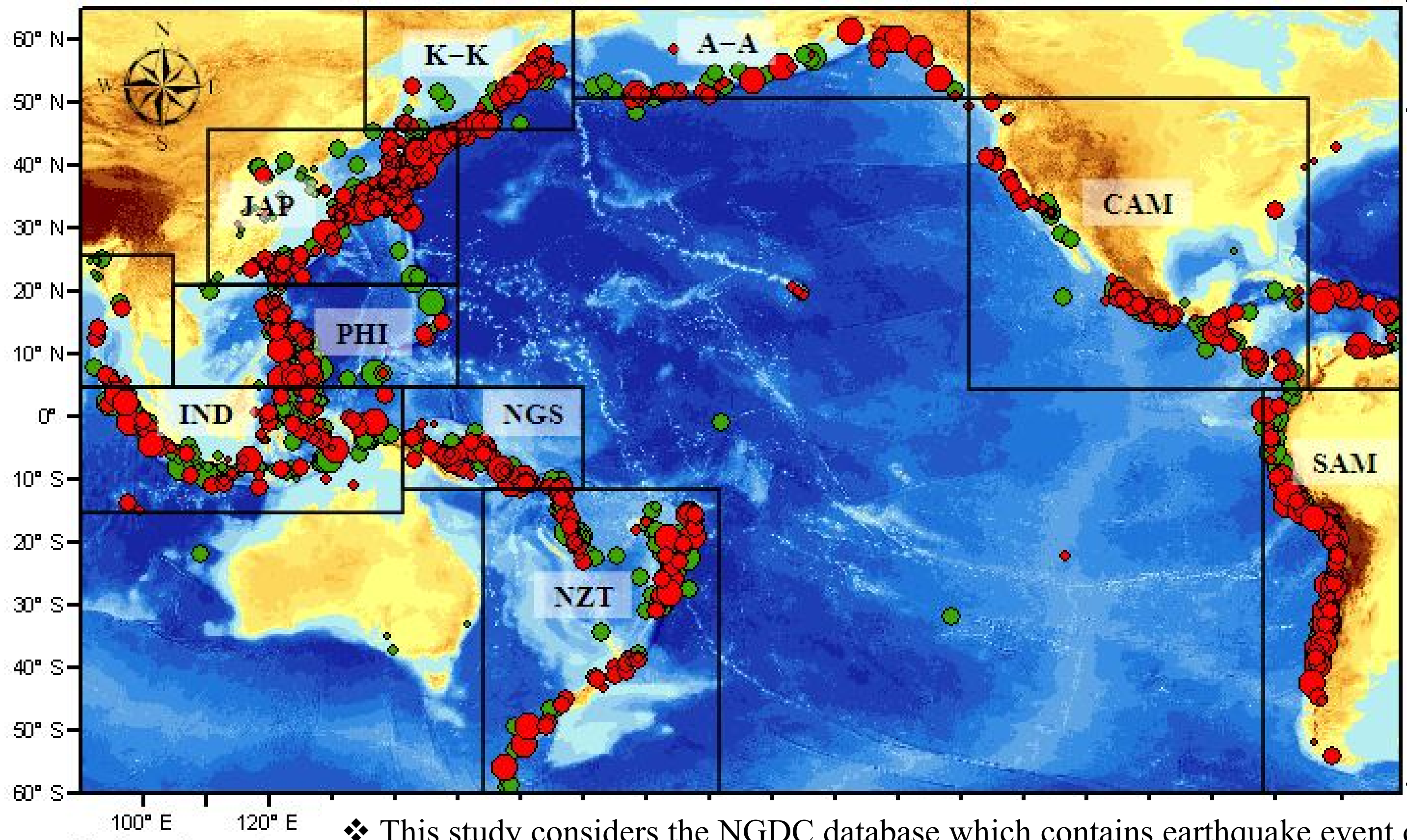
Tsunami Generation

Tsunami Propagation

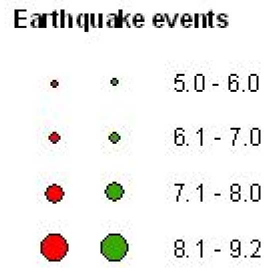
Tsunami Inundation
(Human and Building)

Tsunamigenic ratio in the Pacific Ocean

Earthquake events and tsunamigenic zone in the Pacific Ocean

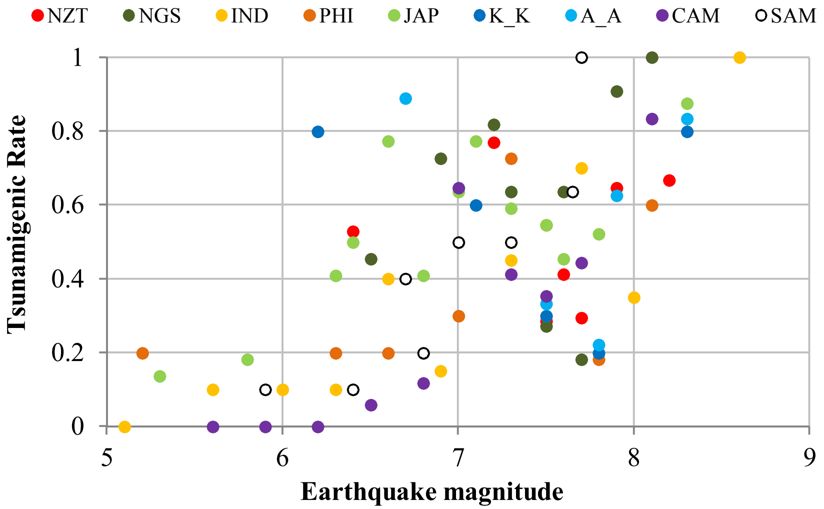


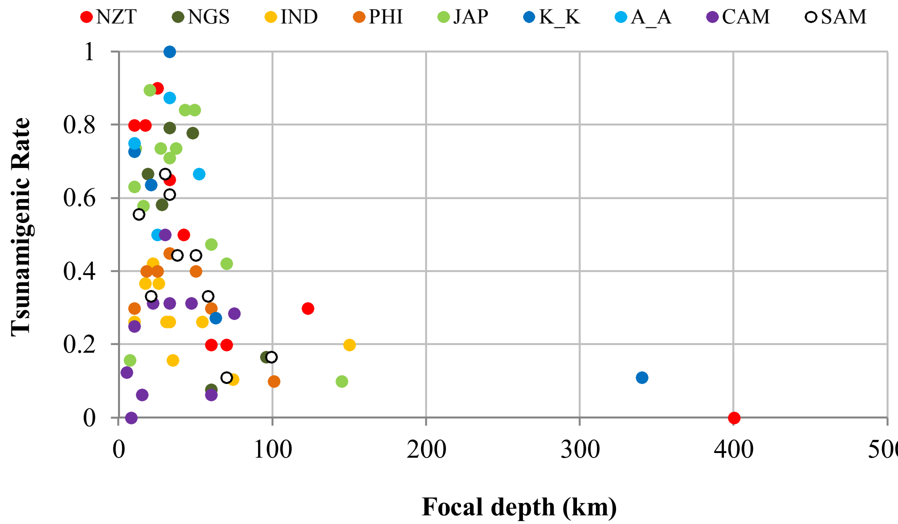
地域 Regions	略記 Abbrev.
New Zealand–Tonga	NZT
New Guinea–Solomon	NGS
Indonesia	IND1
Philippines	PHI
Japan	JAP
Kuril–Kamchatka	K–K
Alaska–Aleutians	A–A
Central America	CAM
South America	SAM

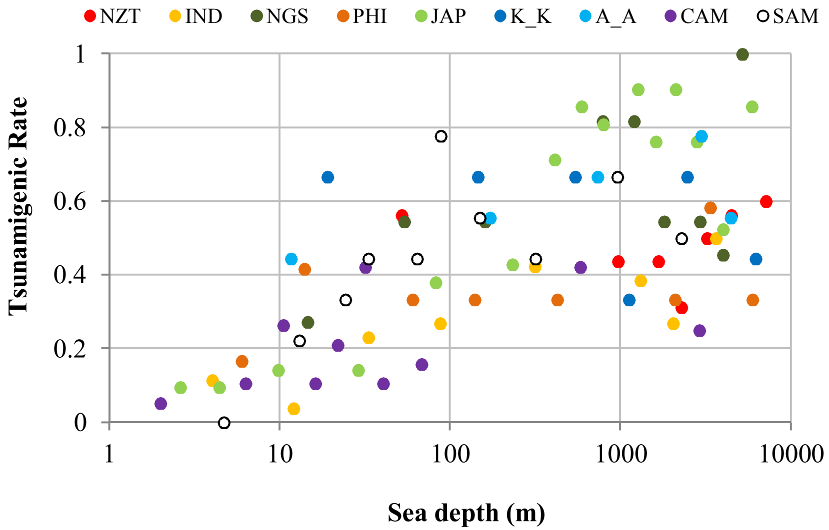


- ❖ This study considers the NGDC database which contains earthquake event of 200 B.C. to present (from year -193 to 2010) and separated into 4 different periods (pre-instrumental (prior 1900), early instrumental (1900-1962), instrumental (1963-1990) and modern instrumental (1991-present).
- ❖ The earthquake event excludes an event that the epicenter located longer 50 km from a shoreline.
- ❖ The Tsunamigenic Rate (TR) is calculated from earthquake event of the magnitude varies from 5.0 to 9.0, focal depth is as deep as 200 km and sea depth is as deep as 7,000 m.
- ❖ The Pacific Ocean is geographically divided into 9 regions namely, New Zealand–Tonga (NZT), New Guinea–Solomon (NGS), Indonesia (IND), Philippines (PHI), Japan (JAP), Kuril–Kamchatka (K–K), Alaska–Aleutians (A–A), Central America (CAM) and South America (SAM).

Tsunamigenic ratio for each region







Suppasri, A., Imamura, F. and Koshimura, S. (2012) Tsunamigenic Ratio of the Pacific Ocean Earthquakes and a proposal for a Tsunami Index, *Natural Hazards and Earth System Sciences, 12(1), 175–185*

- **Earthquake magnitude**

  Great earthquake magnitude → high possibility of tsunami occurrence (Generally > 7.0)

- **Focal depth**

  Shallow focal depth → high possibility of tsunami occurrence (Generally < 100 km)

- **Sea depth**

  Deep sea depth → high possibility of tsunami occurrence (Generally > 1,000 m)

Tsunami Generation

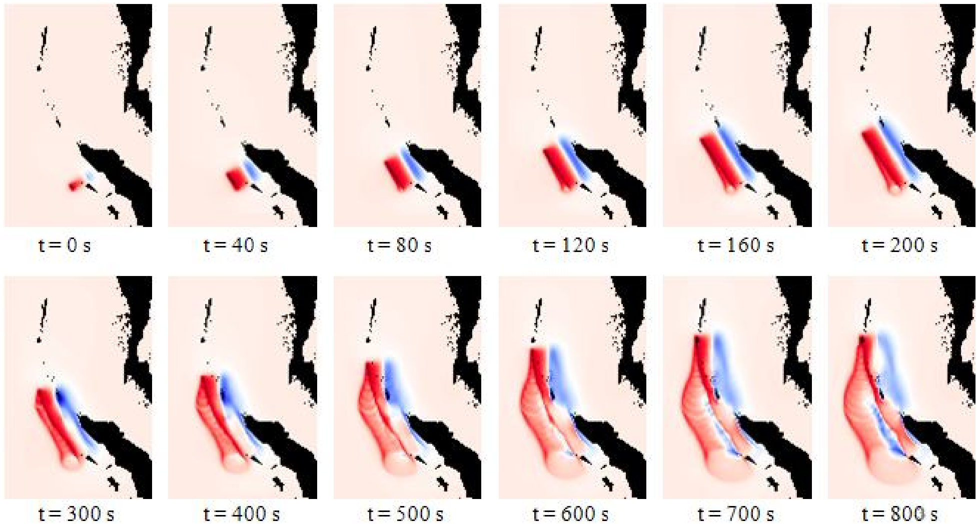
Tsunami Propagation

Tsunami Inundation
(Human and Building)

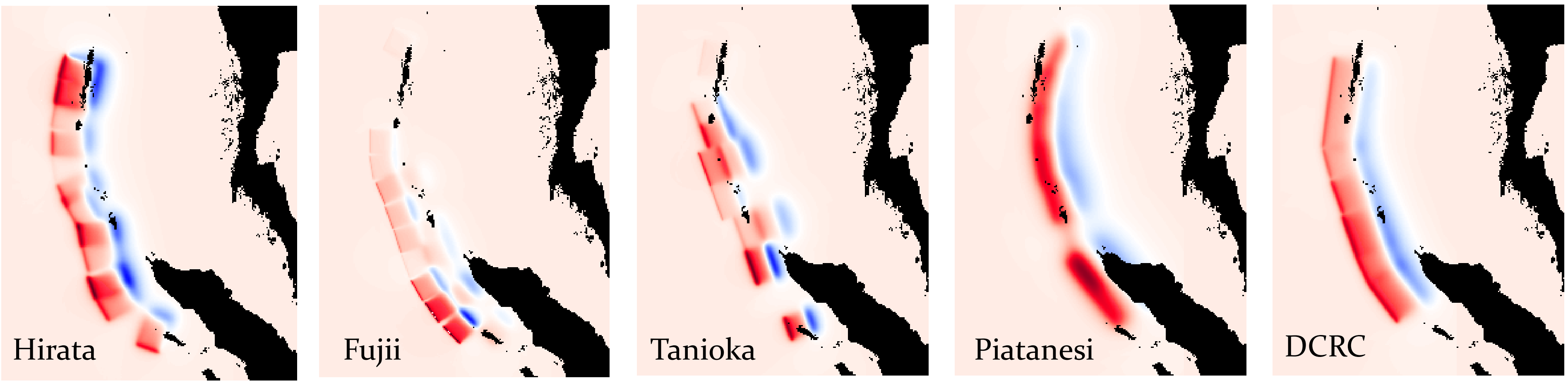
Effect of fault rupture velocity on tsunami propagation

Examples of the 2004 Indian Ocean tsunami

- DCRC (2007): Static model
- Hirata (2006) : Dynamic model, Vr = 0.7 km/s
- Fujii (2007) : Dynamic model, Vr = 1.0 km/s
- Tanioka (2006) : Dynamic model, Vr = 1.7 km/s
- Piatanesi (2007) : Dynamic model, Vr = 2.0 km/s

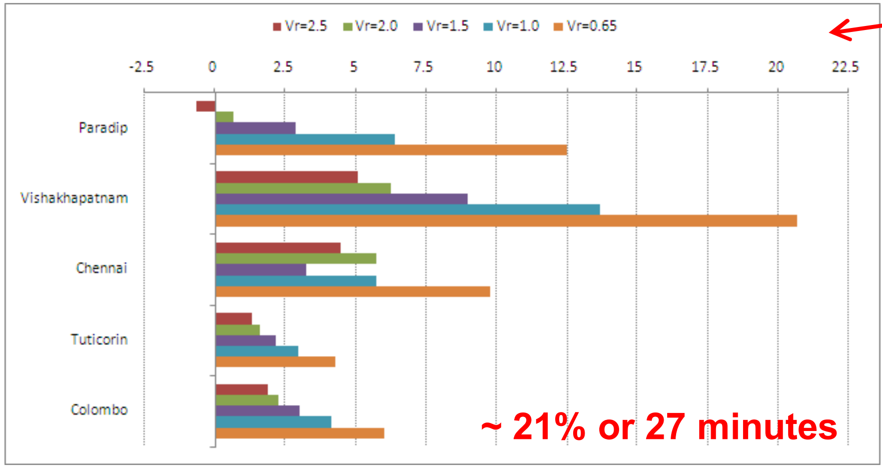


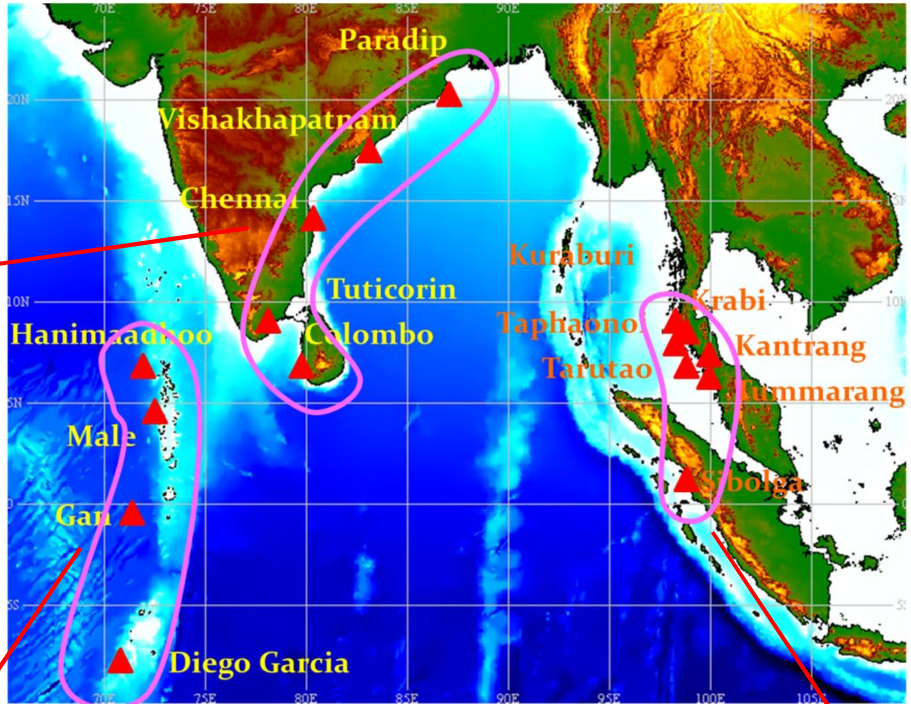
Suppasri, A., Imamura, F. and Koshimura, S. (2010) Effect of the rupture velocity of fault motion, ocean current and initial sea level on the transoceanic propagation of tsunami, *Coastal Engineering Journal*, 52(2), 107–132

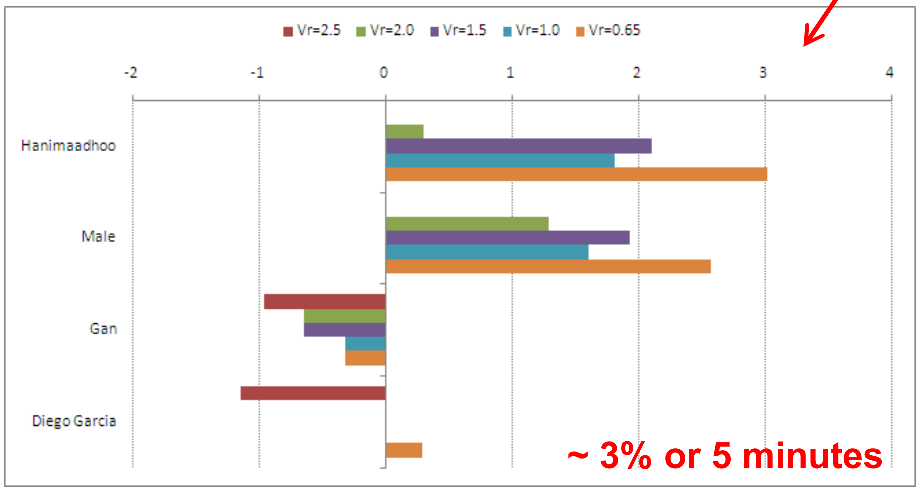


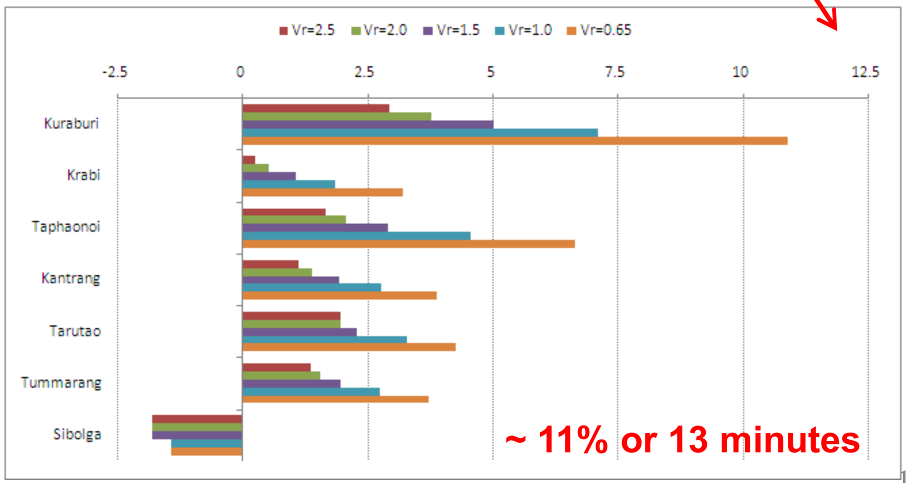
Effect of fault rupture velocity on tsunami propagation

Effect to tsunami arrival time at each tide gauge station around Indian Ocean

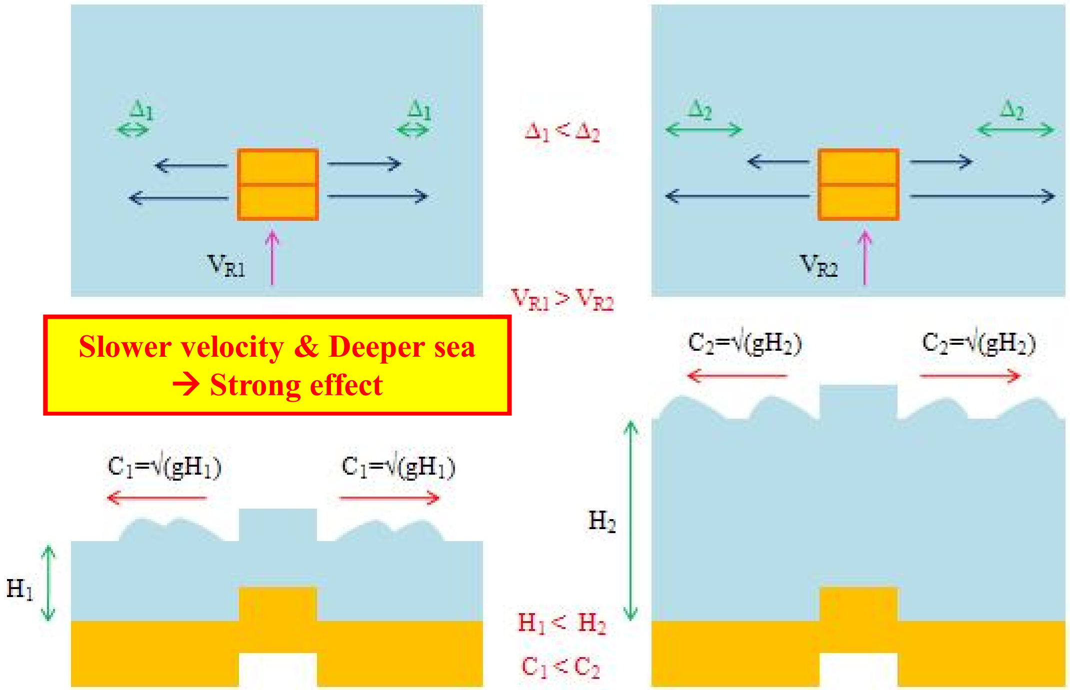




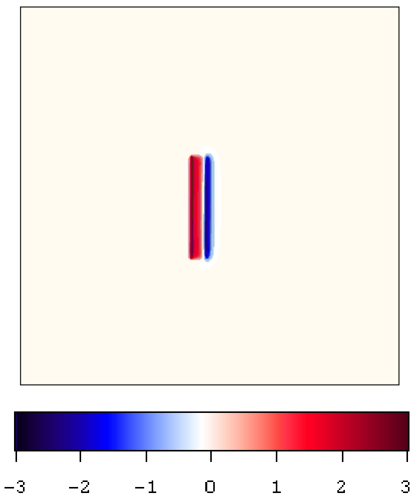




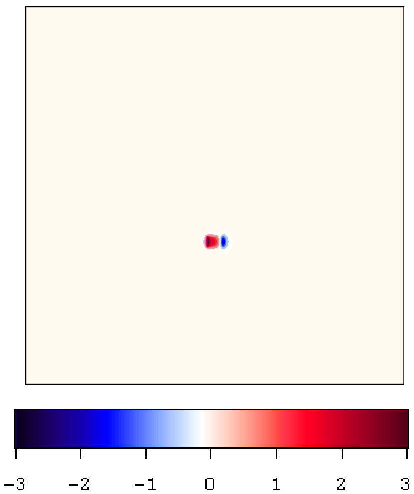
Numerical experiment:
Effect on tsunami amplitude and arrival time



Slower velocity & Deeper sea
→ Strong effect



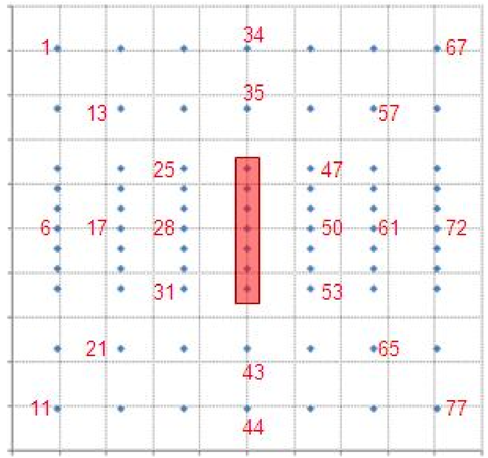
Simple fault with flat bottom
depth = 4000 m

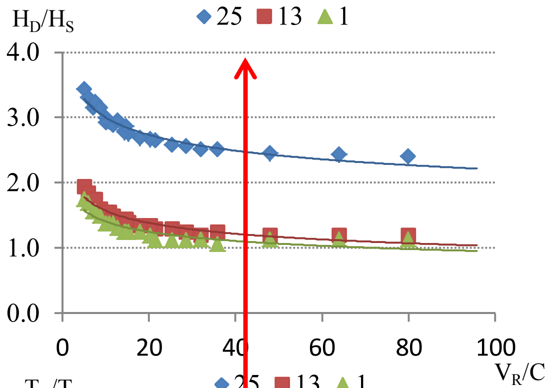


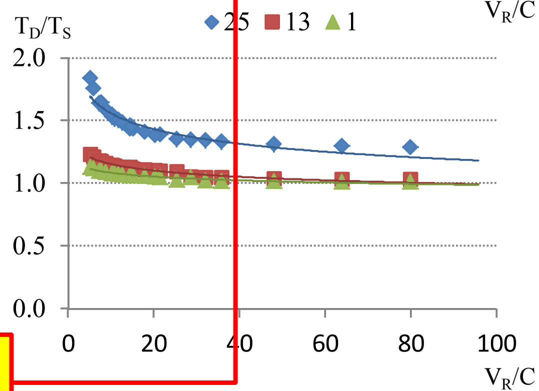
Velocity = 1.0 km/s (1.0 ~ 2.5)
depth = 4000 m (4000 ~ 100)

Location for output calculation

Fault length
= 1,000 km
Distance btw 2 points
= 500km







Non-dimensional V_R/C

V_R = Rupture velocity (m/s)
C = Tsunami velocity
= $(gH)^{1/2}$ (m/s)
g = Gravitational acceleration (m/s^2)
H = Sea depth (m)

Dynamic effect can be negligible if $V_R/C > 40$

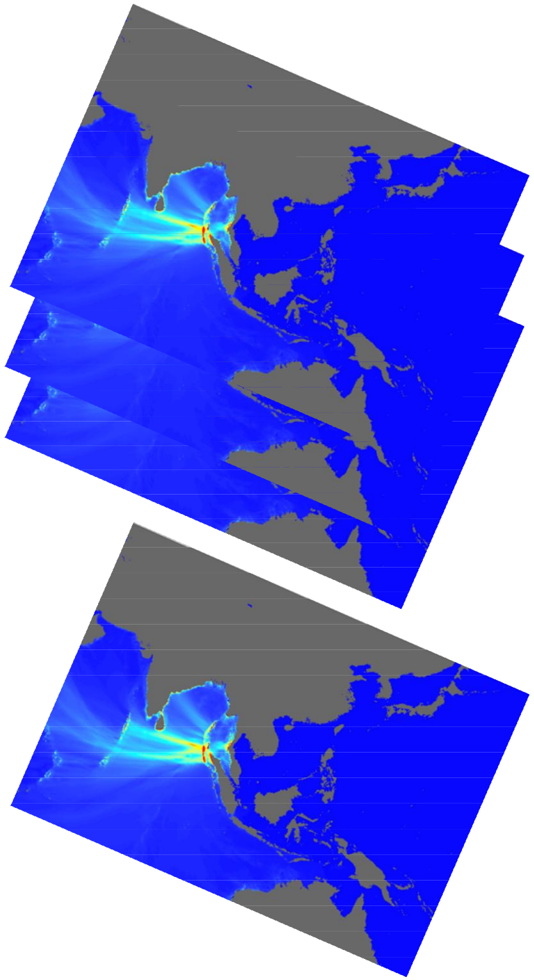
Tsunami Generation

Tsunami Propagation

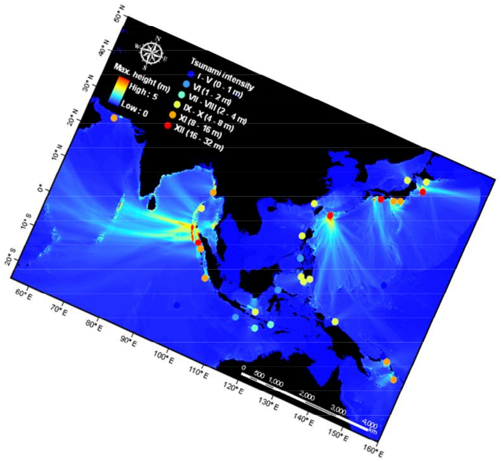
Tsunami Inundation
(Human and Building)

Tsunami hazard map for different recurrence

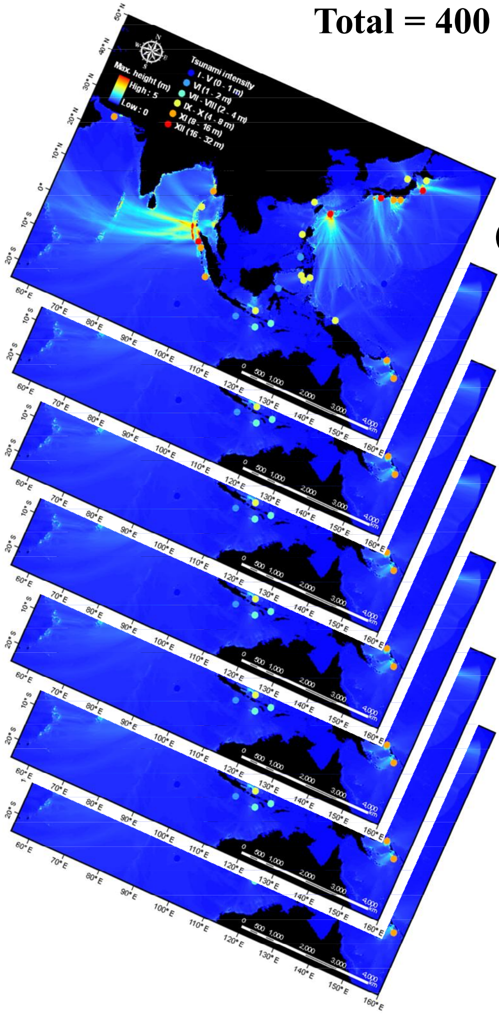
Tsunami hazard map from earthquake **M = 9.0**



M = 9.0
Combined hazard map
For one recurrence (Magnitude)



Tsunami hazard map for different recurrence (Magnitude)
Total = 400 cases



M = 9.3 (1,000 km)

M = 9.0 (600 km)

M = 8.9 (500 km)

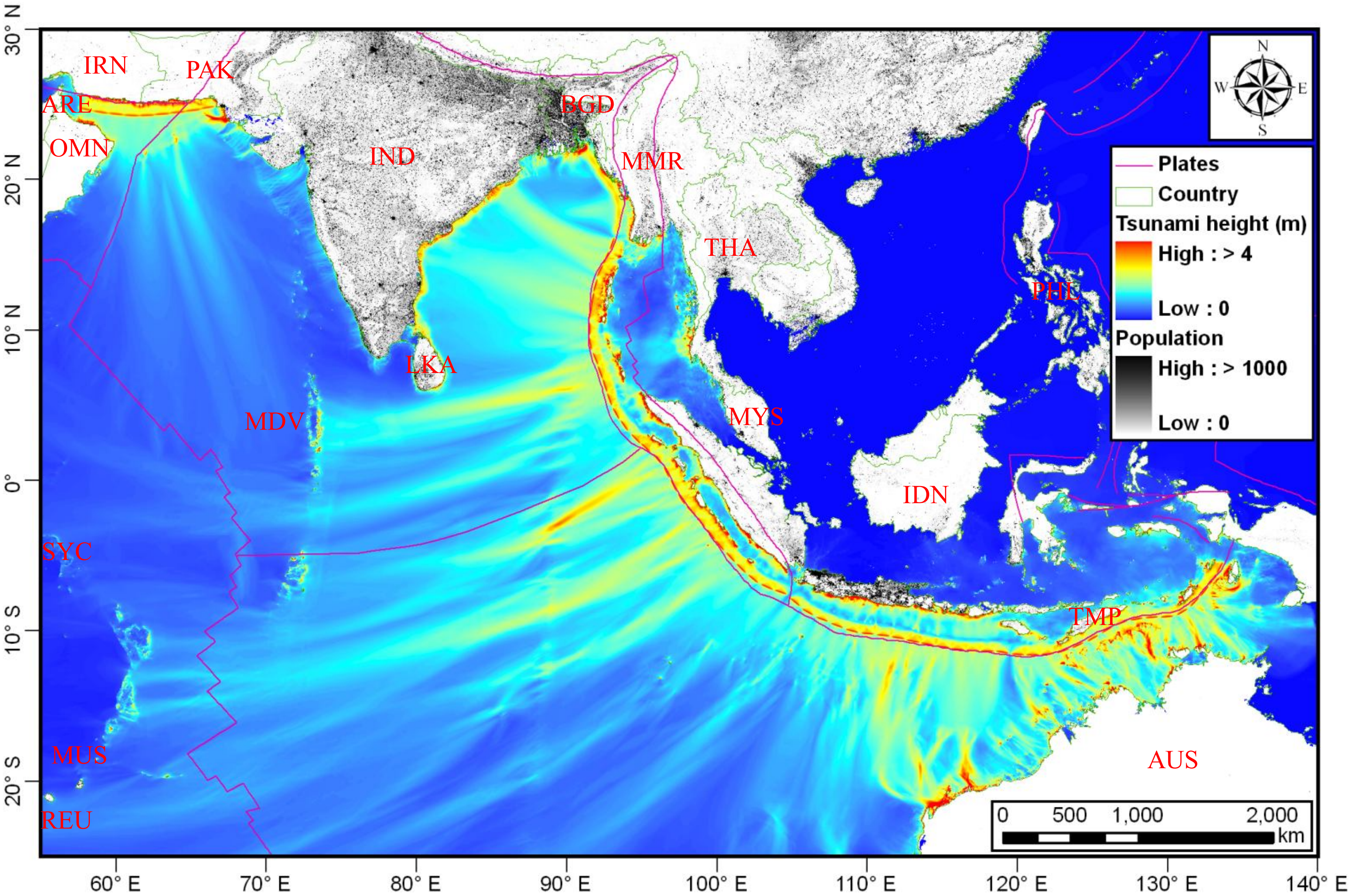
M = 8.7 (400 km)

M = 8.5 (300 km)

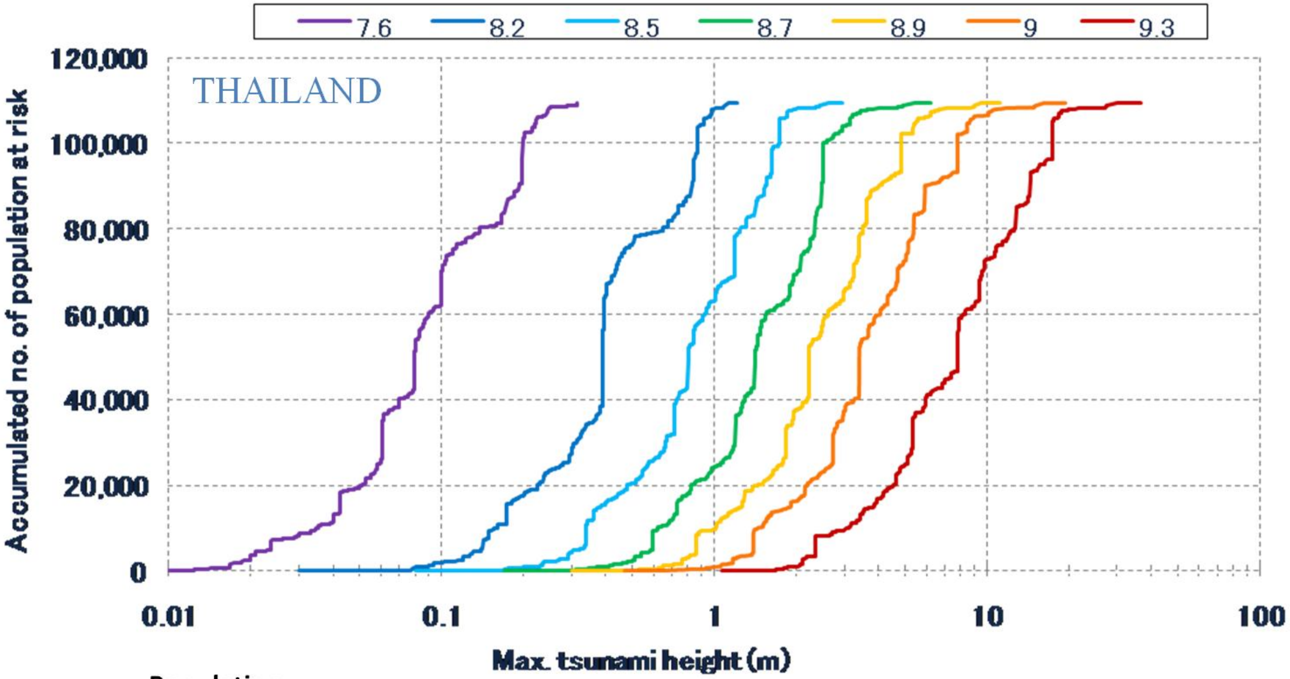
M = 8.2 (200 km)

M = 7.6 (100 km)

Indian Ocean tsunami hazard map for M=9.0



Risk assessment for coastal population



Country's tsunami risk level

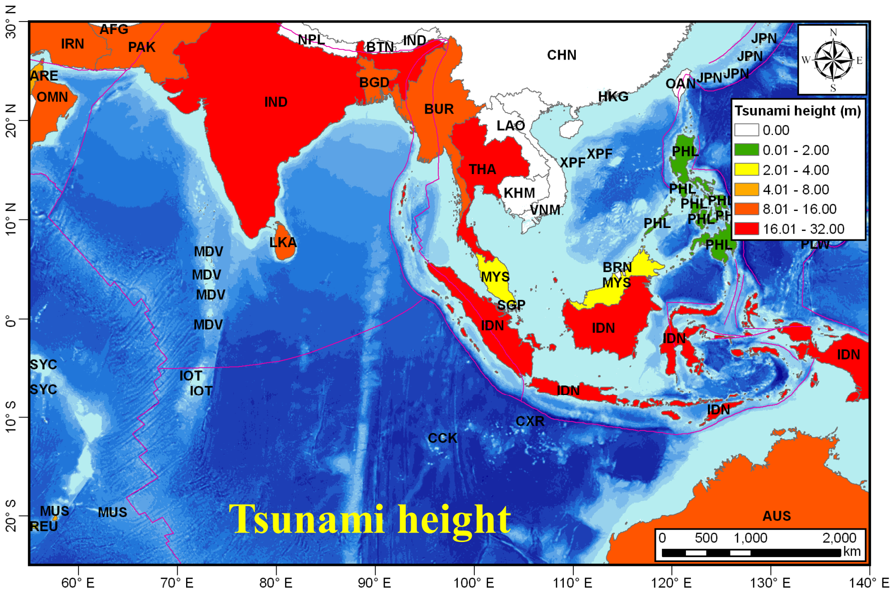
Mw	Tr (yr)	Max. level	Avg. level
9.3	600	81	21
9.0	450	64	18
8.9	400	63	16
8.7	325	54	14
8.5	250	45	11
8.2	170	35	8
7.6	65	18	4

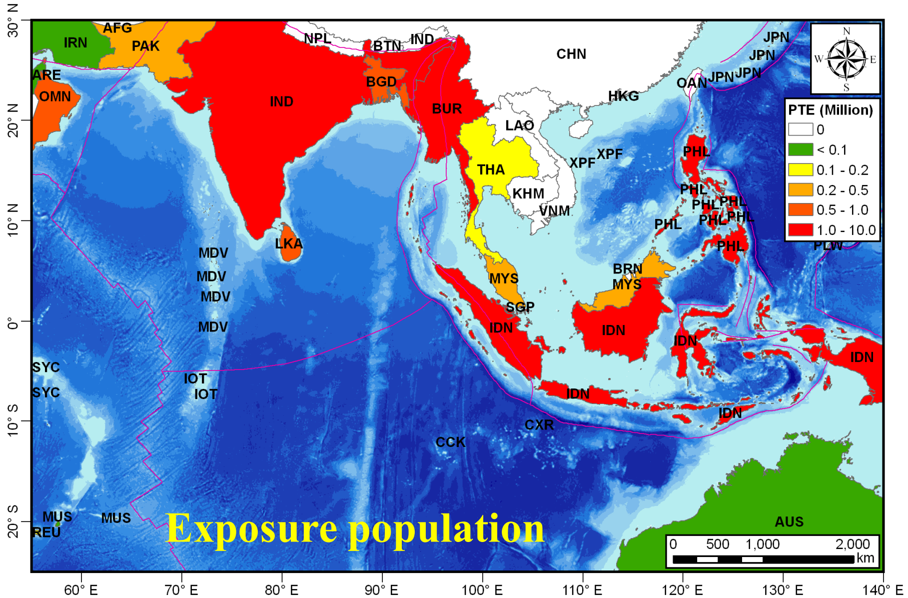
	Population per km²	= 1	< 5	< 10	< 50	< 100	< 500	< 1,000	< 5,000	< 10,000	> 10,000
Height (m)	Score	1	2	3	4	5	6	7	8	9	10
< 0.125	1	1	2	3	4	5	6	7	8	9	10
< 0.25	2	2	4	6	8	10	12	14	16	18	20
< 0.5	3	3	6	9	12	15	18	21	24	27	30
< 1	4	4	8	12	16	20	24	28	32	36	40
< 2	5	5	10	15	20	25	30	35	40	45	50
< 4	6	6	12	18	24	30	36	42	48	54	60
<8	7	7	14	21	28	35	42	49	56	63	70
< 16	8	8	16	24	32	40	48	56	64	72	80
< 32	9	9	18	27	36	45	54	63	72	81	90
> 32	10	10	20	30	40	50	60	70	80	90	100

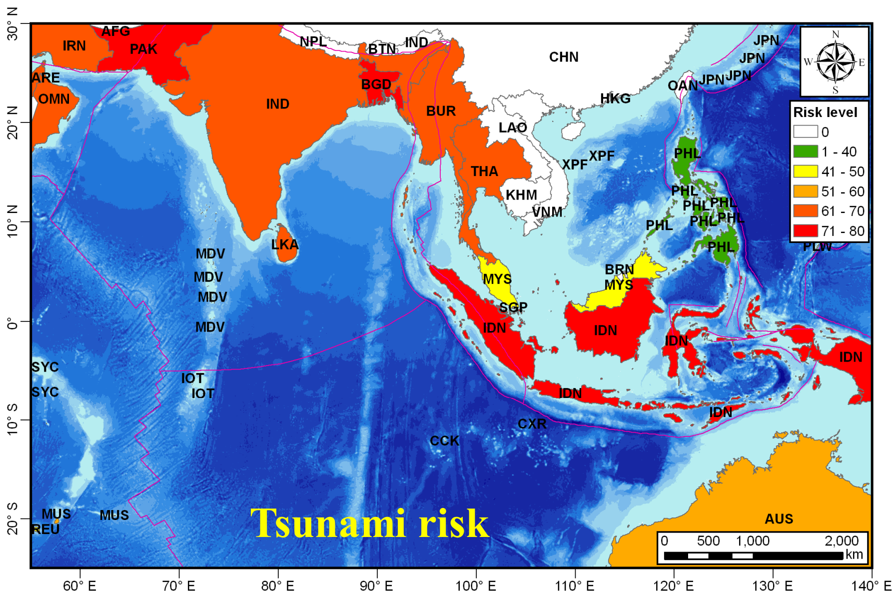
Calculation method of "Risk level"

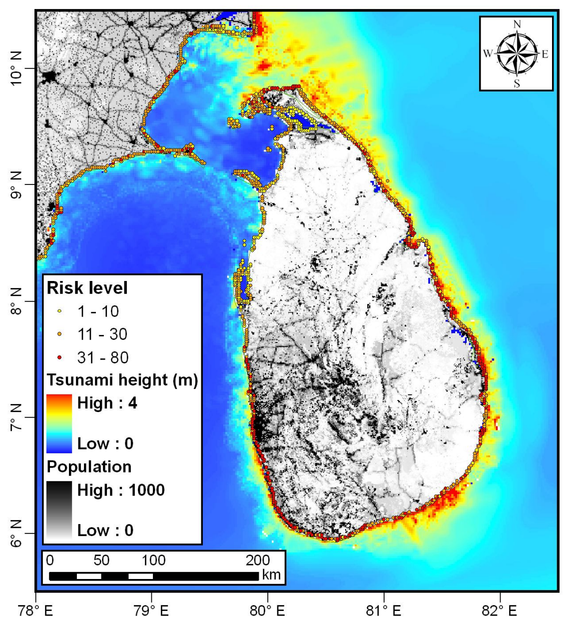
- Exponential scale
- Score range 1 - 10
- Max. level = 100
- Easy to understand

Tsunami risk map for M_w 9.0 earthquake



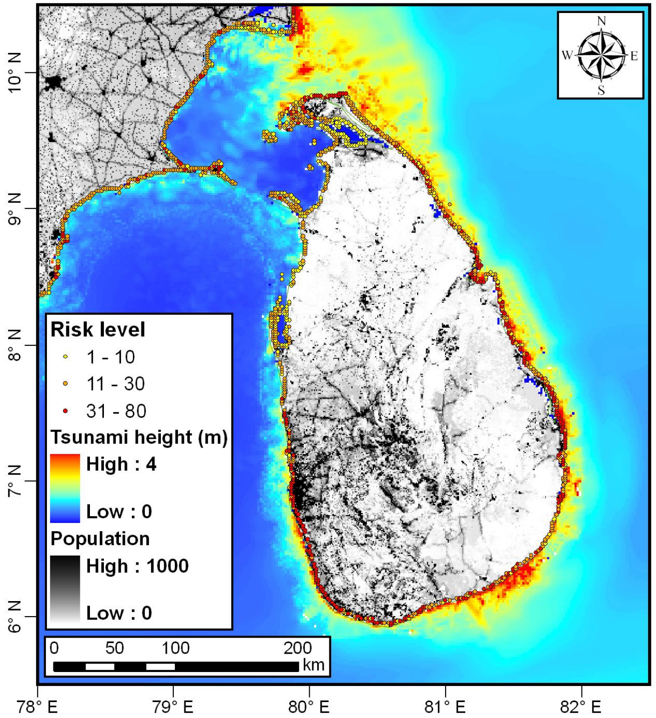


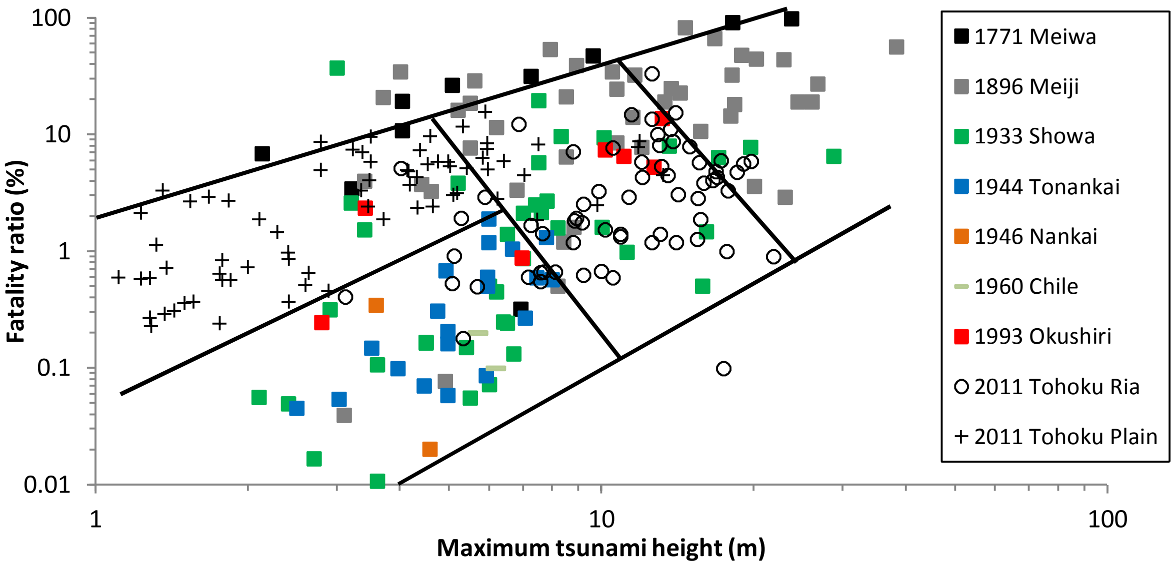




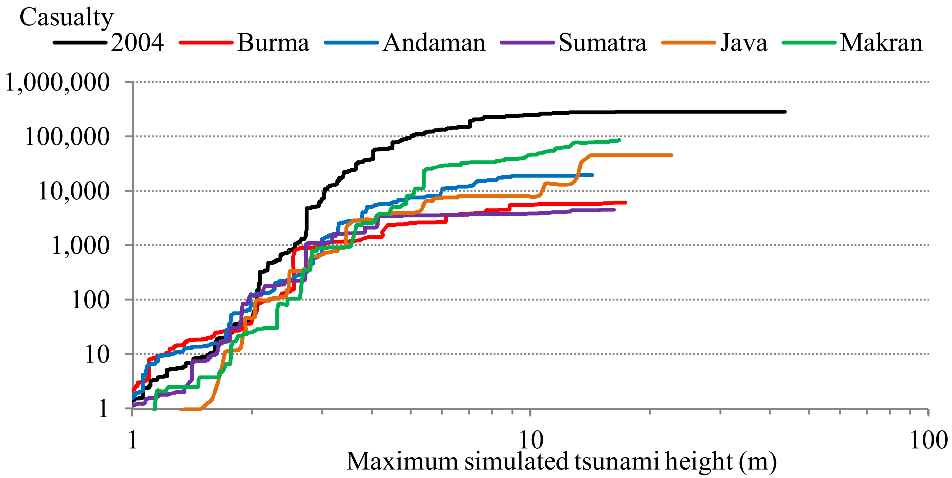
Example for one country

Rough estimation of number of casualty





Tsunami fatality ratio



Nearly 100,000 in Makran and Java.
About 30,000 for Andaman.
Nearly 10,000 for Burma and Sumatra.

Estimation of possible casualty in the Indian Ocean

Tsunami Generation

Tsunami Propagation

Tsunami Inundation
(Human and Building)

Criteria for structural destruction by tsunami

Tsunami event	Location	Frame	Damage description as a function of inundation depth
Multiple events [Shuto, 1993 and Matsutomi and Harada, 2010]	Various	Wood	< 1.5 m: moderate damage
			< 2.0 m: severe damage
		Concrete block	< 3.0 m: moderate damage
		RC	< 7.0 m: severe damage
2006 Java tsunami [Reese et al., 2007]	South Java, Indonesia	Wood/bamboo	< 1 m: light to moderate damage
			1.5 – 2.0 m: 70% destroyed, 30% lightly to heavily damaged but repairable
			> 2 m: total destruction
		Brick traditional	< 1 m: light to moderate damage
			1.5 – 2.0 m: 70% destroyed, 30% lightly to heavily damaged but repairable
			> 2 m: some houses remained but not repairable
		Brick with RC column	< 1 m: minor damage only
			1.5 – 2.0 m: light to moderate damage (repairable)
			3.0 – 4.0 m: serious damage but probably repairable
		RC with brick wall	< 1 m: zero to light damage
			1.5 – 2.0 m: light to moderate damage (repairable)
			3.0 – 4.0 m: moderate damage but repairable
2004 Indian Ocean tsunami [Ruangrassamee et al., 2006 and Suppasri et al., 2011]	Southern Thailand	Wood	< 1.5 m: no damage up to damage to secondary members only
			< 2.5 m: damage to some primary members up to collapse
			> 3 m: collapse
		RC with brick wall	< 1.0 m: no damage
			1.0 – 2.0 m: no damage up to damage to secondary members only
			2.0 – 3.0 m: damage to secondary up to some primary members
			> 3.0 m: damage to some primary members up to collapse
			> 7.0 m: collapse
2011 East Japan tsunami [Suppasri et al.., 2012]	Miyagi prefecture, Japan	Wood	> 2.5 m: minor damage
			> 3.0 m: moderate damage
			> 4.0 m: major damage
			> 4.5 m: completely damage

Developing fragility curves

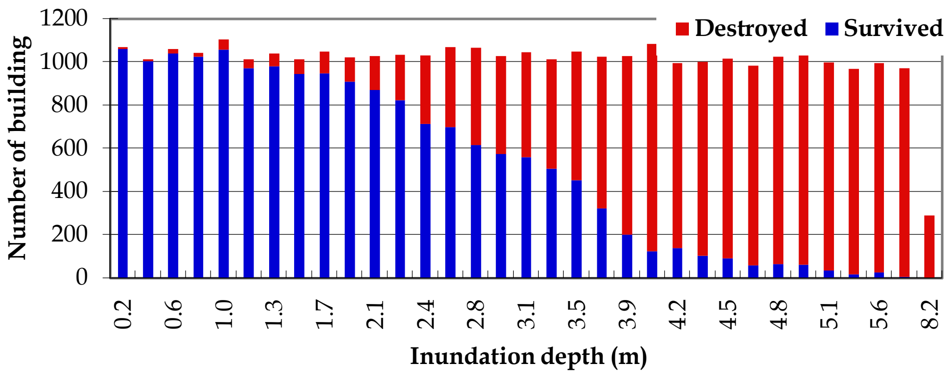
Field survey VS Simulation + Satellite image

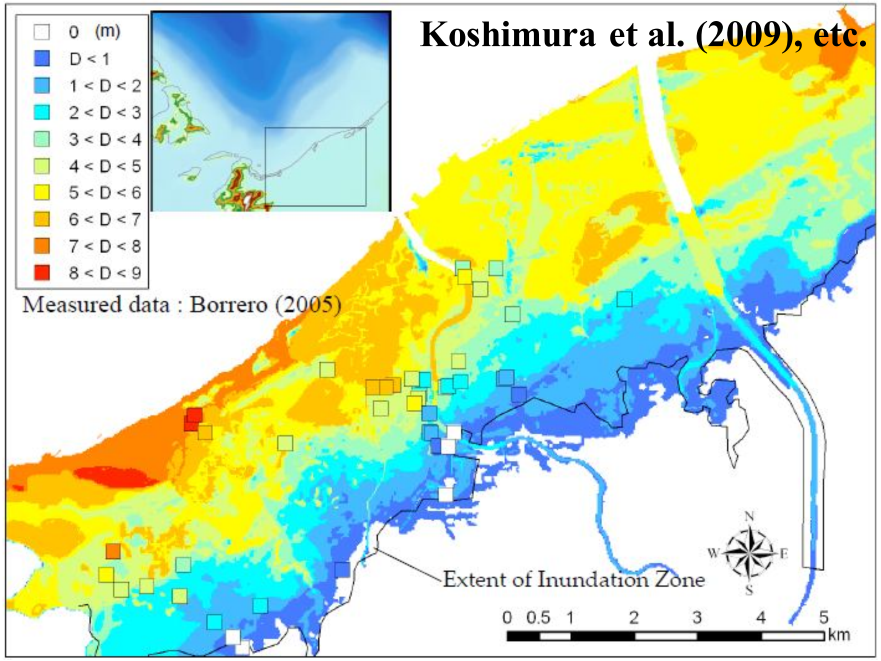
Only inundation depth	Include velocity, force
Multi damage level	Only for washed away
Small area but high accuracy	Large area but accuracy?

Level 1: Roof and wall

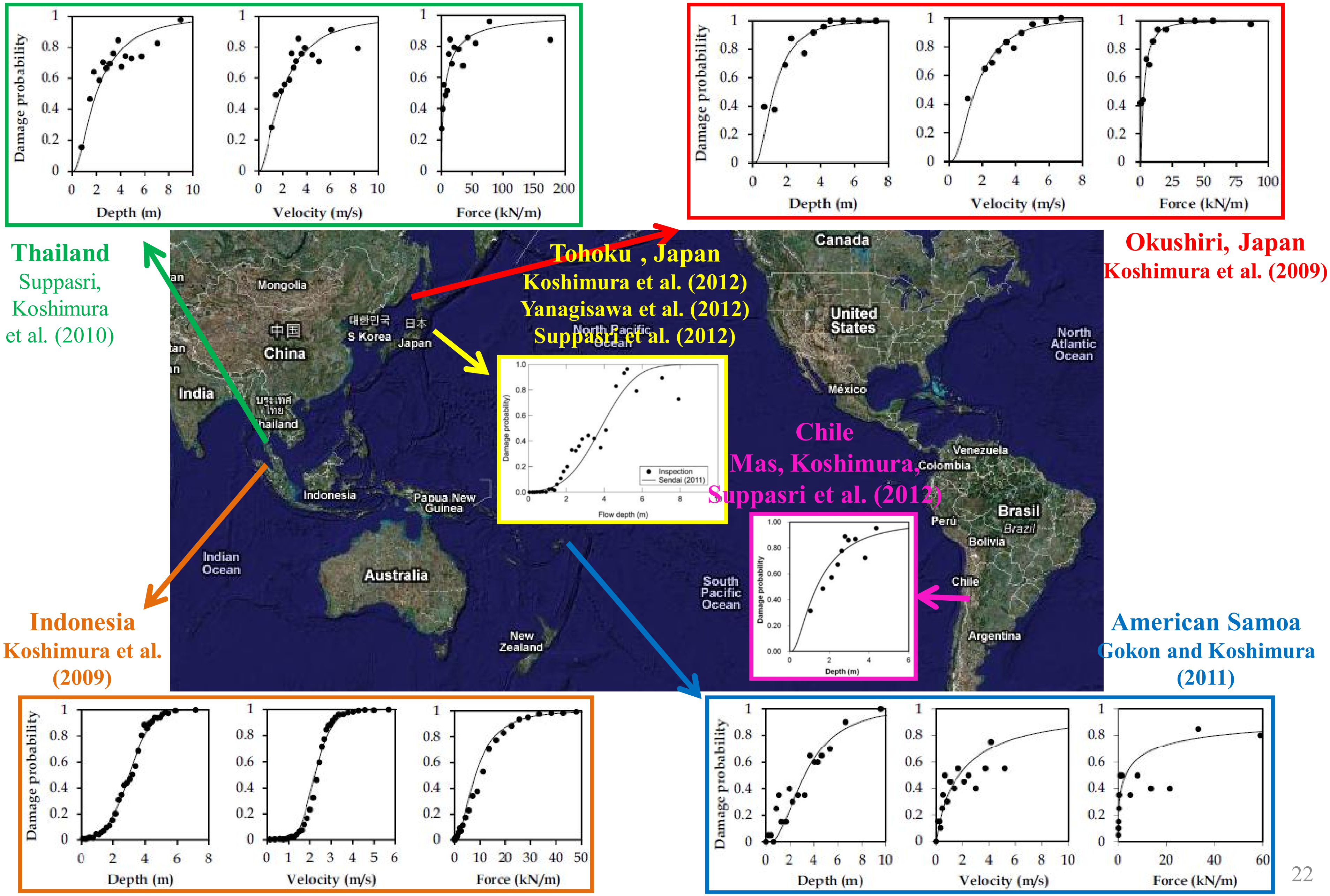
Level 2: Beam and column

Level 3: foundation





Global tsunami fragility curves



Tsunami fragility curves based on the 2011 tsunami data

VERSION 1

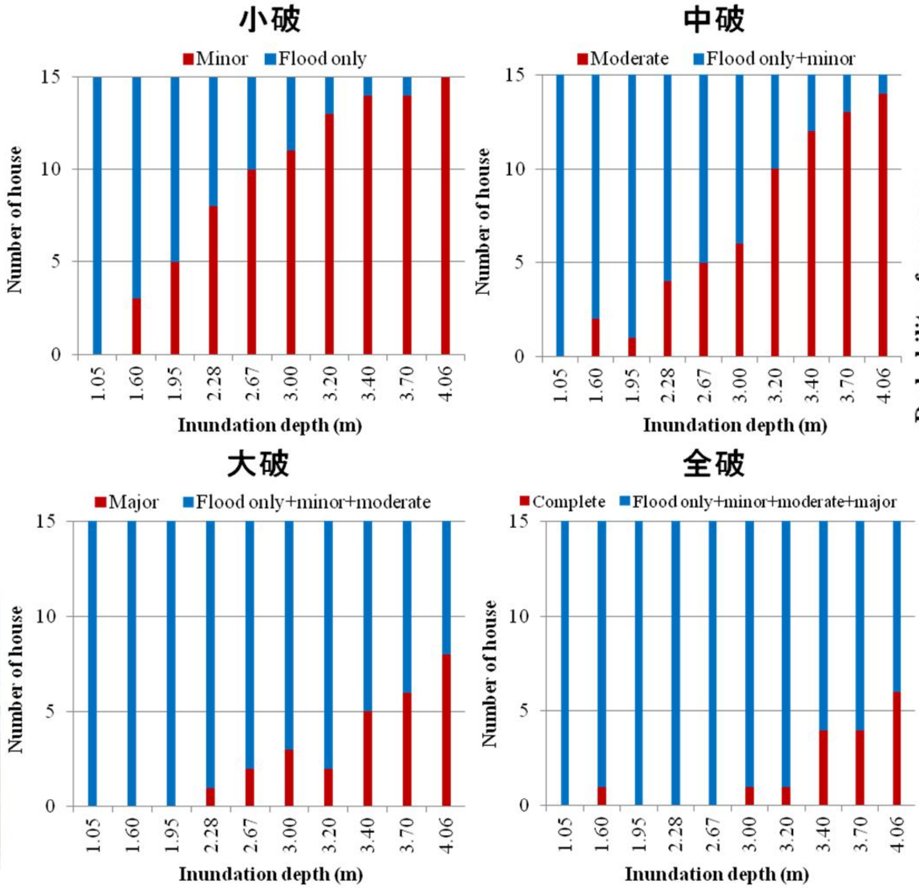
Minor damage

Moderate damage

Major damage

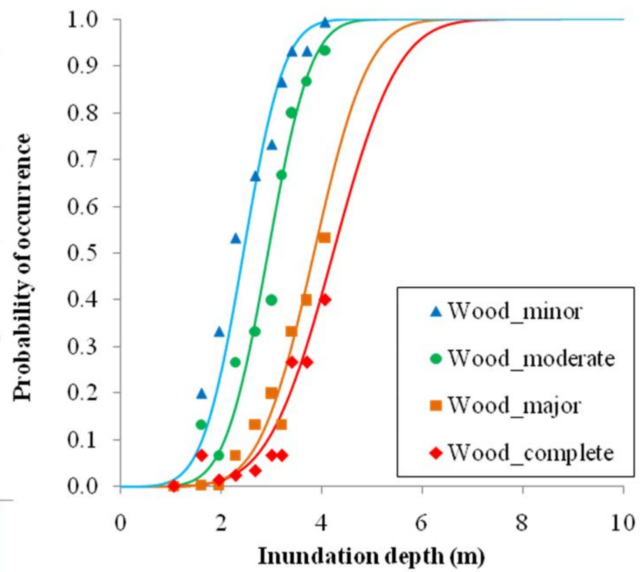
Complete damage

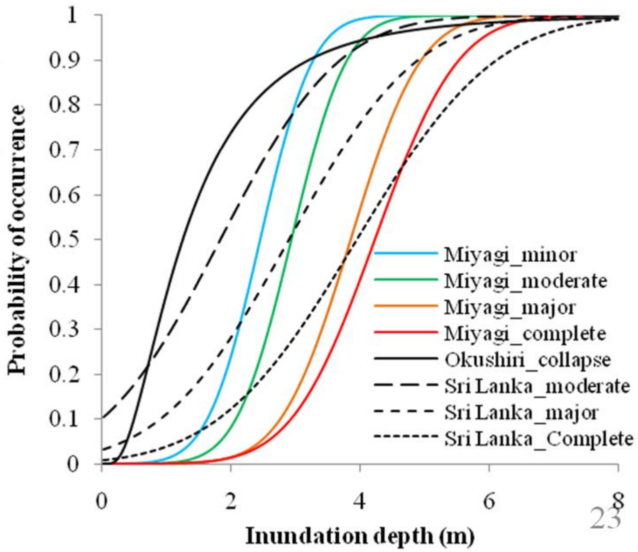
Inundation depth measured at 150 wooden houses in Ishinomaki and Sendai Plain



Inundation depth and number of damaged house (Blue: Not damage and Red: Damaged)

Suppasri, A., Mas, E., Koshimura, S., Imai, K., Harada, K. and Imamura, F. (2012) Developing tsunami fragility curves from the surveyed data of the 2011 Great East Japan tsunami in Sendai and Ishinomaki Plains, *Coastal Engineering Journal*, 54(1), 1250008



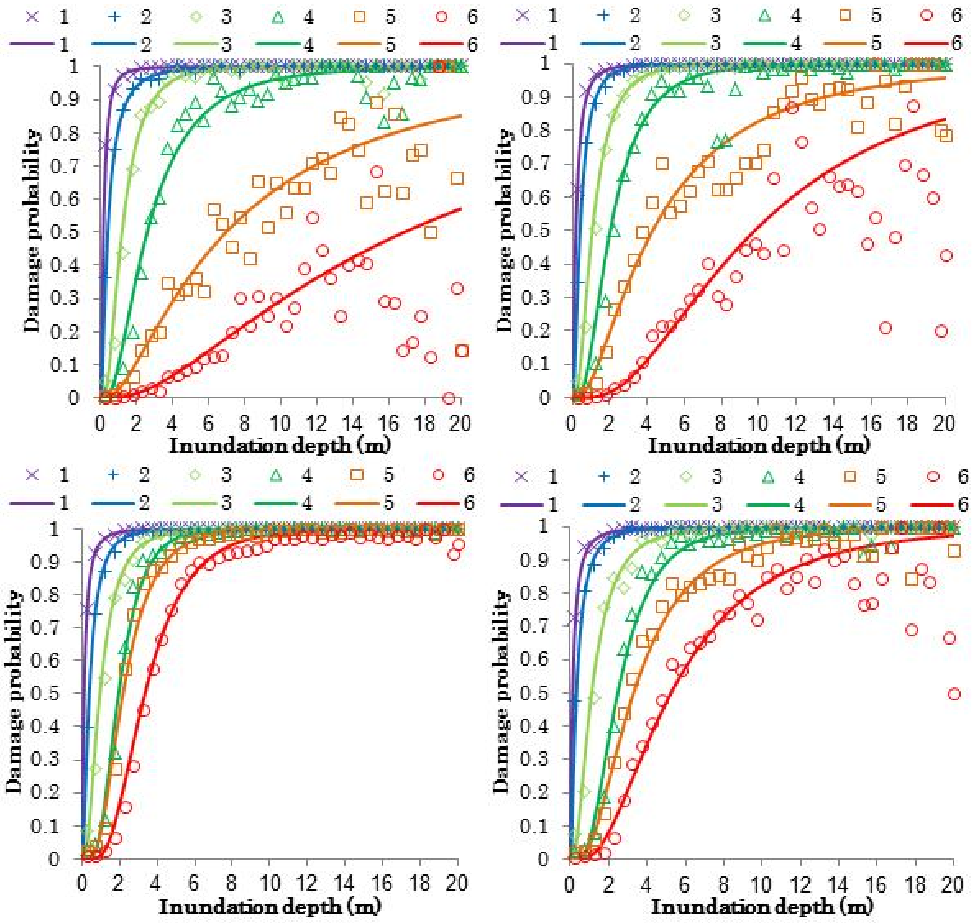


Classified building material and no. of story

VERSION 2

About 250,000 buildings in MLIT database but no detail for each building
http://www.mlit.go.jp/toshi/toshi-hukkou-arkaibu.html

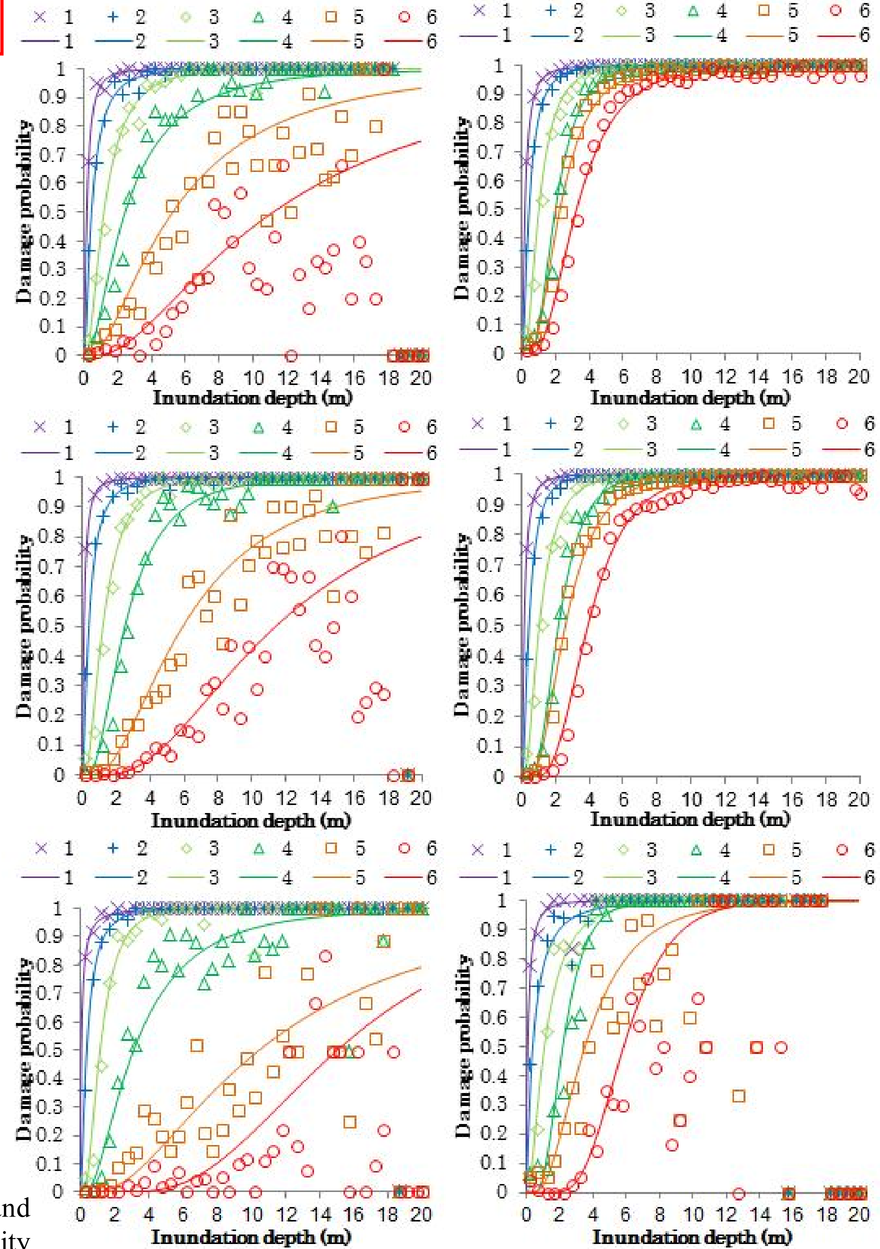
RC **Steel**



Wood **Masonry**

RC
1, 2 and > 3 stories

Wood
1, 2 and > 3 stories



Suppasri, A., Mas, E., Charvet, I., Gunasekera, R., Imai, K., Fukutani, Y., Abe, Y. and Imamura, F. (2012) Building damage characteristics based on surveyed data and fragility curves of the 2011 Great East Japan tsunami, *Natural Hazards*, (published online)

Problems to be solved in the future

Tsunami generation: Need to consider more on earthquake fault parameter such as dip, rake and slip and apply more statistical parameters

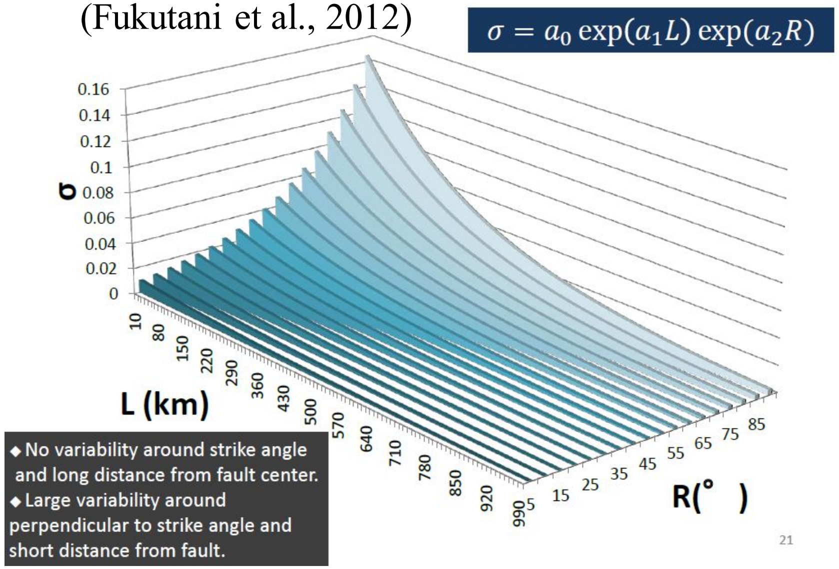
Tsunami propagation: Need to apply a Probabilistic Tsunami Hazard Analysis (PTHA)

Tsunami inundation

Impact to human: Need to further discuss on human behavior effect and applying tsunami evacuation model based on results from questionnaire surveys

Impact to building: Need to consider more on impact from different coastal topography, building function, construction year, surrounding environment and floating debris

Uncertainties from effect of rupture velocity (Fukutani et al., 2012)



Evacuation model applied to Thailand (Erick and Suppasri et al, 2012)


ご静聴ありがとうございました
Sendai
Natori
Iwanuma
Watari
Yamamoto