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Earthquake Risk in Indonesia: How worried should we be?

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Outline

Australian Government
Geoscience Australia

- Earthquake hazard and Risk
- Java Population and Urbanisation
- Tectonics of Indonesia
  - Sunda Megathrust
  - Flores Back-arc Thrust
  - Palu-Koro Fault
- Java Historical Earthquakes
- Jakarta seismic hazard and risk
- Building Fragility and Construction Practice

Acknowledgements:

Australian Aid

Institut Teknologi Bandung 1959

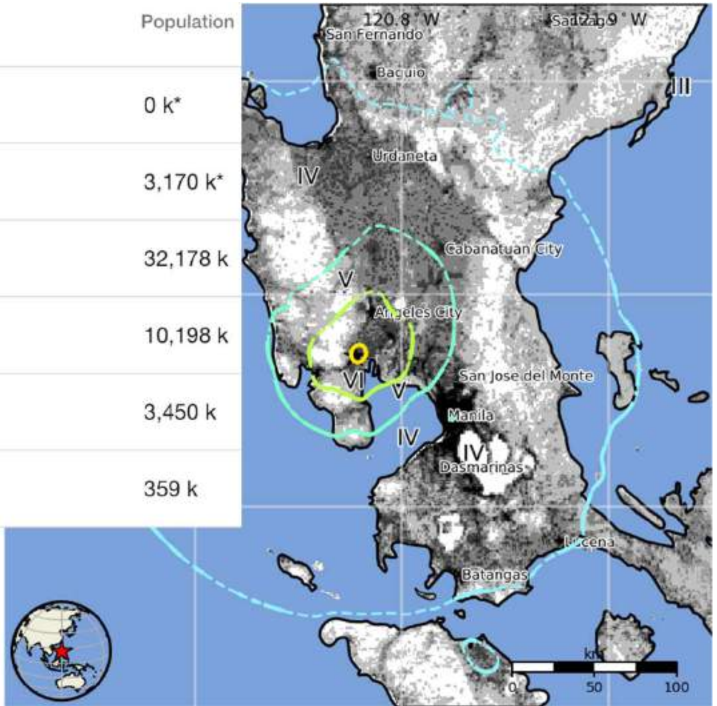
Badan Informasi Geospasial

LIPI

Expect the unexpected

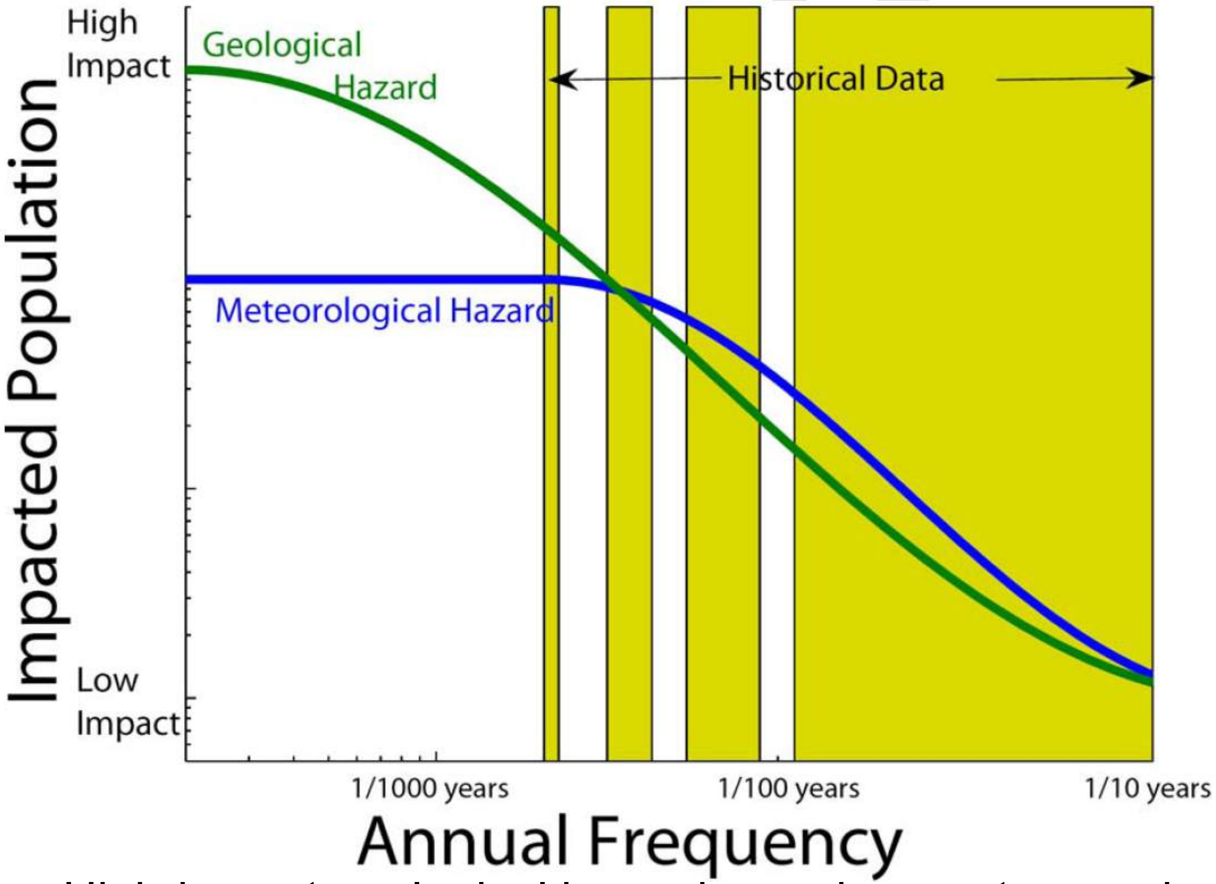
Mag 6.1 Earthquake 80 km from Manila caused light shaking - so why all the water?

MMI	Shaking	Population
I	Not Felt	0 k*
II-III	Weak	3,170 k*
IV	Light	32,178 k
V	Moderate	10,198 k
VI	Strong	3,450 k
VII	Very Strong	359 k



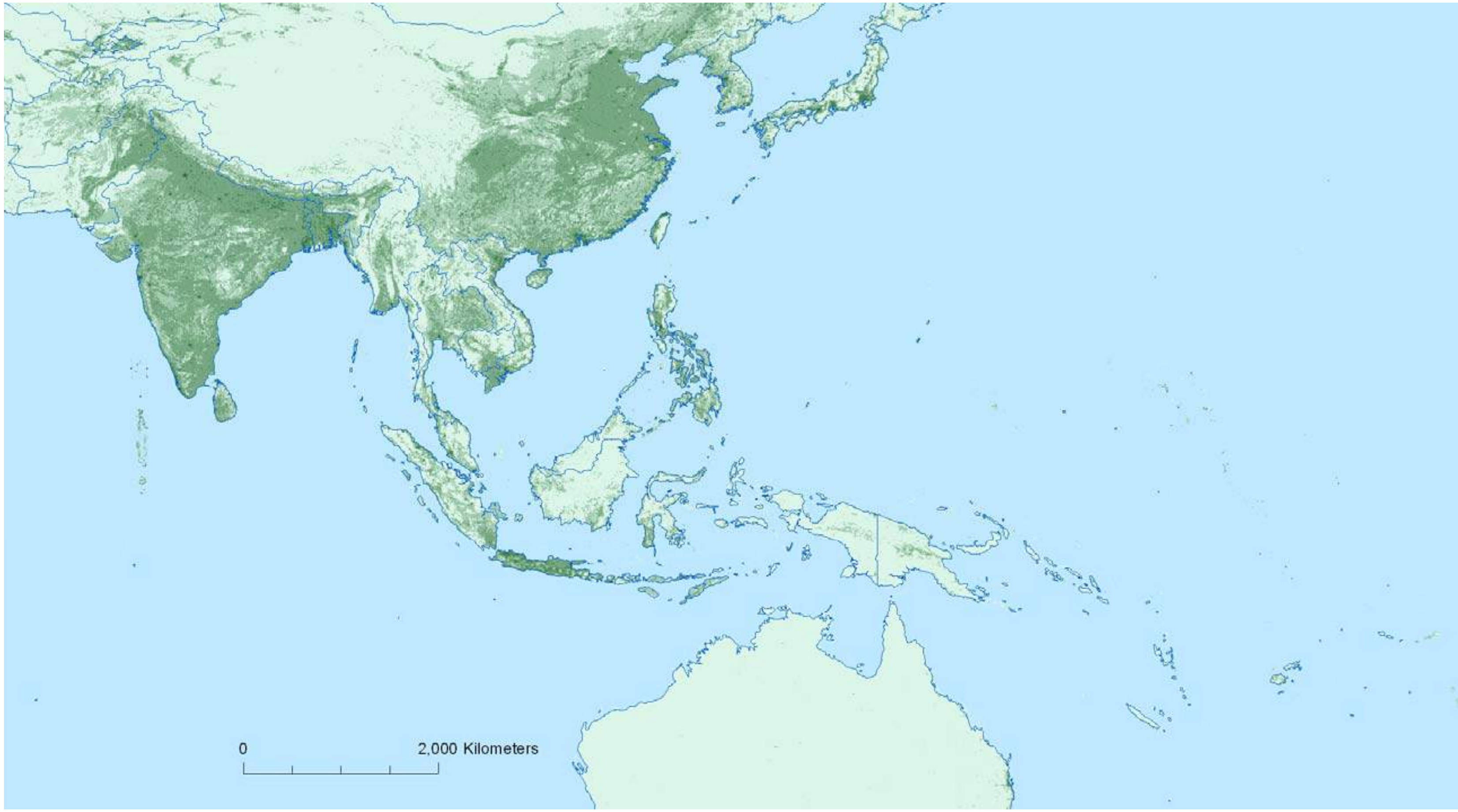
(US Geological Survey)

Can Hazard be Inferred from Historical Experience?



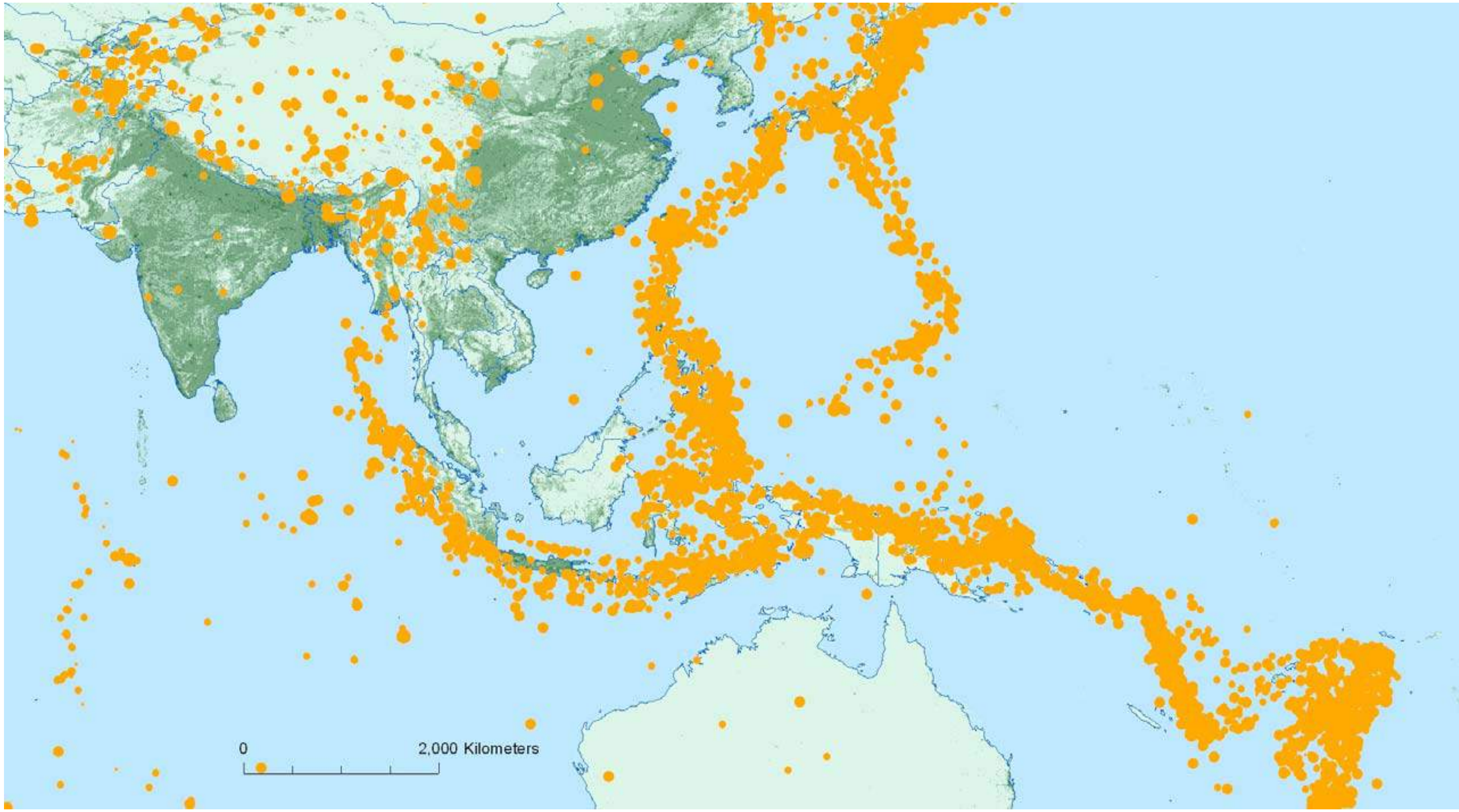
High-impact geological hazards can have return periods much longer than the historical record.

Exposure: Population

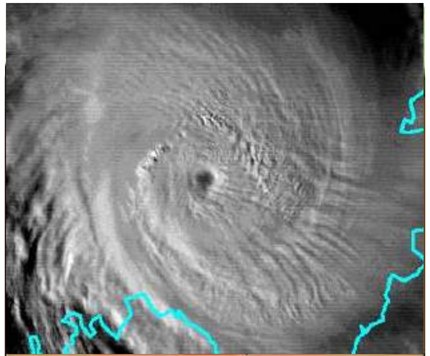


Hazard: Earthquakes

480 million people in the Asia-Pacific live in areas of high to very high earthquake hazard.



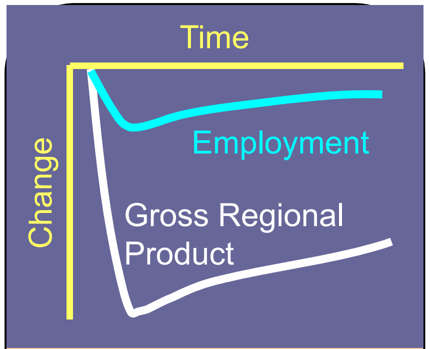
Hazard X Exposure X Vulnerability = Risk/Impact



Hazard

Exposure

Vulnerability



Impact

If hazard, exposure or vulnerability increase, so does risk.

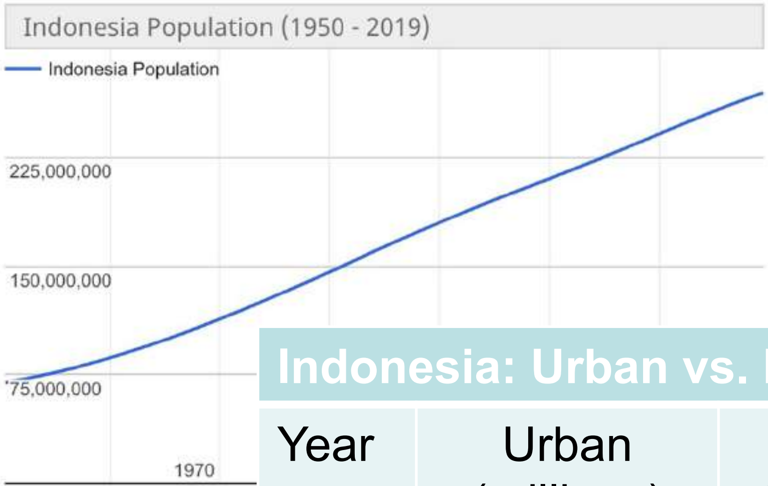
If all three increase, we are in big trouble…

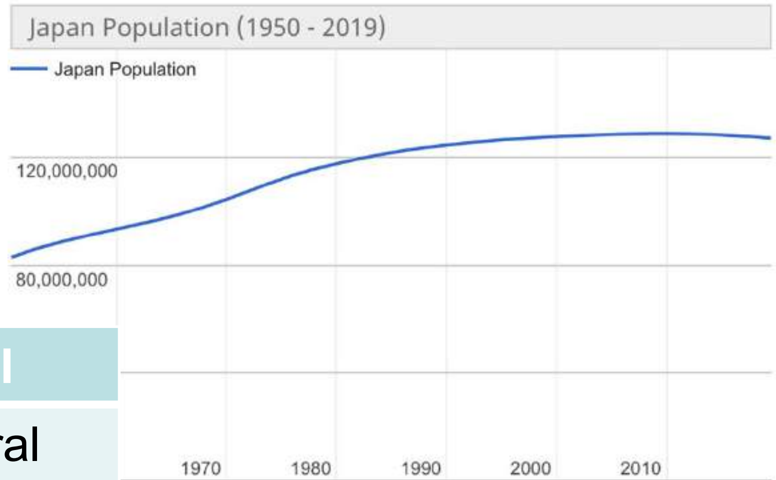
Indonesia Population (LIVE)

268,371,783

Japan Population (LIVE)

126,994,018





Indonesia: Urban vs. Rural

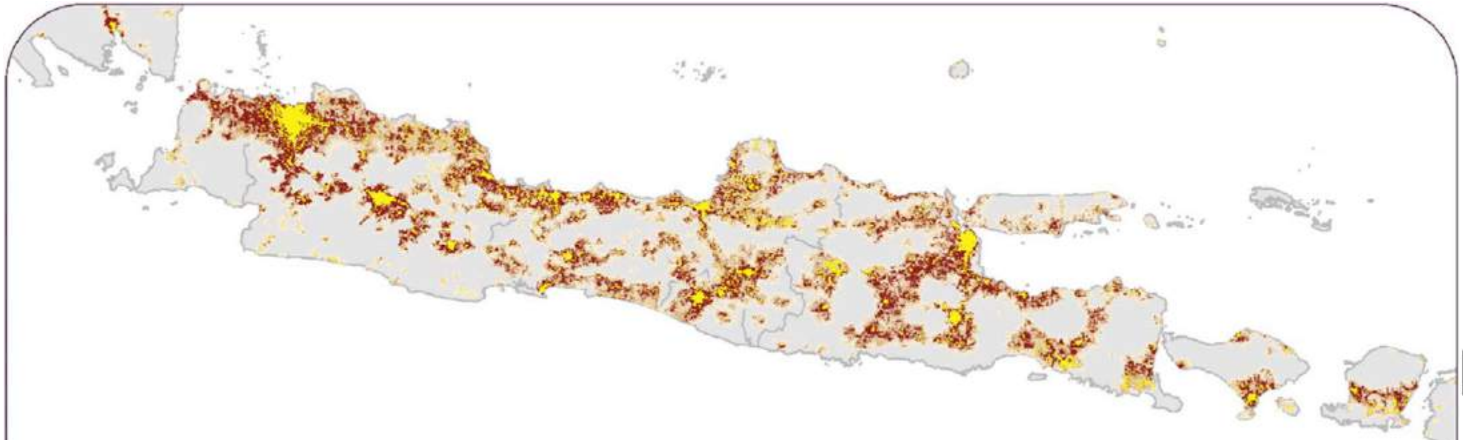
Year	Urban (millions)	Rural (millions)
2010	118.8	119.7
2015	136.2	119.3
2020	153.7	117.4
2025	170.9	113.9
2030	187.9	108.5
2035	203.6	102.1

Java's Population: Large and vulnerable

- Population currently 145 Million, 57% of Indonesia's total
- Poverty (<$2/day) rate about 10%
- Urbanization: Currently 5% land area, expected to expand 2-3 times that by 2030 (75% of Indonesia's urban area will be on Java)

Rapidly expanding high-rise construction

Seismically non-resilient residential construction



Urban extent 2000

Probability of urbanization 2030

0% 100%

(Muis et al., *Science Total Env.*, 2015)

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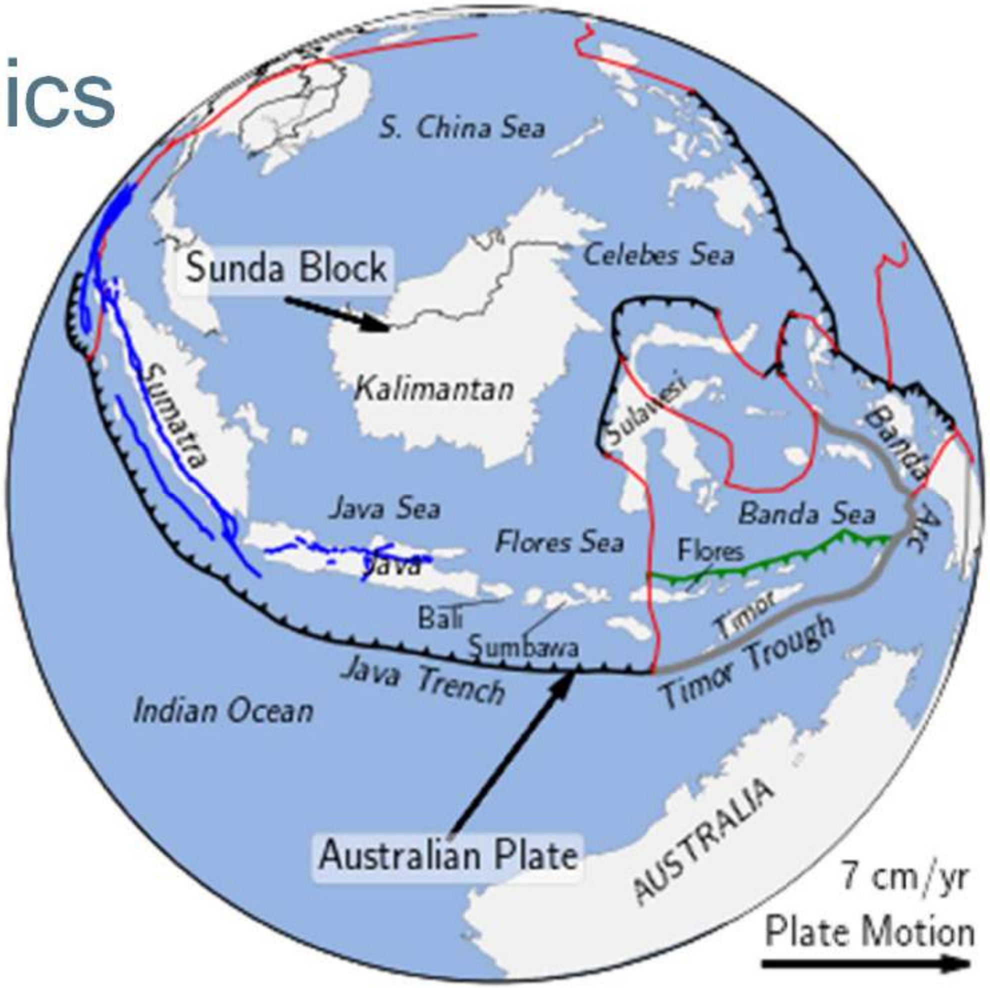
How does Indonesia’s population growth affect risk?

- Greater exposure (obviously)
- The massive growth in population since late 20th century has occurred during a period of apparent seismic quiescence
- Poverty forces settlement in hazard-prone areas and use of poor construction material
- Predominantly young mobile population with less access to local knowledge (Banda Aceh & Palu vs. Nias)
- Urbanisation
  - Large populations affected by even small-foot-print events (2006 Yogyakarta)
  - Dependence on fragile networks for critical services
- Huge investment in residential construction and infrastructure – potential lock-in of unpreparedness

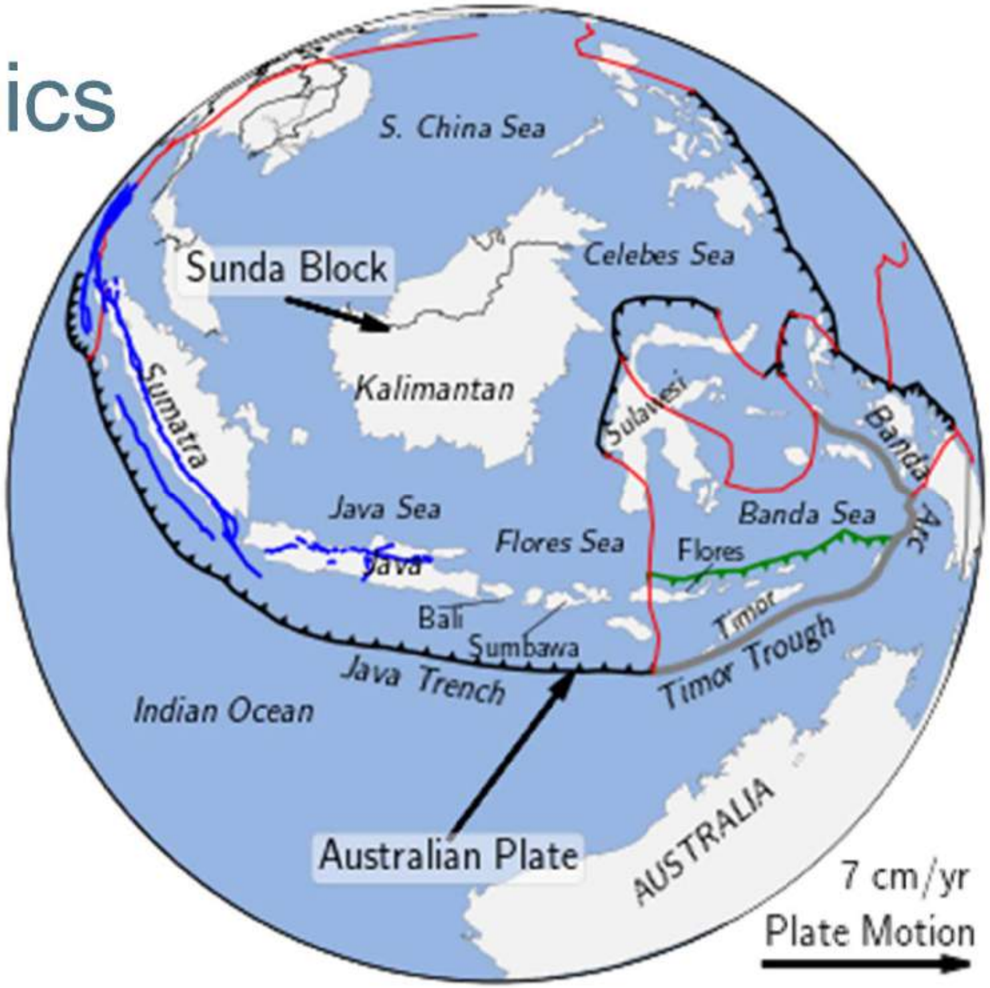
Indonesian Tectonics

- Over 18,000 km of major tectonic plate boundary, more than twice Japan or Papua New Guinea, including:
- The Great Sumatran Fault, at 1900 km 50% longer than the San Andreas and North Anatolian faults;
- 6,000 km length of convergent plate margin, stretching from Sumatra to the Banda Sea that has experienced the world's 2nd largest megathrust and its largest intraslab earthquake.



Indonesian Tectonics

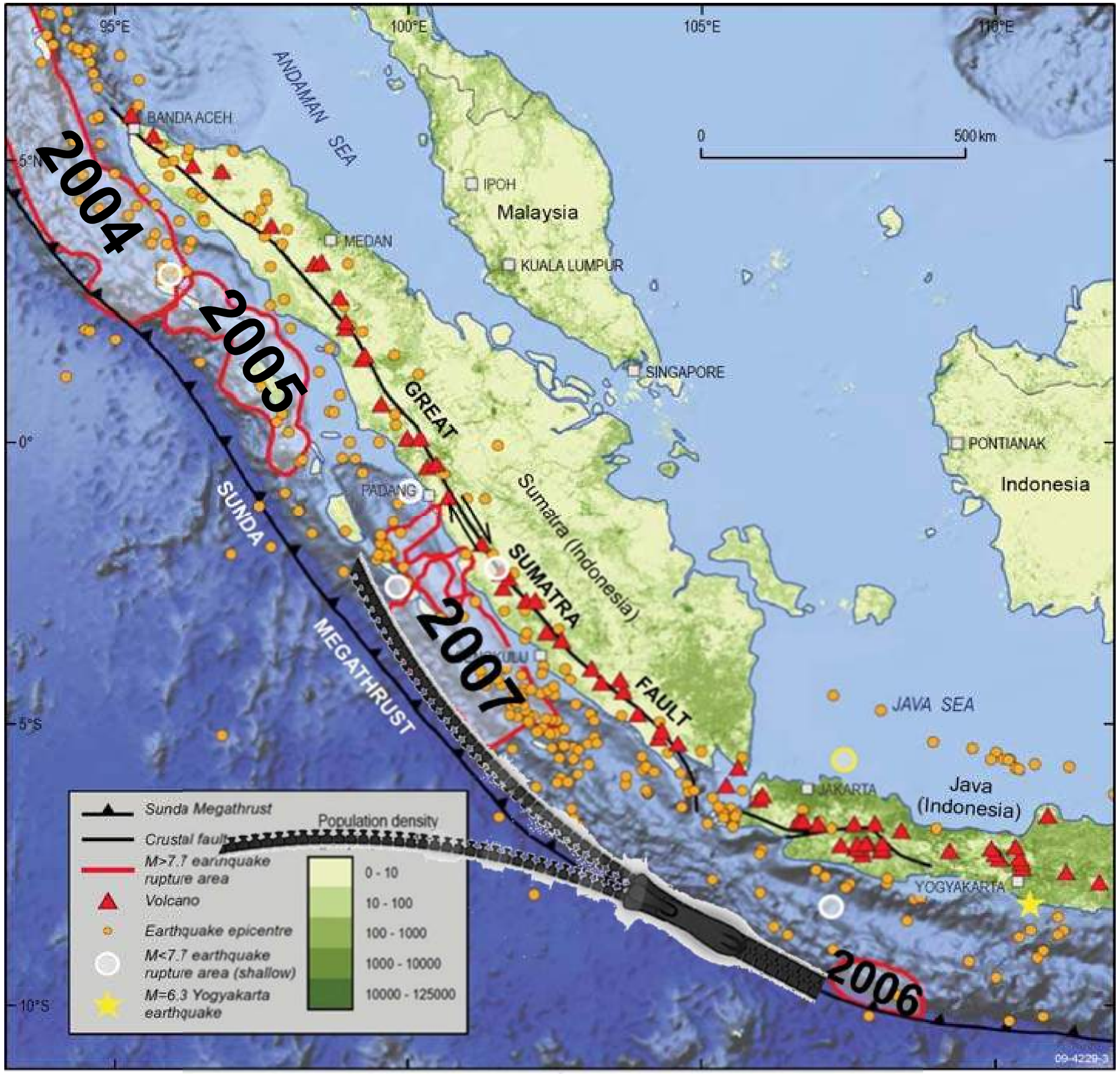
- Over 129 volcanoes thought to have erupted in the Holocene, more than any other country in the world
- Witnessed 3 of the largest and deadliest eruptions in human history: Toba, Krakatau, Rinjani
- But the big question is, what don't we know?



'Unzipping' of the Sumatra Mega-thrust – Will it continue to Java?

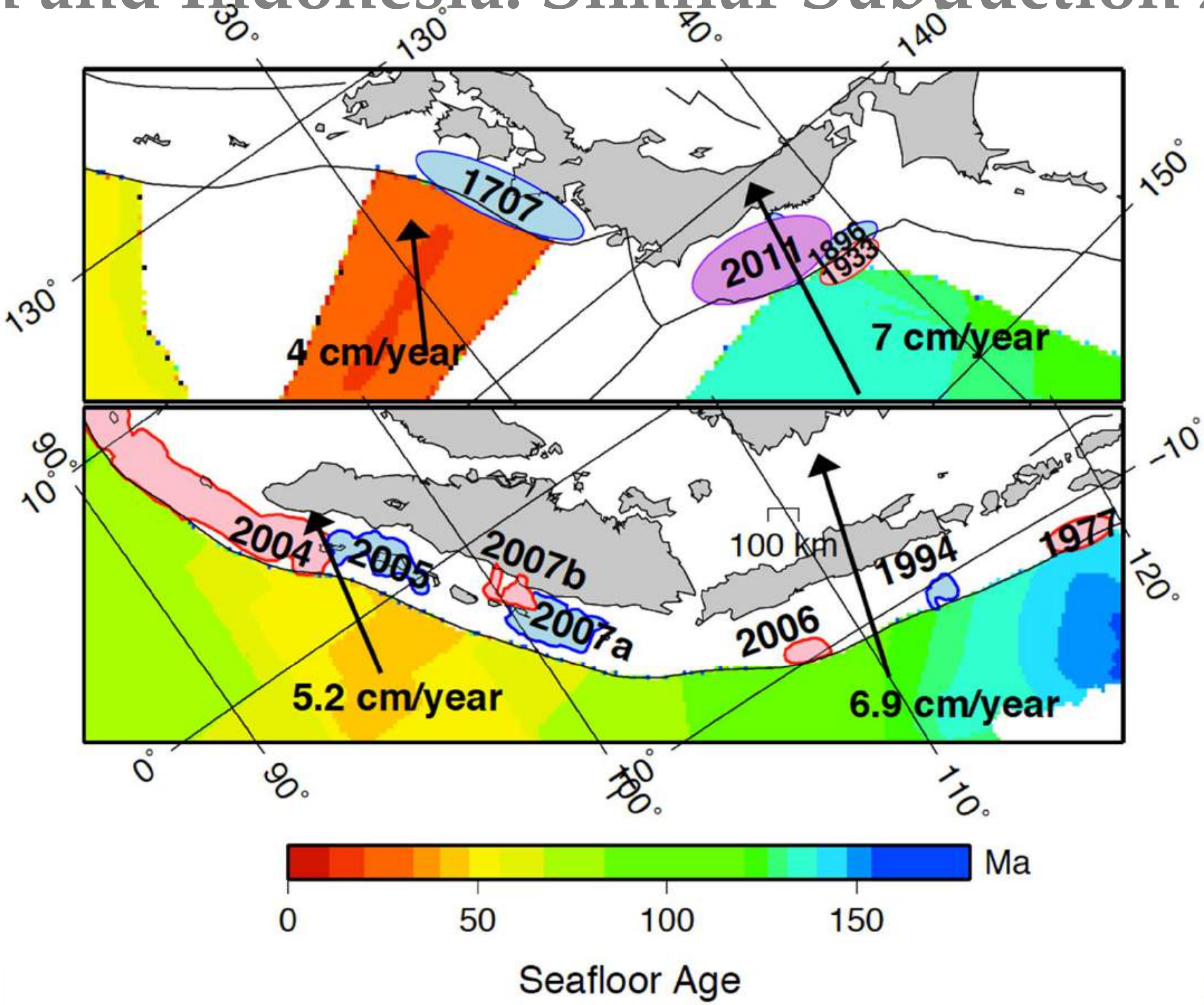
The 21st century began with a series of major megathrust earthquakes – in 2004, 2005 and 2007 – off Sumatra.

Will this sequence continue to the much more densely populated island of Java?



Brugmann, 2009

Japan and Indonesia: Similar Subduction Zones



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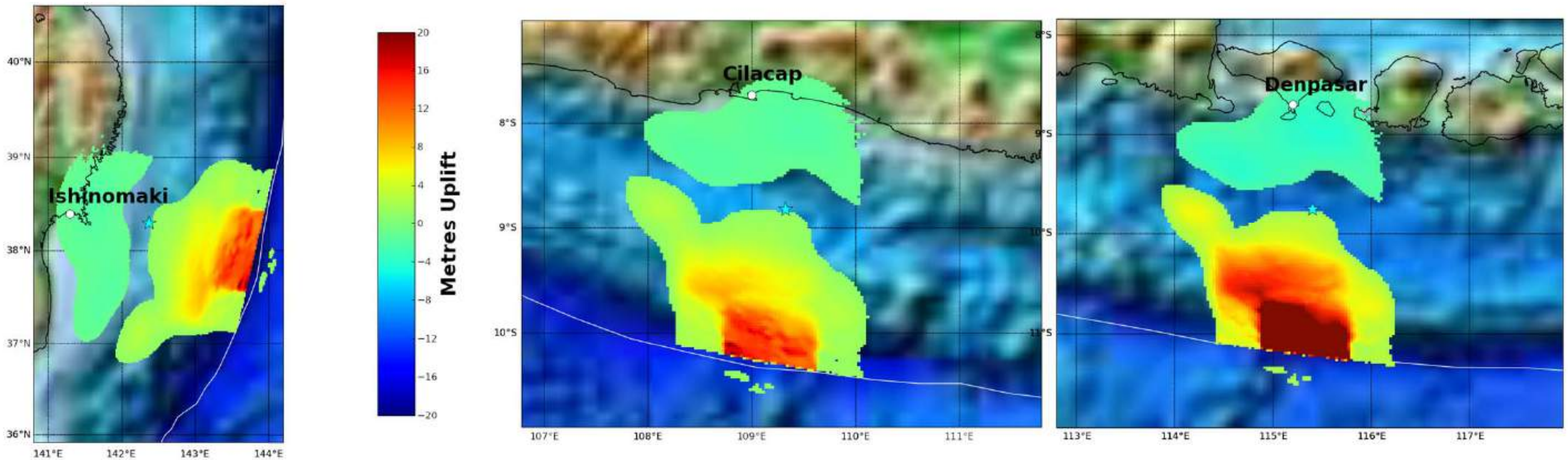
What might happen if an event like the 2011 Tohoku earthquake occurred in the Java Trench?



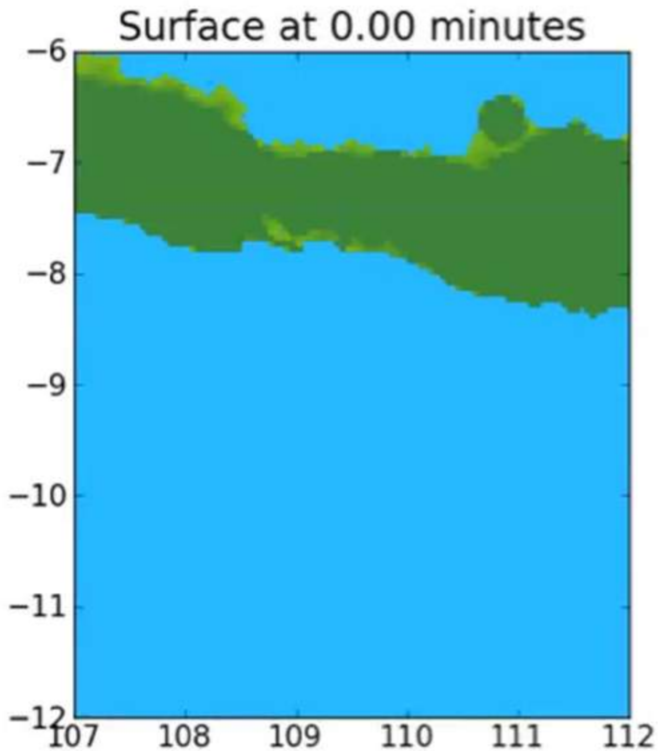
Fujii et al. (2011) tsunami source model shifted to:

Scenario 1: south of west Java

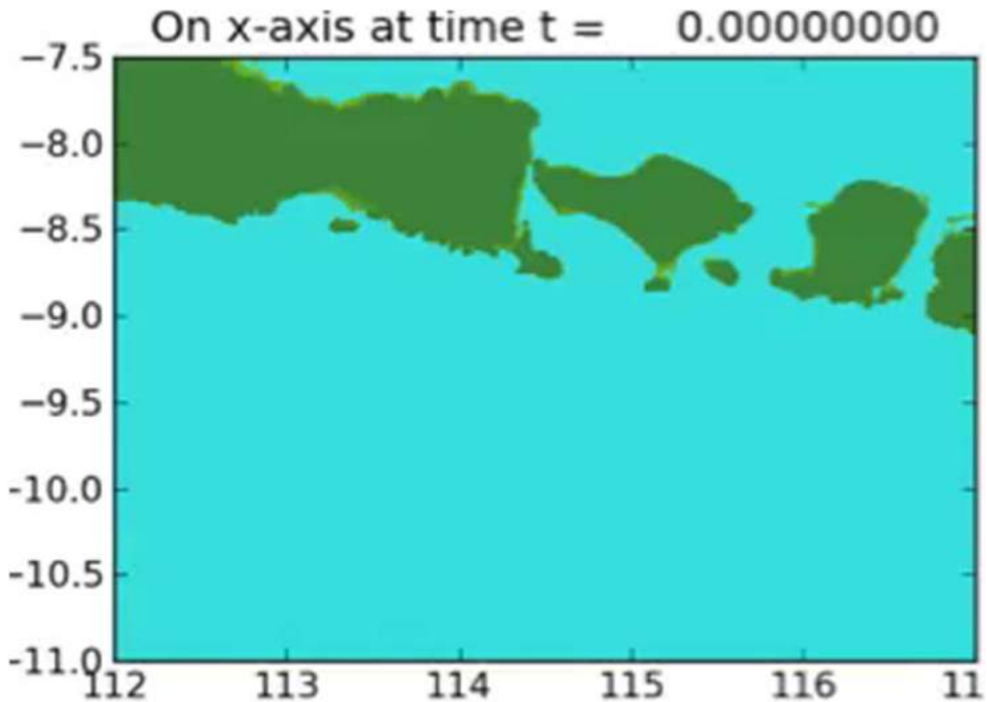
Scenario 2: south of Bali

Java Trench Earthquake Scenarios

Offshore Cilacap



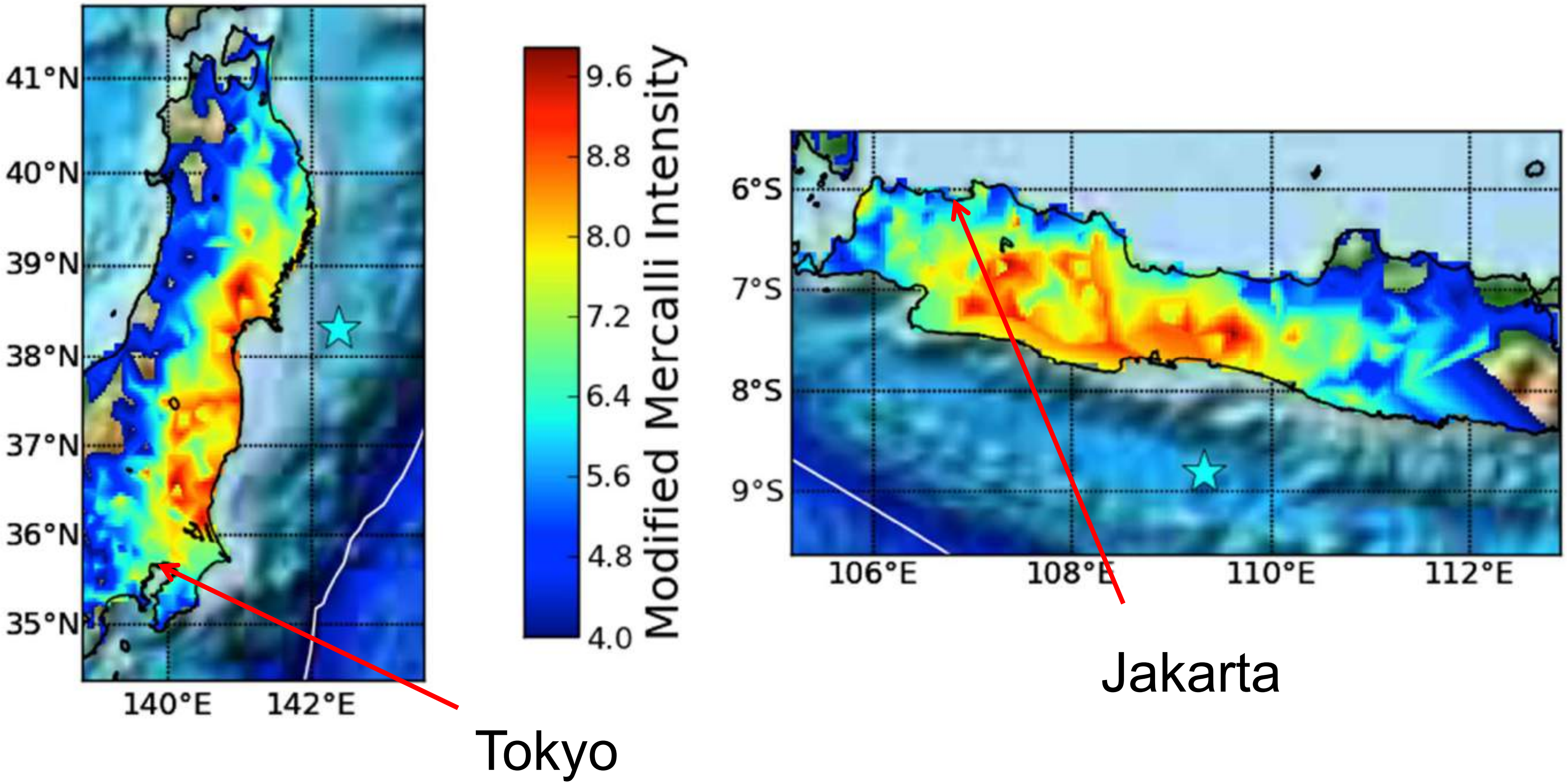
Offshore Bali



A tsunami of 7-10 m height impacting a 300 km section of south Java coast, e.g. completely inundating Cilacap

A tsunami of 7-10 m height impacts the coasts of East Java, Bali and Lombok, completely overwashing the Kuta Isthmus

2011 Tohoku Earthquake Ground Motions Translated to off Java



Comparison with recent high-fatality earthquakes

	Event		MMI VII	MMI VIII	MMI IX	MMI X
	Damage	Resilient	Moderate	Mod/heavy	Heavy	V. Heavy
		Vulnerable	Mod/heavy	Heavy	V. Heavy	V. Heavy
USGS Pager	2010 Haiti (M 7.0)		598k	2,030k	908k	118k
USGS Pager	2011 Tohoku (M 9.0)		34,740k	5,816k	257k	0
This study	2010 Wenchuan (M7.9)		4,006k	1,245k	528k	2k
This study	???? Java (M9.0)		29,747k	25,642k	6,313k	121k
	???? Bali (M9.0)		10,676k	10,055k	3,293k	58k

- Exposure to MMI 9 similar to Haiti EQ
- Ground motions at MMI 8 and 9 have much higher exposure than any recent earthquake

Conclusions – Java Trench Megathrust

- The kind of disaster that could be caused by a giant Java Trench megathrust earthquake is one both Australia and Indonesia should be concerned about:

  Indonesia: Many fatalities through both building collapse and tsunami, huge setback in economic development

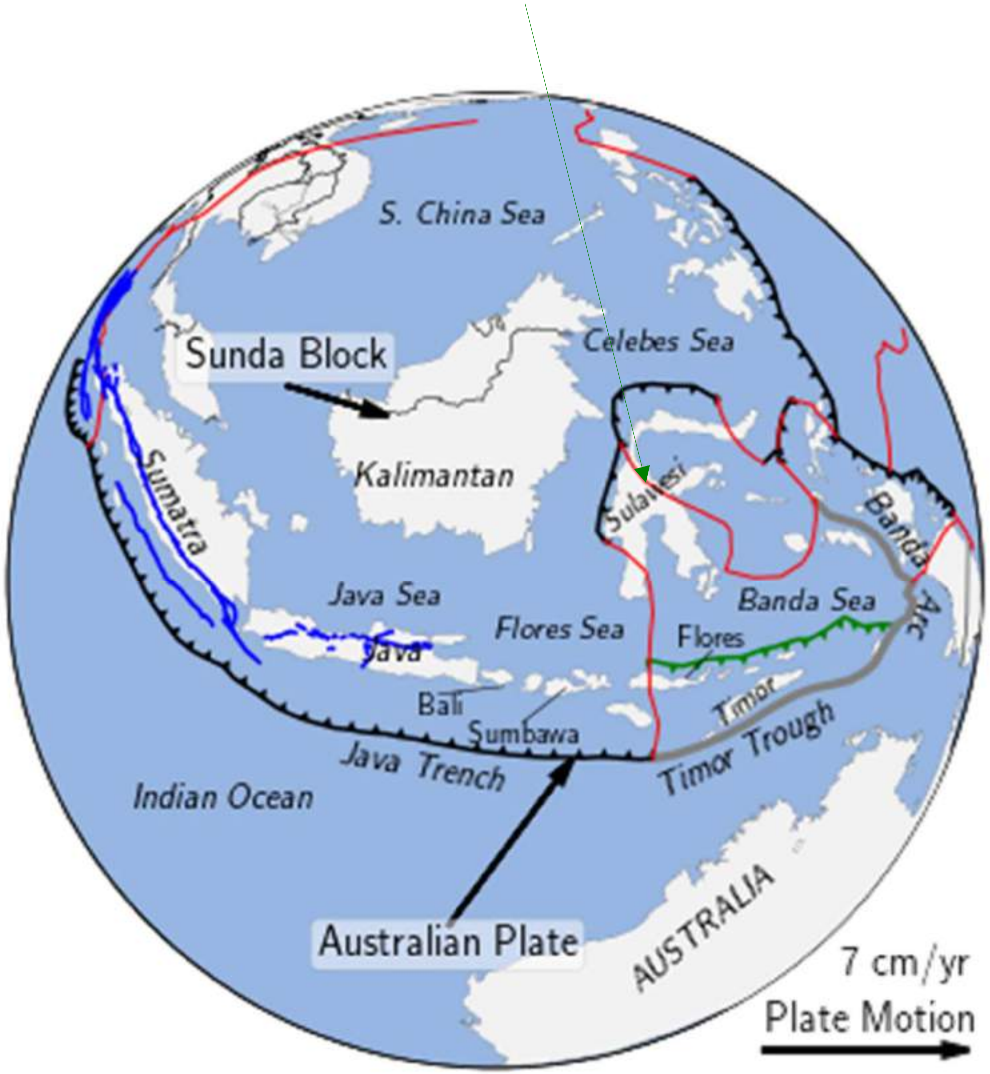
  Australia: Potentially many fatalities in Bali, and large loss in export income due to damage to ports/shipping

- Could be the world's first real "compound" earthquake-tsunami disaster – i.e., *major* fatalities due to *both* building collapse and tsunami inundation. *Except for Palu?*

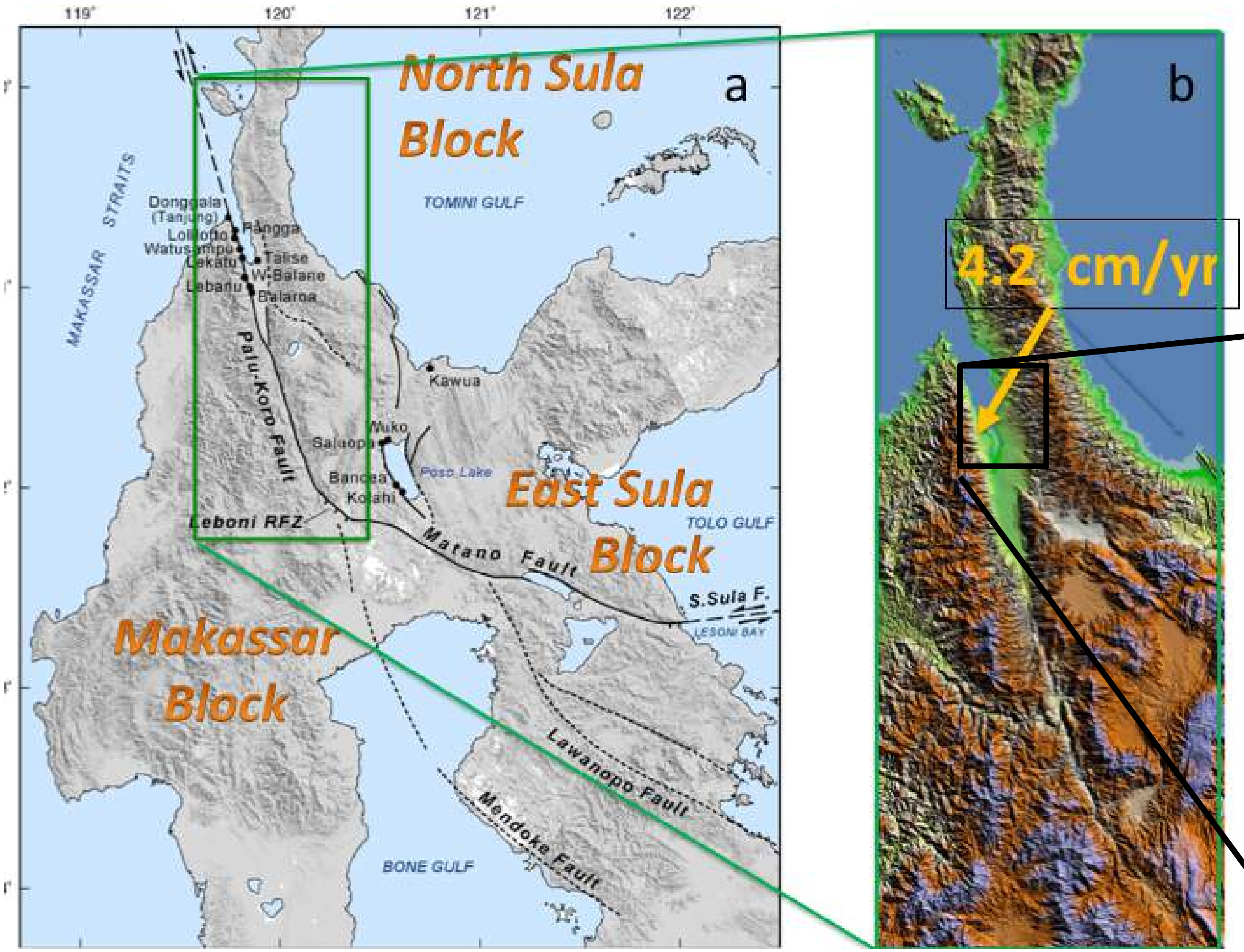
Sulawesi Tectonics

- Sulawesi is comprised of several ”micro-plates”: the Makassar, North Sulu and South Sulu Blocks.
- The Palu-Koro Fault is a major strike-slip fault, that accommodates left-lateral movement of two of these microplates.

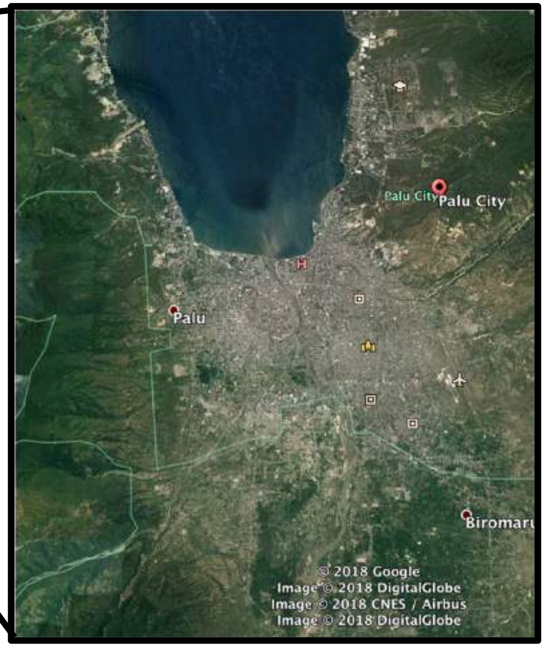
The Palu-Koro Fault



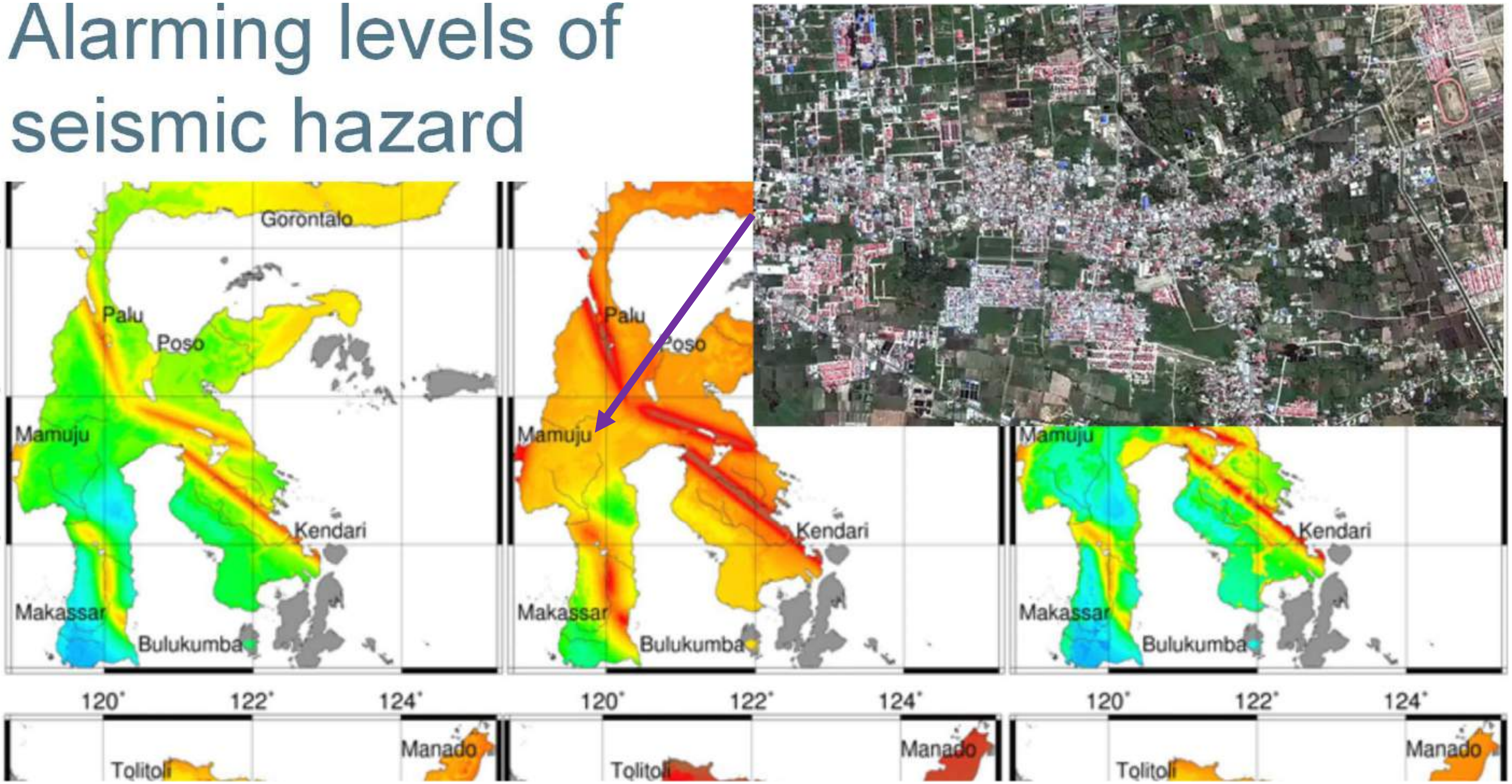
The Palu-Koro Fault and Palu city



Palu City
Population > 350,000



Alarming levels of seismic hazard



Very high levels of ground shaking and massive accumulations of poorly consolidated, water-saturated sediments led to liquefaction on an unprecedented scale

Petobo and Balaroa Villages Wiped Out

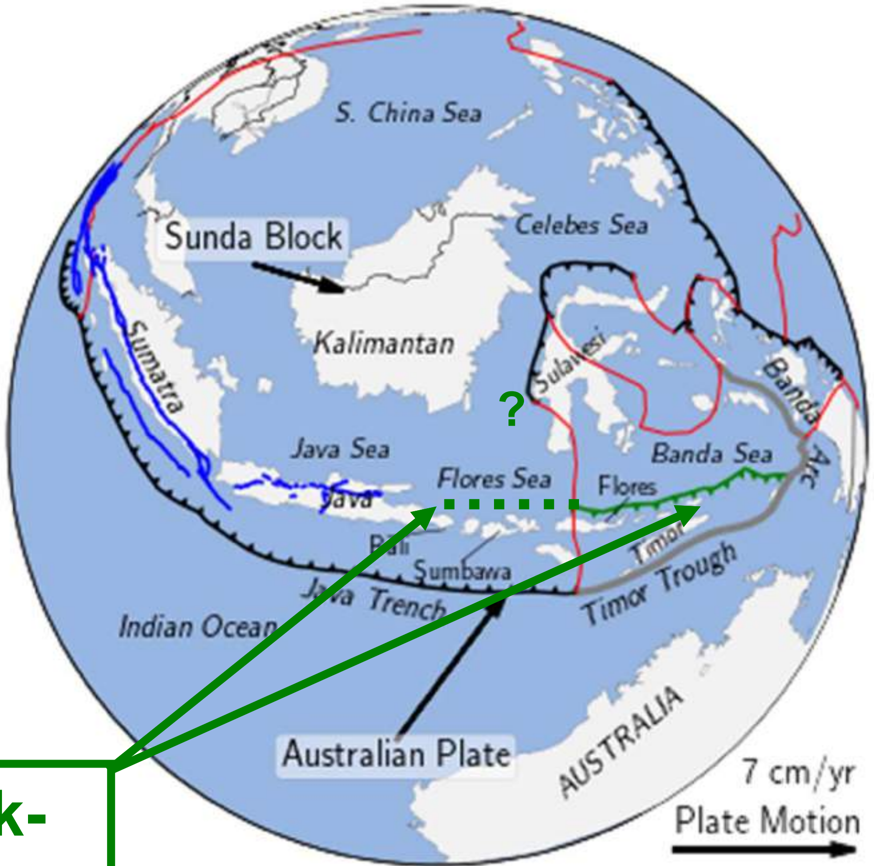
It is thought roughly 2000 may have died in the Palu landslide/ liquefaction, but the exact figure may never be known because the bodies are buried beneath so much mud and debris.


(image: Australian Broadcasting Corporation)

Reports suggest the liquefaction was exacerbated by irrigation, with the initiation of the landslides aligning with a large irrigation channel running up the eastern side of the Palu Valley.

Flores Back-arc Thrust

- Widely used plate boundary models (e.g. Bird, 2002, at left) present a Flores Back-arc Thrust as extending eastward from Flores.
- This fails to explain the occurrence of major historical (and recent) earthquakes west of Flores.



Flores Back-arc Thrust

GPS Campaign in Nusa Tenggara, East Indonesia

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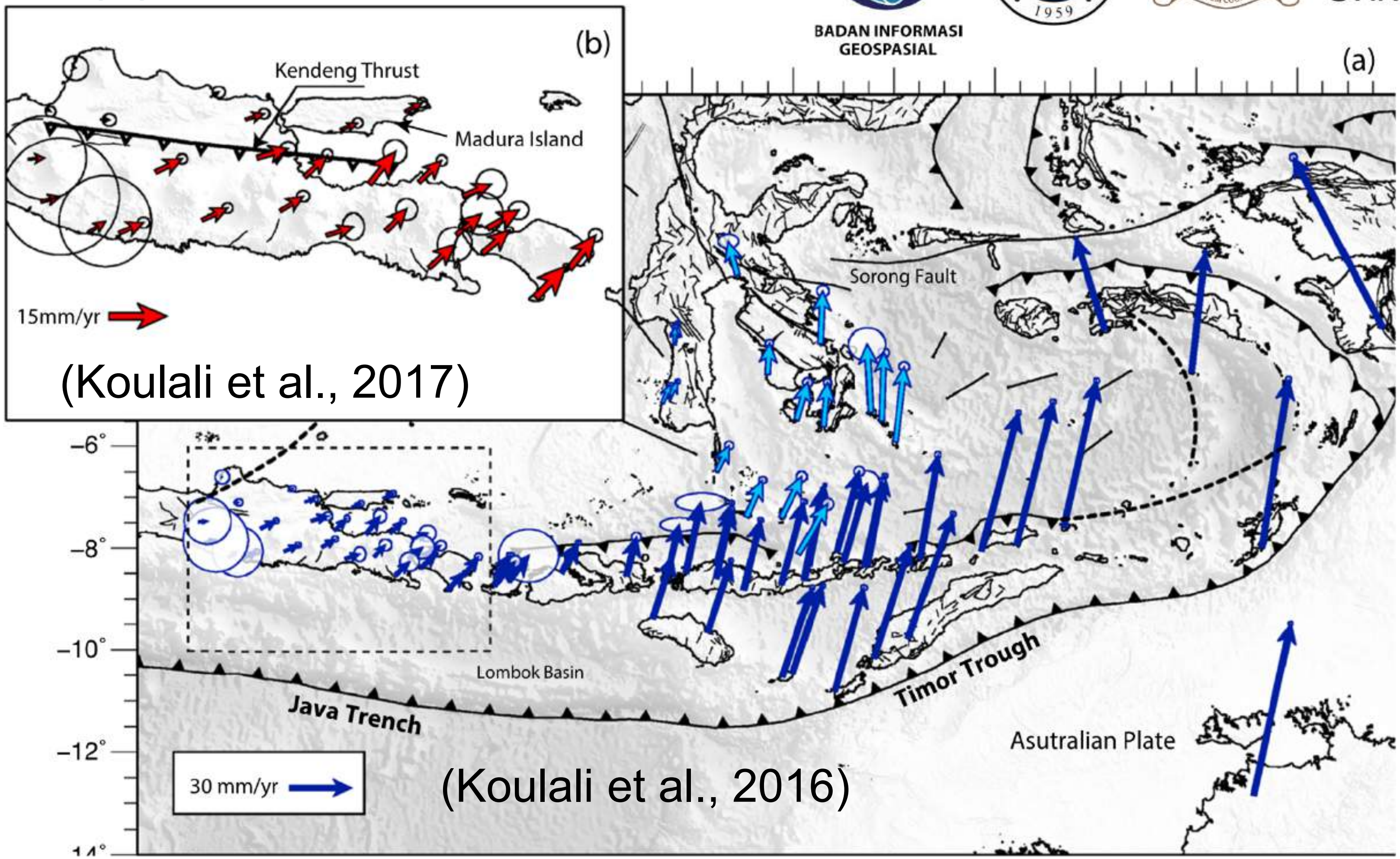

(Koulali et al., 2017)

(Koulali et al., 2016)

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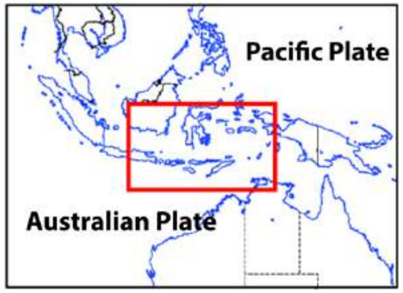
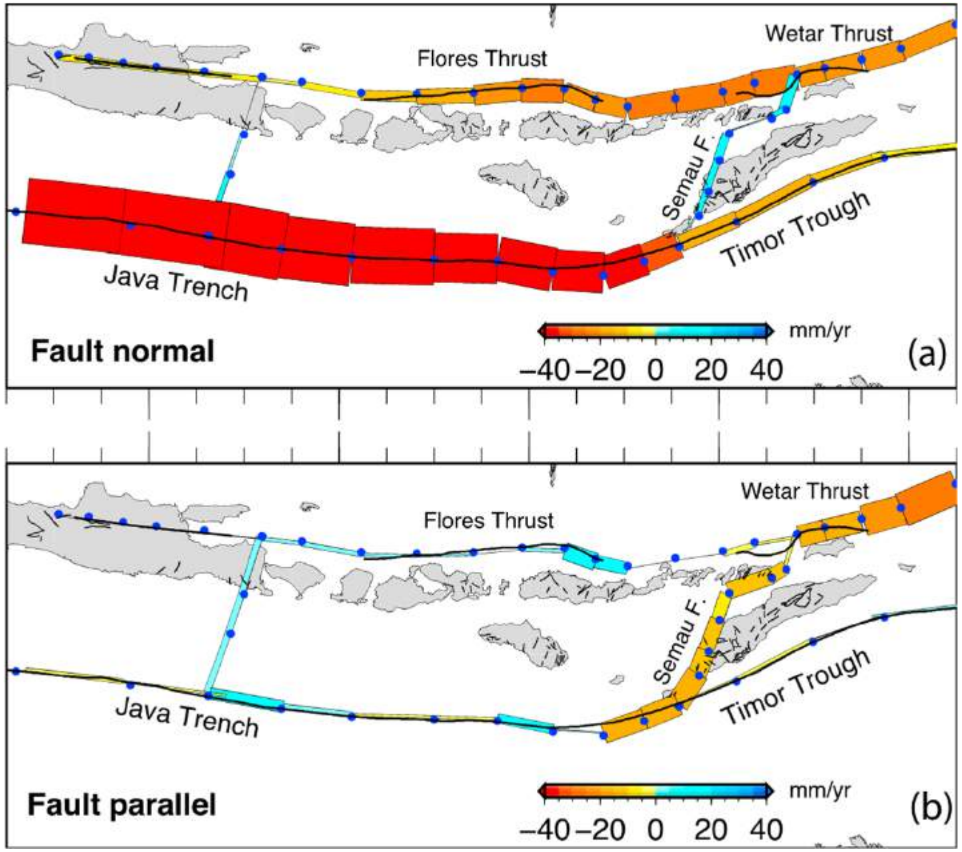
GPS Campaign in East Indonesia

- Almost all convergence accommodated by Java Trench offshore Java and Bali, gradually decreasing to almost none east of Timor
- Small but significant (6mm/yr) convergence on Kendeng Thrust, increasing to accommodate all convergence along the Flores-Wetar Backarc Thrust
- Transfer of convergence facilitated by strike-slip motion along Semau Fault

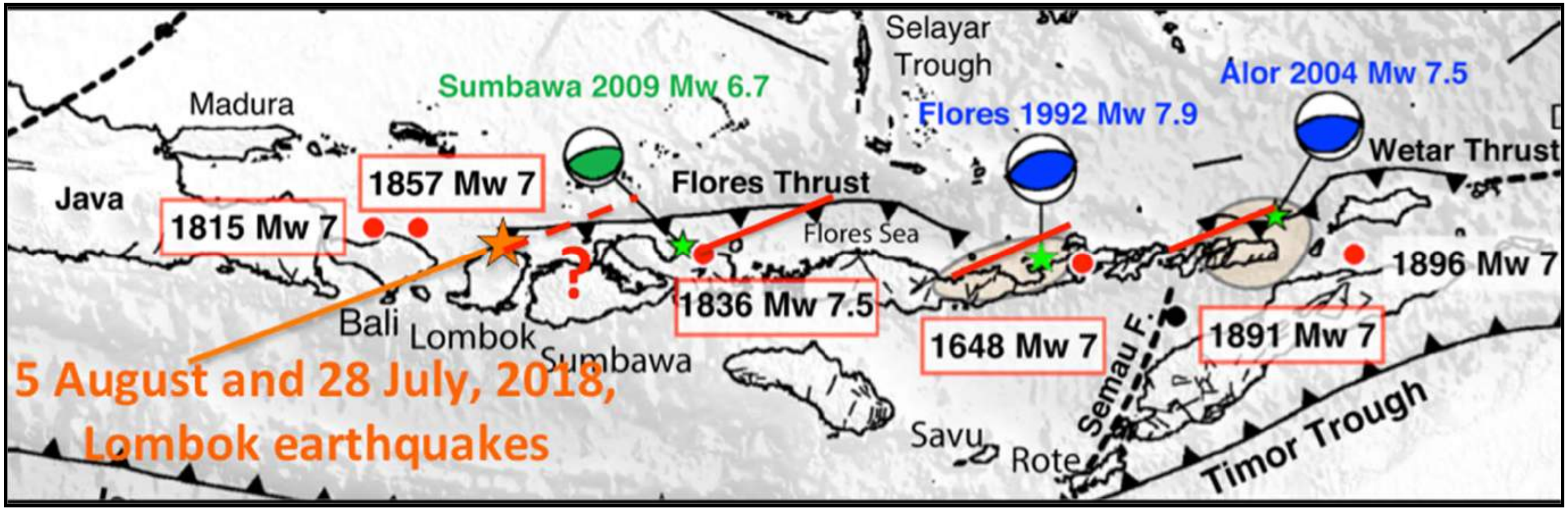


(Koulali et al., 2016)



Is the Flores Back-arc Thrust Segmented?

- Detailed analysis of historical events suggest strikes trending 70-75°, that cannot be connected across the full E-W extent of the back-arc thrust.
- Significant implications for earthquake and tsunami hazard
- Does not match strike of current Lombok events (at least not yet)



GPS Crustal Strain Measurements in Java

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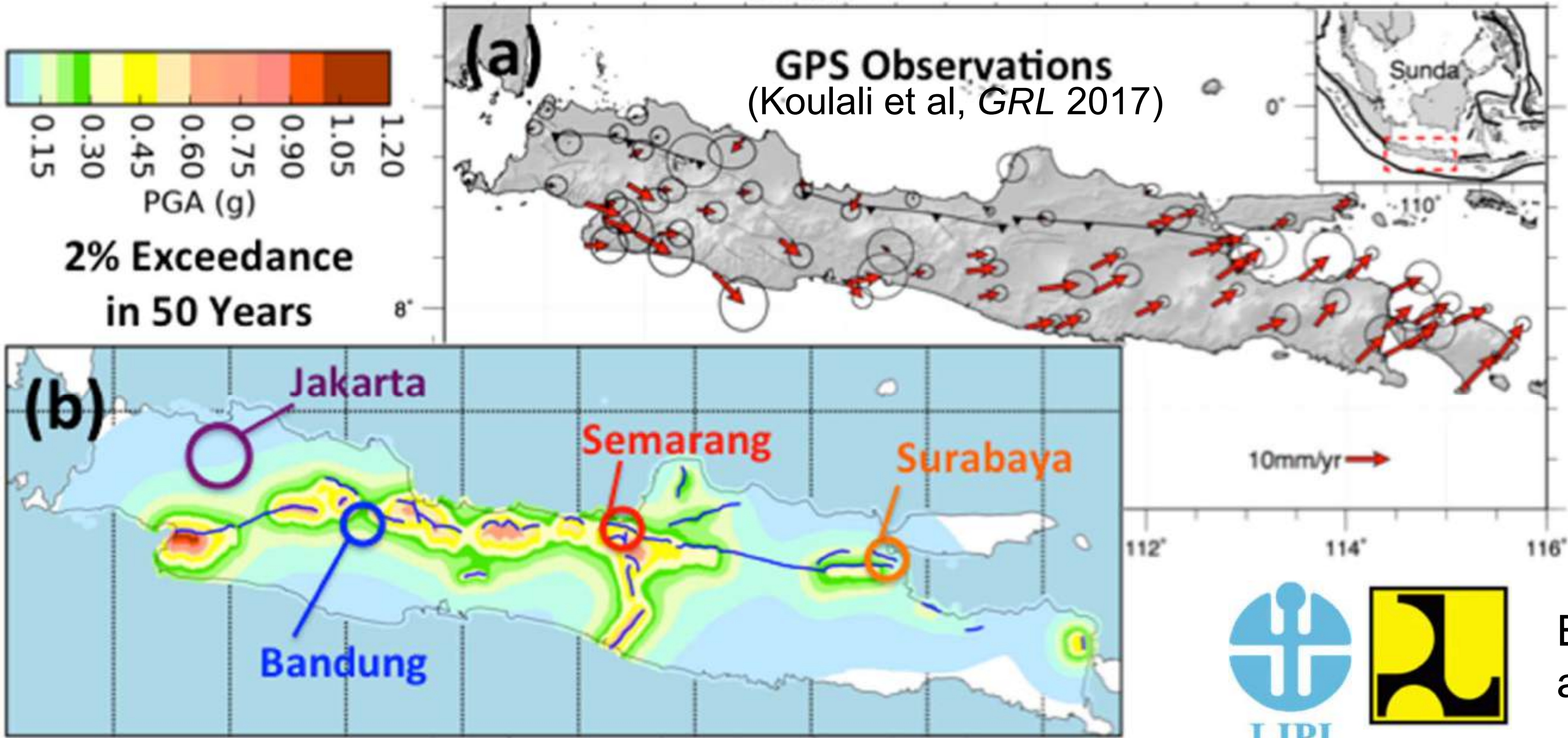


LIPI

Et al.

Earthquakes: Large vs. Deadly

Largest Earthquakes	Magnitude	Fatalities* (almost all due to tsunami)
1960 Chile	9.5	1886
2004 Sumatra	9.3	227,898
1964 Alaska	9.2	131
2011 Japan	9.0	20,350
1952 Kamchatka	9.0	0
2010 Chile	8.9	523
1906 Ecuador	8.8	500-1500
1965 Alaska	8.7	0
2005 Sumatra	8.6	1300

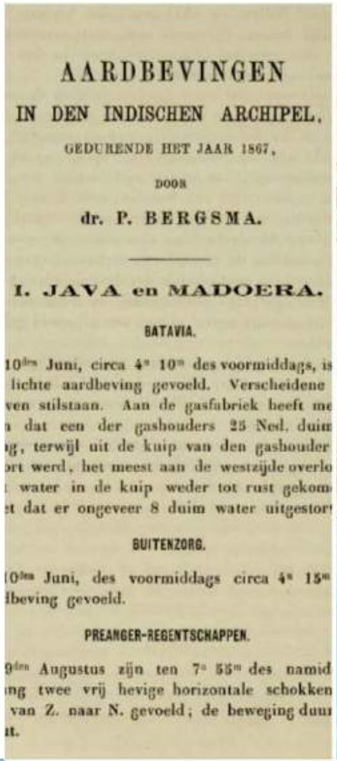
Recent Deadly Earthquakes	Magnitude	Fatalities* (Ground Shaking)
2010 Haiti	7.0	316,000
2008 Wenchuan	7.9	87,587
2005 Pakistan	7.6	80,361
2003 Iran	6.6	31,000
2001 India	7.7	20,023
1999 Turkey	7.9	17,118
2015 Nepal	7.8	8669
2006 Java	6.3	5749
1995 Kobe	6.9	5530

* US Geological Survey

Historical Earthquakes in Java

- Most of Java experienced MMI >5 between 1699 and 1867.
- Intraslab earthquakes more important than previously thought.
- Important historical events occurred on as yet unmapped active faults
- If they re-occurred today, some historical events could kill 10 000s of people and potentially displace 10s millions.
- A repeat of the 1699 Jakarta earthquake could kill 100 000 people (with high level of uncertainty)

(Griffin et al., BSSA, 2018, Nguyen et al., *GA Record*, 2015)



AARDBEVINGEN

IN DEN INDISCHEN ARCHIPEL,

GEDURENDE HET JAAR 1867,

DOOR

dr. P. BERGSMA.

I. JAVA en MADOERA.

BATAVIA.

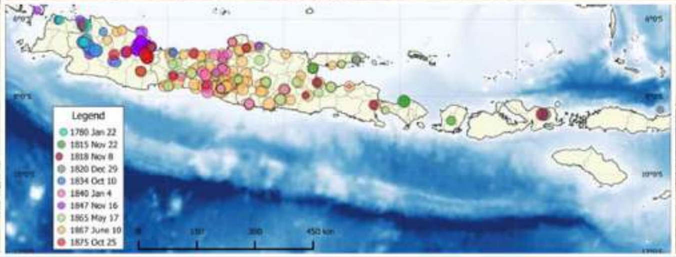
10den Juni, circa 4u 10m des voormiddags, is
lichte aardbeving gevoeld. Verscheidene
ven stilstaan. Aan de gasfabriek heeft me
n dat een der gashouders 25 Ned. duim
ng, terwijl uit de kuip van den gashouder
ort werd, het meest aan de westzijde overlo
t water in de kuip weder tot rust gekom
et dat er ongeveer 8 duim water uitgestor

BUITENZORG.

10den Juni, des voormiddags circa 4u 15m
dbeving gevoeld.

PREANGER-REGENTSCHAPPEN.

9den Augustus zijn ten 7u 55m des namid
ng twee vrij hevige horizontale schokken
van Z. naar N. gevoeld; de beweging duu
it.



What would be the impact of historical Earthquakes were they to re-occur today?

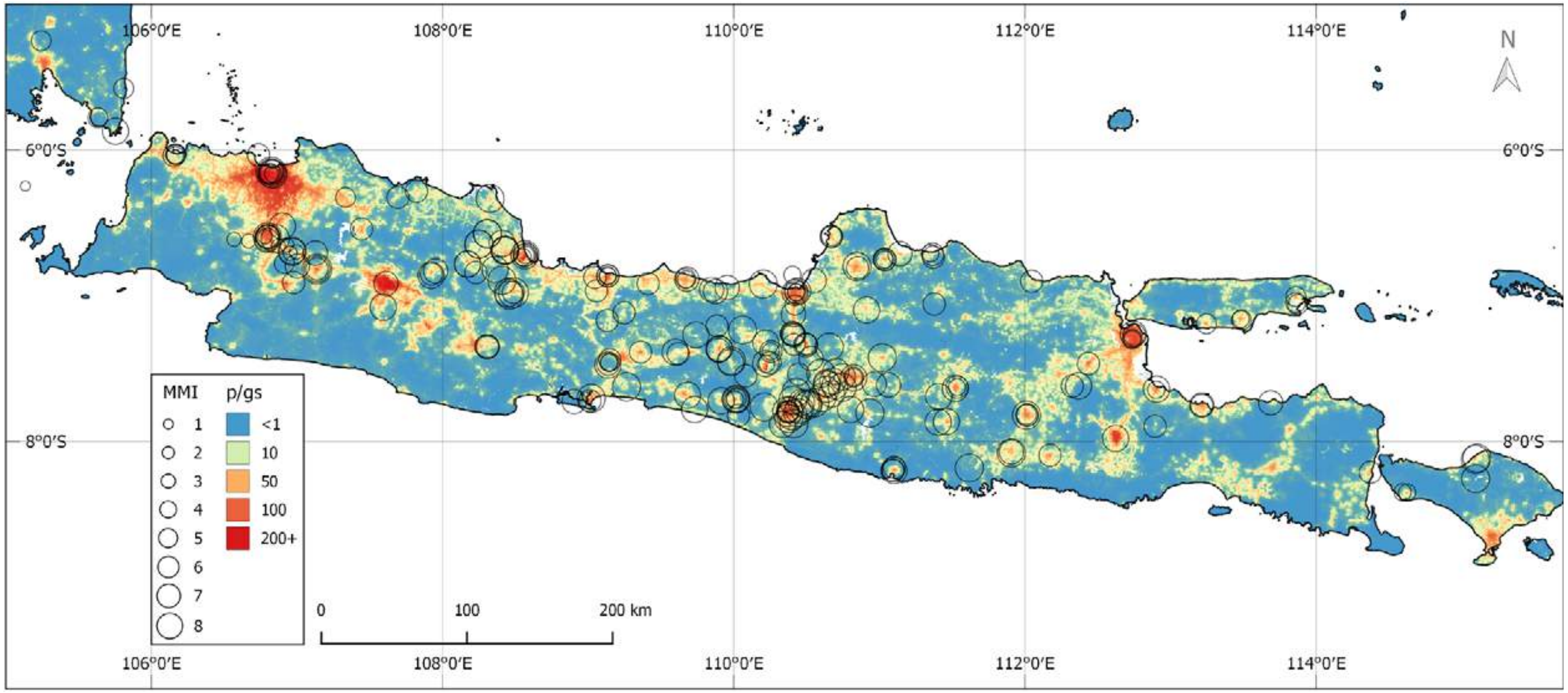


Figure 1.1 Estimates of persons per grid square (p/gs) (~100 m at the equator) in for Java for 2015 (adjusted to match United Nations' projections by Gaughan et al., 2013)*), with observed MMI from all events modelled. Data from WorldPop* (2015).

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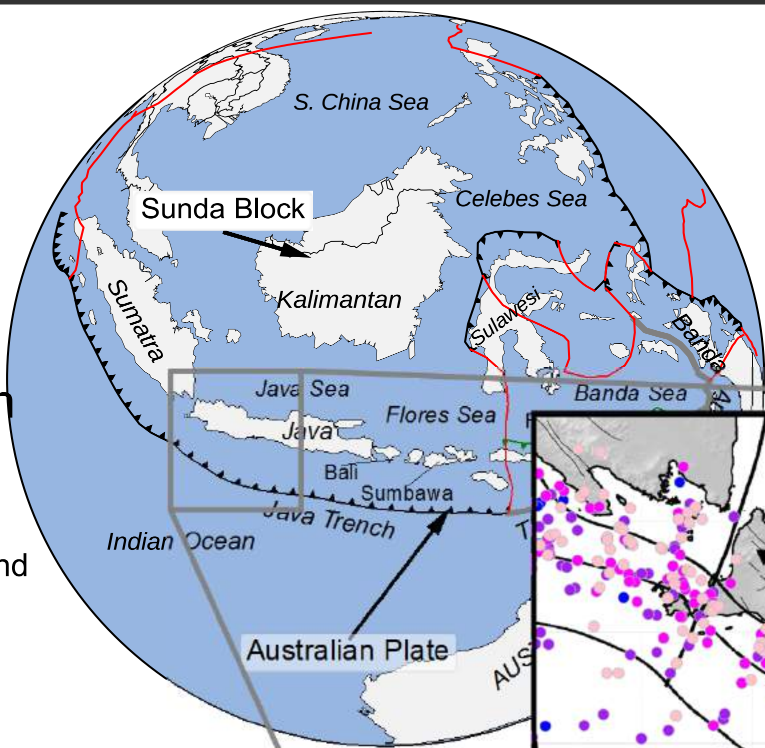
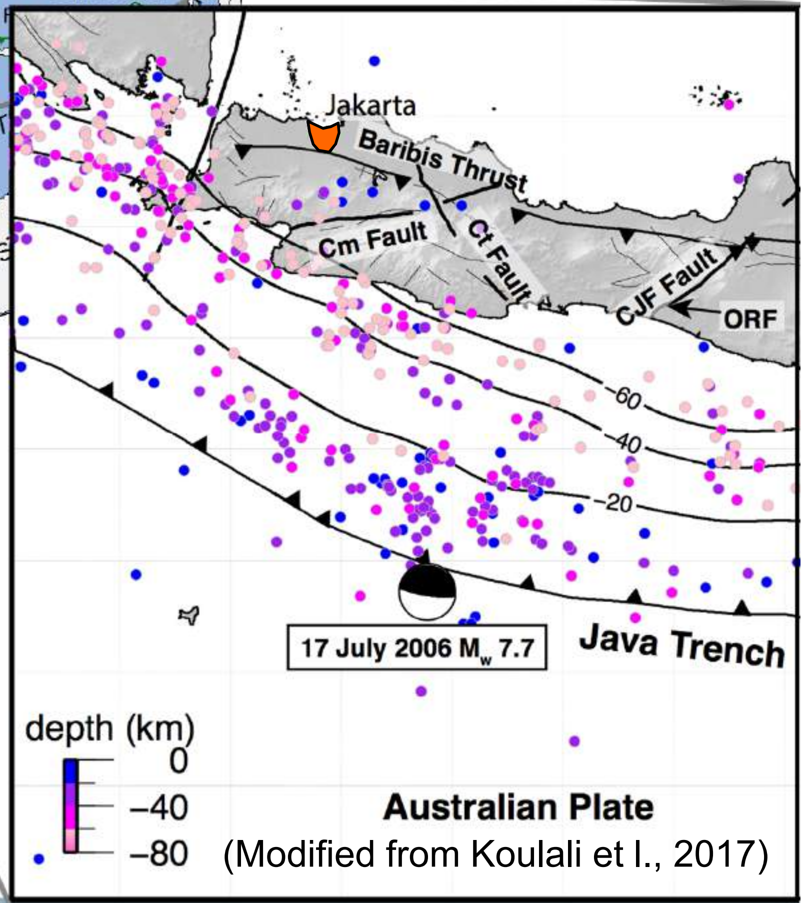
Jakarta

- The city of Jakarta (shown) has population 10 million, but greater Jakarta has 30 million, making it the world's 2nd largest megacity (Allianz).
- Jakarta lies about 300 km from the Java Trench megathrust, where the Australian dives beneath the Sunda Plate with a ≈6 cm/yr convergence rate.
- The city is also close to several large and possibly active faults, and lies above a very active Benioff zone



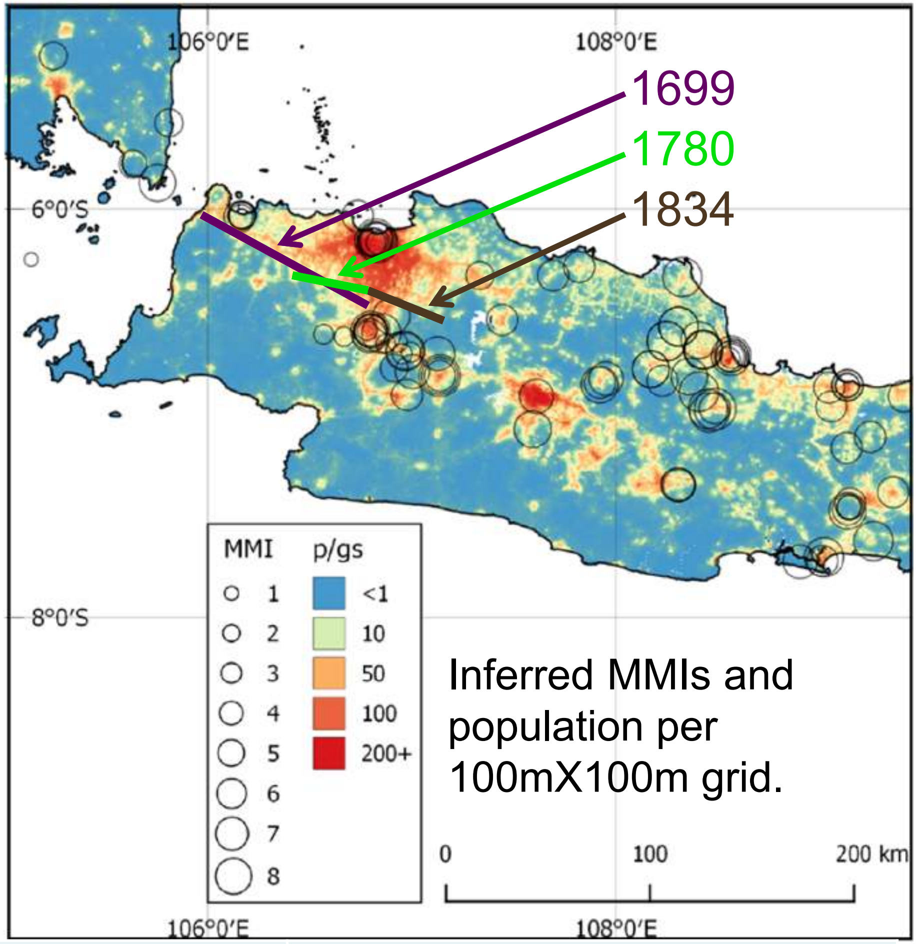


(Modified from Koulali et l., 2017)

Historical Earthquakes

While no earthquakes have caused widespread damage in West Java since before the 20th century, large events impacting Jakarta (then Batavia) occurred in the 18th and 19th centuries.

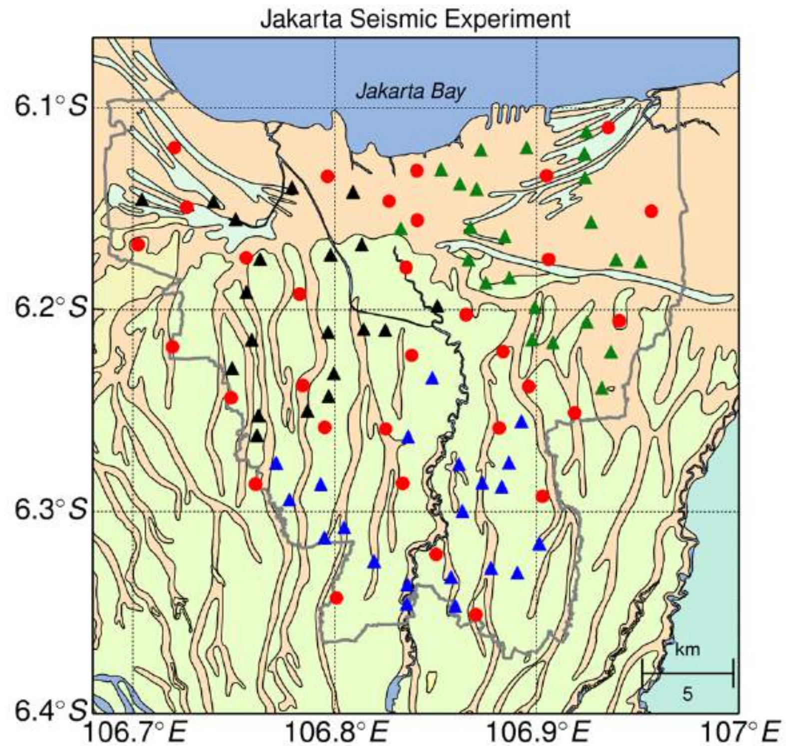
These historical events have been studied by Albini et al. (2014), Musson et al. (2012), and by Nguyen et al. (2015), who modeled historical intensity observations to infer locations and magnitudes.



January 5, 1699	January 22, 1780	October 10 1834
Wide damage area extending from W Java to Sumatra: M=8, intraslab.	Felt throughout Java, most damage in Jakarta: M=7 on Baribis Fault.	Felt as far as Central Java and Sumatra: M=7 on Baribis Fault.

Jakarta Broadband Passive Seismometer Deployment

From Oct 2013-Feb 2014, the Australian National University collaborated with the Indonesian Bureau of Meteorology, Climatology and Geophysics and Bandung Institute of Technology to deploy 50 instruments in a “rolling” deployment across Jakarta, occupying 96 sites for at least 1 month each. Instruments were compact Trillium sensors with ANU seismic recorders.



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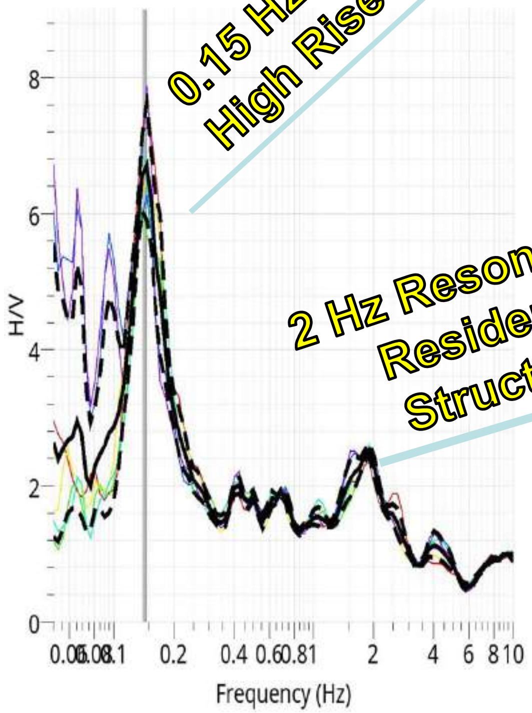
BMKG
JAYA RAYA
INSTITUT TEKNOLOGI BANDUNG 1959

Resonance Example: 1985 Mexico City EQ M = 8.1

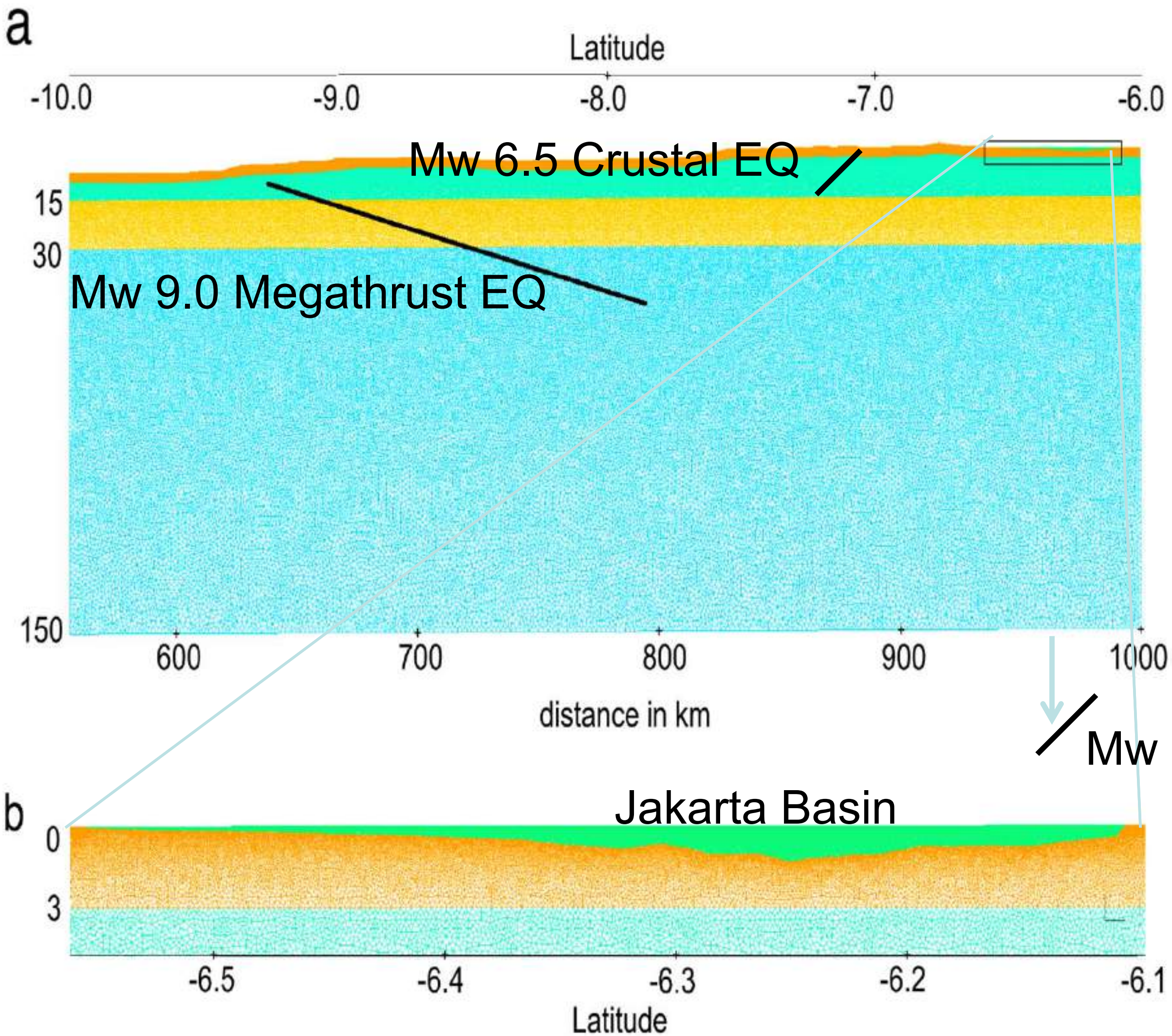
- Amplitude decreased with epicentral distance, but 400 km away shaking intensified beneath Mexico City
- Horizontal shaking amplified 10x at T = 1-2 s for areas built on old lake bed (soft clay)
- Severe damage to 6-16 storey buildings, much less to taller or shorter buildings
- 8000 deaths, 500 buildings destroyed

Basin Response using HVSR

- HVSR curves in Jakarta typically have double-peaked character
- High frequency peak -> sediment compaction in top 100 m
- Low frequency peak -> Depth to Tertiary basement

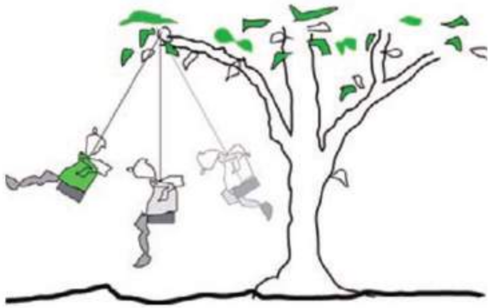


Earthquake scenario simulations using Specfem2D (Komatitsch & Vilotte, *BSSA* 1998)



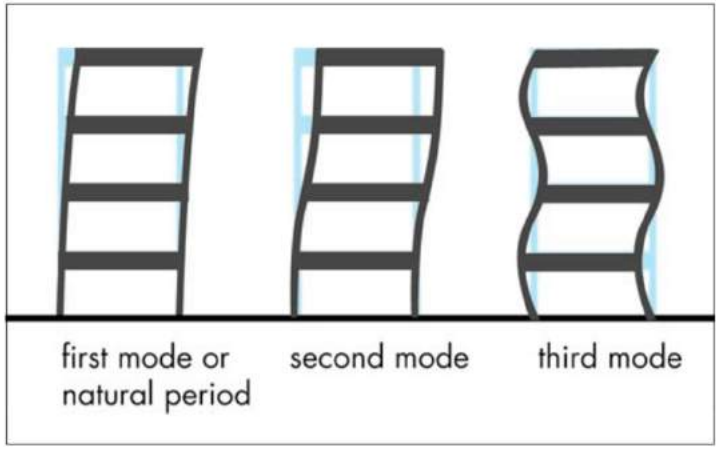
Domain area: 445 x 150 km
Basin model: HVSR
Max basin depth 1350 m
Smallest grid-size +/- 15 m
Vp and V_s in the basin are set to be 582 and 1764 m/s
Sources: megathrust, crustal, intraslab
Simulation type: P-SV

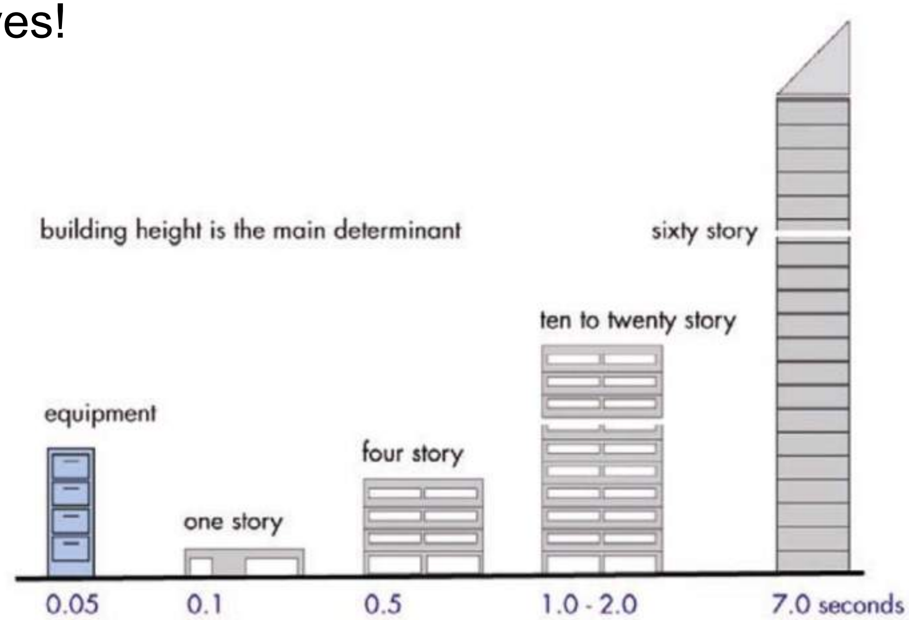
Building Resonance



Just as a child on a swing finds a particular period for which the swing travel is greatest, buildings experience resonant modes at which they sway back and forth most readily. We don't want this period to match that of earthquake waves!

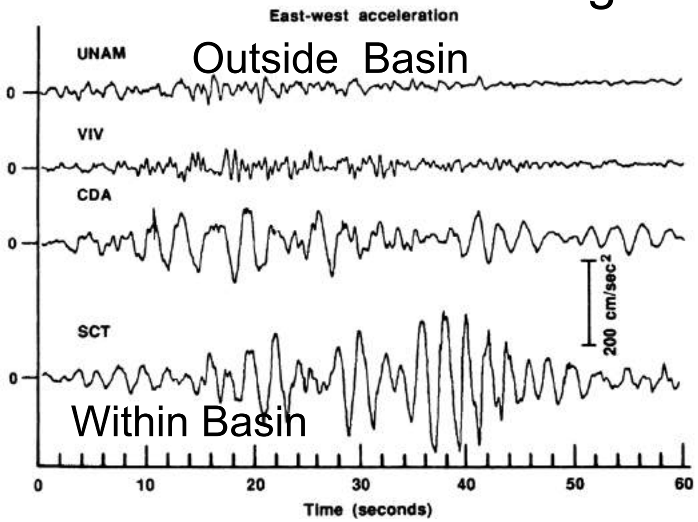
Building Resonant Models of Vibration





19 Sept. 2017 Mexico City (Puebla) M7.1 Earthquake

- 70 km from city and 50 km deep
- Over 200 fatalities
- At least 44 buildings collapsed
- Nearly 4,000 buildings were declared severely damaged
- 150m+ Buildings: 19



1985 Michoacan earthquake records (Anderson et al., 1986)

Booming San Francisco takes unprecedented step to target earthquake-vulnerable high-rise towers

By RONG-GONG LIN II OCT 04, 2018 | 5:35 PM | SAN FRANCISCO

The New York Times

At Risk in a Big Quake: 39 of San Francisco's Top High Rises

A report by the U.S. Geological Survey includes a list of buildings that are potentially vulnerable to a large quake. Some of San Francisco's most prominent high rises are on the list.

BRIEFING

San Francisco is building skyscrapers like crazy -- and there could be a deadly downside

JEREMY BERKE
APR 19, 2018, 11:15 PM

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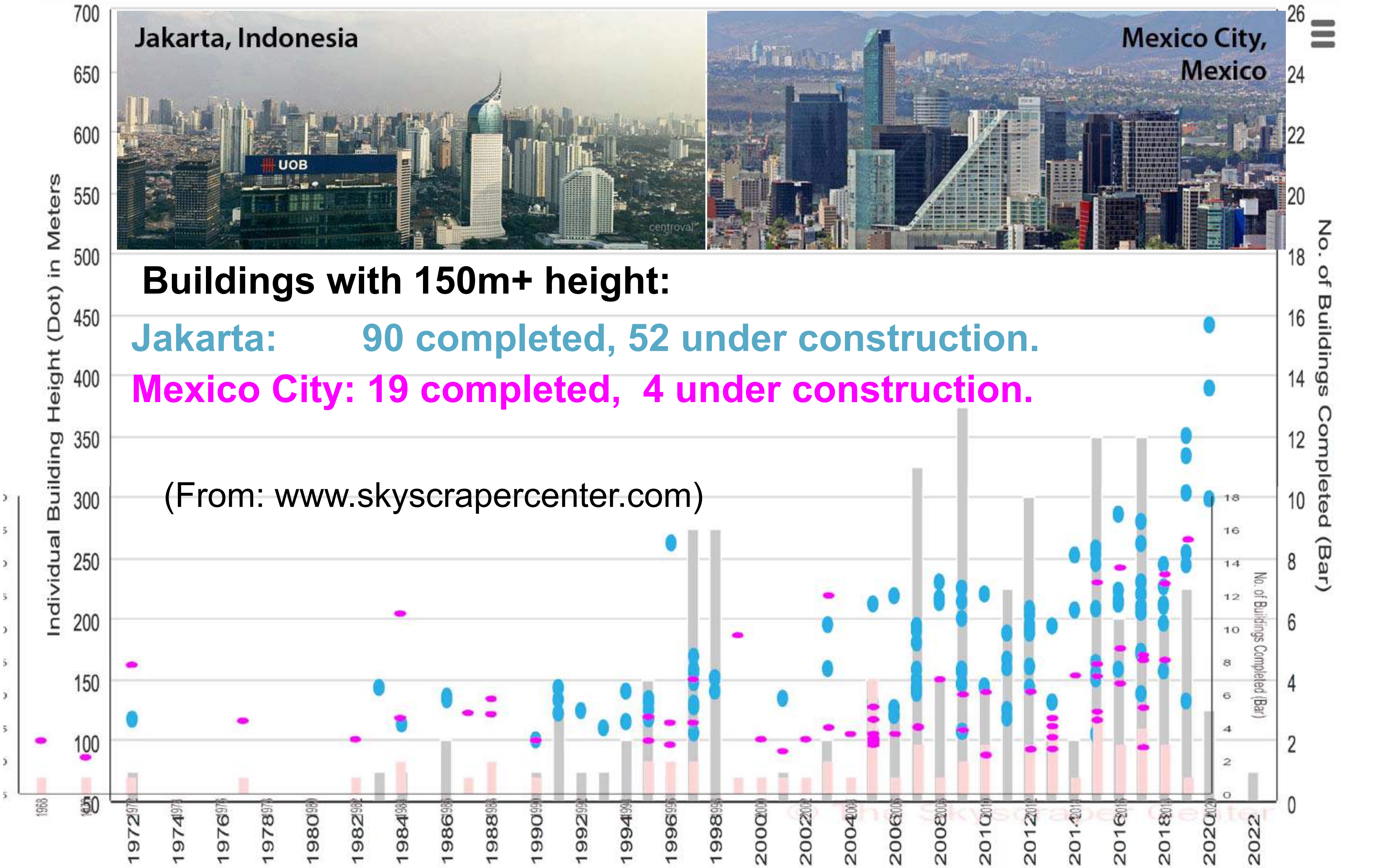

Jakarta, Indonesia
Mexico City, Mexico
Buildings with 150m+ height:
Jakarta: 90 completed, 52 under construction.
Mexico City: 19 completed, 4 under construction.
(From: www.skyscrapercenter.com)
Individual Building Height (Dot) in Meters
No. of Buildings Completed (Bar)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

Conclusions Jakarta Basin

- The 2015 Nepal and 2017 Mexico earthquake highlight the need for more careful consideration of basin response in Indonesian cities.
- Results for the Jakarta Basin indicate the following:
  - Vs less than ≈200 m/s in top 100 m
  - Depth to Tertiary bedrock is 300-500 m in southern, 1 km and more in the northern part of the basin.
  - Abrupt thickening occurs along the NS cross-section about halfway through basin.
- All suggest a fundamental frequency of several seconds, which may influence the response of high-rise buildings in Jakarta to earthquakes

Residential Construction in Java

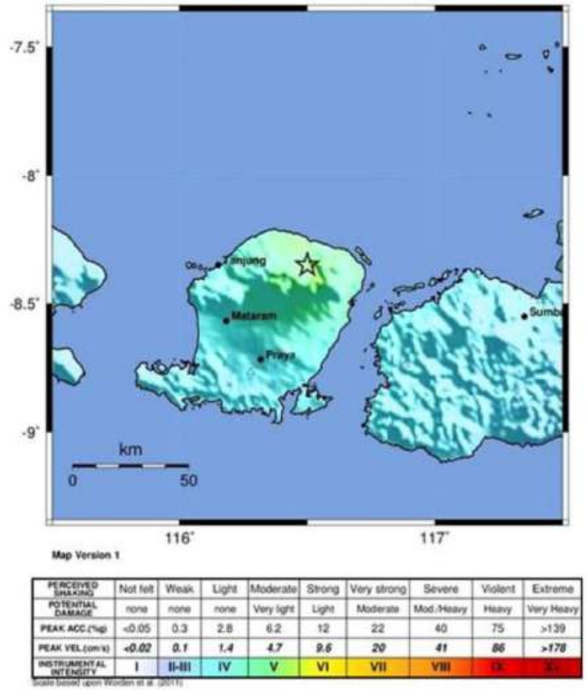
Traditional wood home (Lombok)

- Tradional wood construction largely abandoned in favor of URM.
- Non-engineered construction following popular practice, without input by building experts.
- Buildings typically experience severe damage or collapse in the earthquakes in Indonesia.
- Confined masonry is also common, but issues with concrete quality and adequate reinforcing

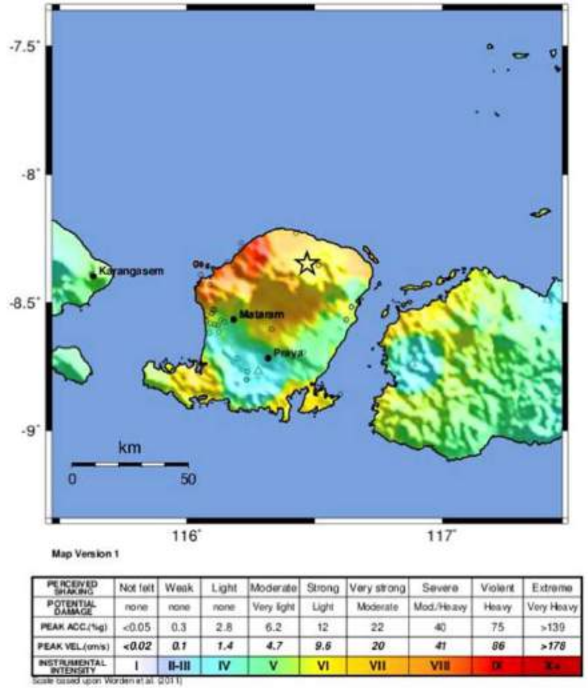
(http://db.world-housing.net)

2018 Lombok Earthquakes

BMKG



M6.4, 29 Juli 2018



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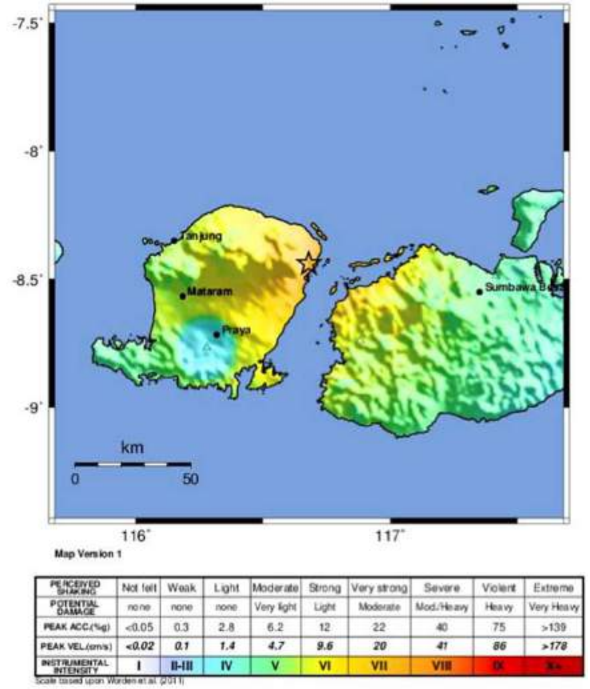


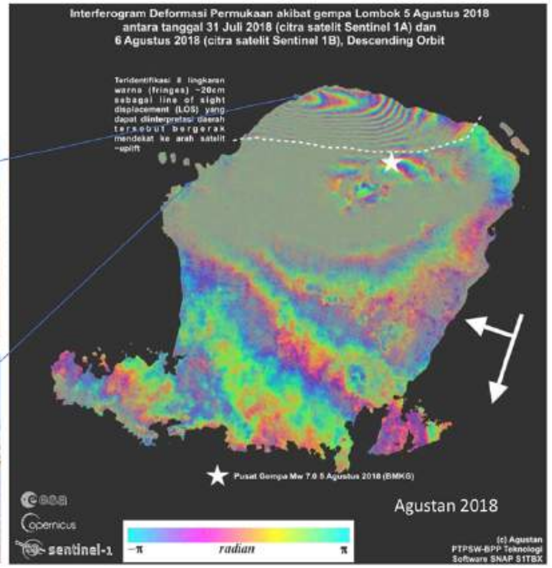
M6.9, 19 Agustus 2018

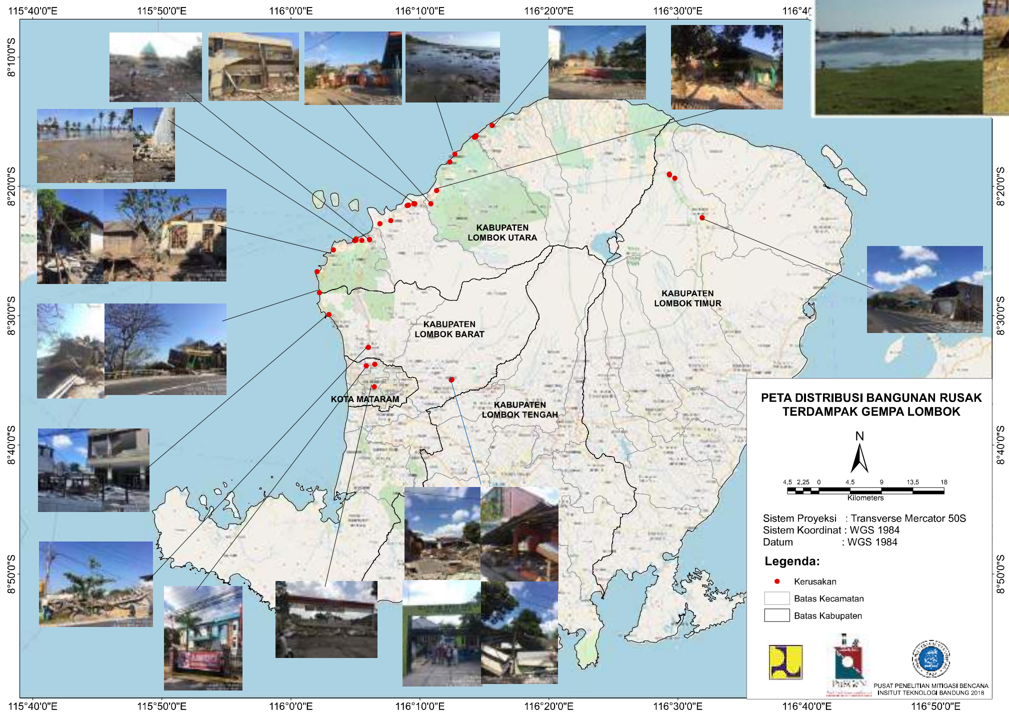
All three earthquakes caused extensive damage, but the 5 August event was particularly devastating. Impacts include displacement of 417 000 and deaths of 563 people, as well as 70% of buildings damaged.

Lombok Earthquakes Damage & Uplift

Pusat Studi Gempa Nasional (PuSGeN)
Pusat Litbang Perumahan dan Pemukiman, Balitbang PUI

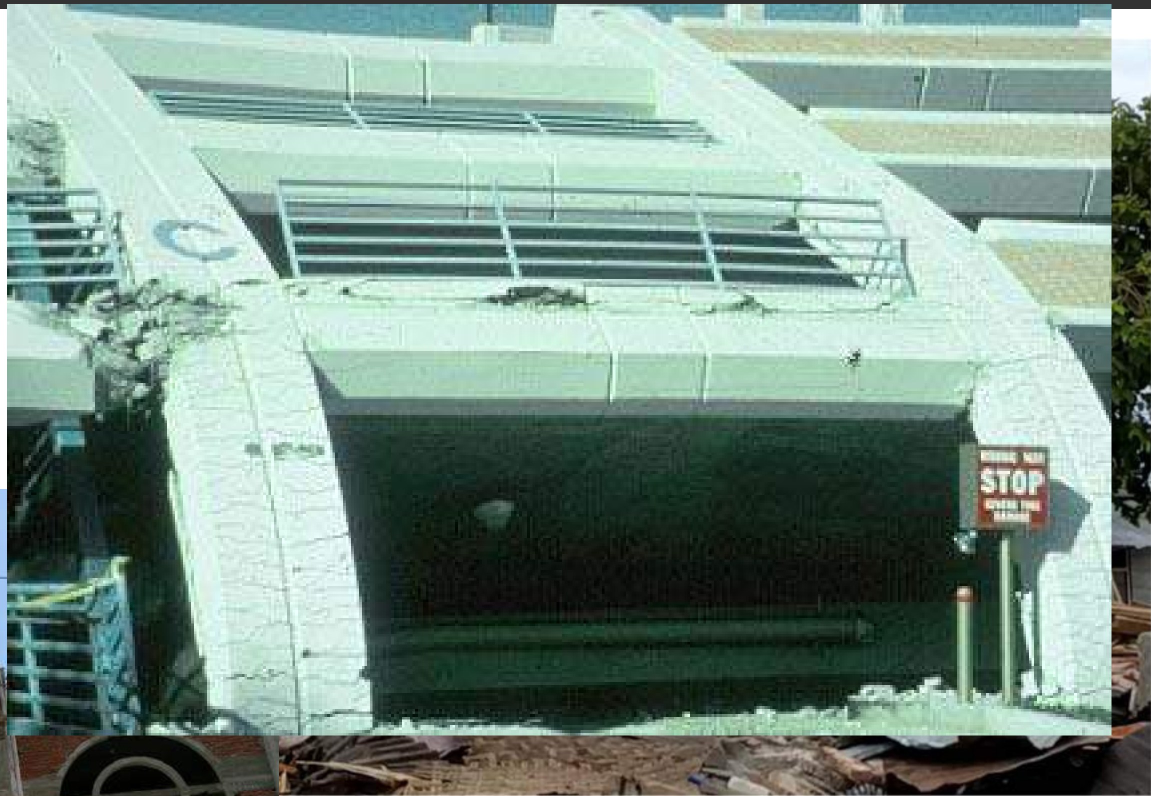
Observasi Lapangan tim PuSGeN-LIPI-ITB-BPPT tanggal 10-12 Agustus 2018. Koral mikroatoll terangkat di wilayah pesisir Lombok Utara daerah Kayangan-Bayan. Subsidence disertai likuifkasi terobservasi di daerah Pemenang, Kab. Lombok utara di pesisir timur.





Australian National University

Concrete Quality and Rebar Re-use



Examples of concrete disintegrating and failing to adhere to rebar, and possible re-use of the rebar in rebuilding.

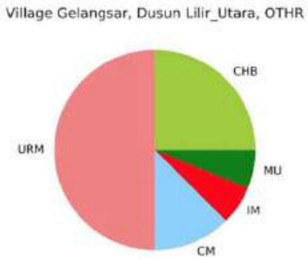
Australian National University

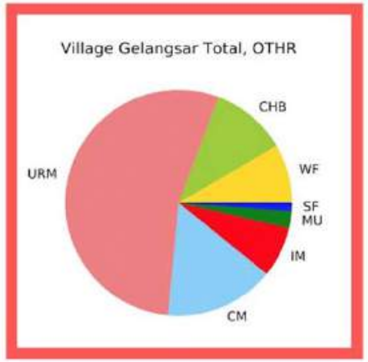
Lombok Pilot Damage Survey

In order to obtain quantitative information on building damage, we conducted a pilot survey in December 2018. 15 subvillages (*dusun*) were surveyed, to collect information in no. buildings, damage state, etc.

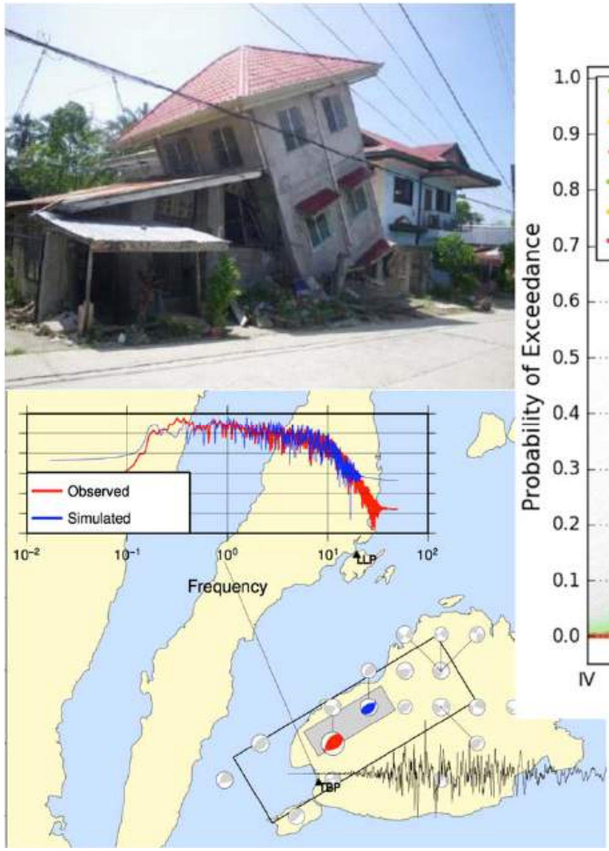
KEY

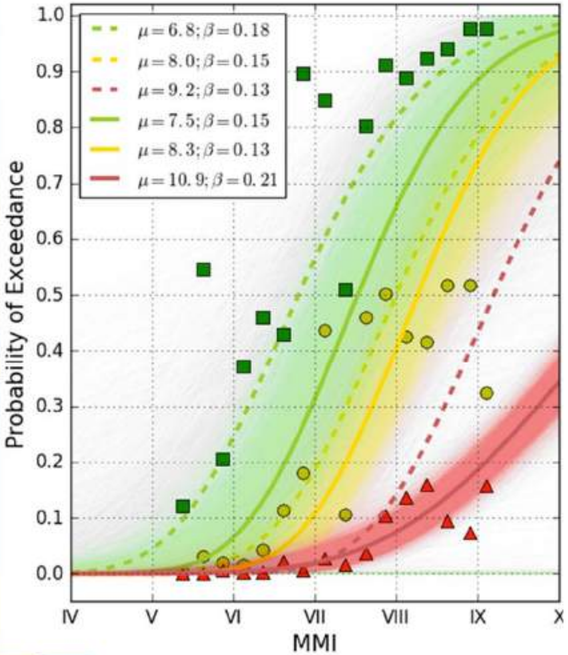
- URM: Unreinforced Masonry (pure brick
- CM: Confined Masonry
- IM: Infill Masonry
- WF: Wood Frame
- SF: Still Frame
- MWM: Mixed Wood/Masonry
- MU: Masonry Unknown





Improve Understanding of Building Performance During Actual Earthquakes





- More systematic collection of post-disaster data would improve knowledge of real-world building performace.
- Allow reliable forecasts of fatalities and economic loss

(Work by Muriel Naguit on building fragility revealed by the 2013 Bojol, Philippines, earthquake)

Australian Government
Geoscience Australia
Australian National University
PHIVOLCS

Not all Retrofits are so Expensive

(a) Steel cage (b) PP-band mesh

(c) Polymer mesh (d) Bamboo mesh (e) Plastic carrier bag

Novel low-cost techniques for reinforcing low-rise masonry construction

(Naravatnarajah, 2015)

Conclusions (general)

- Is a massive-fatality earthquake in Java in thus century all but inevitable?
  - Population explosion occurring during seismic quiescence
- How can science reduce earthquake fatalities?
  - Improve impact (fatalities, loss) forecasts
  - Change public perception of earthquake potential
- How to achieve cultural change to adopt earthquake resilient building construction?
  - Enforcement of building codes?
  - Increased wealth = increased ability to invest in preparedness
  - Prevent “lock-in” of fragile building stock

New Colombo Plan trip to Lombok to study earthquake damage/recovery planned for 17-29 June, 2019. Funding available to undergraduates who are Australian citizens and have not received NCP funding previously.

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