Training/Workshop on

Tsunami Evacuation Maps, Plans, and Procedures and the UNESCO-IOC Tsunami Ready Recognition Programme for the Indian Ocean Member States

Hyderabad - India, 15-23 April 2025

Tsunami Inundation Modelling and MAP

TIMM: Source Considerations for ComMIT

TEMPP 2025

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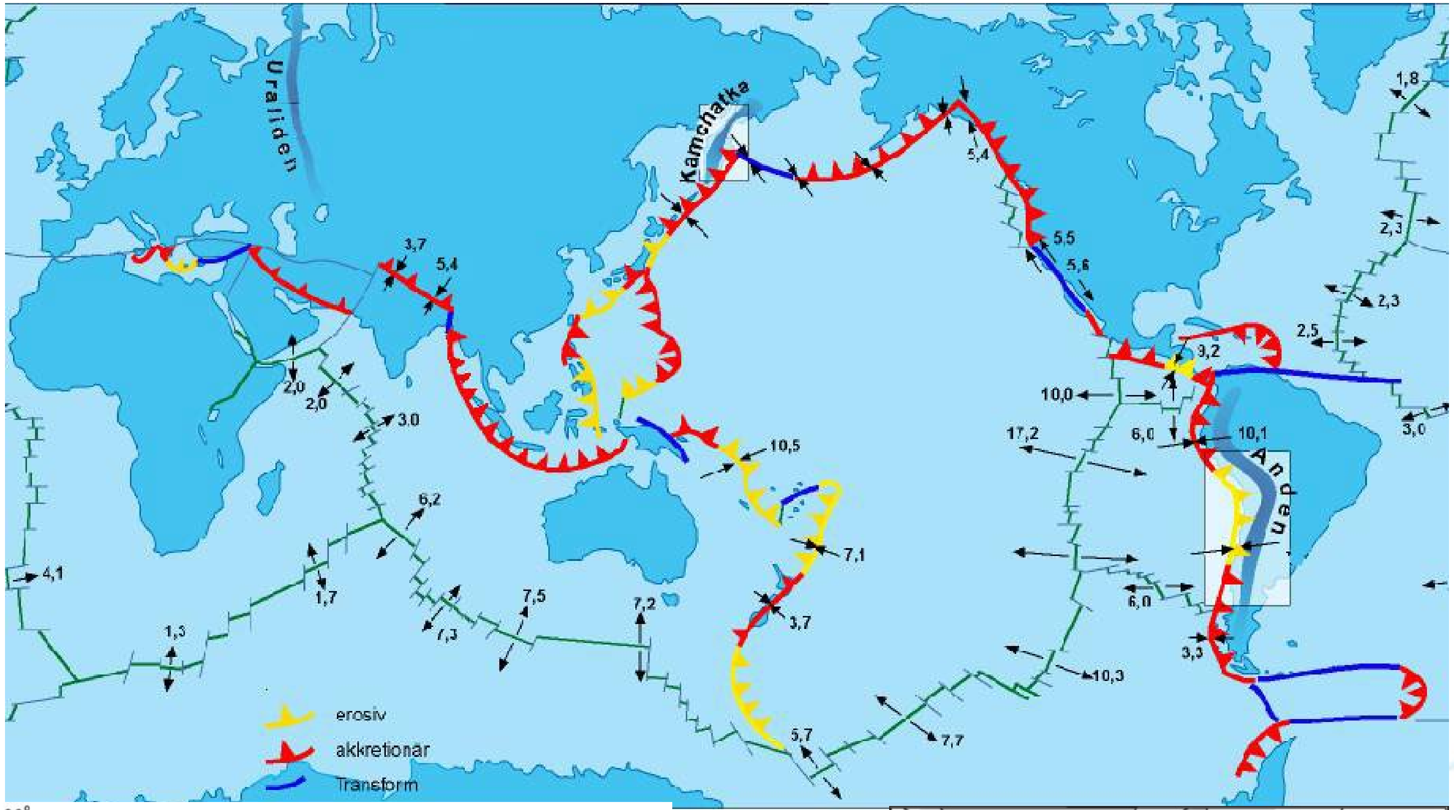
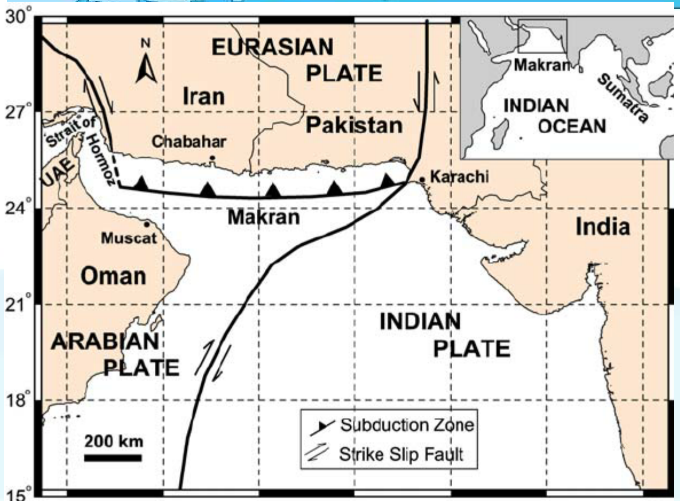
Important Questions

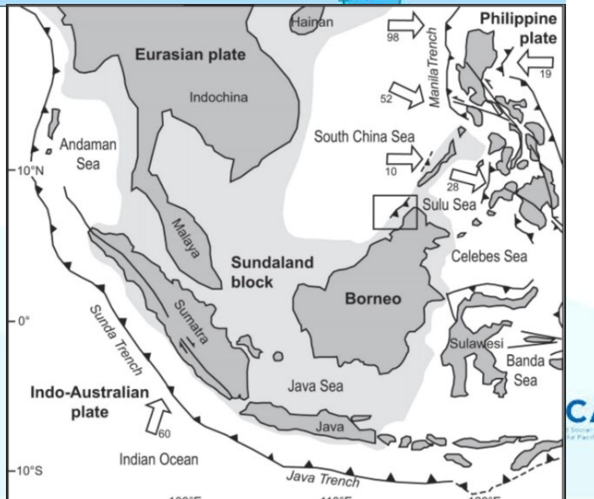
Which of your coastal communities face a threat from tsunamis significant enough to call for inundation modelling, and which tsunami scenarios would you choose for such modelling?

- Where is the tsunami hazard along your coast significant?
- What are the important source zones in the Indian Ocean?
    - Sumatra & Makran
    - Near Source: India (A&N), Indonesia, Oman, Malaysia
    - Far Source: India (Mainland), Maldives, Seychelles
- DTHA or PTHA
    - Source Locations & Magnitudes ?
    - Was the 2004 IOT the “worst case”, or does the potential for even higher impacts exist?
    - Can the results of IO PTHA guide your decision on a credible scenario
- Understanding uncertainty?

Subduction Zones







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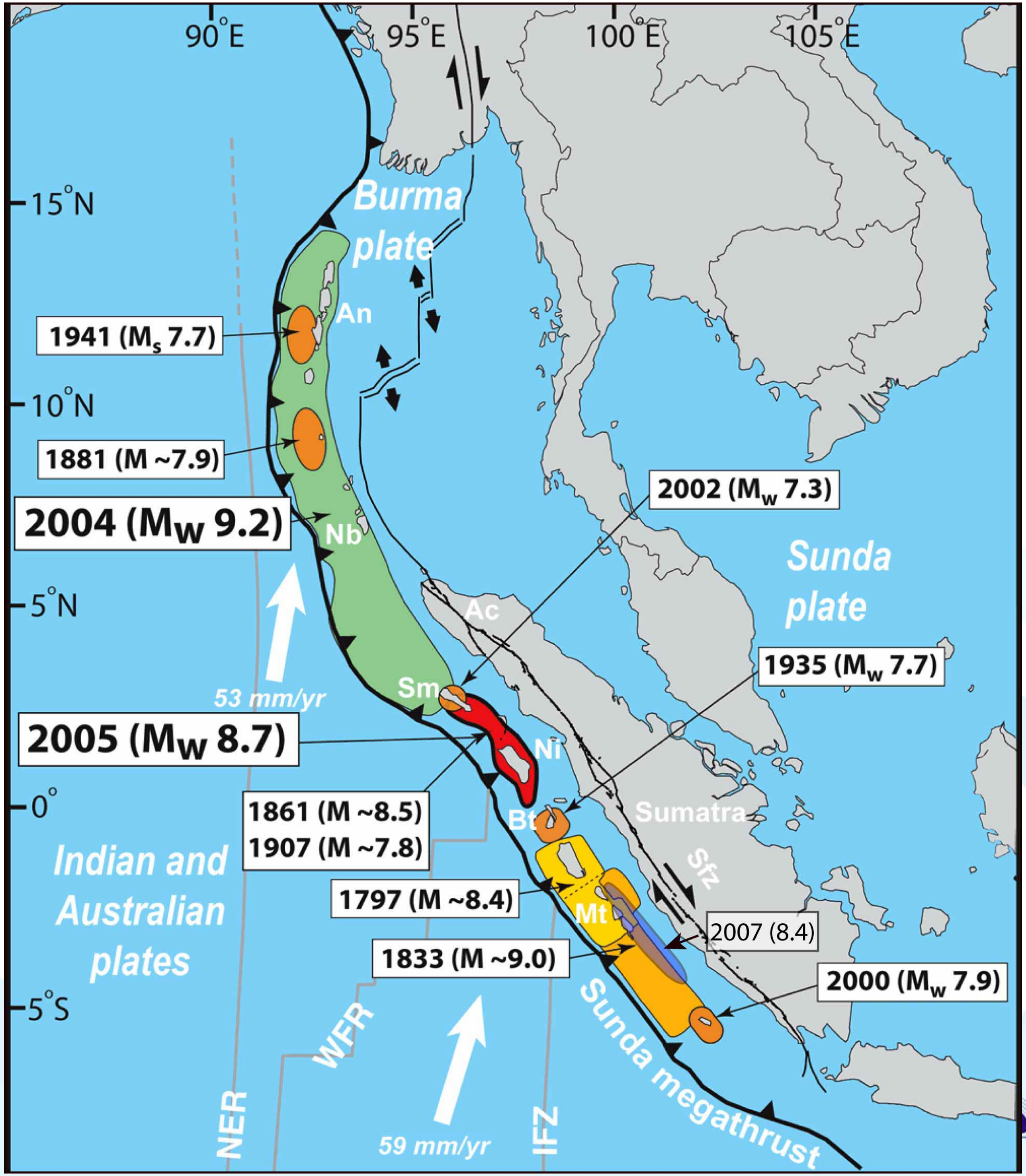
CAP INCOIS BMKG Tsunami Ready

Historical Earthquakes in Sumatra

Satish Singh, 2009



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BMKG

Tsunami Ready

Historical earthquakes in Makran

Ref: Mohammad Heidarzadeh et al 2008

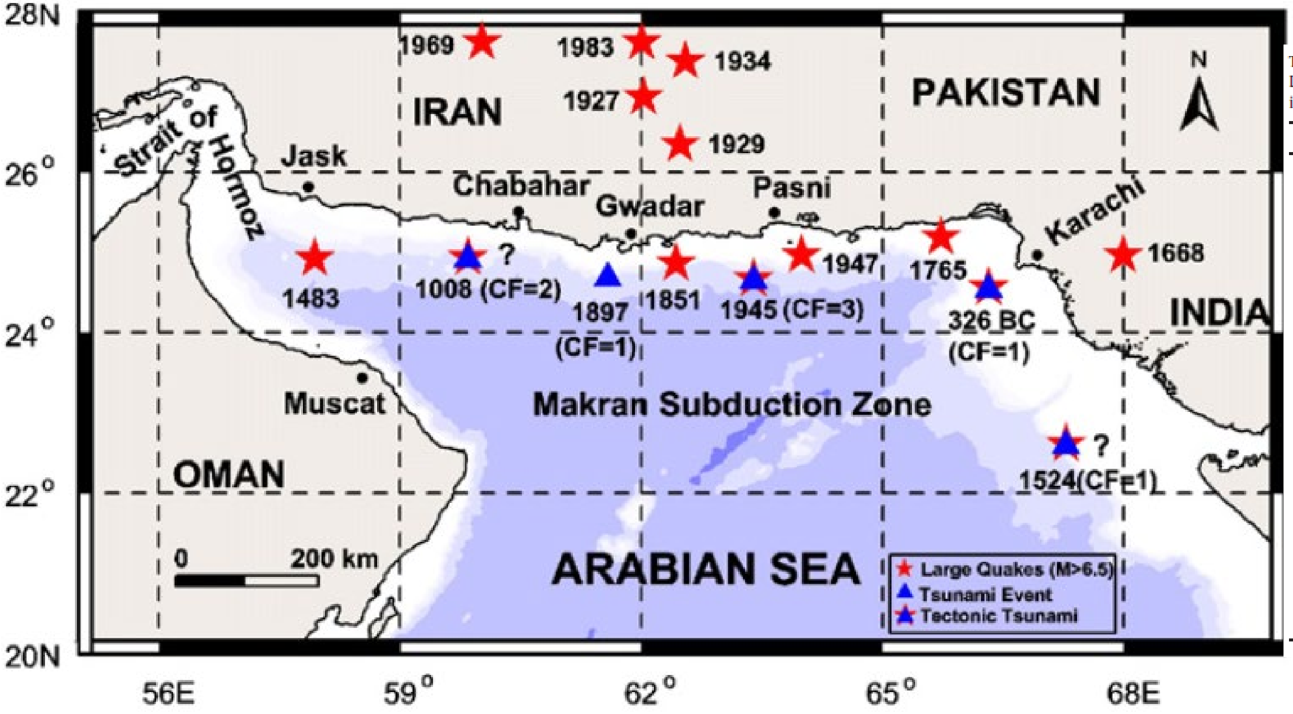
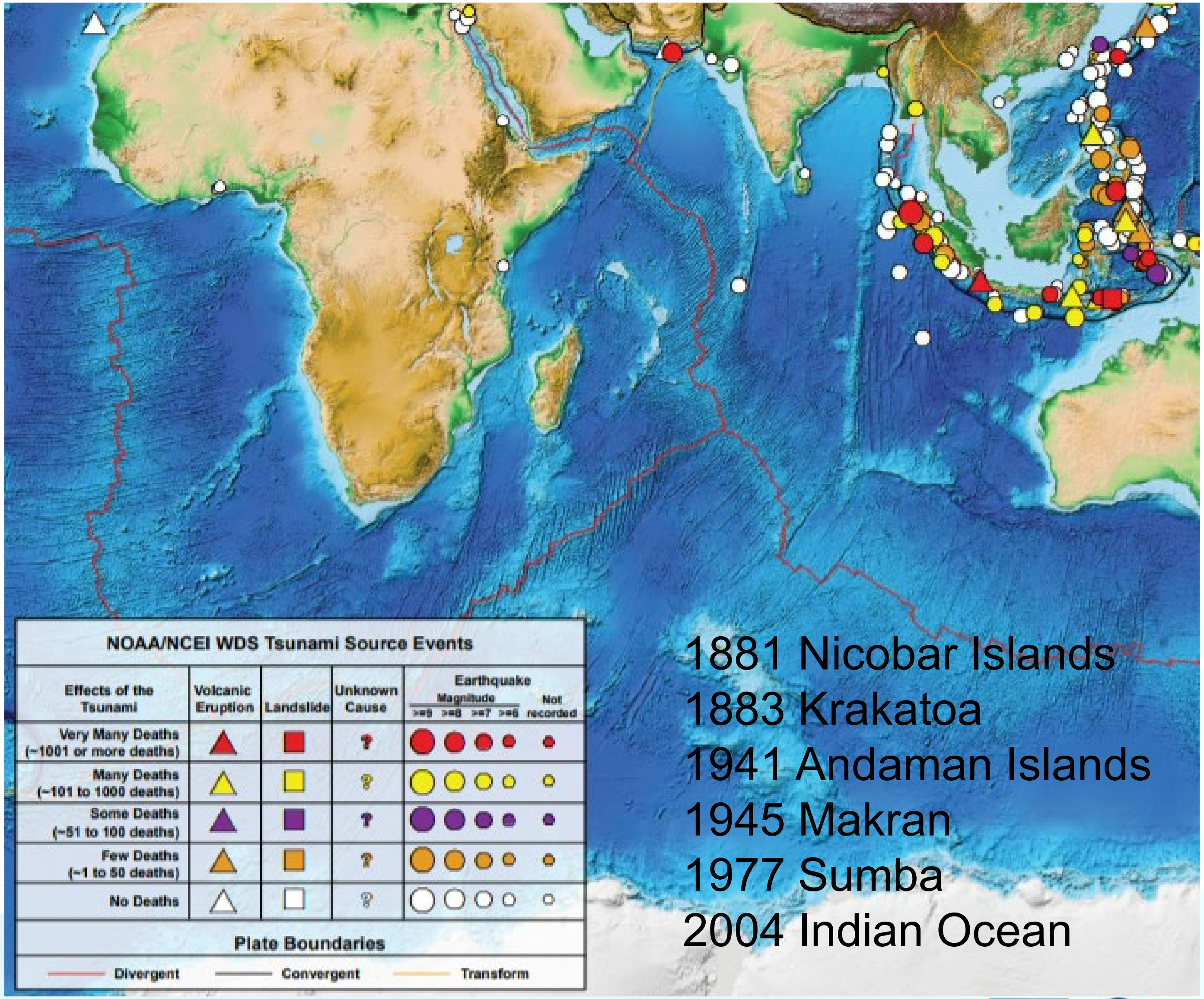


Table 1
List of large earthquakes and tsunamis around the Makran subduction zone as attested in historical records.

Year	Location	Remarks	References
326 BC	Eastern Makran near the Indus Delta	Destruction of a Macedonian fleet in Western India by huge waves is described in Greek and Indian historical records.	Murty and Bapat, 1999; Pararas-Carayannis, 2006b; Rastogi and Jaiswal, 2006.
1008 AD	Western Makran, near the strait of Hormoz	An earthquake and tsunami on the southern coast of Iran.	Ambraseys and Melville, 1982.
1483 AD	Western Makran, near the strait of Hormoz	Destructive earthquake in the strait of Hormoz, northwestern Oman was affected by the earthquake.	Quittmeyer and Jacob, 1979; Ambraseys and Melville, 1982.
1765 AD	Eastern Makran	A strong earthquake in the eastern Makran.	Quittmeyer and Jacob, 1979; Byrne et al., 1992.
1851–1864 AD	Middle part of Makran, Near Gwadar	Two great earthquakes in the middle part of Makran affected the town of Gwadar	Quittmeyer and Jacob, 1979; Byrne et al., 1992.
1945 AD	Offshore Pakistani coast near Pasni	Magnitude 8 to 8.3 tsunami wave run-up was 11 to 13 m in the near coast, claimed about 4000 lives.	Quittmeyer and Jacob, 1979; Ambraseys and Melville, 1982; Pararas-Carayannis, 2006a.

Tsunami Sources (NGDC/NOAA)



1881 Nicobar Islands
1883 Krakatoa
1941 Andaman Islands
1945 Makran
1977 Sumba
2004 Indian Ocean

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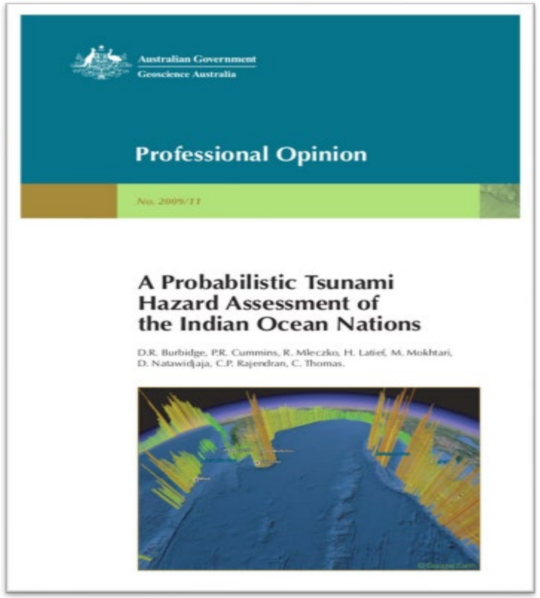
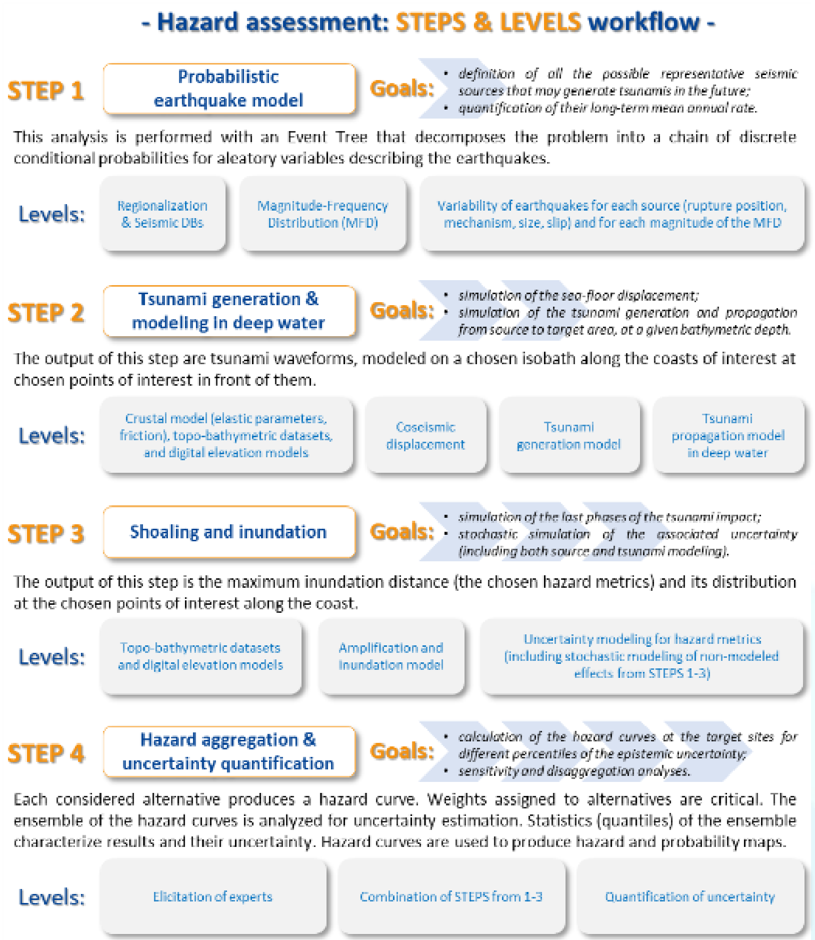
IO Hazard Assessment Resources





Inundation PTHA in Western Australia

- **Collaboration with Geoscience Australian & local emergency services (DFES)**
  - June 2021 – June 2024
- **Tsunami inundation hazard maps for Western Australia**
  - PTHA18 + Large-scale inundation model
  - Methodology from this paper →

- **Design of onshore evacuation maps**
  - Strong involvement of DFES staff
  - Derived from models & DFES expertise
    - Consider practicalities of communication / action
    - As well as model results

Gareth Davies

Makran PTHA

PCTWIN PTHA

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Sources used for 2009 PTHA

Subduction Zone	Segment	Maximum Magnitude (Mw): Historical	Maximum Magnitude (Mw): Low Hazard	Maximum Magnitude (Mw): High Hazard
Andaman-Sunda Arc	A	unknown (1762[1])	0.0	9.5
	B	9.2 (1881[2], 2004[3])	9.2	
	C	8.7 (1861,2005[4])	8.7	
	D	9.1 (1797,1833,2007[5])	9.1	
	E	7.6 (2000[5])	7.6	
	F	7.8 (1994[7],2006[8])	7.8	
	G	none	0.0	
Makran	H	unknown (1483[8])	0.0	9.1
	I	8.1 (1945[9])	8.2	
South Sandwich		none	0.0	9.0

Table 2: Summary of megthrust earthquake tsunami source zones used in the low-hazard and high-hazard maps. The three subduction zones considered are shown, along with the segmentation that was used for the low-hazard maps (see Fig. 5a). The maximum magnitude of the historical earthquakes listed in brackexts is listed in the third column. The maximum magnitudes used to generate the low-hazard and high-hazard assessments are shown in columns four and five. Where the maximum magnitude for historical earthquakes is listed as 'unknown' that indicates that a large (possibly megathrust) earthquake occurred, but its magnitude is unknown. By contrast 'none' indicates that there is no known historical occurrence of a megathrust earthquake large enough to generate a destructive tsunami. The years of historical earthquakes are indicated in parentheses with superscripts to indicate the following references: [1] Cummins (2007), [2] Ortiz and Bilham (2003), [3] Stein and Okal (2005), [4] Briggs *et al* (2005), [5]Natawidjaja *et al* (2006), [6]Abercrombie *et al* (2003), [7] Abercrombie *et al* (2001), [8]Ammon *et al* (2007), [8]Abraseys and Melville (1982), [9]Byrne *et al* (1992). These studies were used to infer the width of the megathrust seismogenic zone used in the low-hazard map, indicated as (full) or (half).

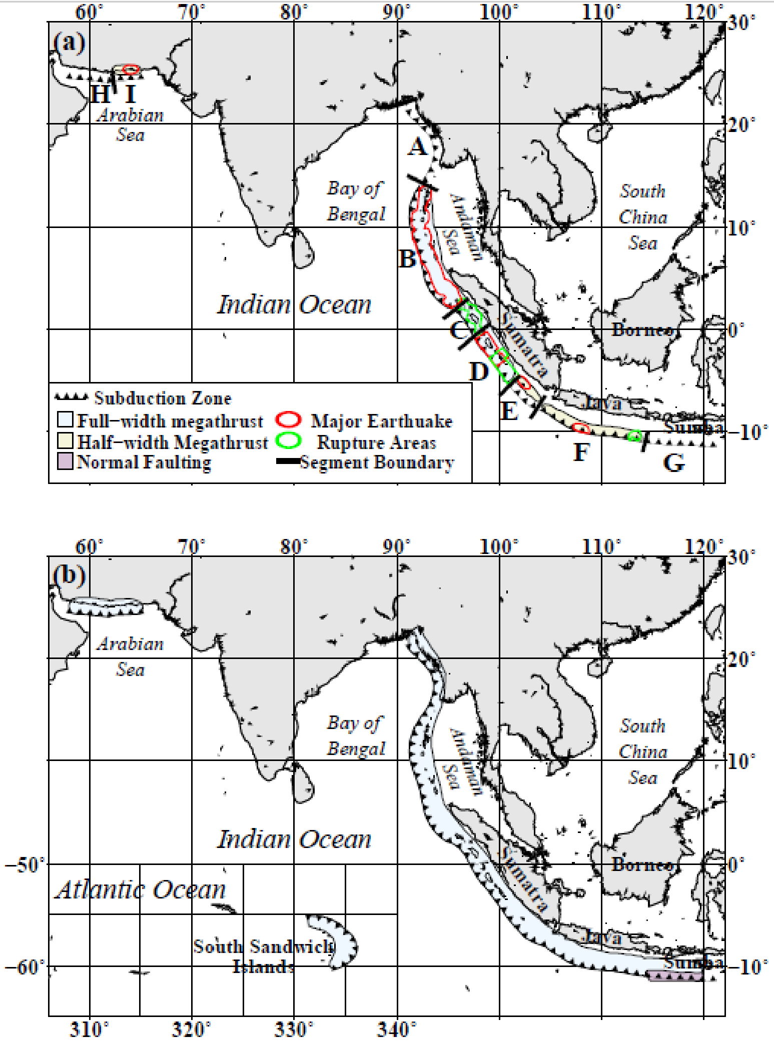

Figure 5: Map of megathrust earthquake sources of tsunami in the Indian Ocean, illustrating the source characterisation used for the low-hazard and the high-hazard maps. (a) The megathrust segmentation for the low hazard map. Also shown are the megathrust seismogenic zones characterized as "full-width" and "half-width". (b) The segmentation for the high-hazard assessment. This figure alsoincludes the South Sandwich Arc, which is a source of tsunami for the high-hazard map but not for the low-hazard one. The Puysegur subduction zone south of New Zealand was included, but made no significant contribution to the hazard along the coastlines coinsidered here. Plate boundaries from Bird (2002).

Results of Indian Ocean PTHA

Indian Ocean nation	1/2000yr tsunami amplitude (m)		Most Important Subduction Zone Segments
	low	high	
Bangladesh	0.5	0.6	Andaman
British Ocean Territory	1.1	1.7	Andaman, Sumatra
Burma	1.1	1.5	Andaman, Sumatra
Comoros	0.3	0.5	Makran, Andaman, Sumatra
Djibouti	0.2	0.4	Makran
India	1.9	3.1	Makran, Andaman, Sumatra
Indonesia	5.6	7.1	Andaman, Sumatra, Java and Sumba
Iran	0.3	2.7	Makran
Kenya	0.5	0.8	Andaman, Sumatra
Madagascar	1.0	2.2	Andaman, Sumatra, Java, Sth Sandwich
Maldives	2.2	3.0	Andaman, Sumatra, Makran
Mauritius	1.2	1.7	Andaman, Sumatra, Makran
Mayotte	0.3	0.4	Andaman, Sumatra, Makran
Mozambique	0.5	1.4	Andaman, Sumatra, Sth Sandwich
Oman	0.6	3.8	Andaman, Sumatra, Makran
Pakistan	0.9	2.8	Makran
Reunion	0.7	1.4	Andaman, Sumatra, Sth Sandwich
Seychelles	0.8	1.2	Andaman, Sumatra, Makran
Somalia	0.7	1.1	Andaman, Sumatra, Makran
South Africa	0.6	1.6	Andaman, Sumatra, S Sandwich
Sri Lanka	2.9	3.7	Andaman, Sumatra
Tanzania	0.5	0.9	Andaman, Sumatra, Makran
Thailand	1.9	2.6	Andaman, Sumatra
United Arab Emirates	0.1	0.8	Makran
Yemen	0.8	1.3	Makran, Andaman, Sumatra

Table 1: Summary of results for all the nations considered in the study for one particular measure of the offshore tsunami hazard, the name of country is listed in the first column. The second and third columns show the maximum tsunami amplitude with a 1 in 2000 year chance of being exceeded for any point off the Indian Ocean nation shown in the first column for the low hazard and high hazard assessments, respectively. The nations shown in red have the highest (greater than 2m maximum tsunami amplitude in the high hazard map) hazard at this return period. The nations shown in green have the lowest (tsunami amplitude is less than 1m in the high hazard map) at the 2000 year return period. The fourth column lists the subduction zones which make the greatest contribution to the 1 in 2000 year hazard for that particular nation.

- A 2000 year return period is typically the upper limit used for emergency planning because it is normally associated with a large, but still reasonably probable, event.
- Tsunami height at 100m water depth
  - Less than 25 cm is likely insignificant
  - 25 to 75 cm could cause significant localized run-up
  - Greater than 75 cm, a significant threat
- You may need to modify these as you learn more from inundation modelling
- Greens Law

5.27 Oman (low hazard)

Figure 42(a) shows that the maximum amplitudes increase from south to north across the points offshore Oman. Values range from about 0.1m in the north to 0.6m in the south at the 2000 year return period (Figure 42(a)). Tha main source of the hazard to Oman is the Makran and Andaman zones with some contributions from central Sumatra (Figure 42(b)) for this return period.

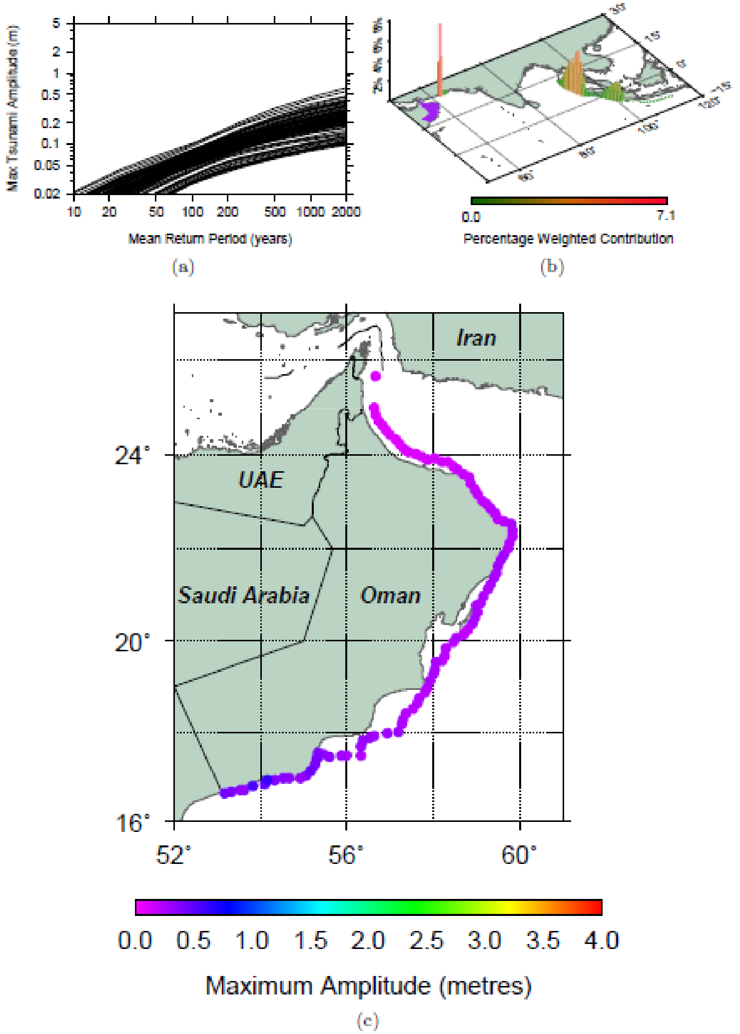

Figure 42: Oman:- (a) Hazard curves for all model output points. (b) National weighted deaggregated hazard. (c) Maximum amplitude at a 2000 year return period for all model output points.

5.28 Oman (high hazard)

In the high hazard assessment the hazard off northeast Oman which directly faces the western Makran is significantly larger than any other section of the Omani coast (Figure 43(c)). One isolated point has a maximum exceedence amplitude at 2000 years of 5m, however since that point is isolated it should be treated with caution (Figure 43(c)). The hazard for the rest of the Omani coast ranges from 0.5m to 3.8m (Figure 43(a)). In this high hazard assessment the hazard at the 2000 year return period is dominated by the Western Makran, with a relatively small contribution from Sumatra (Figure 43(b)).

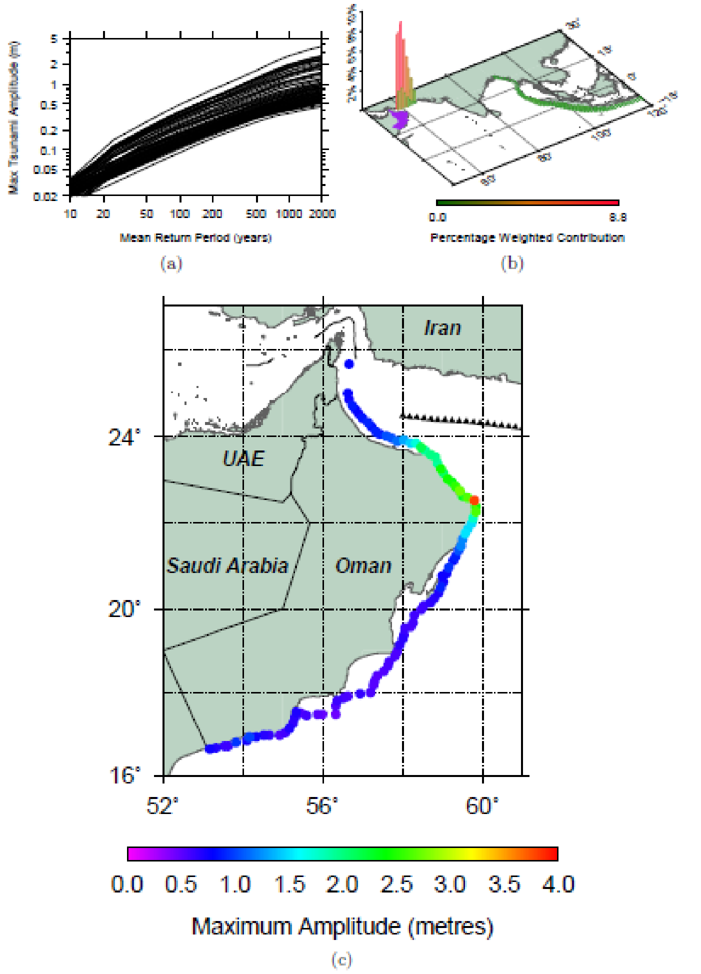

Figure 43: Oman:- (a) Hazard curves for all model output points. (b) National weighted deaggregated hazard. (c) Maximum amplitude at a 2000 year return period for all model output points.

5.11 India

5.11.1 Indian Mainland (low hazard)

The large 2000 year maximum amplitude has a very large spread of values for India. It is far higher on the east coast than on the west coast (Figure 18(c)). the 2000 year return period range from 0.1m (west coast) to 1.9m (east coast). Tl here is dominated by the southern and central Andaman zone (Figure 18(b))

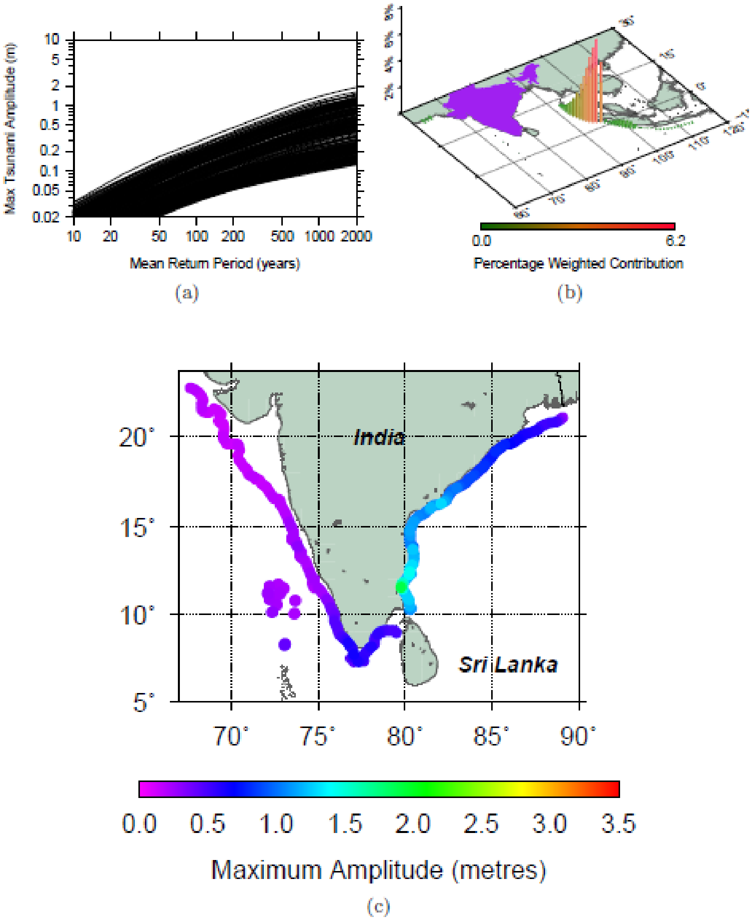

Figure 18: India:- (a) Hazard curves for all model output points. (b) National weighte gated hazard. (c) Maximum amplitude at a 2000 year return period for all model outpu

5.11.2 Indian Mainland (high hazard)

The large 2000 year maximum amplitude in the high hazard again is much higher on the east coast than the west (Figure 19(c)). The hazard ranges from over 3m (east coast) to 0.3m (west coast). The single high hazard value for the east coast in both the low and high hazard maps should be interpreted with caution as this could be due to a local bathymetric anomaly in the global bathymetry dataset used in this assessment. The deaggregated hazard map (Figure 19(b) shows that the most important zone is the Andaman, but significant contributions also come from the Arakan (east coast) and Makran (west coast).

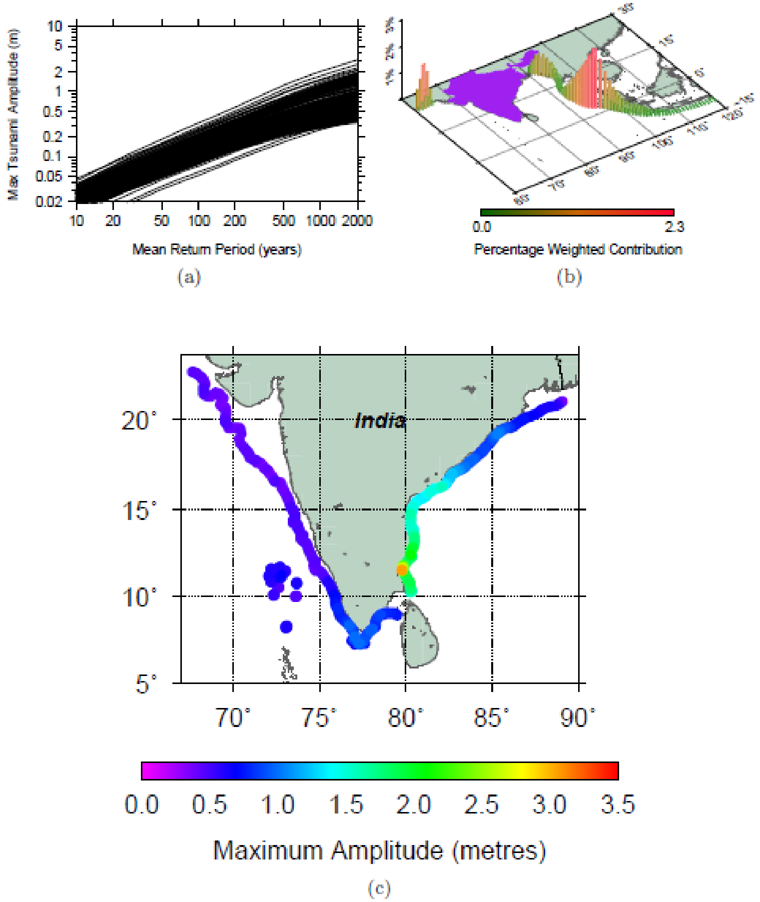

Figure 19: India:- (a) Hazard curves for all model output points. (b) National weighted deaggregated hazard. (c) Maximum amplitude at a 2000 year return period for all model output points.

5.11.3 Andaman and Nicobar Islands (low hazard)

The 2000 year maximum amplitude ranges from 0.5m to over 4m along the An of islands (Figure 20(a)). The hazard naturally mostly comes from the cent Andaman zone itself (Figure 20(b)). The hazard is significantly lower offshore Andaman islands which lie to the north of the end of the Andaman zone (Fig

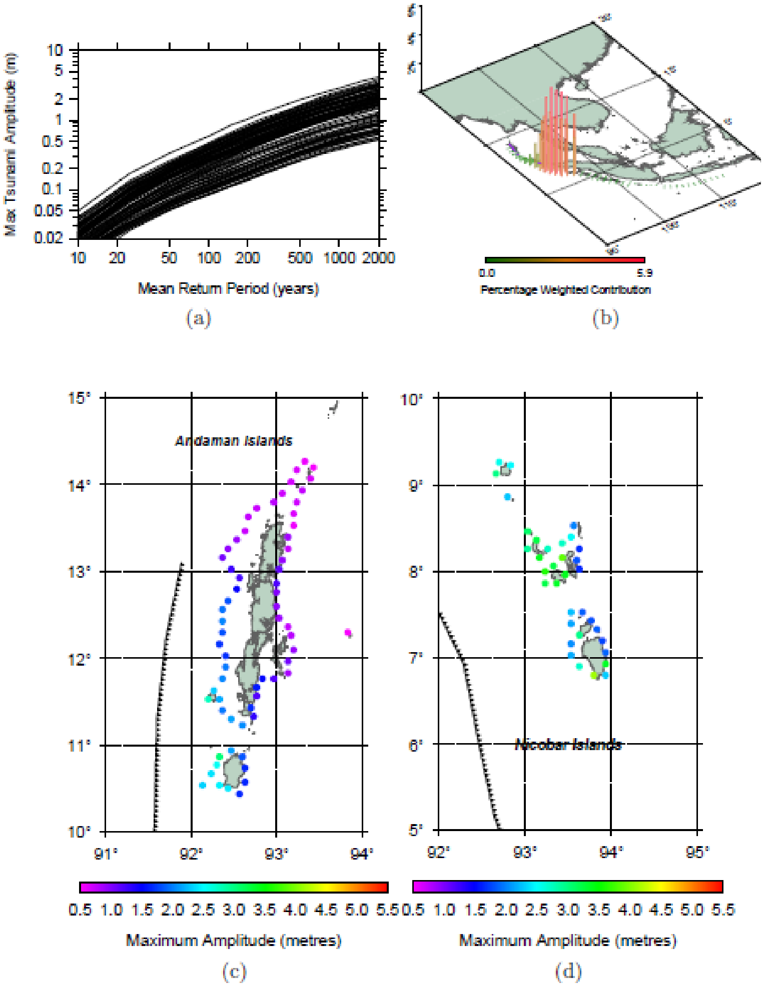

Figure 20: Andaman and Nicobar Island:- (a) Hazard curves for all model outpu National weighted deaggregated hazard. (c) Maximum amplitude at a 2000 year ret all model output points.

5.11.4 Andaman and Nicobar Islands (high hazard)

The large 2000 year maximum amplitude for the Andaman Islands in the high hazard model ranges from over 0.7m to just over 5m (Figure 21(a)). The hazard again mostly originates from the southern and central Andaman, with only a very small contribution from the Arakan zone (Figure 21(b)). The hazard again is again higher in the north than the south (Figure 21(c))

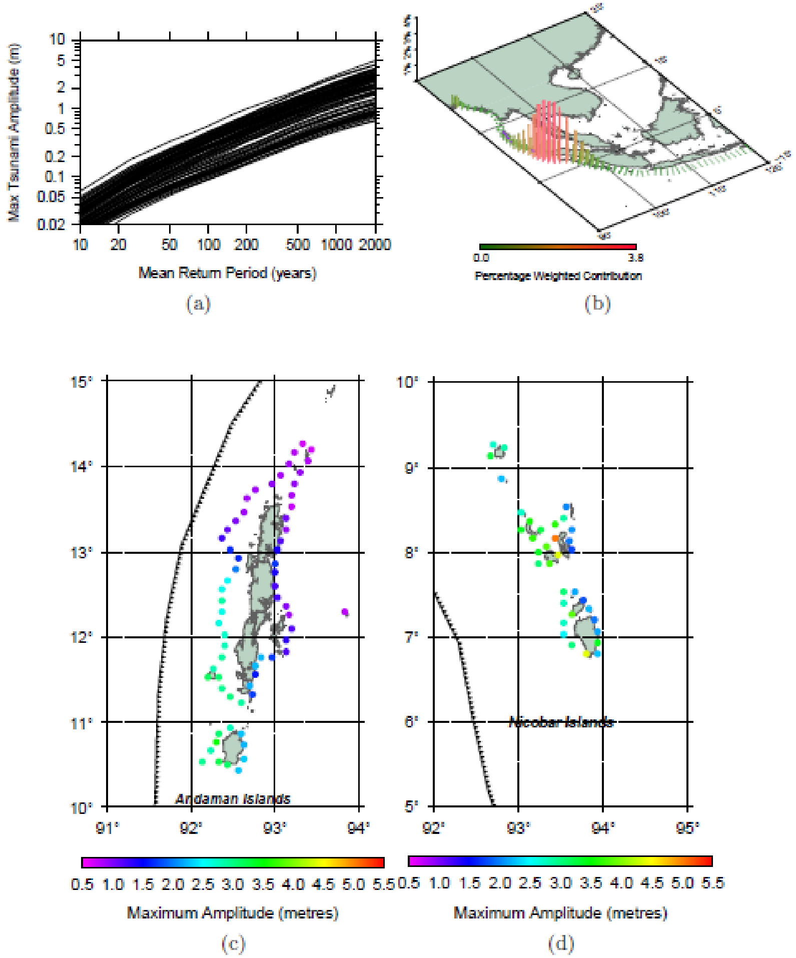

Figure 21: Andaman and Nicobar Island:- (a) Hazard curves for all model output points. (b) National weighted deaggregated hazard. (c) Maximum amplitude at a 2000 year return period for all model output points.

Guidance for Selection of Scenarios

- Selection of appropriate scenarios and magnitude may be based on the results of PTHA which provides a range of maximum tsunami amplitude with a 1 in 2000-year chance of being exceeded for each country for a low and high hazard source. The table also provides information on the subduction zone segments that contribute to tsunami hazard for each country.

Indian Ocean nation	1/2000yr tsunami amplitude (m)		Most Important Subduction Zone Segments
	low	high	
Bangladesh	0.5	0.6	Andaman
British Ocean Territory	1.1	1.7	Andaman, Sumatra
Burma	1.1	1.5	Andaman, Sumatra
Comoros	0.3	0.5	Makran, Andaman, Sumatra
Djibouti	0.2	0.4	Makran
India	1.9	3.1	Makran, Andaman, Sumatra
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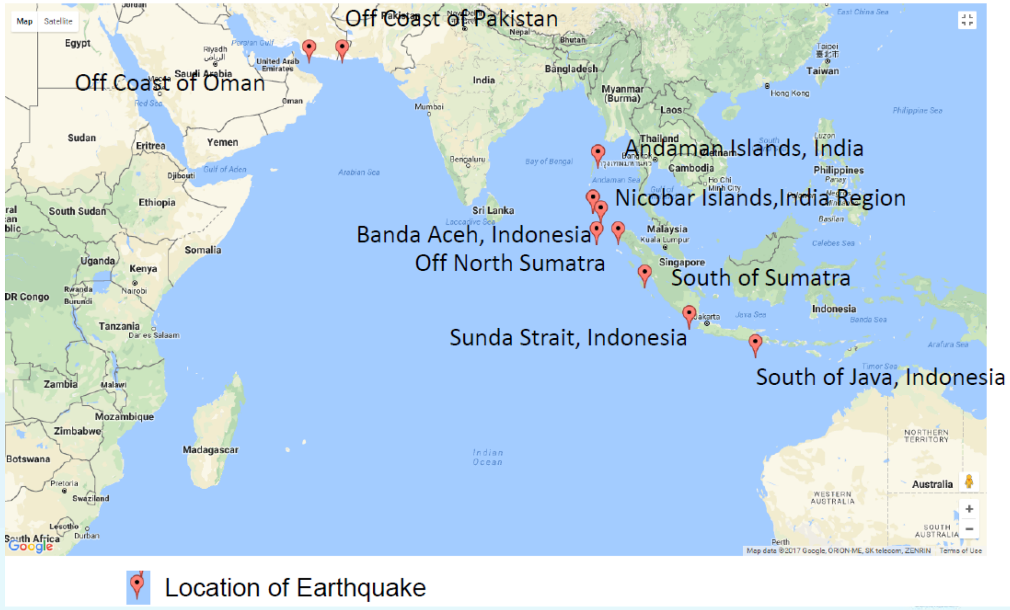
Iran	0.3	2.7	Makran
Kenya	0.5	0.8	Andaman, Sumatra
Madagascar	1.0	2.2	Andaman, Sumatra, Java, Sth Sandwich
Maldives	2.2	3.0	Andaman, Sumatra, Makran
Mauritius	1.2	1.7	Andaman, Sumatra, Makran
Mayotte	0.3	0.4	Andaman, Sumatra, Makran
Mozambique	0.5	1.4	Andaman, Sumatra, Sth Sandwich
Oman	0.6	3.8	Andaman, Sumatra, Makran
Pakistan	0.9	2.8	Makran
Reunion	0.7	1.4	Andaman, Sumatra, Sth Sandwich
Seychelles	0.8	1.2	Andaman, Sumatra, Makran
Somalia	0.7	1.1	Andaman, Sumatra, Makran
South Africa	0.6	1.6	Andaman, Sumatra, S Sandwich
Sri Lanka	2.9	3.7	Andaman, Sumatra
Tanzania	0.5	0.9	Andaman, Sumatra, Makran
Thailand	1.9	2.6	Andaman, Sumatra
United Arab Emirates	0.1	0.8	Makran
Yemen	0.8	1.3	Makran, Andaman, Sumatra

Table 1: Summary of results for all the nations considered in the study for one particular measure of the offshore tsunami hazard, the name of country is listed in the first column. The second and third columns show the maximum tsunami amplitude with a 1 in 2000 year chance of being exceeded for any point off the Indian Ocean nation shown in the first column for the low hazard and high hazard assessments, respectively. The nations shown in red have the highest (greater than 2m maximum tsunami amplitude in the high hazard map) hazard at this return period. The nations shown in green have the lowest (tsunami amplitude is less than 1m in the high hazard map) at the 2000 year return period. The fourth column lists the subduction zones which make the greatest contribution to the 1 in 2000 year hazard for that particular nation.

Guidance for Selection of Scenarios

- Each country may consider selecting 4 scenarios from the table below run inundation model using ComMIT. Based on the results of the model runs, a composite inundation line may be generated for further hazard assessment

S. No.	Latitude	Longitude	Magnitude	Region	Comments
1	24.8 N	62.2 E	9.0	Off Coast of Pakistan	
2	24.8 N	58.2 E	9.2	Off Coast of Iran	IOWave 18 Scenario ???
3	12.65 N	93.5 E	9.0 to 9.2	Andaman Islands	
4	7.2 N	92.9 E	9.0 to 9.2	Nicobar Islands	
5	3.3 N	96.0 E	9.3	Banda Aceh / Off North Sumatra	Dec 26, 2004 Event IOWave18 Scenario???
6	1.93 S	99.22 E	9.2	South of Sumatra	
7	6.94 S	104.7 E	9.0 to 9.2	Sunda Strait	
8	10.4 S	112.8 E	9.1	South of Java	



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ComMIT Unit Sources for PTHA Suggested Scenarios

cut and paste into "Model->Sources from Solution/Combination"

- Off Coast of Pakistan
  Mw 9.0, mk2-7, rows a-b, alpha=14.7839
  14.7839*mk2b+14.7839*mk2a+14.7839*mk3b+14.7839*mk3a+14.7839*mk4b+14.7839*mk4a+14.7839*mk5b+14.7839*mk5a+14.7839*mk6b+14.7839*mk6a+14.7839*mk7b+14.7839*mk7a

- Off Coast of Iran
  Mw 9.2, mk4-10, rows a-b, alpha=25.284
  25.284*mk4a+25.284*mk4b+25.284*mk5a+25.284*mk5b+25.284*mk6a+25.284*mk6b+25.284*mk7a+
  25.284*mk7b+25.284*mk8a+25.284*mk8b+25.284*mk9a+25.284*mk9b+25.284*mk10a+25.284*mk10b

- Andaman Islands
  Mw 9.2, io5-12, rows a-b, alpha=22.123
  22.123*io5a+22.123*io5b+22.123*io6a+22.123*io6b+22.123*io7a+22.123*io7b+ 22.123*io8a+22.123*io8b+22.123*io9a+22.123*io9b+22.123*io10a+22.123*io10b+
  22.123*io11a+22.123*io11b+22.123*io12a+22.123*io12b

- Nicobar Islands
  Mw 9.2, io11-18, rows a-b, alpha=22.123
  22.123*io11a+22.123*io11b+22.123*io12a+22.123*io12b+22.123*io13a+22.123*io13b+22.123*io14a+22.123*io14b+22.123*io15a+22.123*io15b+22.123*io16a+22.123*io16b+22.123*io17a+22.123*io17b+22.123*io18a+22.123*io18b

- Banda Aceh, North Sumatra
  Mw 9.3, io17-24, rows a-b, alpha=31.250
  31.250*io17a+31.250*io17b+31.250*io18a+31.250*io18b+31.250*io19a+31.250*io19b+31.250*io20a+31.250*io20b+31.250*io21a+31.250*io21b+31.250*io22a+31.250*io22b+31.250*io23a+31.250*io23b+31.250*io24a+31.250*io24b

- South of Sumatra
  Mw 9.2, io24-31, rows a-b, alpha=22.123
  22.123*io24a+22.123*io24b+22.123*io25a+22.123*io25b+22.123*io26a+22.123*io26b+22.123*io27a+22.123*io27b+22.123*io28a+22.123*io28b+22.123*io29a+22.123*io29b+22.123*io30a+22.123*io30b+22.123*io31a+22.123*io31b

- Sunda Strait
  Mw 9.2, io33-40, rows a-b, alpha=22.123
  22.123*io33a+22.123*io33b+22.123*io34a+22.123*io34b+22.123*io35a+22.123*io35b+22.123*io36a+22.123*io36b+22.123*io37a+22.123*io37b+22.123*io38a+22.123*io38b+22.123*io39a+22.123*io39b+22.123*io40a+22.123*io40b

- South of Java
  Mw 9.1, io44-49, rows a-b, alpha=14.7839
  14.7839*io44b+14.7839*io44a+14.7839*io45b+14.7839*io45a+14.7839*io46b+14.7839*io46a+14.7839*io47b+14.7839*io47a+14.7839*io48b+14.7839*io48a+14.7839*io49b+14.7839*io49a

Thank you