# From PTHA 1.0 to a regional consensus model: a Roadmap

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# Why PTHA*?

***PTHA** stays for **P**robabilistic **T**sunami **H**azard **A**ssessment

- Requires treatment of ALL possible seismic tsunamigenic sources, not only those with the large magnitudes

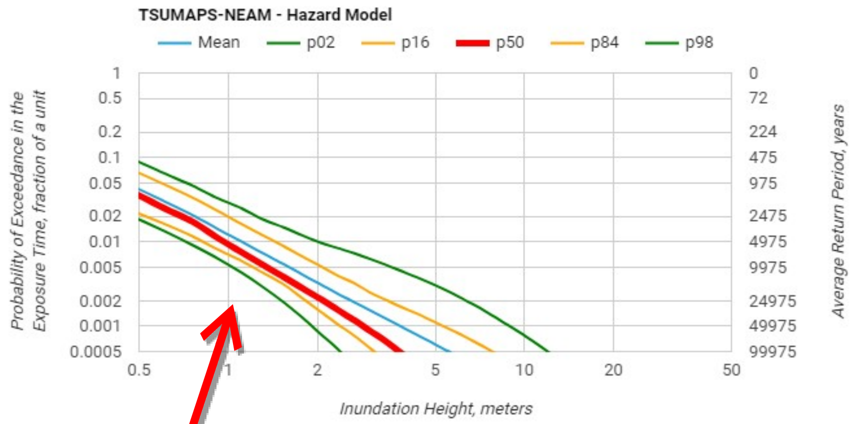
- Byproduct: Tsunami database which could be used for any kind of further studies and applications, e.g., for early warning, inundation mapping, evacuation planning

- Sources and, hence, their tsunami impacts, come with probabilities of occurance

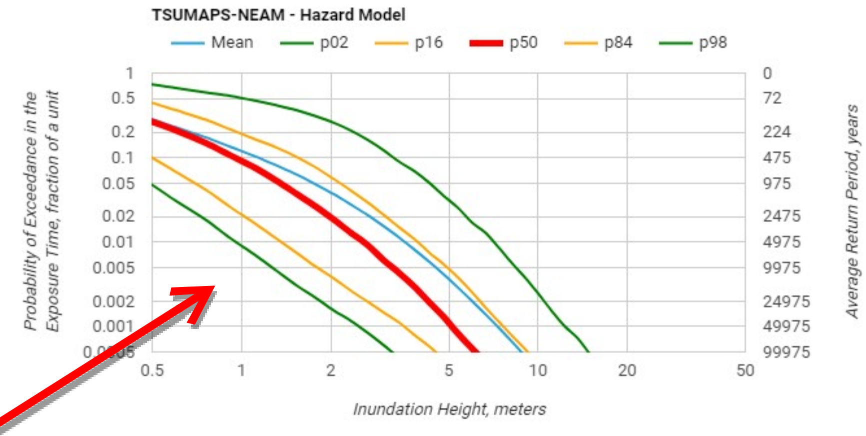
- That allows to answer questions like: what is the probability of a tsunami wave height above 1 m within the next 50 years?

# Approach: make PTHA following the methodology of http://tsumaps-neam.eu

## Lisbon, Portugal

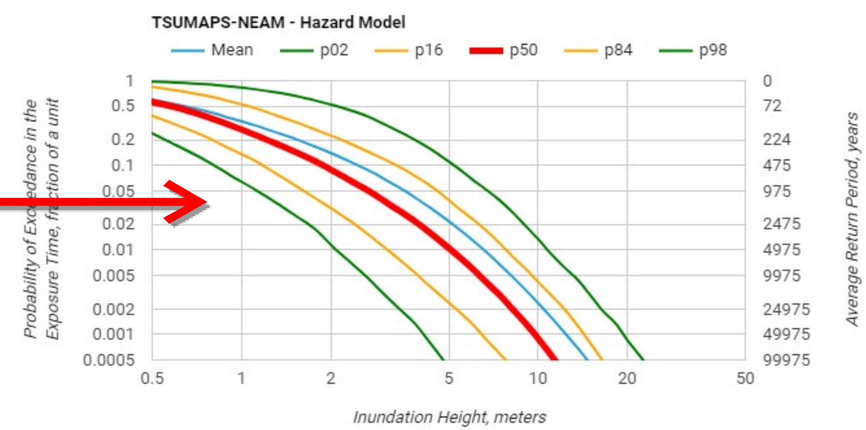



## Messina, Italy





## Alexandria, Egypt

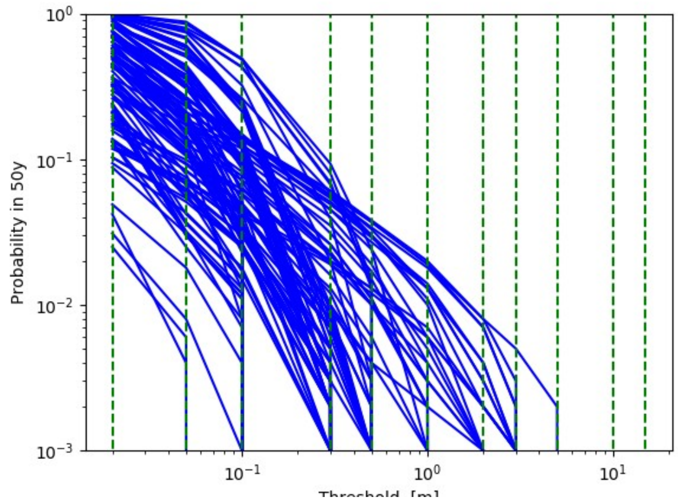


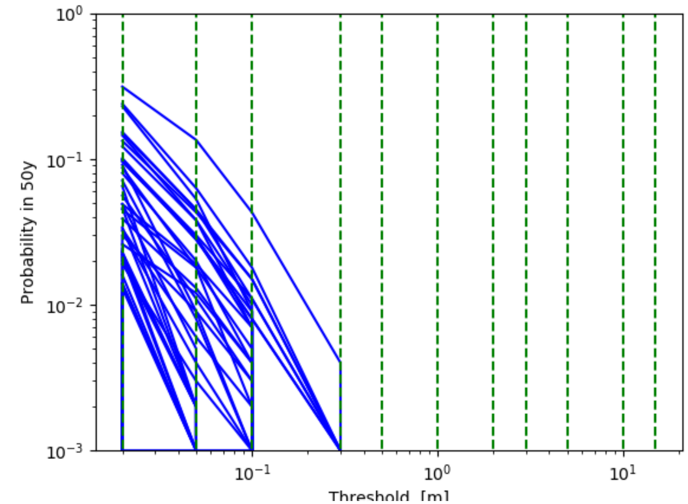
# PTHA Makran Region v.1.0
## Hazard Curves

**Arabian Sea**
(all 111 POIs)

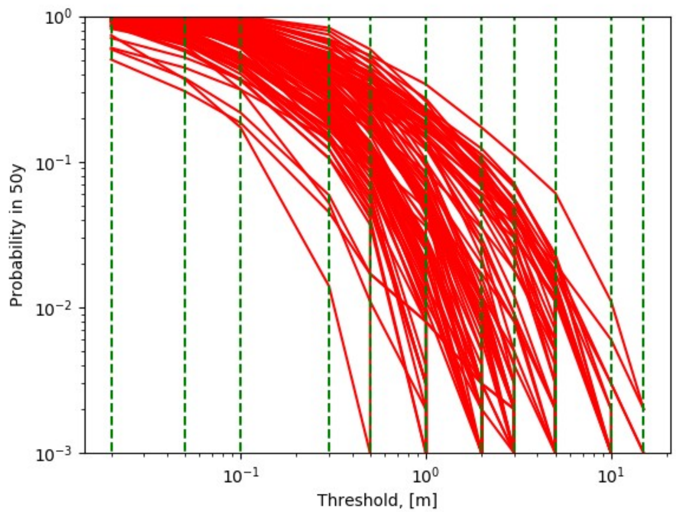
**Persian Gulf**
(all 197 POIs)

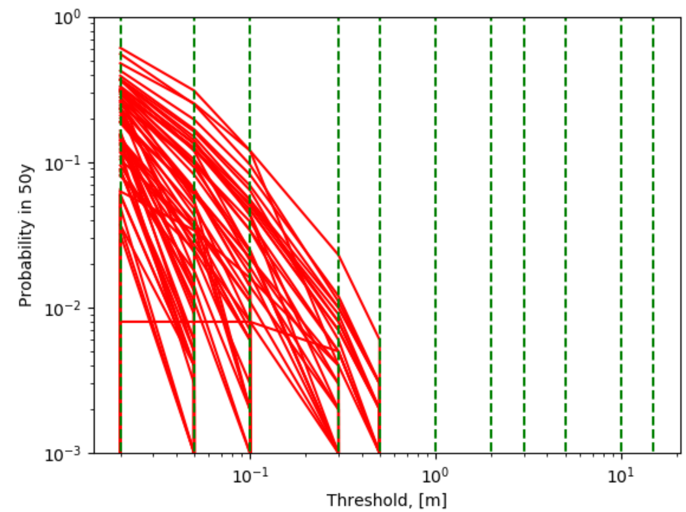
**M1**



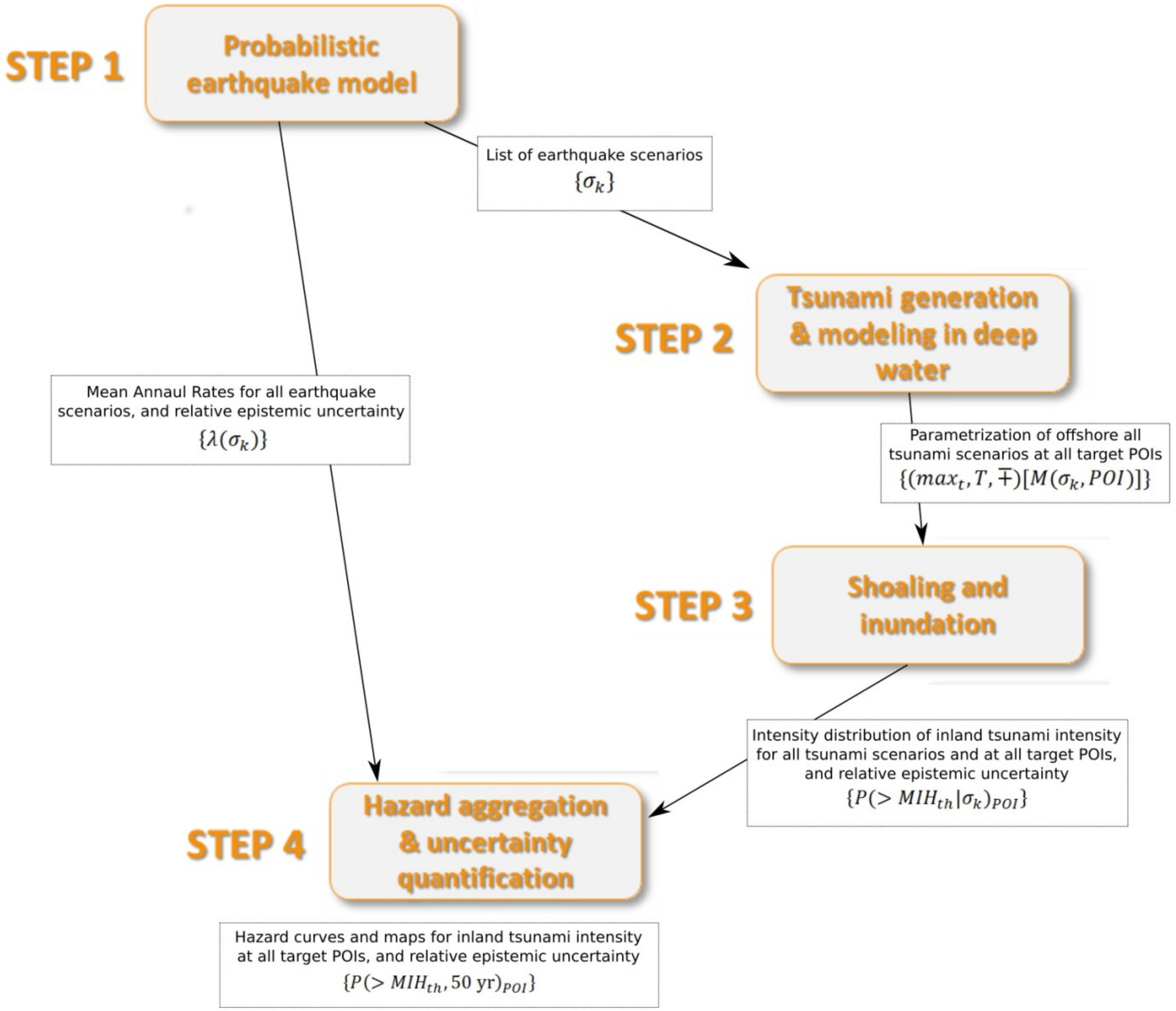




**M2**



# PTHA method
## as implemented in TSUMAPS-NEAM

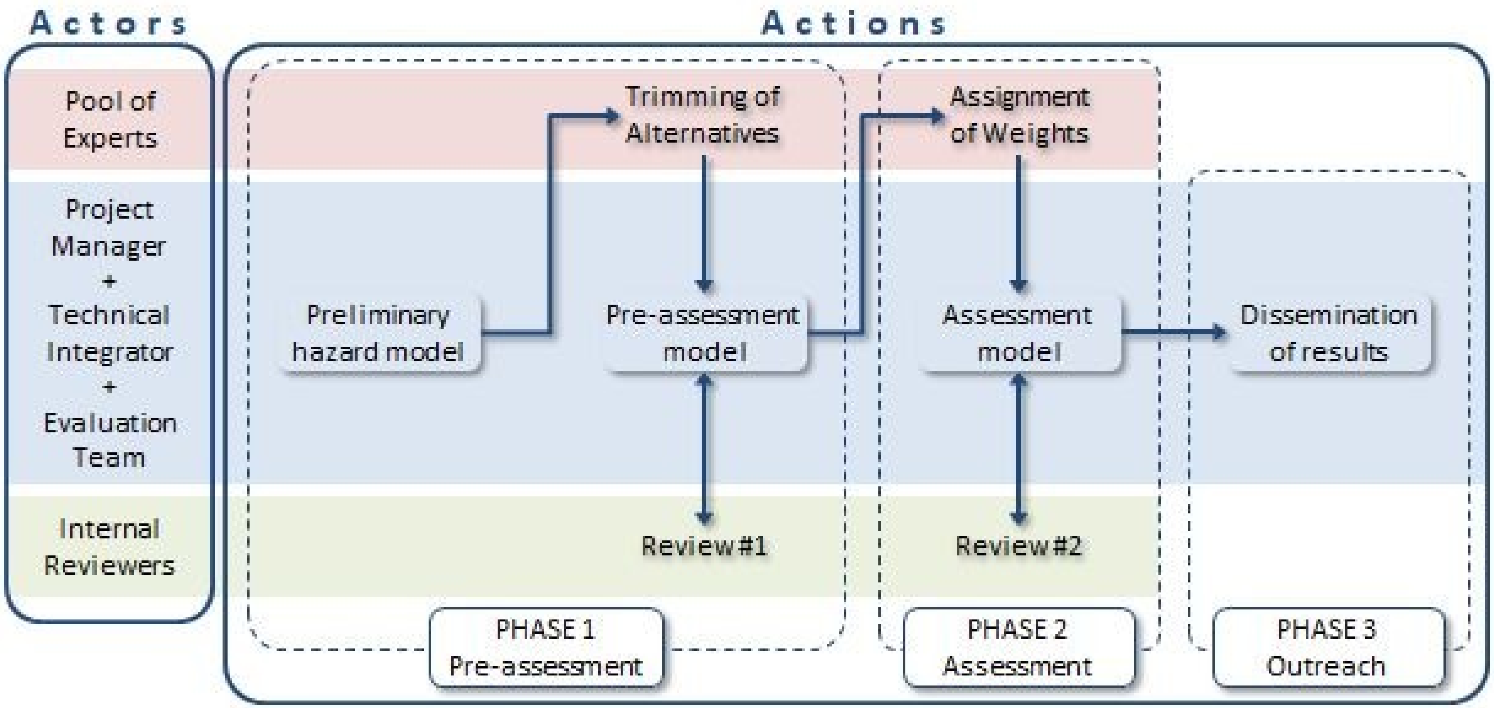


# PTHA method
## as implemented in TSUMAPS-NEAM

# PTHA method
## as implemented in TSUMAPS-NEAM

**Problem:** Too many alternatives at each step but especially by constructing earthquake source model – which of them are “better”? What means “better”? Who should decide which alternatives are better than others? And on which criteria?

**Solution attempt:** Let’s ask experts. Ask them about their preferencies. And then we will use expert’s recommendations to “weight” the alternatives.



# Makran PTHA :: STEP 1 “Earthquake Model” :: BS

Arabian Journal of Geosciences (2018) 11: 435
https://doi.org/10.1007/s12517-018-3797-7

ORIGINAL PAPER

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## Developing a seismic source model for the Arabian Plate

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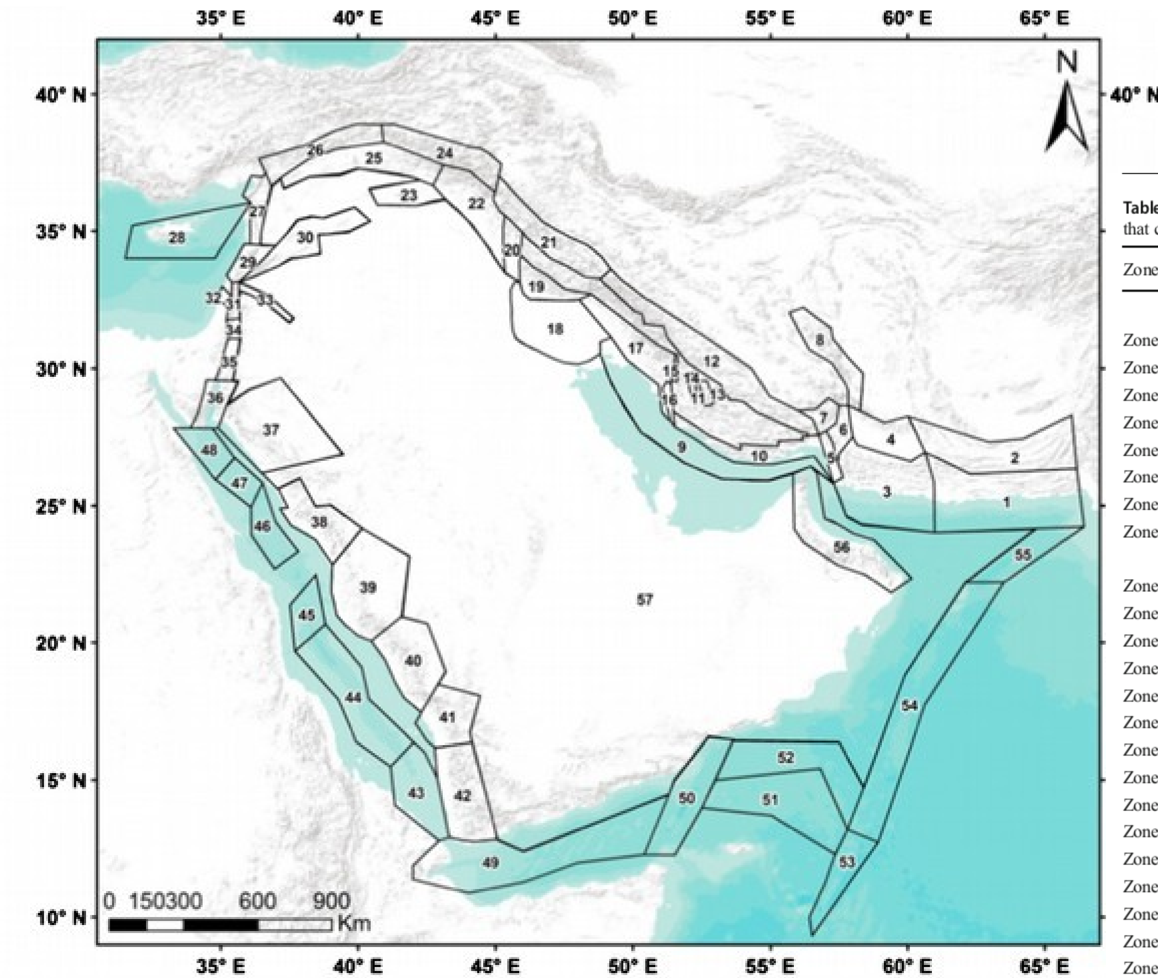
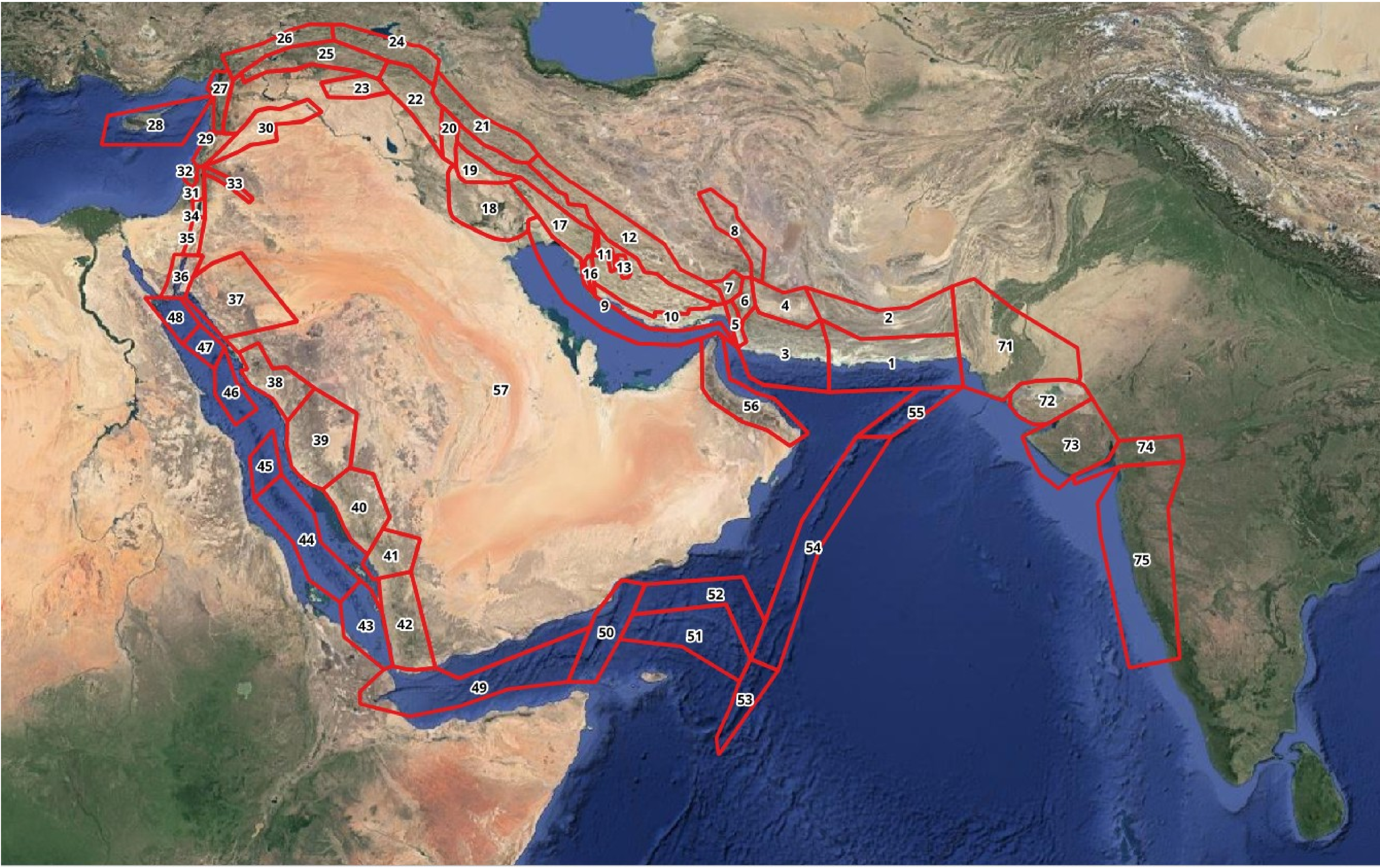



**Table 1** Earthquake recurrence parameters for the delineated seismic sources. Italic font are the recurrence parameters for tl
that contains the delineated seismic sources (All Makran, All Zagros, All Gulf of Aqaba-Dead Sea Fault, All Red Sea, All A

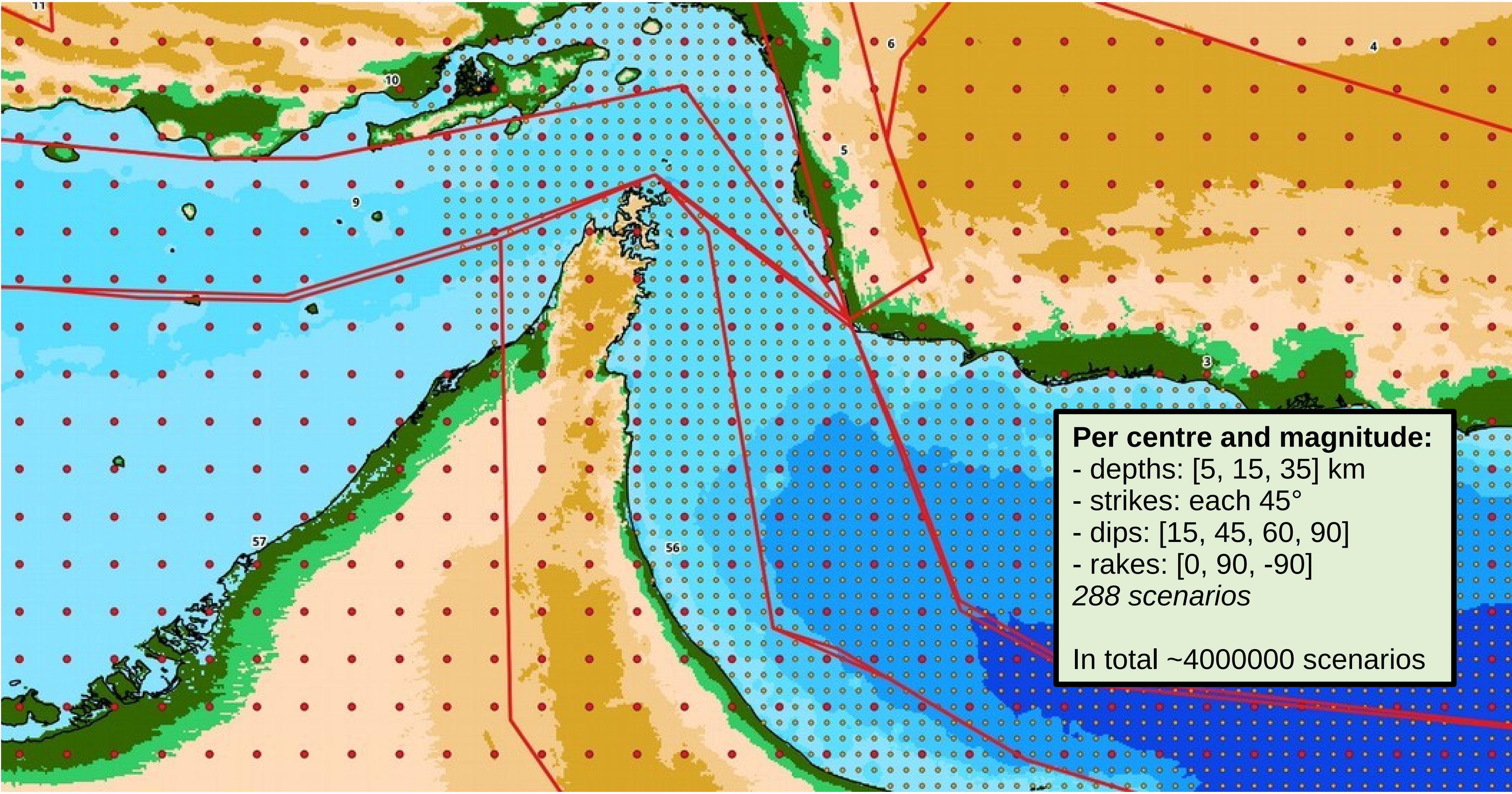
| Zone No. | Zone Name | $M_{max}$ | $\sigma M_{max}$ | $M_{min}$ | $M_{max}$obs | β | σβ | b | σb |
|---|---|---|---|---|---|---|---|---|---|
| | *All Makran* | *8.4* | *0.27* | *4* | *8.1* | *1.67* | *0.07* | *0.73* | *0.03* |
| Zone 1 | Makran East | 8.4 | 0.1 | 4 | 8.1 | 1.57 | 0.14 | 0.68 | 0.06 |
| Zone 2 | Makran Intraplate | 7.8 | 0.3 | 4 | 7.3 | 1.49 | 0.16 | 0.65 | 0.06 |
| Zone 3 | Makran West | 6.2 | 0.23 | 4 | 5.9 | 1.65 | 0.19 | 0.72 | 0.08 |
| Zone 4 | Jaz Murian | 6.8 | 0.82 | 4 | 6.1 | 1.56 | 0.2 | 0.68 | 0.09 |
| Zone 5 | Zendan Fault | 6.3 | 0.22 | 4 | 6.1 | 1.30 | 0.2 | 0.57 | 0.09 |
| Zone 6 | Jiroft Fault | 6.0 | 0.14 | 4 | 5.8 | 1.70 | 0.17 | 0.74 | 0.07 |
| Zone 7 | Ali Abad | 6.8 | 0.18 | 4 | 6.6 | 1.52 | 0.14 | 0.66 | 0.06 |
| Zone 8 | Gowk Fault | 7.5 | 0.34 | 4 | 7.2 | 1.68 | 0.13 | 0.73 | 0.06 |
| | *All Zagros* | *7.5* | *0.12* | *4* | *7.4* | *1.84* | *0.04* | *0.8* | *0.02* |
| Zone 9 | Arabian Gulf | 6.2 | 0.26 | 4 | 6.1 | 1.74 | 0.16 | 0.76 | 0.07 |
| Zone 10 | Zagros Foredeep | 6.8 | 0.21 | 4 | 6.7 | 1.83 | 0.11 | 0.79 | 0.05 |
| Zone 11 | Zagros Simple Fold | 6.9 | 0.21 | 4 | 6.8 | 1.82 | 0.07 | 0.79 | 0.03 |
| Zone 12 | High Zagros | 7.6 | 0.24 | 4 | 7.4 | 1.75 | 0.1 | 0.76 | 0.04 |
| Zone 13 | Sabz Pushan Fault | 6.3 | 0.34 | 4 | 6.1 | 1.69 | 0.19 | 0.73 | 0.08 |
| Zone 14 | Karebas Fault | 5.8 | 0.46 | 4 | 5.4 | 1.81 | 0.22 | 0.78 | 0.09 |
| Zone 15 | Kazerun Fault | 6.0 | 0.21 | 4 | 5.9 | 1.60 | 0.19 | 0.69 | 0.08 |
| Zone 16 | Borazgan Fault | 5.8 | 0.22 | 4 | 5.7 | 1.61 | 0.19 | 0.7 | 0.08 |
| Zone 17 | Dezful Embayment | 6.8 | 0.12 | 4 | 6.7 | 1.86 | 0.1 | 0.81 | 0.04 |
| Zone 18 | Mesopotamia | 6.5 | 0.3 | 4 | 6.4 | 2.15 | 0.18 | 0.93 | 0.08 |
| Zone 19 | MFF | 6.4 | 0.22 | 4 | 6.3 | 1.59 | 0.15 | 0.69 | 0.06 |
| Zone 20 | Khanagin Fault | 7.3 | 0.32 | 4 | 7.2 | 1.76 | 0.16 | 0.76 | 0.07 |
| Zone 21 | Posht-E Kuh Arc | 7.0 | 0.31 | 4 | 6.9 | 1.86 | 0.14 | 0.81 | 0.06 |
| Zone 22 | Kirkuk Embayment | 6.6 | 0.3 | 4 | 6.5 | 1.68 | 0.17 | 0.73 | 0.07 |
| Zone 23 | Abdelaziz-Sinjar | 5.4 | 0.36 | 4 | 5.2 | 1.91 | 0.22 | 0.83 | 0.1 |
| Zone 24 | Bitilis | 6.9 | 0.32 | 4 | 6.8 | 1.91 | 0.2 | 0.83 | 0.09 |
| Zone 25 | Karacadag Extension | 6.9 | 0.31 | 4 | 6.8 | 1.72 | 0.23 | 0.75 | 0.1 |

# Makran PTHA :: STEP 1 “Earthquake Model”



# Makran PTHA :: STEP 1 “Earthquake Model” :: BS

## Modeling of volume-distributed (background) seismicity




- centres of back-ground seismicity (distance ~**25 km**)

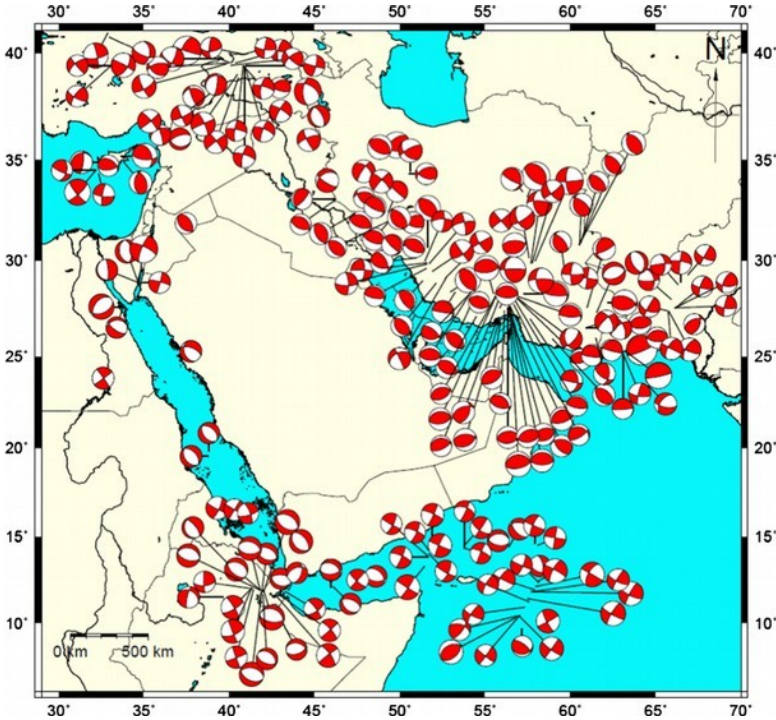
# Makran PTHA :: STEP 1 “Earthquake Model” :: BS

## Modeling of Mmax, G-R parameters, focal mechanisms

### Arabian plate zones:

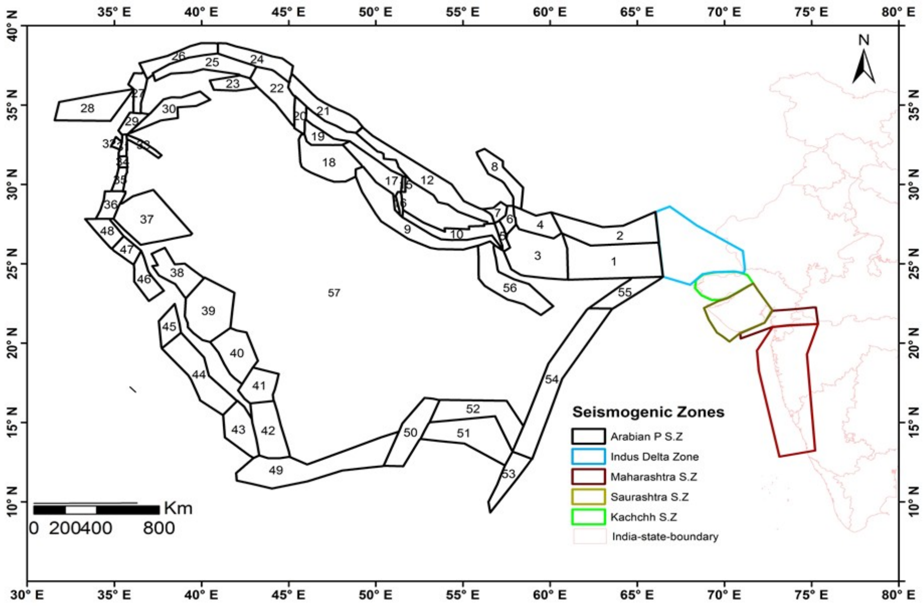
- Mmax and G-R based on PSHA (El-Hussain et al.’2018)

- Focal mechanisms: PDF derived from CMT compilation (A.Deif pers.comm)



### West Indian zones (71-75):

- All parameters based on pers. comm. S. Chopra

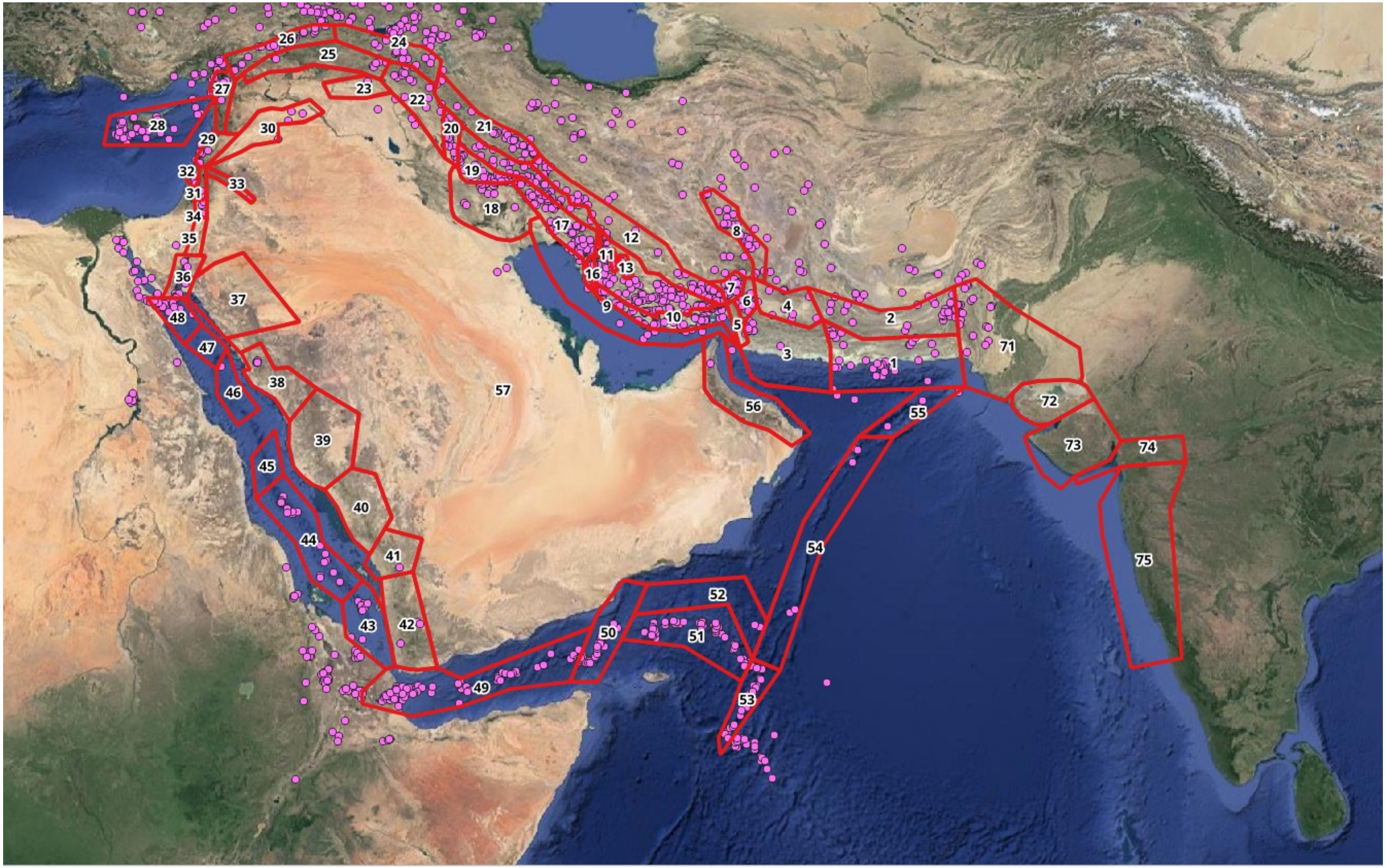


# Makran PTHA :: STEP 1 “Earthquake Model” :: BS

**Modeling of seismicity: Mmax, G-R parameters, focal mechanisms**

**Arabian plate zones**

**Problem with focal mechanism statistics:** Few observations for many zones



## Makran PTHA :: STEP 1 “Earthquake Model” :: BS

## Alternatives to consider?

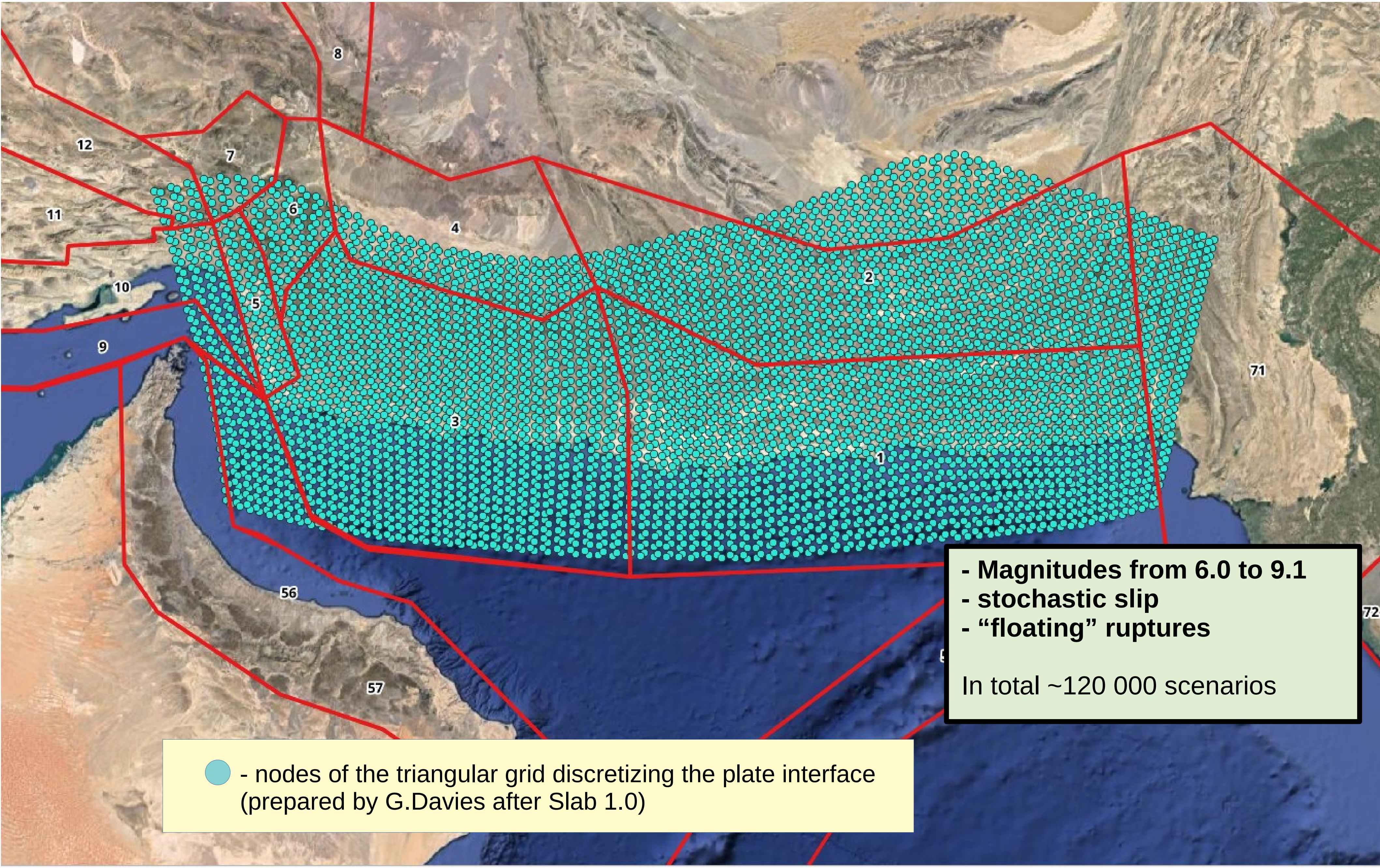
1) Alternative zone **rates** based on re-analysis of the last earthquake catalogs version :: done by INGV+UniNapoli

2) Add a new zone with normal faults (shallow, close to the Makran coast) :: done(?) by INGV+UniNapoli

3) Derive predominant focal parameters (strike, dip, rake) from geology. E.g., for Zagros :: to do by Iranian colleagues(?)

# Makran PTHA :: STEP 1 “Earthquake Model” :: PS

## Modeling of seismicity along the plate interface



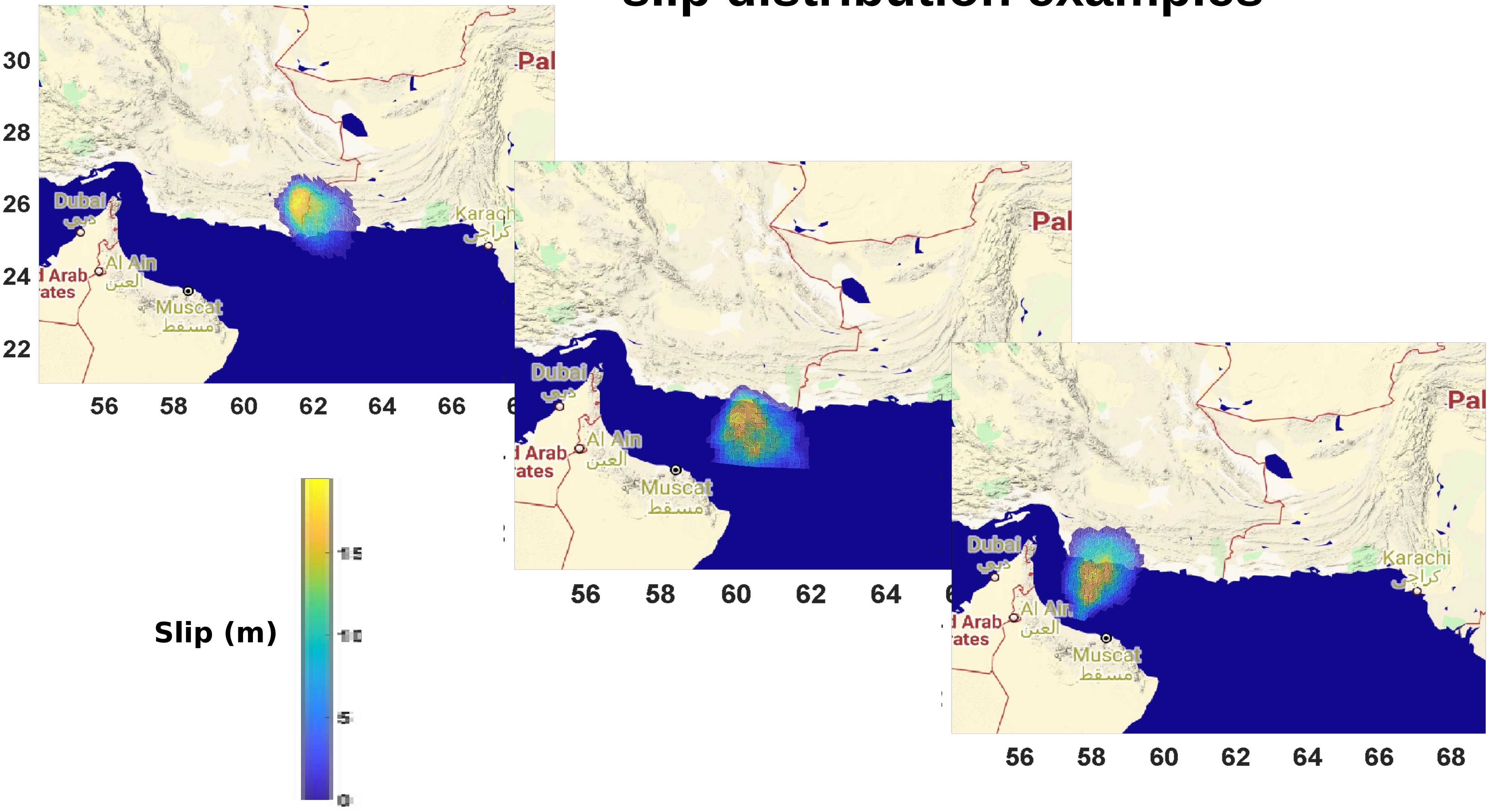

- **Magnitudes from 6.0 to 9.1**
- **stochastic slip**
- **“floating” ruptures**

In total ~120 000 scenarios

- nodes of the triangular grid discretizing the plate interface (prepared by G.Davies after Slab 1.0)

# Makran PTHA :: STEP 1 “Earthquake Model” :: BS

## Makran subduction M8.5 slip distribution examples

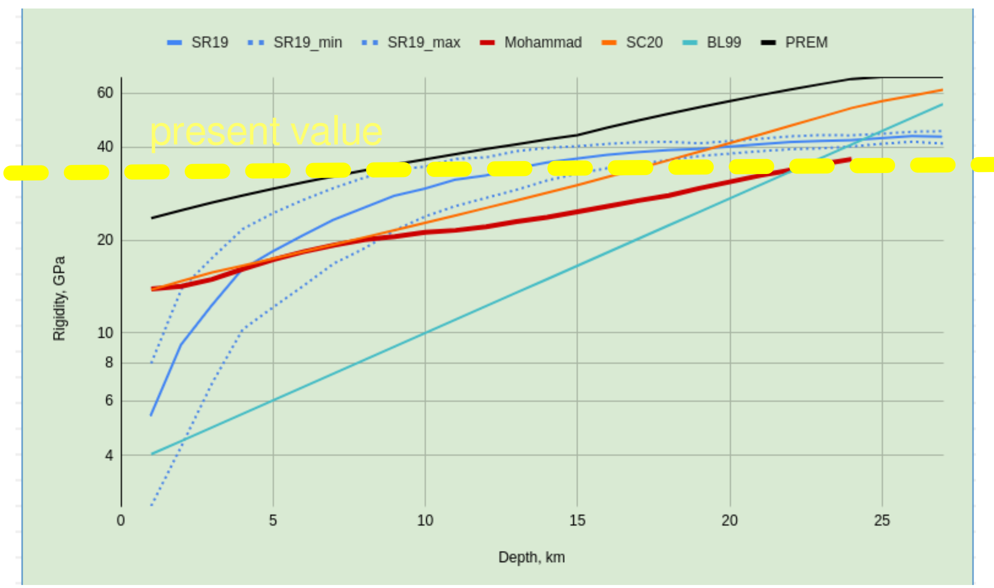


# Makran PTHA :: STEP 1 “Earthquake Model” :: PS

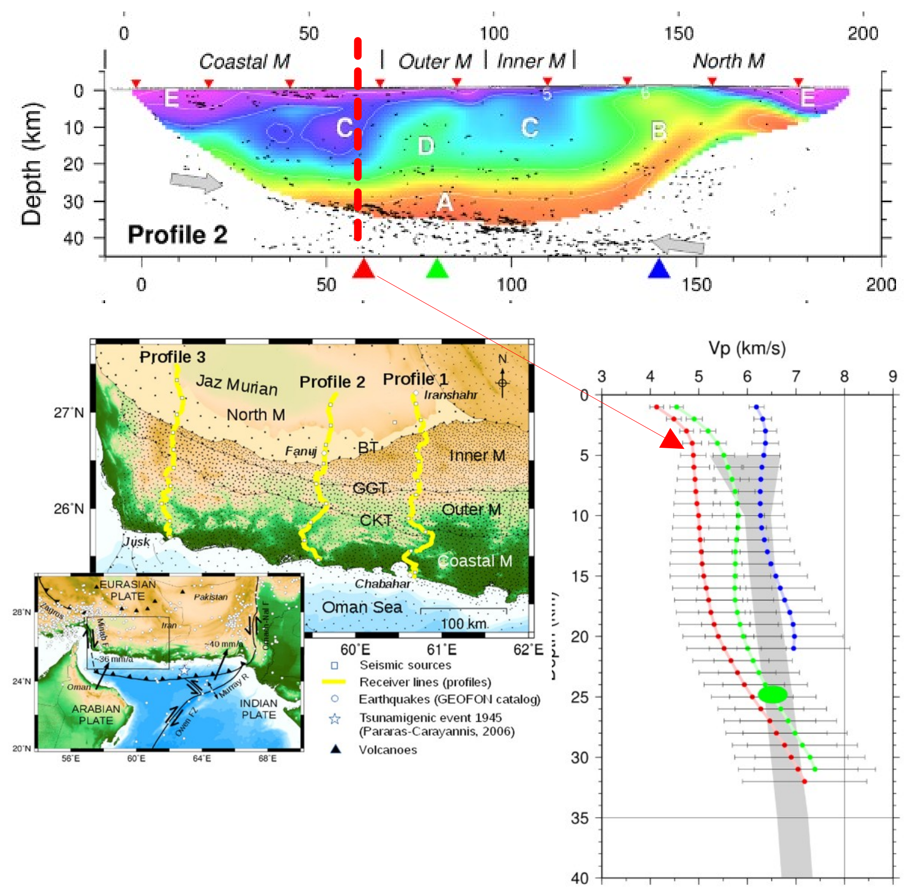
## Alternatives to consider?

**Rigidity of the upper crustal layer**

The **lower** is rigidity, the **higher** will be slip (and uplift!) for the same magnitude




Haberland et al. (2020)

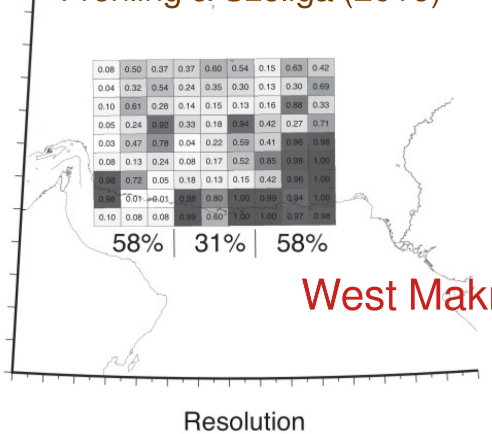


# Makran PTHA :: STEP 1 “Earthquake Model” :: PS

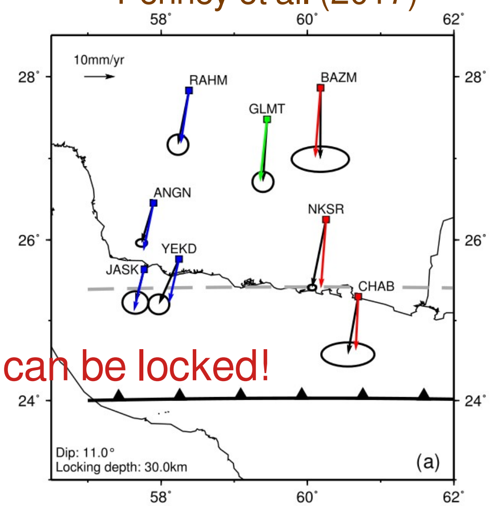
## Alternatives to consider?

1) Segmented/unsegmented (West/East Makran problem)
2) Tectonic and seismic rates
3) Various coupling along the plate interface

Frohling & Szeliga (2016)



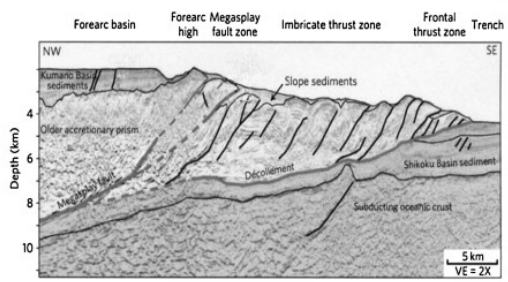

Penney et al. (2017)




West Makran can be locked!

Mokhtari (2014)

**Fig. 4** The splay (imbricate) faults along Nankai accretionary wedge, offshore Japan (Strasser et al. 2009)



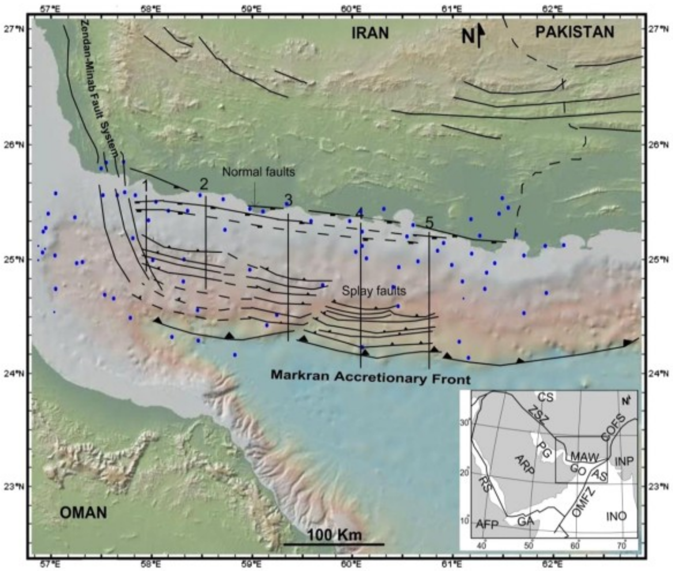
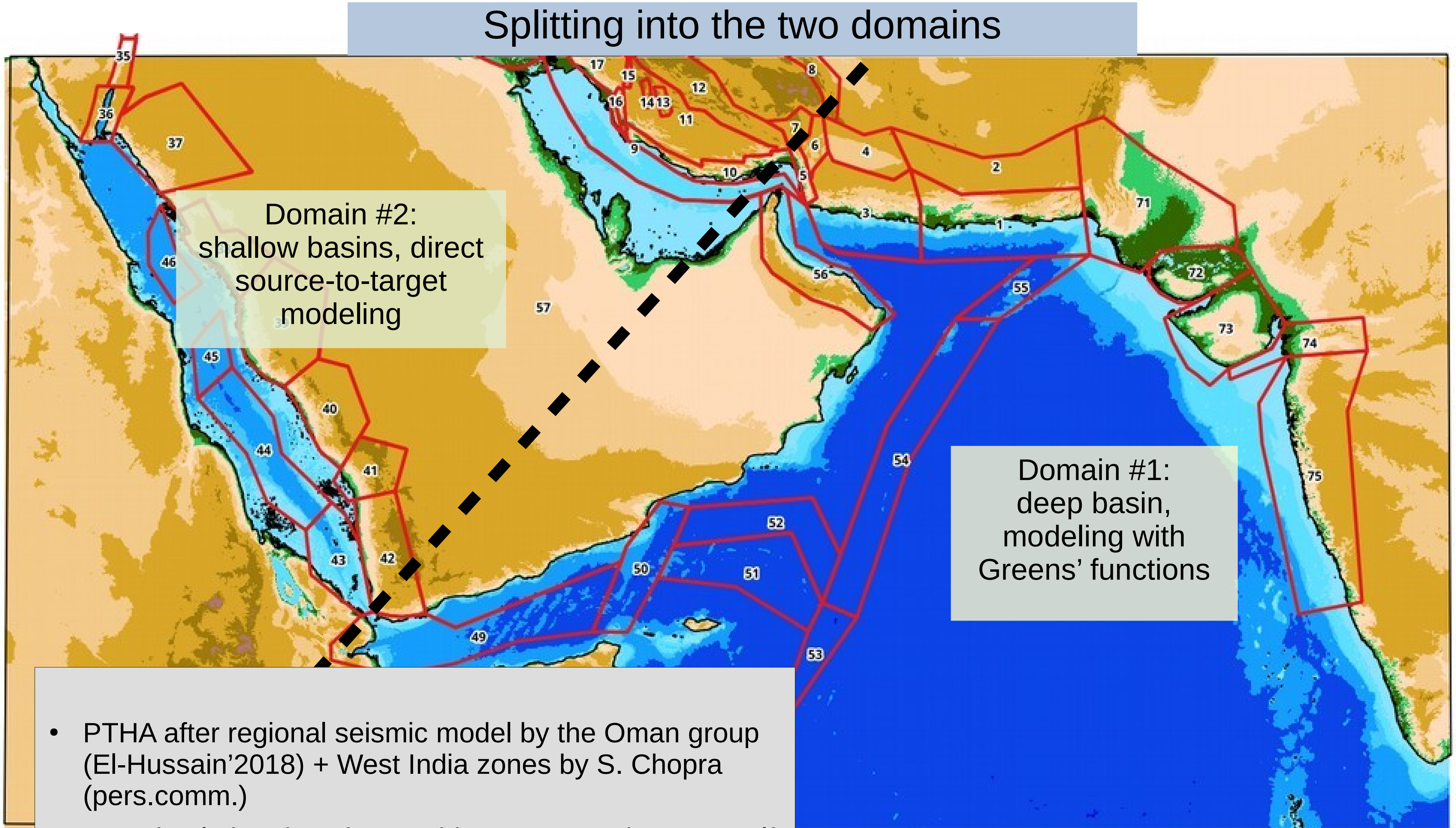




**Fig. 5** The location of seismic profiles used in this study (*vertical solid black lines*), the splay and normal faults (in the south and north, respectively) and earthquake events (*dark blue dots*). The *dashed lines* indicate extrapolated faults due to the lack of seismic reflection data coverage

Springer

4) Also IMPORTANT(!): co-triggered splay faults

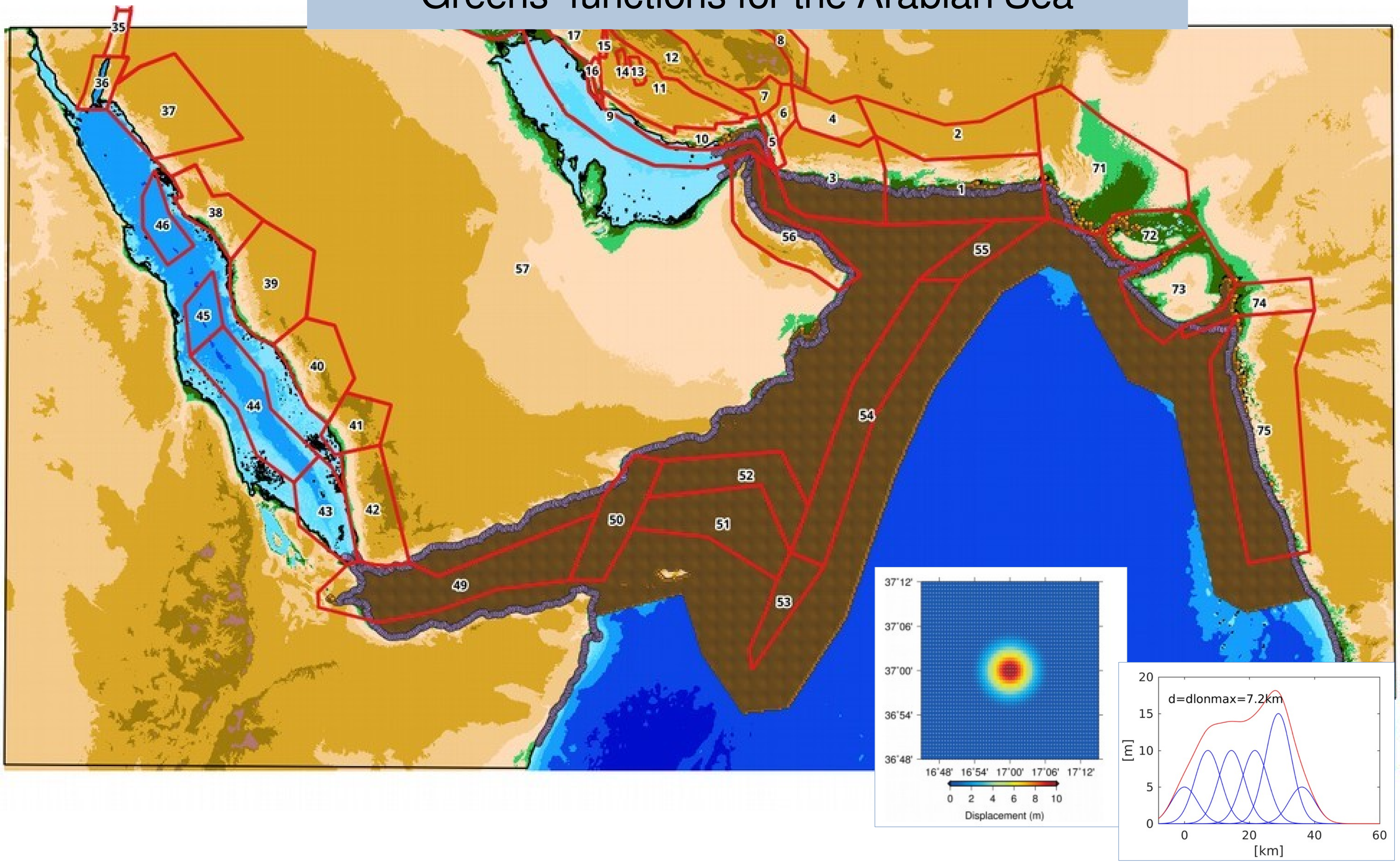
# Makran PTHA :: STEP 2 "Tsunami Modeling"




- PTHA after regional seismic model by the Oman group (El-Hussain'2018) + West India zones by S. Chopra (pers.comm.)
- Two simulation domains: Arabian Sea + Red Sea & Gulf
- ~ 2000 coastal Points-of-Interest
- ~ 40 000 pre-computed Green's functions
- to simulate ~5 000 000 propagation scenarios

# Makran PTHA :: STEP 2 “Tsunami Modeling”

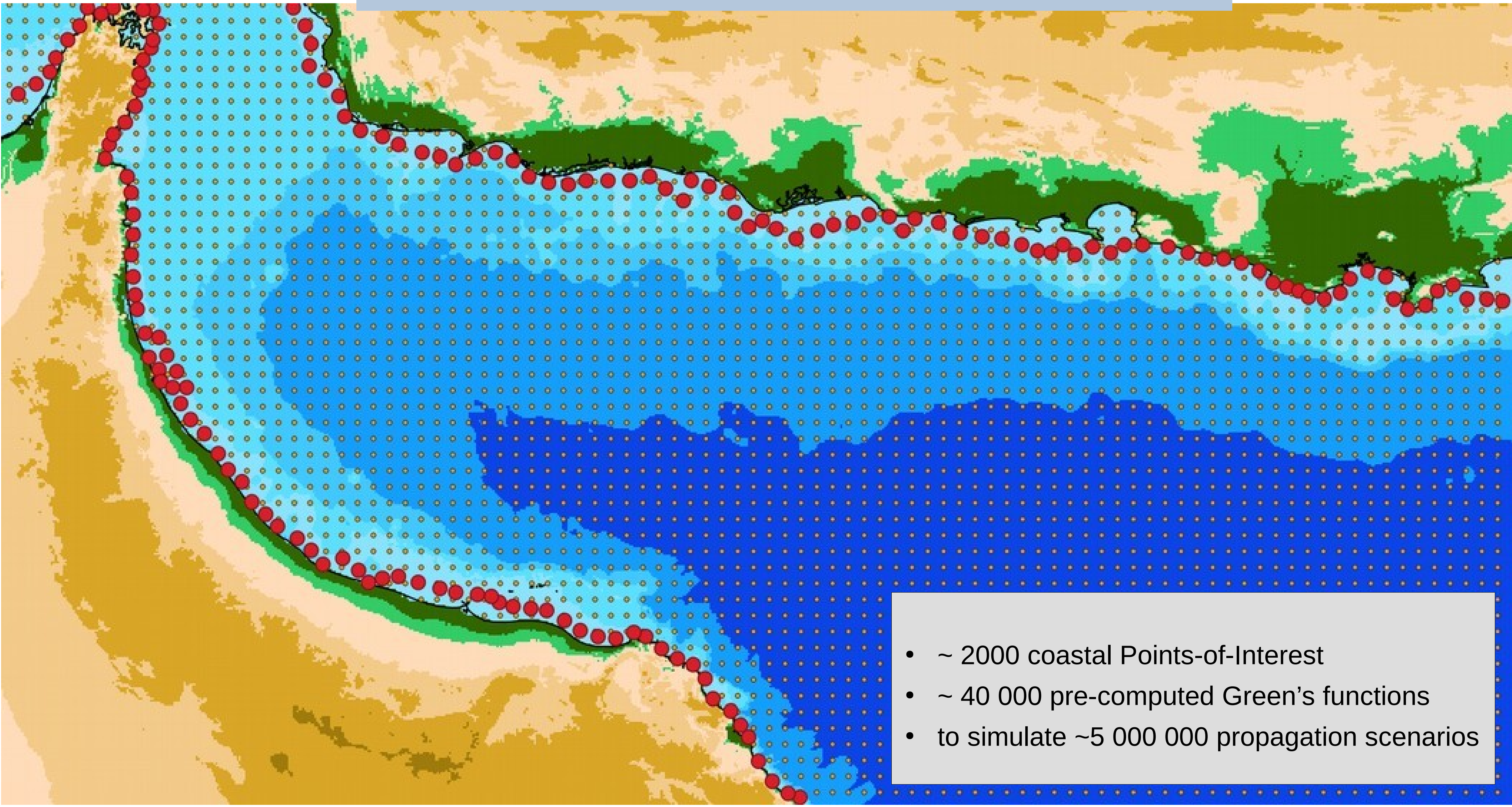
## Greens’ functions for the Arabian Sea




Molinari et al (2016)

# Makran PTHA :: STEP 2 “Tsunami Modeling”

## Greens’ functions for the Arabian Sea



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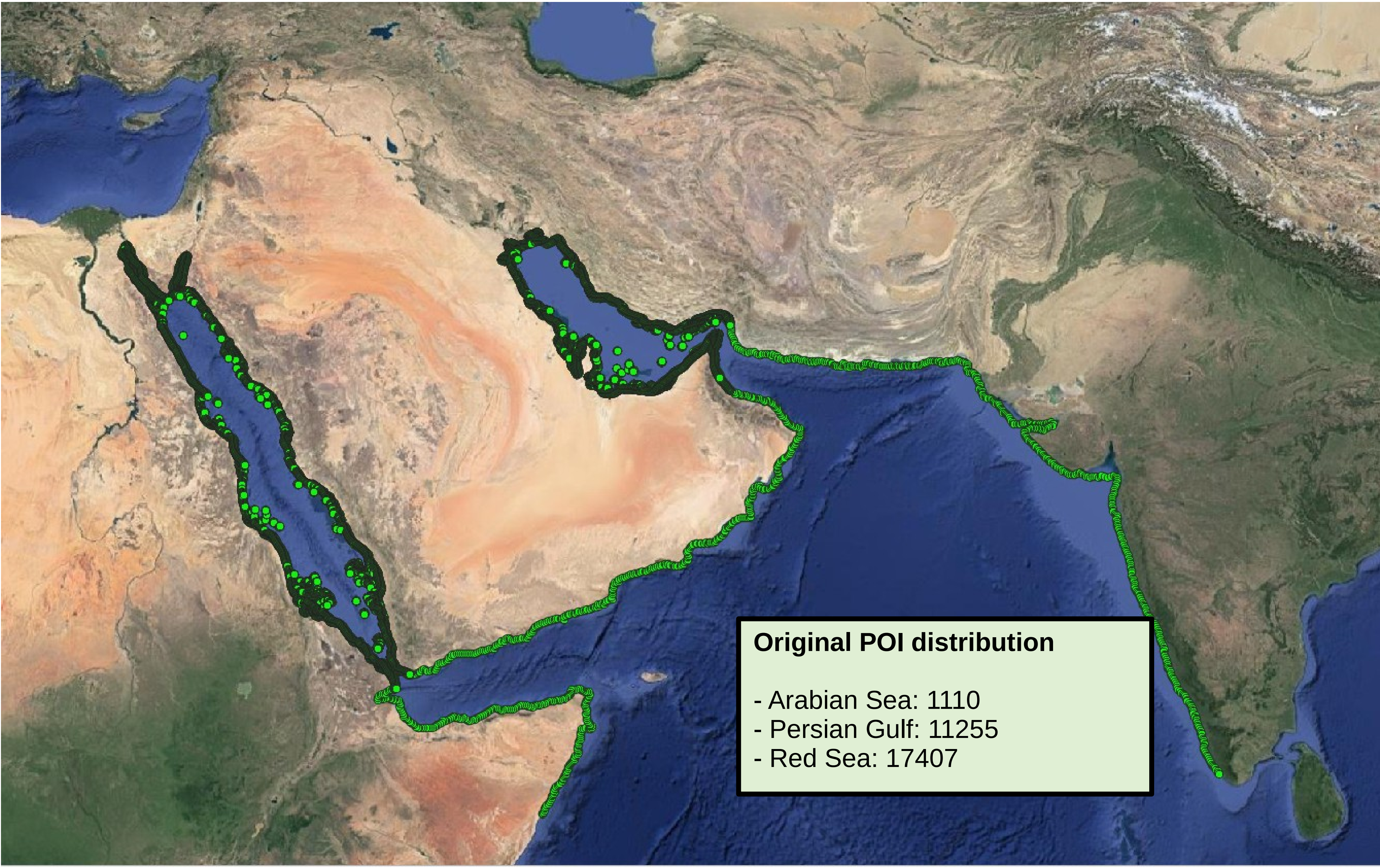
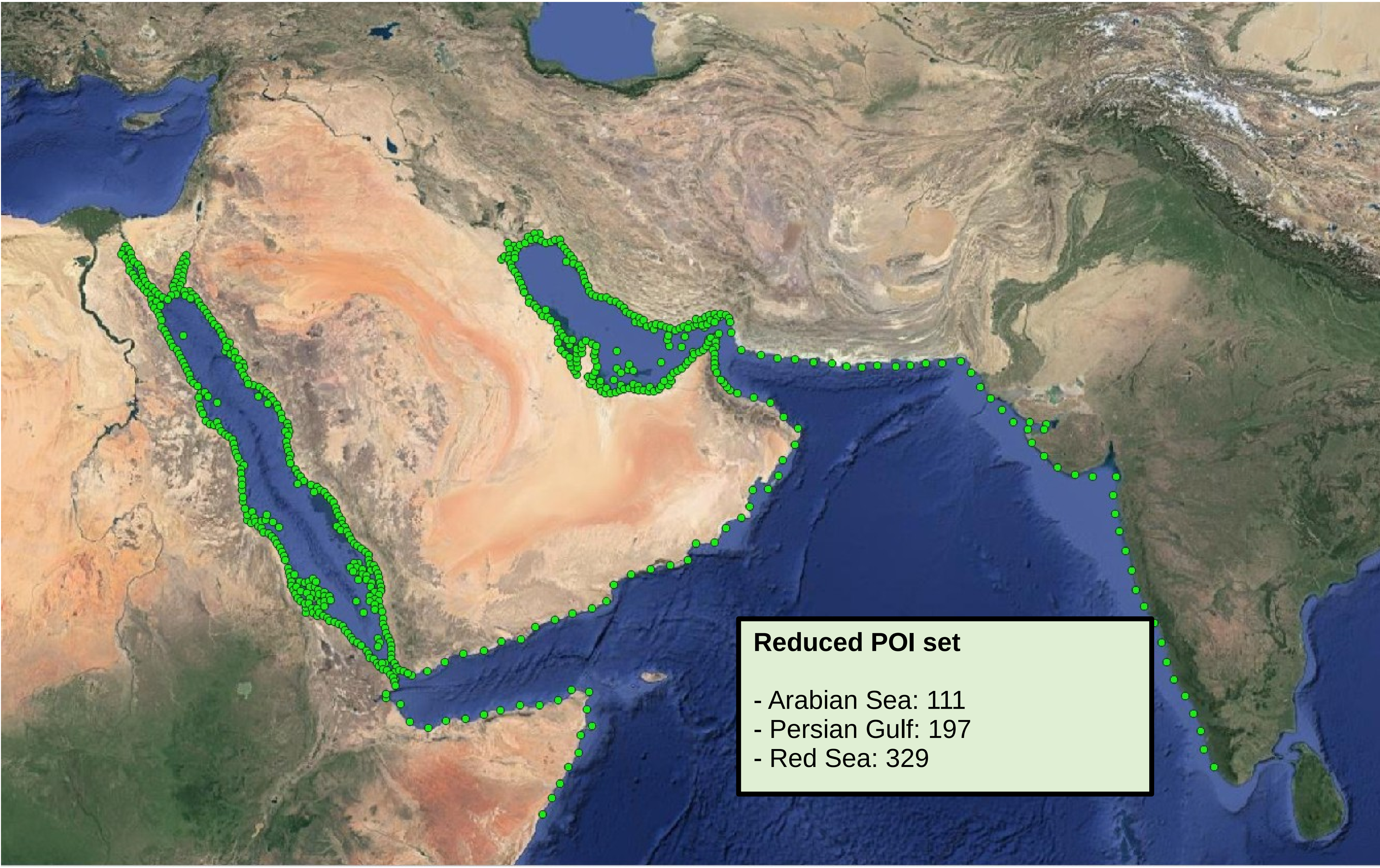


# Makran PTHA :: STEP 2 “Tsunami Modeling”



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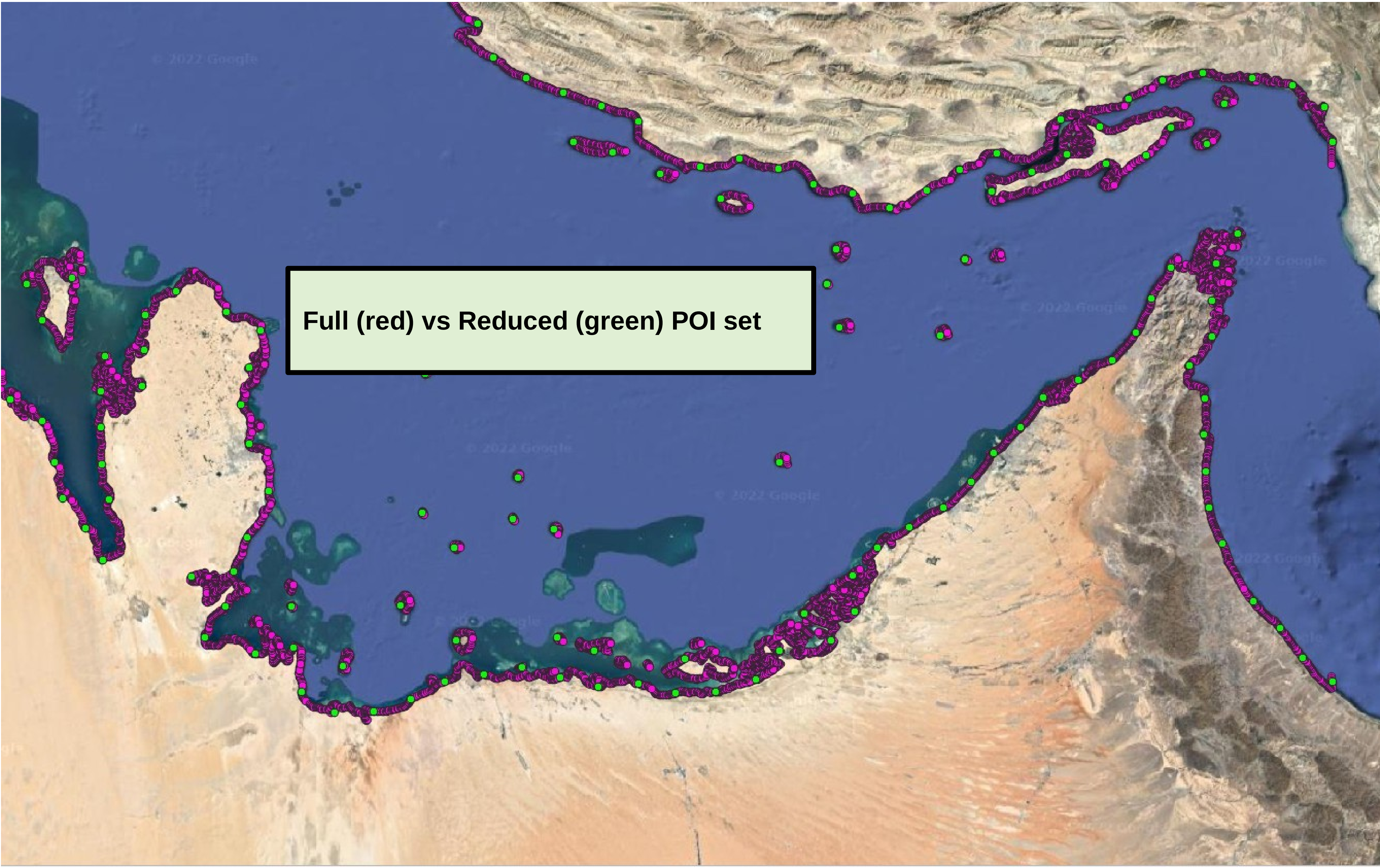

# Makran PTHA :: STEP 2 “Tsunami Modeling”

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## **Alternatives to consider?**

1) Employ Kajiura-type filter when transering sea-floor deformation into the intial conditions on the surface

2) Check tsunami propagation from the Arabian Sea into the Persian Gulf

# Makran PTHA :: STEP 3 “Shoaling and Inundation”

## Alternatives to consider?

1) Add tidal amplitudes (ask local oceanogrphes for values site by site)

2) Use coastal amplificaton factors instead of Green’s law – use global set

3) Apply log-norm uncertainty to max wave height to account for cumulative effect of various uncertainties – use global statistical parameters

# Makran PTHA ver 1.0

Only TWO alternative models up to now:

| **Model 1**<br>**“optimistic”** | **Model 2**<br>**“pessimistic”** |
|---|---|
| **BS**: as in PSHA | **BS**: $M_{max}$ + 3 σ |
| **PS**: segmented as in PSHA<br>($M_{max}$=6.2 for West and 8.4 for East) | **PS**: unsegmented, $M_{max}$=9.1 |
| **STEP2 & 3 – no alternatives** | |

# Maximum modeled wave heights (deterministic)

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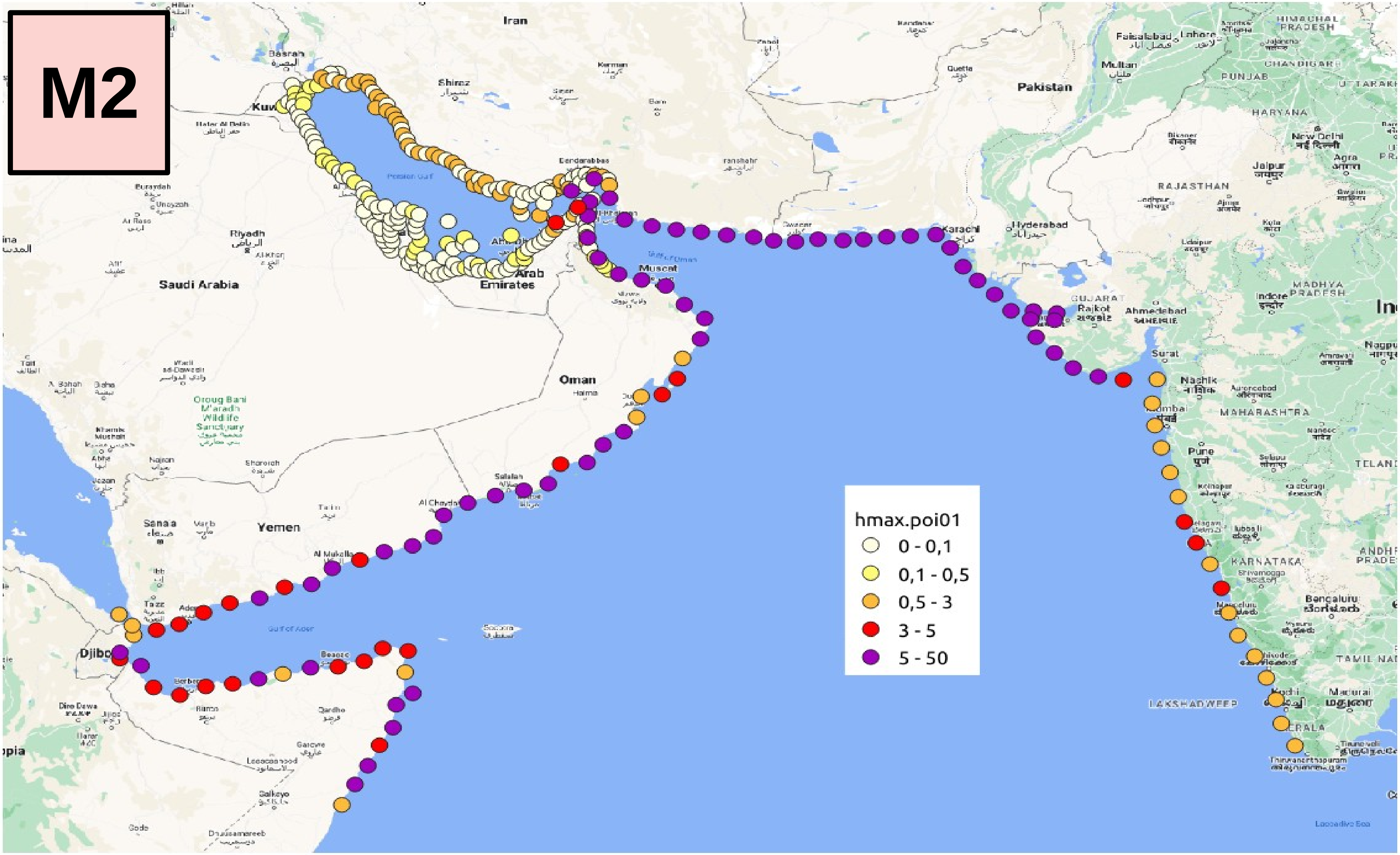
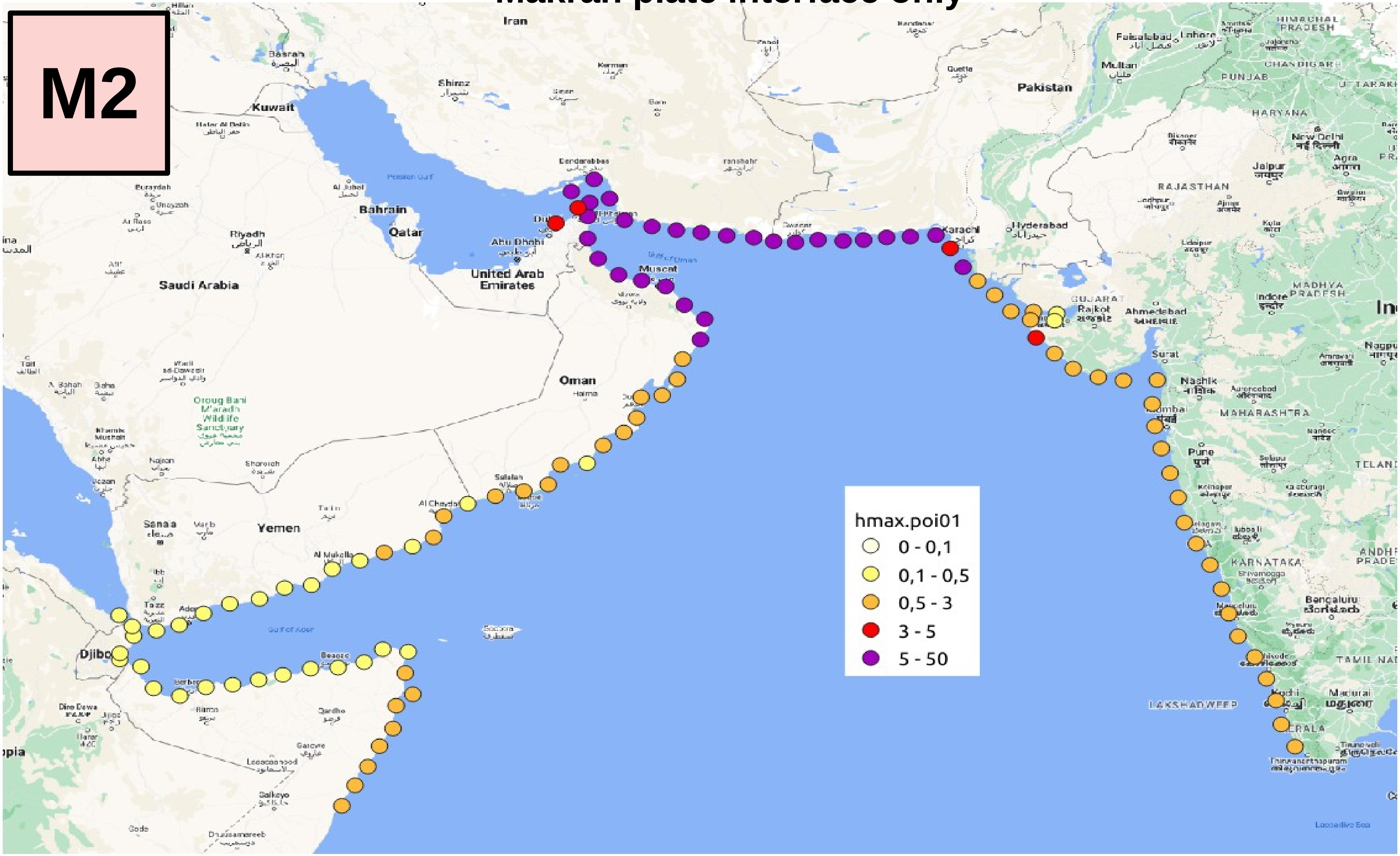
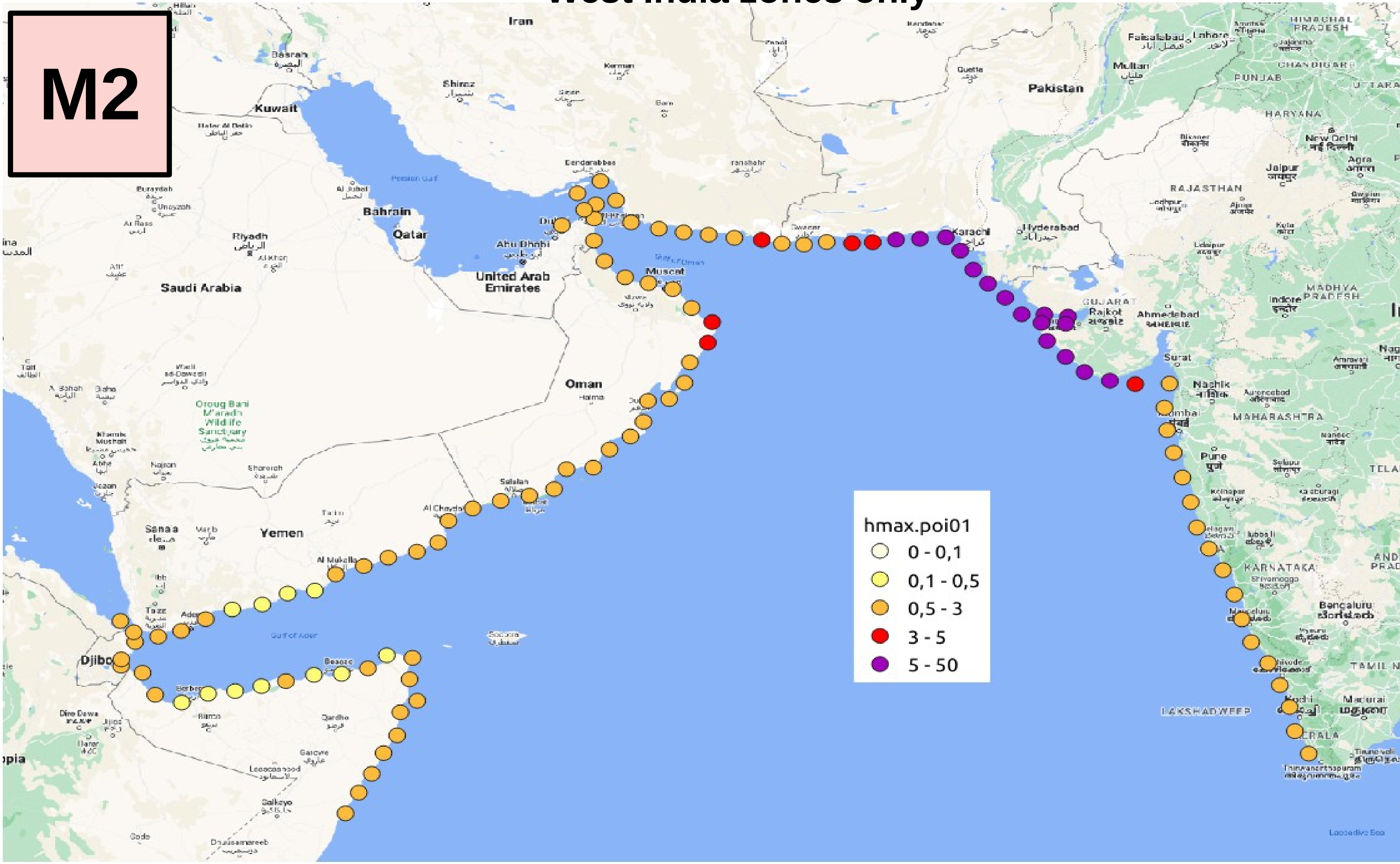


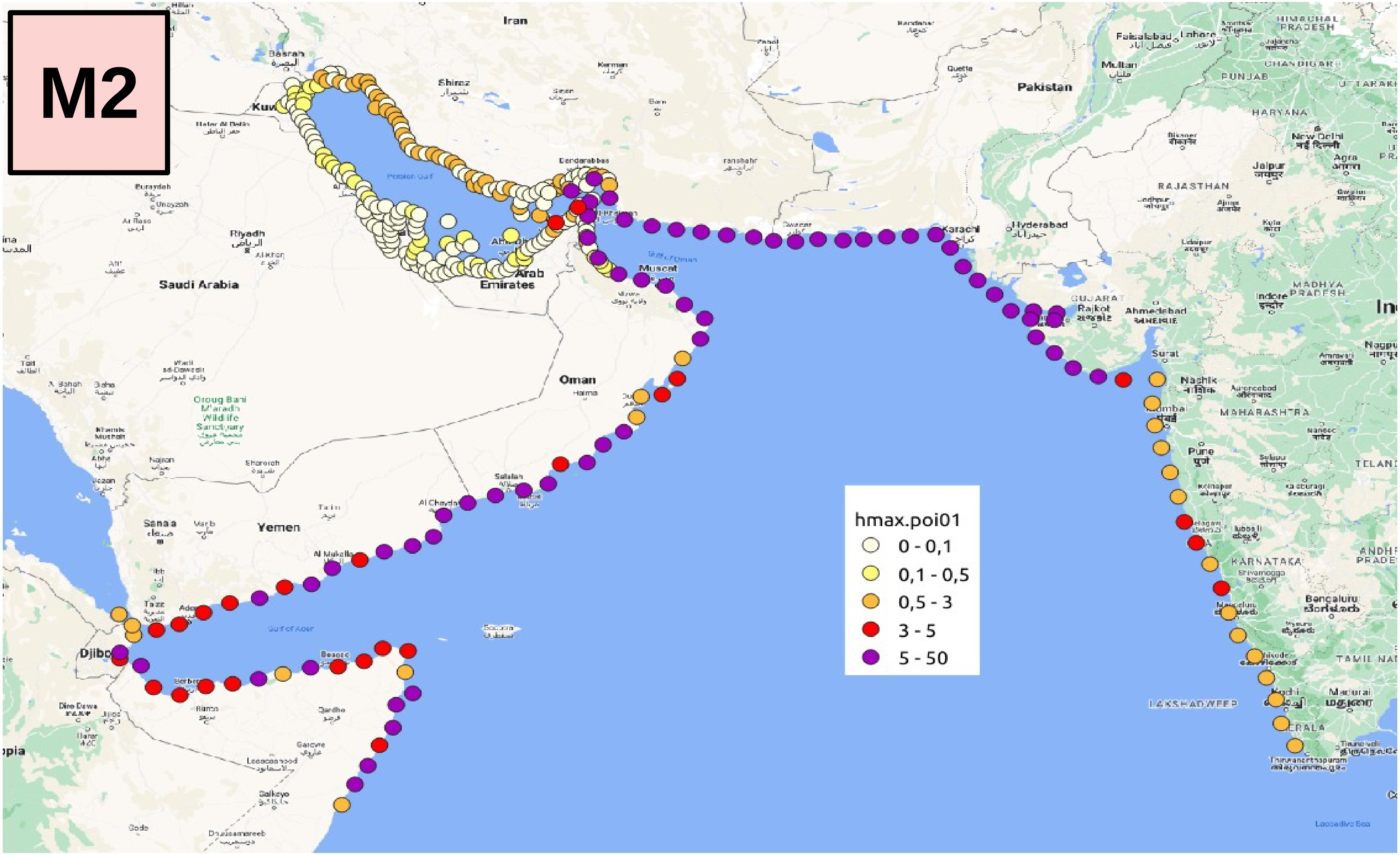
# Maximum modeled wave heights (deterministic)
# Makran plate interface only



# Maximum modeled wave heights (deterministic)
# West India zones only

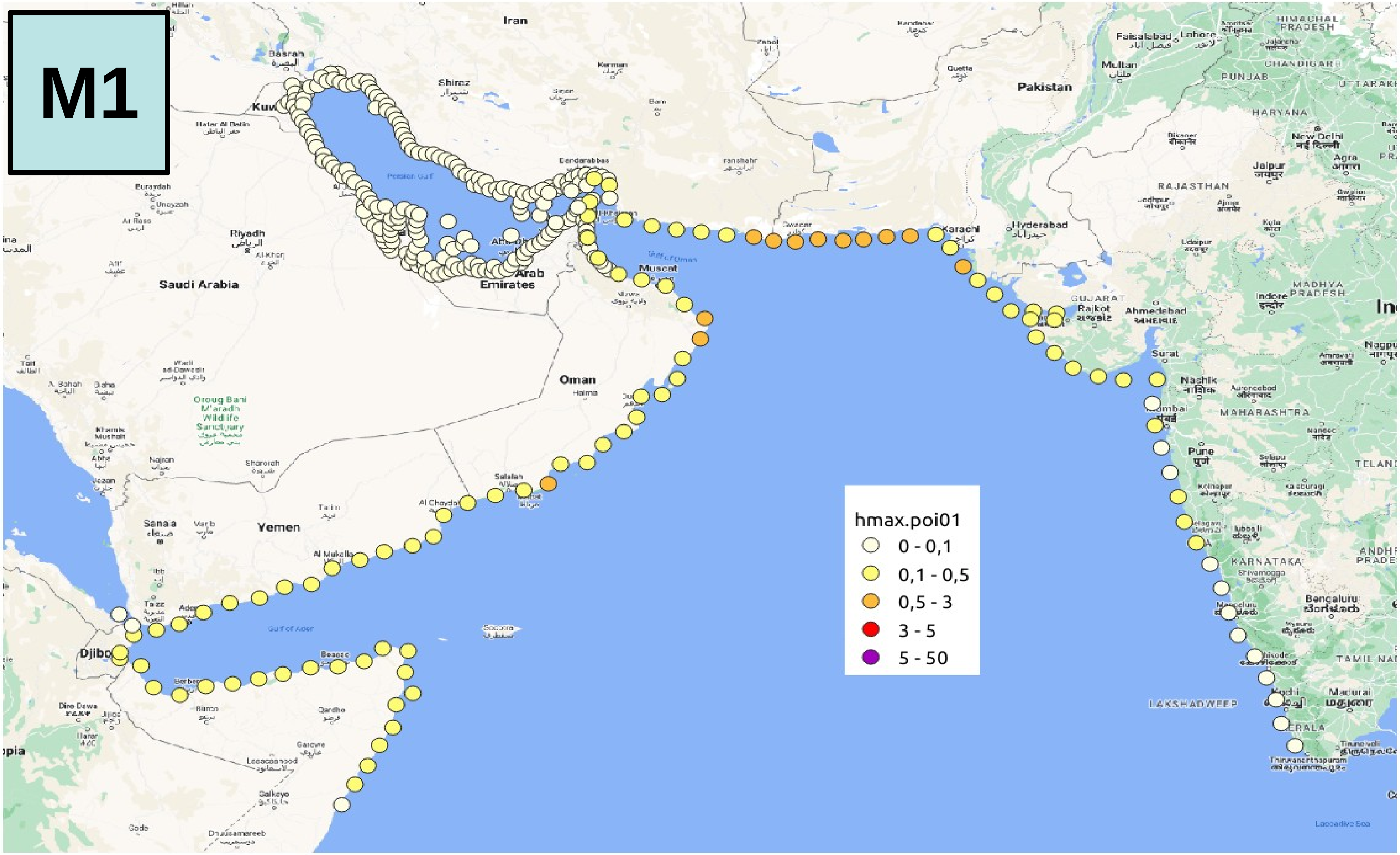


# Maximum modeled wave heights (deterministic)

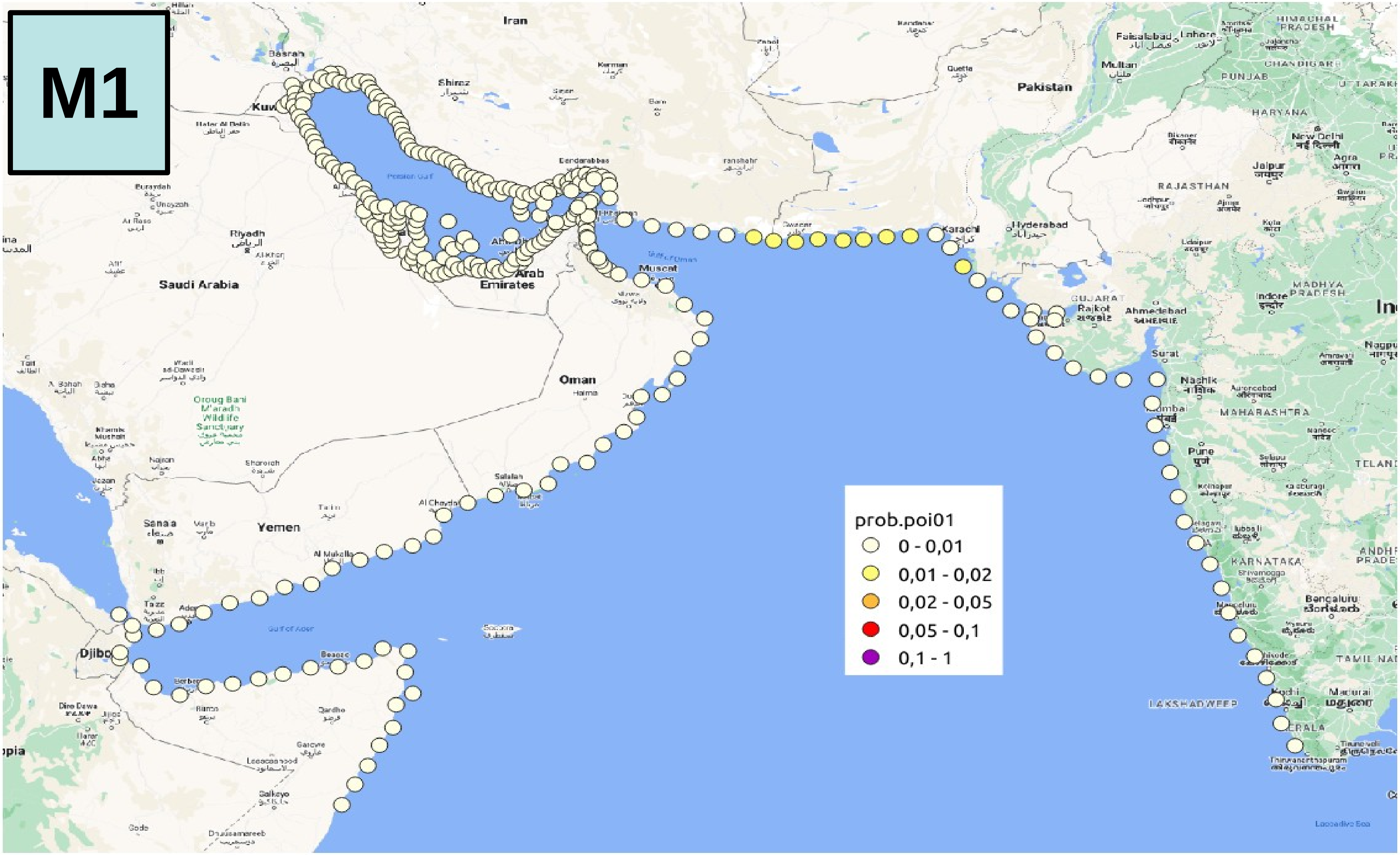


# Maximum expected 2500 years wave height (<u>probabilistic</u>)

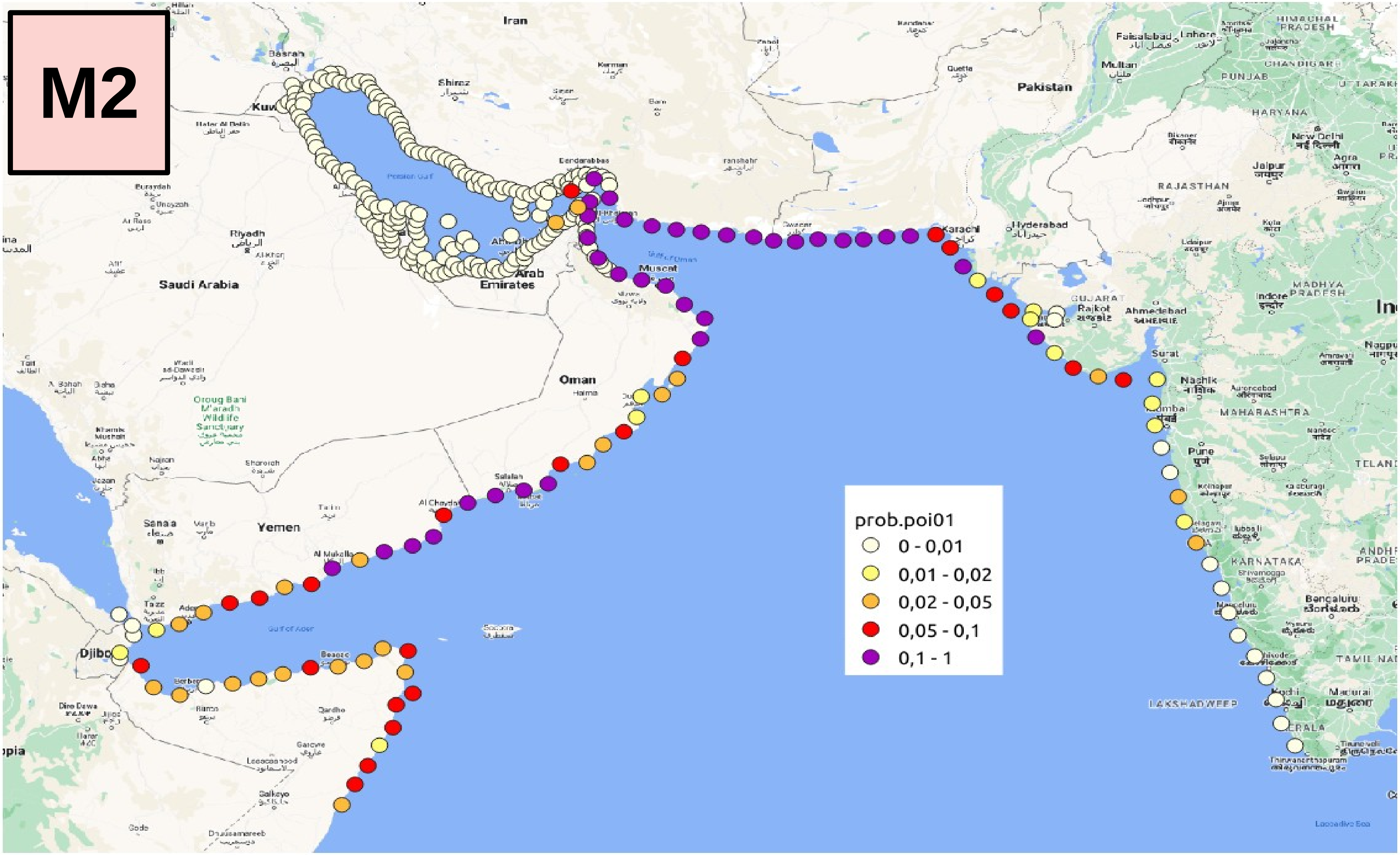
# Maximum expected 2500 years wave height (probabilistic)



# Probability of h>1 meter within next 50 years



# Probability of h>1 meter within next 50 years

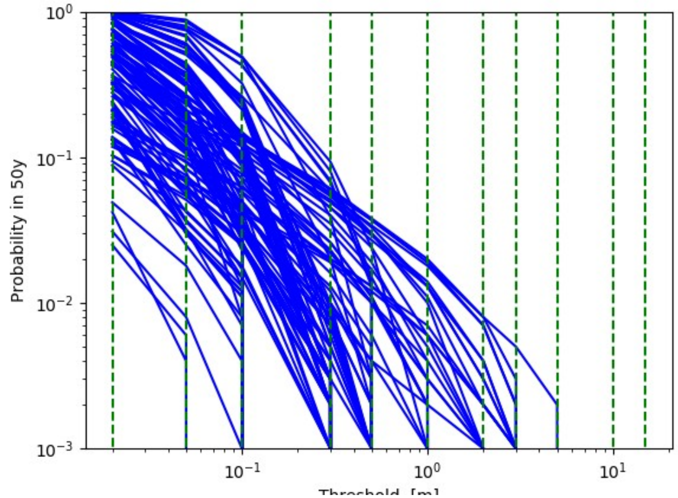


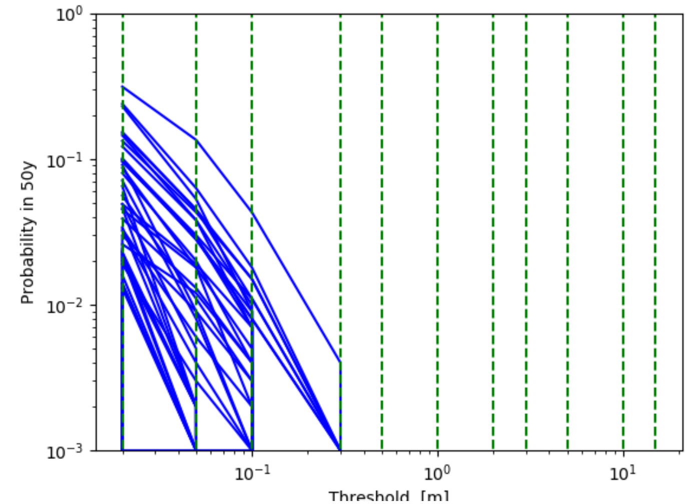
# Looking at the hazard curves

**Arabian Sea**
(all 111 POIs)

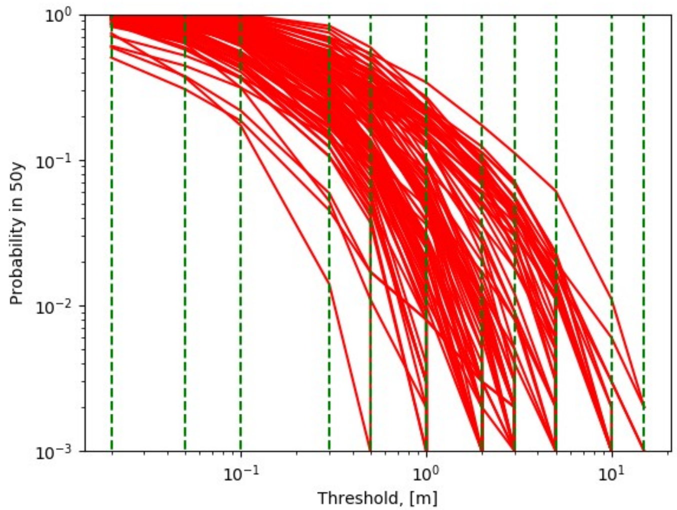
**Persian Gulf**
(all 197 POIs)

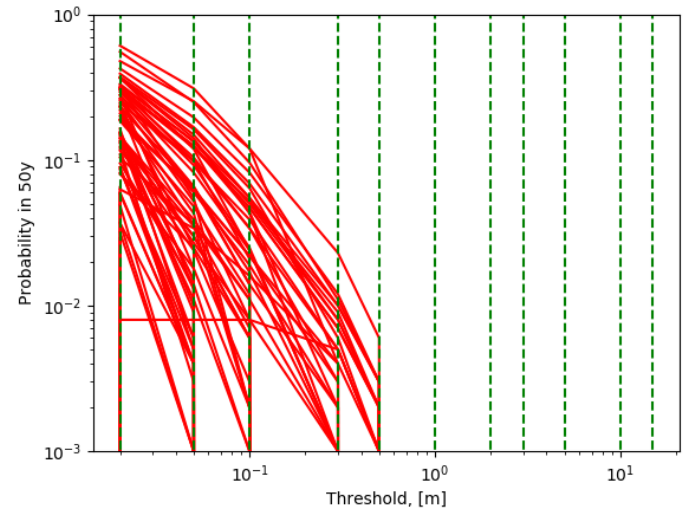
**M1**



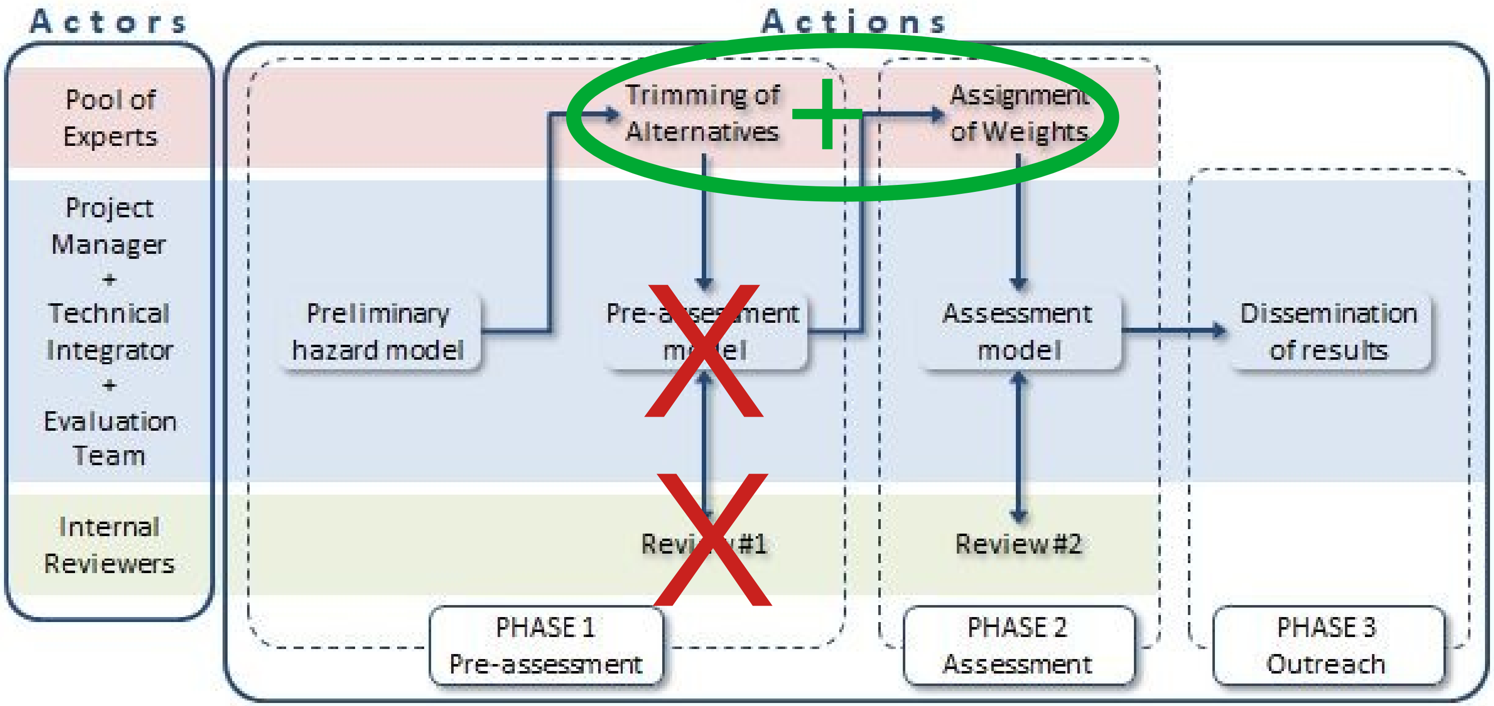




**M2**



# Roadmap to consensus full PTHA




| | |
|---|---|
| Implement alternative models | mid-Sept |
| Elicitation workshop (10-15 experts) on alternatives | mid-Oct |
| Apply weights and send PTHA to ext. Reviewers (2-3 experts) | mid-Nov |
| Feedback from Reviewers | Christmas |
| Full PTHA disseminated | Jan 2025 |