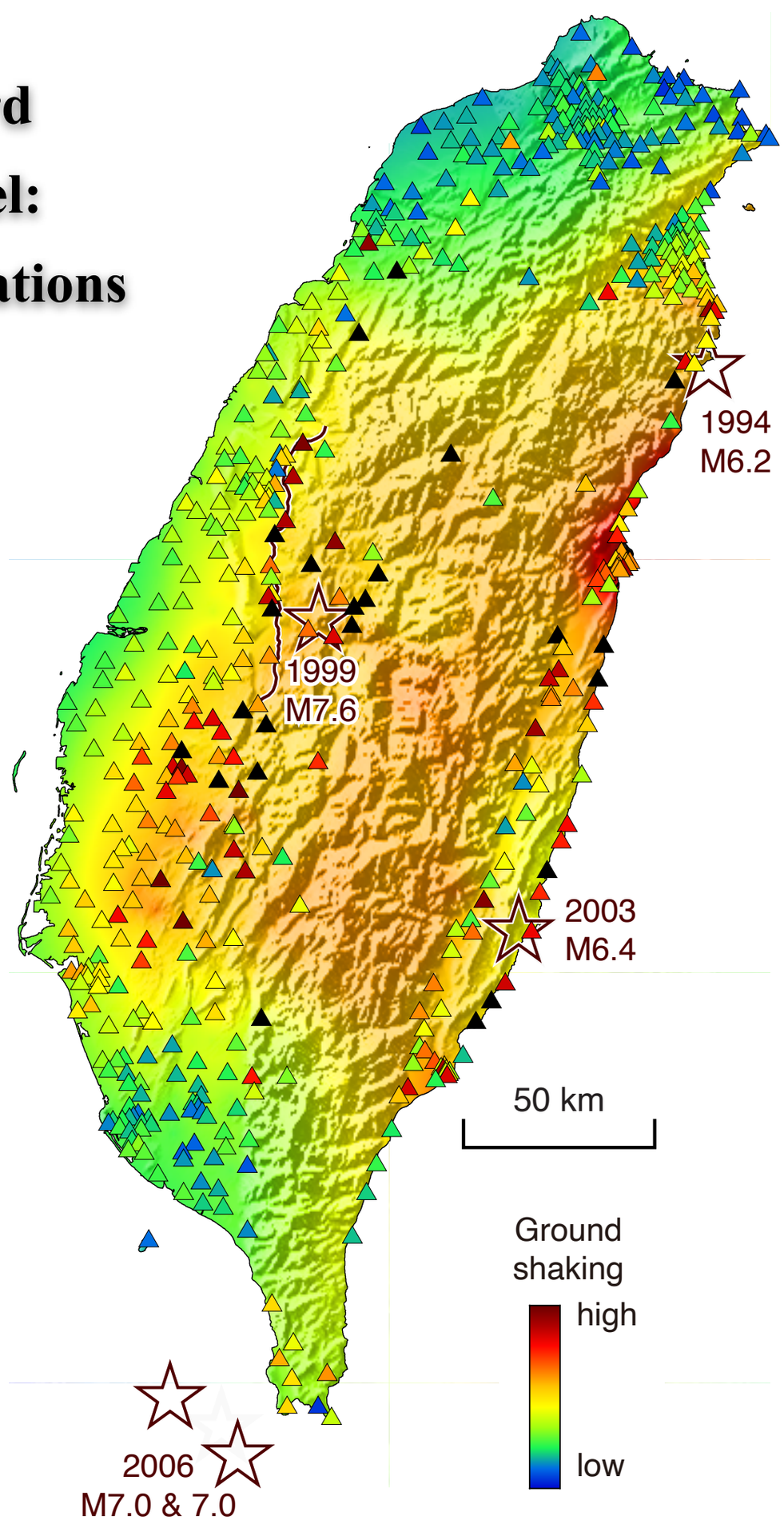
Validation of the probabilistic seismic hazard assessment by the Taiwan Earthquake Model: Comparison with strong ground motion observations

- Comparing the observations and the seismic hazard model reveals similar spatial patterns
- Some records with higher shaking levels could be attributed to some significant earthquake
- The seismic model for seismogenic structures is validated by paleo-seismological observations
- Our validation could provide suggestions for the next generation of PSHA for Taiwan



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An update of the TEM hazard map in 2020

<u>Innovations in this version include:</u>

Seismogenic structure source

- New seismogenic structure database
- Time-dependent rupture probability

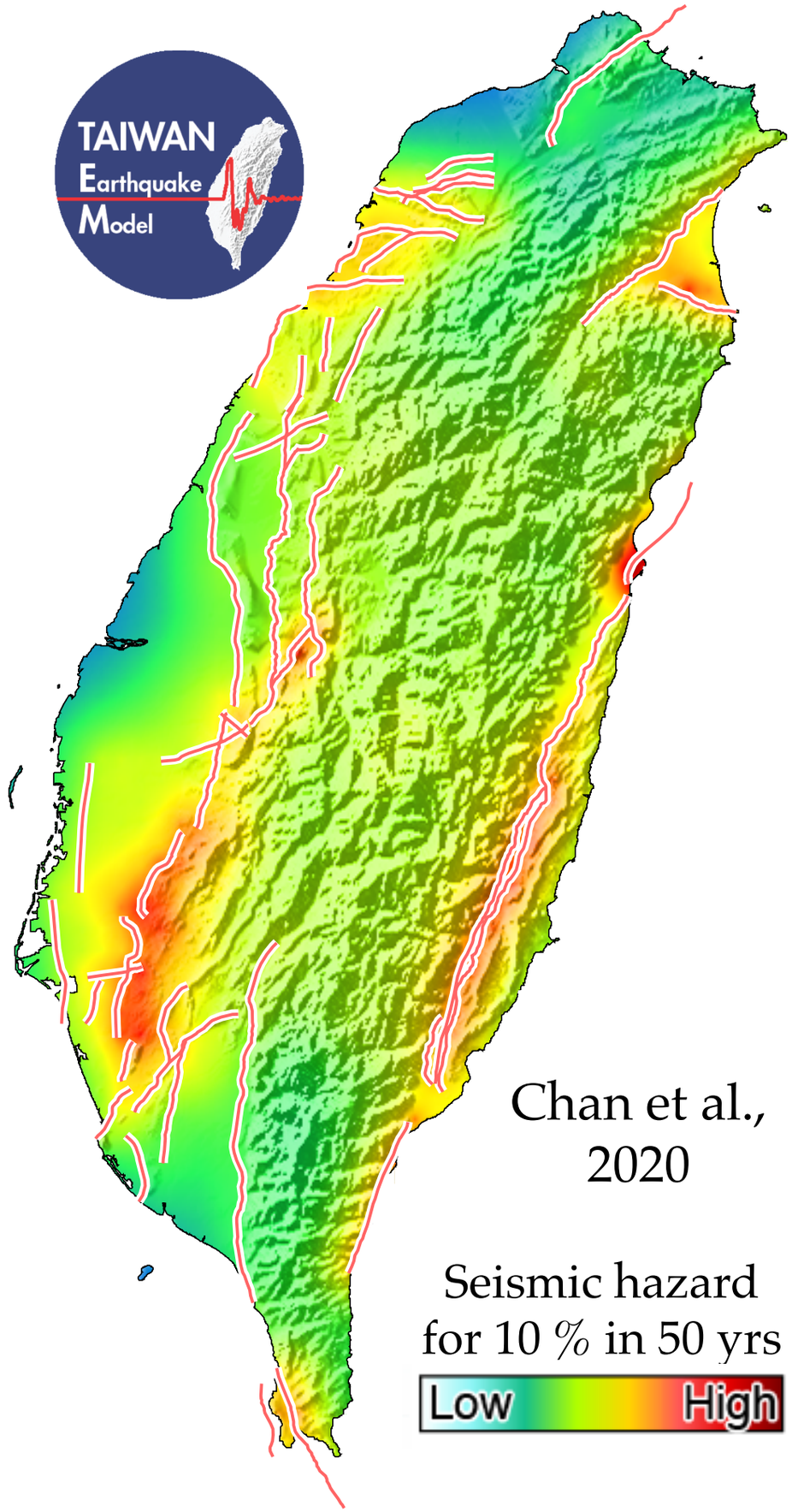
Background source

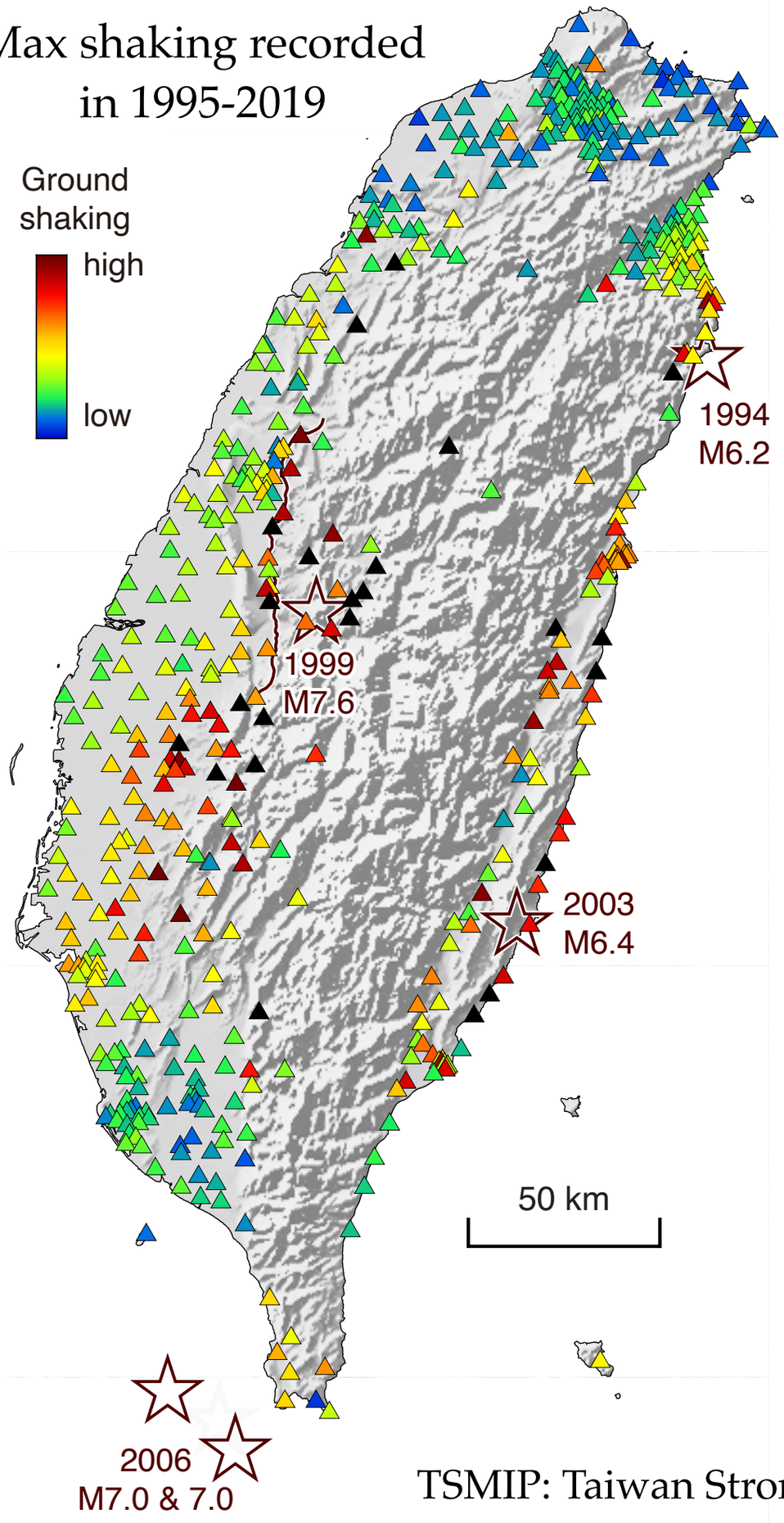
- Smoothing model for background

Path and site effects

- New set of ground motion equations

Model validations are desired to prove credibility and indicate limitations.





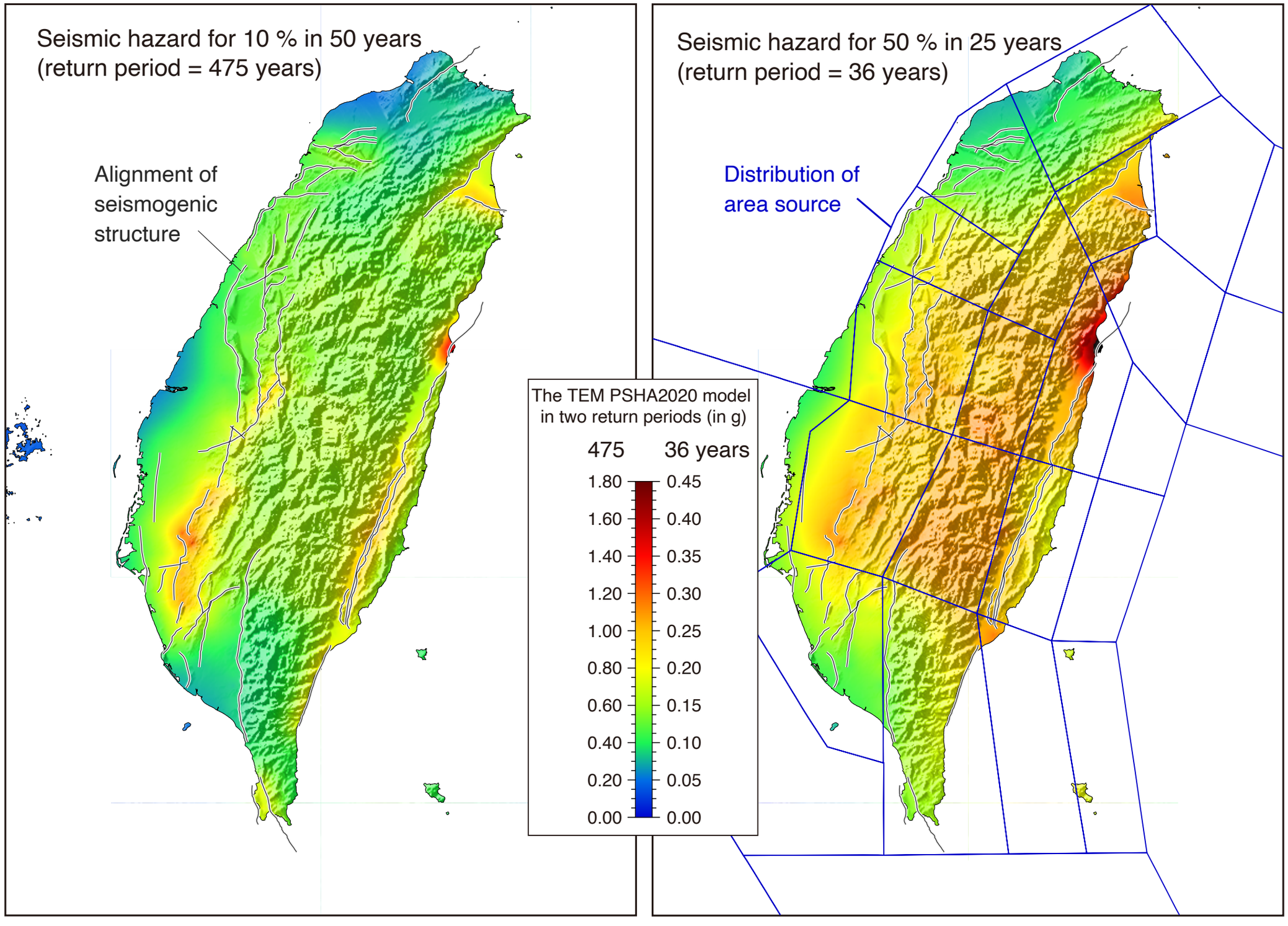
The 25-year TSMIP observations can be implemented for model validation

<u>Procedure of data analysis</u>

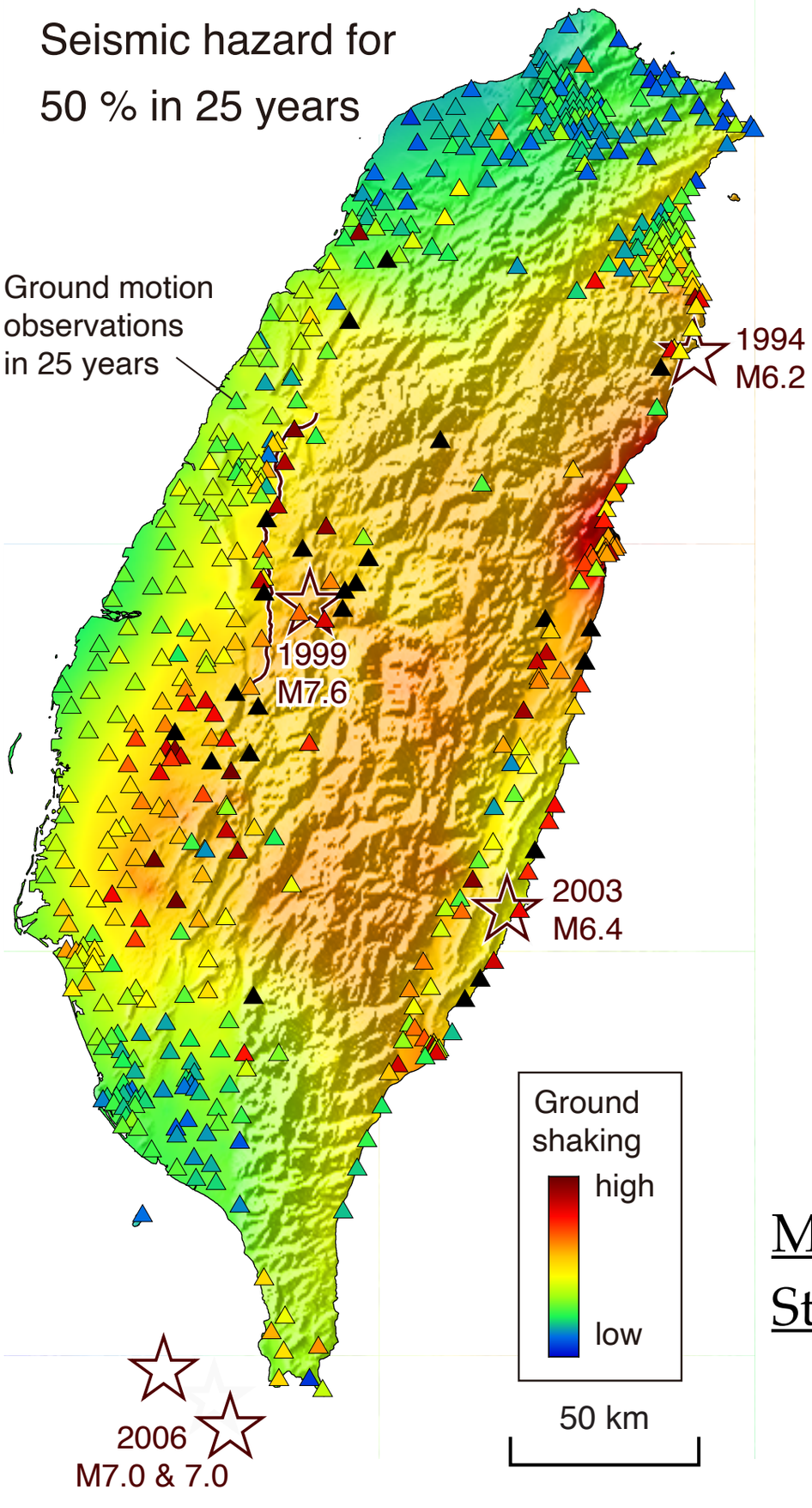
- Filter zero components of PGA
- Eliminate the observations with an unreasonable ground shaking pulse
- Calculate the geometric mean PGA of the two horizontal components
- Report the maximum PGA among all the earthquake records in 1995-2019

TSMIP: Taiwan Strong Motion Instrumentation Program

The hazard model can be converted into different return periods of interest



The hazard for a ***long*** return period is mainly from ***seismogenic structures,*** whereas that for a ***short*** return period is dominated by ***area sources***.



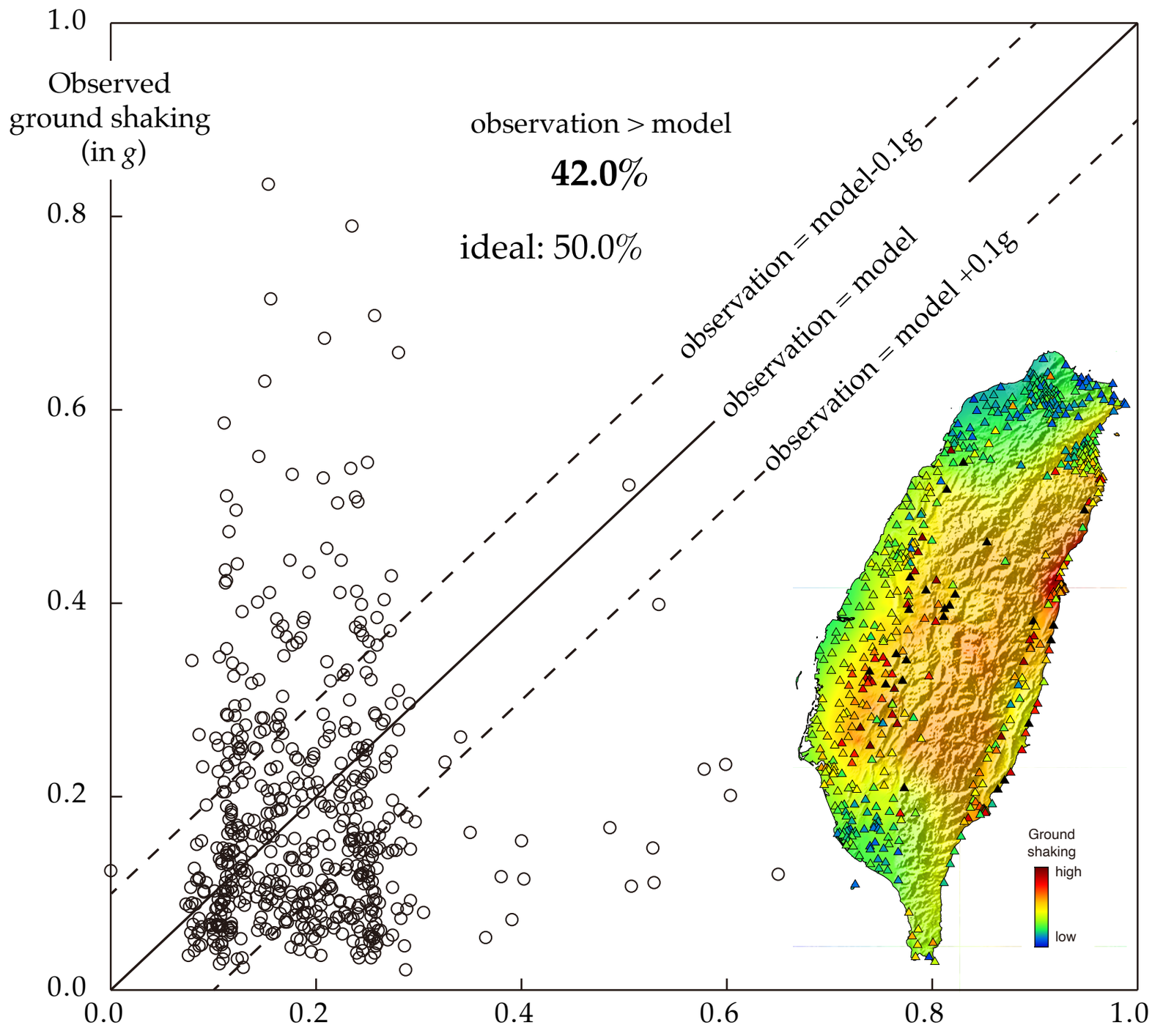
Comparing the observations and the seismic model shows ***similar spatial patterns*** in both

Several stations recorded significantly ***higher*** ground-shaking levels due to the ***large events***

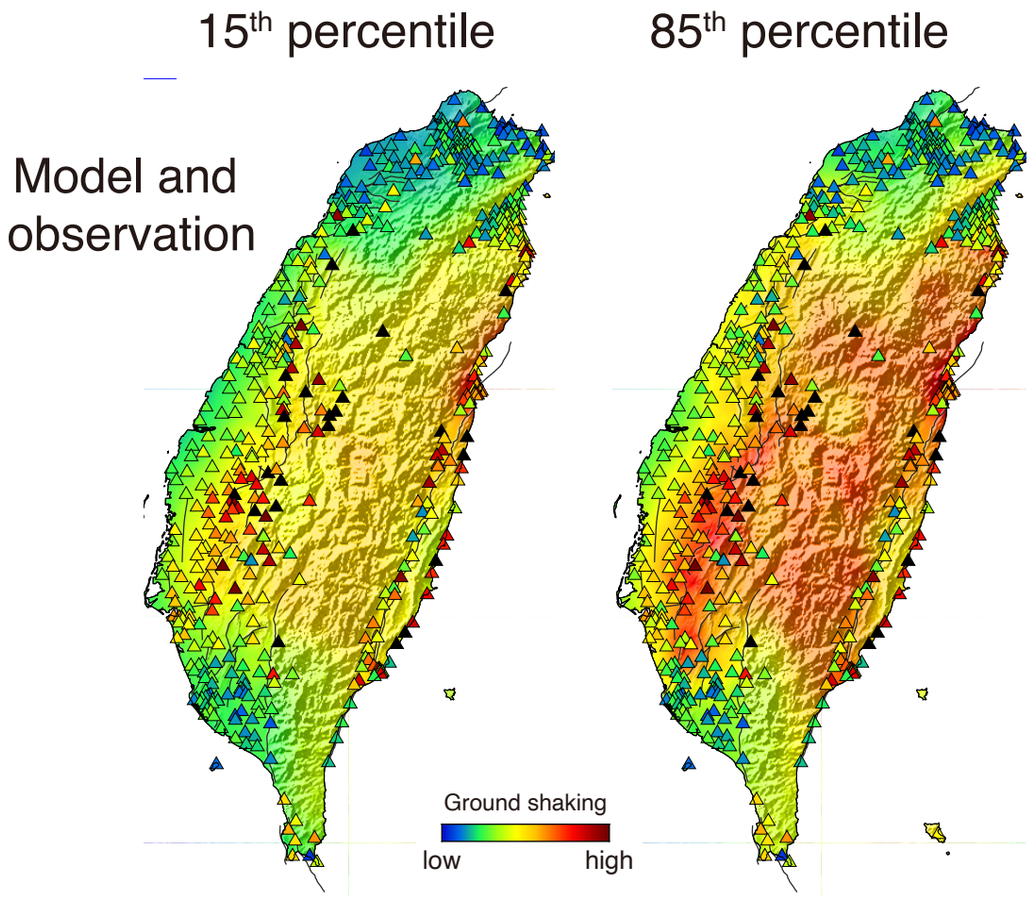
Map: modeled hazard for 50% exceedance in 25 years;
Station: Maximum strong-ground shaking in 25 years.

56.5% stations have a difference between the observation and the model of less than 0.1 g

Our model does not cover some observations with extremely ground-shaking levels

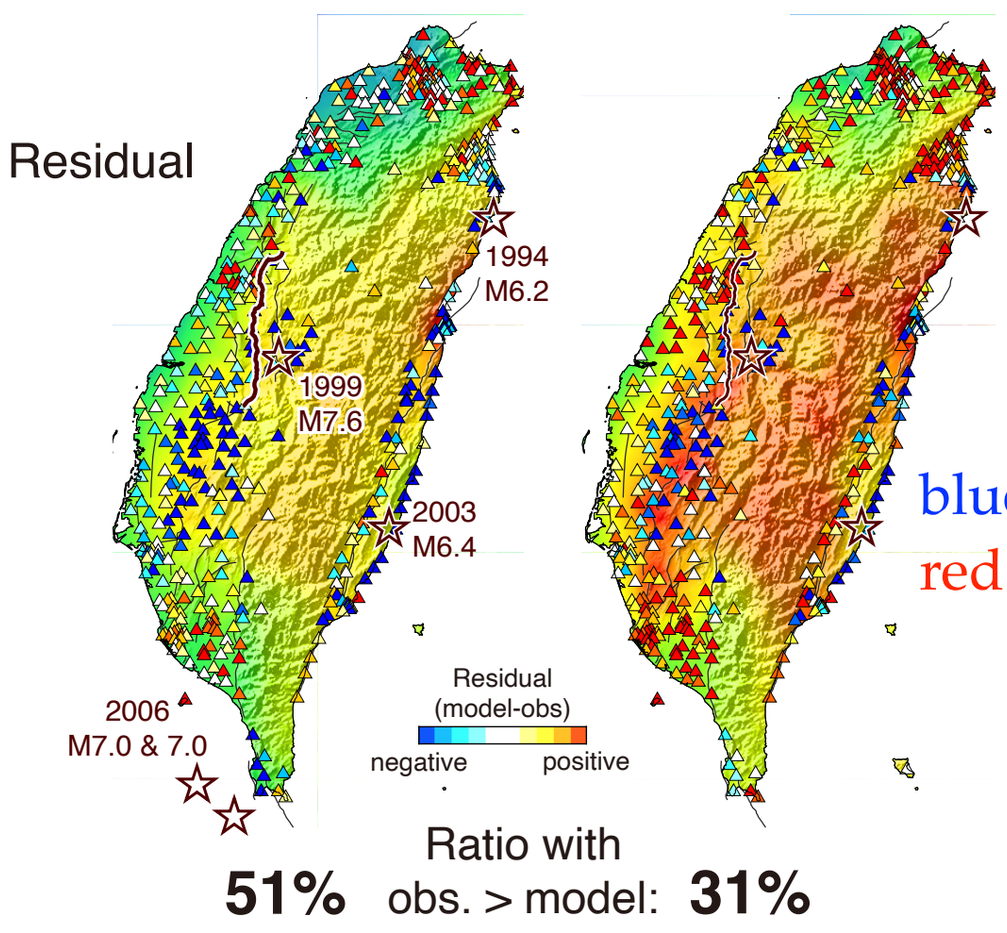


Epistemic uncertainty….



The observations could be well covered when model deviation was implemented

Some ***under-predictions*** could be attributed to the significant events, e.g., the 1999 Chi-Chi eq



The ***over-predictions*** might be associated with model uncertainties, e.g., deviations of GMPE

blue: under-prediction

red : over-prediction

The model deviations are attributed to the uncertainties of GMPEs & seismic sources

The model with 2 std. dev. over-predicted, especially for short recurrence intervals

The model with a smaller std. dev. performed better, regardless recurrence interval

The percentages of stations with higher observation than model

GMPE deviation

Exceedance Probability	1.0%	2.0%	5.0%	10.0%	20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%	90.0%	Average deviation
2.0 sigma	0.6%	1.7%	3.4%	8.2%	15.9%	23.7%	33.6%	41.9%	48.8%	55.0%	62.4%	71.8%	7.6%
1.5 Sigma	1.3%	2.1%	5.6%	10.5%	18.3%	28.8%	37.8%	45.4%	52.3%	59.6%	68.2%	76.8%	4.5%
1.0 Sigma	2.1%	3.7%	7.1%	13.8%	23.0%	33.8%	42.8%	50.8%	57.4%	66.5%	72.9%	81.5%	3.4%

A perfect model: Reported ratio of stations match exceedance probability.

The implemented GMPEs are obtained based on records in Taiwan

To implementing ***non-ergodic GMPEs*** for specific regions could minimize the aleatory variability or the single-path variability

GMPE: Ground motion prediction equation

The ***paleo-seismic observations*** are helpful to validate our seismic model

Recurrence interval (yr.): 415±65 | 370±120 | 170 ±70 | 560±100 | 340 ±180

Time (A.D.): 1999 | 1650-1520 | 1270-1160 | 1060-1030 | 570-400 | 240-50

Site: A B C D E F G

Fault trace

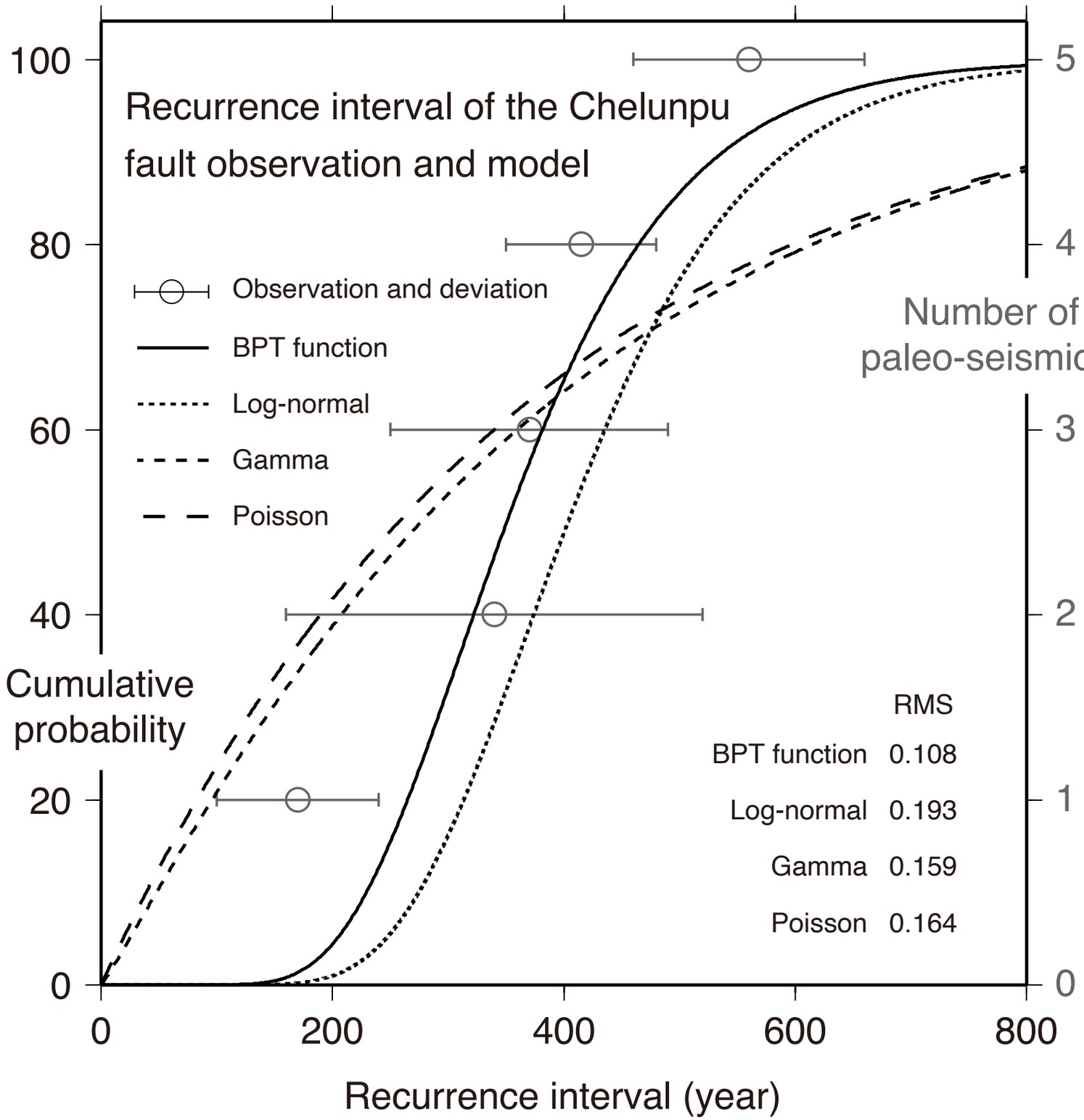
by courtesy of *Chen et al.*, 2007

2000 Year (A.D.) 1500 1000 500 0

The paleo-seismic events along the Chelungpu fault were determined based on the excavation data at various sites

Avg. interval: ***371*** years

The rupture probability can be forecasted by various models



In this case, the ***BPT model*** has the best fit with paleo-seismic observations

The rupture probability along the CLP fault in the 25 years is

13.2%

BPT: Brownian Passage Time

1 fault with **1 %** probability = **1.0 %**

10 faults with **1 %** probability = **9.6 %**

44 faults with **3 %** probability = **73.8 %**

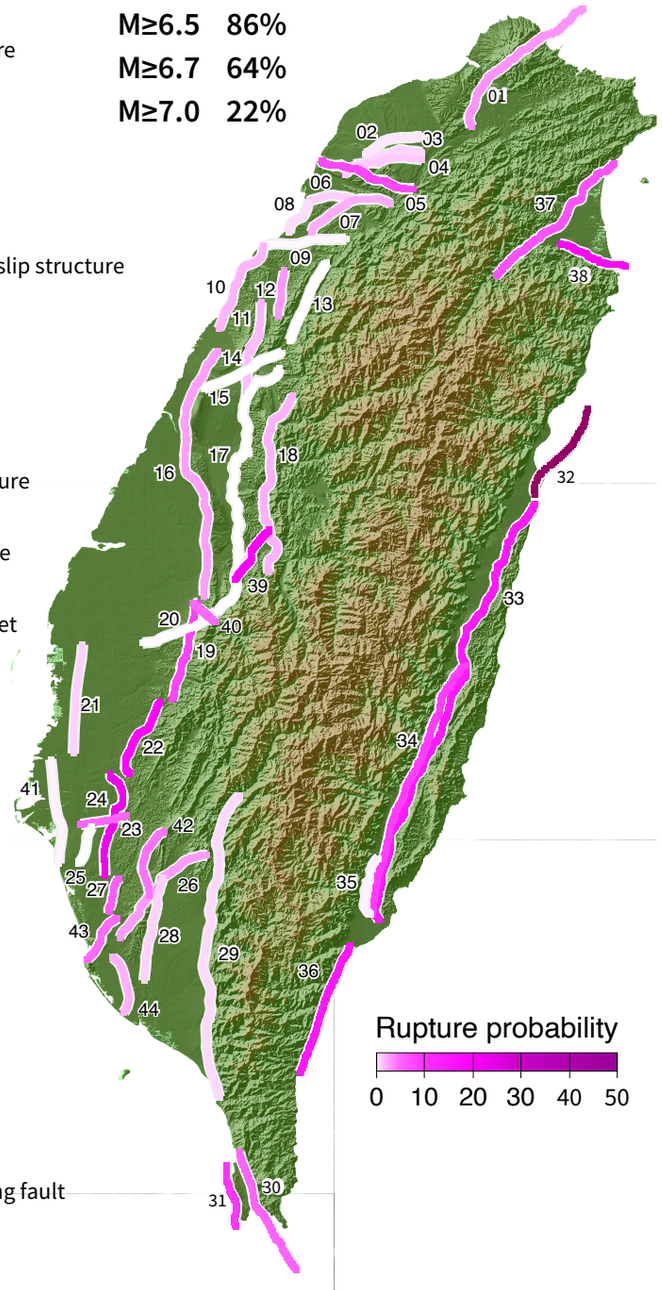
*Based on the Poisson distribution:

$100\ \% - (100\ \% - 1\ \%)^{10} = 9.6\ \%$; $100\ \% - (100\ \% - 3\ \%)^{44} = 73.8\ \%$

Rupture probability map in the next 25 years

Whole Taiwan

M≥6.5 86%
M≥6.7 64%
M≥7.0 22%



01 Shanchiao fault
Mw 7.0 3%

02 Shuanglienpo structure
Mw 6.2 <1%

03 Yangmei structure
Mw 6.0 1%

04 Hukou fault
Mw 6.8 1%

05 Fengshan river strike-slip structure
Mw 6.7 8%

06 Hsinchu fault
Mw 6.4 1%

07 Hsincheng fault
Mw 6.9 2%

08 Hsinchu frontal structure
Mw 6.5 1%

09 Touhuanping structure
Mw 6.5 <1%

10 Miaoli frontal structuret
Mw 6.8 2%

11 Tunglo structure
Mw 6.2 2%

12 East Miaoli structuret
Mw 6.2 3%

13 Shihtan faultt
Mw 6.6 <1%

14 Sanyi faultt
Mw 7.0 1%

15 Tuntzuchiao fault
Mw 6.6 <1%

16 Changhua fault
Mw 7.6 3%

17 Chelungpu fault
Mw 7.6 <1%

18 Tamaopu - Shuangtung fault
Mw 7.0 2%

19 Chiuchiungkeng fault
Mw 7.0 8%

20 Meishan fault
Mw 6.6 <1%

21 Chiayi frontal structure
Mw 7.2 1%

22 Muchiliao - Liuchia fault
Mw 6.9 19%

23 Chungchou structure
Mw 6.9 22%

24 Hsinhua fault
Mw 6.4 8%

25 Houchiali fault
Mw 6.1 <1%

26 Chishan fault
Mw 6.7 3%

27 Hsiaokangshan fault
Mw 6.3 6%

28 Kaoping River structure
Mw 6.7 1%

29 Chaochou fault
Mw 7.1 1%

30 Hengchun fault
Mw 6.9 5%

31 Hengchun offshore structure
Mw 6.3 10%

32 Milun fault
Mw 6.6 65%

33 Longitudinal Valley fault
Mw 7.0-7.5 15%

34 Central Range structure
Mw 7.4 9%

35 Luyeh fault
Mw 6.2 >1%

36 Taimali coastline structure
Mw 6.7 15%

37 Northern Ilan structure
Mw 6.9 7%

38 Southern Ilan structure
Mw 6.4 19%

39 Chushiang structure
Mw 6.0 20%

40 Gukeng structure
Mw 6.1 5%

41 Tainan frontal structure
Mw 7.2 <1%

42 Longchuan structure
Mw 6.6 4%

43 Youchang sturcture
Mw 6.4 5%

44 Fengshan hills frontal structure
Mw 6.8 2%

Multiple-structure rupture probability

06+08	Mw 6.7	2%	13+15	Mw 6.8	<1%	21+41	Mw 7.4	2%	29+30	Mw 7.2	2%
09+10	Mw 6.9	2%	20+21	Mw 7.2	2%	25+41	Mw 7.3	1%	35+33(N)	Mw 7.0	2%

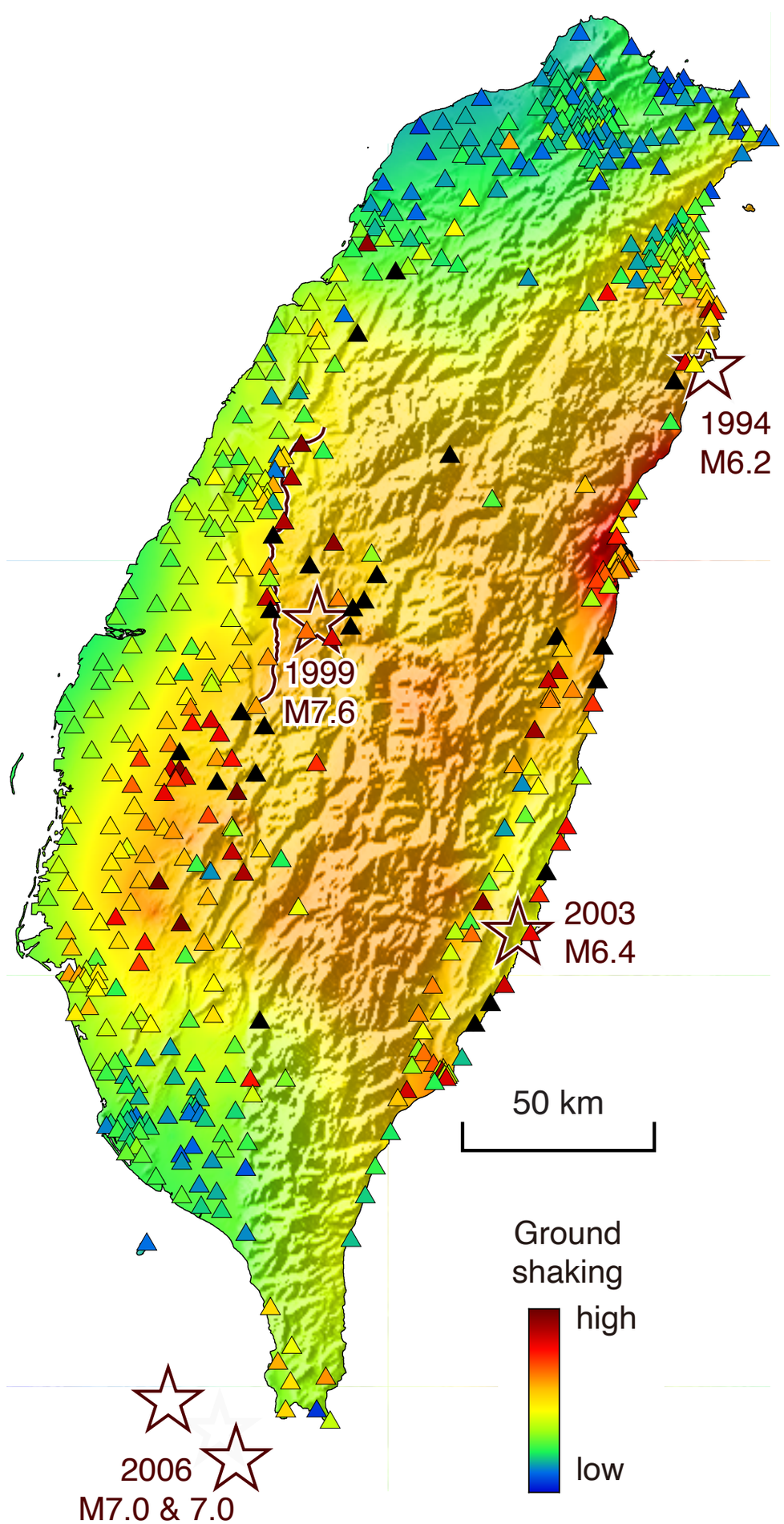
A significant event like Chi-Chi could occur within a short period in Taiwan

Most of the seismic structures obtain rupture probabilities lower than 3%

Summarized rupture probabilities are significantly high, regardless magnitude

Conclusions:

- The strong motion observations confirmed the credibility of the seismic hazard model;
- Our validation could provide suggestions for updating Taiwan PSHA in the future;
- Our outcomes might be beneficial to urban planning and building code legislation.



Reference: Gao et al., *SRL*, 2022

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