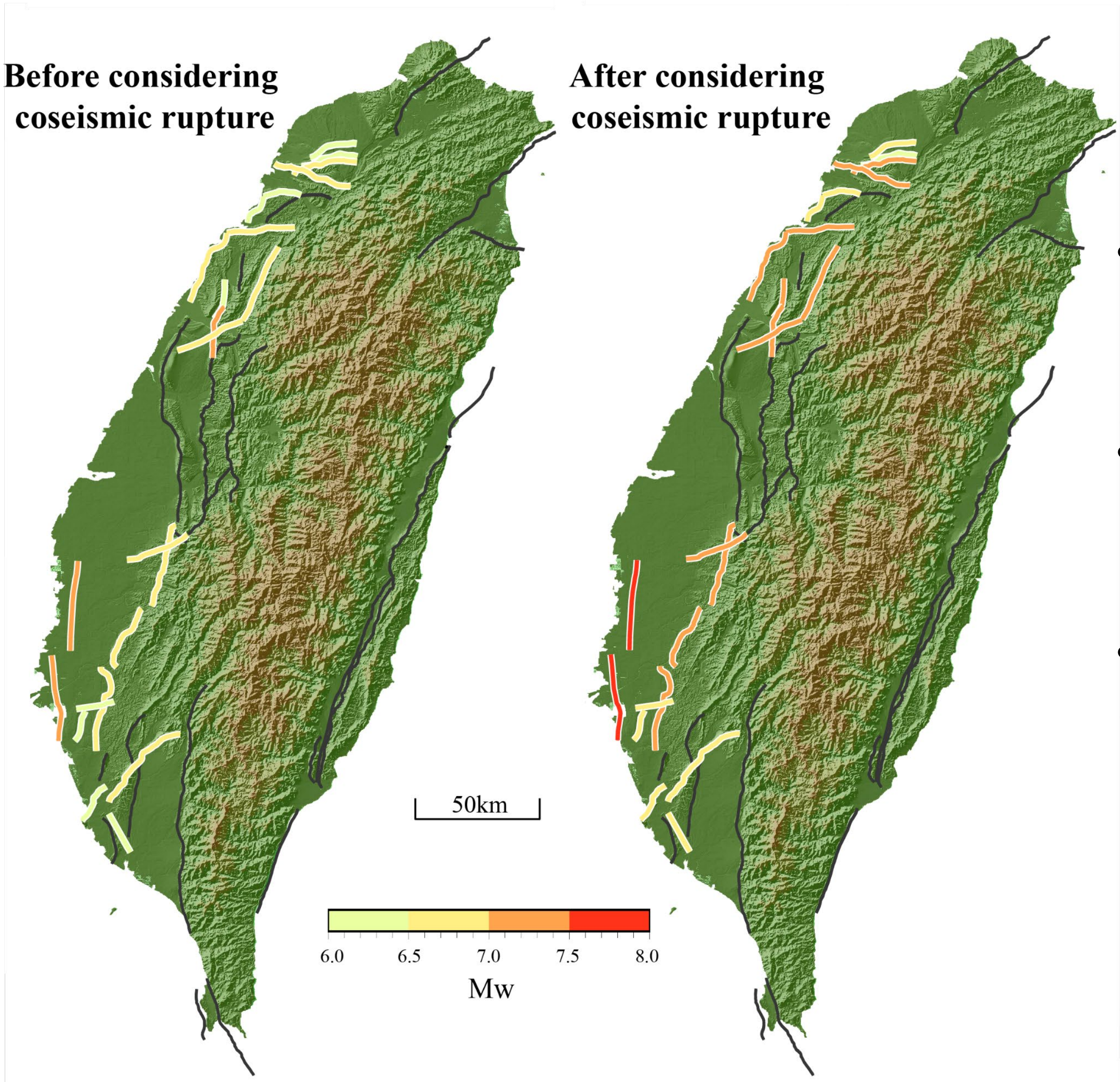
Quantifying the probability and uncertainty of multiple-structure rupture and its recurrence intervals for Taiwan



- Highlighting instances of multiple-structure rupture
- Measuring recurrence intervals while considering uncertainties
- Quantifying seismicity rate through the SHERIFS model

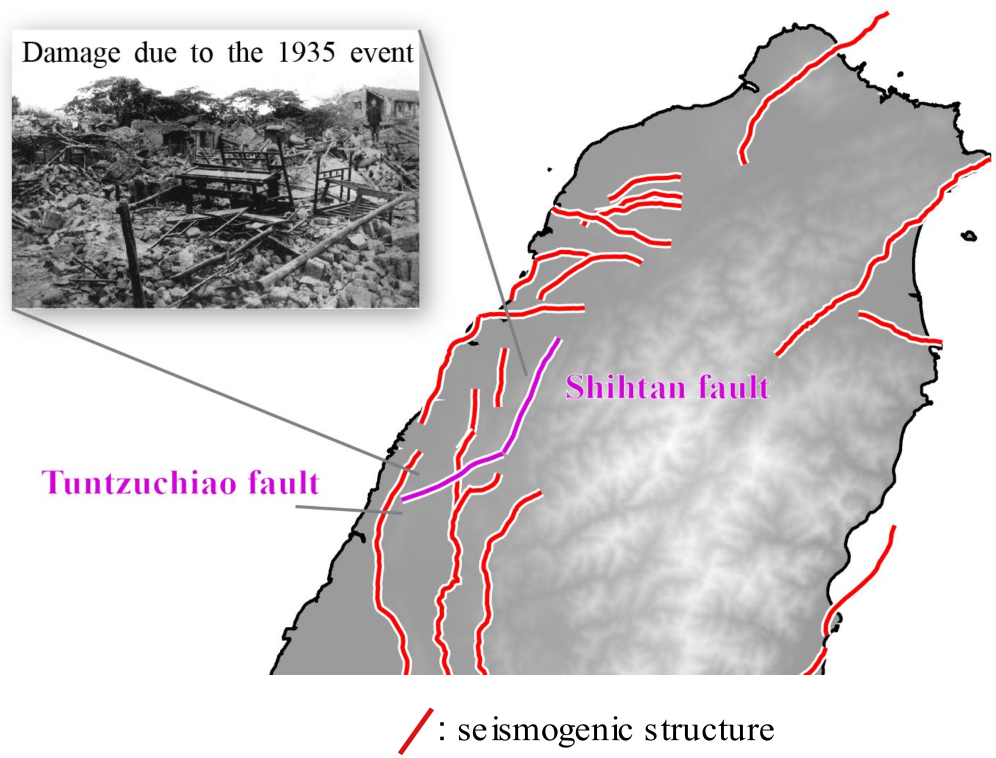
The 1935 M_L 7.1 Hsinchu-Taichung earthquake can be attributed to multiple-structure rupture

- Without considering coseismic rupture:

    The Shitan or Tunzichiao fault could only cause an M_L 6.6 event

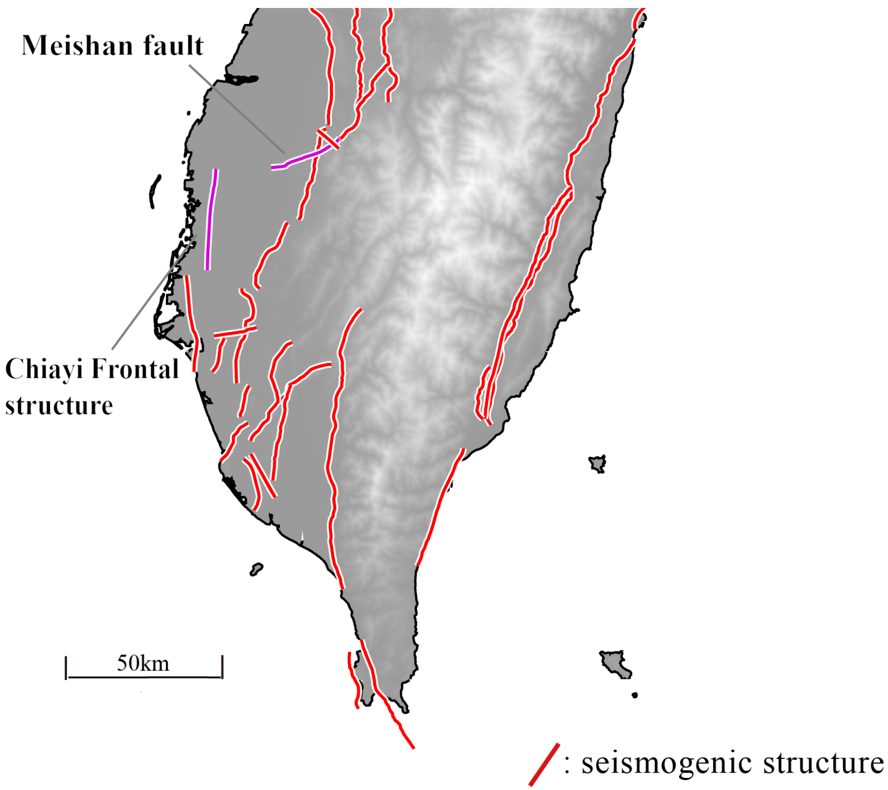
- Multiple-structure rupture:

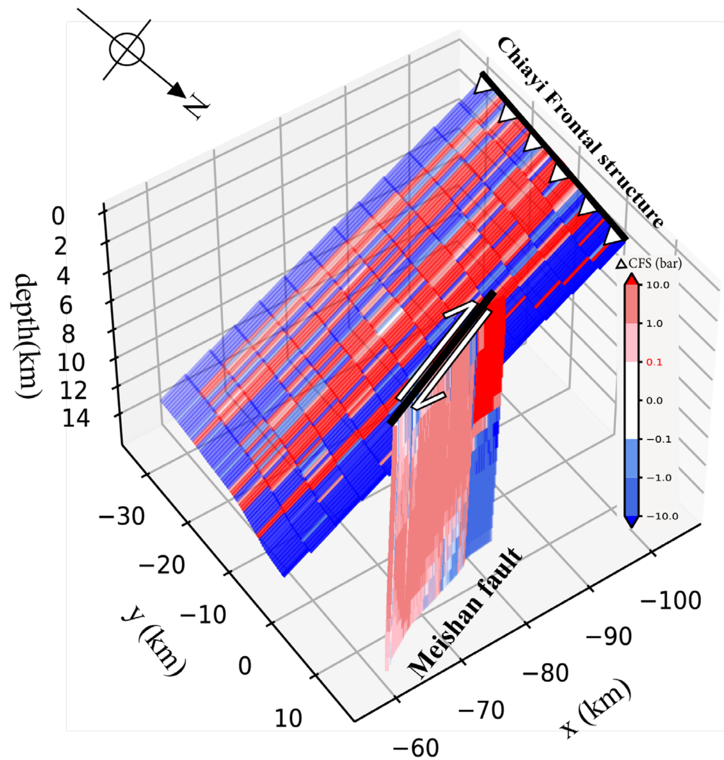
    1. results in a larger magnitude
    2. leads to catastrophe



*The seismogenic structure parameters we obtained by the Taiwan Earthquake Model

The Chiayi Frontal Structure and the Meishan fault could trigger each other





Structure distance: 1.87 km

72 % of the Meishan fault was triggered

64 % of the Chiayi Frontal structure was triggered

Longer recurrence intervals are expected for considering multiple-structure rupture

The G-R law* $$\log(N) = a - bM$$

N = number of earthquakes
M = magnitude
a & b are constants

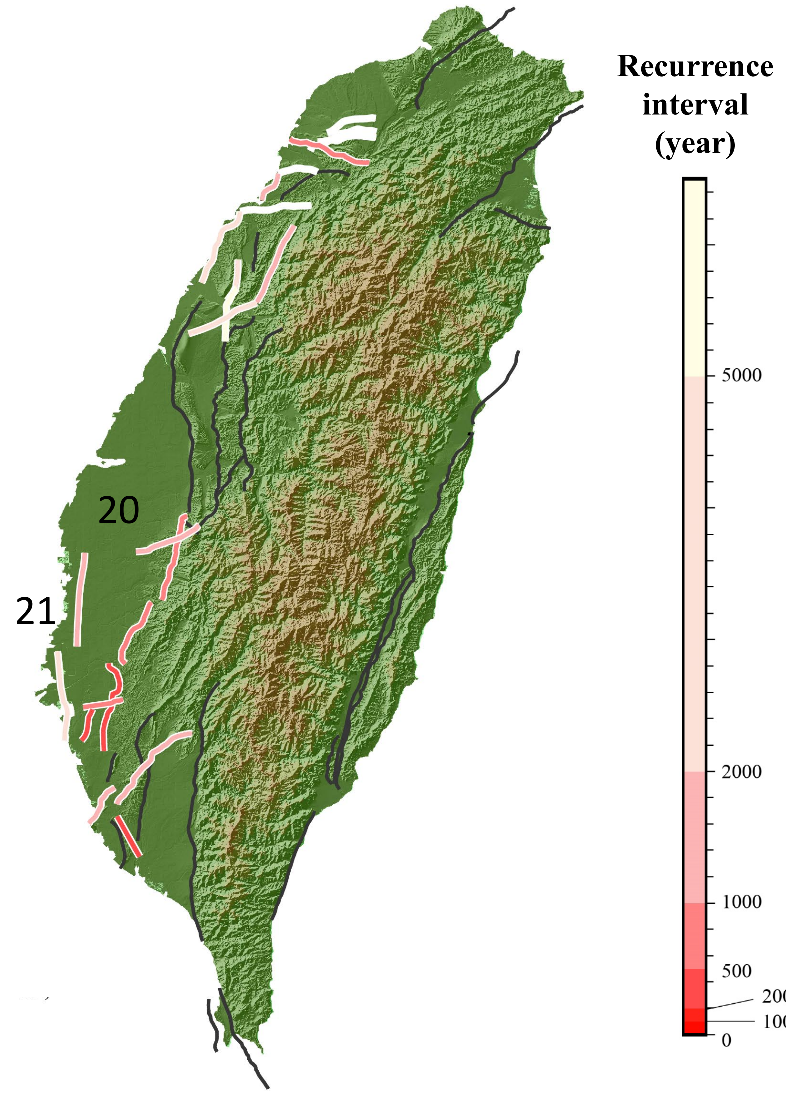
The scaling law $$\log(AD) = c + dM$$

$$\log(A) = e + fM$$

AD = average displacement M = magnitude
c, d, e and f are constants A = structure area

ID	Mw	Recurrence interval (yr)	
		Original	Multiple
20	6.60	350	1059
21	7.21	510	1724
20+21	7.29	1553	

ID 20: Meishan fault
ID 21: Chiayi Frontal structure



* G-R law = Gutenberg–Richter law

Revised of recurrence interval could improve probabilistic seismic hazard assessment

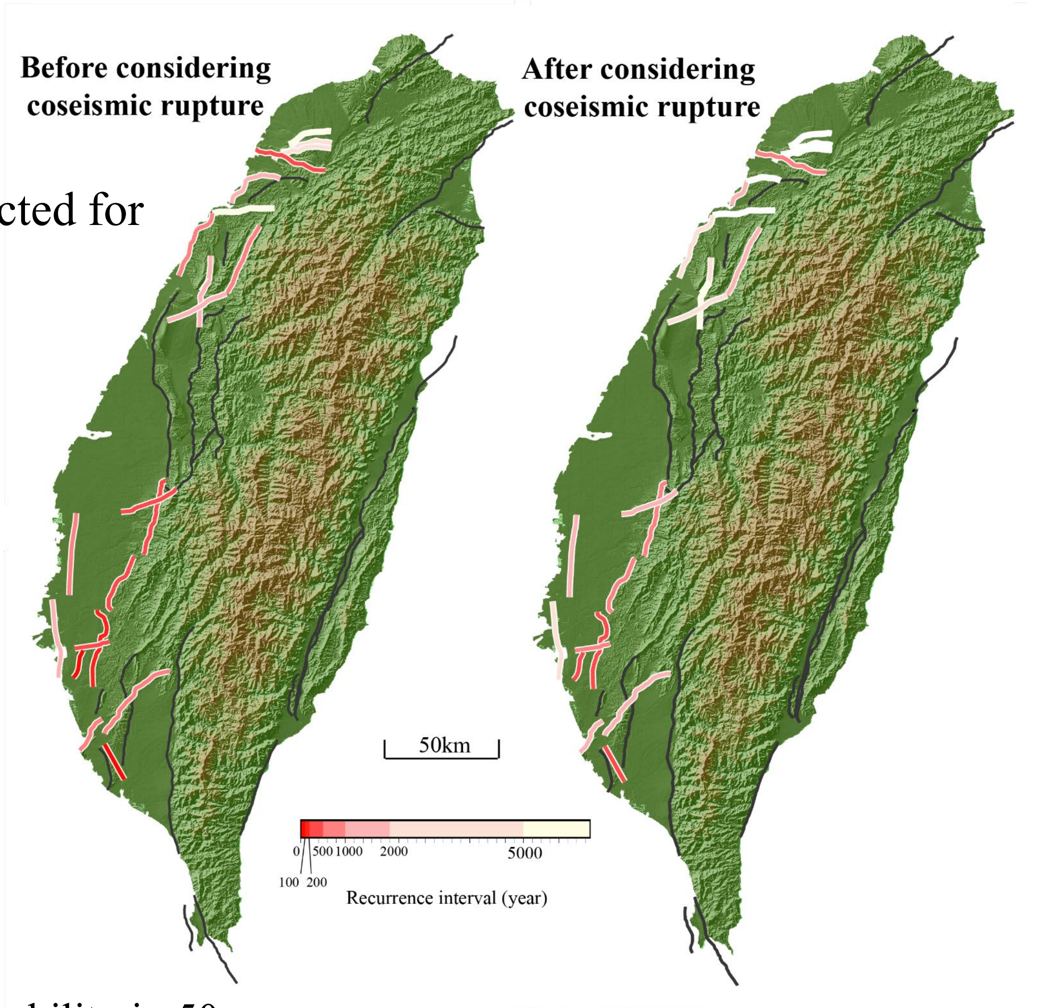
- Due to slip rate partitioning,

  Longer recurrence intervals are expected for

  1. multiple-structure ruptures and
  2. each individual structures

- Larger recurrence interval

  The seismic hazard level for a <u>short return period</u>* would be lower.



*e.g., 475 years, corresponding to a 10% probability in 50 years

The maximum magnitudes for each structure increases after considering coseismic multiple-rupture

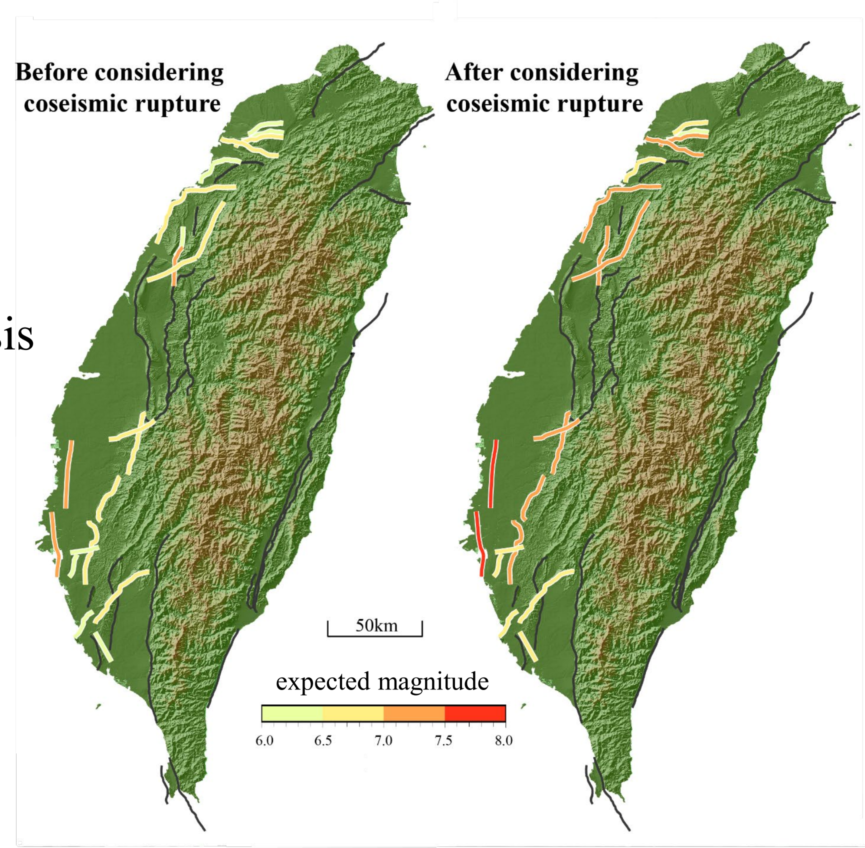
- Use scaling law & consider multiple-structure

  → ***Larger*** maximum characteristic magnitude

- Improve the accuracy of seismic hazard analysis

- The hazard level for a long return period*

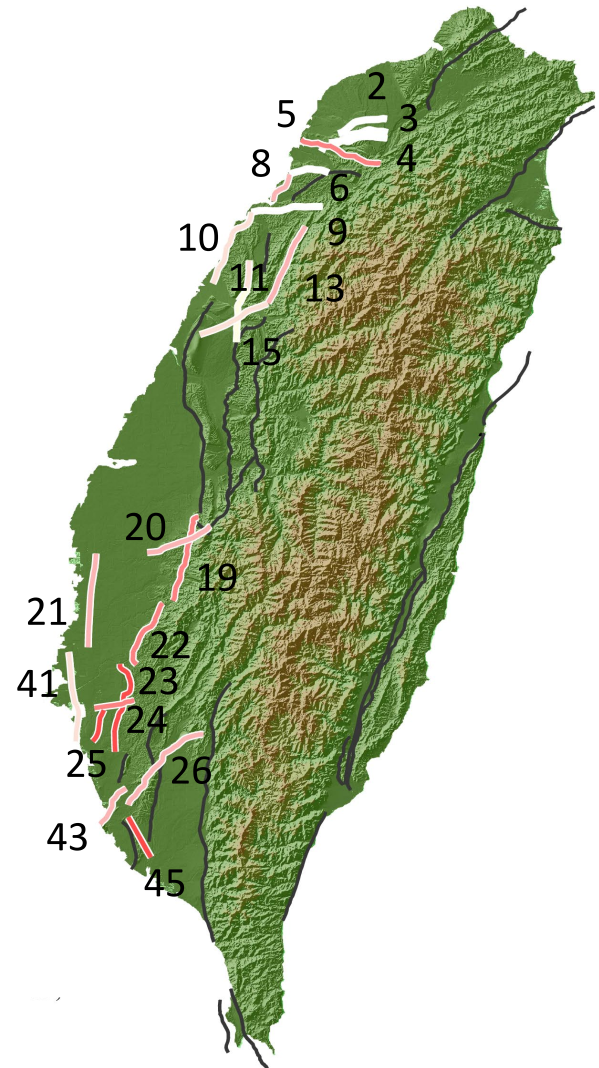
  might be higher

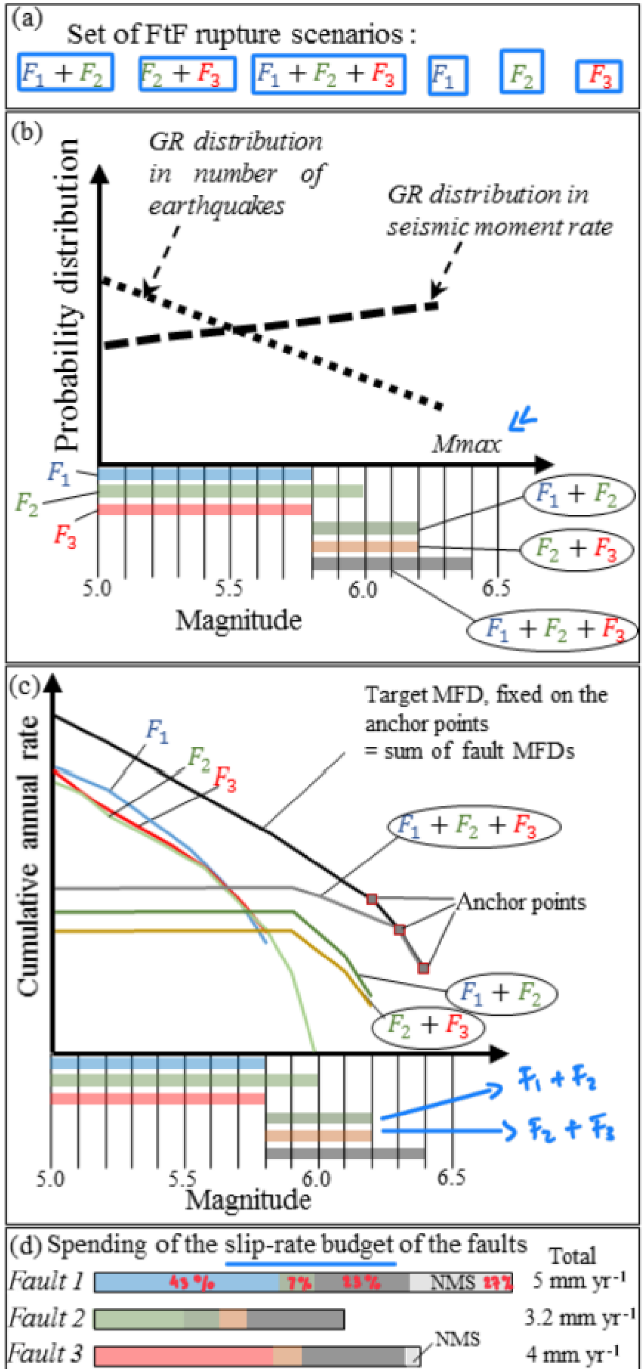


*e.g., 2475 years, corresponding to a 2% probability in 50 years

Paring uncertainties could come from ***structure gap*** & ***ΔCFS triggering threshold***

ID	5.0 km				2.5 km			
	0.01 bar	0.05 bar	0.1 bar	0.2 bar	0.01 bar	0.05 bar	0.1 bar	0.2 bar
2, 3	✓	✓	✓	✓	✓	✓	✓	
2, 4	✓	✓	✓	✓	✓	✓	✓	✓
4, 5	✓	✓	✓	✓	✓	✓	✓	✓
4 ,6	✓	✓	✓		✓	✓	✓	
4, 8	✓	✓			✓			
6, 8	✓	✓	✓	✓	✓	✓	✓	✓
6, 9	✓	✓	✓	✓	✓			
9, 10	✓	✓	✓		✓	✓	✓	
10, 15	✓	✓	✓	✓	✓	✓	✓	✓
10, 16	✓	✓			✓	✓		
11, 14	✓	✓	✓		✓	✓	✓	
11, 16	✓				✓			
13, 14	✓	✓	✓		✓	✓	✓	
13, 16	✓				✓			
14, 17	✓	✓			✓	✓		
15, 16	✓				✓			
16, 19	✓	✓			✓	✓		
16, 20	✓				✓			
16, 40	✓							
17, 19	✓				✓			
17, 20	✓				✓			
17, 40	✓							
19, 22	✓	✓	✓	✓	✓			
20, 21	✓	✓	✓		✓	✓	✓	
21, 41	✓	✓	✓		✓			
22, 23	✓	✓	✓	✓	✓	✓	✓	✓
23, 27	✓	✓			✓	✓		
24, 25	✓	✓	✓		✓	✓	✓	
24, 41	✓				✓			
26, 45	✓	✓	✓	✓	✓	✓	✓	✓
27, 42	✓	✓			✓	✓		
30, 31	✓							
32, 33	✓				✓			
43, 45	✓	✓	✓	✓	✓			
Total pairs of each criteria:	34	23	17	10	31	18	13	6





Seismicity activity in a complex fault system could be modelled SHERIFS

(a) Set of fault-to-fault rupture scenarios

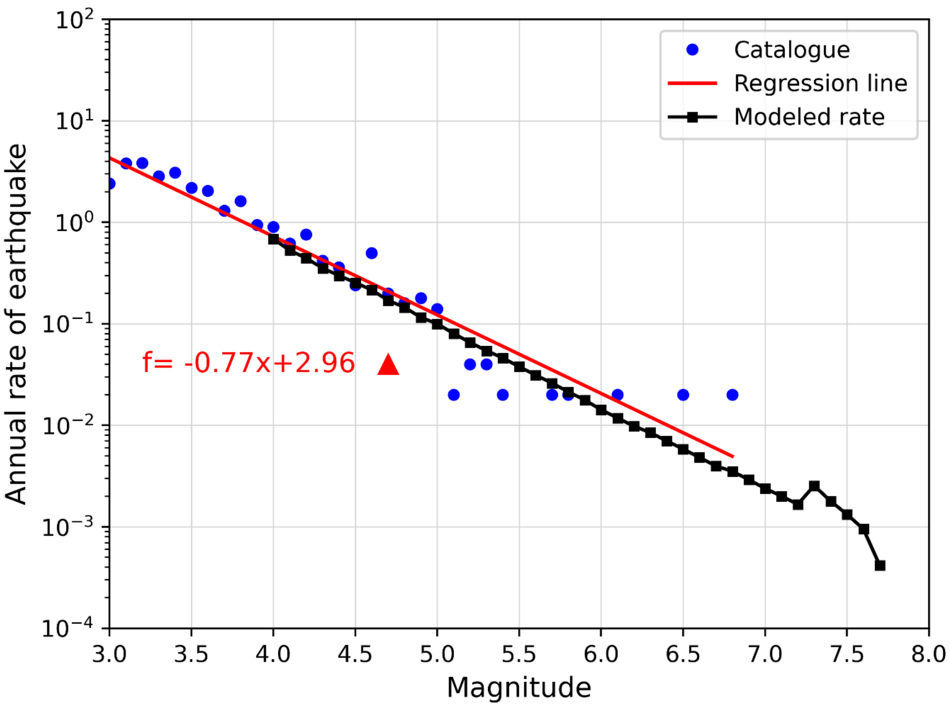
(b) Picking of the magnitude bins and of the sources

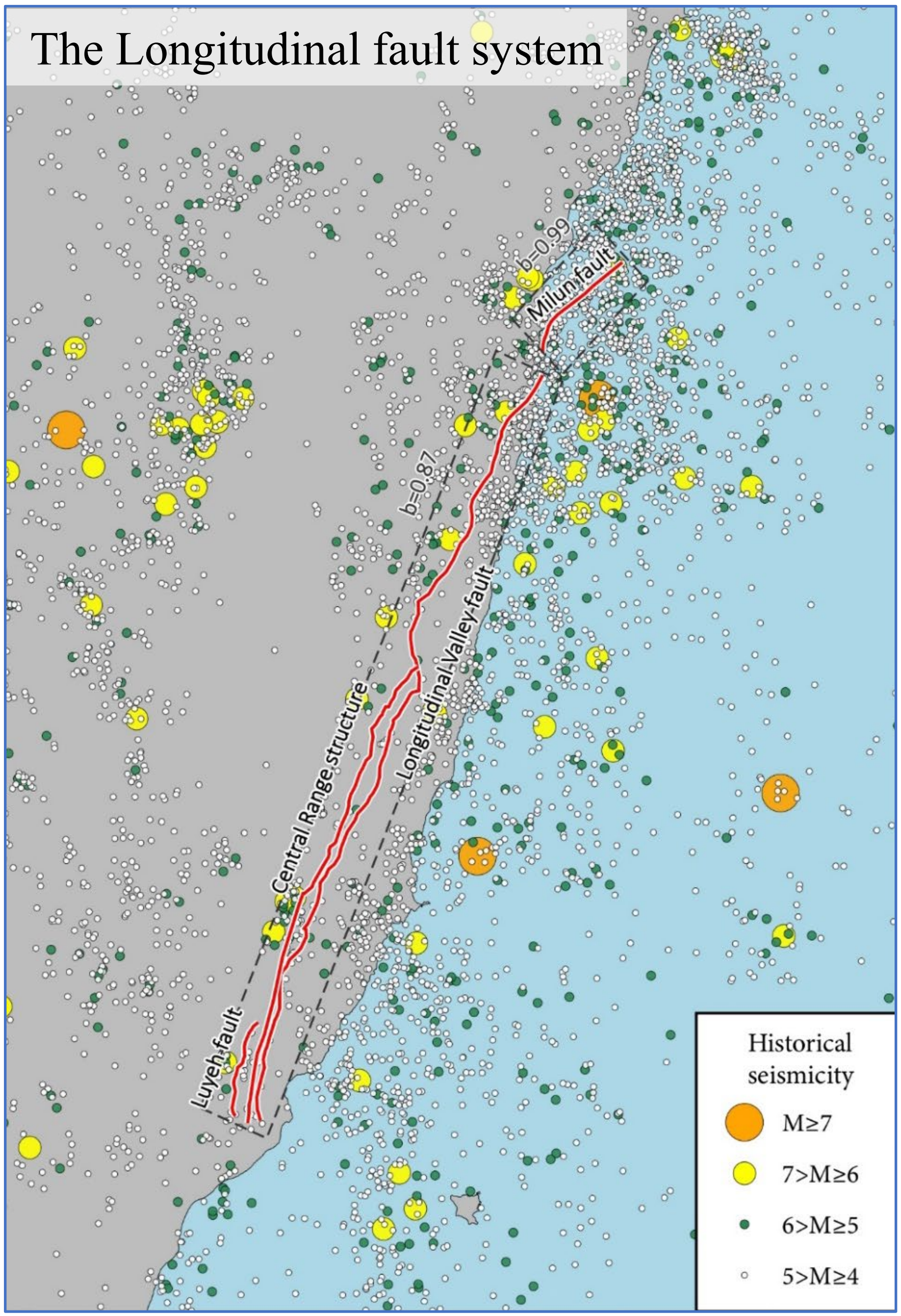
(c) Building the target MFD

(d) Partitioning of each fault's slip-rate budget

Chartier et al., 2019

- The model fits with observations in small to moderate magnitudes well
- Seismicity activity for the multiple-structure rupture could be modeled
- SHERIFS provides OpenQuake inputs for seismic hazard assessment





Conclusion:

Considering multiple-structure rupture improves PSHA, crucial for both Ryukyu and Taiwan

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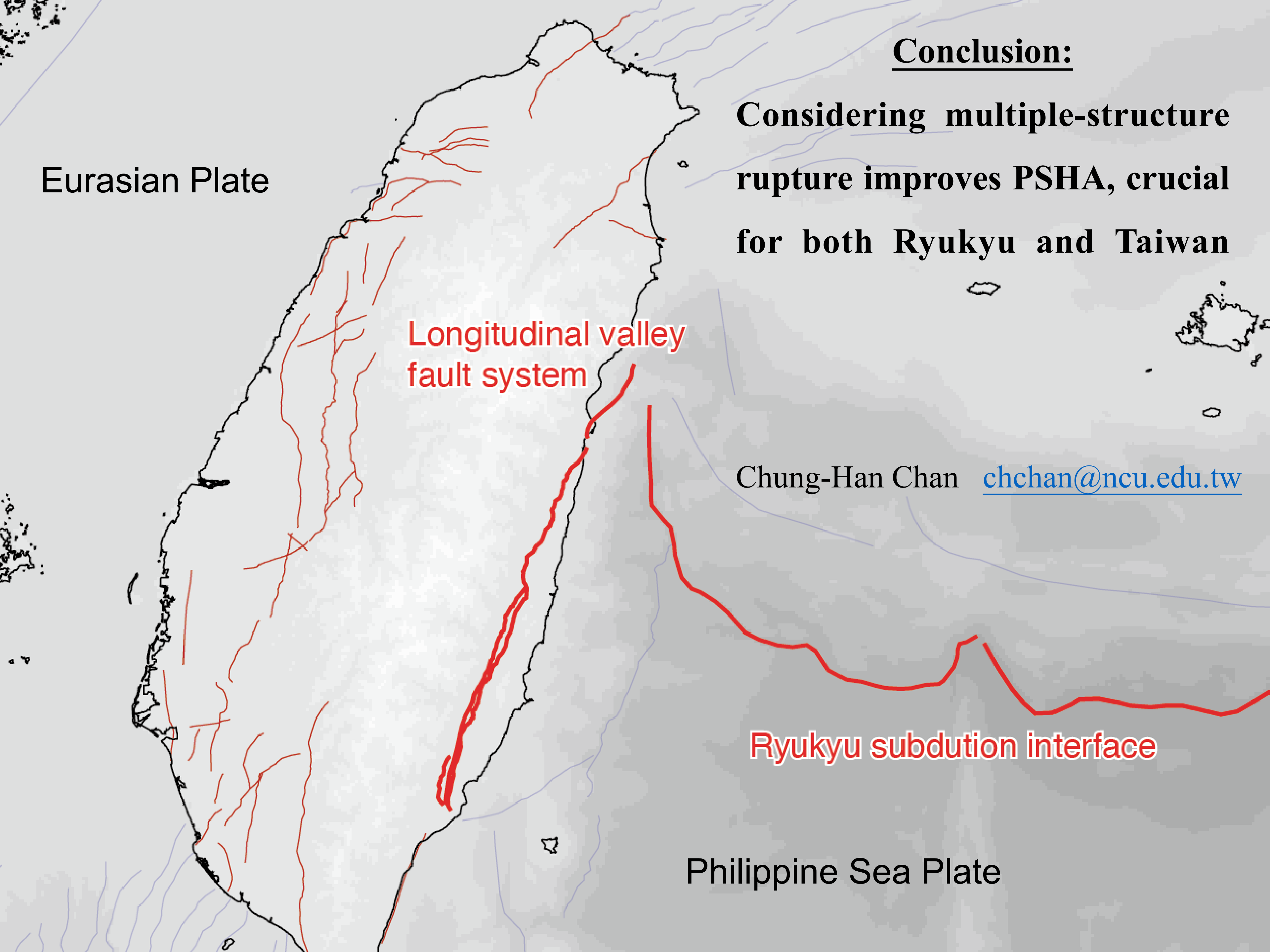
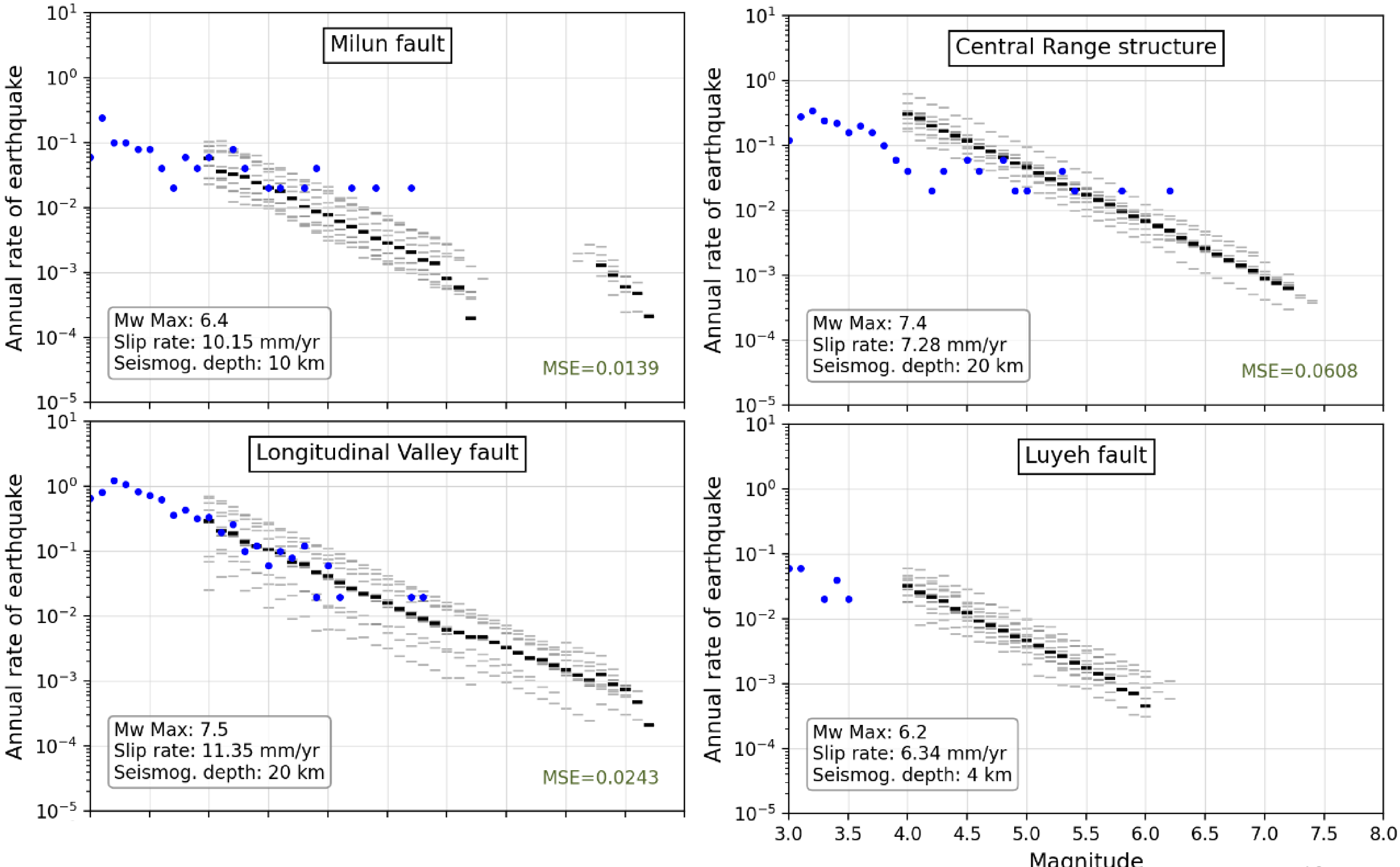
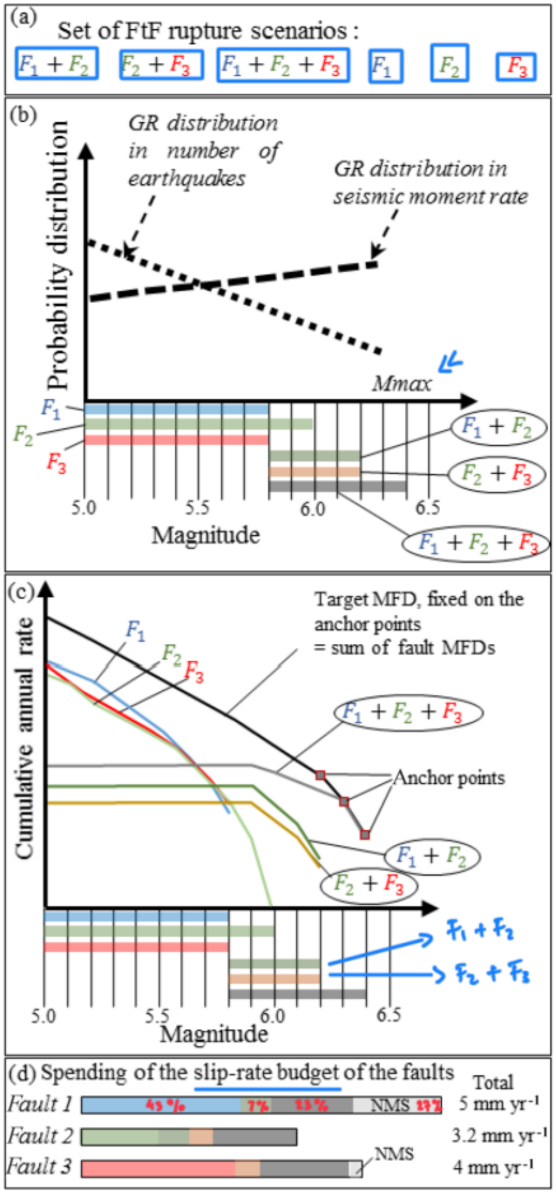


Detailed model for each structure could be quantified



Application of SHERIFS



(a) Set of FtF rupture scenarios.

(b) Picking of the magnitude bins and of the sources.

(c) Building the target MFD: the black curve is the target MFD an-chored at the mean of the three highest magnitude bins (magnitude bin of 0.1). The sum of the resulting MFDs of the six sources has to be equal to the target MFD.

(d) Visualization of the partitioning by the iterative methodology of each fault's slip-rate budget (colors correspond to the individual rupture or the FtF rupture; NMS is non-main-shock slip).

NMS: that faults accommodate important amounts of slip in either post-seismic slip or creep events

Coulomb stress change is controlled by both source and receiver faults

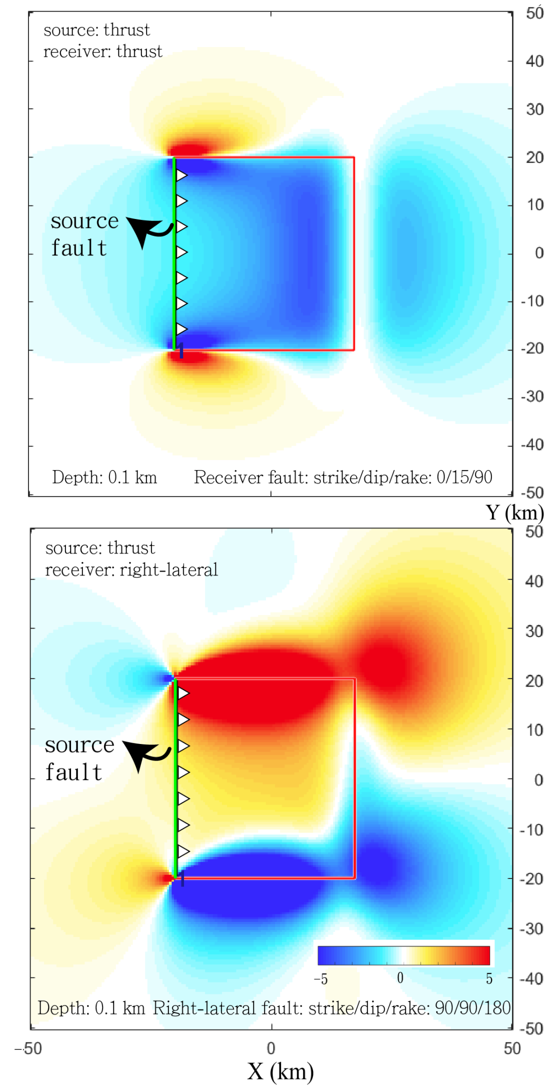
- Focal mechanism of source and receiver fault

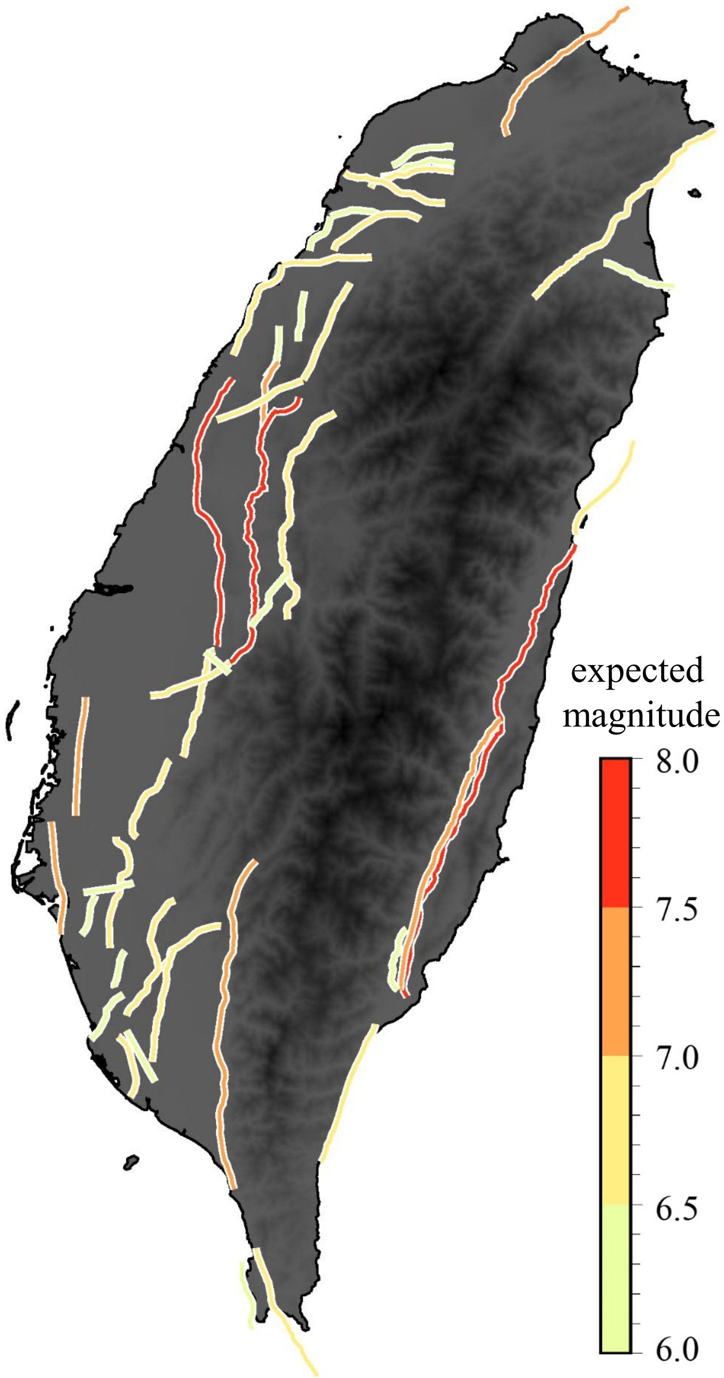
  → distribution of coulomb stress change

- Criteria that faults could trigger each other

  1. Coulomb stress increases greater than 0.1 bar

  2. Distance between two structures is less than 5.0 km





A larger rupture area could result in a large magnitude

The scaling law : *log(A) = e + f * M*

A = structure area, e and f = constants

(Wells and Coppersmith, 1994)

The seismogenic structure parameters were obtained by the Taiwan Earthquake Model.

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4, 8	✓	✓			✓			
6, 8	✓	✓	✓	✓	✓	✓	✓	✓
6, 9	✓	✓	✓	✓	✓			
9, 10	✓	✓	✓		✓	✓	✓	
10, 15	✓	✓	✓	✓	✓	✓	✓	✓
10, 16	✓	✓			✓	✓		
11, 14	✓	✓	✓		✓	✓	✓	
11, 16	✓				✓			
13, 14	✓	✓	✓		✓	✓	✓	
13, 16	✓				✓			
14, 17	✓	✓			✓	✓		
15, 16	✓				✓			
16, 19	✓	✓			✓	✓		
16, 20	✓				✓			
16, 40	✓							
17, 19	✓				✓			
17, 20	✓				✓			
17, 40	✓							
19, 22	✓	✓	✓	✓	✓			
20, 21	✓	✓	✓		✓	✓	✓	
21, 41	✓	✓	✓		✓			
22, 23	✓	✓	✓	✓	✓	✓	✓	✓
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24, 41	✓				✓			
26, 45	✓	✓	✓	✓	✓	✓	✓	✓
27, 42	✓	✓			✓	✓		
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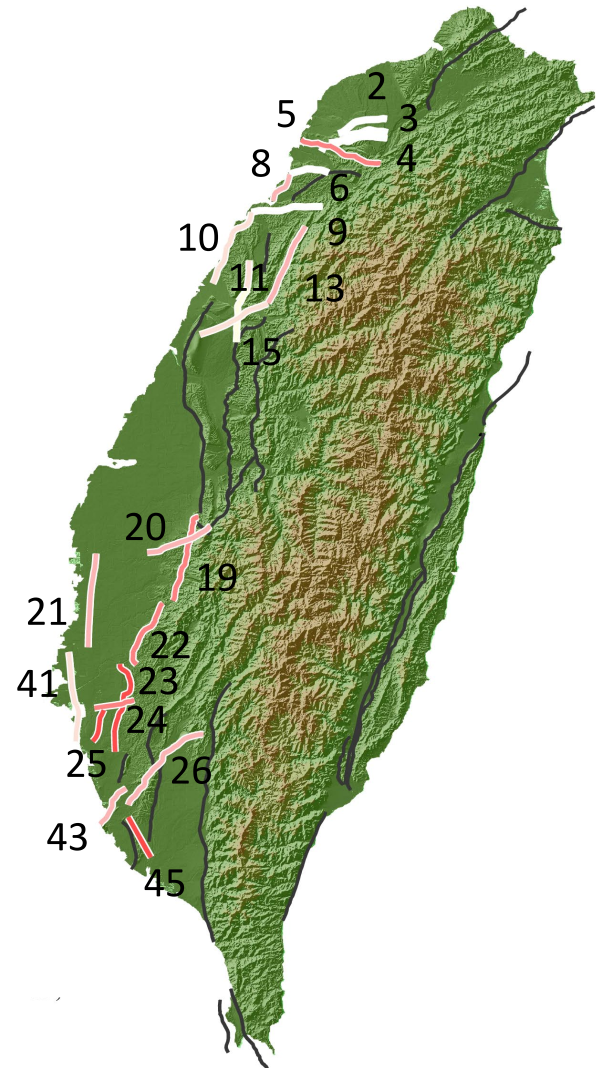
Paring uncertainties could come from ***structure gap*** & ***ΔCFS triggering threshold***



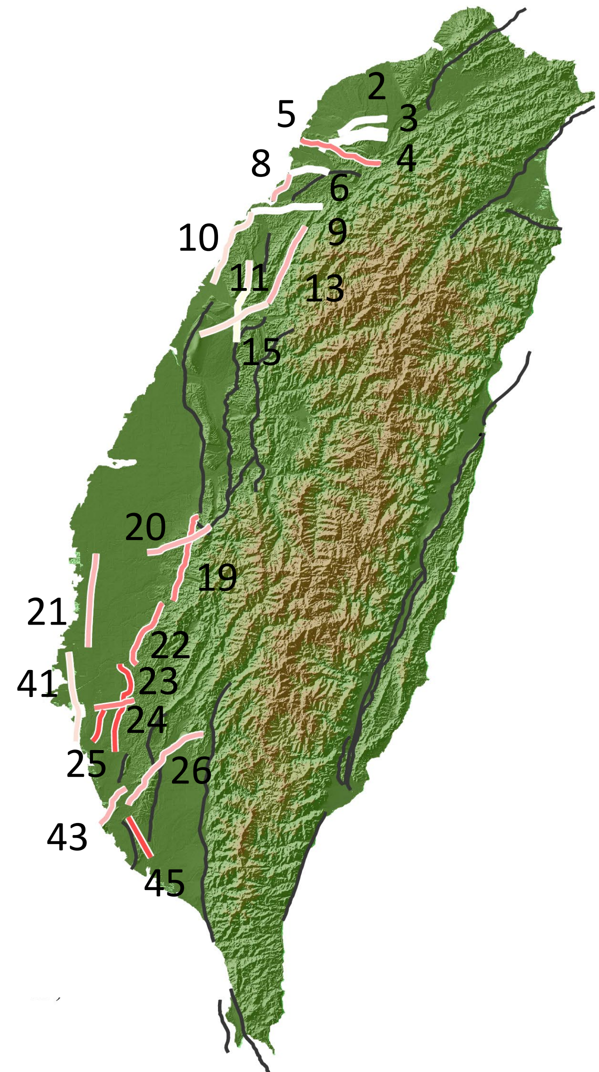
Paring uncertainties could come from ***rake angle orientation of receiver structures***

Rake angle rotation	+10°	-10°	+20°	-20°
	2 3	2 3	2 3	2 3
	2 4	2 4	2 4	2 4
	4 5	4 5	4 5	4 5
	4 6	4 6	4 6	4 6
	6 8	6 8	6 8	6 8
Paired structures at each specific rake condition	6 9	6 9	6 9	6 9
	9 10	9 10	9 10	9 10
	10 15	10 15	10 15	10 15
	11 14	11 14	11 14	11 14
	13 14	13 14	13 14	13 14
	19 22	19 22	19 22	19 22
	20 21	20 21	20 21	20 21
	21 41	21 41	21 41	21 41
	22 23	22 23	22 23	22 23
	24 25	24 25	24 25	24 25
	26 45	26 45	26 45	26 45
	43 45	43 45	43 45	43 45
Number of pair	16	15	13	11

Paired structures at the condition

Not paired structures at the condition

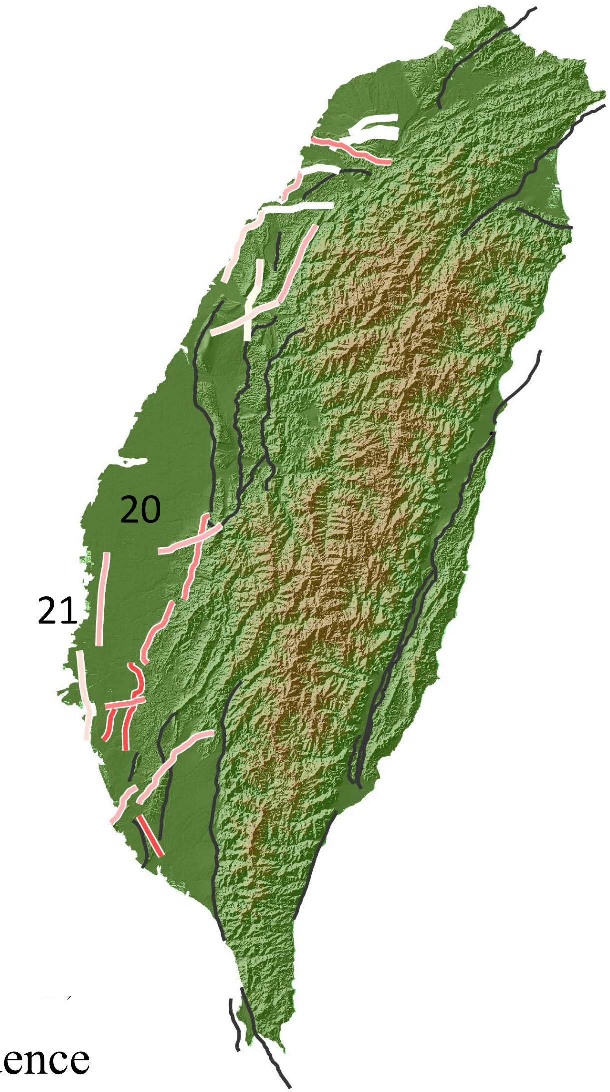
Number of pairs without rake angle rotation: 17



Variations of ***rupture magnitude*** & ***recurrence interval*** could be assessed considering ***rupture area*** & ***slip rate*** uncertainties

Magnitude	Min rate	Mean rate	Max rate
7.14	2104	1251	345
7.29	2722	1553	409
7.48	3871	2097	527

in *year*



Magnitude determined by combined rupture area

Recurrence interval $= \frac{Slip}{Slip\ rate}$

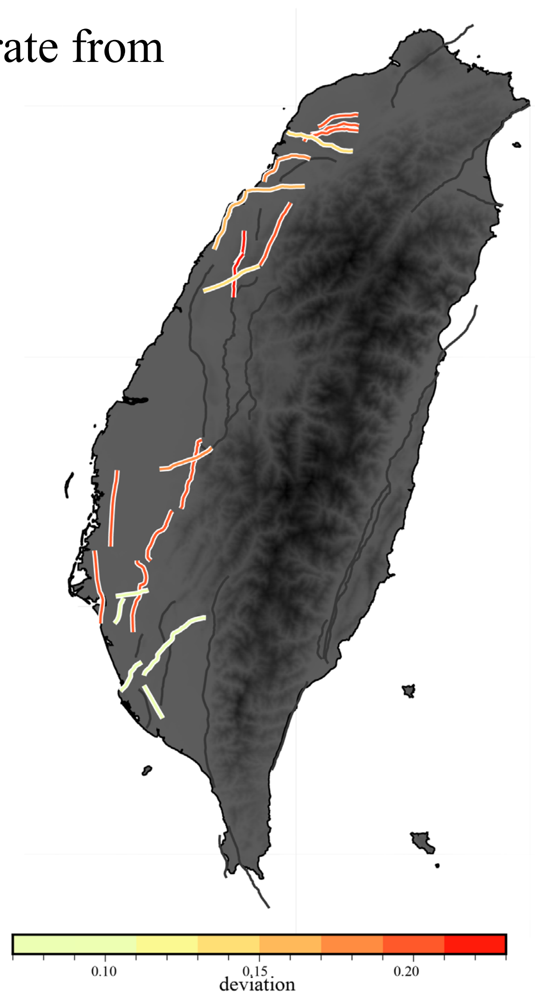
Slip rate uncertainty based on geomorphological evidence

Uncertainties of magnitude and recurrence interval could be quantified and contribute to determination of a ***logic tree approach*** in a PSHA

- Deviation of rupture area and slip rate from the TEM database.
- Magnitude deviation:
  - $\frac{M_{max}-M_{min}}{2}$
- Recurrence interval deviation:
  - $\frac{R_{max}-R_{min}}{R_{mean}} \times 100\%$

The uncertainties from other factors were examined and showcased in our paper:

Magnitude (Mw) Deviation



Recurrence interval deviation