Near-real time earthquake forecasting and short-term earthquake forecasting and probabilistic seismic hazard assessment for Taiwan

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PSHA in Christchurch

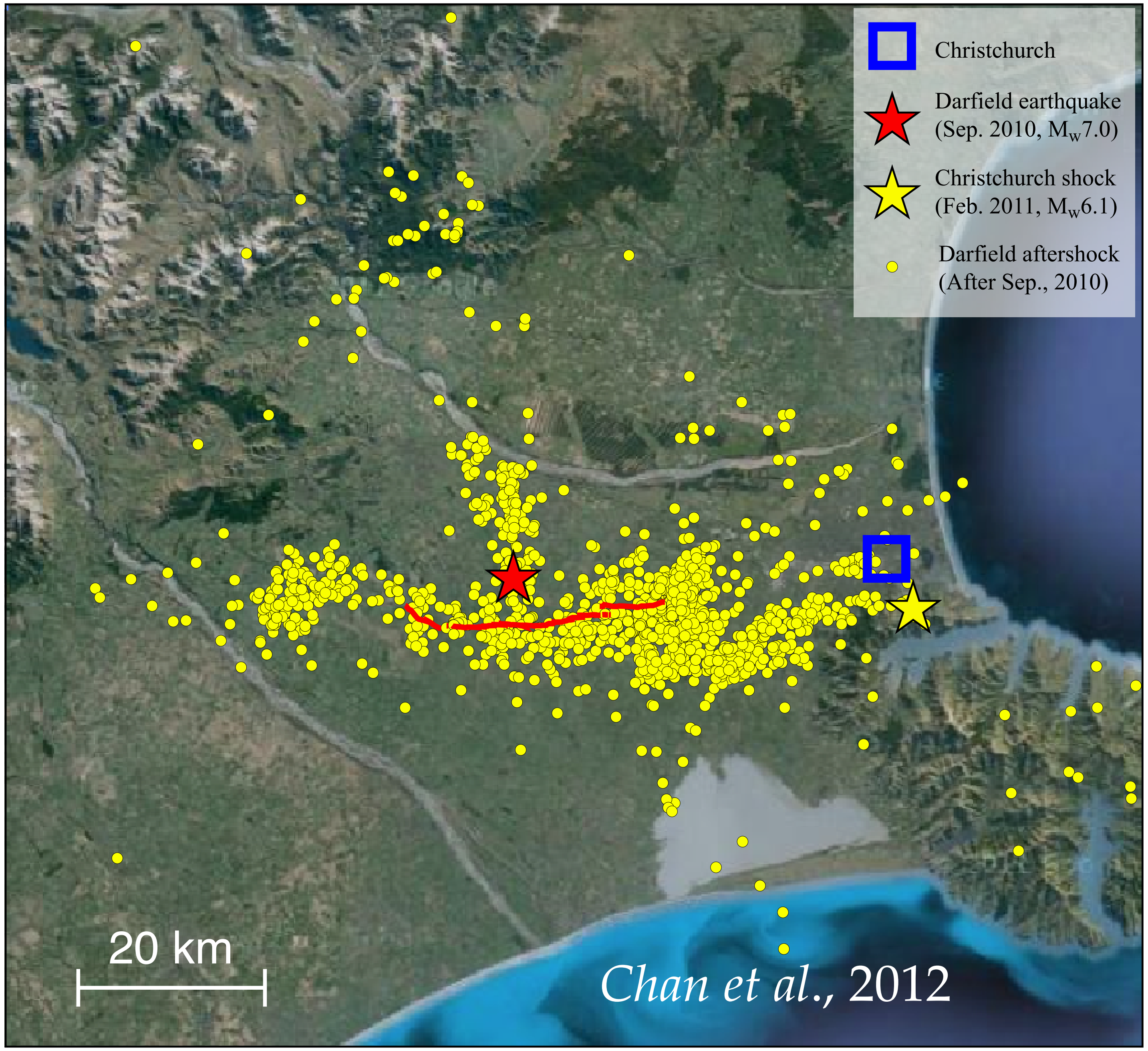
Any alert before the Feb. 21st, 2011 Christchurch eq?


Cathedral of the Blessed Sacrament


Canterbury TV building


ChristChurch Cathedral

Darfield sequence....



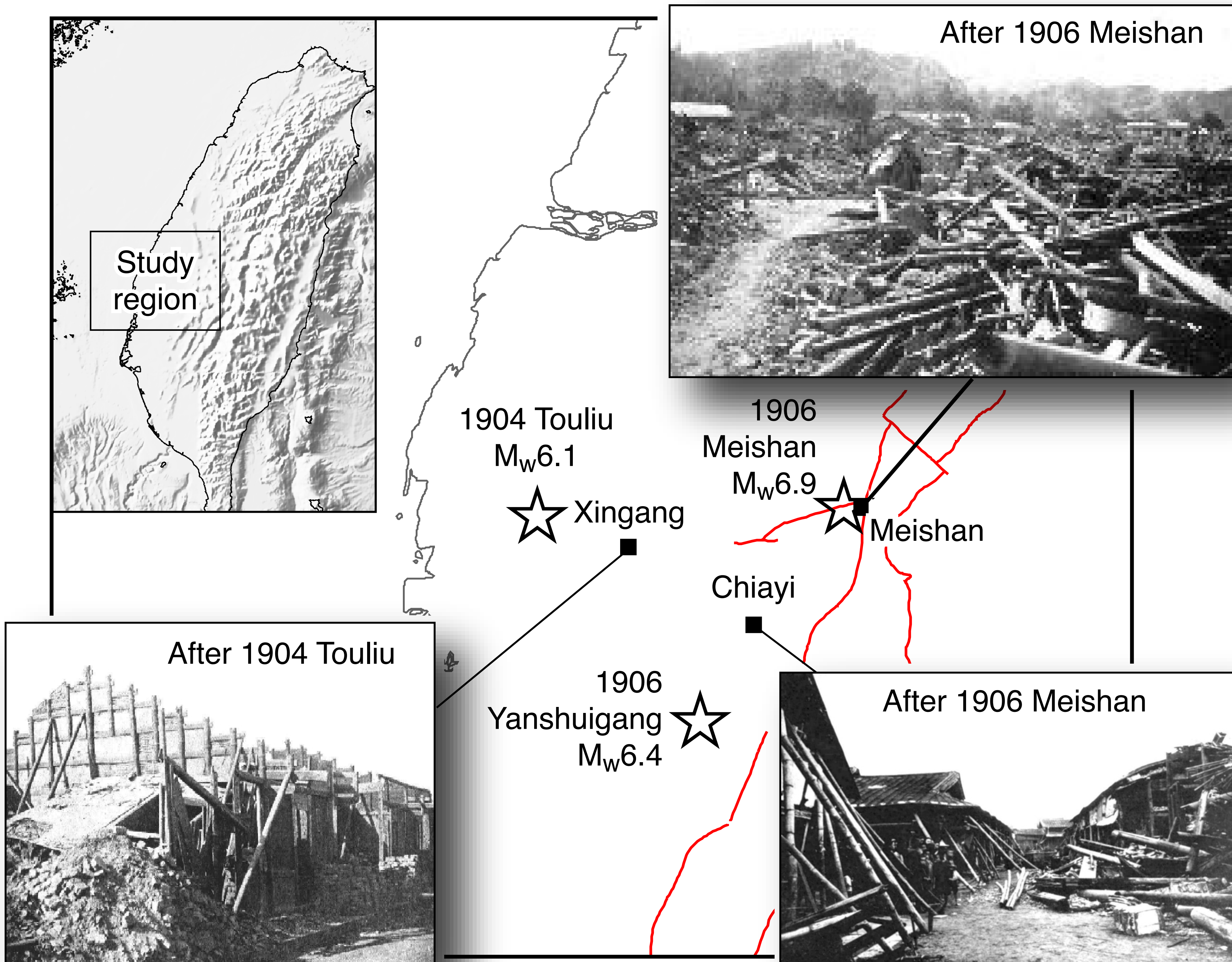
- ***Christchurch*** eq. can be regarded as a aftershock in the ***Darfield*** sequence
- ***Larger*** ground shaking by aftershock due to ***shorter*** epicentral distance

Importance of ***consequent events*** to seismic hazard evaluation

Earthquake	Distance to Christchurch	PGA in Christchurch
2010 Darfield	40 km	0.30 g
2011 Christchurch	5 km	1.88 g

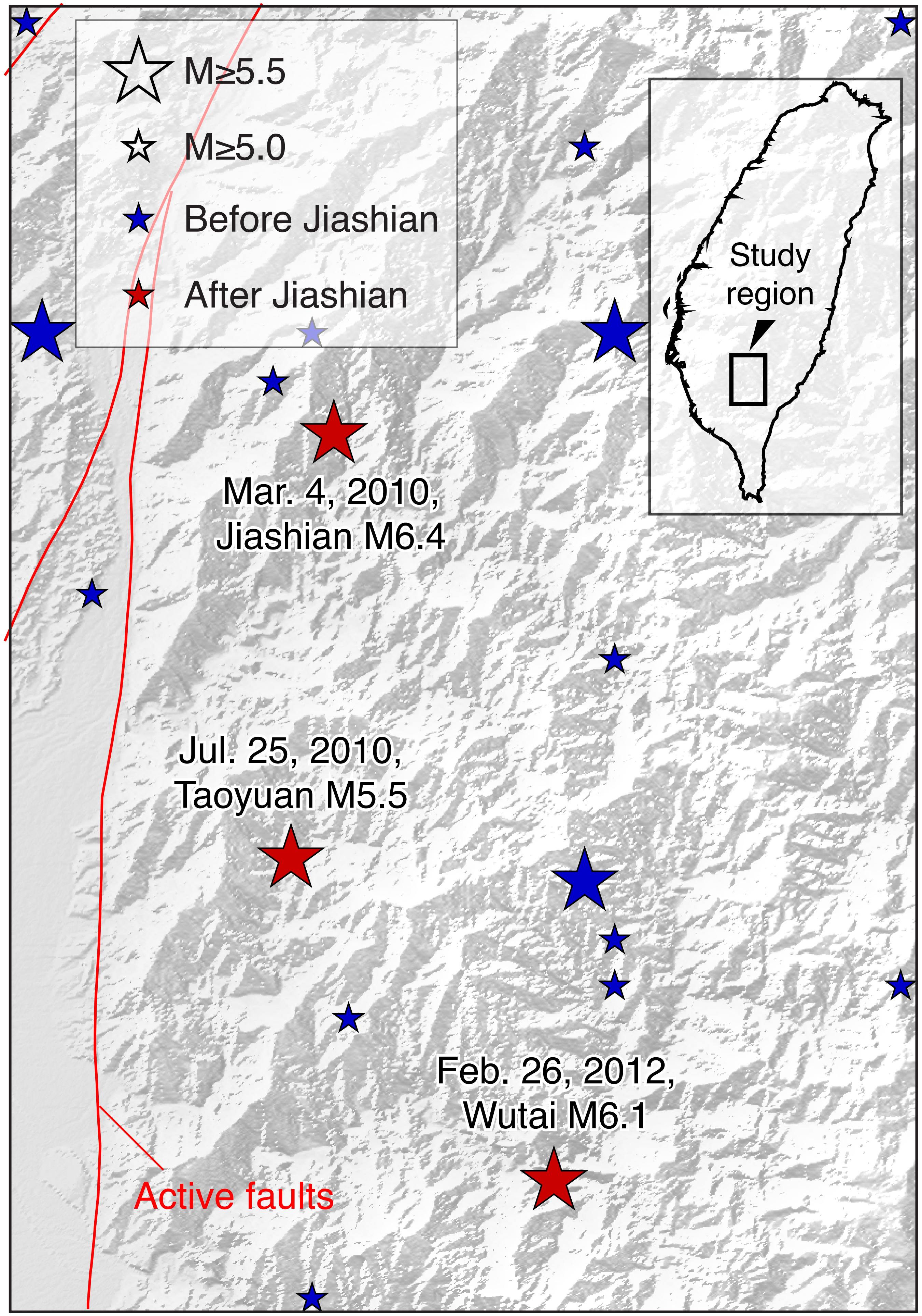
Meishan case…

All the three events in the Meishan sequence caused casualties in the Chiayi region



After *Cheng et al.*, 2012

Jiashian case…



Higher seismicity rate after Jiahsian

Before Jiashian:

M≥5.5 events: 3 (0.03 event/year)

M≥5.0 events: 12 (0.11 event/year)

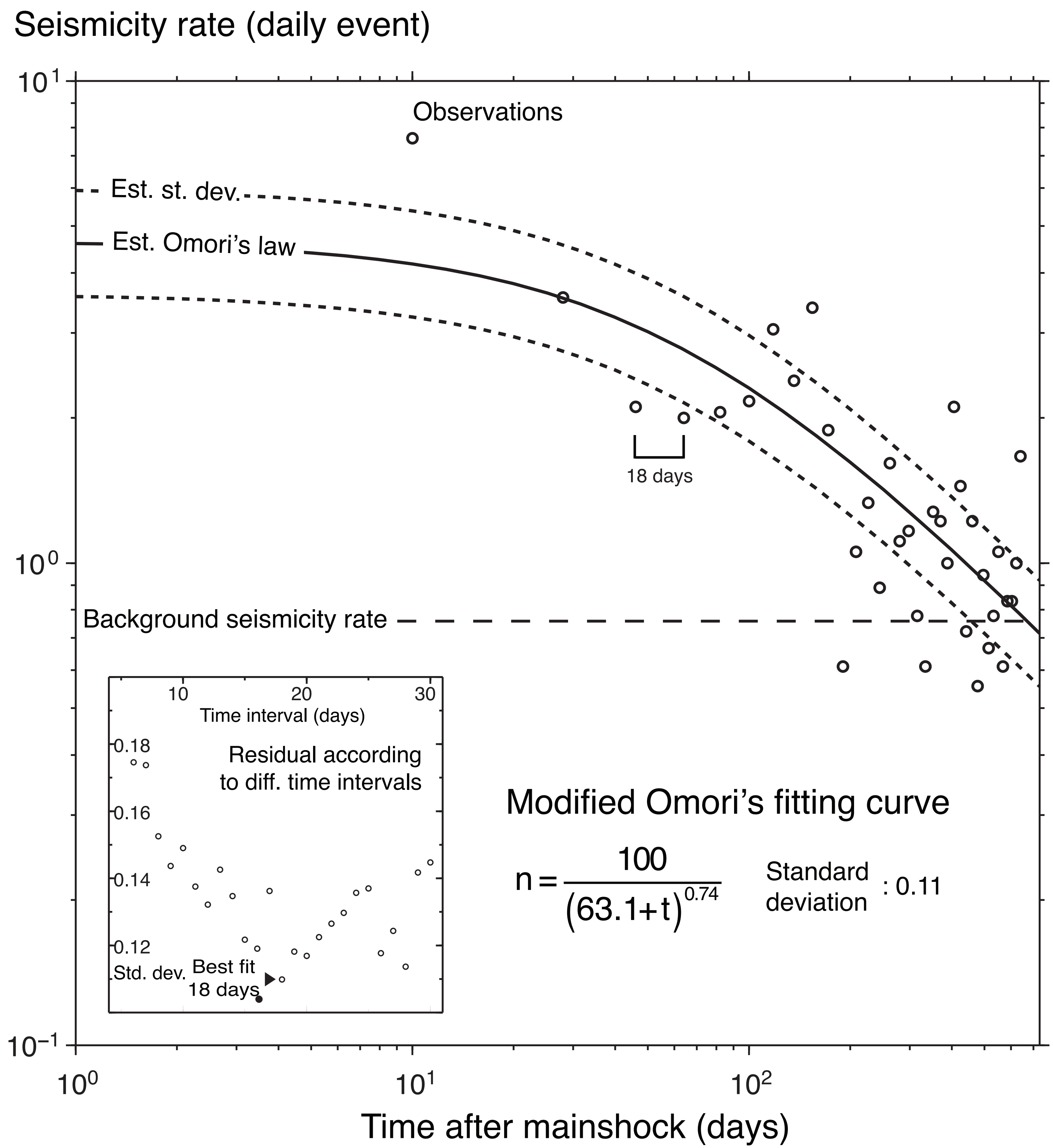
After Jiashian:

M≥5.5 events: 3 (1.00 event/year)

M≥5.0 events: 3 (1.00 event/year)

Chan & Wu, 2012

Omori decay.....



Taoyuan occurred within the decay period

Wutai occurred within the deviation of decay pattern

Back to background: ***670*** days
+1 st. dev.: ***970*** days

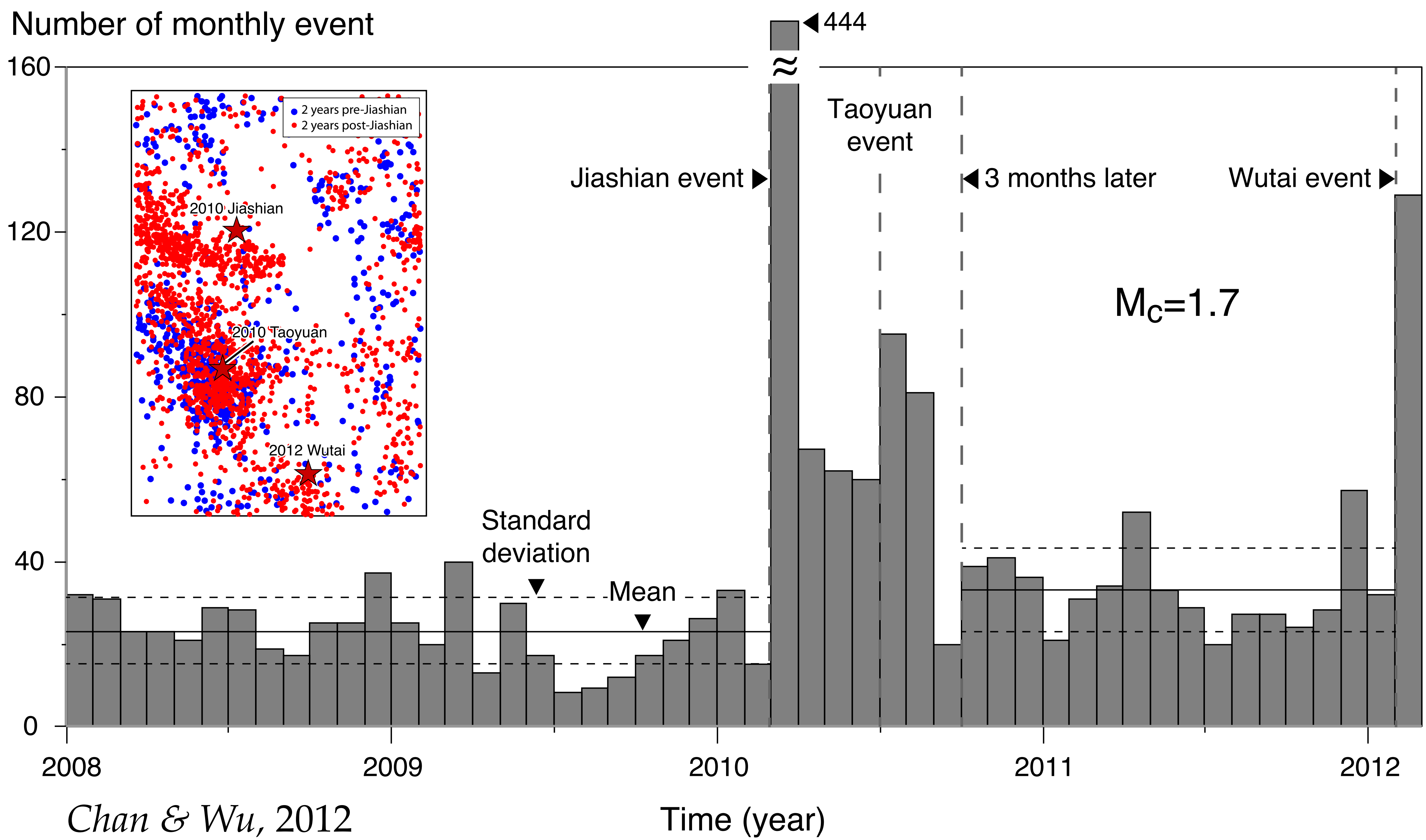
Jiashian-Taoyuan: ***143*** days
Jiashian-Wutai: ***724*** days

Chan & Wu, 2012

Time series.....

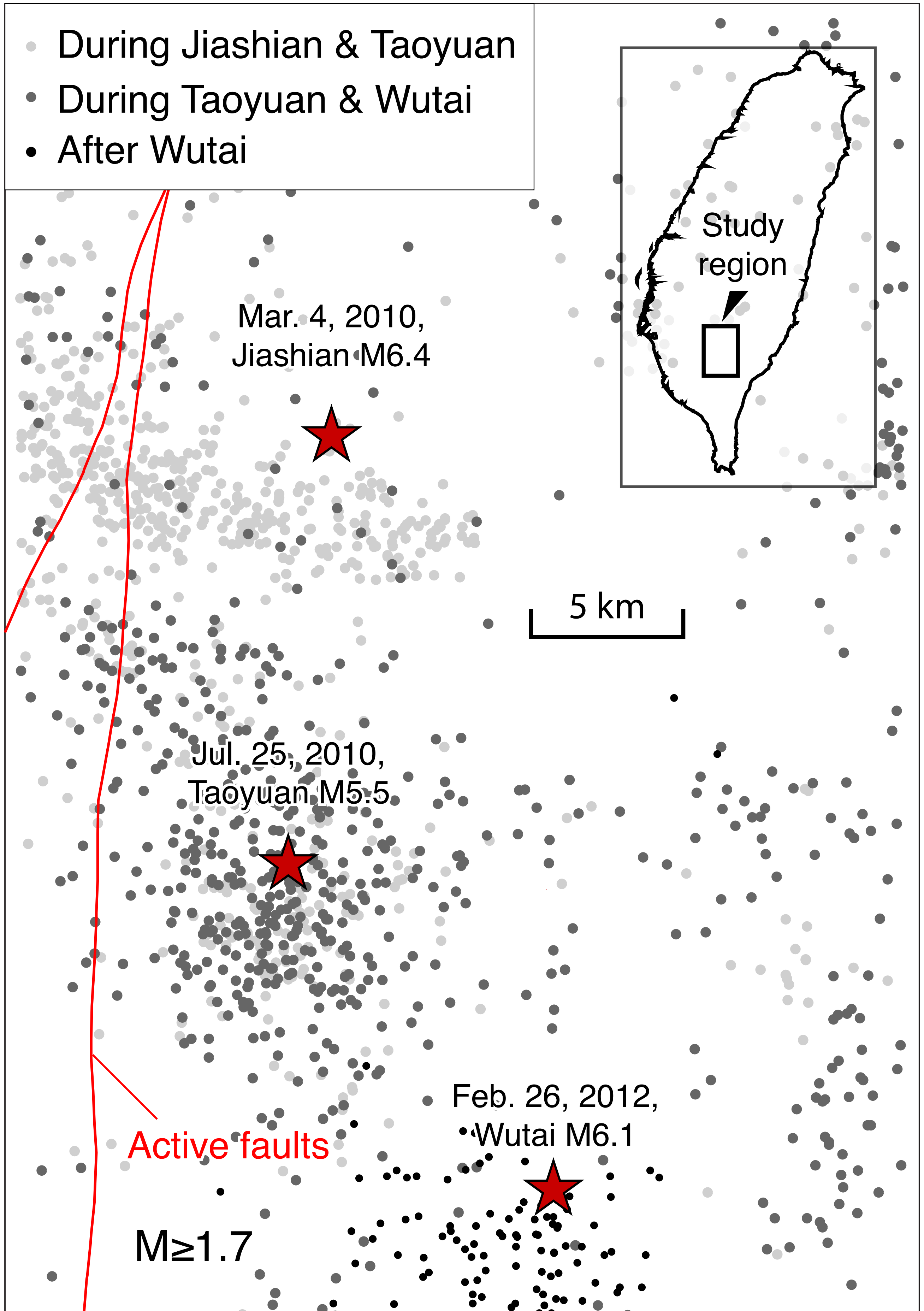
Seismicity rate becomes ***higher*** after the Jiashian earthquake

Omori's decay cannot explain the ***stationary*** rise of seis. rate



Chan & Wu, 2012

Spatial evolution....



Seismicity activity migrates to the ***south***

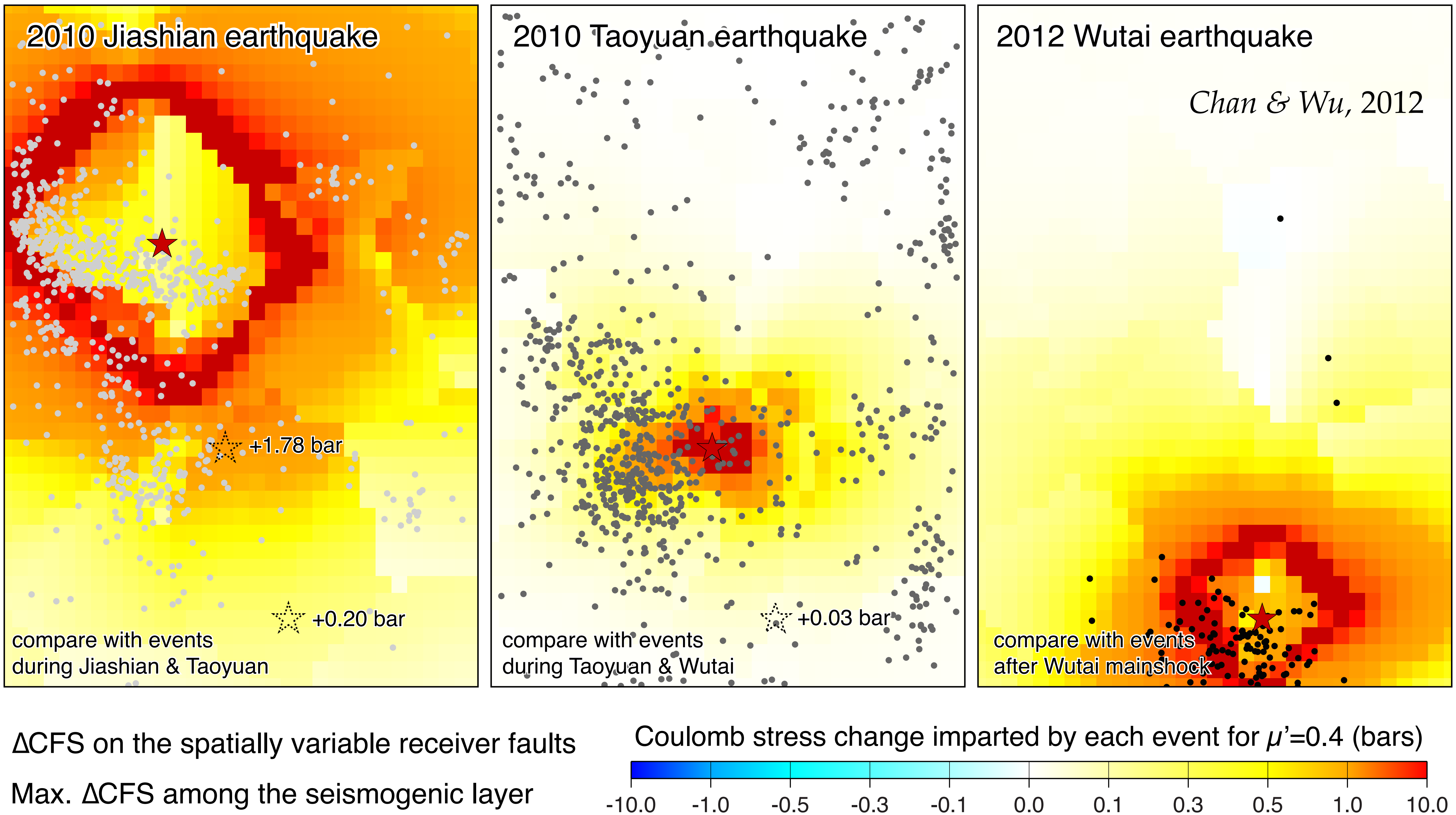
The three large events are ***thrust***

Insignificant correlation between seismicity and active faults (*red lines*)

Outlines of the our approach

- Short-term seismicity rate evolution
  - Coulomb stress change
  - Rate-and-state friction model
- Long-term and short-term PSHA
- Applications
  - The Jiashian sequence during 2010-2012
  - The Meishan sequence during 1904-1906
  - The Hualien City during 2006-2010

Jiashian earthquake ***promotes*** the occurrence of Taoyuan
Both Jiashian & Taoyuan ***promote*** the occurrence of Wutai

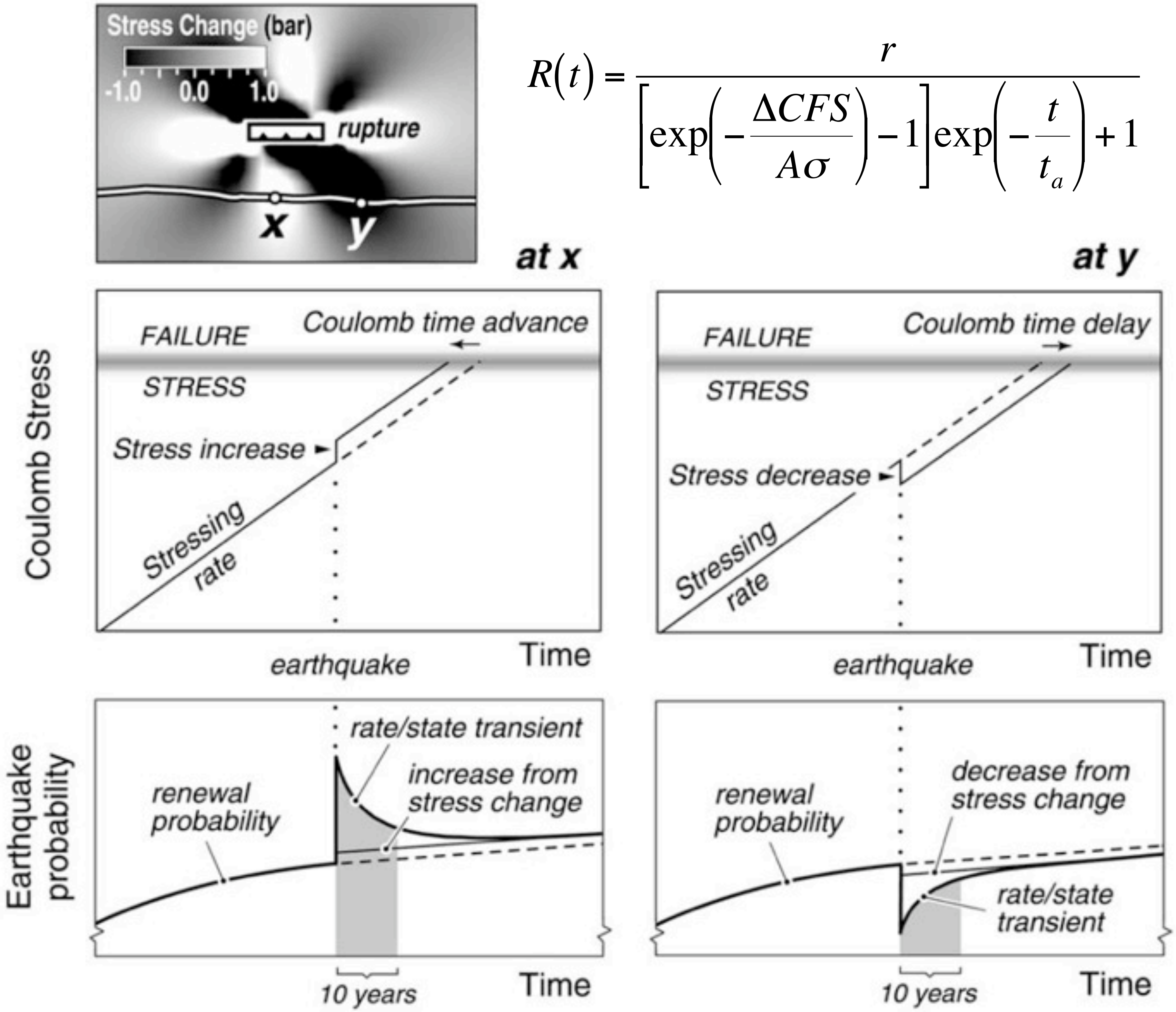


Southward migration of the seismicity can be associated with ***ΔCFS evolution***

rate/state.....

Rate-and-state friction model (*Dieterich*, 1994)

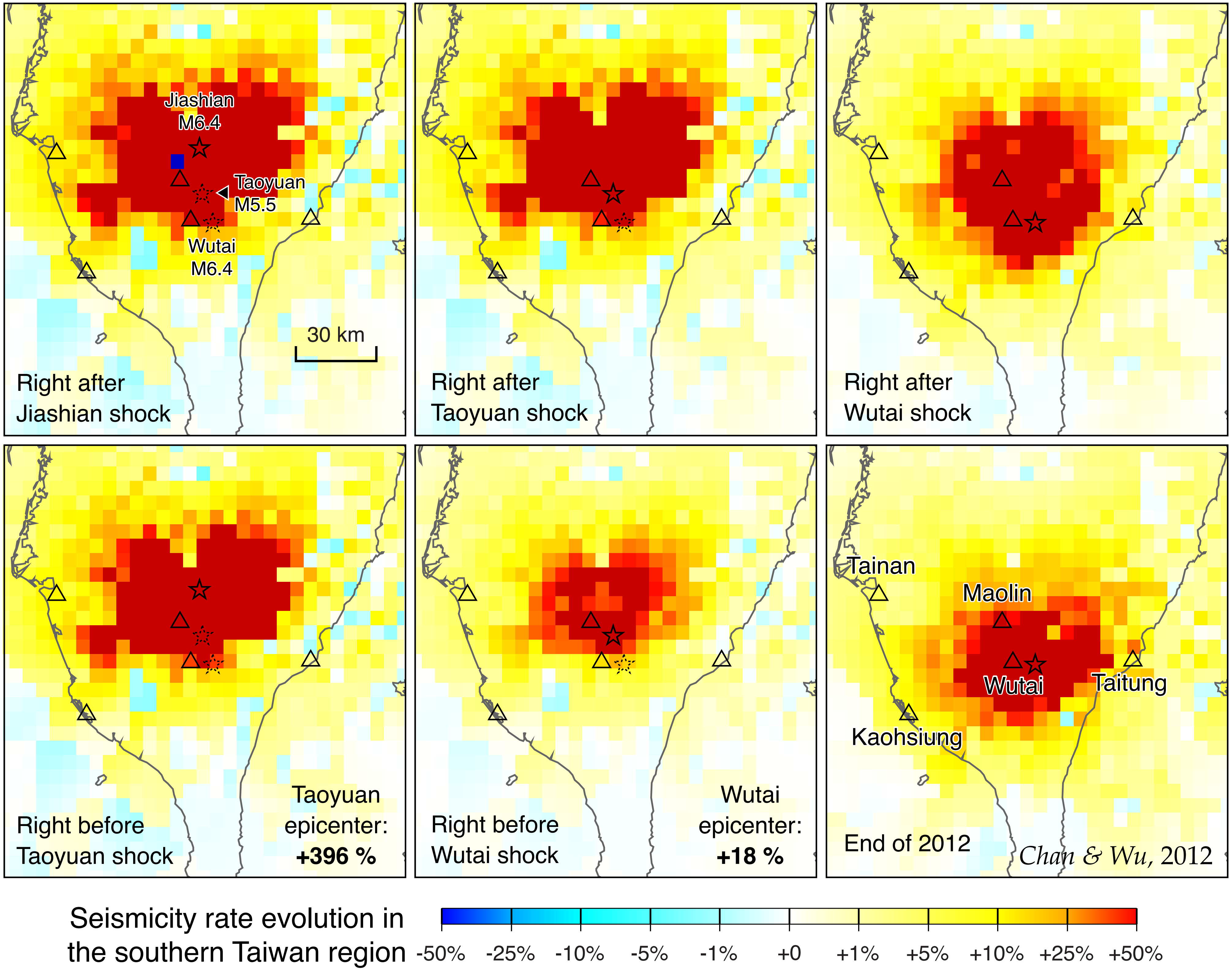
$$R(t) = \frac{r}{\left[\exp\left(-\frac{\Delta CFS}{A\sigma}\right)-1\right]\exp\left(-\frac{t}{t_a}\right)+1}$$



ΔCFS by Jiashian seq.....

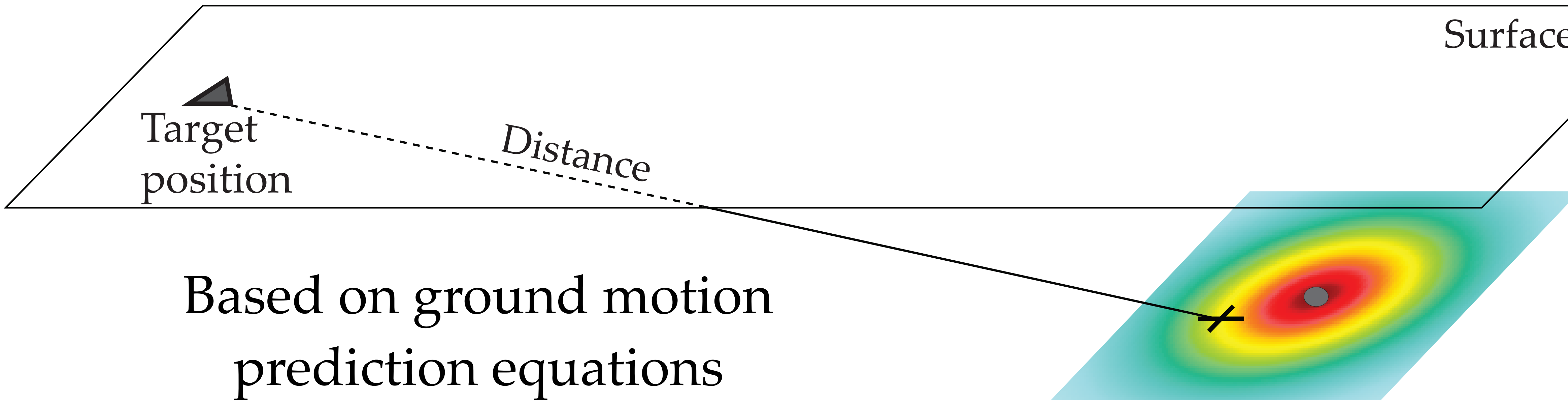
Illustrated by *Toda & Stein*, 2003

Higher rate is expected near epicenters
Consequent events can be *forecasted*



GMPEs.....

Considering ***ground motion prediction equations*** for probabilistic seismic hazard assessment



Based on ground motion prediction equations

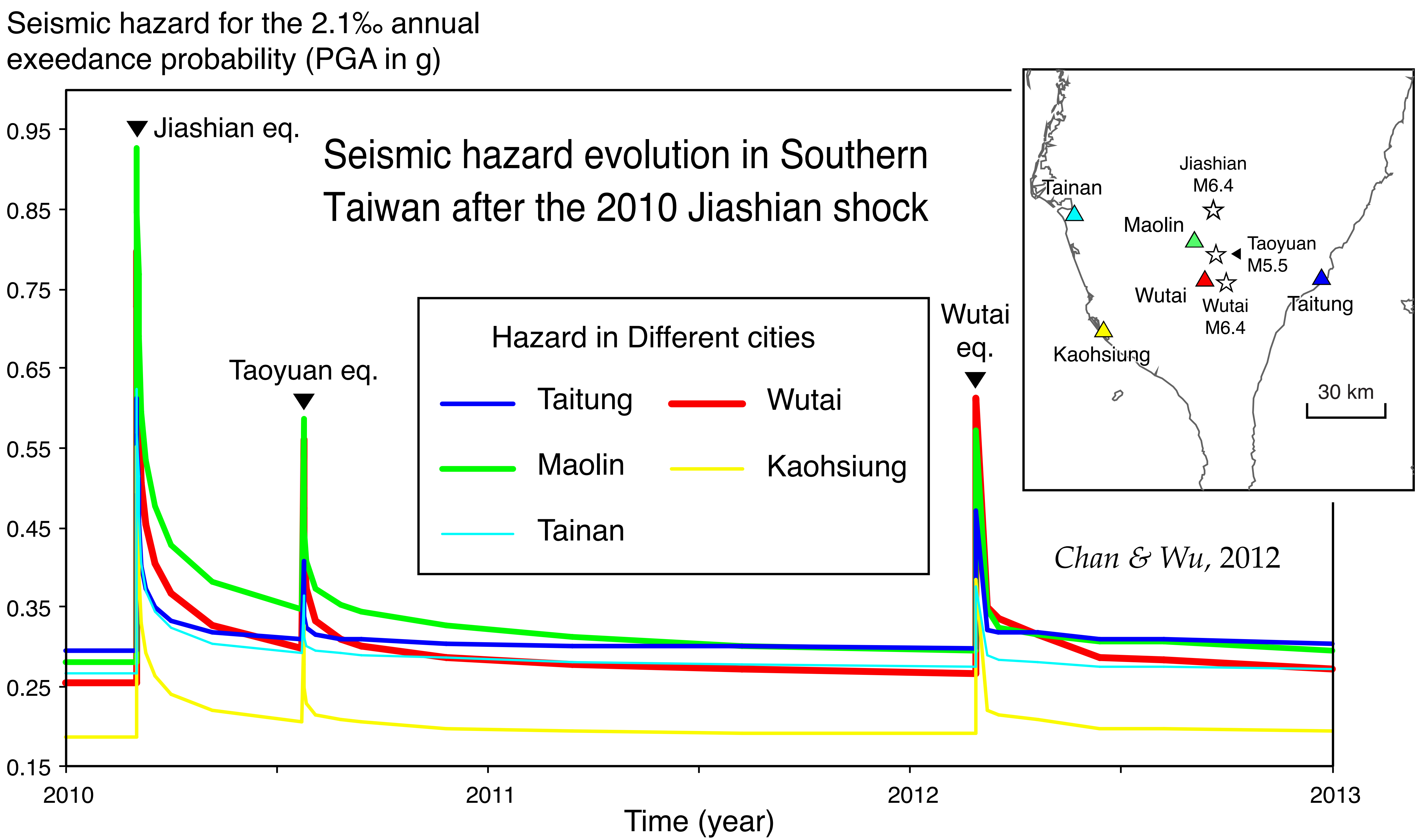
Ground motion prediction equations used in this study:

Crustal events	$\ln y = -2.5 + 1.205 M_W - 1.905 \ln\left(R + 0.51552 \exp\left(0.63255 M_W\right)\right) + 0.0075 H$	Lin & Lee, 2008
Interface events	$\ln y = -0.9 + 1.0 M_W - 1.9 \ln\left(R + 0.99178 \exp\left(0.52632 M_W\right)\right) + 0.004 H$	Lin, 2009
Intraslab events	$\ln y = -0.9 + 1.0 M_W - 1.9 \ln\left(R + 0.99178 \exp\left(0.52632 M_W\right)\right) + 0.004 H + 0.31$	Lin, 2009

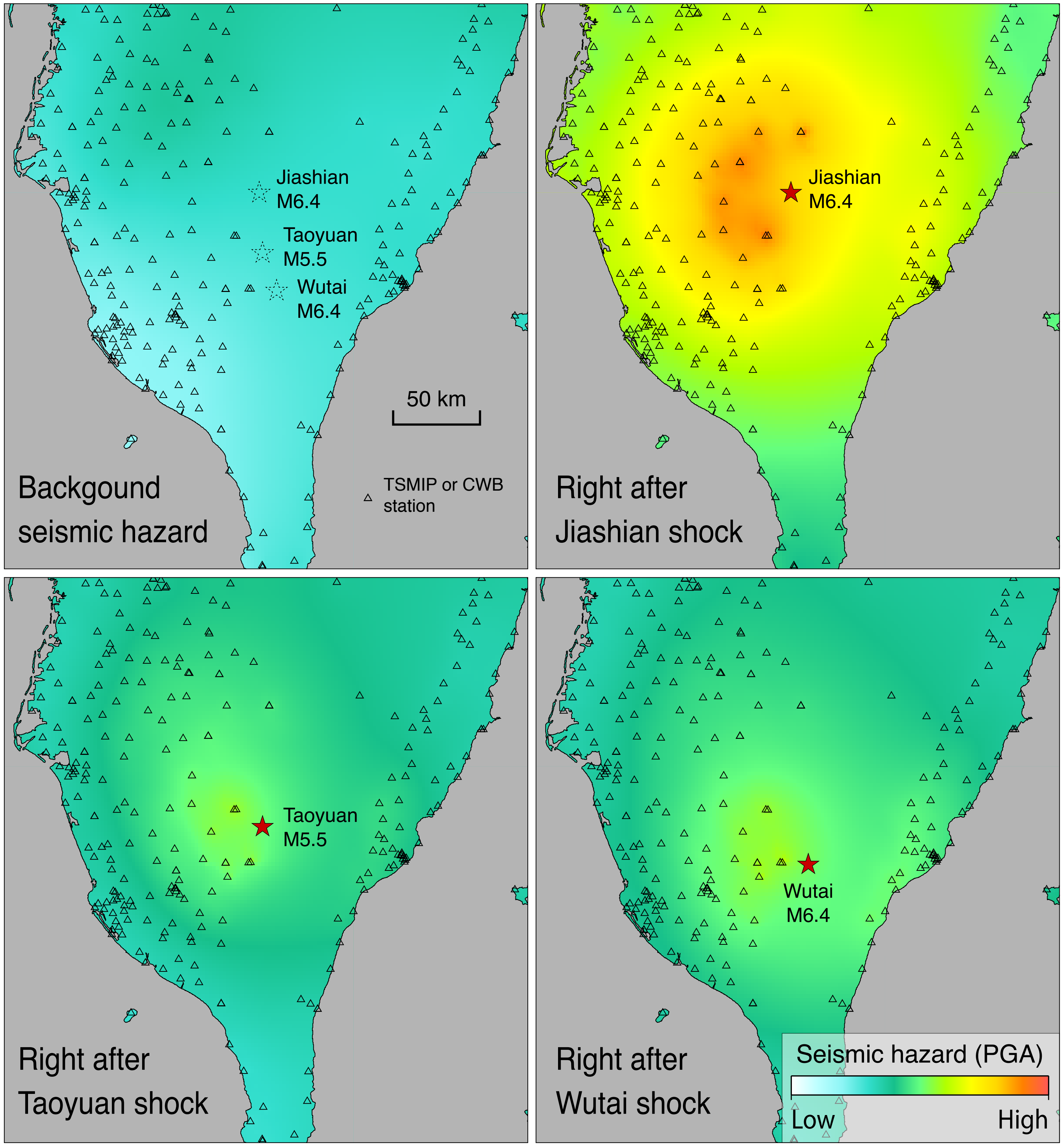
R: distance to the site; H: hypocentral depth

seismic hazard evolution.....

Higher seismic hazard is evaluated after occurrence of each large earthquake



hazard maps....

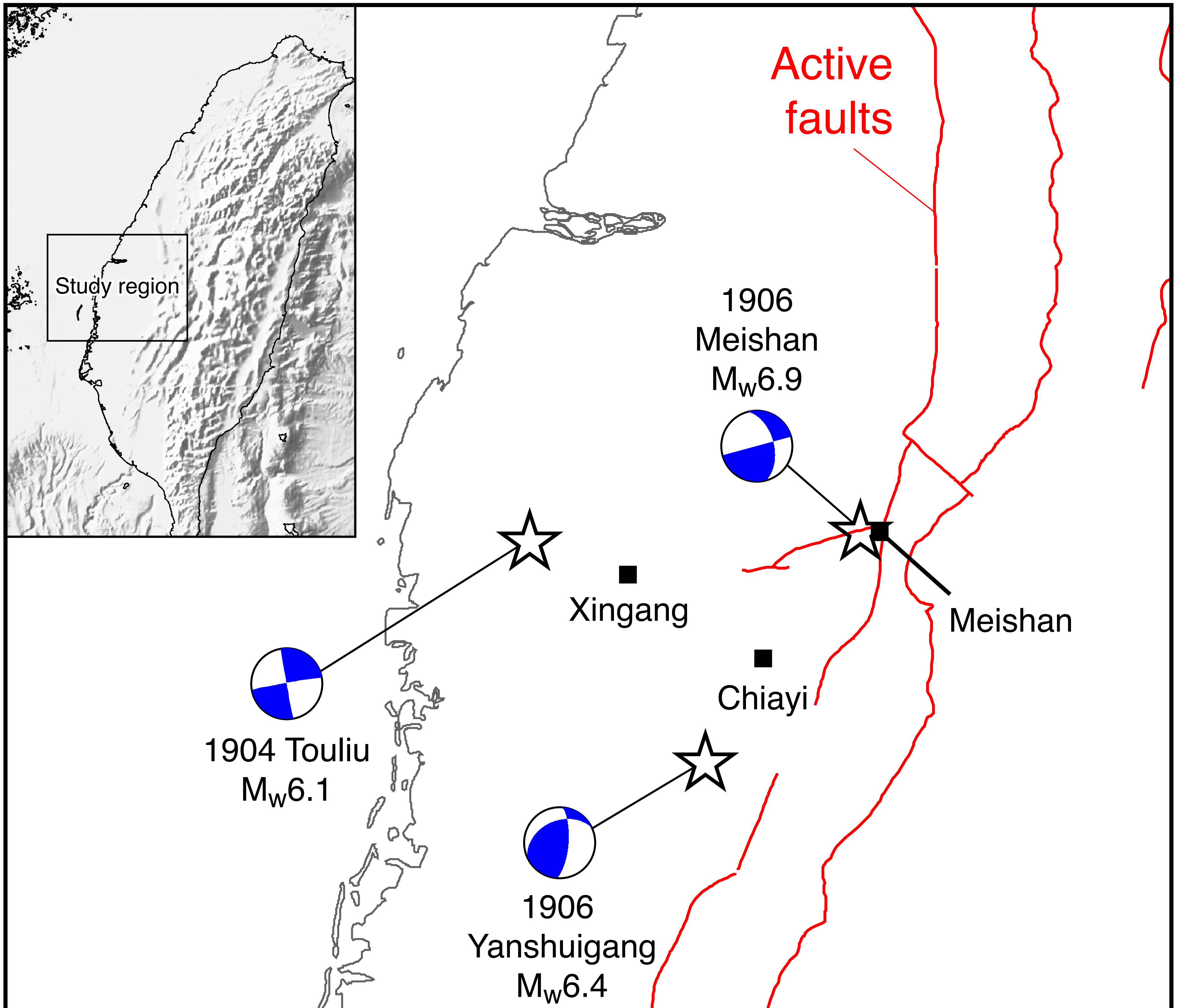


Chan & Wu, 2012

Higher seismic hazard is evaluated after occurrence of each large earthquake

Meishan scenario....

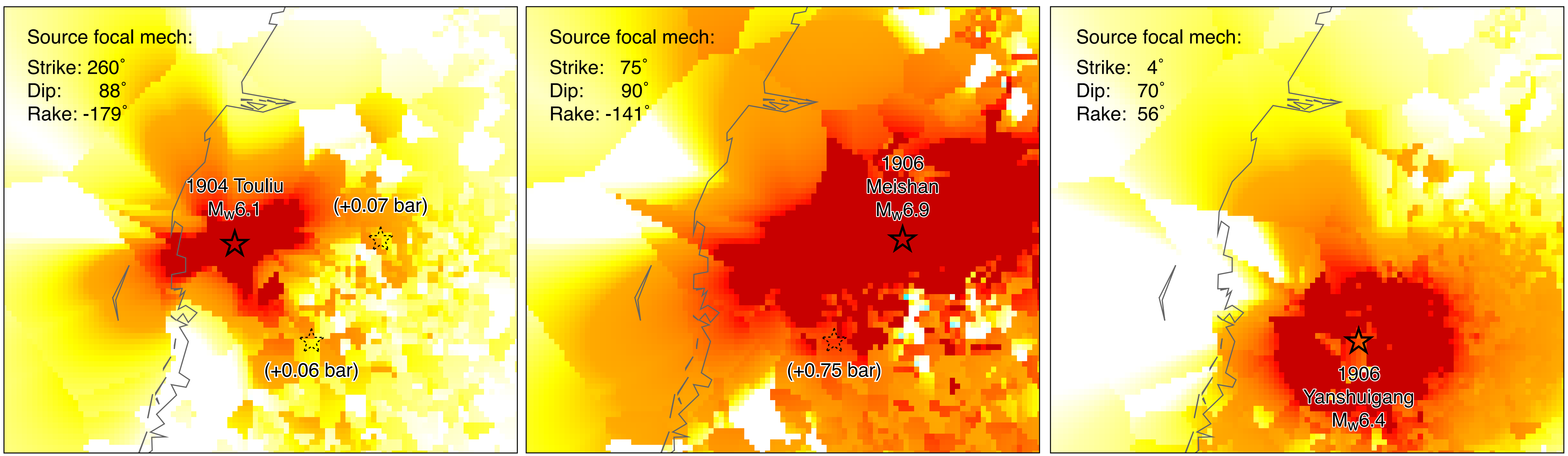
Are the three earthquakes relative?



ΔCFS....

Significant ΔCFS *increase* close to each epicenters
Triggering interactions of the sequence is proved

ΔCFS imparted by the three events of the Meishan sequence

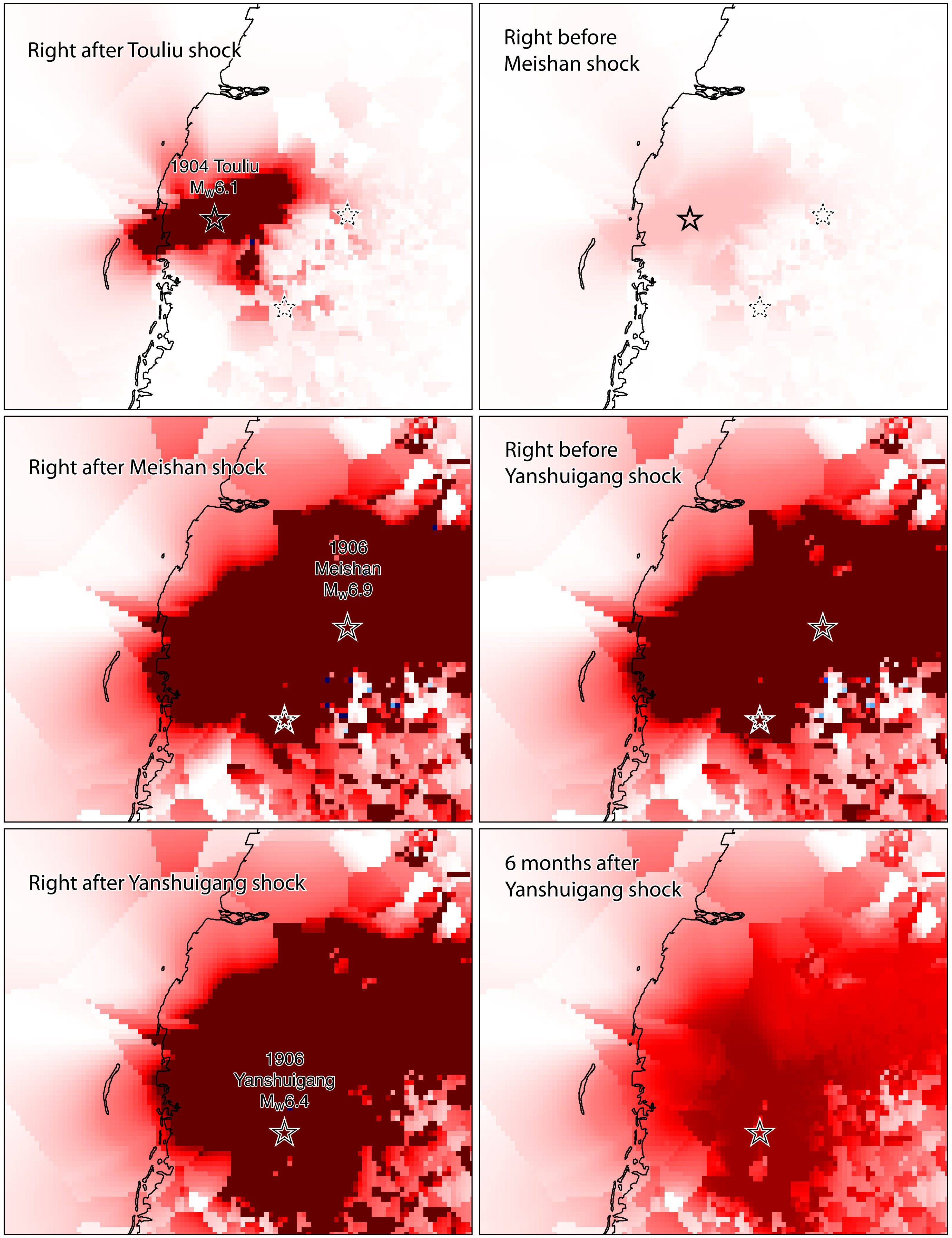


ΔCFS solved on patial variable receiver fault

Max. ΔCFS among the seismogenic layer (0-30 km depth)

ΔCFS by each event of the Meishan sequence for μ'=0.4 (bar)

rate/state.....

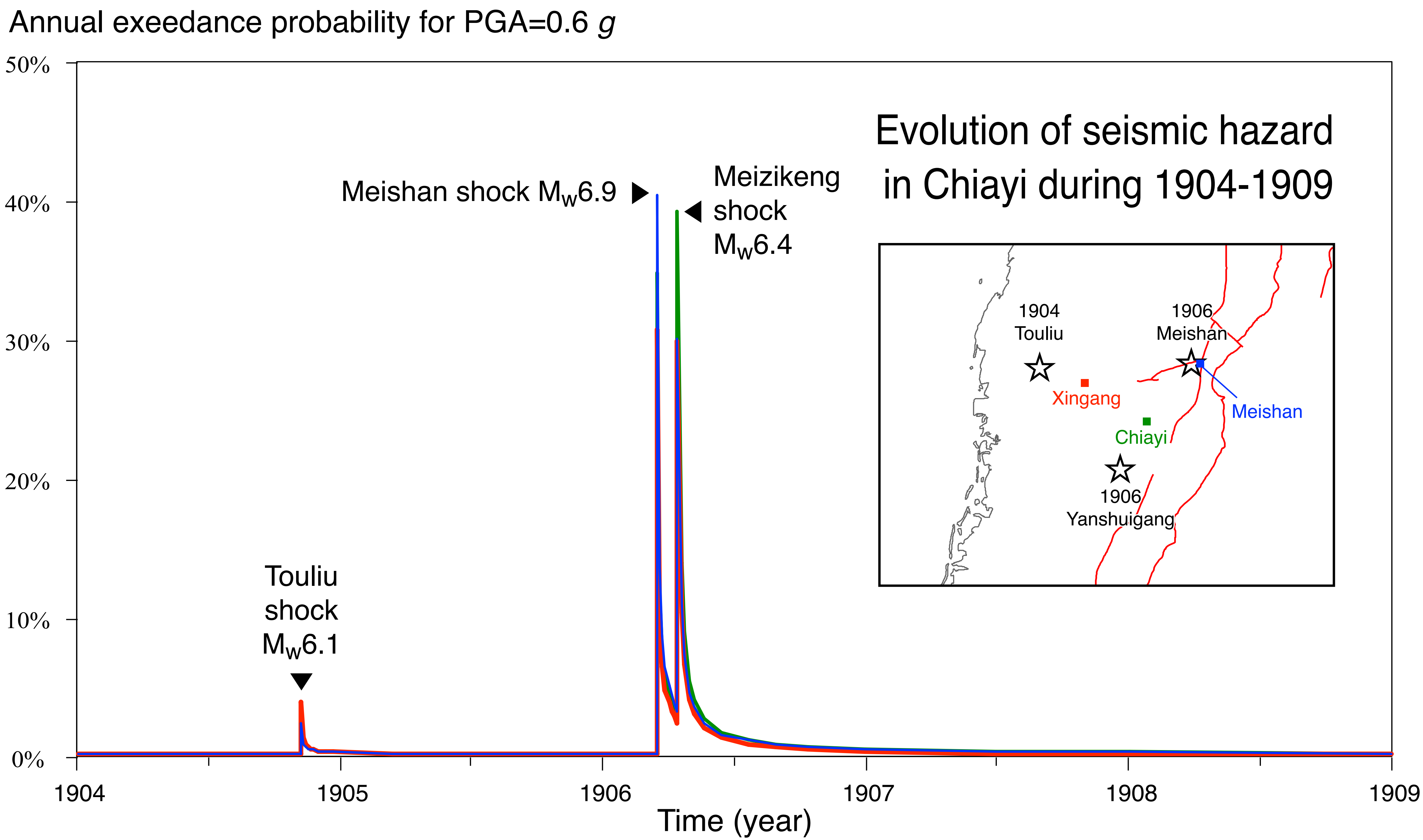


Seis. rate evolution at different time points

Larger events cause *longer* and *higher* rate perturbations

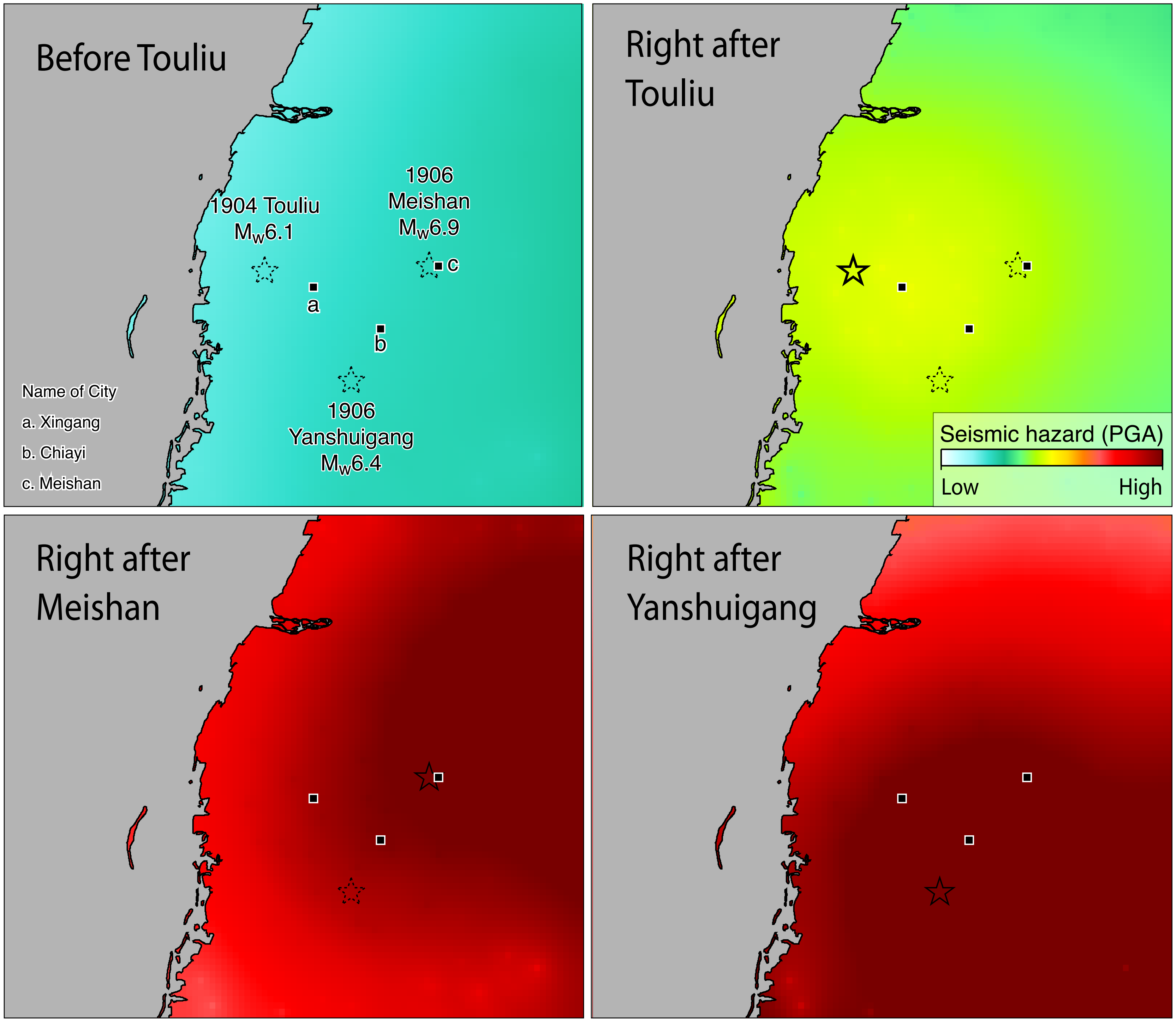
PSHA.....

Higher hazard after each earthquake
Higher hazard in the neighboring city



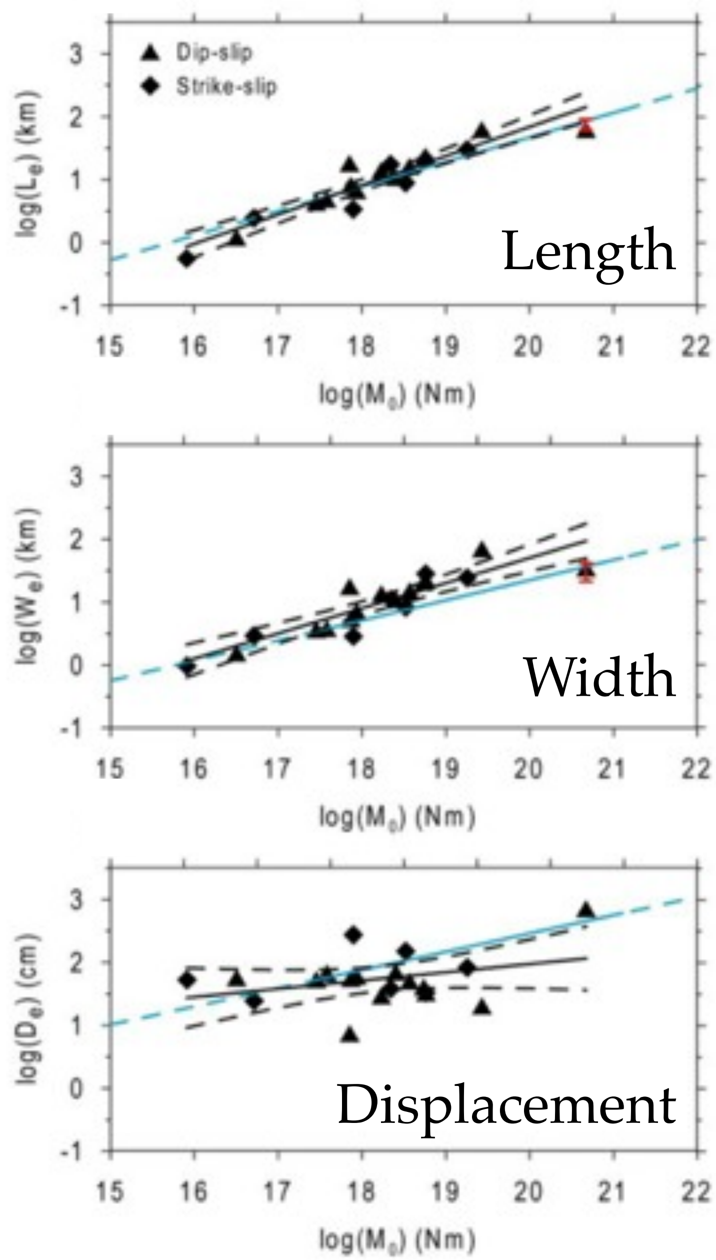
hazard maps....

Higher seismic hazard following occurrence of each large earthquake



TW forecast....

Short-term earthquake forecasting



After *Yen & Ma*, 2011

Acquirement of source slip model for each earthquake based on the ***scaling law***

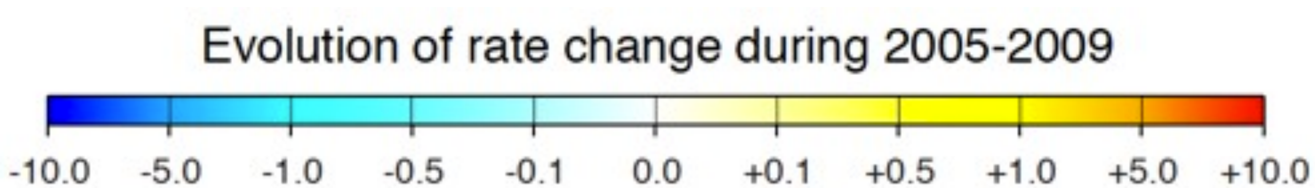
No.	Year	Month	Day	Longitude(˚)	Latitude (˚)	M_L	Depth (km)	Strike (˚)	Dip (˚)	Rake (˚)
1	2006	3	9	120.56	23.64	5.1	13	20	46	52
2	2006	4	1	121.12	22.83	6.2	22	92	70	165
3	2006	6	5	122.05	21.38	5.0	46	205	28	130
4	2006	12	26	120.39	21.95	7.0	30	144	26	-12
5	2007	1	25	122.02	22.65	6.2	20	241	71	-179
6	2007	7	23	121.72	23.67	5.8	29	32	17	91
7	2008	3	4	120.72	23.21	5.2	20	358	43	61
8	2008	12	23	120.57	22.95	5.3	18	326	41	84
9	2009	5	26	119.52	21.73	5.7	47	314	18	174
10	2009	11	5	120.72	23.79	6.2	22	230	57	145
11	2009	12	19	121.75	23.78	6.9	41	238	37	121
12	2010	2	26	122.84	23.60	5.8	44	201	34	98
13	2010	3	4	120.73	23.00	6.4	18	318	41	68
14	2010	7	9	122.66	24.66	5.8	116	216	61	20

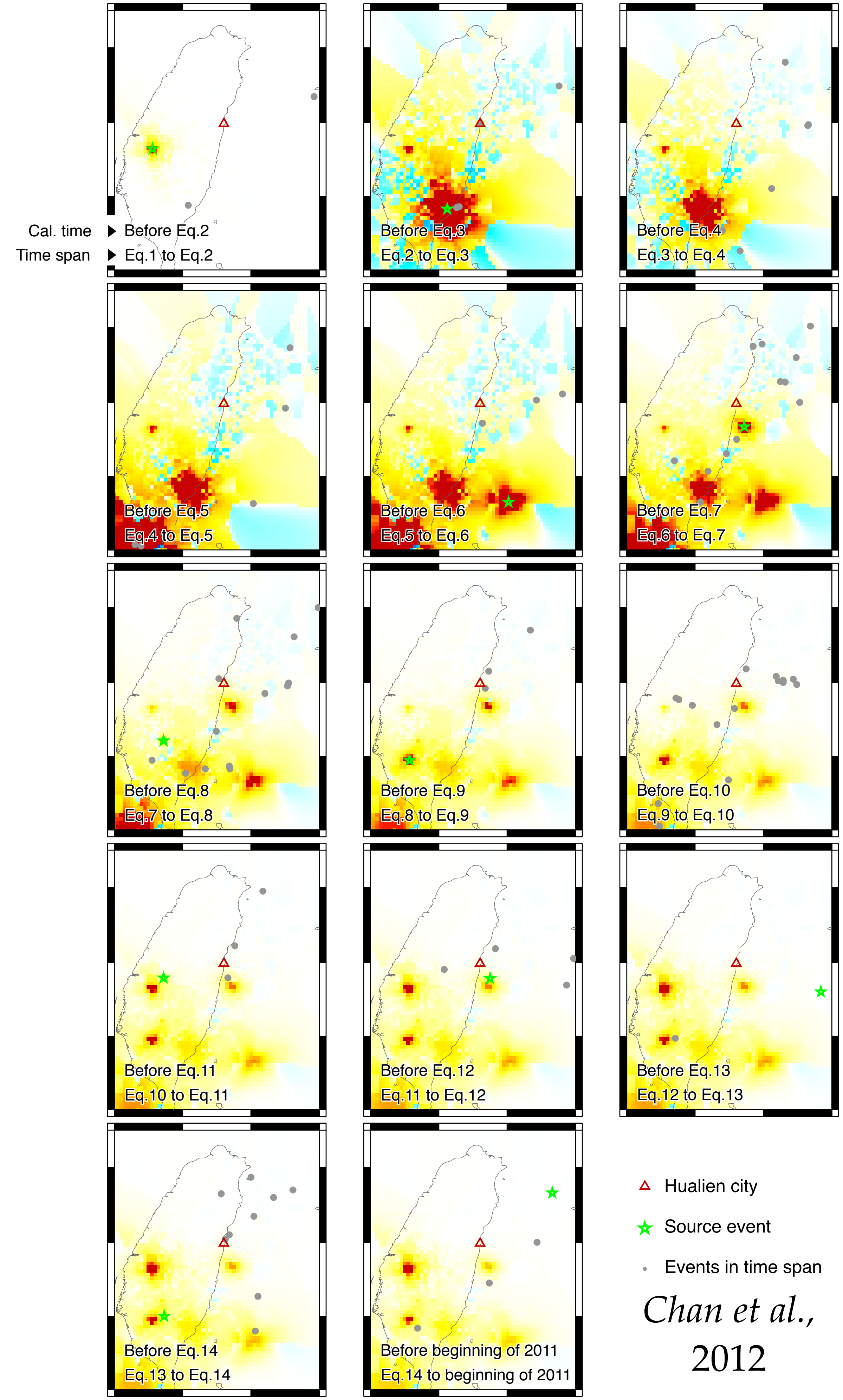
Form BATS catalog

rate evolution....

Evolution of seismic rate during 2006-2010

according to the rate/state friction model

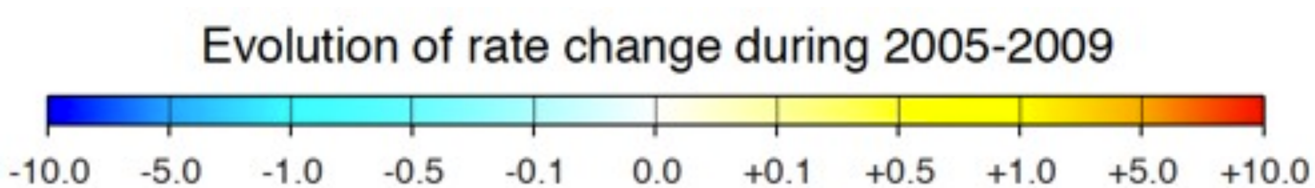


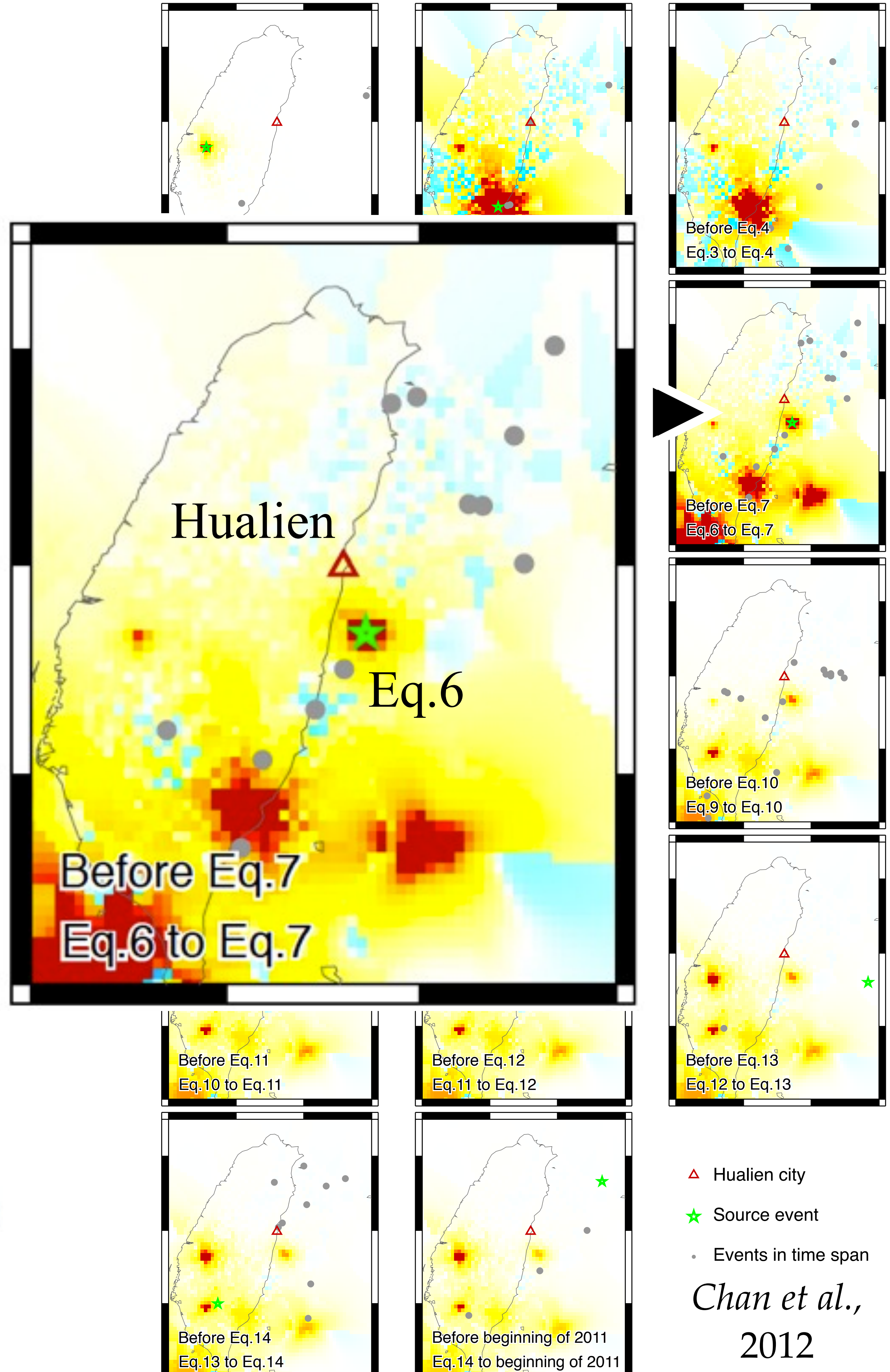


Chan et al., 2012

Evolution of seismic rate during 2006-2010

Significant rate increase near Hualien after **eq.6 (M5.1)**

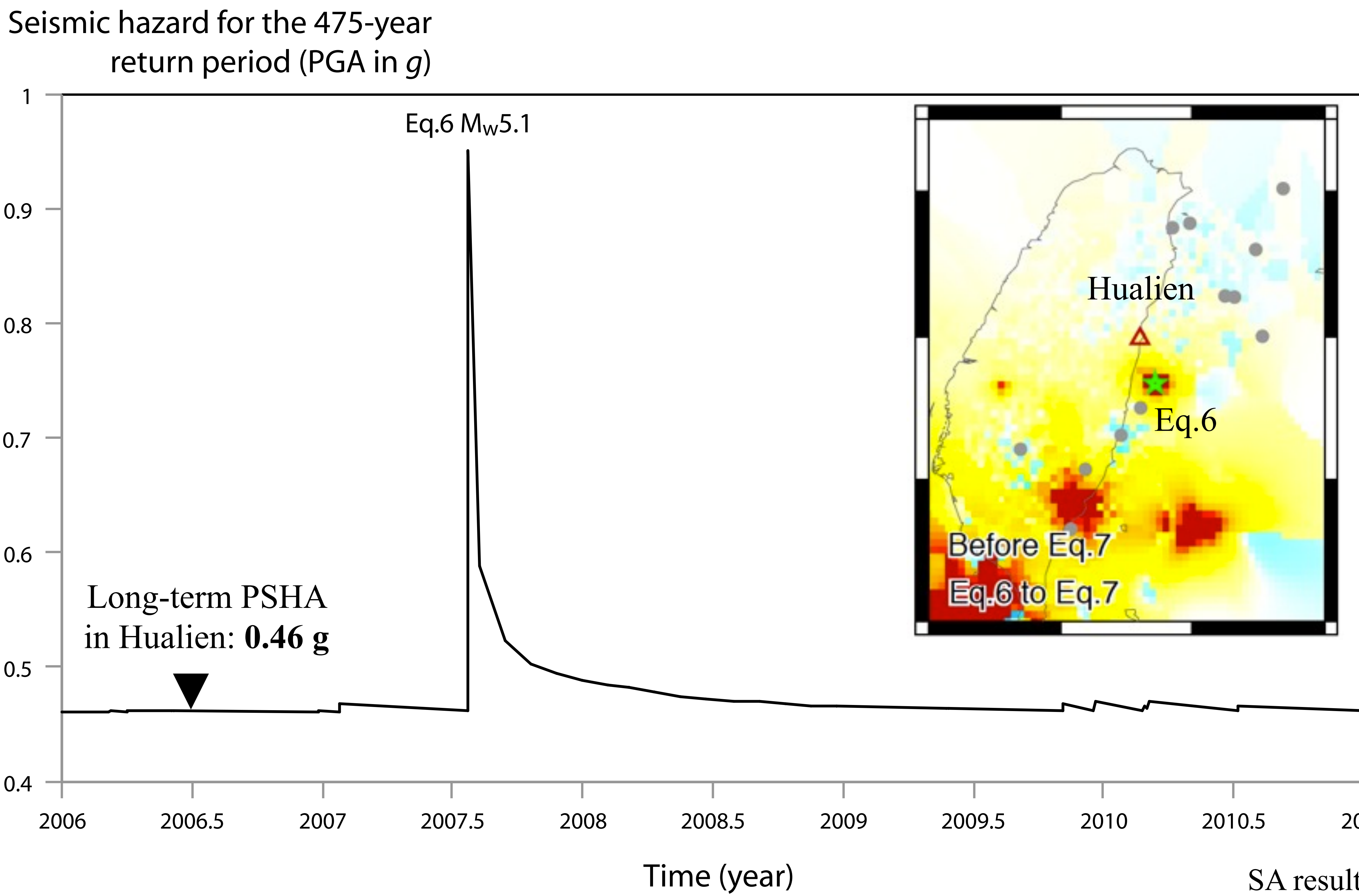




Chan et al., 2012

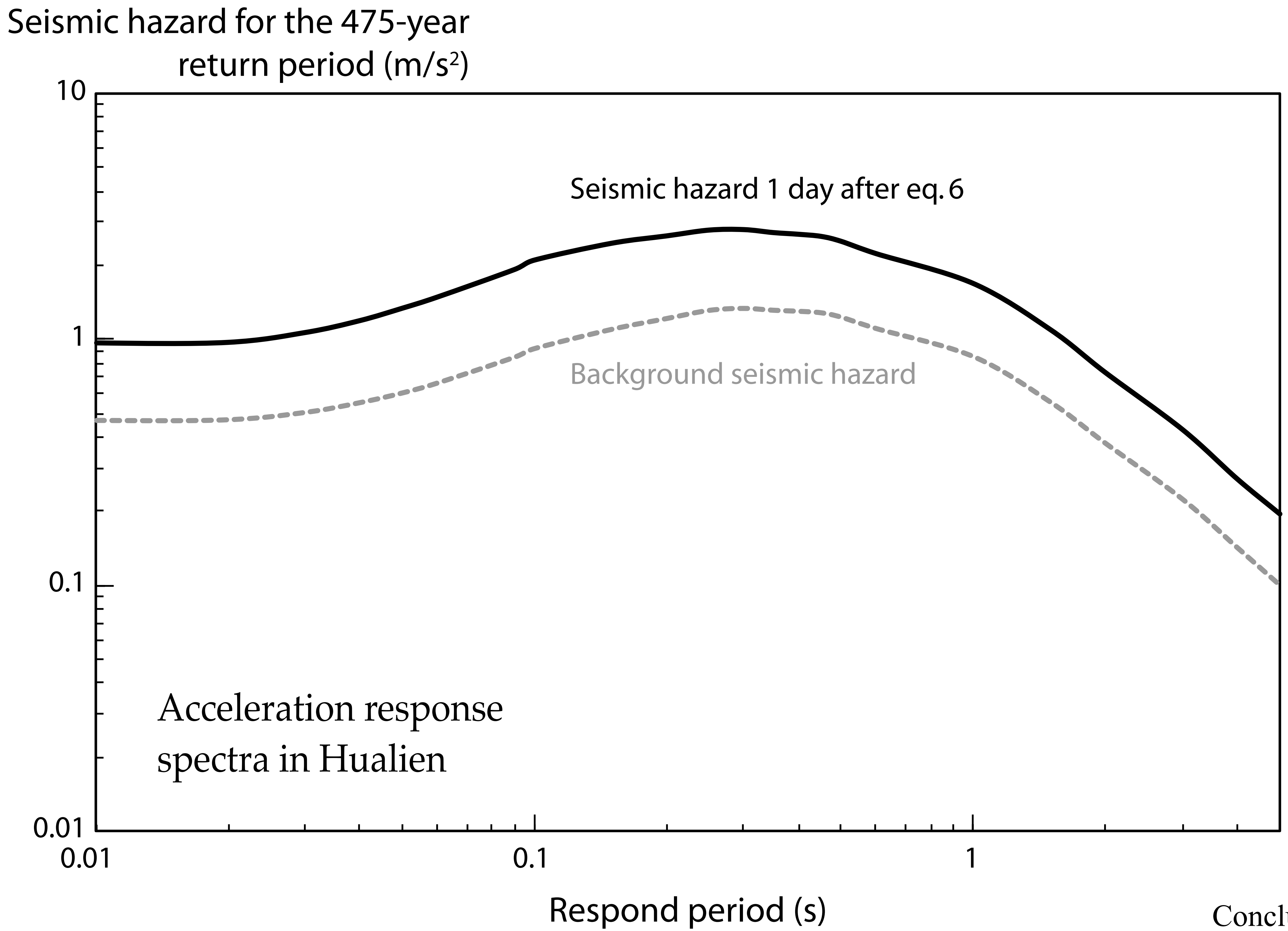
hazard evolution......

Significant rise of seismic hazard after eq.6

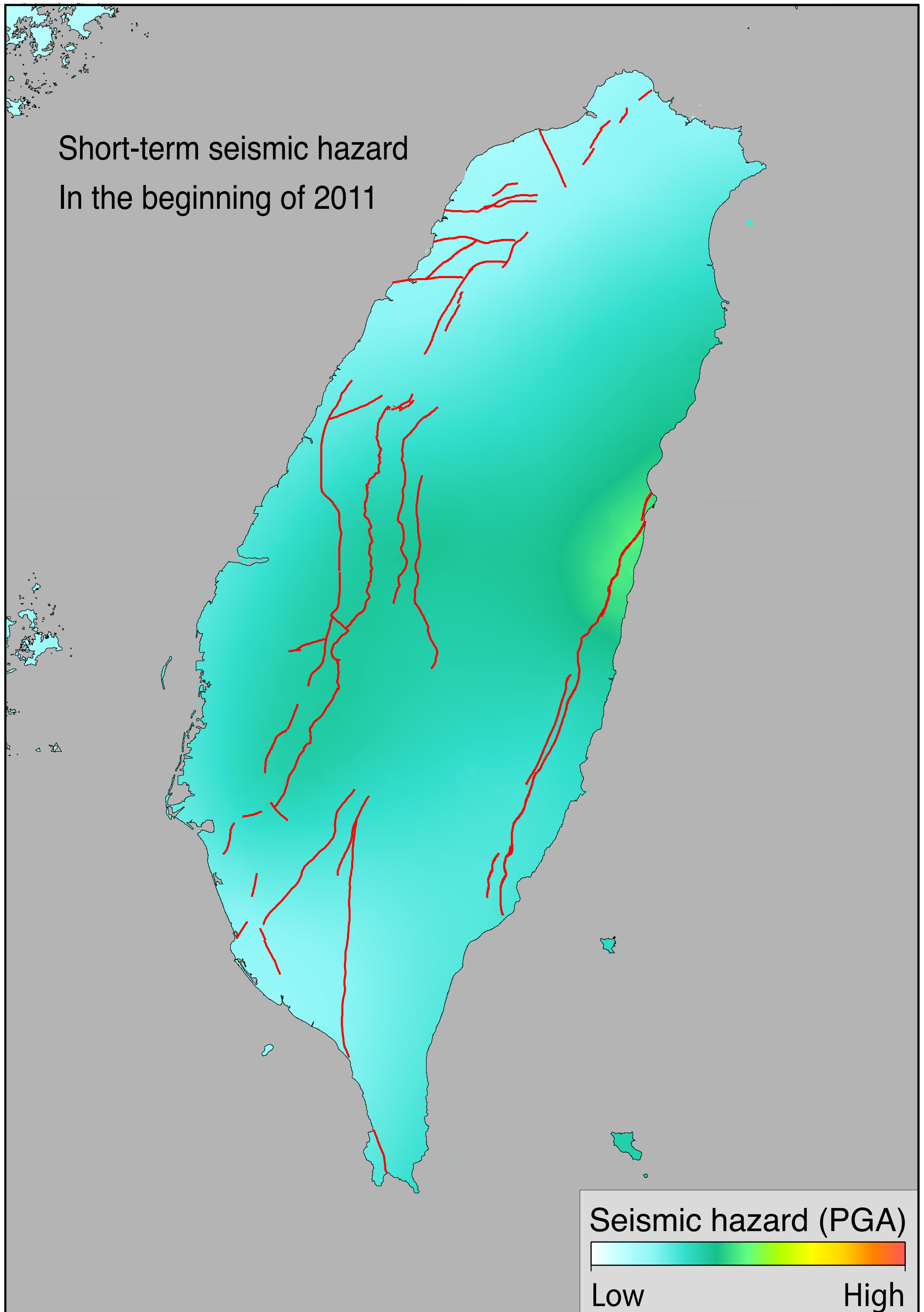


SA results.....

Twice of seismic hazard is evaluated after eq.6



Conclusions.....



<u>What we have obtained:</u>

- Short-term earthquake forecasting
- Short-term PSHA

<u>What we have applied:</u>

- The Jiashian sequence
- The Meishan scenario
- The Hualien City

<u>Further applications:</u>

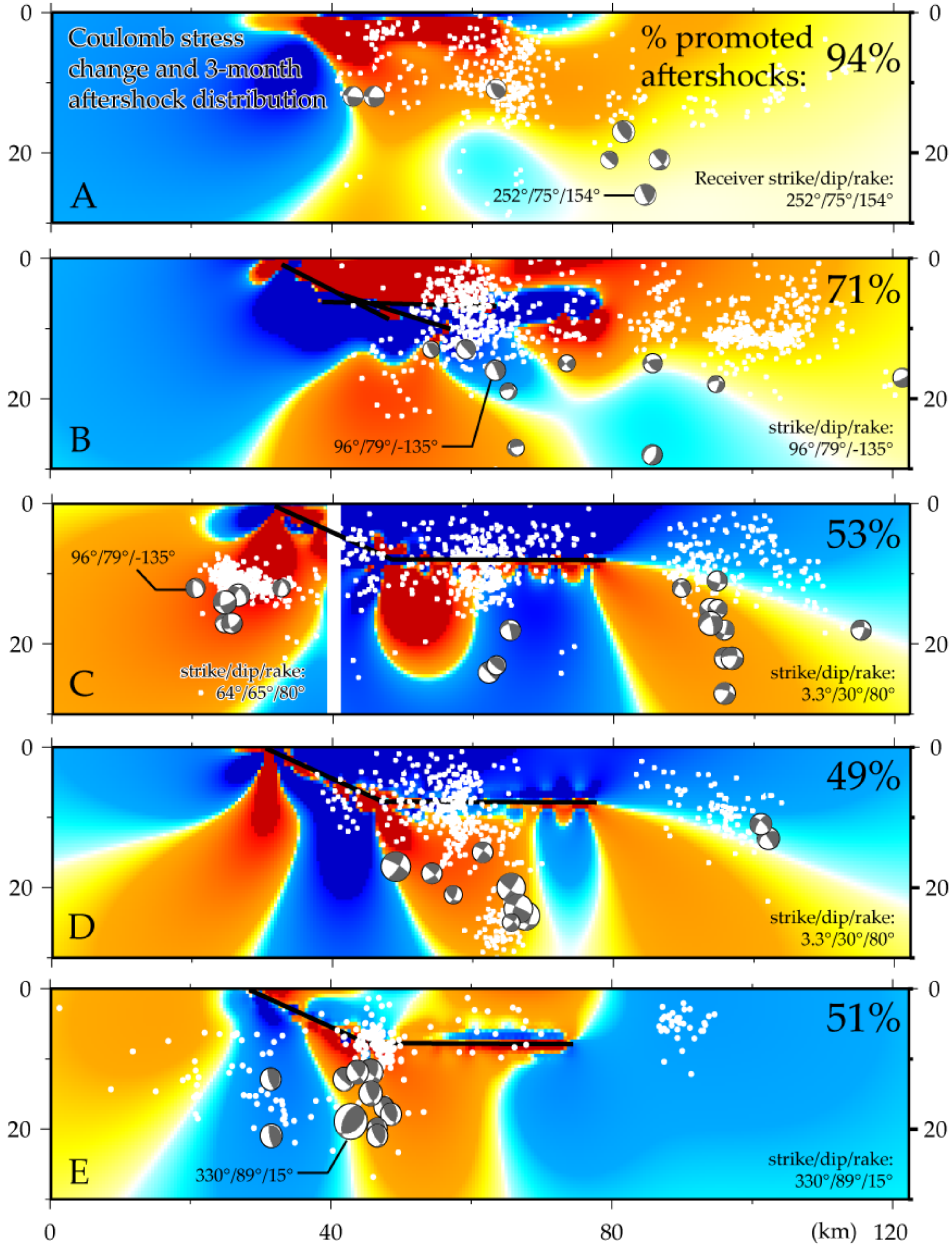
- Monitor a specific site
- Near real-time earthquake forecasting & hazard map
- Consider different ***scenarios*** for each ***seismogenic source*** in Taiwan

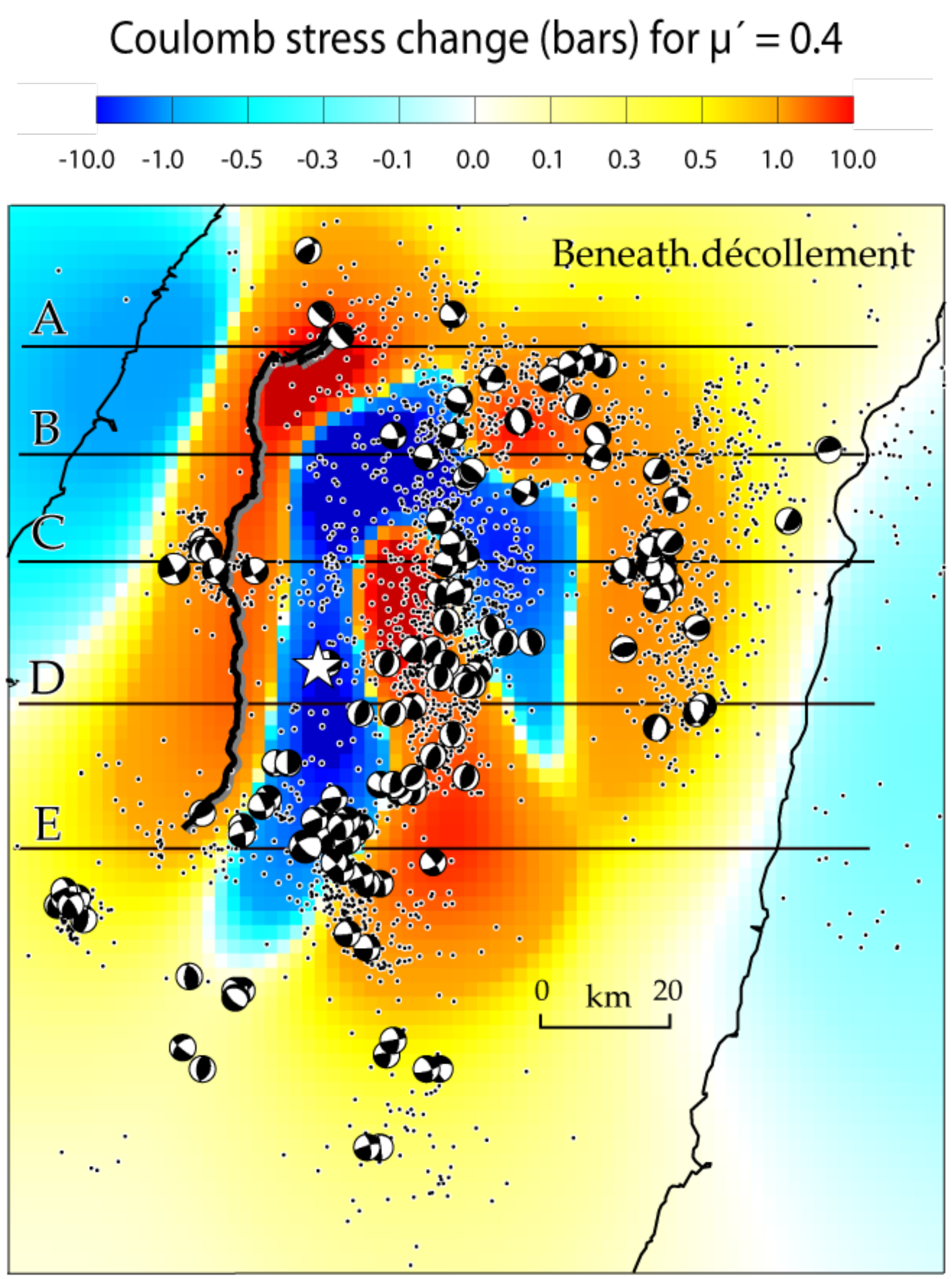
Thanks!

References:

New Zealand case: *Chan et al., TAO, 2012*
Jiashian sequence: *Chan & Wu, JAES, 2012*
Real-time ΔCFS: *Catalli & Chan, GJI, 2012*
Forecasting: *Chan et al., NHESS, 2012*

Δ***CFS*** can forecast the spatial distribution of ***3-month aftershocks***.

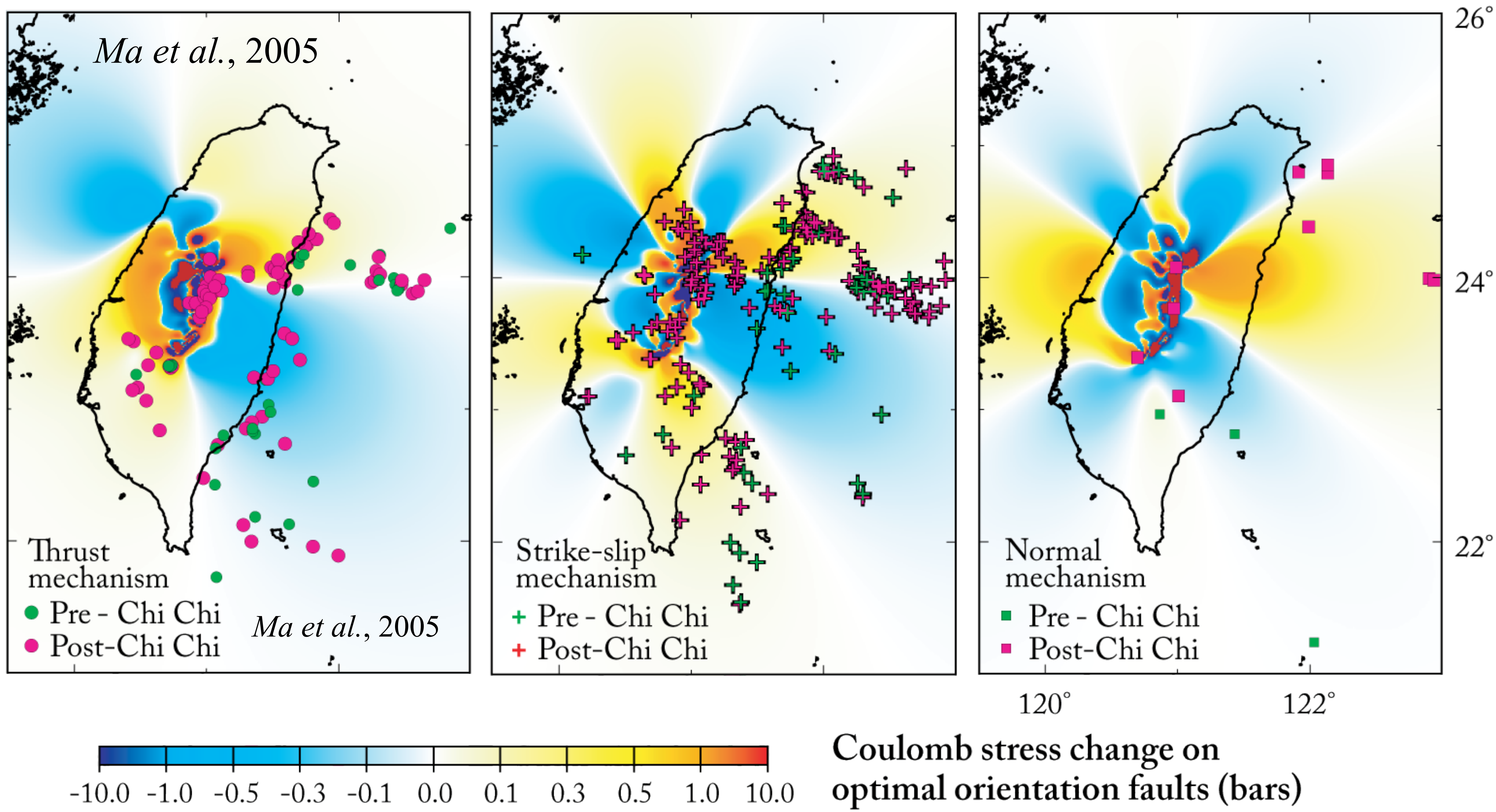




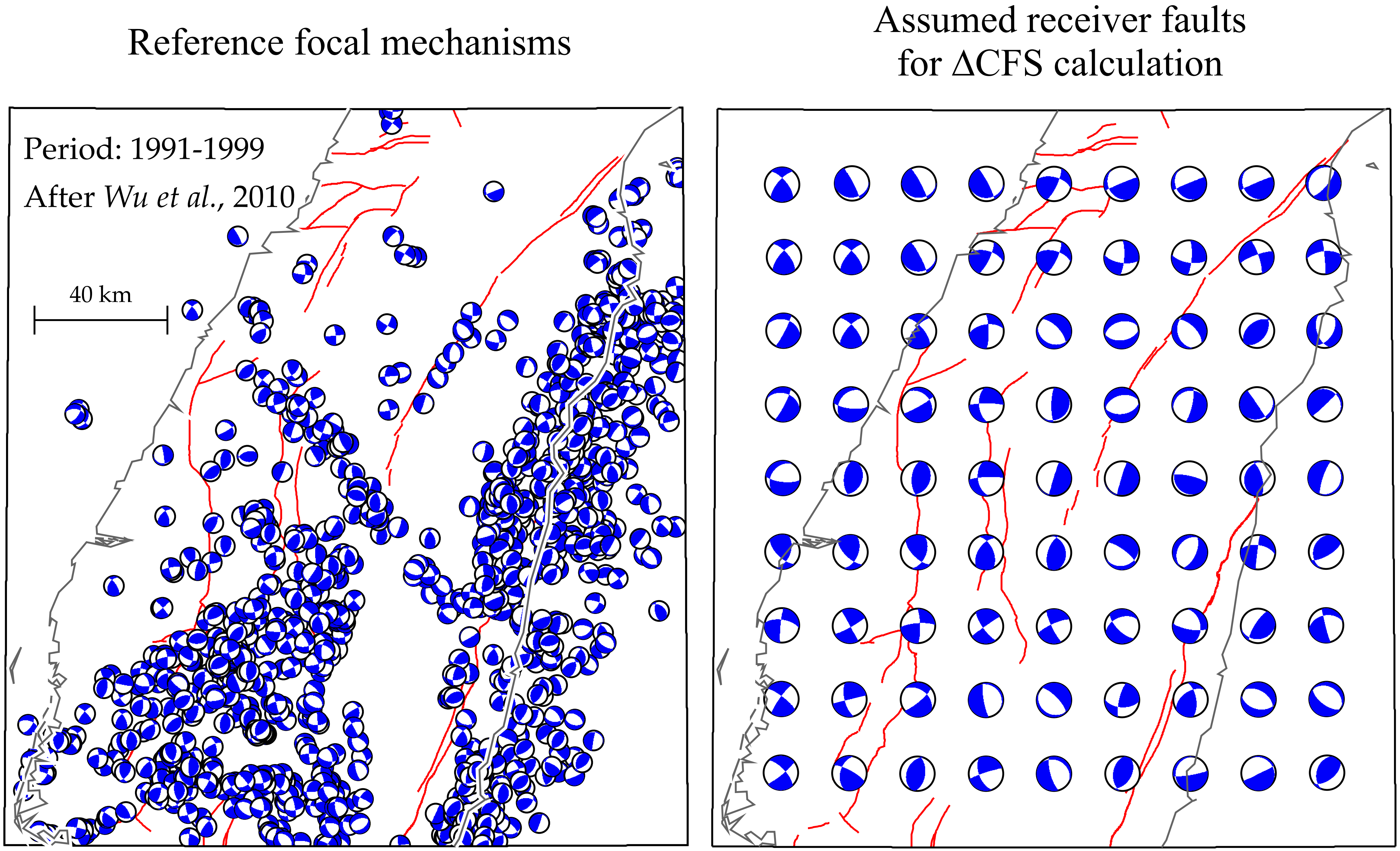
Chan & Stein, 2009

ΔCFS can forecast the spatial distribution of ***50-mo. consequent earthquakes***.

A priori assumption of ***receiver faults*** is required for ***real-time*** forecasting.



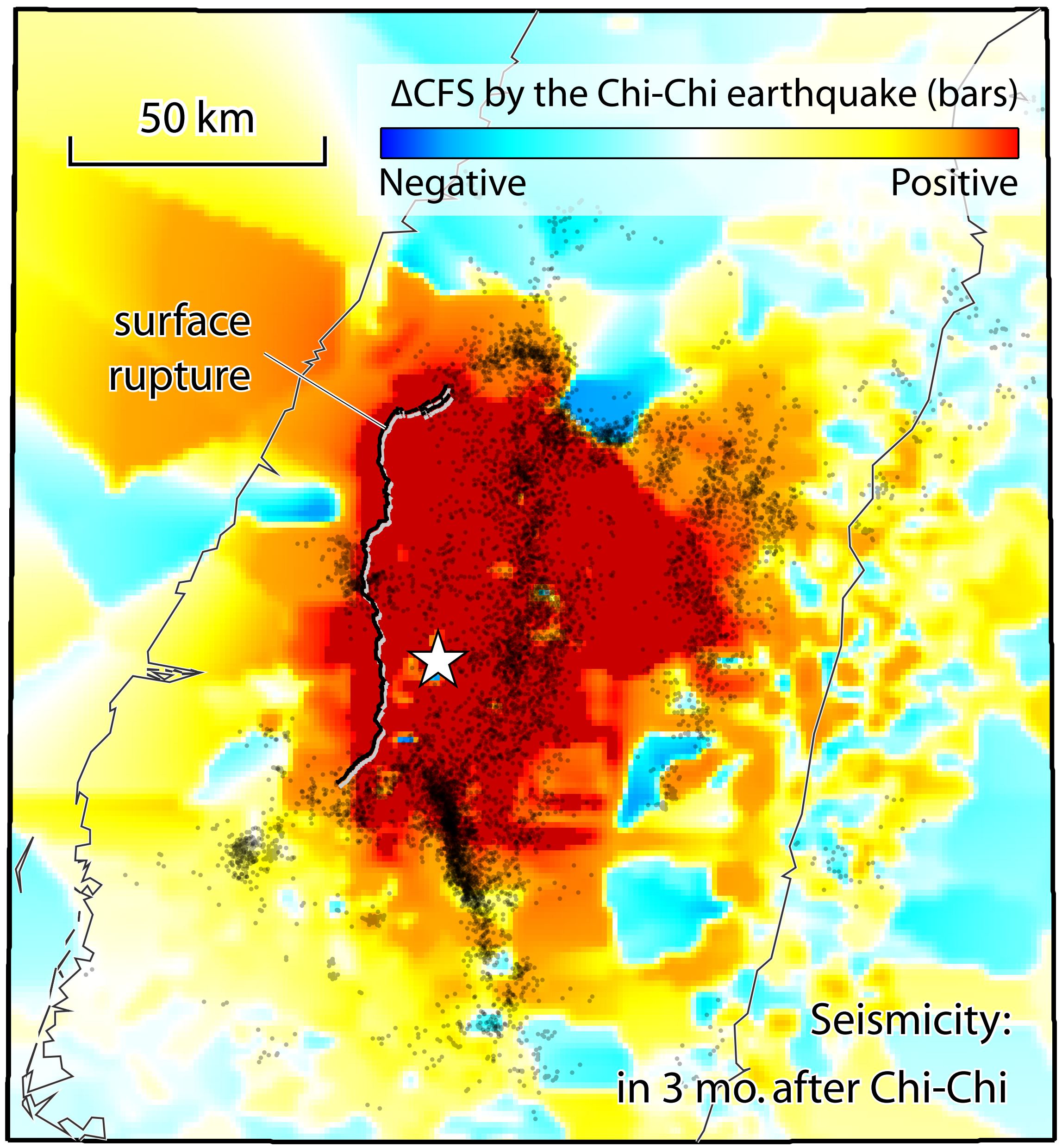
Assumed the same focal mechanisms as nearest references for ΔCFS calculations



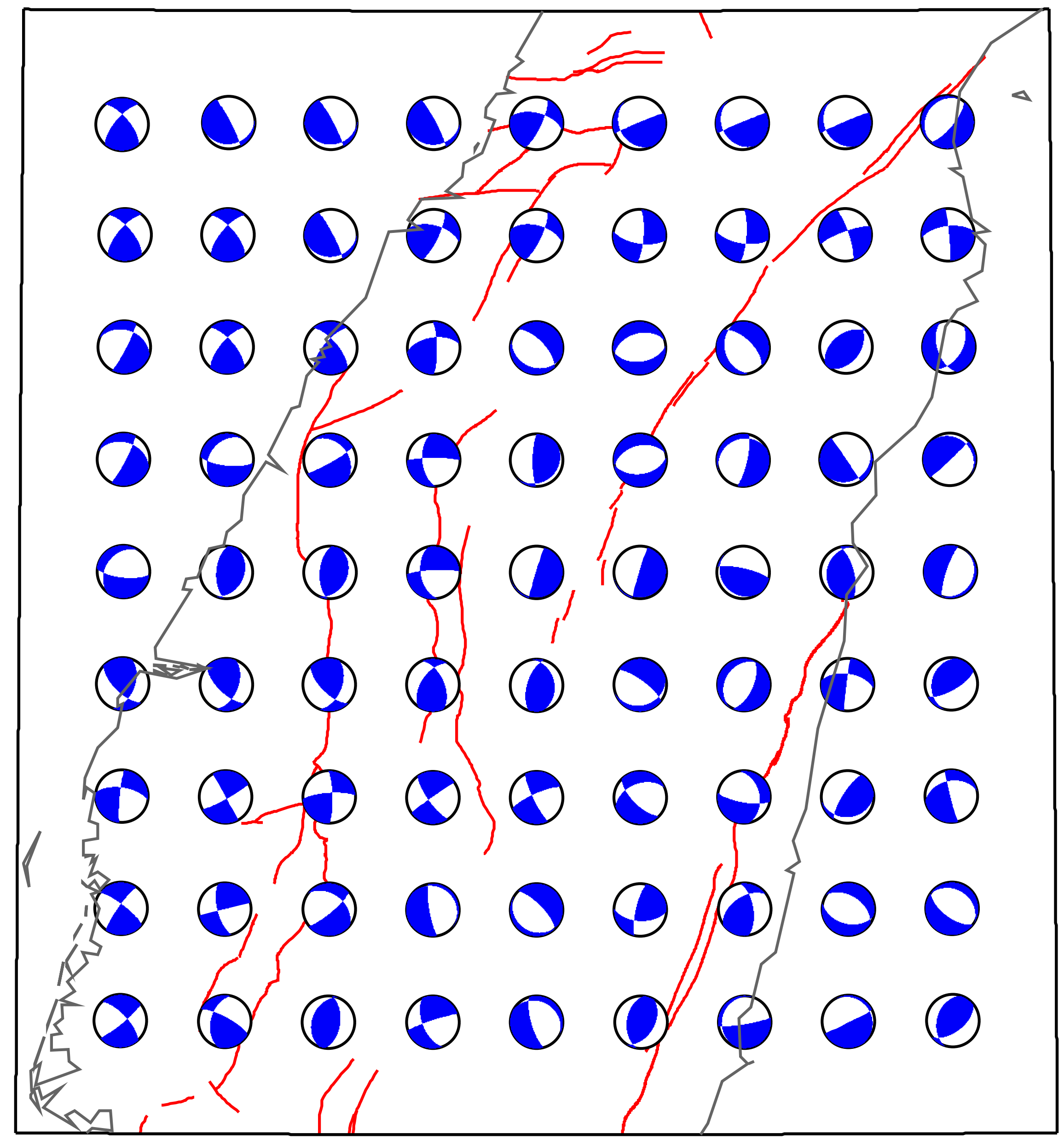
Catalli & Chan, 2012

Good forecasting ability by ***spatial variable receiver faults*** & ***Max. ΔCFS*** among entire seismogenic zone

ΔCFS compares with aftershocks



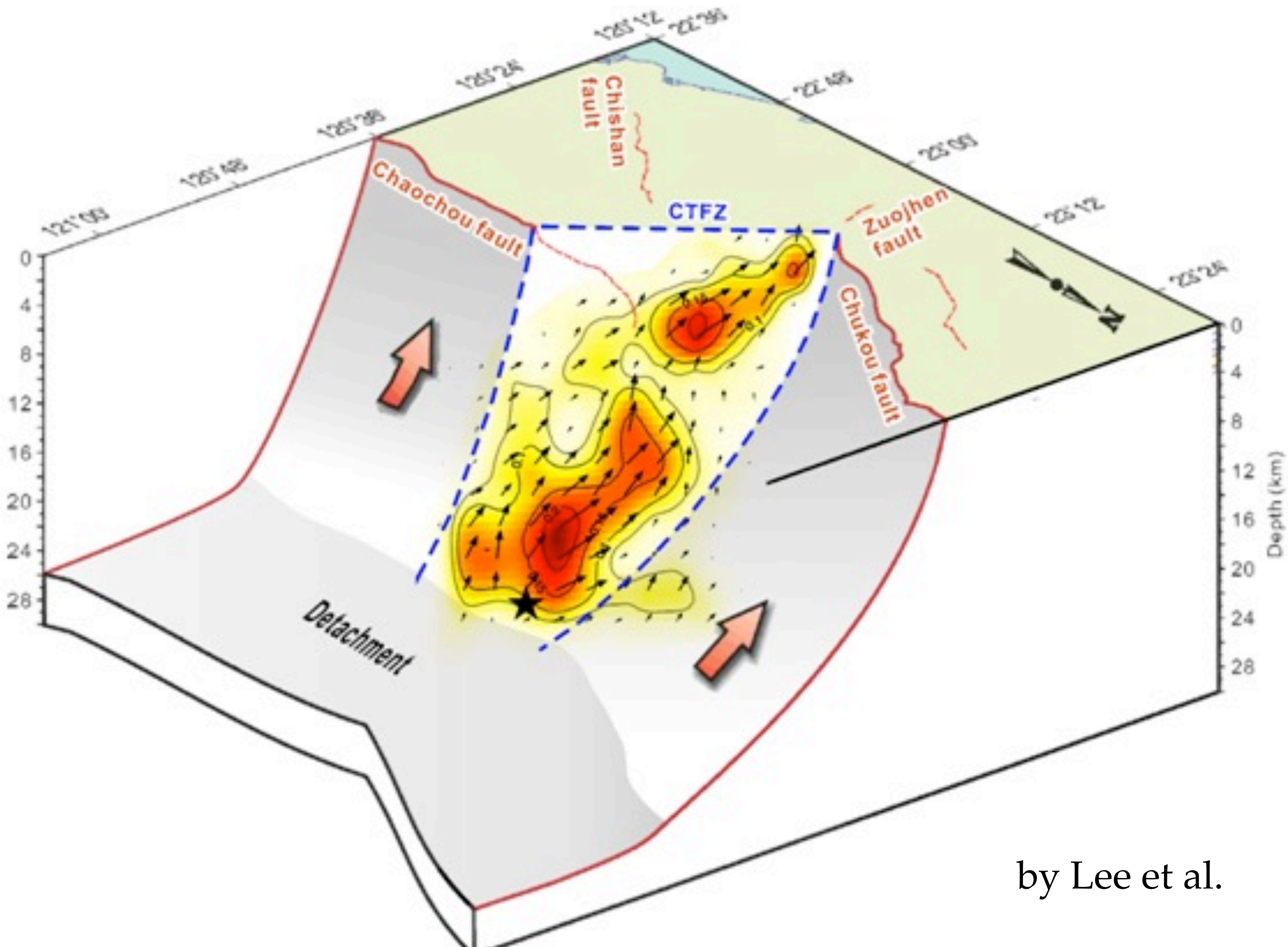
Assumed receiver faults for ΔCFS calculation



Catalli & Chan, 2012

Rate/state....

Conceptual tectonic model for southern Taiwan inferred from the 2010 Jiashian earthquake



by Lee et al.

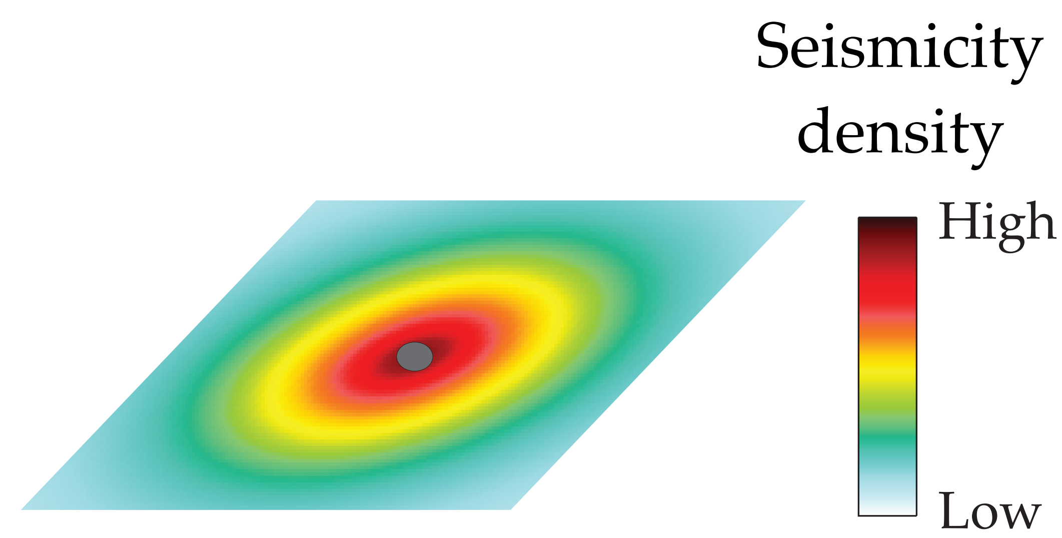
Distribution of seismicity density in the surrounding area

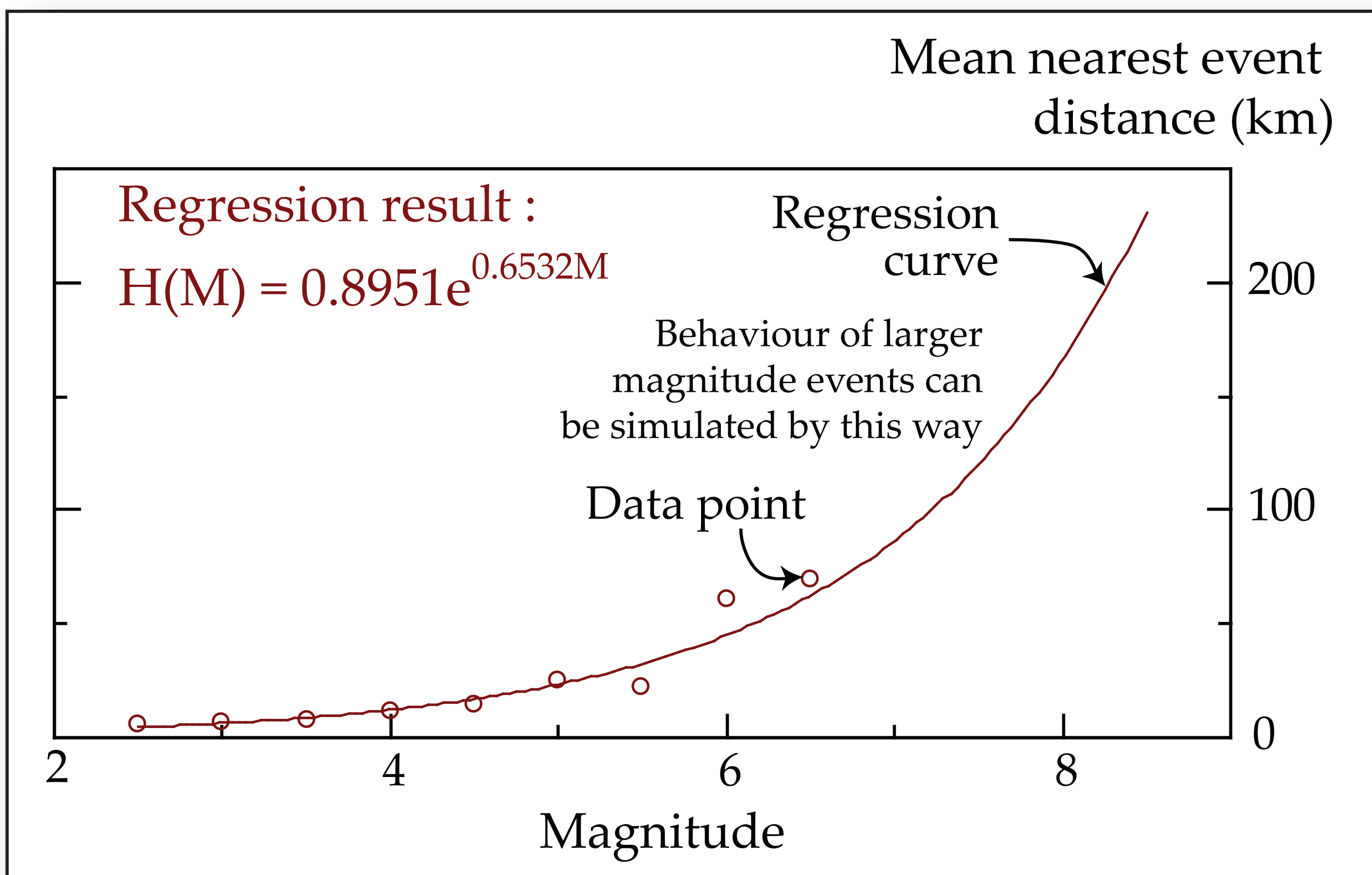
Kernel density function

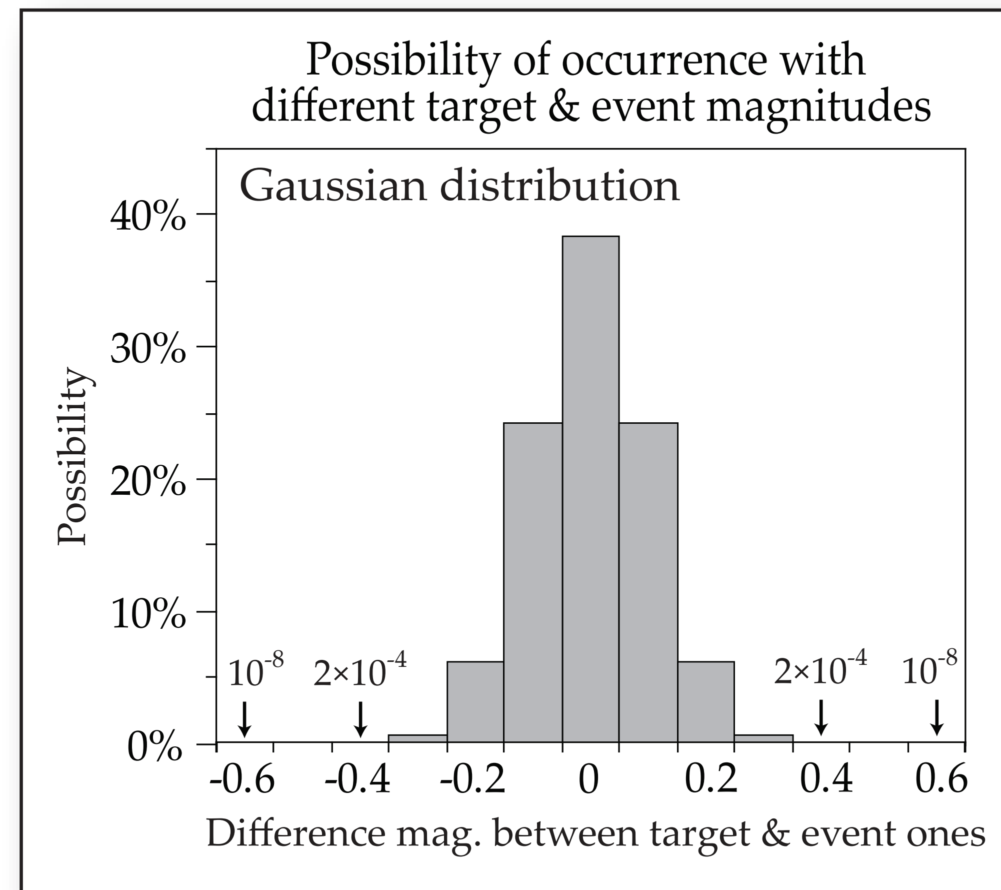
$$K(M,r)=\frac{PL-1}{\pi\ H^2(M)}\left(1+\left(\frac{r}{H(M)}\right)^2\right)^{-PL}$$

Power Law index (1.5-2.0)

Bandwidth function



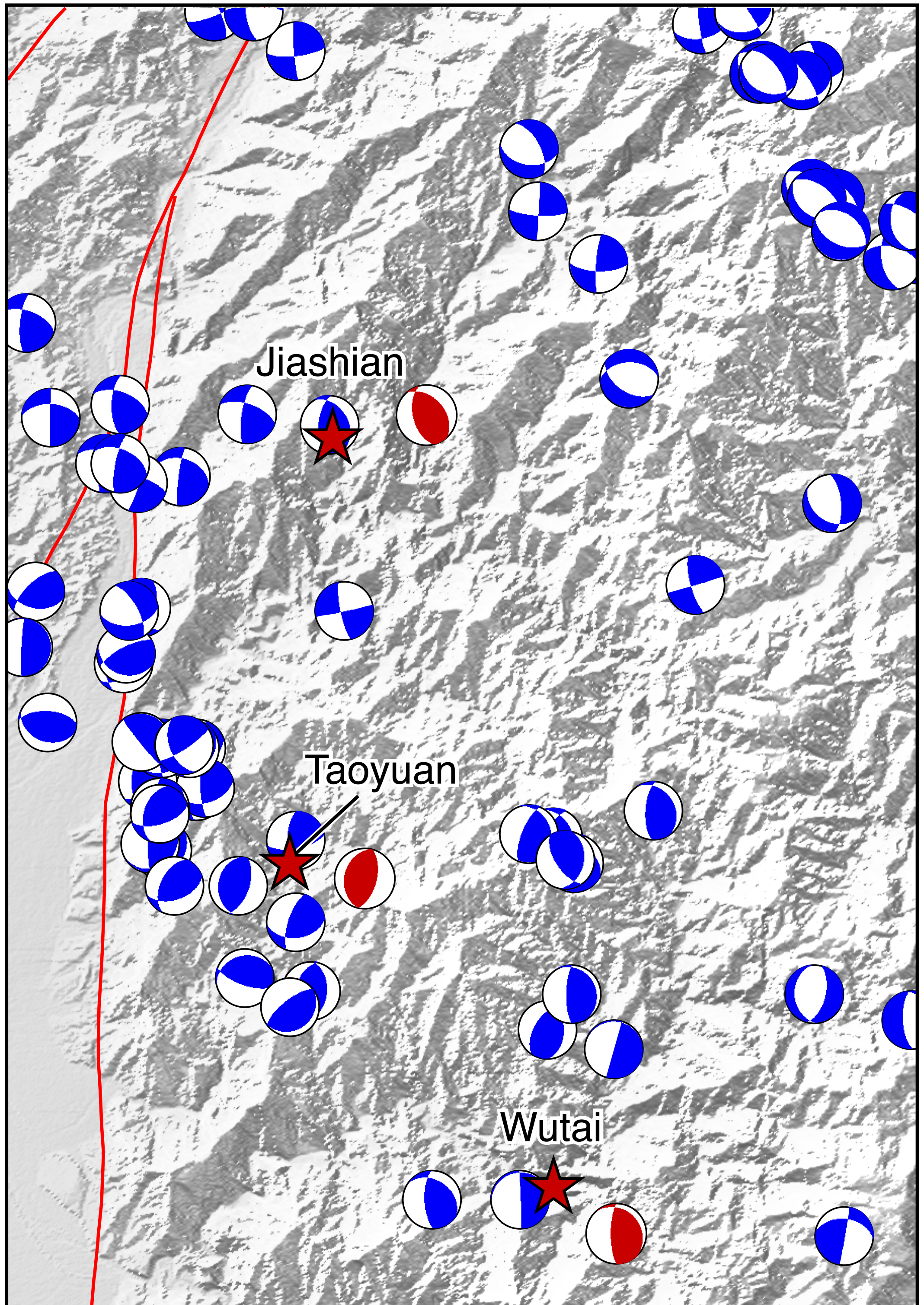




Traditional zoneless approach (*Wu, BSSA*, 1996)

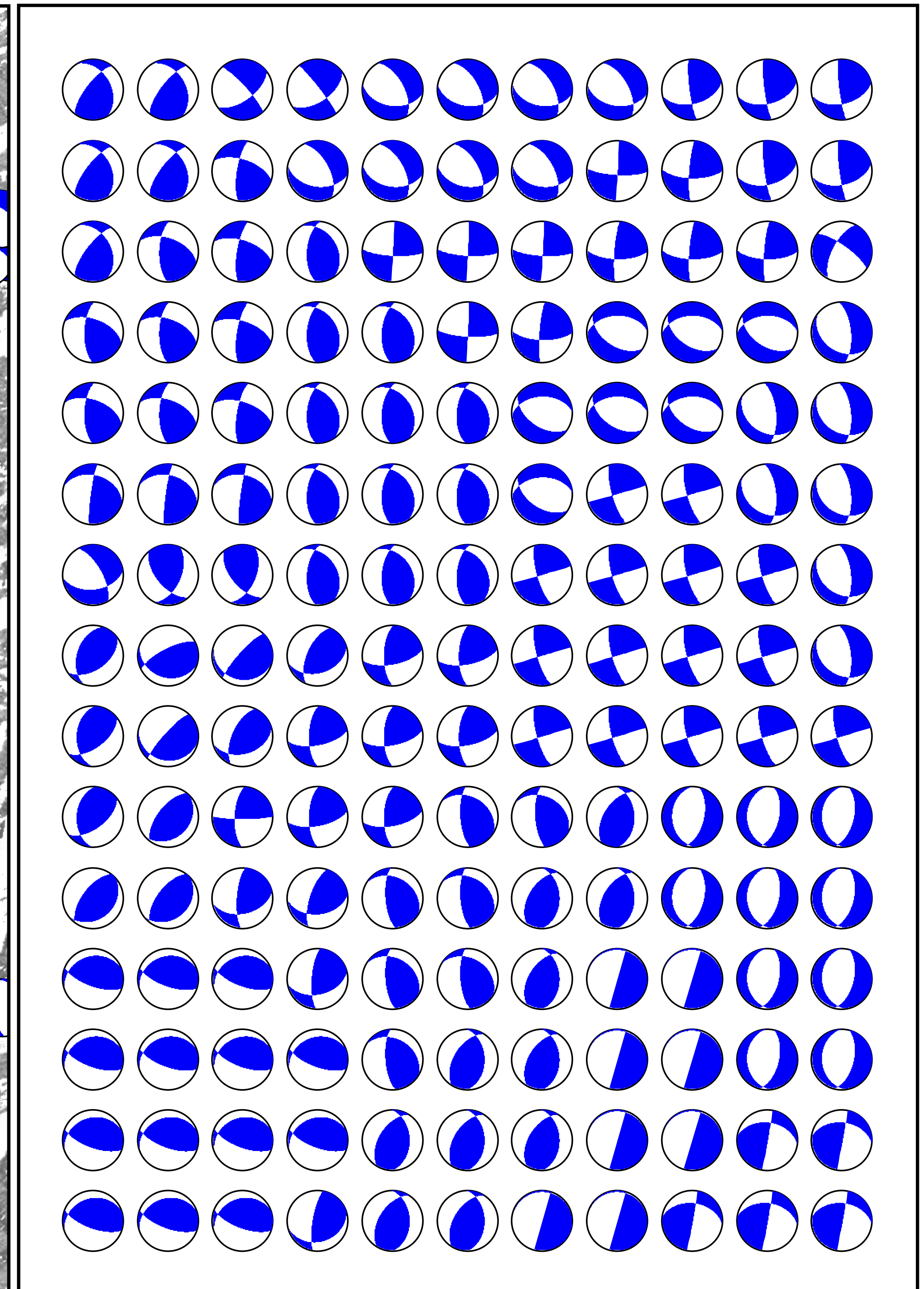
Most earthquakes ***cannot*** be associated with the rupture of active faults
Assumed ***spatially variable receiver faults*** for ΔCFS calculation

Reference focal mechanisms (M≥3.5) (1991-2007)



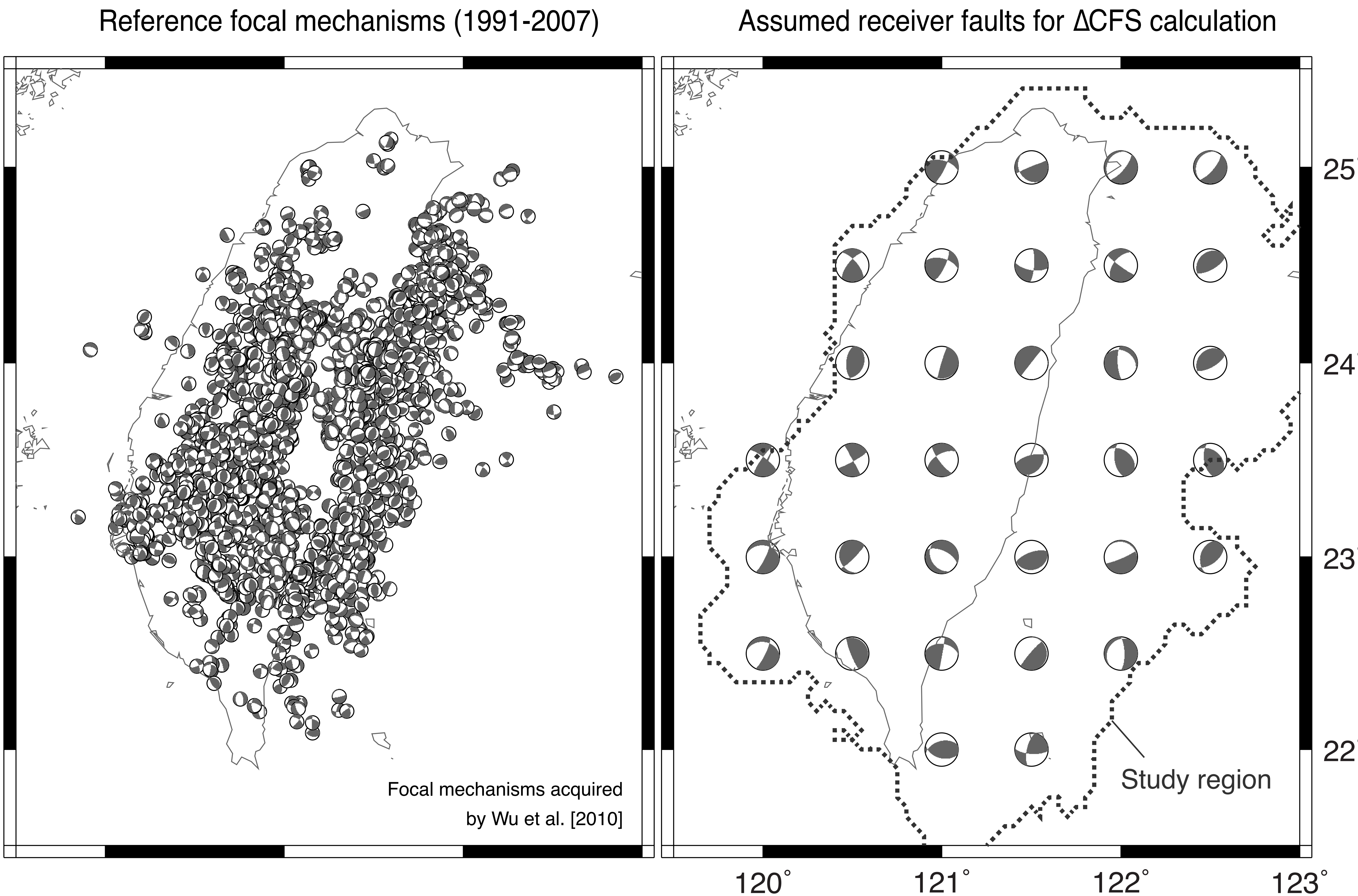
Focal mechanisms acquired by Wu et al., *EPSL*, 2010

Assumed receiver faults for ΔCFS calculation

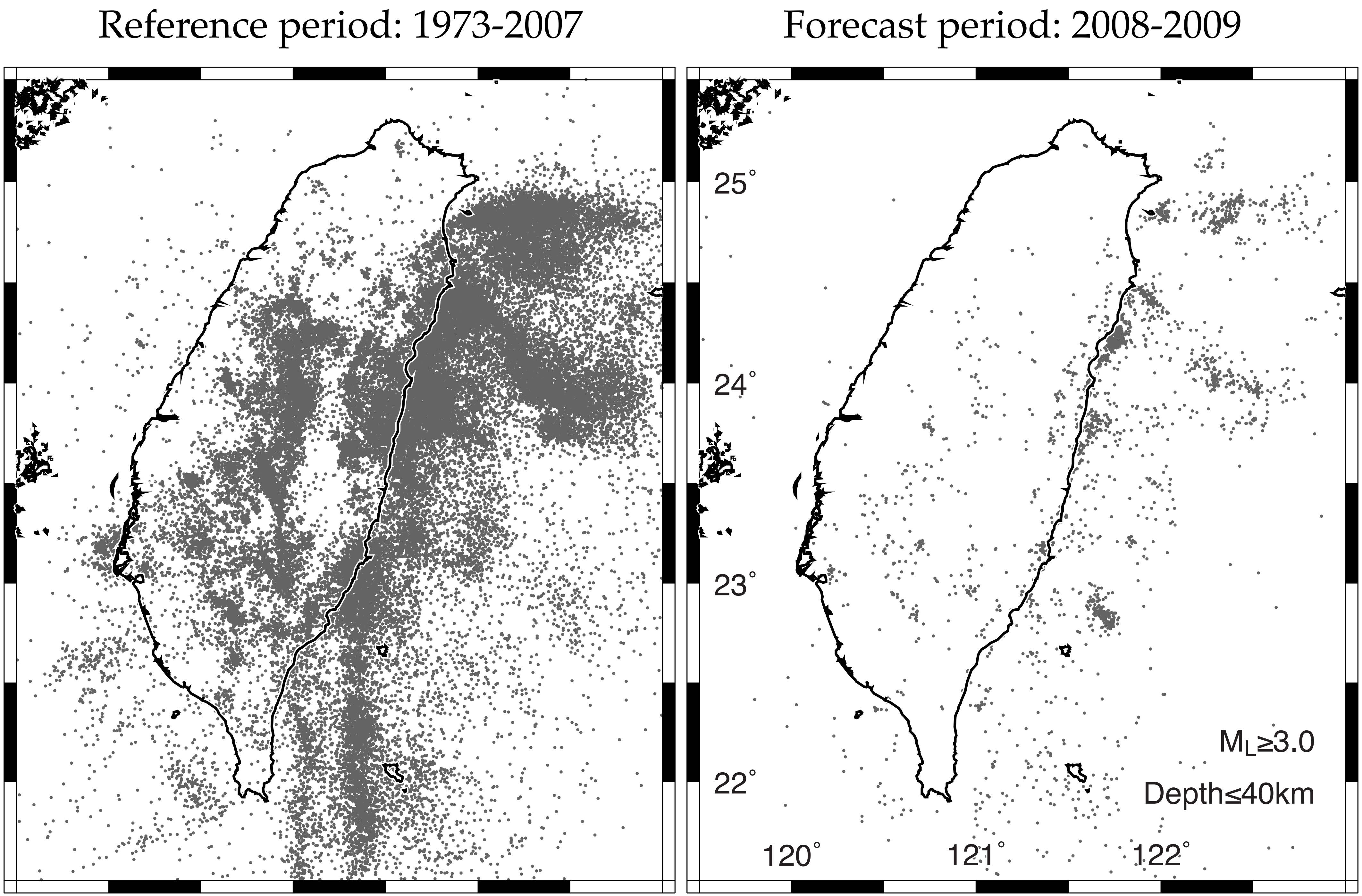


*The actual calculation grids are denser than the spacing presented here

Assumed the same focal mechanisms as nearest references for ΔCFS calculations

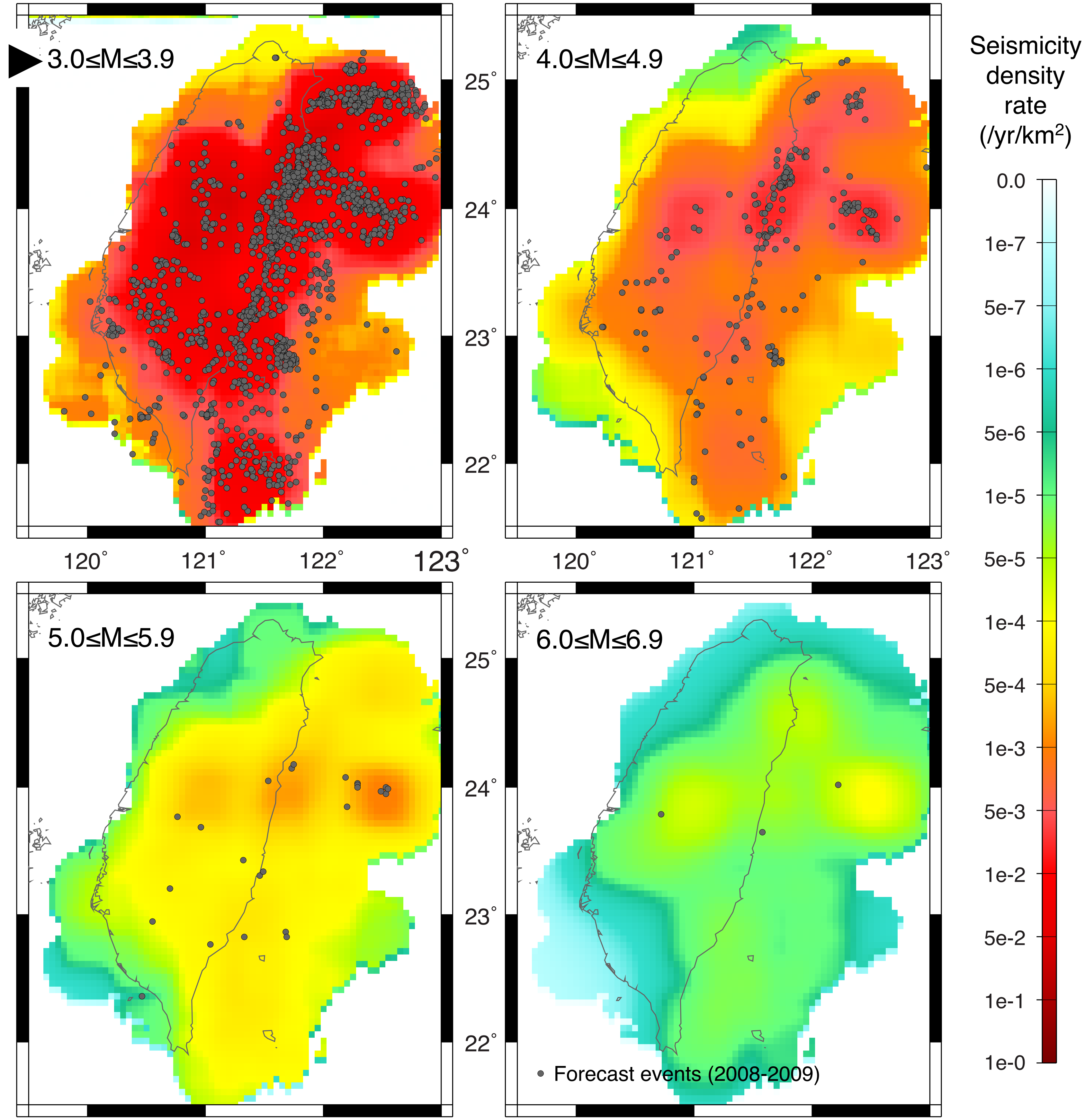


Distribution of seismicity for ***reference*** & ***forecast period***



Source of catalogue: 1973-1993 TTSN; 1994-2009: CWBSN

Ranges of magnitude

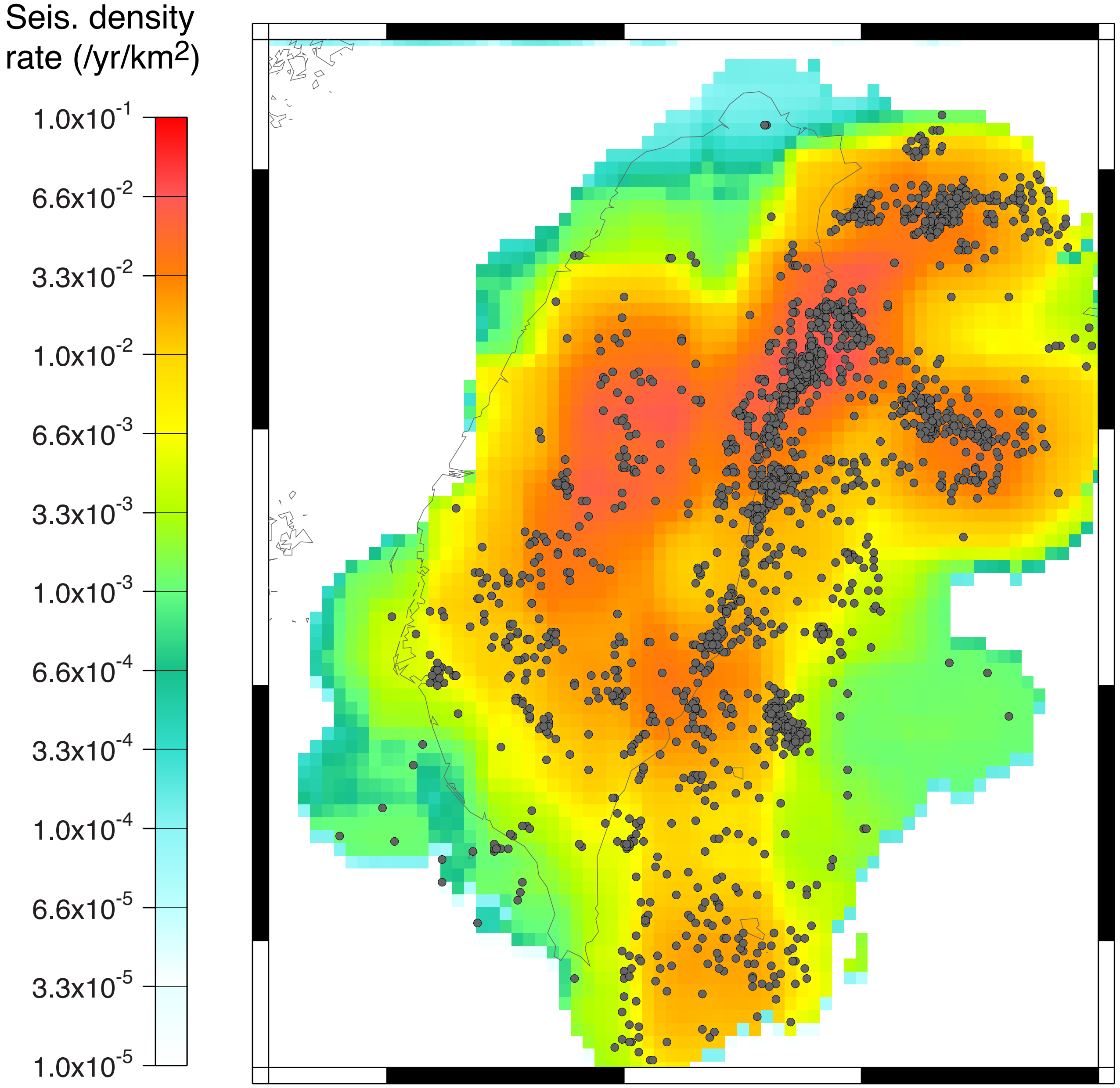


Higher seismicity density rate for ***smaller magnitudes*** and ***at eastern offshore***

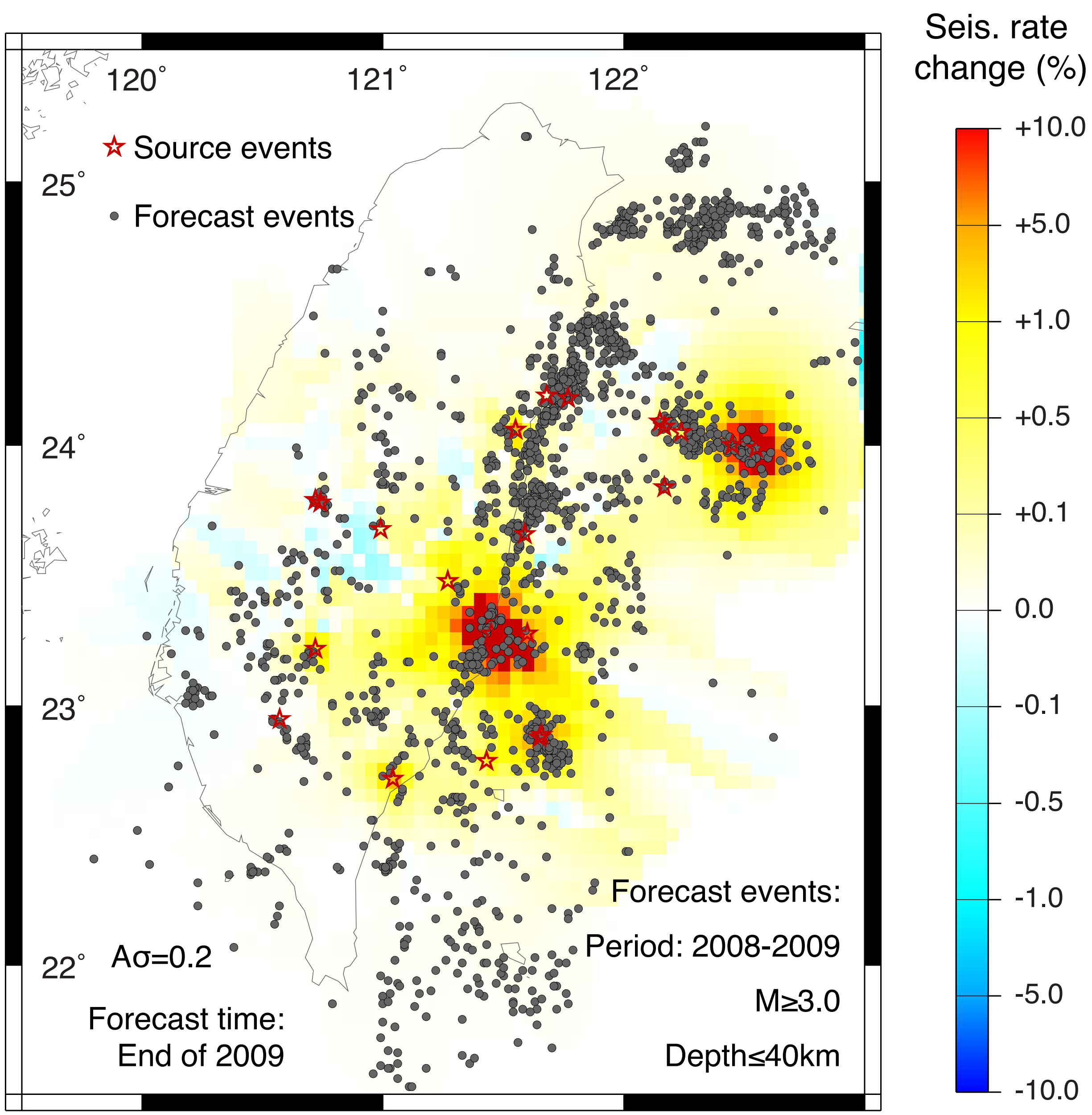
Good correlation with the forecasting event distribution

Reference period: 1973-2007
Forecast period: 2008-2009

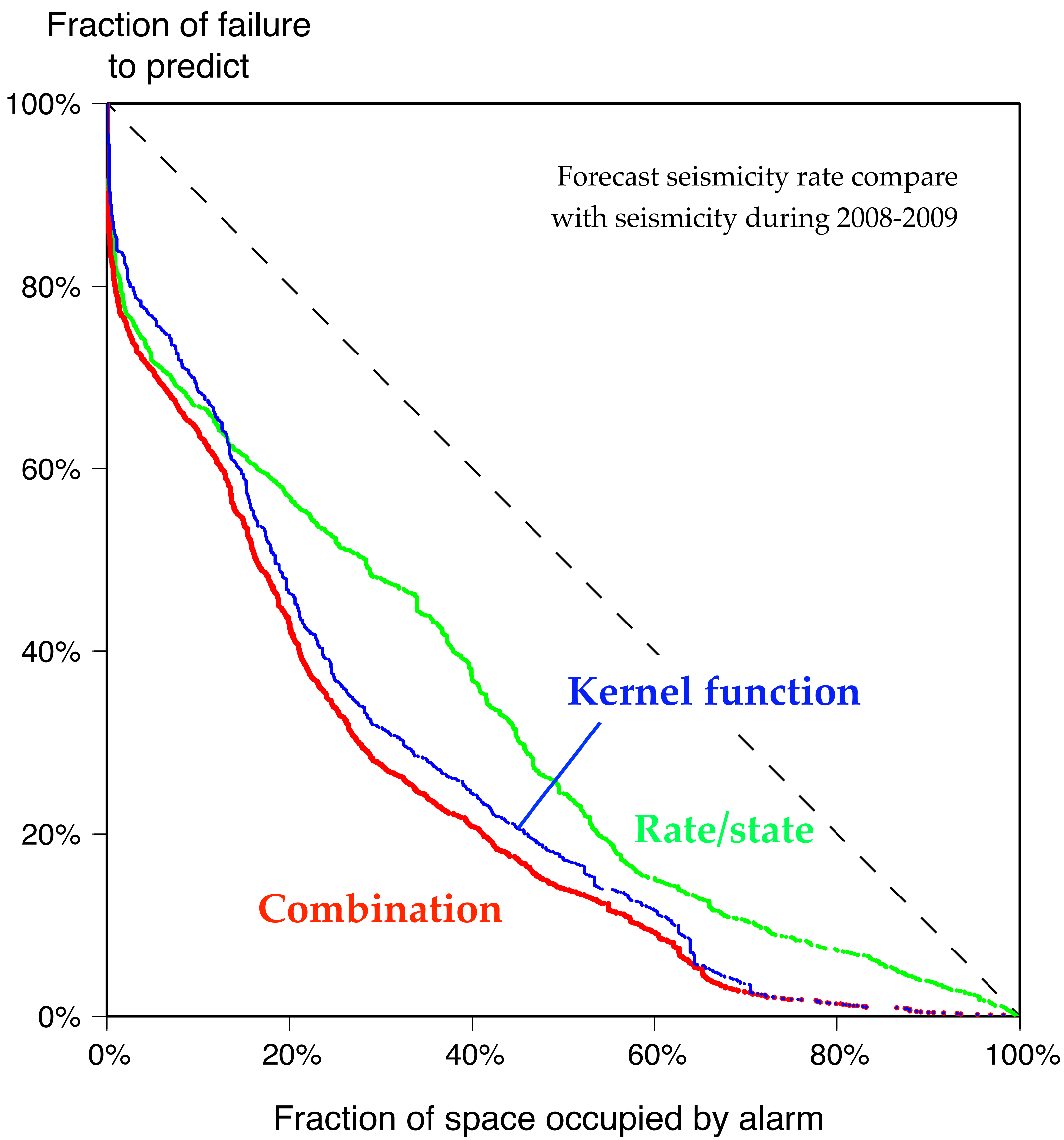
Combine the Kernel function and the rate/state friction model for another forecasting model



Smoothing Kernel function



rate-and-state friction law

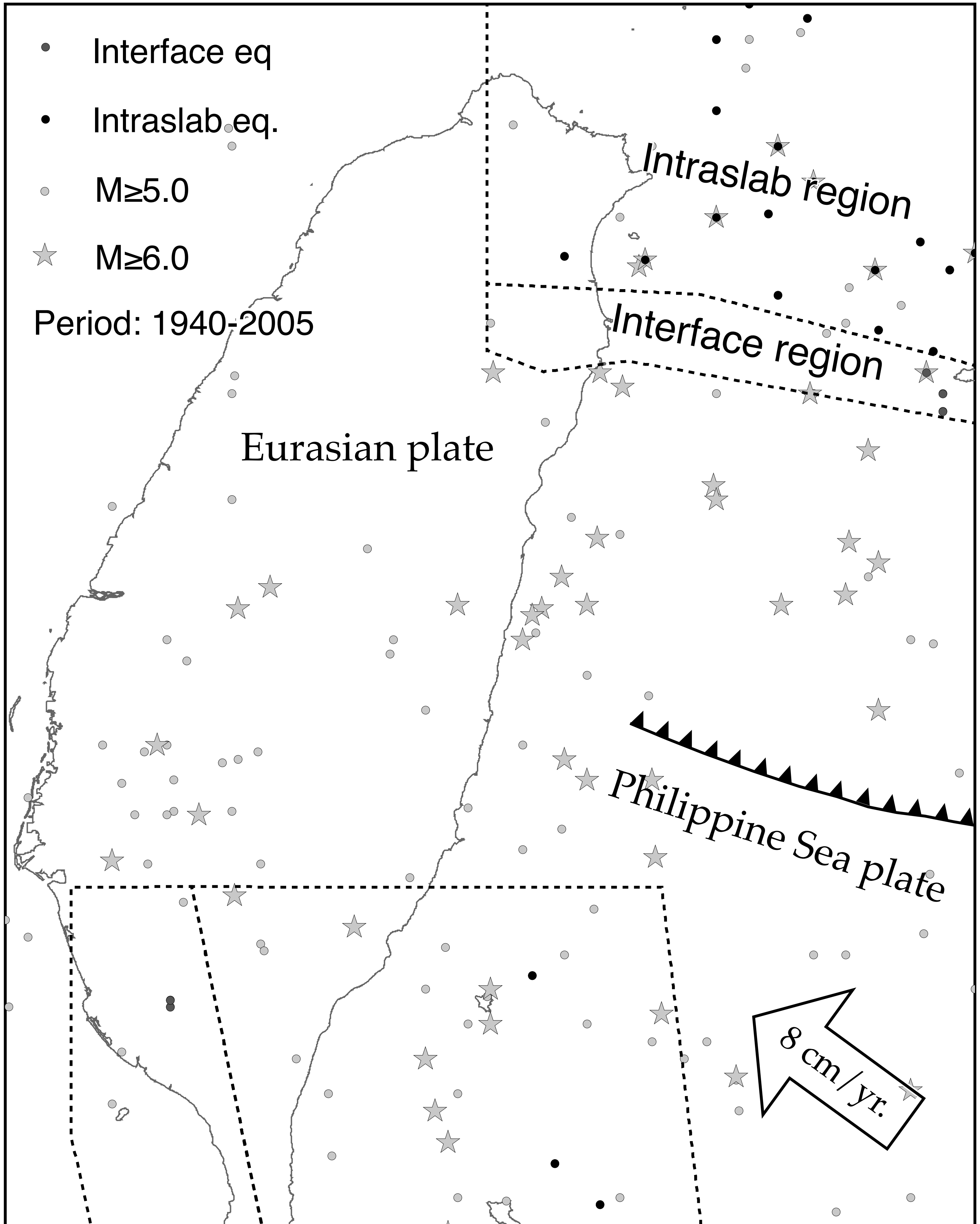


Only ***16%*** of the forecast events occurred on the ***half*** lowest seismic density region

Combination of the two models has ***the best forecasting ability***

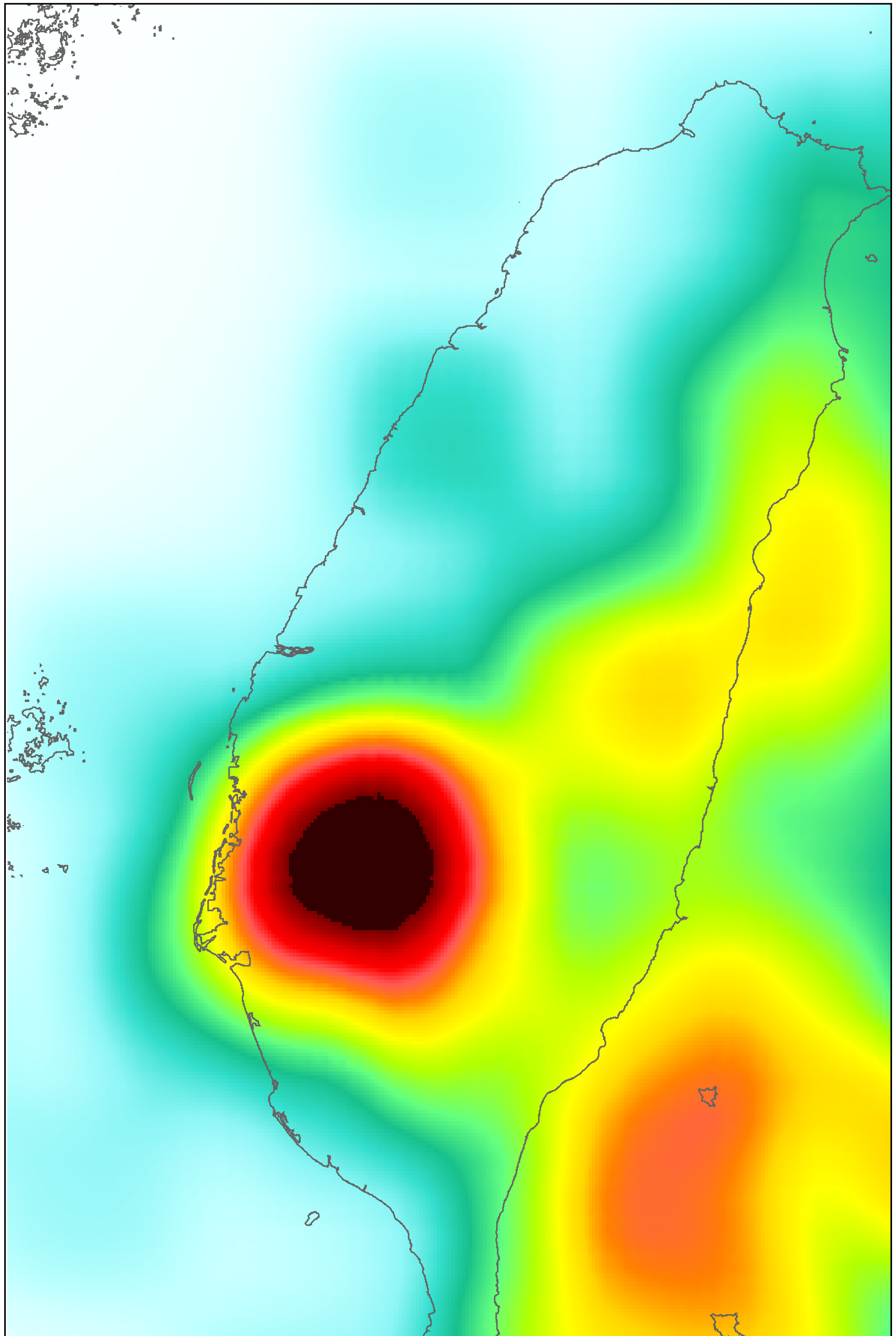
Reference period: 1973-2007

Forecast period: 2008-2009



Seismicity in Taiwan

Higher seis. rate *near* ***Tainan*** and ***east offshore***



Long-term seis. density rate by ***the zoneless approach***

Higher seis. rate in Tainan and the east offshore region.