Directivity Effect In The Empirical Green's Function Method For Ground-motion Simulation

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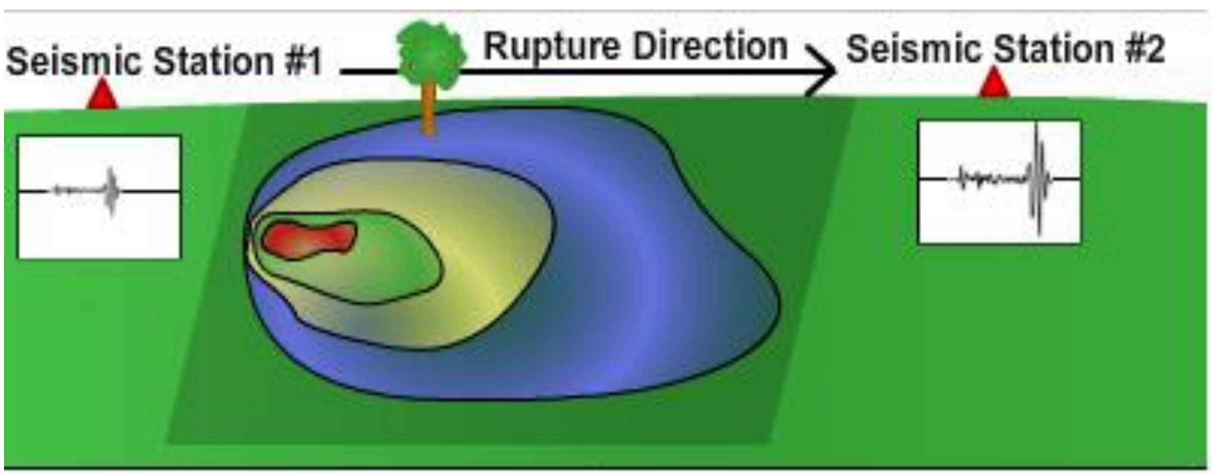
Outline

1. Introduction
2. Method
3. Simulating ground-motion directivity
4. Conclusion

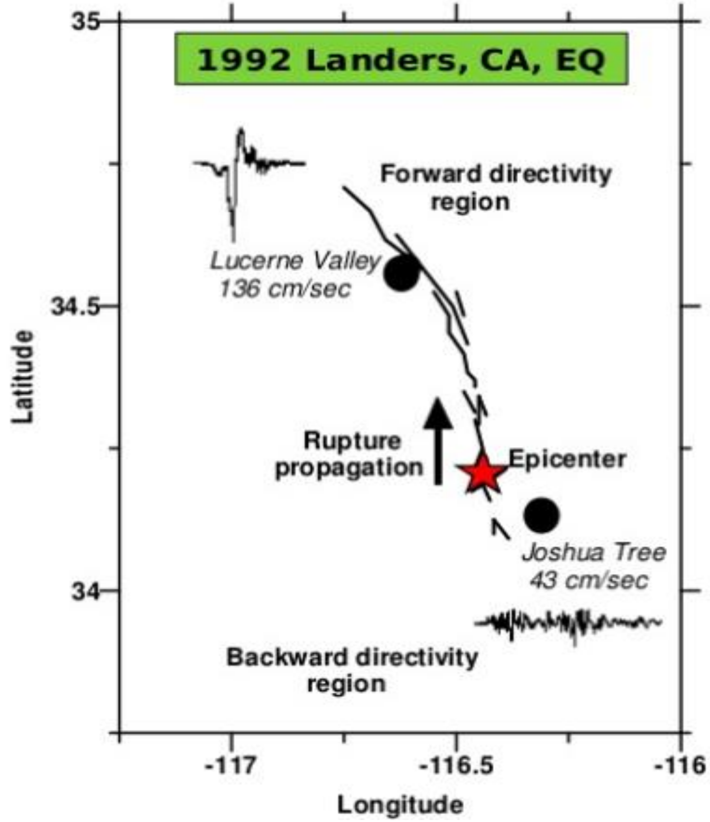
Introduction

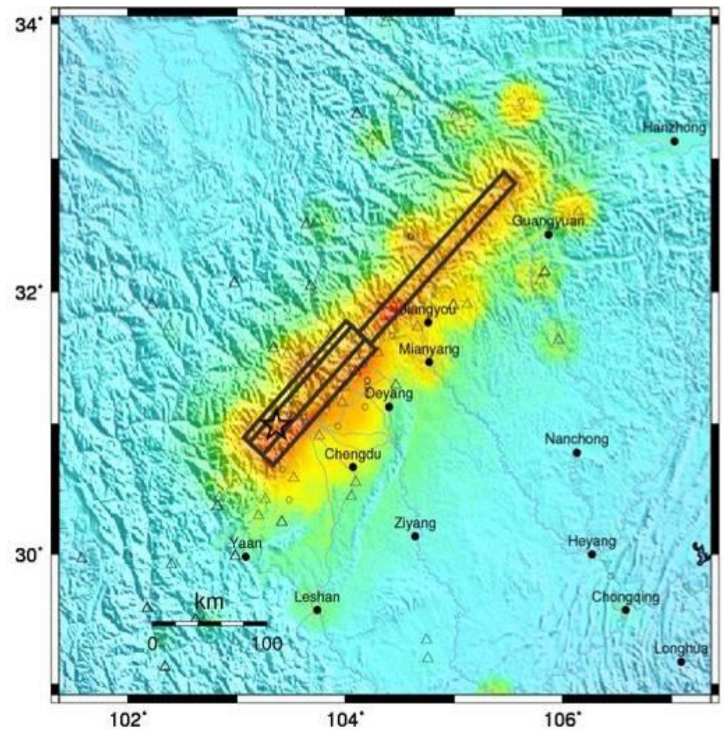
Directivity is an effect of a fault rupturing whereby earthquake ground motion in the direction of rupture propagation is more severe than that in other directions from the earthquake source.

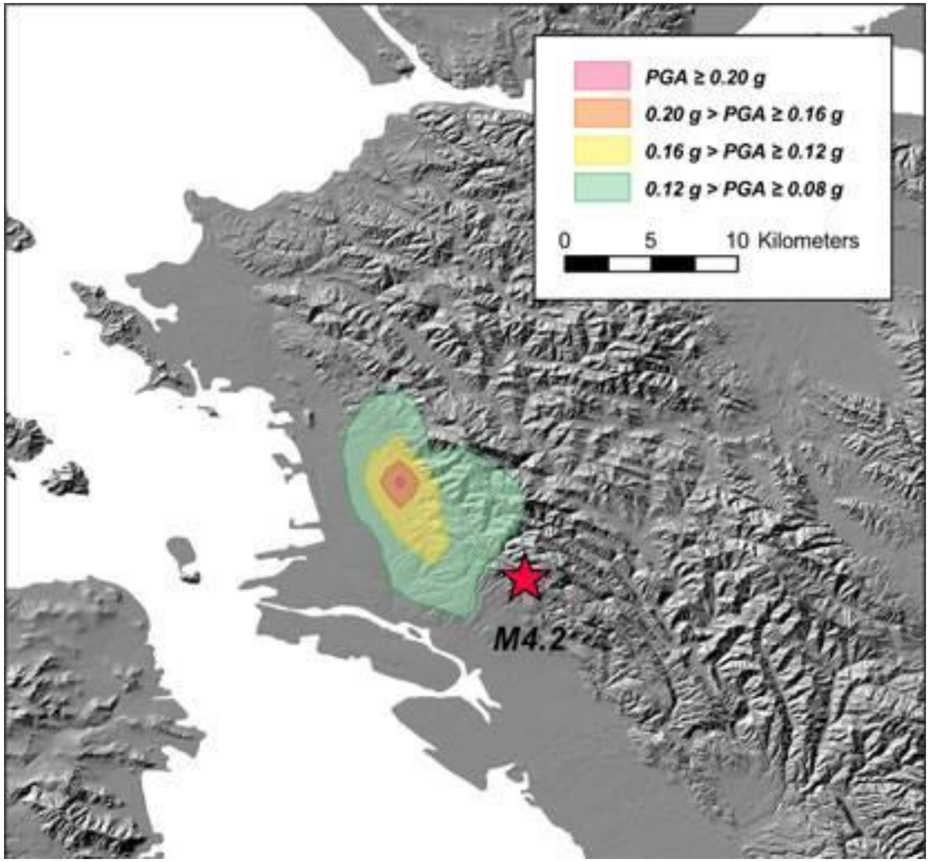


Predicting ground motions for future earthquakes is a major task for seismic hazard assessment.

Rupture directivity has significant effects on ground motions, not only for the larger earthquake, but also in case of smaller earthquake.







Peak accelerations and epicenter from the *M*4.2 Piedmont earthquake of July 20, 2007. Similar to the other map, the distribution is asymmetrical, with higher values in the northwest, along the strike of the fault.

For Small earthquake

- the 11 May 2011 *M*w 5.2 Lorca, Spain, earthquake (Lopez-Comino et al., 2012),
- three 2012 moderate earthquakes (*M* 4.2, *M* 4.9 and *M* 5.4) in Northern Italy (Convertito and Emolo, 2012)
- seven 3.5≤*M*≤4.1earthquakes in November 2002 and February 2003 near San Ramon, California (Boatwright, 2007),
- a large number of small earthquakes (2<*M*<5) at Parkfield (Kane et al., 2013), numerous microearthquakes (*M* 0.5~3.0) on the San Andreas fault (Wang and Rubin, 2011)
- …

What will happen if the small earthquake selected as Empirical Green's Function Method for ground-motion simulation?

Method

Two-step stochastic EGF method (Kohrs-Sansorny *et al*., 2005)

$$S_i(t) = ESTF_i(t) * s(t) \qquad (1)$$

$$ESTF_i(t) = \kappa \sum_{d=1}^{\eta_d} \sum_{c=1}^{\eta_c} \delta(t - t_c(i) - t_d(i)) \qquad (2)$$

$$\eta = \eta_c \eta_d, \kappa = C/N$$

Scaling relation of source parameters ($M_0 \propto \Delta\Sigma \cdot F_c^{-3}$)

Scaling relation of source spectra (ω^{-2} model)

$$N = f_c / F_c, C = \Delta\Sigma / \Delta\sigma, CN^3 = M_0 / m_0$$

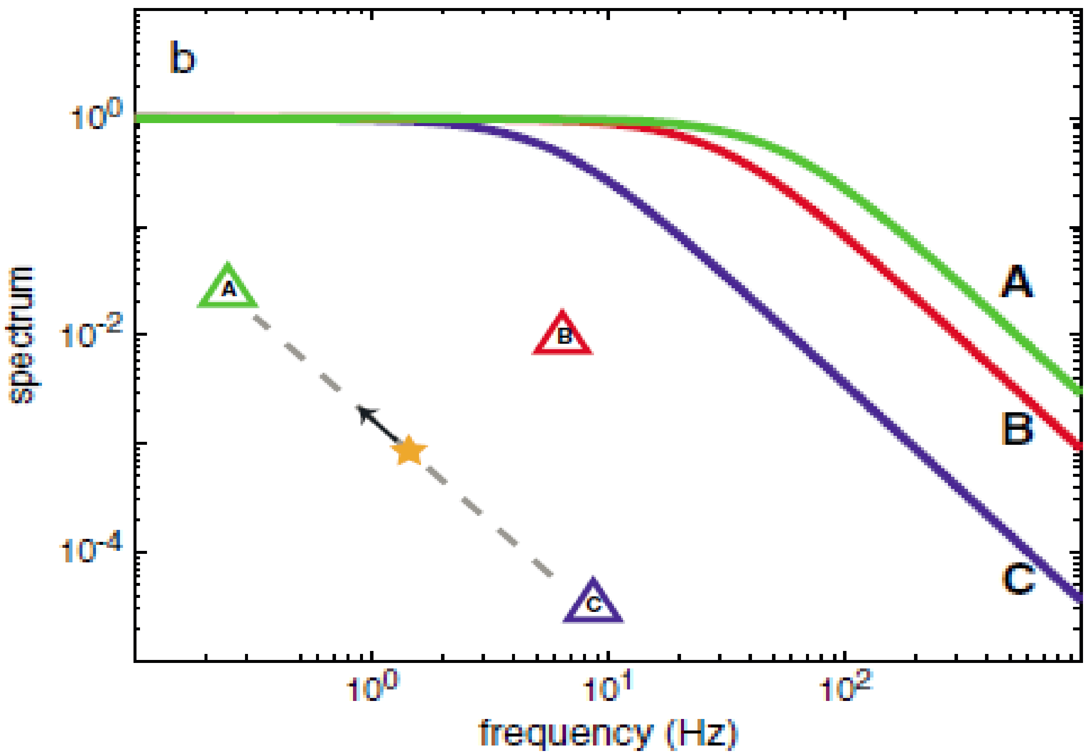
Method

Advantages:

1. *Fewer input parameters* (*Seismic moment , stress drop ratio*)
2. *More realistic and significantly different ground motions*

Disadvantages:

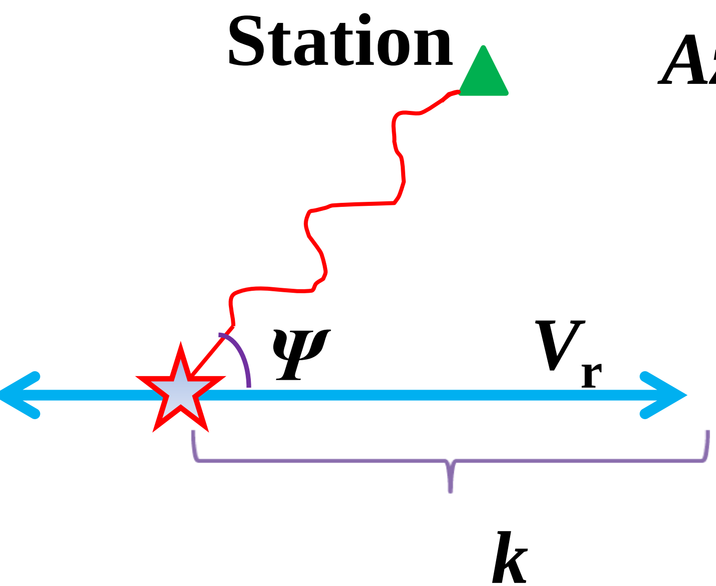
This method can not account for possible directivity effects due to the point-source hypothesis



Displacement source spectrum platforum is same; corner frequency is changed with the spatial location

Method

How to consider the directivity ?



is the proportion of rupture

Azimuthal apparent corner frequency f_a

$$f_{\mathrm{a}} = D \cdot f_{\mathrm{c}}$$

$$D = \left[\left(\frac{k^2}{1 - \frac{v_{\mathrm{r}}}{c} \cos\psi} \right) + \left(\frac{(1-k)^2}{1 + \frac{v_{\mathrm{r}}}{c} \cos\psi} \right) \right]^{1/4}$$

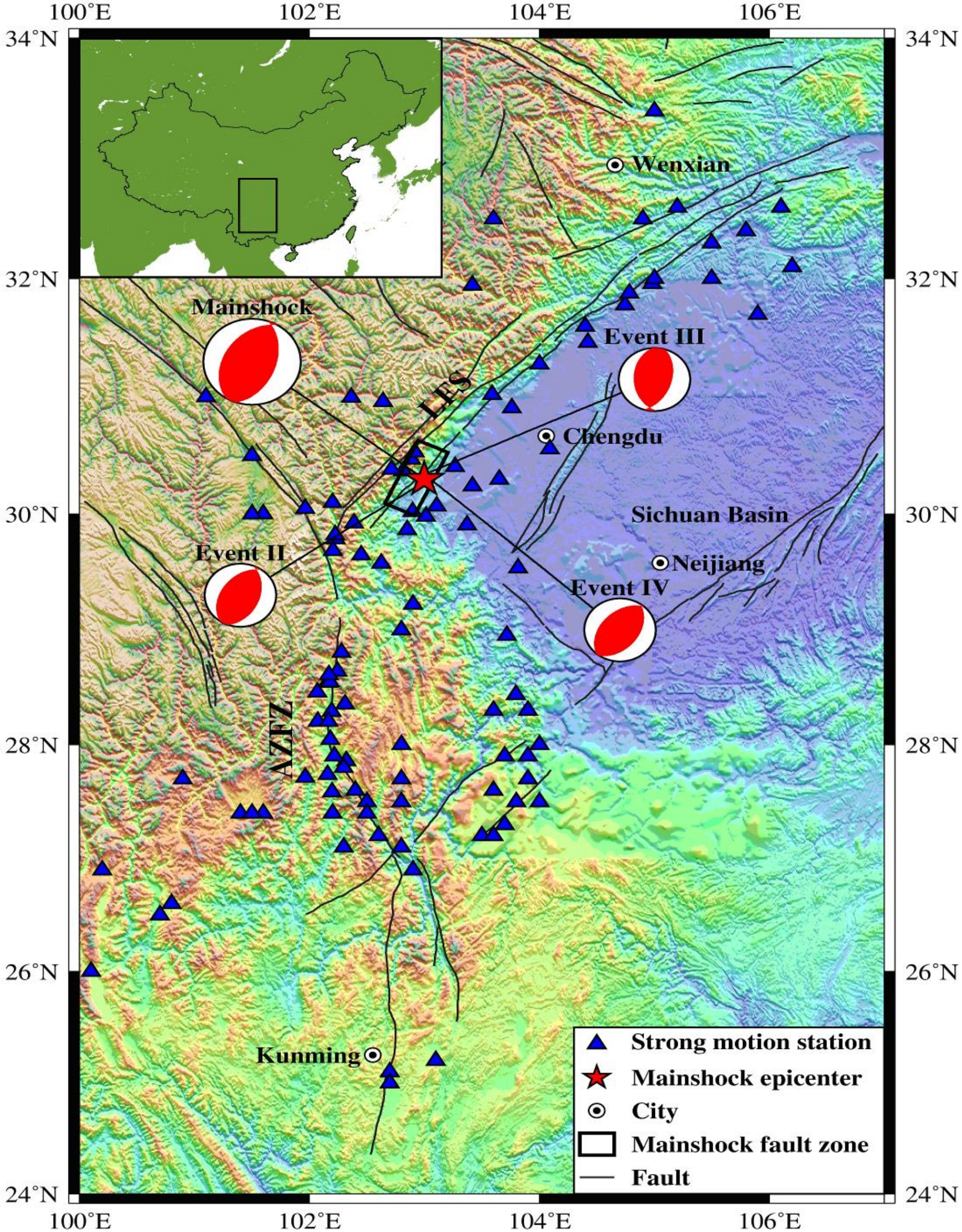
Method

New parameters N_a and C_a substitute for N and C

Smaller earthquake as EGF:

$$N_\mathrm{a} = D \cdot N,\ \ C_a = C / D^3$$

Strong-Motion Recordings of the 2013 Lushan Earthquake



The surface fault projection of the fault plane was inverted for by Wang *et al*. (2013). Although the Lushan mainshock did not show a dominant rupture direction (Zhang et al., 2013), the large number of recordings of the Lushan aftershocks met the engineering requirements for determining the directivity effect of smaller earthquakes.

Basic Seismic Parameters of the Lushan Mainshock and the Four Aftershocks

Date (yyyy/mm/dd)	Time (Beijing Time) (hh:mm:ss)	Latitude (° N)	Longitude (° E)	Focal Depth (km)	M	M_W	First Nodal Plane (Strike/Dip/Rake) (°)	Second Nodal Plane (Strike/Dip/Rake) (°)
2013/04/20	08:02:46	30.30	103.00	13.0	7.0	6.6	212/42/100	19/49/81
						6.7*	205.0/38.5/88.0*	26.5/51.5/91.2*
2013/04/20	08:07:30	30.32	102.92	10.0	5.4	-	-	-
2013/04/20	11:34:17	30.24	102.94	15.0	5.4	5.4	215/45/100	21/46/80
2013/04/21	04:53:44	30.36	103.05	27.0	5.4	4.8	177/42/74	17/50/103
2013/04/21	17:05:24	30.34	103.00	17.0	5.4	5.2	221/45/94	35/45/86

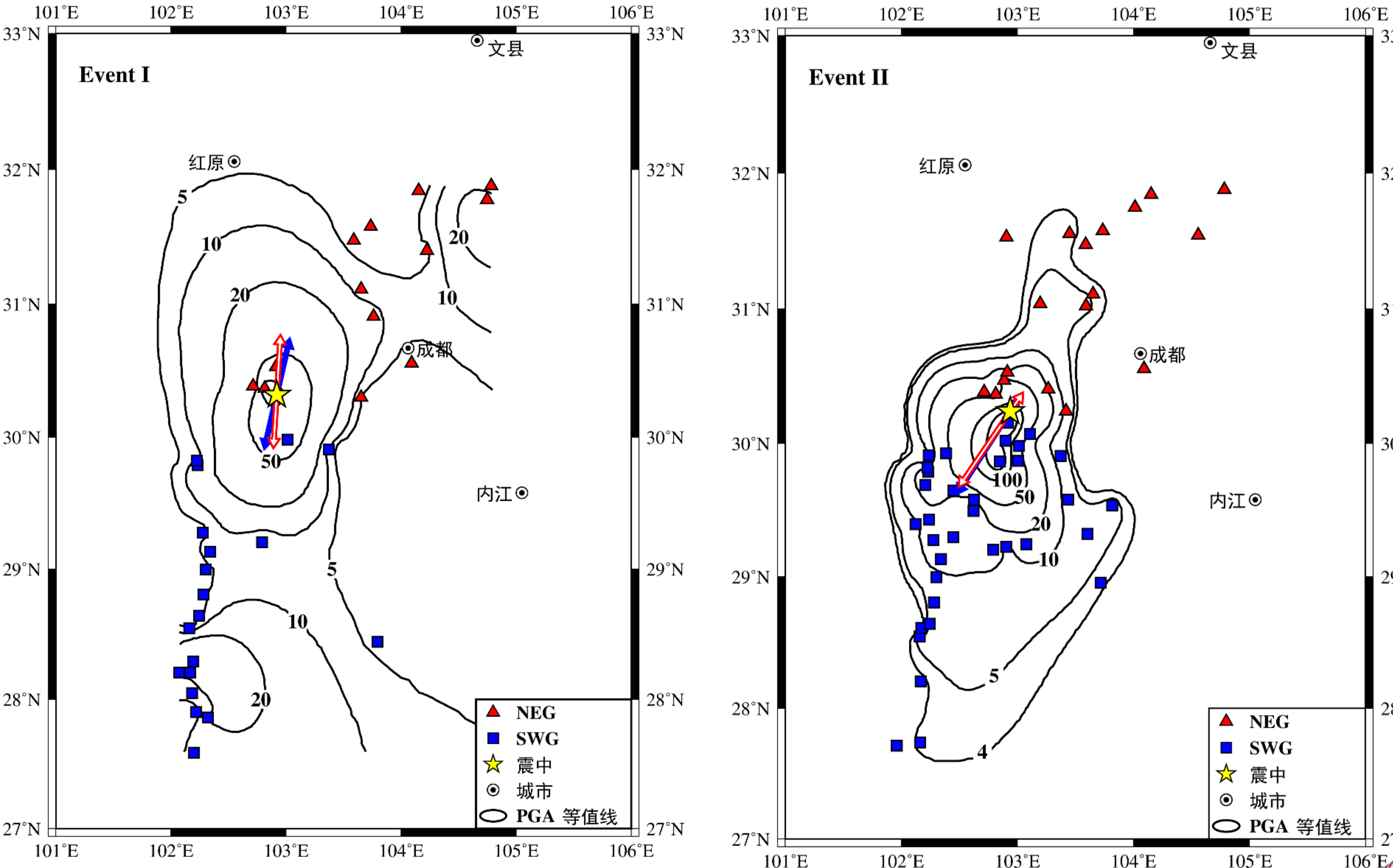
Rupture Parameters of the Four Events That Were Independently Inverted Using PGA and PGV

Event	Peak Parameter	φ	v_r/c	K	e
I	PGA	3.6 ± 27.5	0.66 ± 0.13	0.53 ± 0.18	0.06 ± 0.36
	PGV	12.9 ± 12.5	0.67 ± 0.07	0.51 ± 0.08	0.02 ± 0.16
II	PGA	214.2 ± 11.6	0.61 ± 0.04	0.80 ± 0.07	0.60 ± 0.14
	PGV	212.9 ± 3.3	0.64 ± 0.02	0.86 ± 0.02	0.72 ± 0.04
III	PGA	206.5 ± 5.1	0.69 ± 0.02	0.89 ± 0.04	0.78 ± 0.08
	PGV	199.2 ± 5.2	0.67 ± 0.01	0.97 ± 0.01	0.94 ± 0.02
IV	PGA	43.8 ± 7.7	0.55 ± 0.04	0.53 ± 0.03	0.06 ± 0.06
	PGV	59.2 ± 4.1	0.59 ± 0.02	0.55 ± 0.03	0.10 ± 0.06

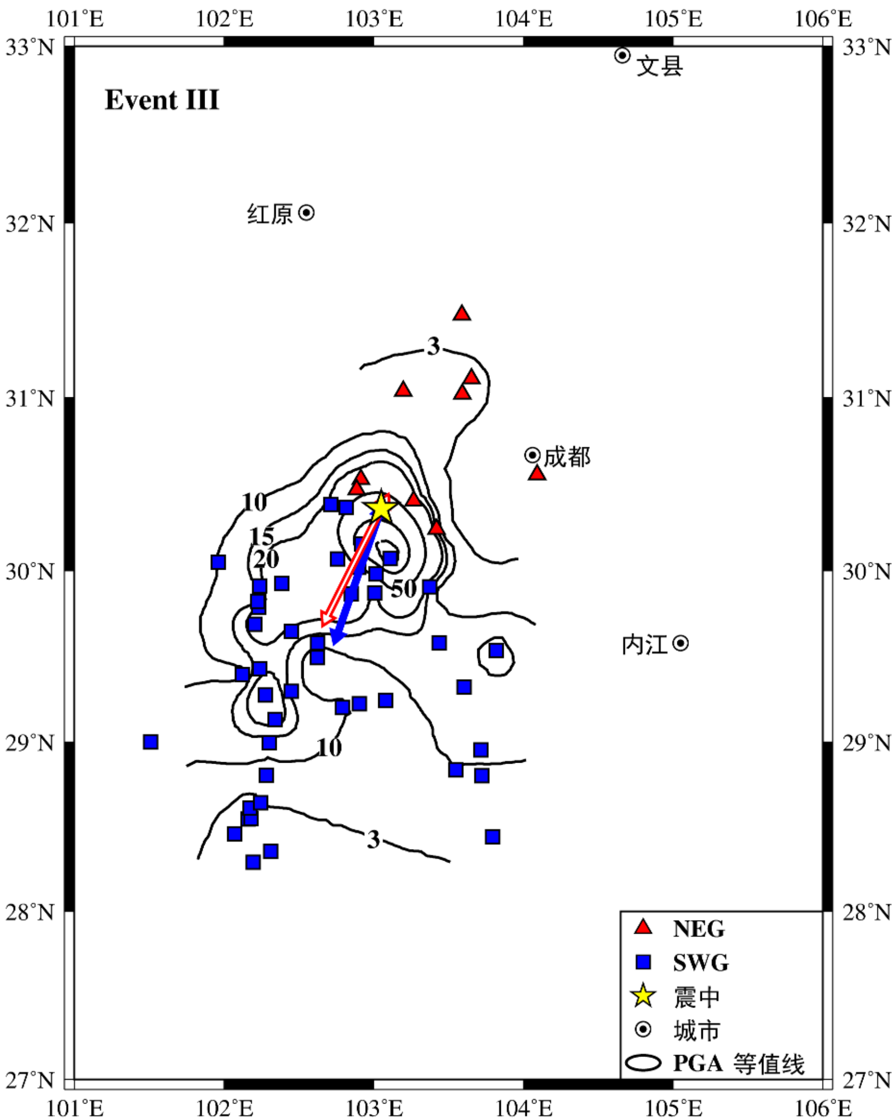
PGA, peak ground acceleration; PGV, peak ground velocity; φ, rupture direction; v_r, rupture velocity; c, shear-wave velocity; k, proportion of rupture in one direction; e, directivity ratio.

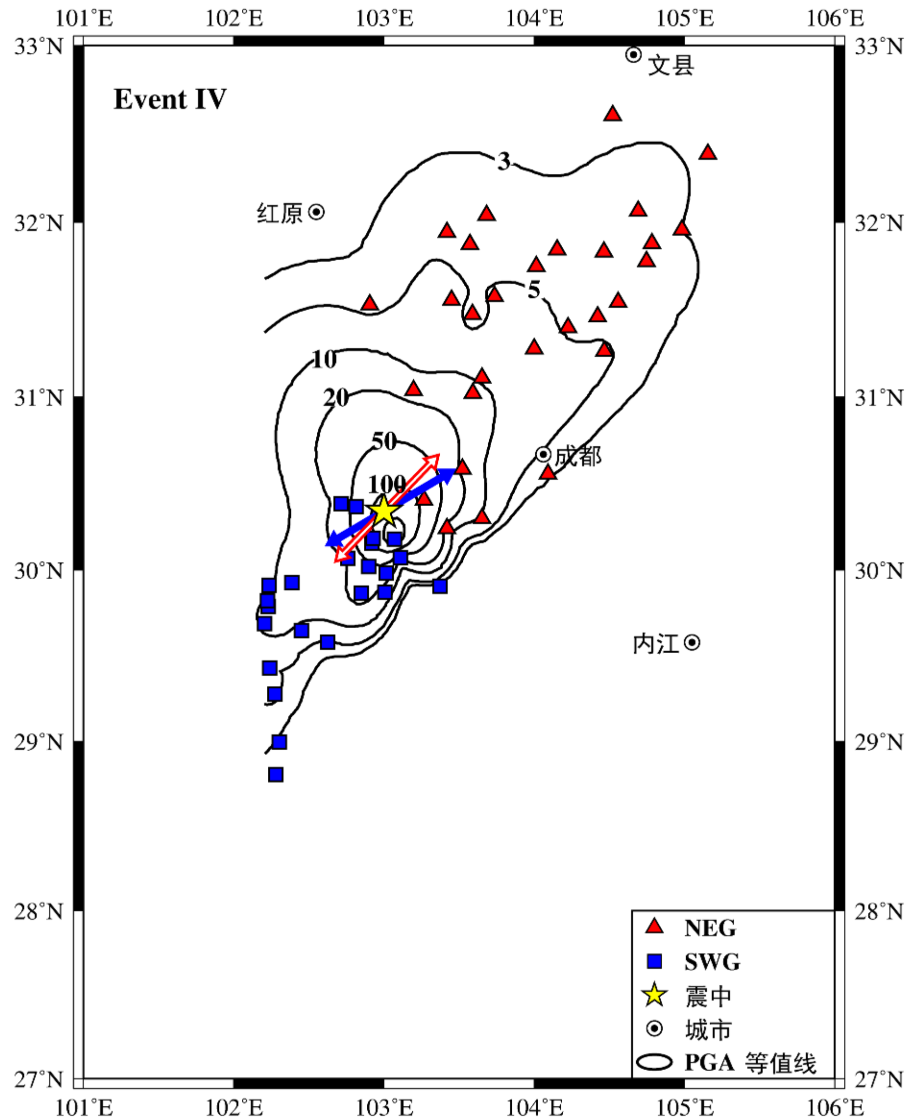
Wen et al, BSSA,Vol. 105, No. 6

Triggered strong-motion stations

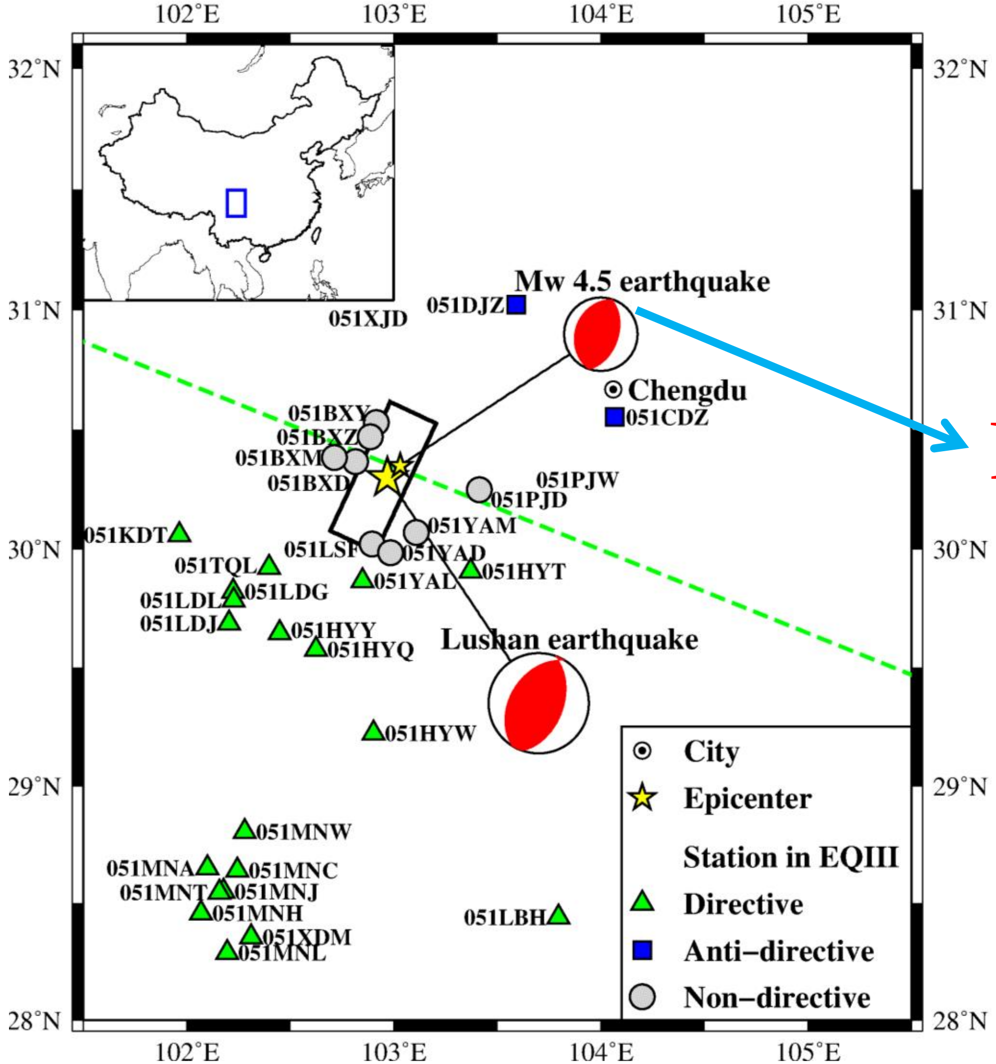


Triggered strong-motion stations





Simulating directivity



Rupture directivity !

Simulating directivity

- Source of the Lushan M_w 6.6 earthquake only includes an asperity
- Regarding M_w 4.5 earthquake as EGF
- Stress drop was determined according to statistical scaling relations, the stress drop ratio C=2.18

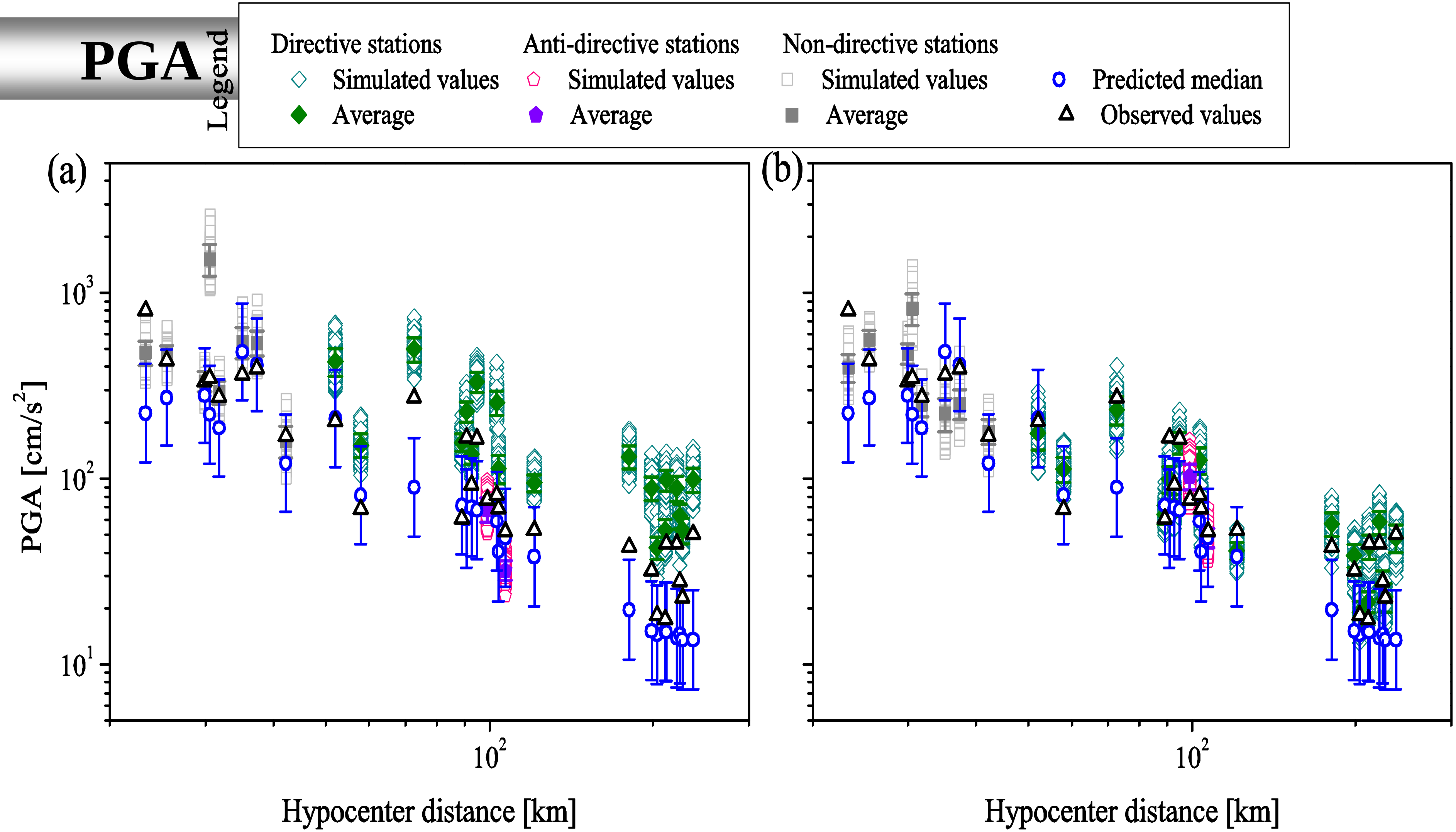
Simulating directivity

Ground motions produced by the Lushan earthquake were simulated in 200 realizations in two cases.

The first case was that rupture directivity was not considered, a constant f_c was used.
The other case was that varied f_a was adopted to consider the rupture directivity

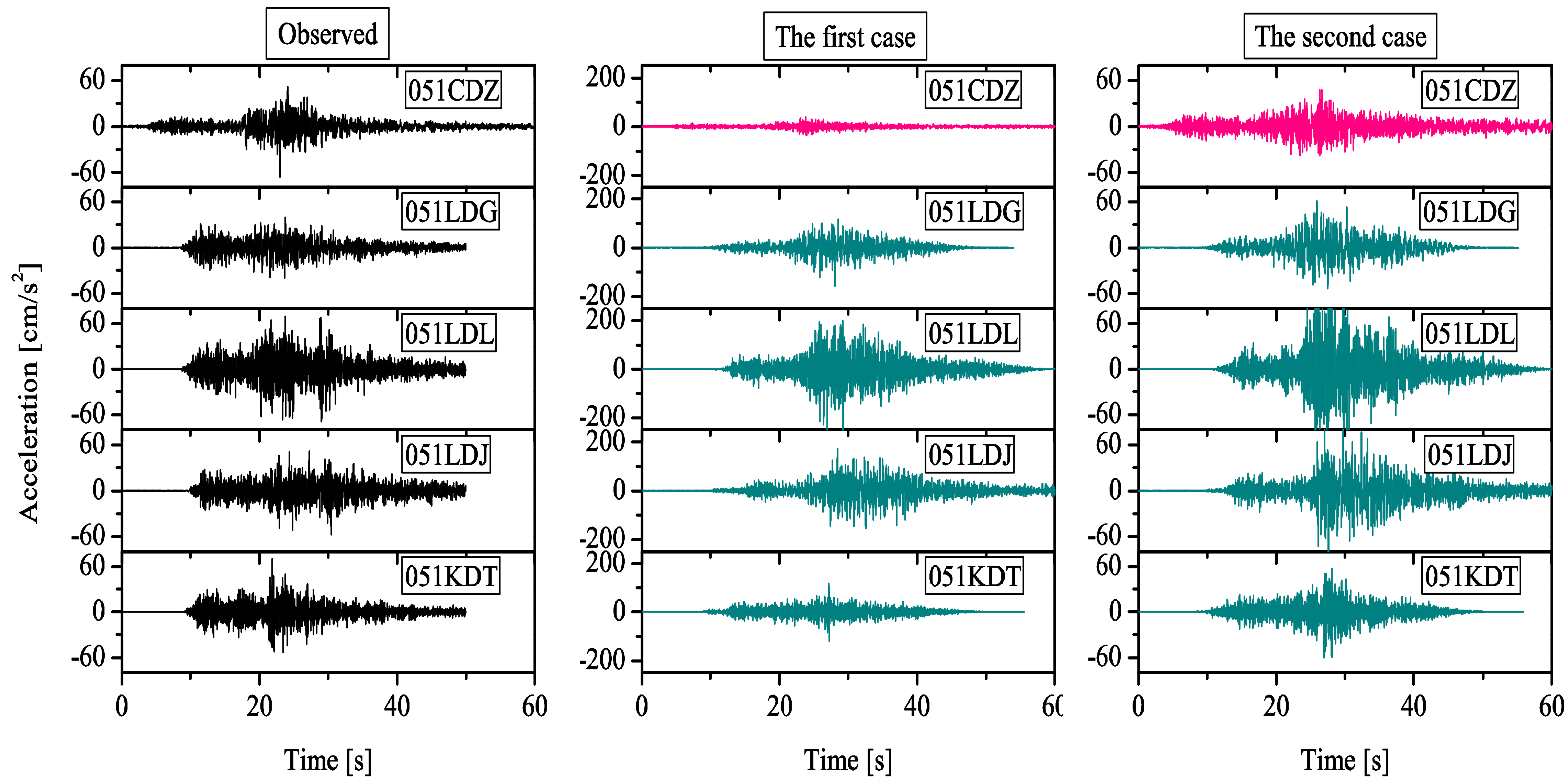
Simulating directivity

PGA



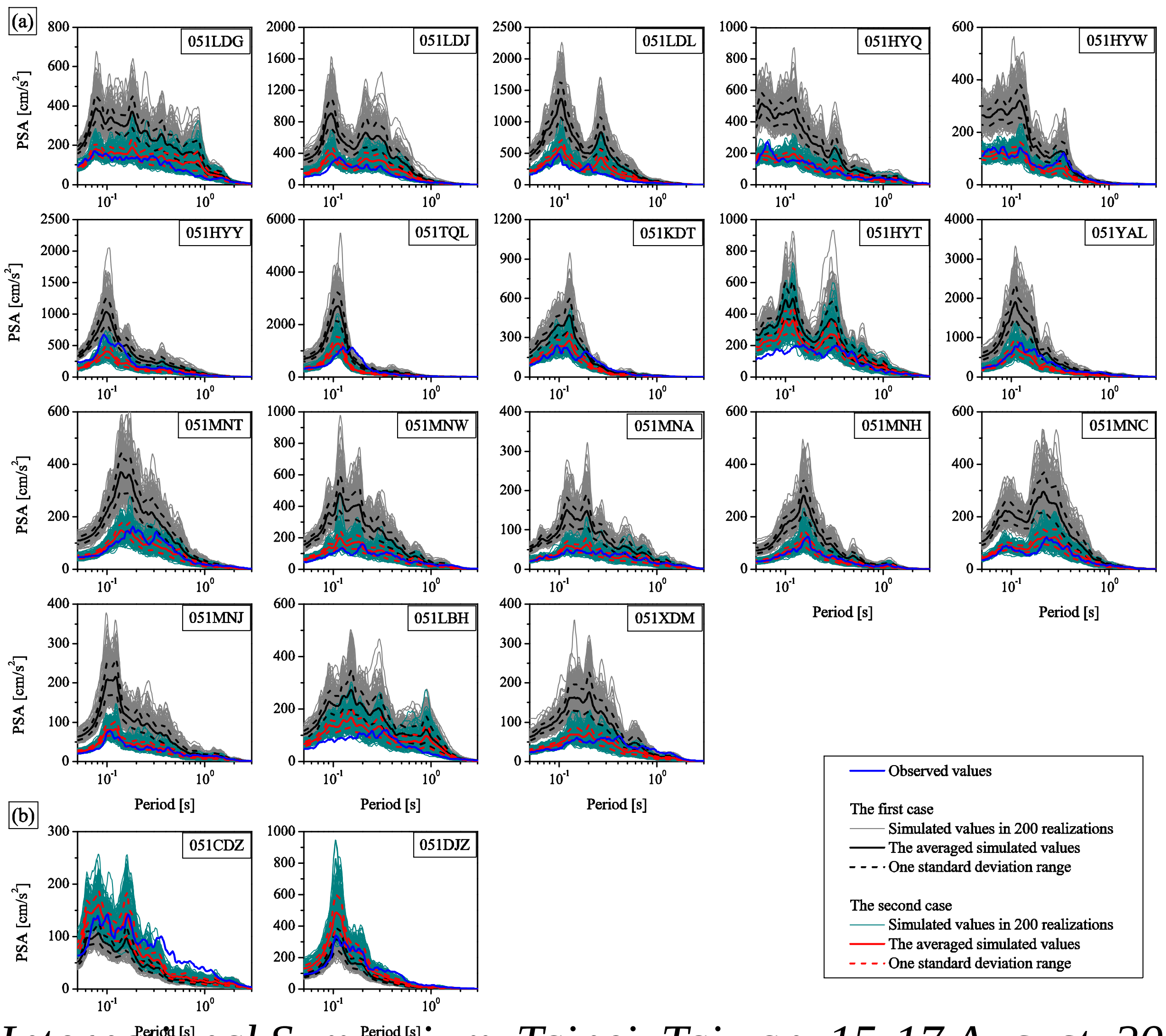
Simulating directivity

Waveform



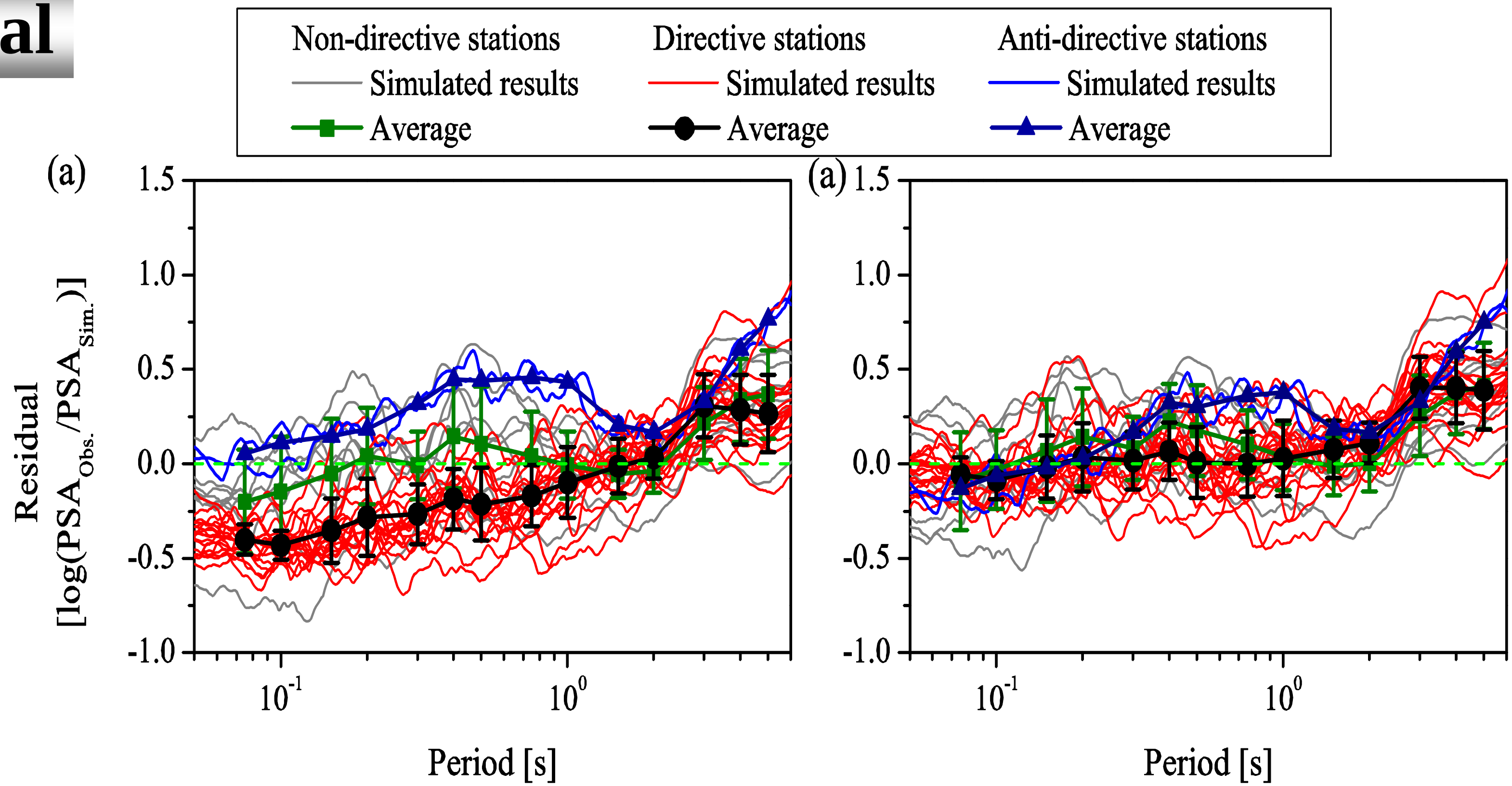
Simulating directivity

PSA



Simulating directivity

Residual



Short-period directivity was simulated well !

Conclusion

1. More significant impacts are exposed on ground motions at directive stations

2. Rupture directivity mainly exerts significant influences on simulated short-period (<2.0s) ground motions

3. High-frequency directivity is successfully simulated using the azimuthal apparent corner frequency

4. Rupture directivity of small earthquake can be used as a condition to select appropriate recordings as EGF

Thank you for your listening !