Synthesis of high-frequency ground motion using Empirical Green's Functions

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Workshop on Seismic Hazard Assessment Issues in the island arc of Taiwan and Japan

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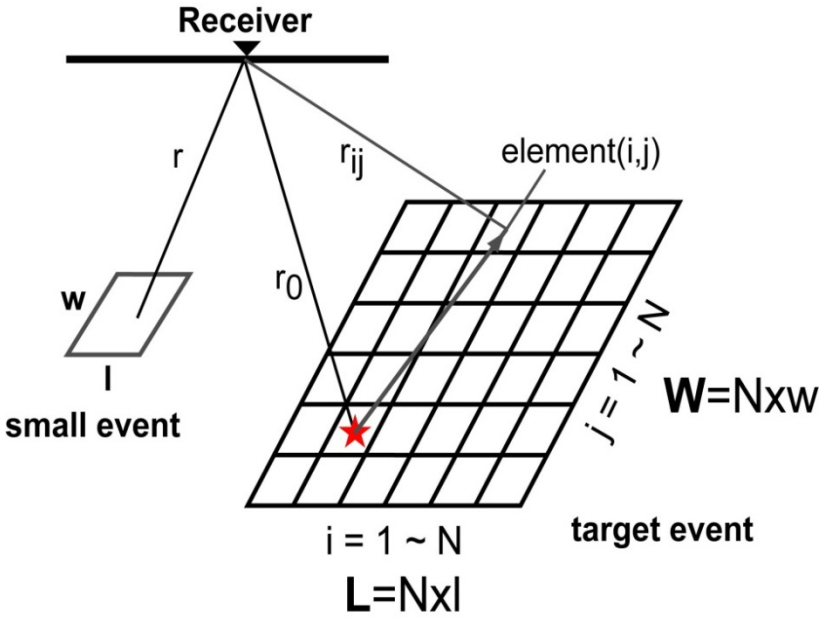
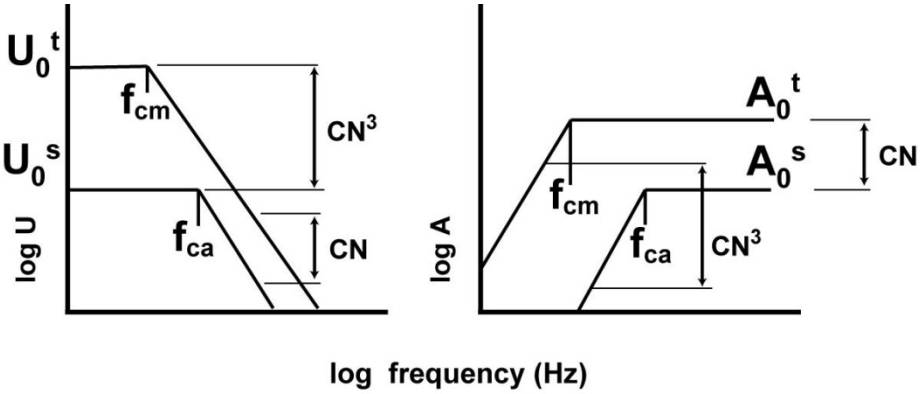
------ OUTLINE ------

- **The introductory of the research and application of Empirical Green's Function Method (EGFM)**
  - Two moderate earthquakes in the southwest Taiwan
  - 2006 Pingtung earthquake
- **The progress of ground motion prediction**
  - Broadband ground motion simulation with the Hybrid method
  - Target sources and specific sites

Empirical Green's Function method

Characterized source model - strong motion generation area, SMGA





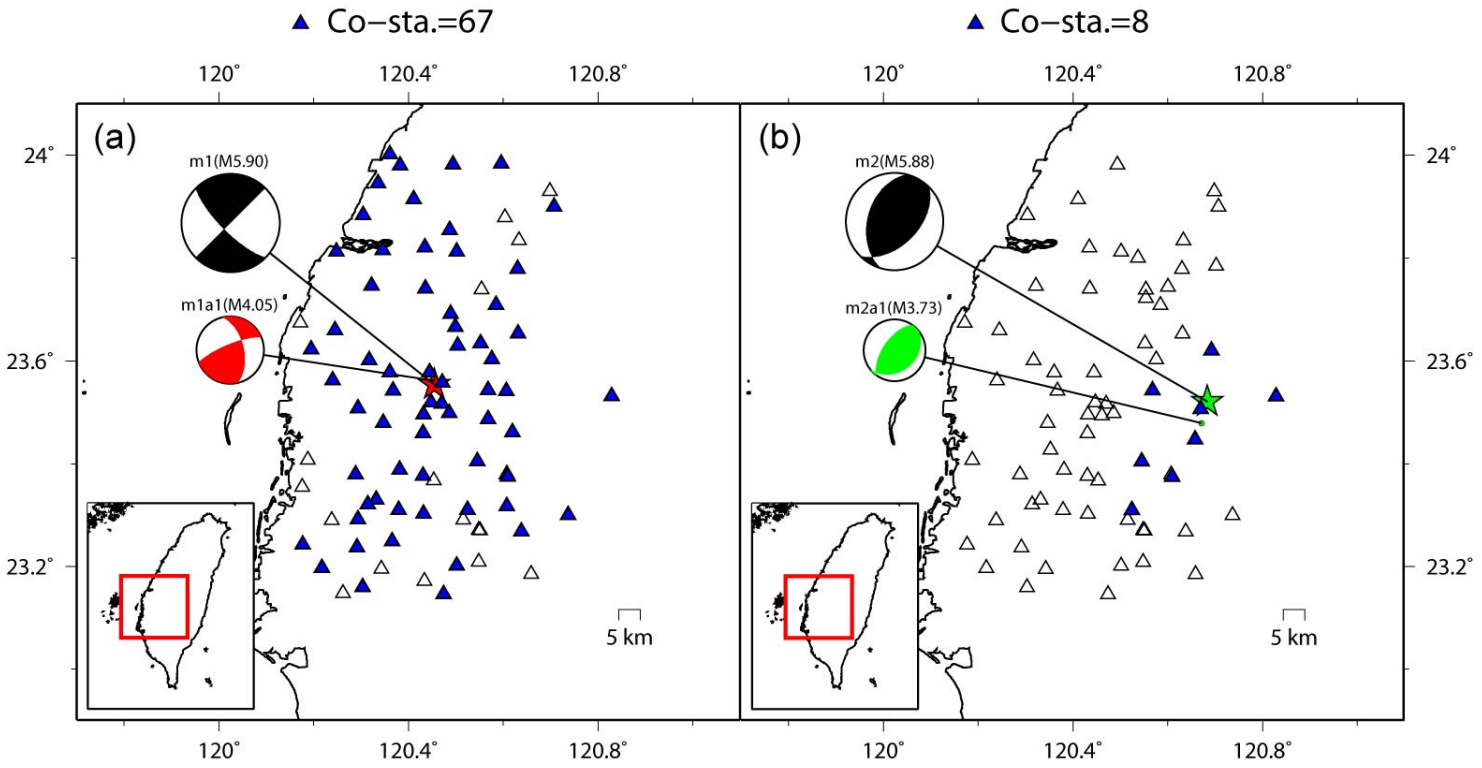
$$\frac{U_0^{\,t}}{U_0^{\,s}} = \frac{M_0^{\,t}}{M_0^{\,s}} = CN^3 \qquad \frac{A_0^{\,t}}{A_0^{\,s}} = CN \qquad \left(\frac{M_0^{\,t}}{M_0^{\,s}}\right)\left(\frac{f_{cm}}{f_{ca}}\right)^2 = CN$$

$$U(t) = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{r}{r_{ij}} F(t) * (C\ u(t))$$

(Irikura, 1983;1986; Irikura and Kamae, 1994; Miyake et al., 2003)

Two moderate earthquakes in the southwest Taiwan

NO.	Date (UTC)	Latitude (deg)	Longitude (deg)	depth (km)	ML	Mw	Strike (deg)	Dip (deg)	Rake (deg)
m1	**1999/10/22 03:10**	**120.431**	**23.533**	**16.74**	**6.00**	**5.90**	**45.00**	**90.00**	**0.00**
m1a1	**1999/10/23 21:53**	**120.433**	**23.540**	**14.83**	**4.46**	**4.05**	**346.76**	**56.41**	**16.18**
m2	1998/07/17 04:51	120.662	23.503	2.80	6.20	5.88	45.00	50.00	110.00
m2a1	2004/01/23 07:51	120.648	23.458	13.06	4.34	3.73	51.97	30.37	104.56



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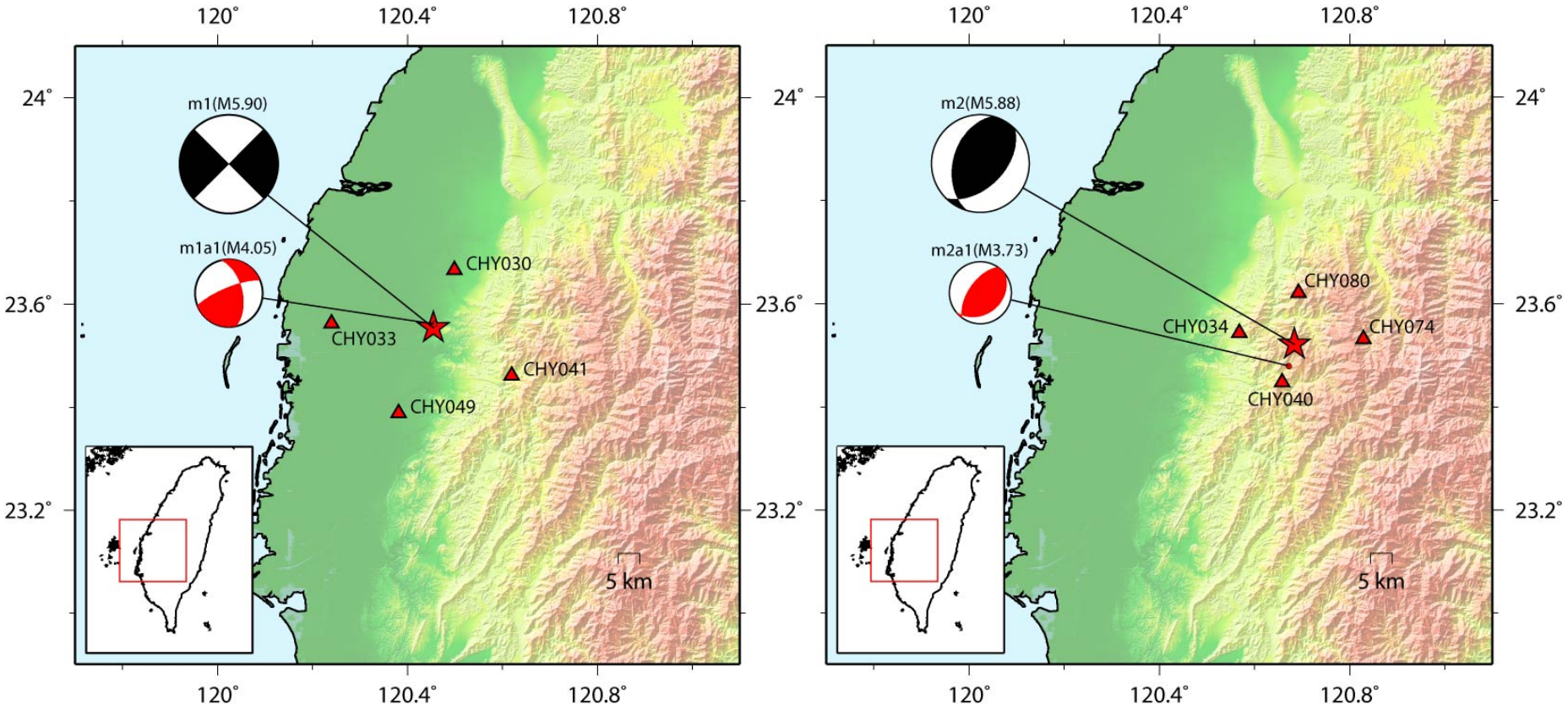
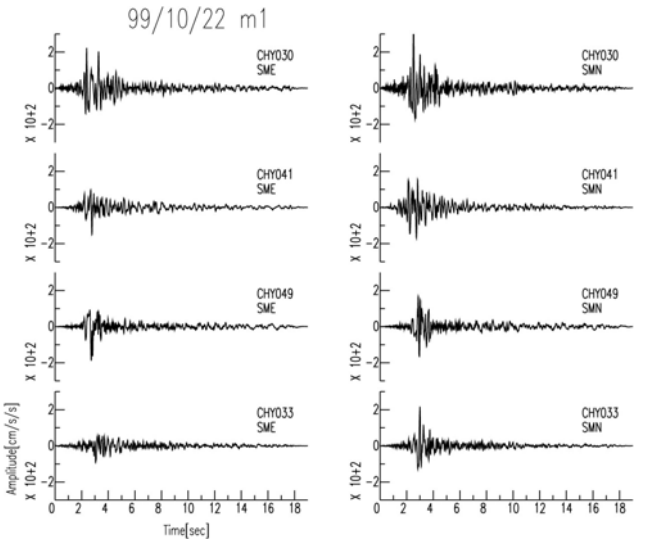
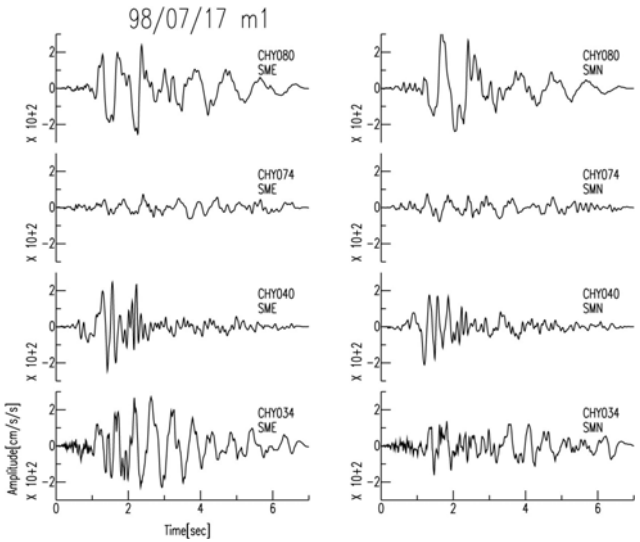
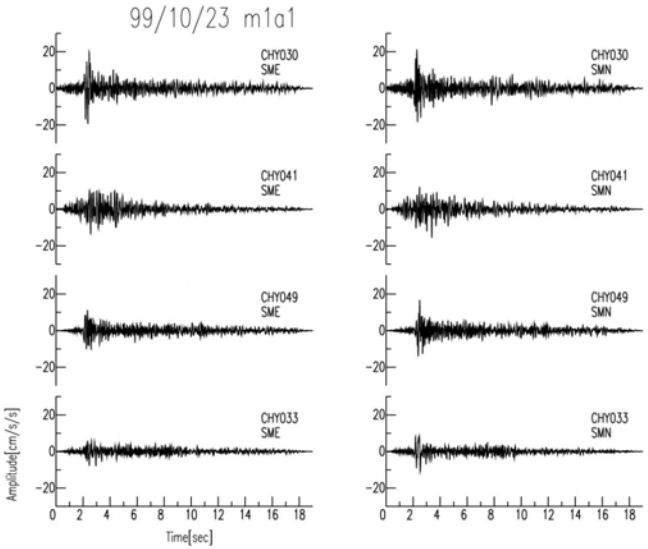
991022 m1 event & 980717 m2 event

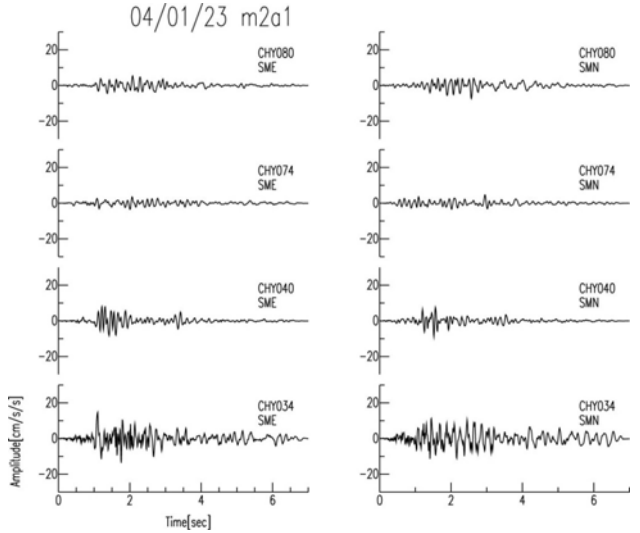


Waveforms of target and small events



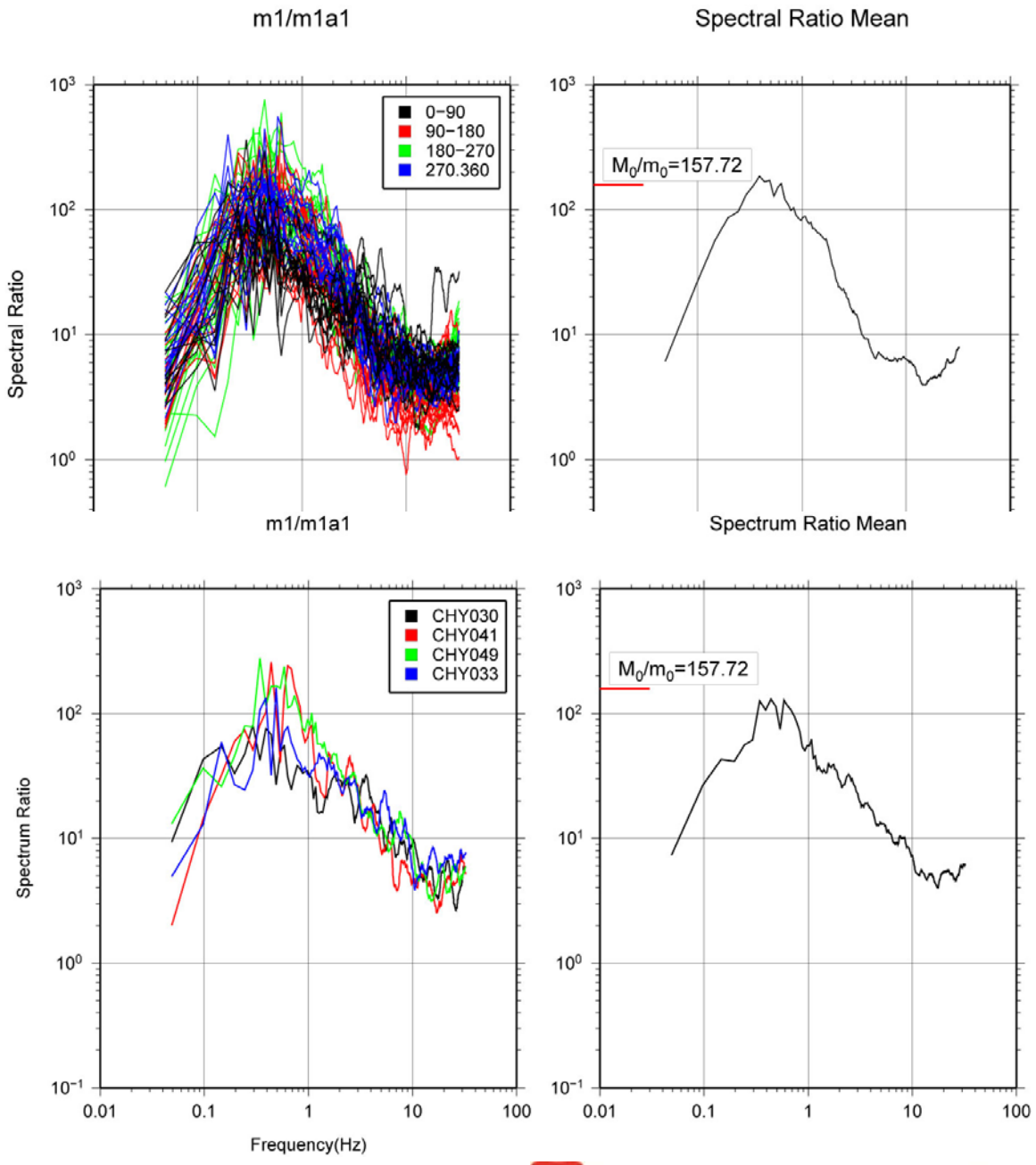






Spectral ratio

The shape of mean spectra using 4 stations is similar the one using 65 stations



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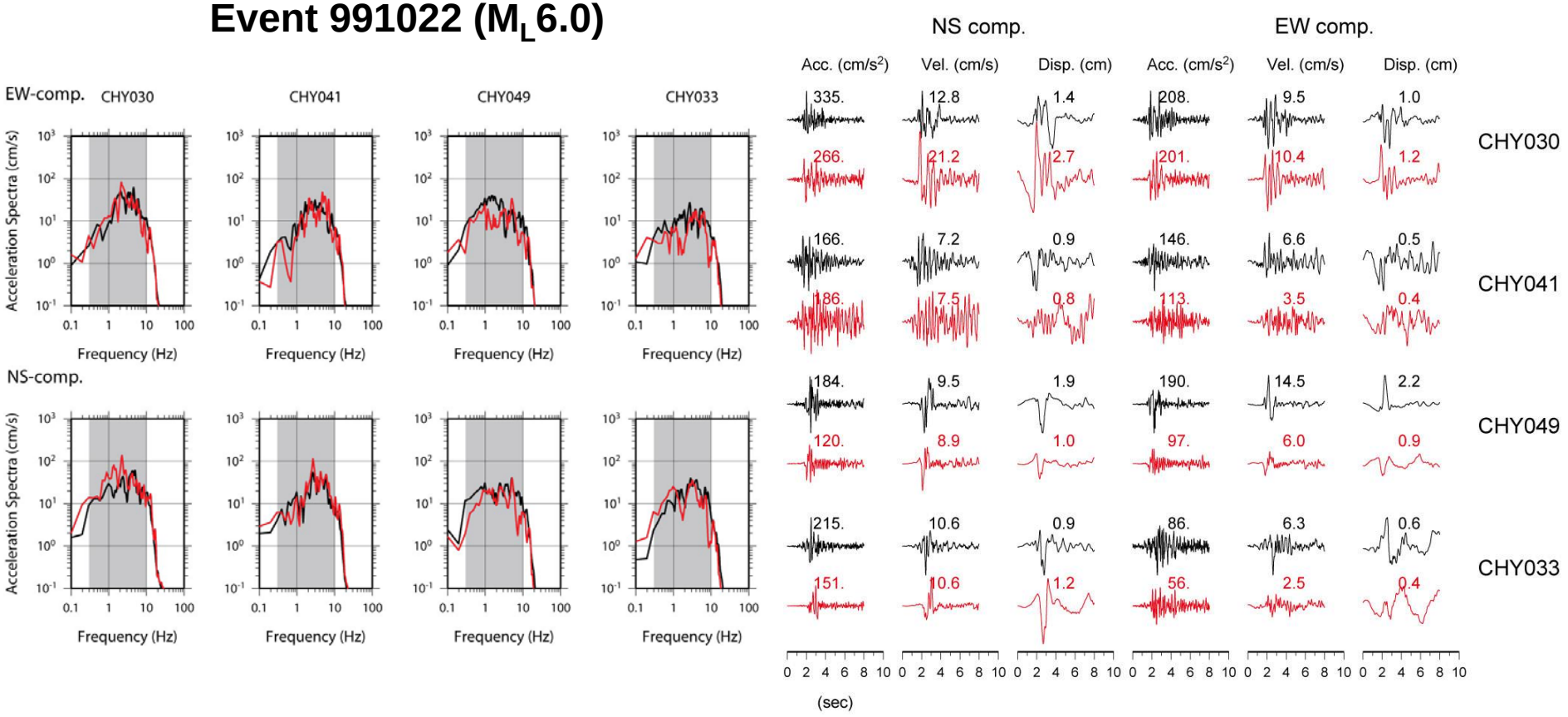
The waveform and spectrum fitting between observed(black) and synthetic(red) ones

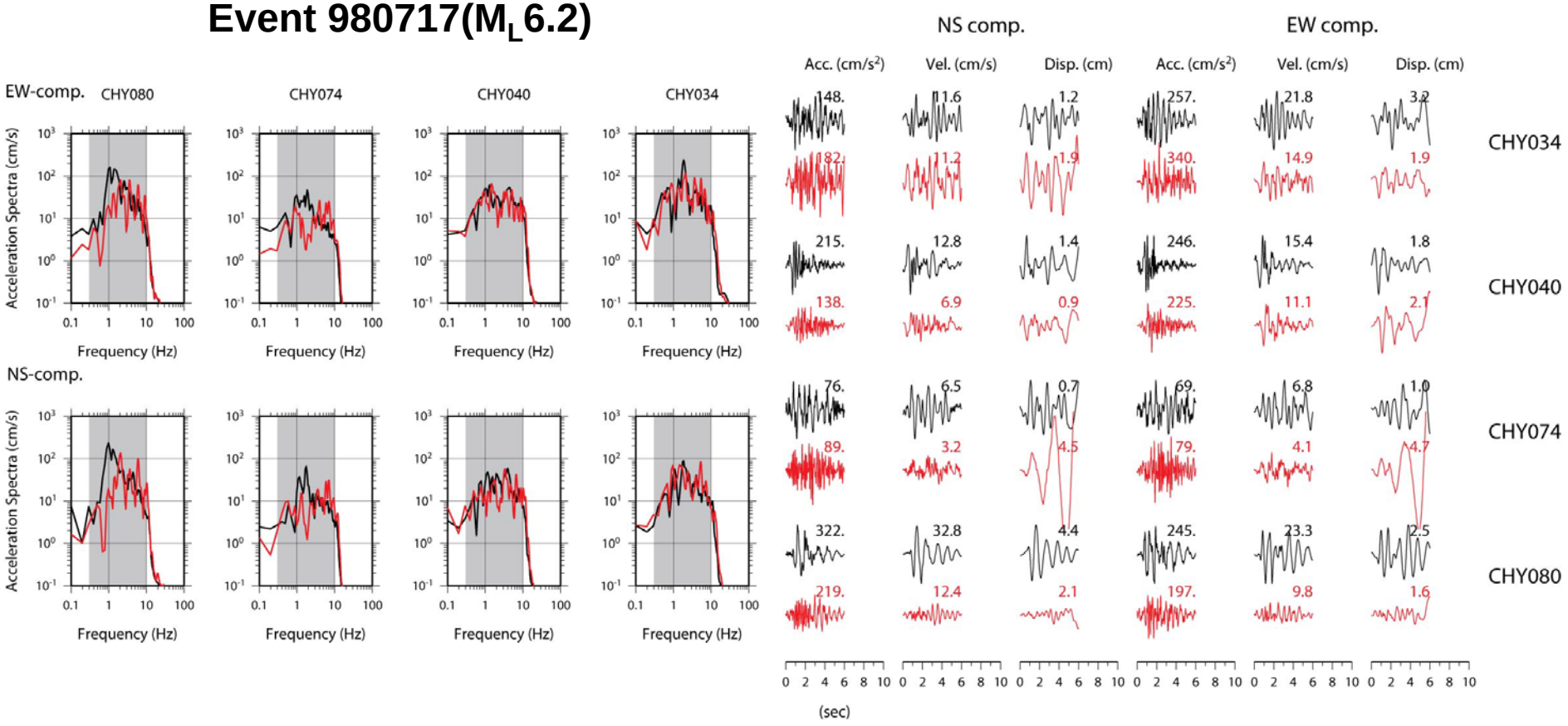
Event 991022 (M_L6.0)



Ref. residual = 12.143

The waveform and spectrum fitting between observed(black) and synthetic(red) ones

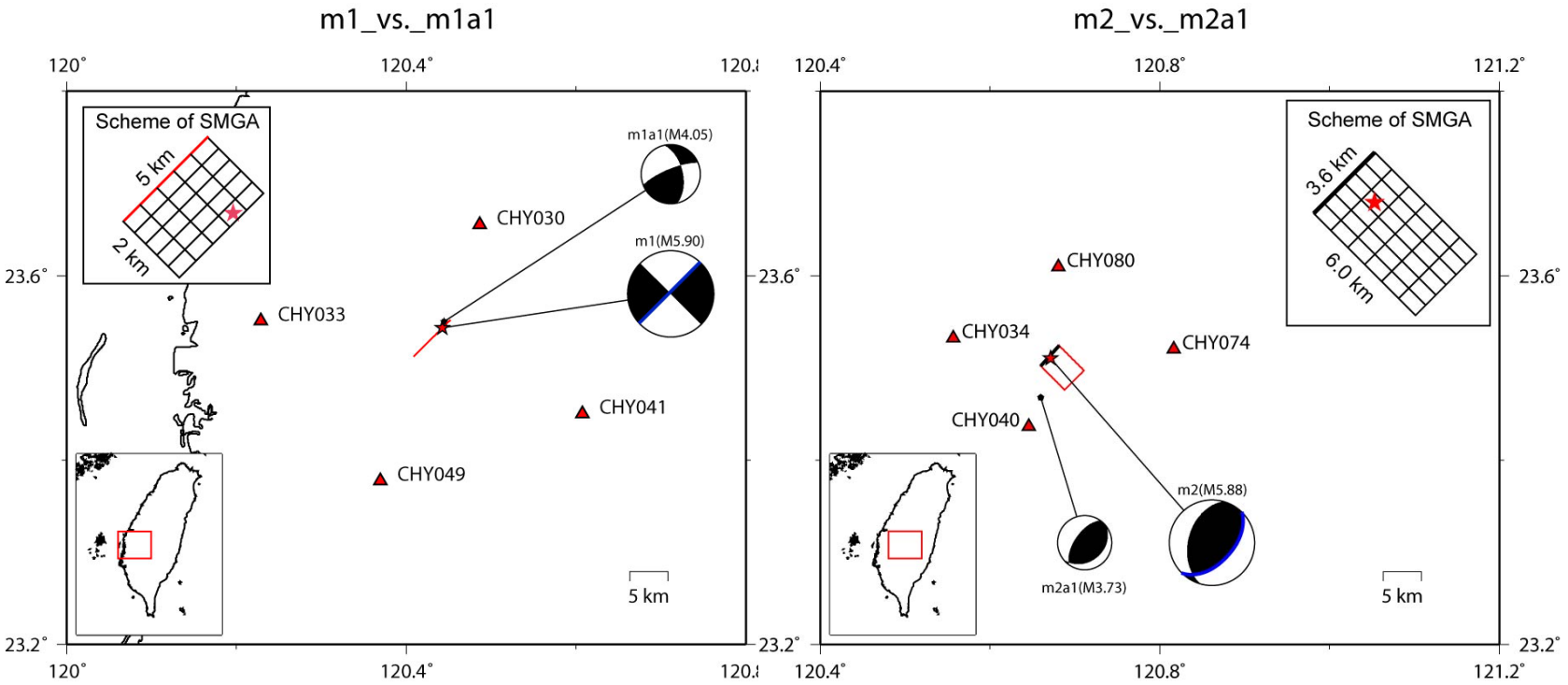
Event 980717(M_L6.2)



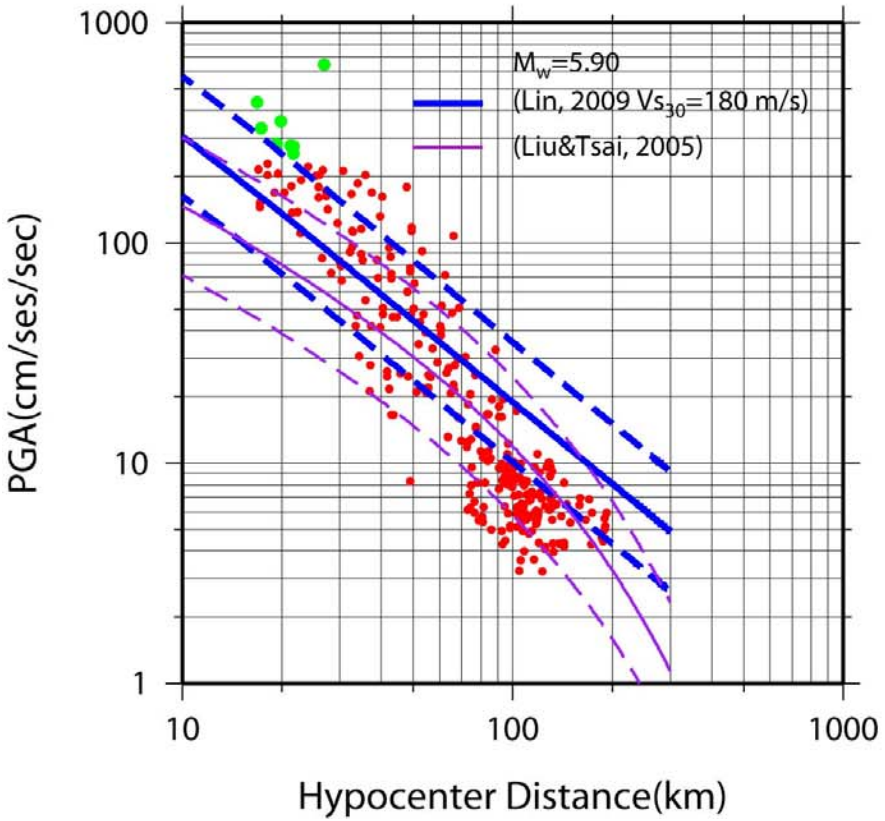
Ref. residual = 19.142

The mapview and scheme of assessed SMGA

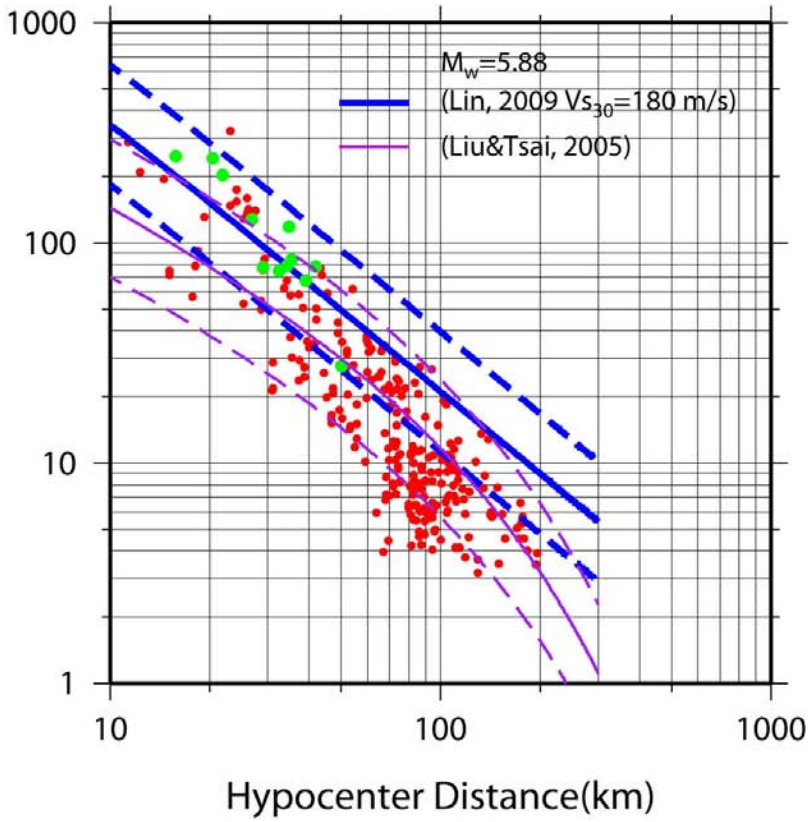
L (km)	W (km)	SMGA (km^2)	stress drop (bar)	Rise time (sec)	Vr (km/s)	Starting Point	Freq. Range (Hz)
5.00	2.00	10.00	**608.60**	0.10	2.84	(4,5)	0.30 - 10.00
3.60	6.00	21.60	**178.61**	0.36	2.80	(4,2)	0.50 - 10.00



Event 991022 (M_L6.0)



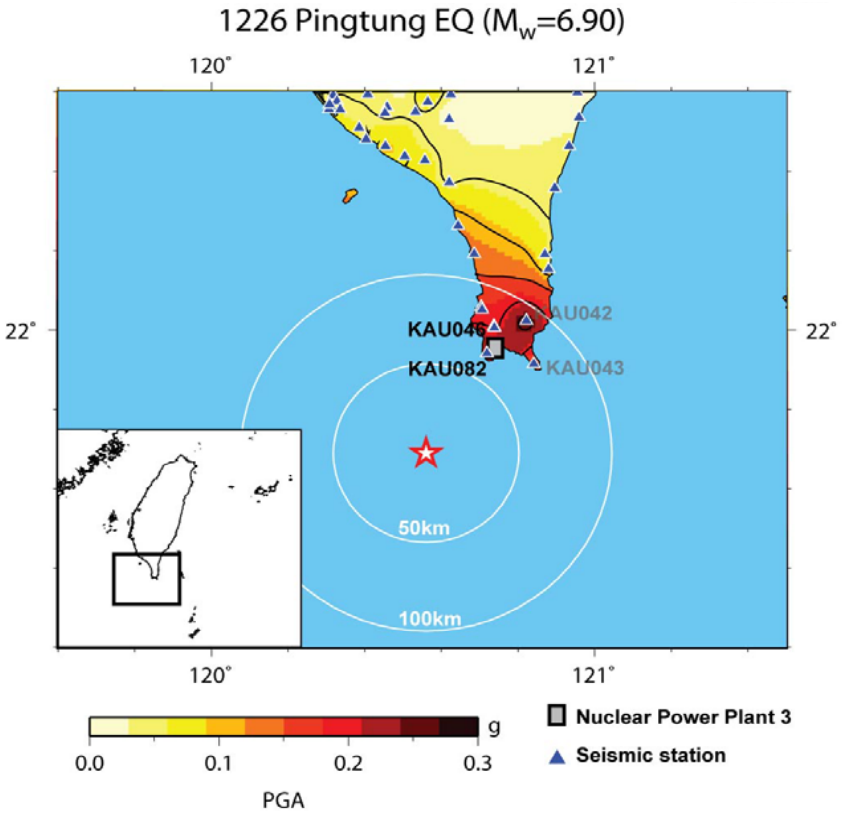
Event 980717(M_L6.2)

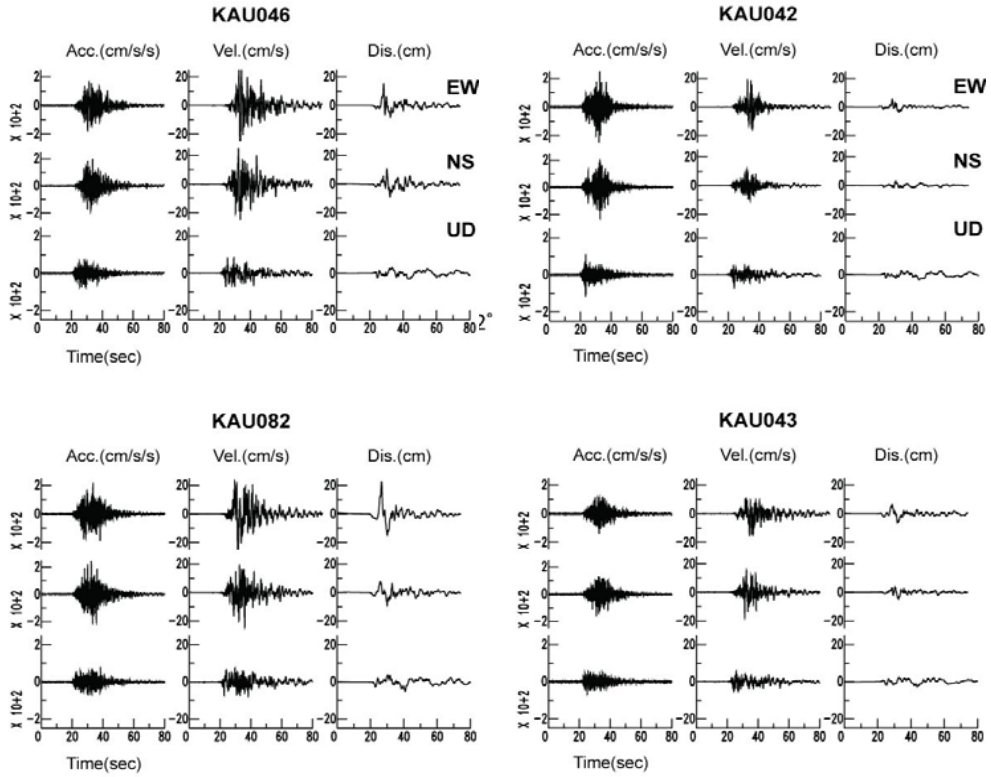


(Yen and Ma, 2011)

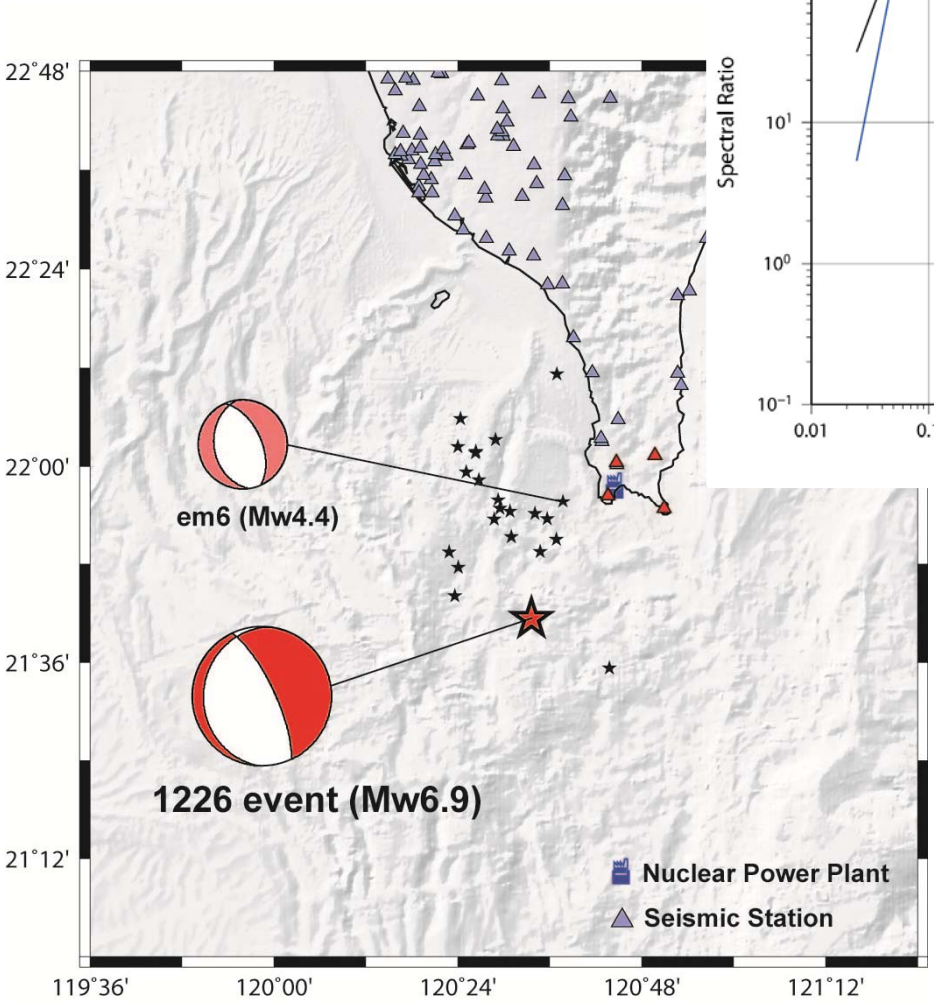
$$\log M_0 = \frac{3}{2}\log A + \log\left(\frac{16}{7\pi^{3/2}}\Delta\sigma\right)$$

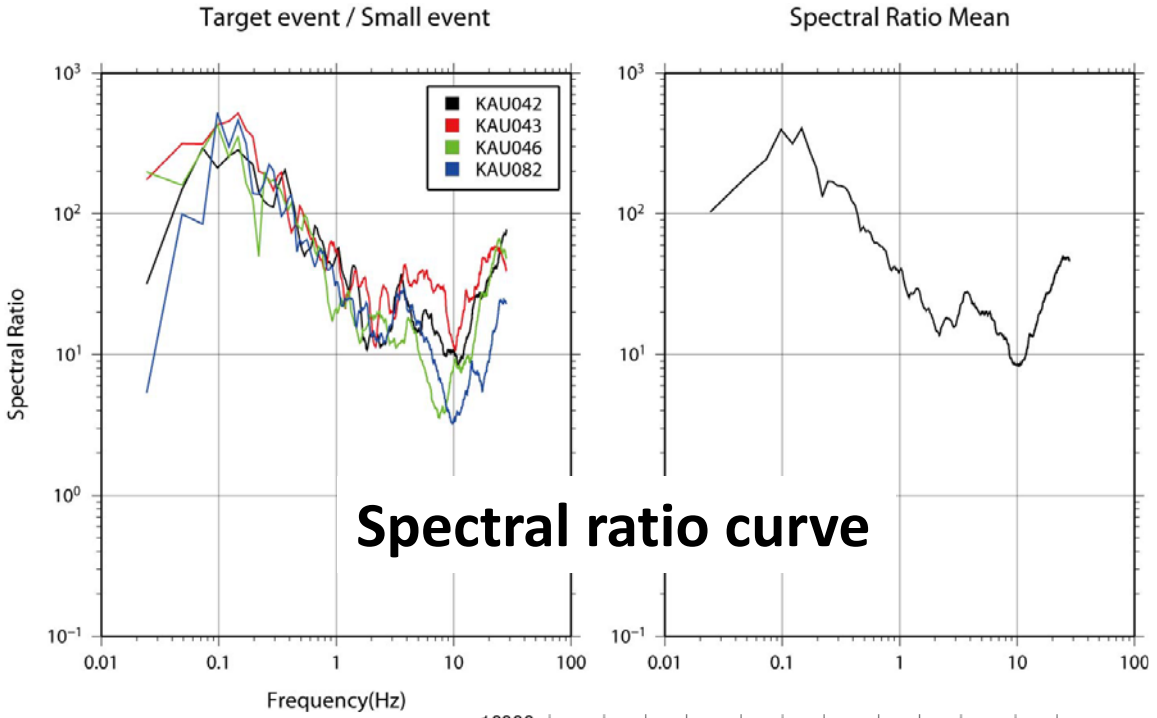
2006 Pingtung earthquake - Observed data



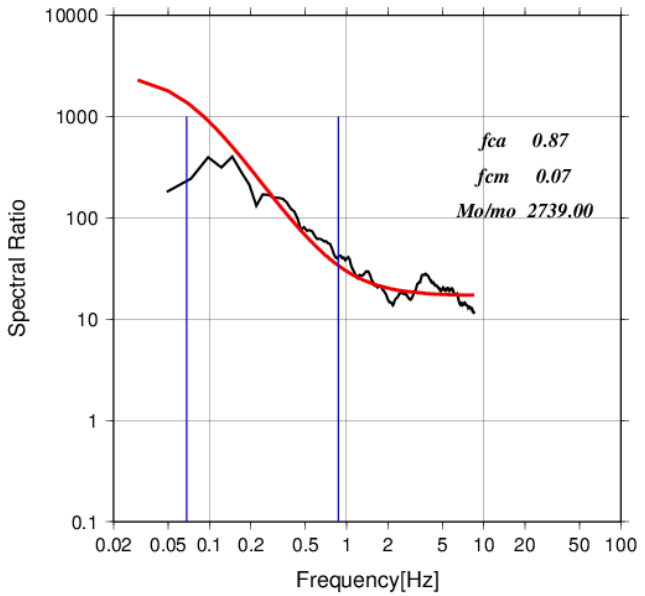


Calculating for the parameters of N, C

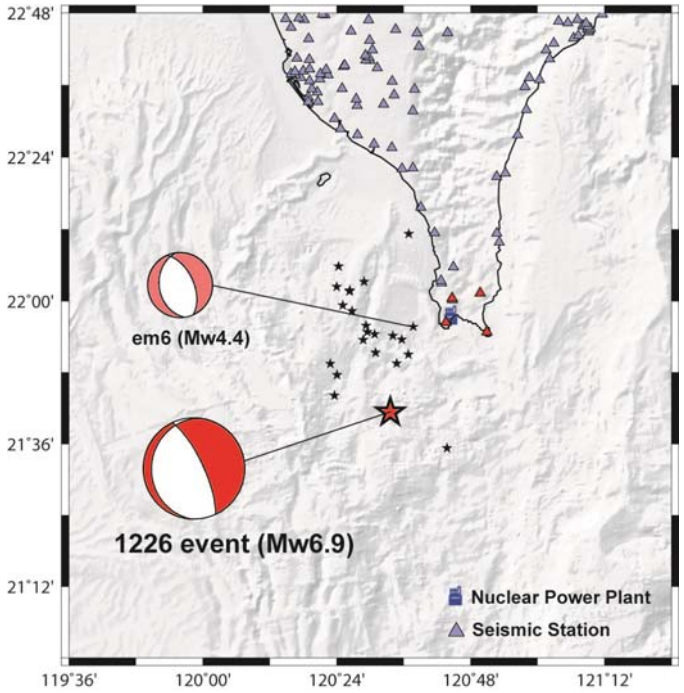


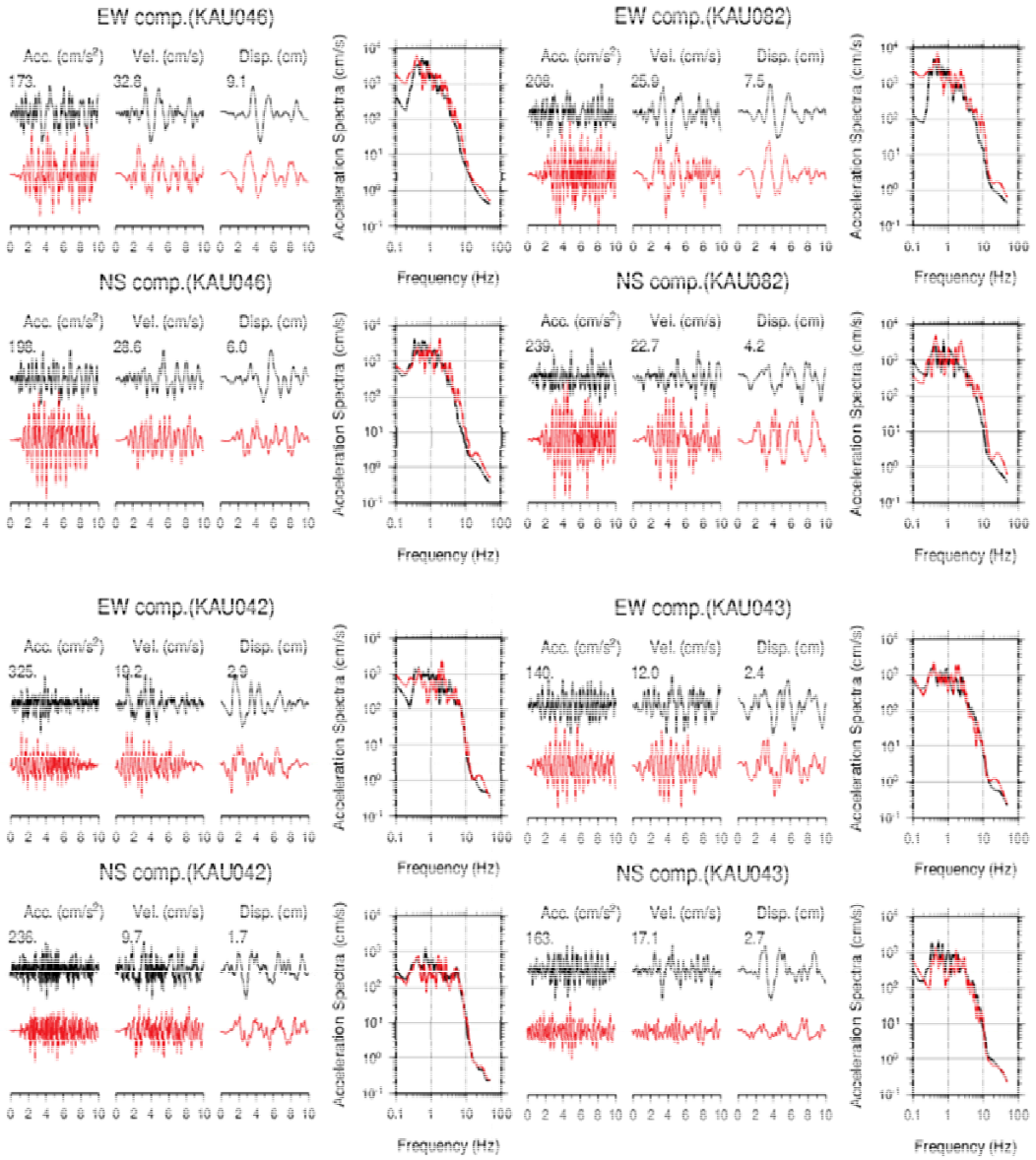


Spectral ratio curve



Waveform & spectra fitting

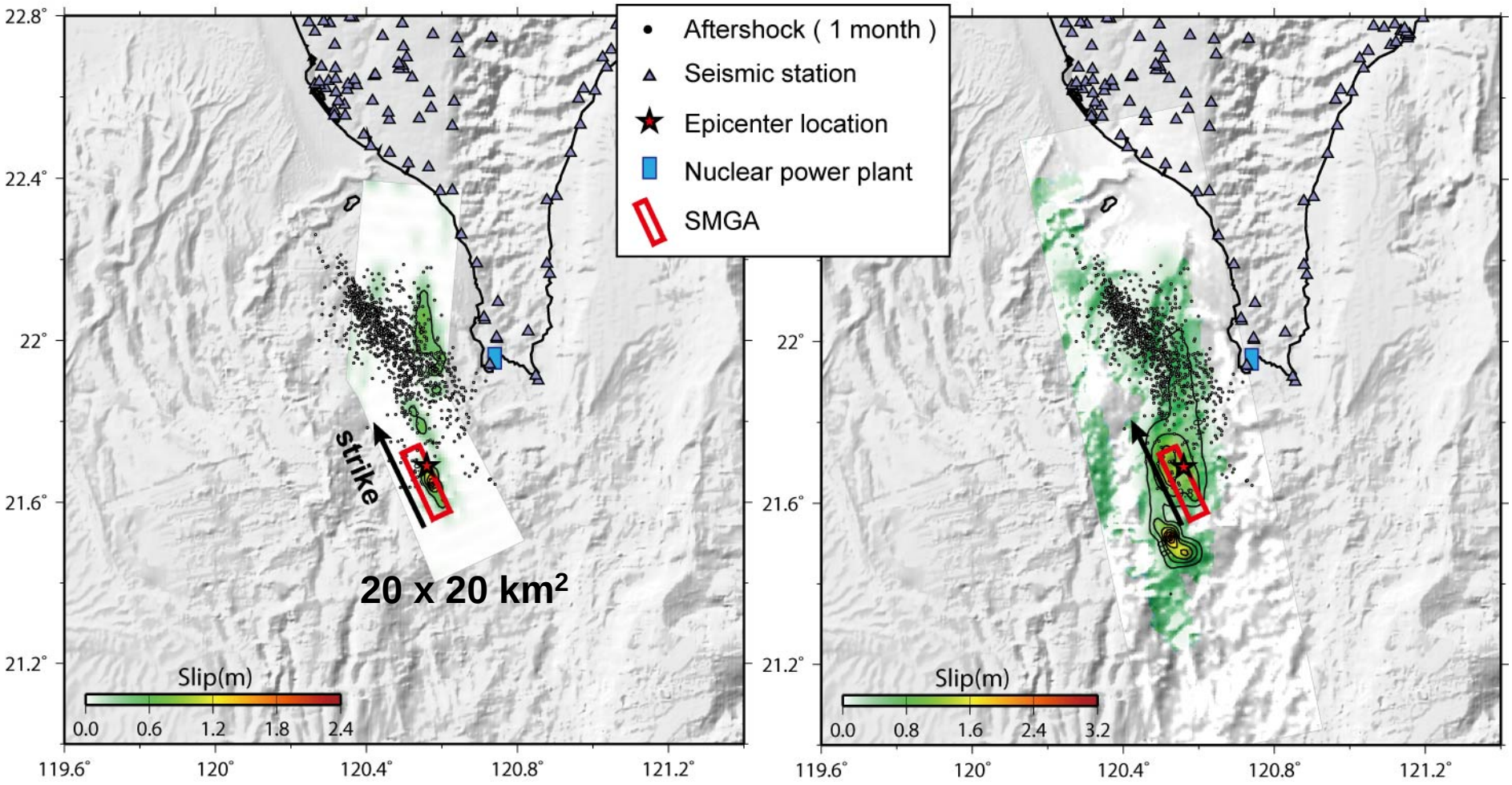




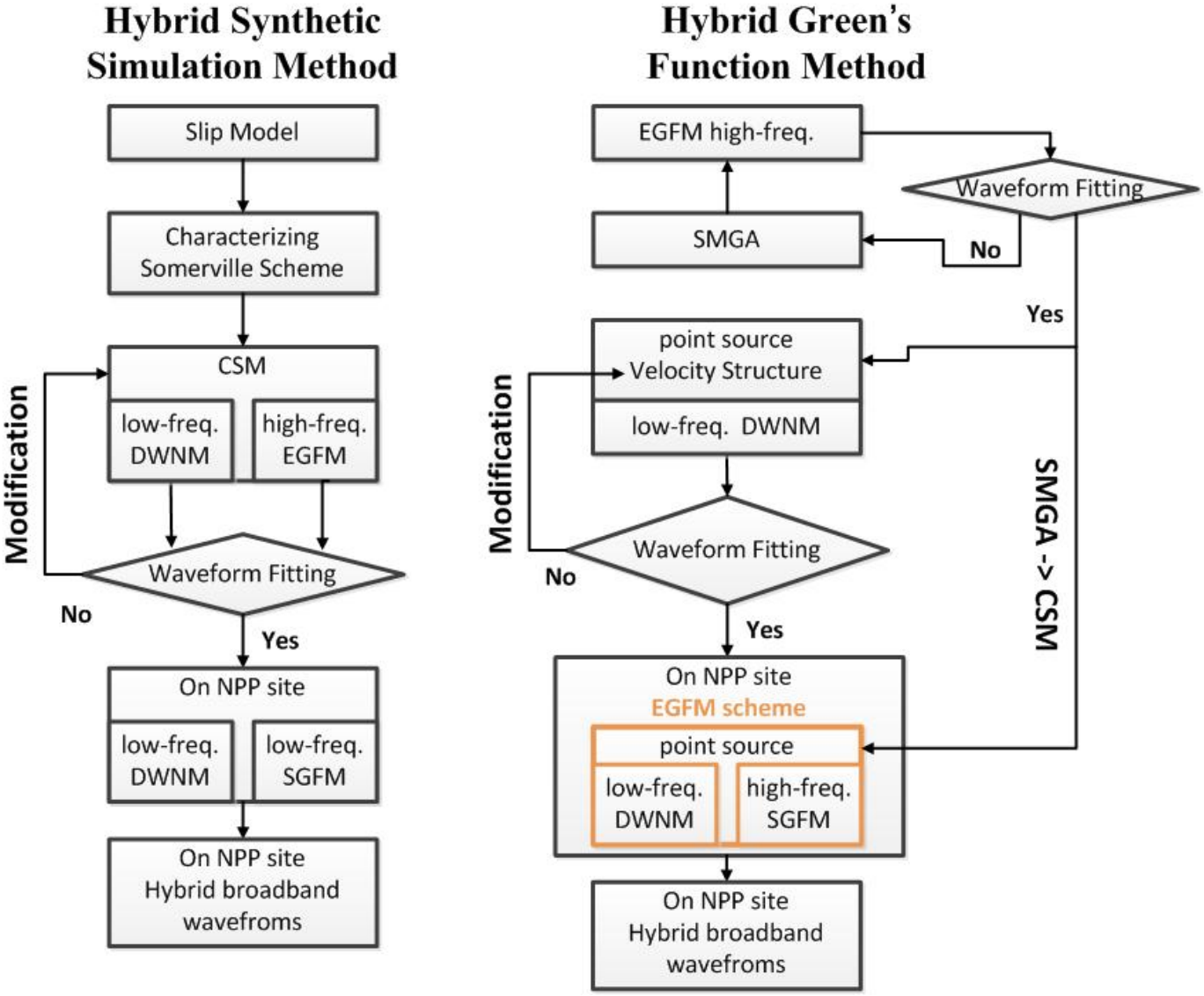
SMGA v.s. Slip model

(Yen et al, 2008)

(Lee et al, 2008)

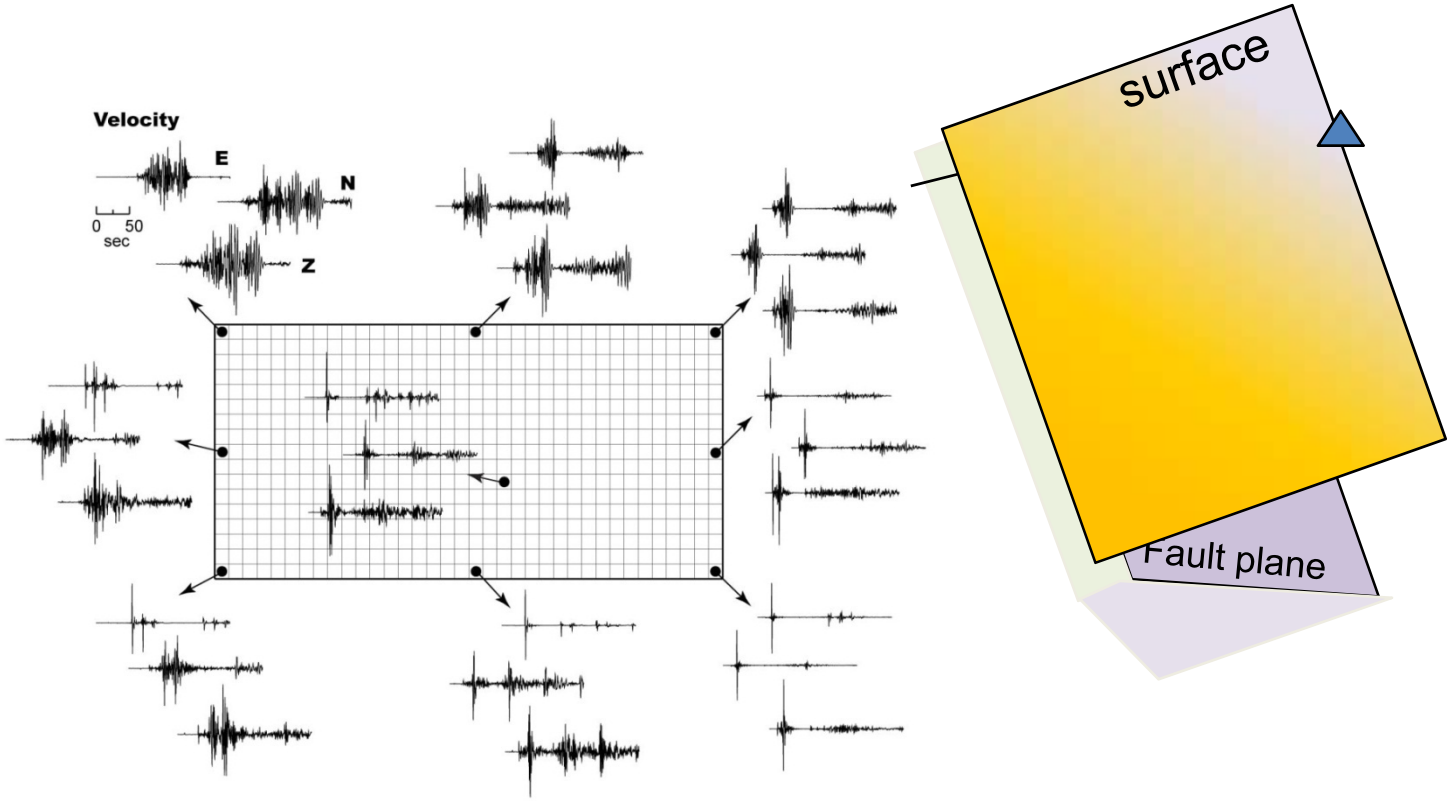


The progress of prediction ground motion with the hybrid method



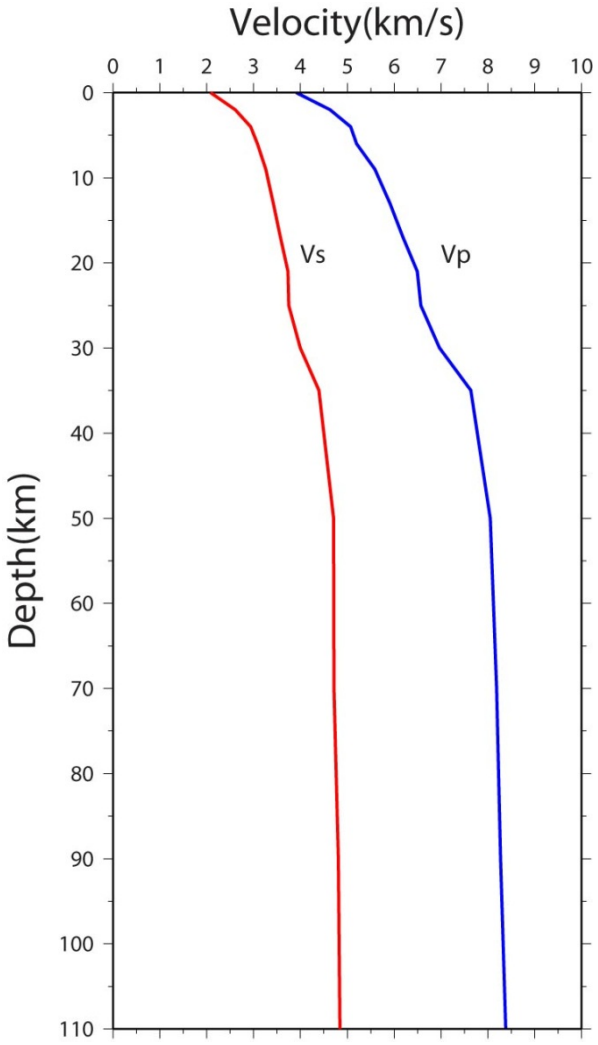
Low-frequency simulation

Green's function calculation for point sources (FK) considering 1 D velocity structure



(Zhu and Rivera, 2002)

Low-frequency simulation

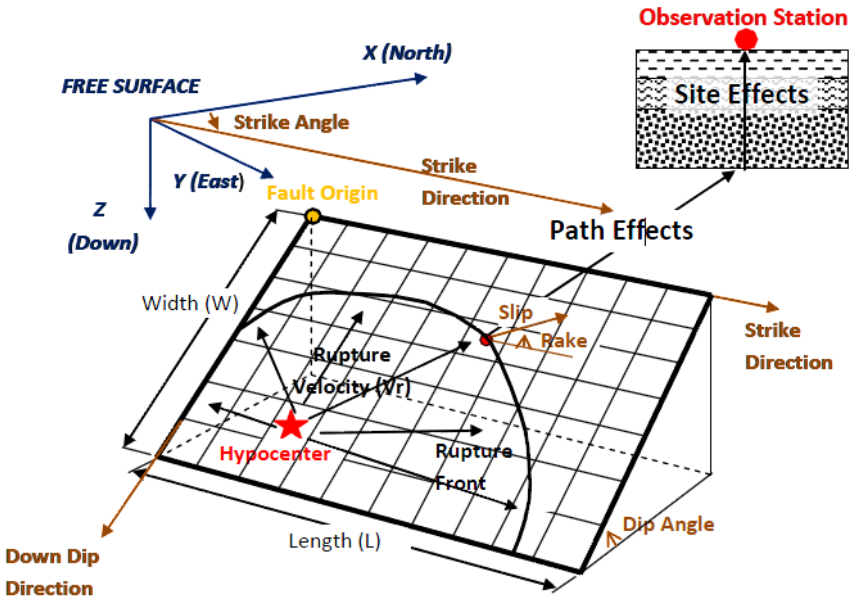


Velocity – Relative references
Density - Birch's Law (Birch 1961)
Qp, Qs - Empirical relation (Brocher, 2008)

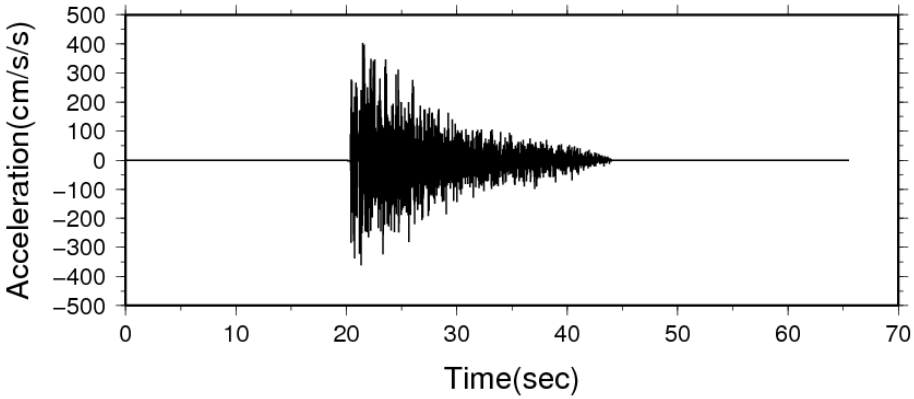
Thickness(km)	Vs(km/s)	Vp(km/s)	Density(g/cm^3)	Qs	Qp
2.00	2.08	3.91	2.02	166	331.
2.00	2.61	4.63	2.25	231	461.
2.00	2.94	5.07	2.39	282	563.
3.00	3.08	5.20	2.43	305	609.
4.00	3.26	5.59	2.56	339	678.
4.00	3.42	5.91	2.66	373	746.
4.00	3.57	6.19	2.75	409	817.
4.00	3.73	6.49	2.85	447	894.
5.00	3.75	6.57	2.87	452	905.
5.00	4.00	6.97	3.00	522	1045.
15.00	4.39	7.64	3.22	652	1304.
20.00	4.71	8.05	3.35	775	1550.
20.00	4.72	8.19	3.39	778	1557.
20.00	4.81	8.27	3.42	816	1633.
30.00	4.84	8.38	3.45	831	1661.
60.00	4.83	8.40	3.46	823	1647.
999.00	5.00	8.70	3.55	901	1803.

high-frequency simulation

The scheme of stochastic Modeling



A M7.0 case (Hypo Dis. = 11 km)



- Duration of ground motion
- Focal mechanism
- Fault dimension
- Stress drop
- Q value
- Site amplification
- ……

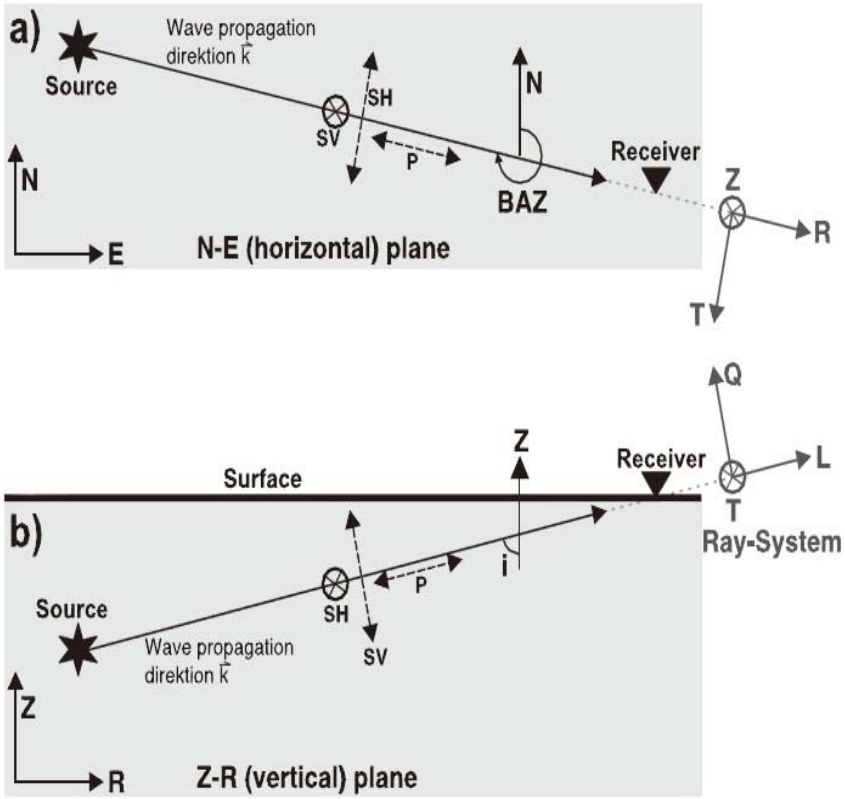
(Boore, 1983; Motazedian and Atkinson, 2005)

high-frequency simulation

Average **radiation pattern** coefficients (Boore, 1984)

The function of **Q factor** (Roumelioti and Beresnev, 2003)

Three types of body waves (P, SV, and SH waves) evaluated from a point source by the stochastic Green's function method and convert to **three-component** (NS, EW, and UD). (Onishi et al., 2004)

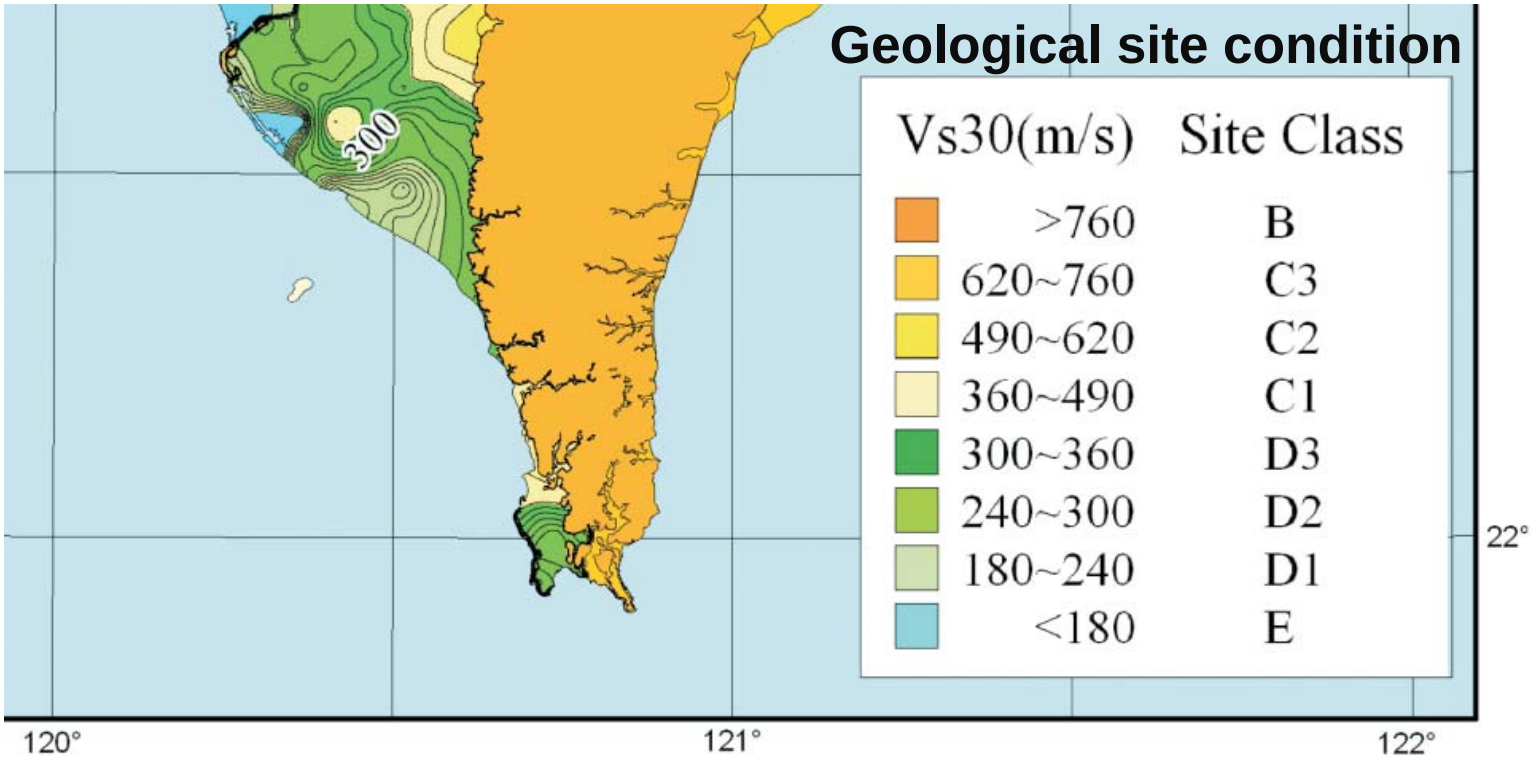


high-frequency simulation

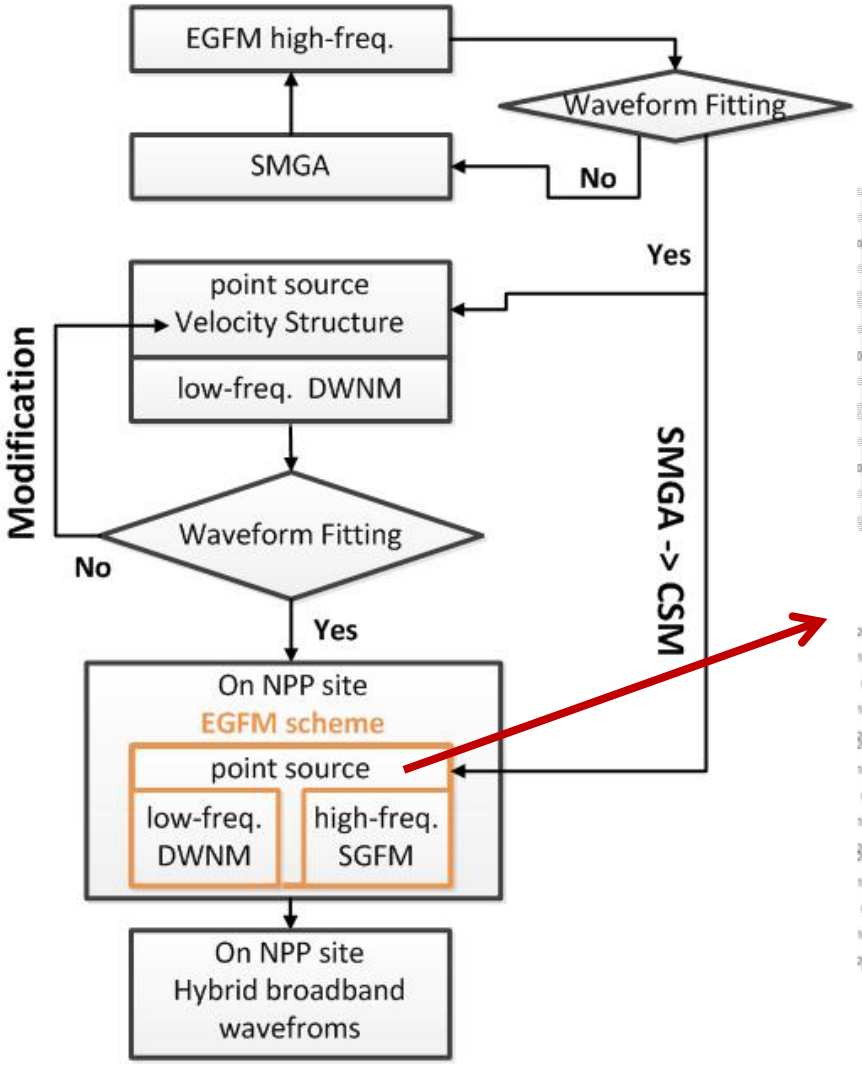
The site amplification function is following :

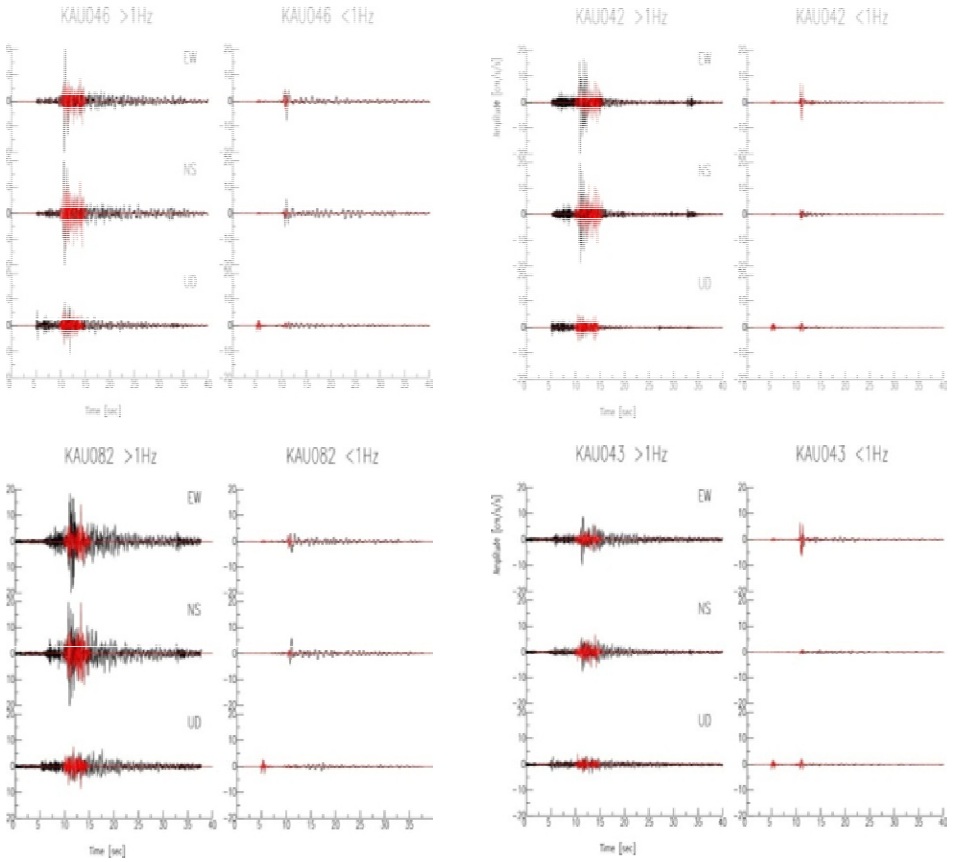
Rock - Boore and Joyner (1997)

Soil - 2 times of rock (Beresnev, 2002)

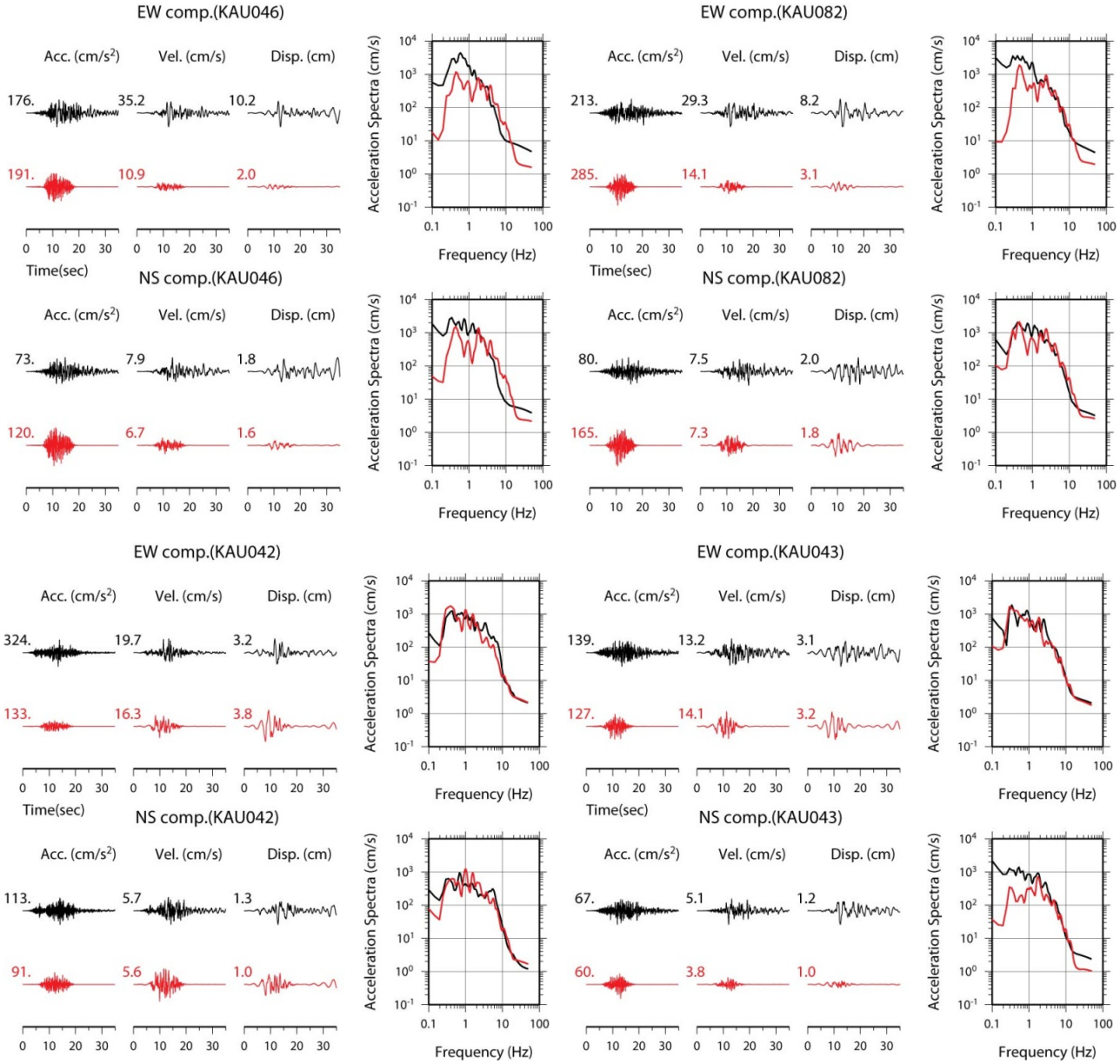


Simulation for point sources (EGF was replaced by SGF)





Hybrid Green's function simulation v.s. Observations



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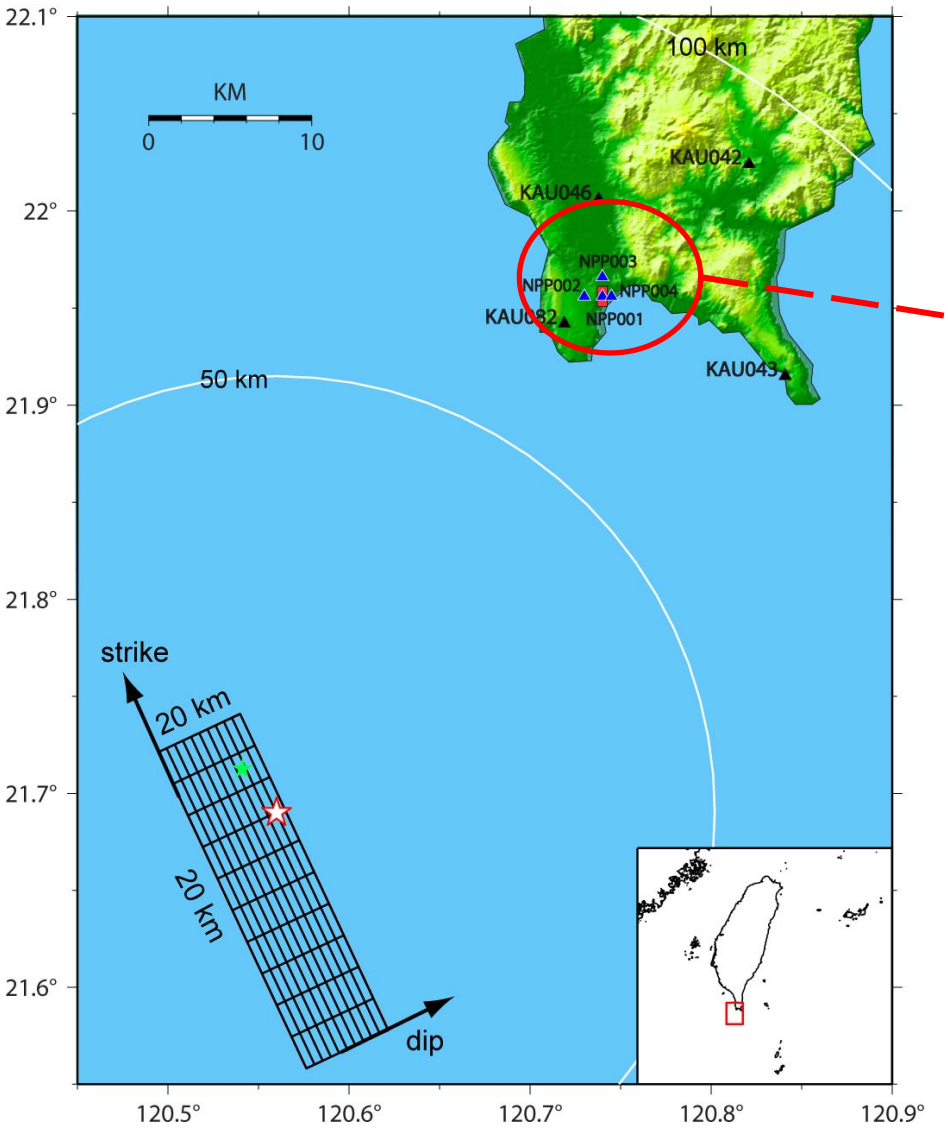
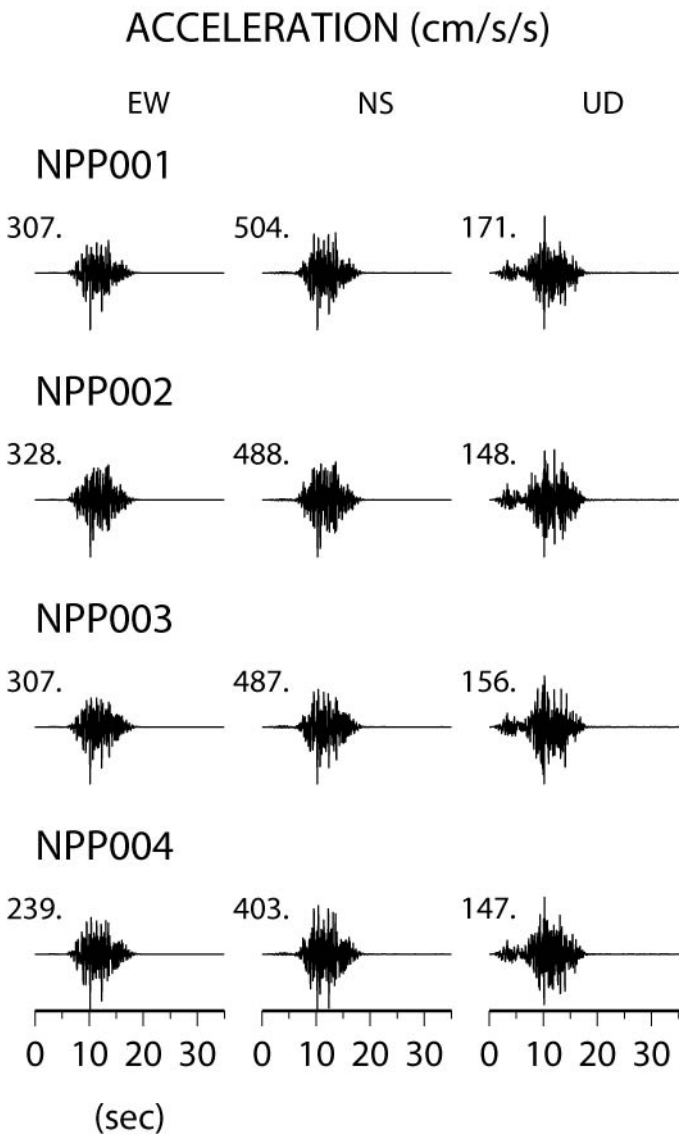
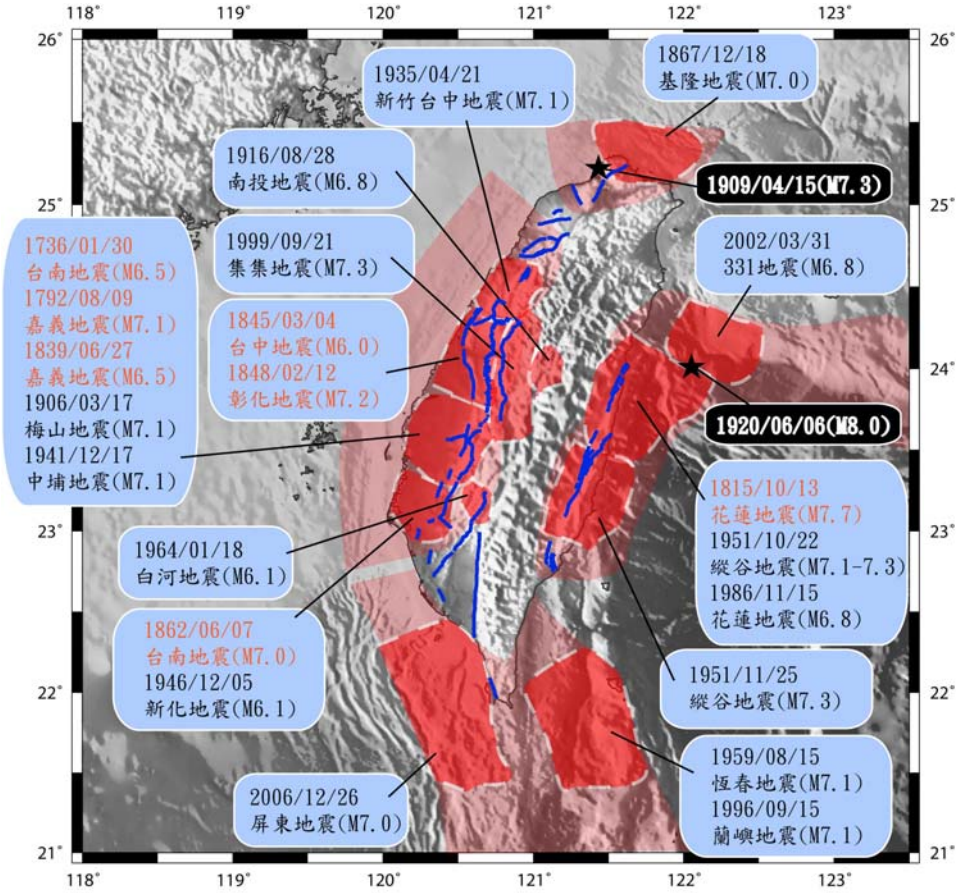
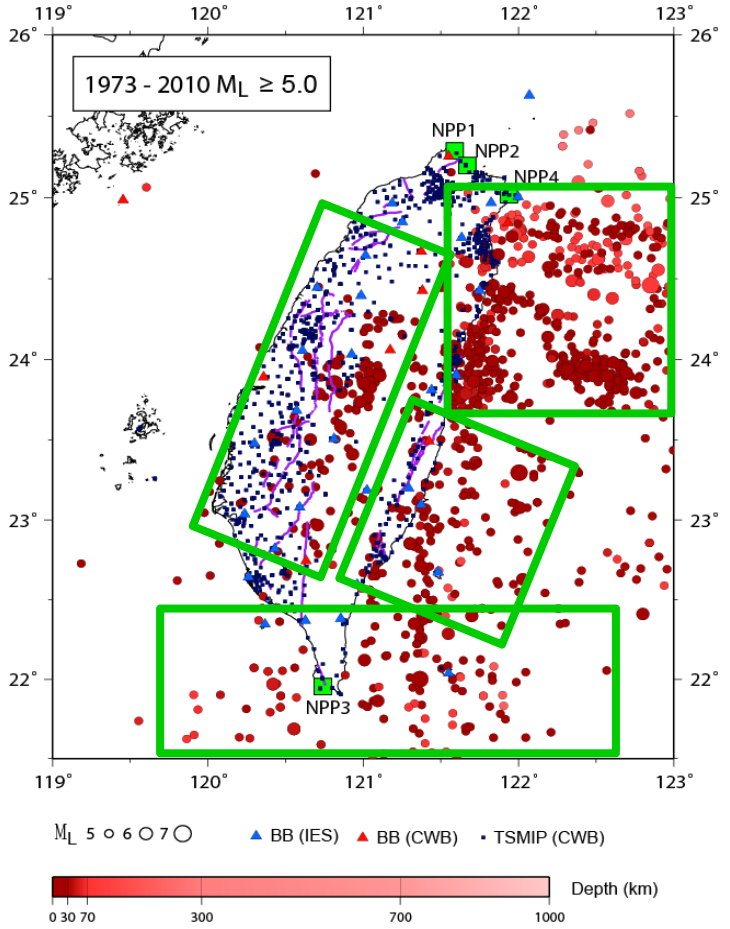

22.1°
22°
21.9°
21.8°
21.7°
21.6°
120.5°
120.6°
120.7°
120.8°
120.9°
KM
0
10
100 km
50 km
KAU042
KAU046
NPP003
NPP002
NPP004
KAU032
NPP001
KAU043
strike
20 km
20 km
dip


ACCELERATION (cm/s/s)
EW
NS
UD
NPP001
307.
504.
171.
NPP002
328.
488.
148.
NPP003
307.
487.
156.
NPP004
239.
403.
147.
0 10 20 30
0 10 20 30
0 10 20 30
(sec)

Database for Empirical Green's Function method

- Seismic stations in the area NPP or specific sites
- Classification of the events for the corresponding sources
- The database of source parameters (length, width, segment etc.)



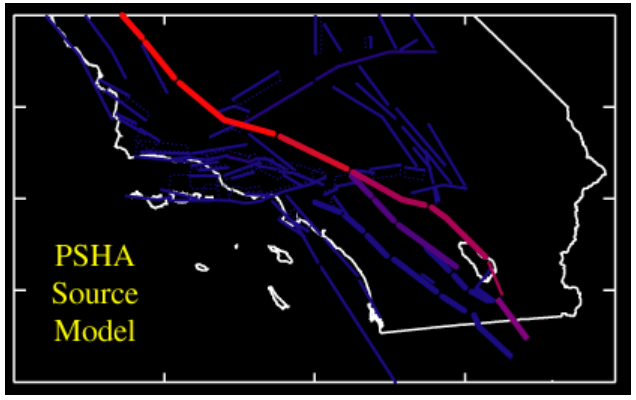


Proceeding for the Seismic Hazard Analysis

Two Components:

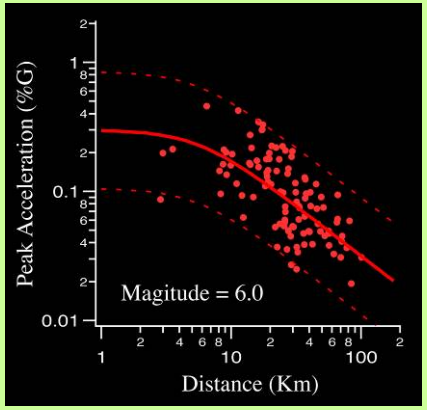
(1) Earthquake Forecast

Probability in time and space of all M≥5 events

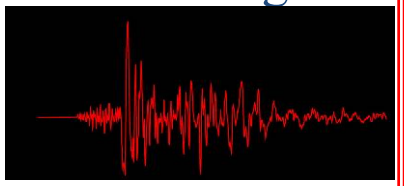


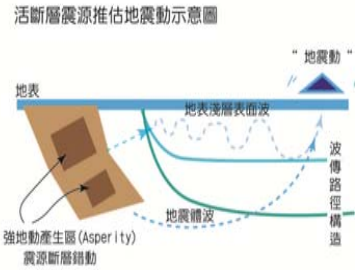
(2) Ground-Motion Estimation

Experience
Intensity Measure
(PGA, Sa) Regressions



Simulation
Full
waveform
modeling





Active fault vs. Characterized source model

- **Lineation**
  - Geodesy & Geology
  - Geomorphology
  - Geophysical Prospecting
- **Fault dipping**
  - Seismic Exploration
  - Seismicity
  - Trenching & Logging
  - Geophysical Prospecting
- **Seismiczone**
  - Seismicity
  - Seismic Exploration
  - Rheology

Strong Motion Prediction for the target faults

Fault parameters
（length、strike and dip angle、segmentation etc.）

↓

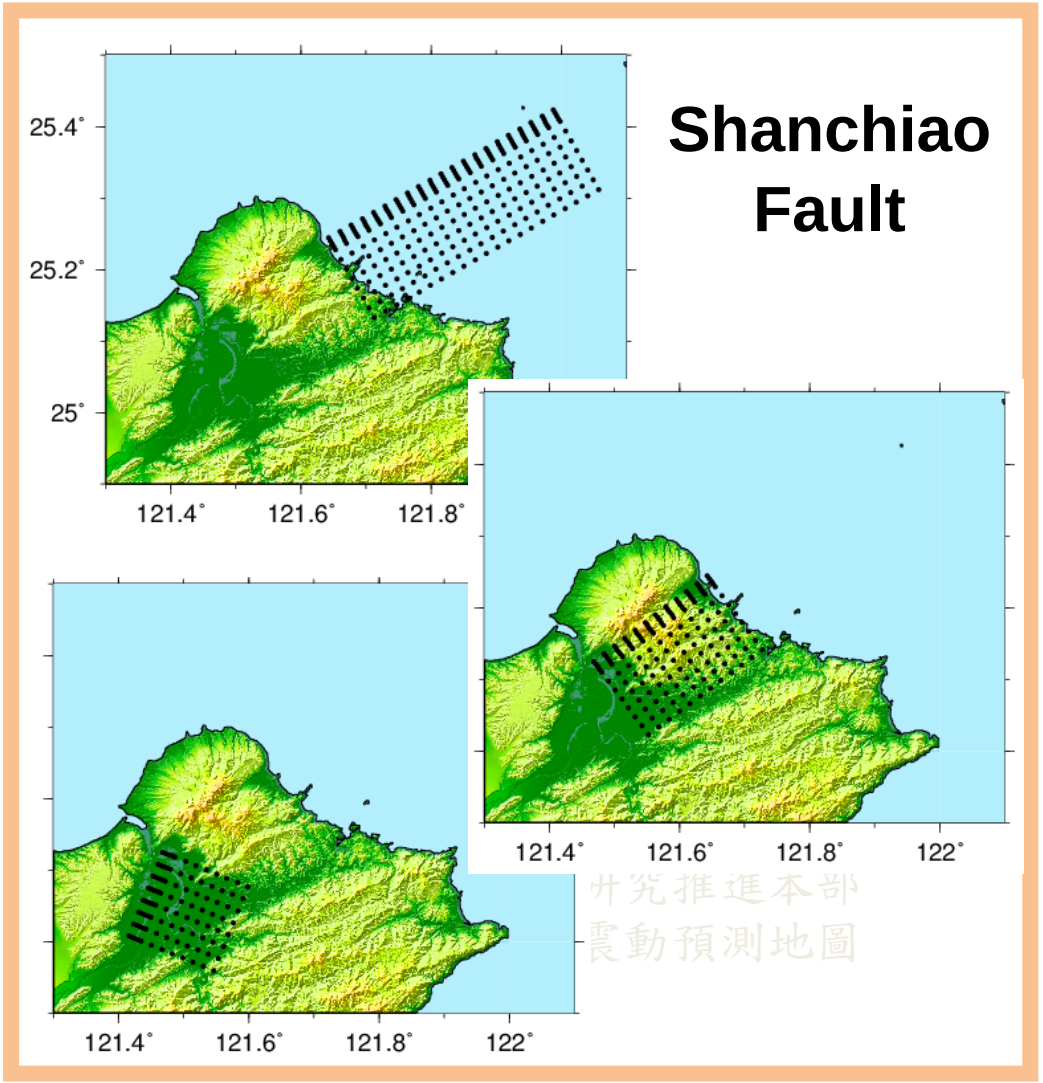
Scaling relation of source parameters

↓

Characterized source model

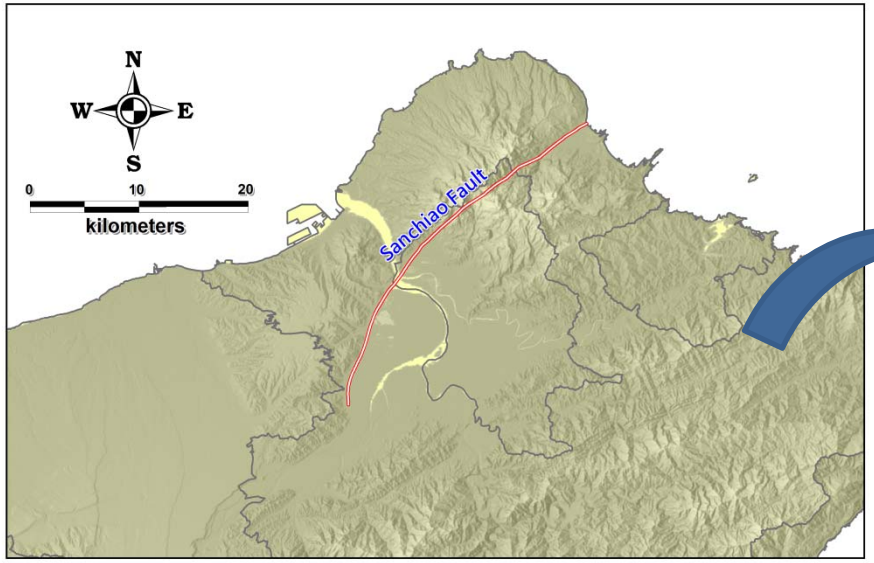
↓

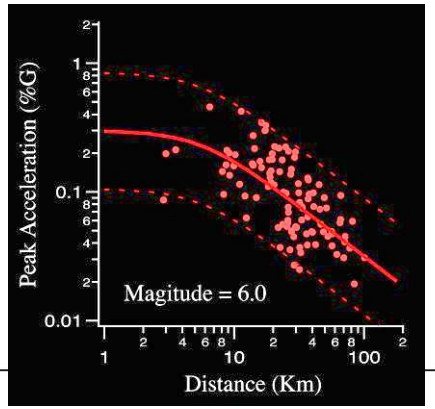
Seismic Hazard Map

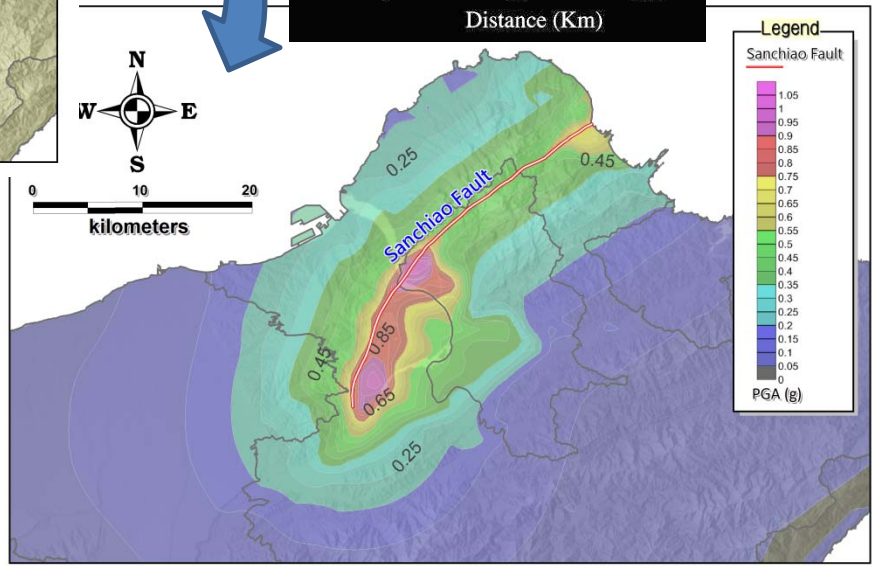


Strong Motion Prediction for the target faults

Ground motion prediction equation







Alternatively,
Seismic Hazard Maps
from hybrid simulation

Summary & Future Directions

- Source characteristic could be taken by the EGF method efficiently (if there are correspond events) .
- Using characterized source model (CSM) offers a relatively easy way to implement ground motion prediction.
- For engineering application, various frequent content of predicted ground motion level on specific earthquake faults could be provided by hybrid simulation.
- The ground motion result of GMPE and hybrid simulation is an alternative way to validate each other,
- Problems need to solve is to specify source parameters of CSM (as no historical records exist), more precise velocity structure and site amplification function.

Thank you
for your attention