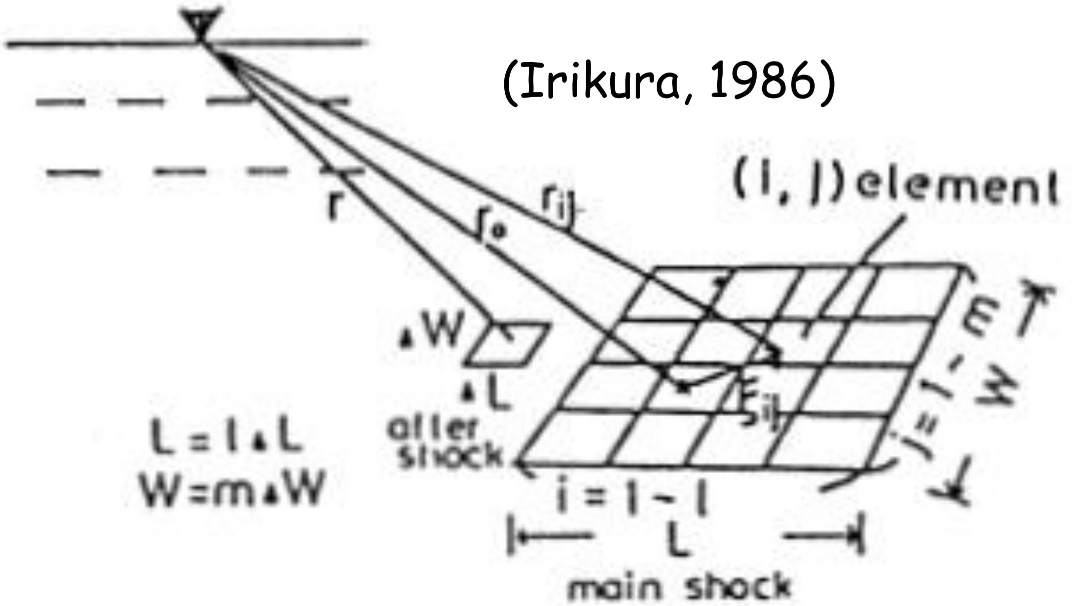
Strong ground motion simulation based on the empirical Green's function method

(Irikura, 1986)



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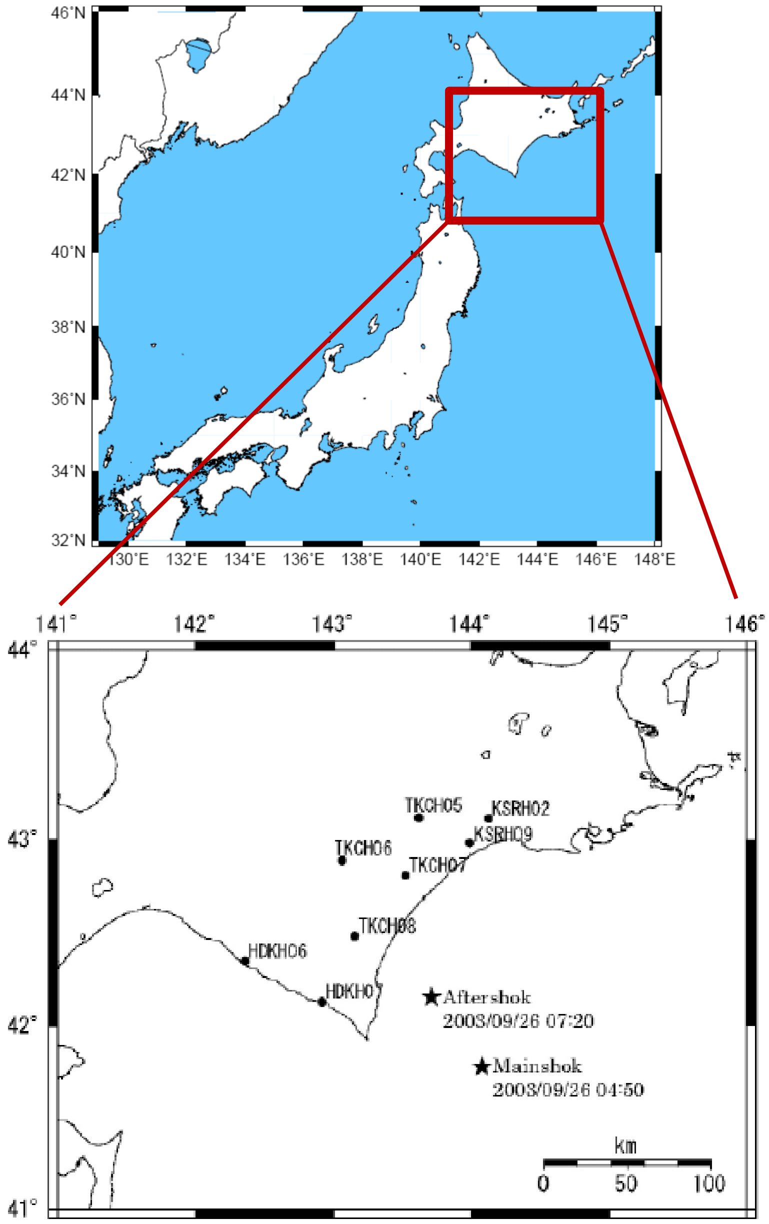
Outline

- Introduction
- Method
- Source Model and Synthetics
- Conclusions

Introduction

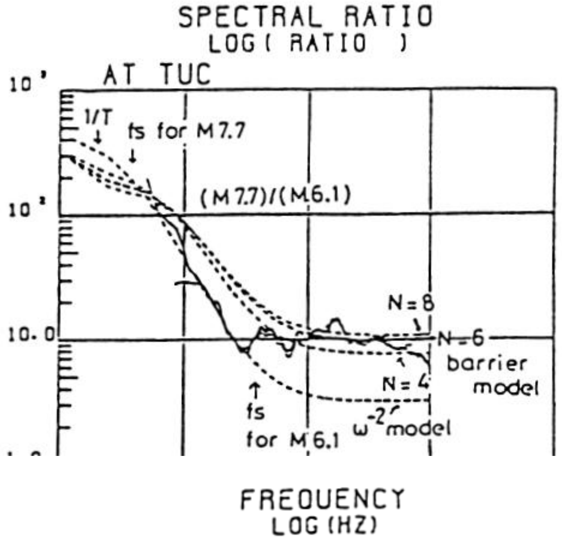


- The September 26, 2003 Tokachi-oki, Japan, earthquake($M_J MA$=8.0) occurred on the plate interface between the North American plate and the subducting Pacific plate.
- Map showing the KiK-net station location and epicenters of the mainshock and the aftershock that are used as the empirical Green's function.

Introduction

$$M_0 = \mu s \bar{D}$$

- The first problem is how the source characteristics change with the seismic moment. We consider the w^{-2} model as a reference model to compare the observed to the theoretical, giving moment and fault size. Next the spectra not explained by the w^{-2} model, are compared to the specific barrier model, assuming additive parameters, crack size and number of cracks.



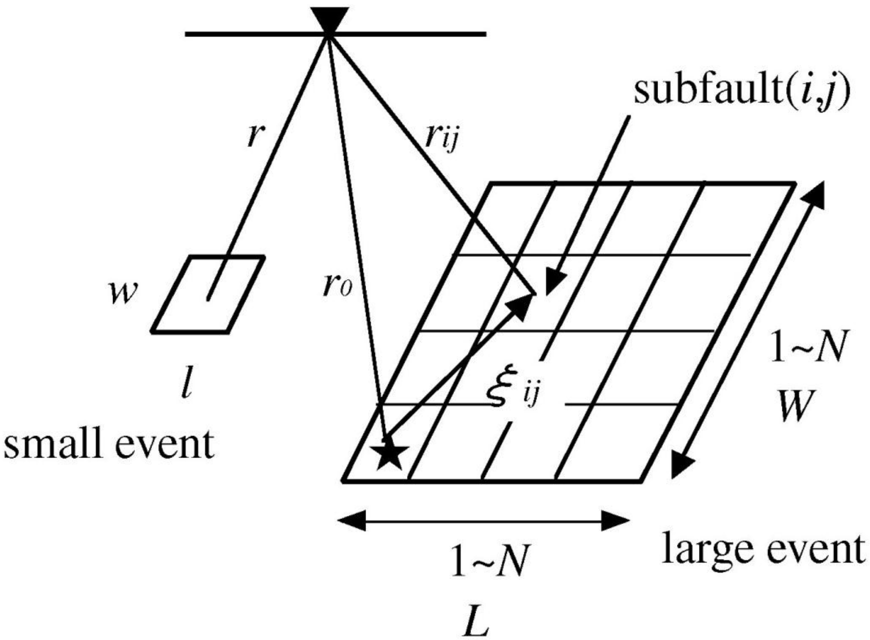
Introduction

- The second problem is how the strong ground motion for large earthquakes can be synthesized by summing the ground motion records from small earthquakes to satisfy the scaling law of the source spectra.

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

Method

Empirical Green's function method (Irikura, 1983, 1986)



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

U(t): simulated waveform for the large event

u(t) : observed waveform for the small event

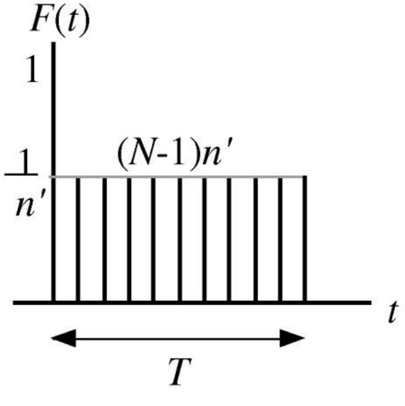
F(t) :filtering function (correction function)

C :the ratio of stress drops

N :the ratio of fault dimensions

Method(correction function F(t))

(a)

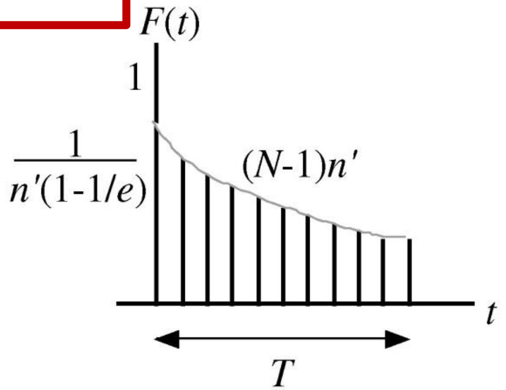


$$F(t) = \delta(t - t_{ij}) + \frac{1}{n'} \sum_{k=1}^{(N-1)n'} [\delta\{t - t_{ij} - \frac{(k-1)T}{(N-1)n'}\}] \quad (1)$$

$$t_{ij} = \frac{r_{ij} - r_o}{V_s} + \frac{\xi_{ij}}{V_r} \quad (2)$$

Irikura (1986)

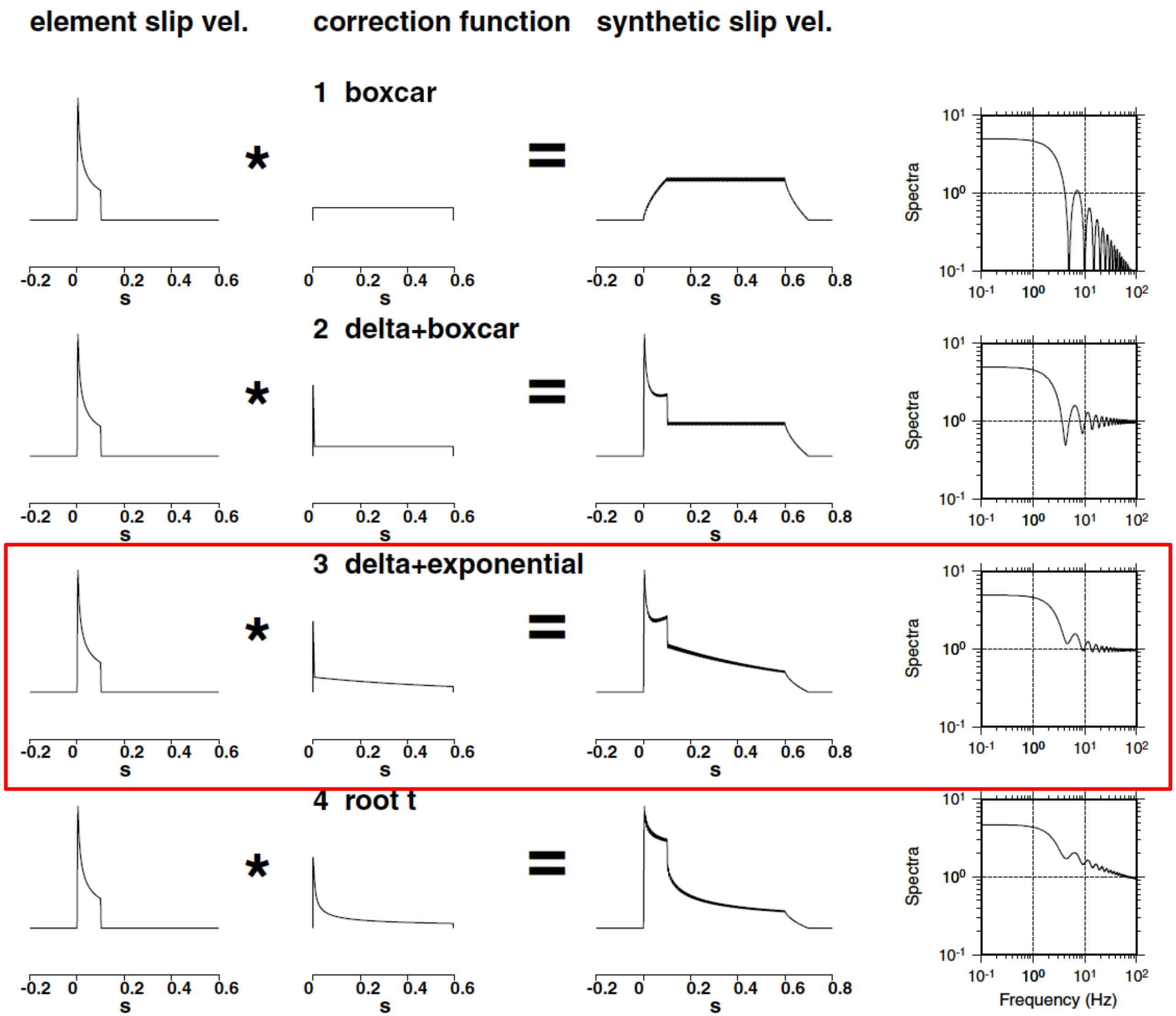
(b)



$$F(t) = \delta(t - t_{ij}) + \frac{1}{n'(1 - \frac{1}{e})} \sum_{k=1}^{(N-1)n'} [\frac{1}{e^{\frac{(k-1)}{(N-1)n'}}} \delta\{t - t_{ij} - \frac{(k-1)T}{(N-1)n'}\}] \quad (3)$$

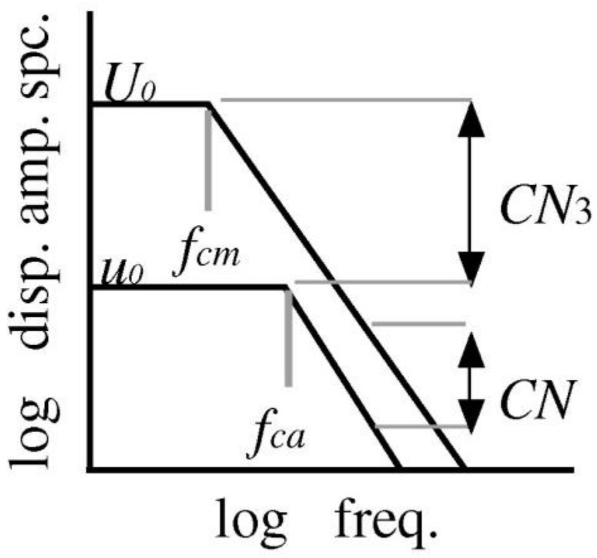
Irikura *et al.* (1997)

Method(slip velocity time function)



Method

In Irikura (1986), the scaling parameter N and C can derived from spectral ratio of disp. or acc. waveforms



$$\frac{U_0}{u_0} = \frac{M_0}{m_0} = CN^3$$

C :the ratio of stress drops

N :the ratio of fault dimensions

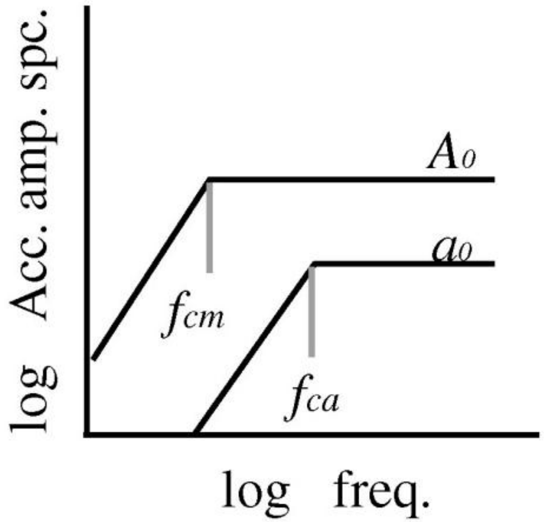
$$\Omega_0 = R_{\theta\phi} M_0 (4\pi\rho R\beta^3)^{-1} \text{ (Brune,1970,1971)}$$

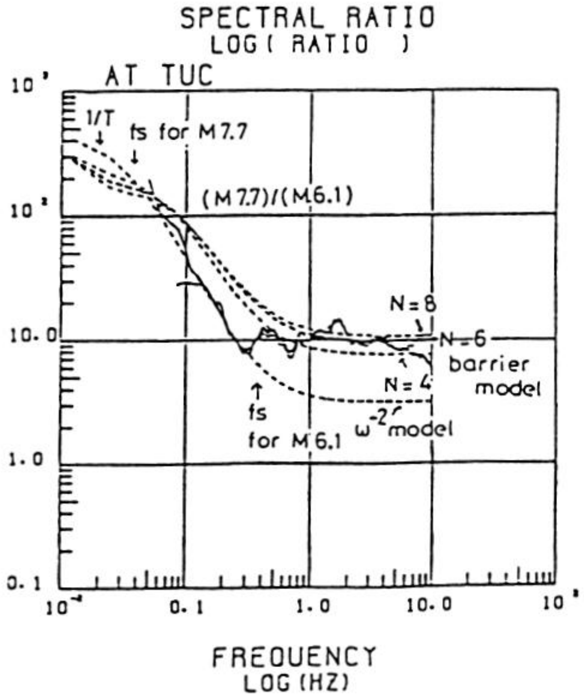
$$\frac{L^t}{L^s} = \frac{W^t}{W^s} = \left[\frac{M_0{}^t}{M_0{}^s}\right]^{1/3} = \left[\frac{U_0{}^t}{U_0{}^s}\right]^{1/3} = N \text{ (Kanamori,1975)}$$

$$N = \left[\frac{M_0{}^t}{CM_0{}^s}\right]^{1/3}$$

Method

In Irikura (1986), the scaling parameter N and C can derived from spectral ratio of disp. or acc. waveforms





$$\frac{U_o}{u_o} = \frac{M_o}{m_o} = CN^3$$

$$\frac{A_o}{a_o} = CN$$

$$\frac{A_o}{a_o} = CN$$

$$\mathrm{A(dyne-cm/s^2) = 2.46 \times 10^{17} \times M_0^{1/3}}\ \text{(Dan, 2001)}$$

Method

Parameter Estimation for the Empirical Green's Function Method by the Source Spectral Fitting Method(Irikura 1986,Miyake et al)

Source Path Site

$$O(t) = S(t) * P(t) * G(t) \Rightarrow O(f) = S(f) \cdot P(f) \cdot G(f)$$

$$\frac{S(f)}{s(f)} = \frac{O(f)/P(f)}{o(f)/p(f)} = \frac{O(f) \Big/ \frac{1}{R} e^{\frac{-\pi f R}{Q_s(f) Vs}}}{o(f) \Big/ \frac{1}{r} e^{\frac{-\pi f r}{Q_s(f) Vs}}}$$

Qs(f): frequency-dependent attenuation factor.

$$S(f) = \frac{M_0}{1 + (f/f_c)^2} \Rightarrow SSRF(f) = \frac{M_0}{m_0} \cdot \frac{1 + (f/f_{ca})^2}{1 + (f/f_{cm})^2}$$

Source spectral ratio function

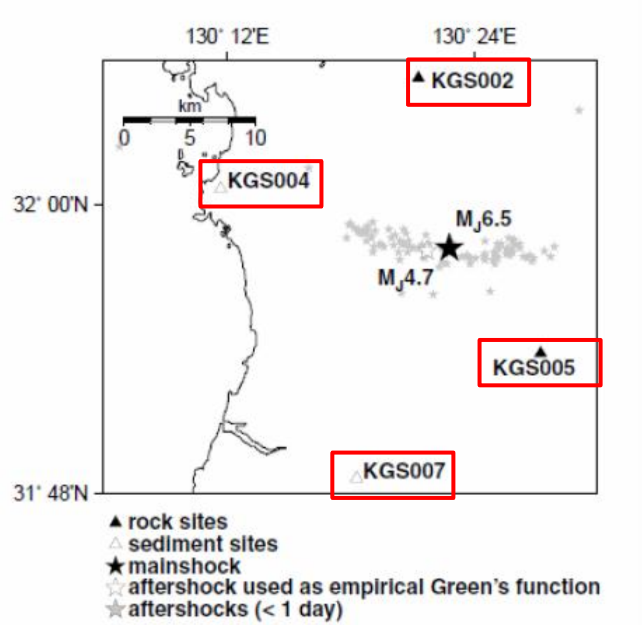
fca: corner frequency for the aftershock

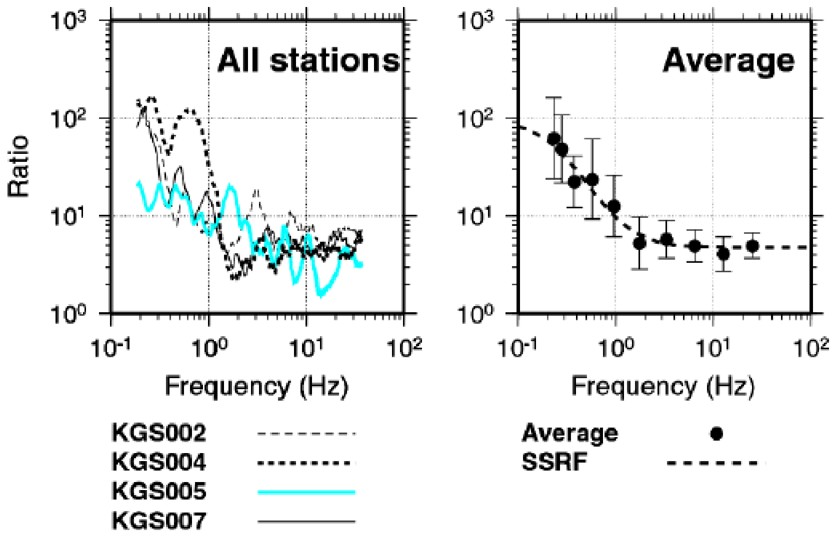
fcm: corner frequency for the mainshock

$$\sum_{i=1}^{nst} \left(\frac{SSRF(f_i) - S(f_i)/s(f_i)}{S.D.(f_i)} \right)^2 = min$$

Method

Parameter Estimation for the Empirical Green's Function Method by the Source Spectral Fitting Method(Irikura 1986,Miyake et al)





$$SSRF(f) = \frac{M_0}{m_0} \cdot \frac{1 + (f/f_{ca})^2}{1 + (f/f_{cm})^2}$$

$$\frac{M_o}{m_o} = CN^3 \qquad (f \to 0)$$

$$\left(\frac{M_o}{m_o}\right)\left(\frac{f_{cm}}{f_{ca}}\right)^2 = CN \qquad (f \to \infty)$$

Method

$$\text{Residual} = \sum_{k=1}^{M}\left(\frac{\sum_{i=1}^{N}(D_o(t_i) - D_s(t_i))^2}{\sum_{i=1}^{N}(|D_o(t_i)| \times |D_s(t_i)|)} + \frac{\sum_{i=1}^{N}(A_o(t_i) - A_s(t_i))^2}{\sum_{i=1}^{N}(|A_o(t_i)| \times |A_s(t_i)|)}\right)$$

D_o : the observed displacement waveform

D_s : the synthetic displacement waveform

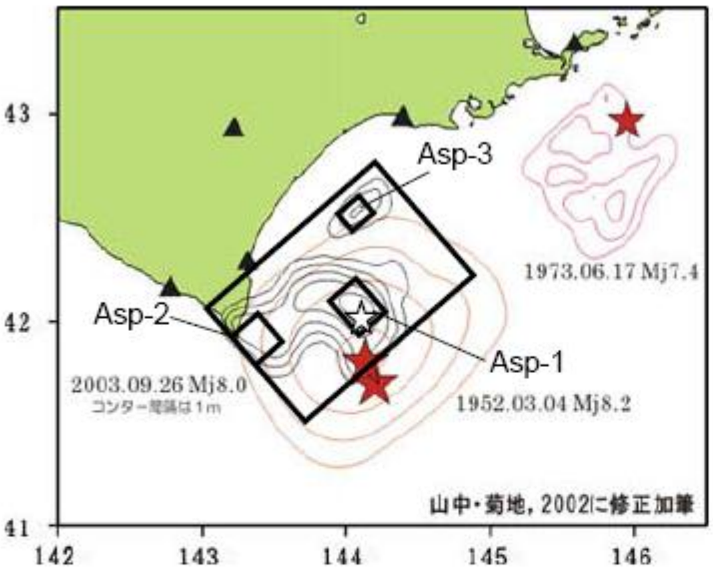
A_o : the observed acceleration envelope

A_s : the synthetic acceleration envelope

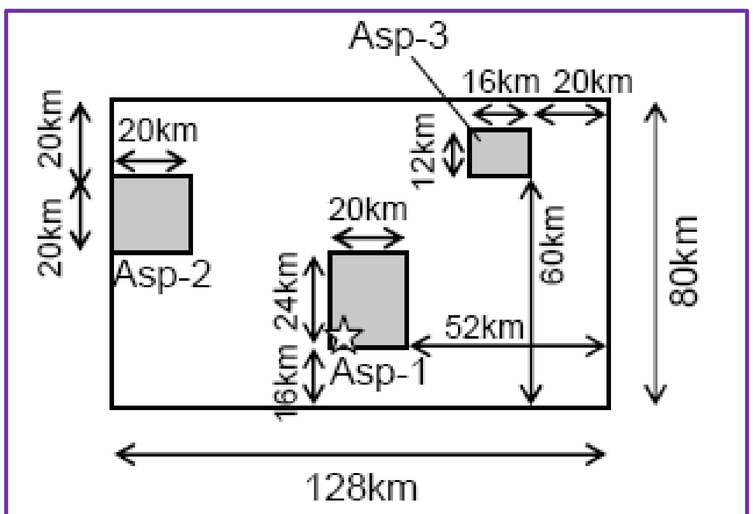
M : the number of stations

N : the time length of waveform

Source Model



mainshock



- Source model consisting of three asperities estimated from forward modeling using the empirical Green's function method. Our model (rectangles) is superimposed on the inverted slip model of Yamanaka (2003).

Table 1. Aftershock and its source parameters.

Date	2003/9/26 7:20
Latitude (deg)	42.154
Longitude (deg)	143.712
Depth (km)	41.4
M_{JMA}	5.4
Strike (deg) #	43.4 / 215.8
Dip (deg) #	26.1 / 64.0
Rake (deg)#	96.8 / 86.7
Seismic moment (N*m)	1.4×10^{17}
Fault area (km²)	16
Stress drop (MPa)	5MPa

Aftershock (EGF)

Source Model

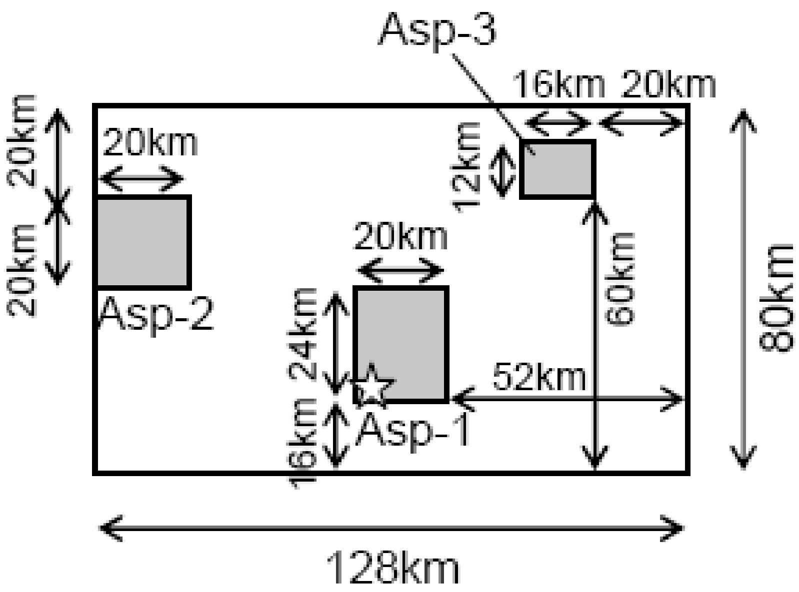
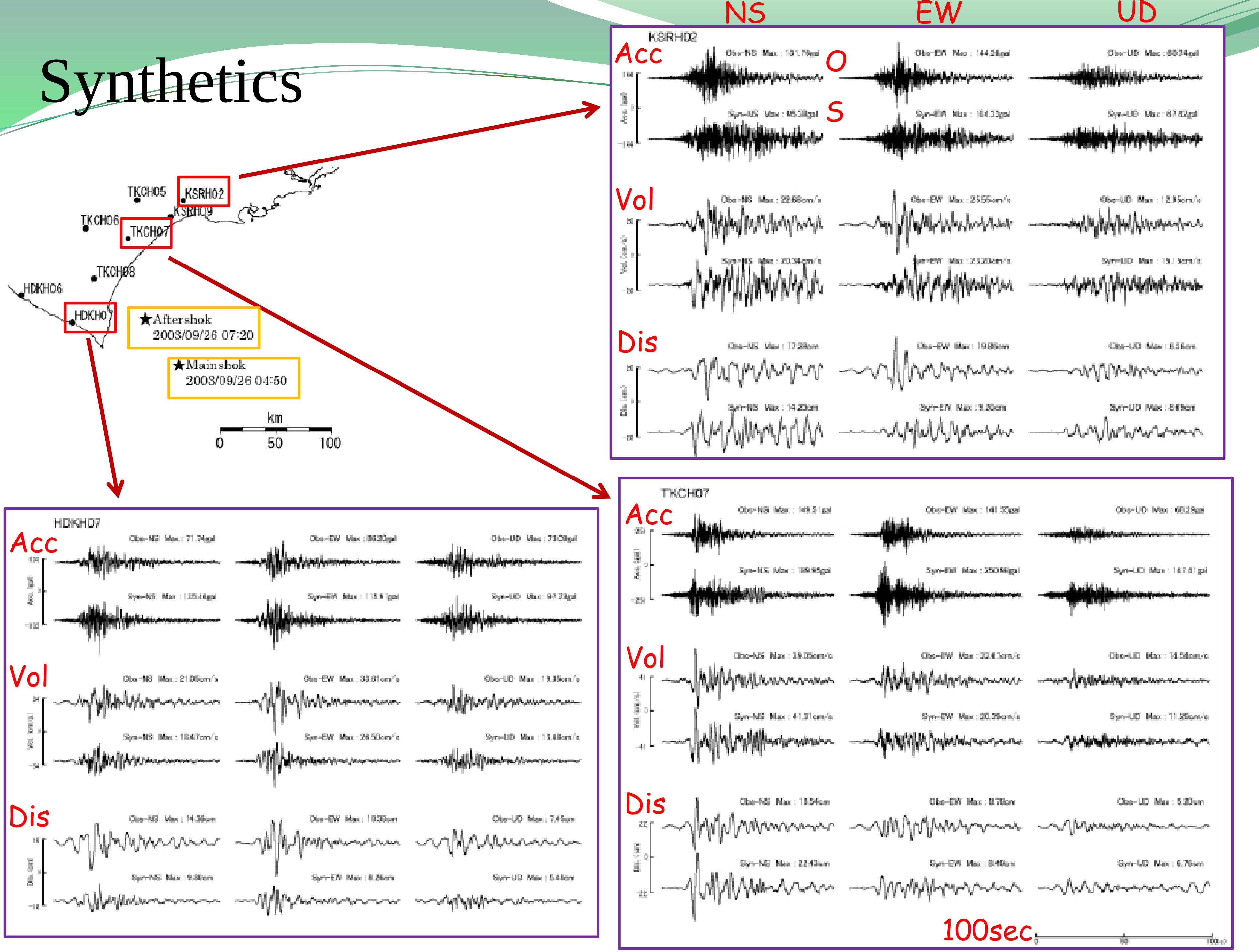


Table 2. Source parameters for each asperity.

	M_0 (N*m)	L(km) × W(km)	Δσ (MPa)
Asp-1	2.31×10^{20}	20 × 24	50
Asp-2	8.75×10^{19}	20 × 20	25
Asp-3	2.94×10^{19}	16 × 12	25

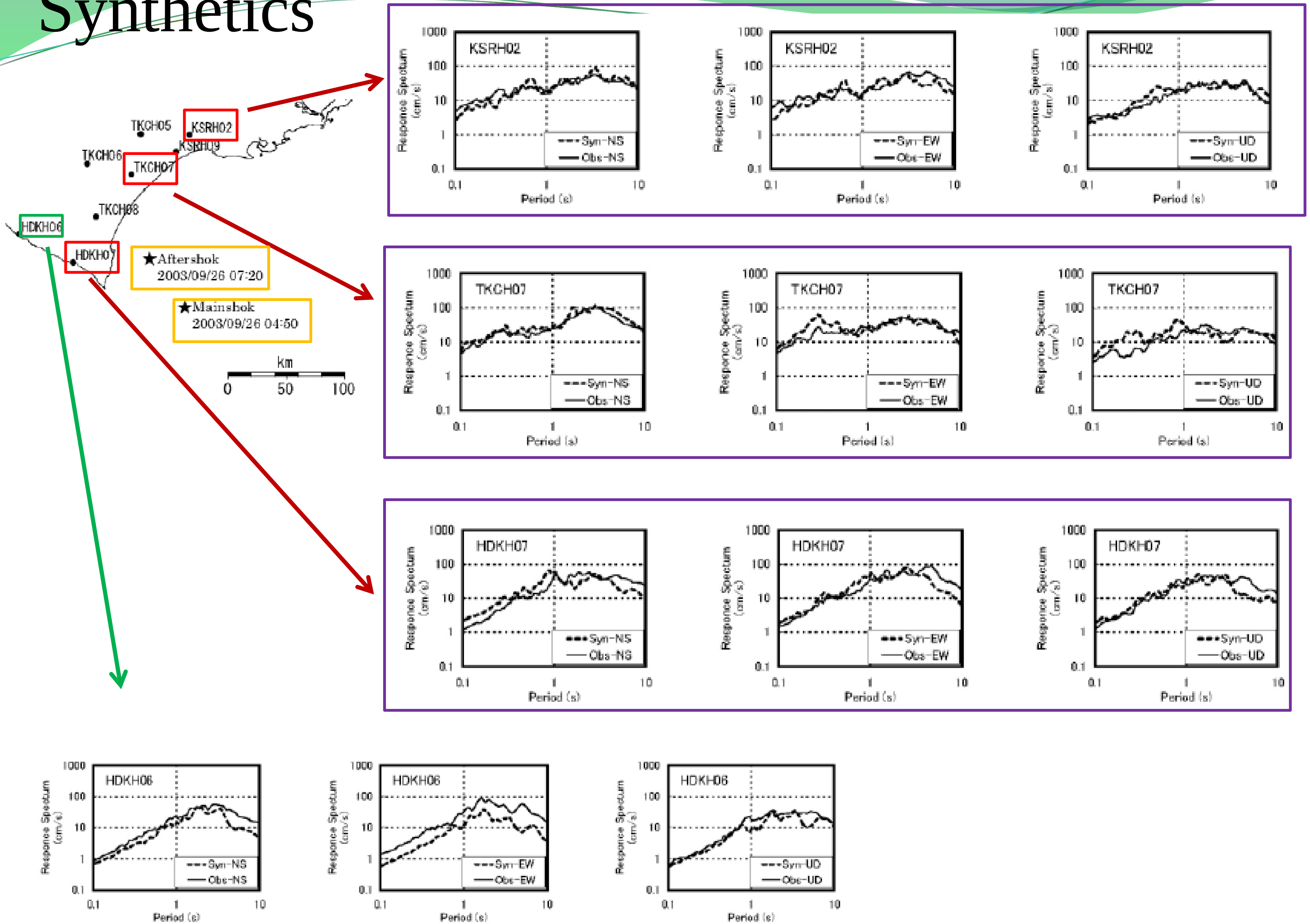
- We adjusted the location, size , and stress parameters of those three subevents to fit the simulated motions.
- S wave velocity of 3.8 km/s
- Rupture velocity of 2.8 km/s
- We assumed that the rupture should start from the inside subevent(Asp-1) near the hypocenter and propagated radially.

Synthetics



NS
EW
UD
KSRH02
Acc
O
S
Vol
Dis
TKCH05
KSRH02
KSRH09
TKCH06
TKCH07
TKCH08
HDKH06
HDKH07
★Aftershok
2003/09/26 07:20
★Mainshok
2003/09/26 04:50
km
0
50
100
HDKH07
Acc
Vol
Dis
TKCH07
Acc
Vol
Dis
100sec

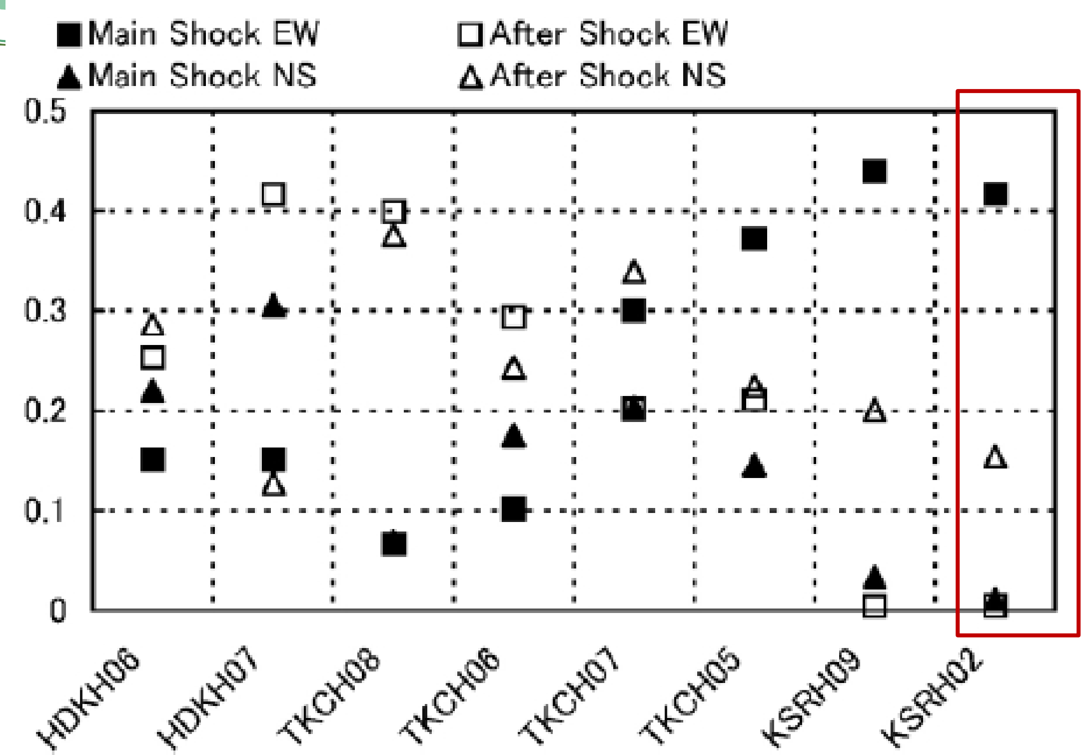
Synthetics

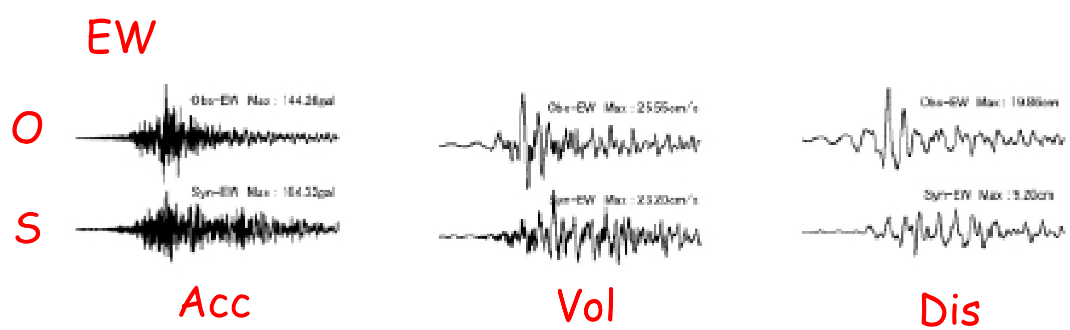


TKCH05
KSRH02
KSRH09
TKCH06
TKCH07
TKCH08
HDKH06
HDKH07
★Aftershok 2003/09/26 07:20
★Mainshok 2003/09/26 04:50
km
0
50
100
KSRH02
TKCH07
HDKH07
HDKH06
Responce Spectum (cm/s)
Period (s)
0.1
1
10
100
1000
Syn-NS
Obs-NS
Syn-EW
Obs-EW
Syn-UD
Obs-UD

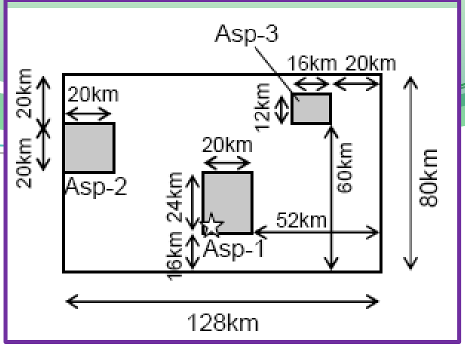
Synthetics

- Radiation coefficients for both horizontal components at eight stations calculated assuming a point source. The estimates for the mainshock are calculated for only Asp-1.





Conclusions



- We tried to estimate the source model composed of asperities by the forward modeling using the empirical Green's function method. Finally, we determined the source parameters for three asperities located on the fault plane from the comparisons between the synthesized and the observed ones.
- We need to revise the estimates of the source parameters for asperities after the more detailed analysis and investigate the validation of the framework of the strong ground motion prediction for future great subduction earthquakes based on the recipe by Irikura *et al. (2003).*