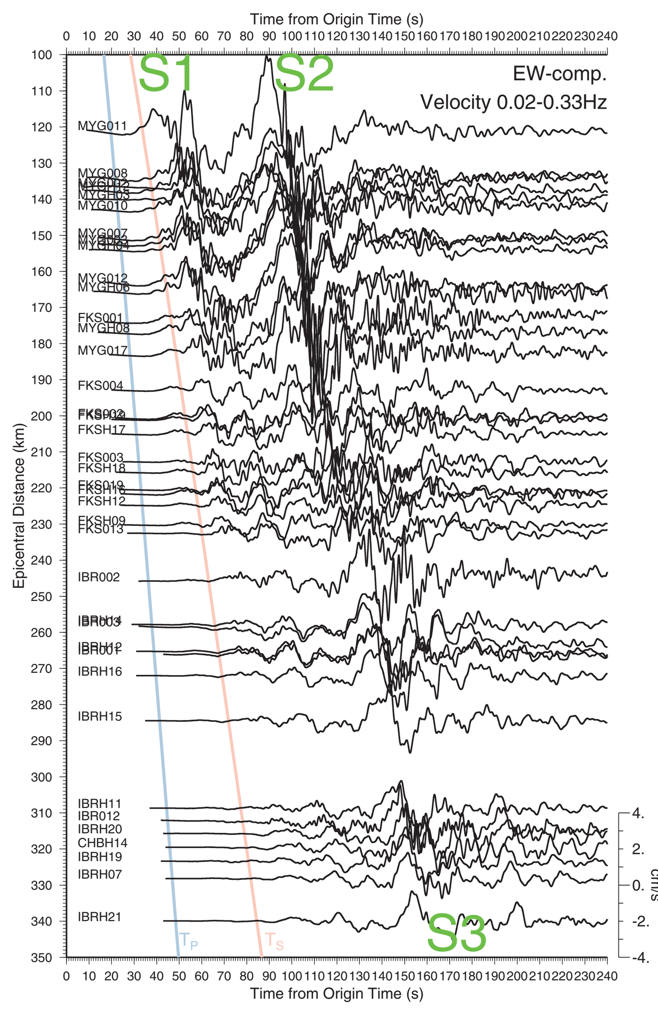
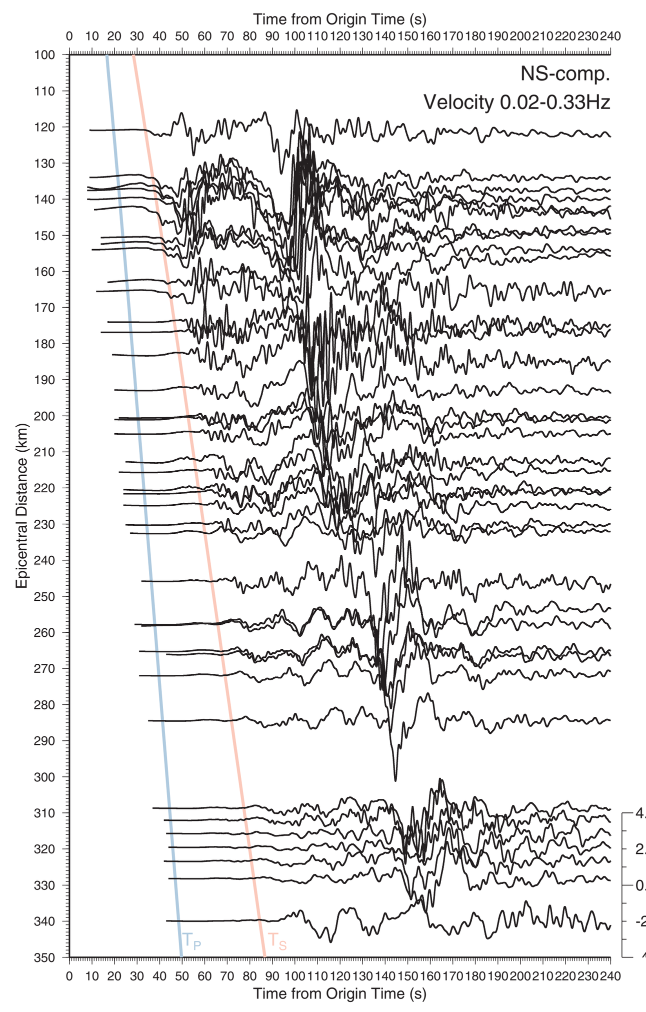
Analysis of Strong Ground Motion Records from the 2011 Off Pacific Coast of Tohoku, Japan Earthquake

Kimiyuki ASANO and Tomotaka IWATA   Disaster Prevention Research Insitute, Kyoto University, JAPAN

A great subduction-zone earthquake of Mw 9.0 occurred along the Japan Trench off the east coast of east Japan on March 11, 2011. This earthquake brought severe Tsunami disasters as well as ground shaking. Strong ground motions from this event were densely observed by the strong motion networks all over Japan. It is quite important to analyze this rich data set for studying the detail structure of the source rupture process and strong motion generation from such a great subduction earthquake. Aligning ground motion time-histories observed by the K-NET and KiK-net of NIED, Japan along the coast, several remarkable pulses were captured in broadband velocity ground motions. In Miyagi and Iwate prefectures, which were close to the northern part of the source fault, two remarkable long-period pulses propagating from the north part of the source region were observed, and these two pulses are separated about 45-50s for all stations in those region, showing the generating area of the second pulse would be neighbor to the first one. Preceding the first distinct pulse the small initial rupture phase can be recognized, it shows that the source of the first strong motion pulse was away from the hypocenter or the rupture starting point. In Fukushima and Ibaraki prefectures, which are close to the southern part of the source fault, another pulse propagating from south part of the source region was observed. We modeled strong ground motions from this complex event for studying the strong motion generation process of this great earthquake.

Paste-up of Observed Velocity Waveforms According to the Epicentral Distance





Three remarkable pulses could be recognized from the observed waveforms. Tp and Ts are the theoretical travel time for P and S waves from the hypocenter.

Acknowledgments: We used the strong motion data of K-NET and KiK-net released from NIED, Japan. JMA hypocenter catalog and Global CMT catalog are also used in this study.

References:
Irikura, K. (1986). Proc. 7th Japan Earthq. Eng. Symp., 151-156.
Miyake, H., T, Iwata, and K. Irikura (2003). Bull. Seism. Soc. Am., 93, 2531-2545.

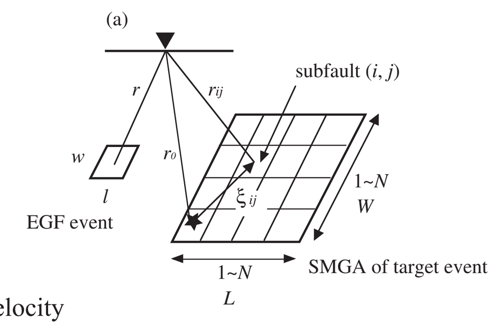
Source Modeling for Broadband Strong Ground Motion Simulation (0.05-5Hz) using the Empirical Green's Function Method

We modeled the broadband strong ground motions by using the empirical Green's function method developed by Irikura (1986),which summing up the small event's records in space and time according to ω^{-2} source spectral model. The source model composed of three Strong Motion Generation Areas (SMGAs) which correspond to the distinct pulses seen in the observed waveforms near the source region.

Brief Introduction of Strong Motion Simulation by the Empirical Green's Function Method of Irikura (1986)

Ground motion of target event

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



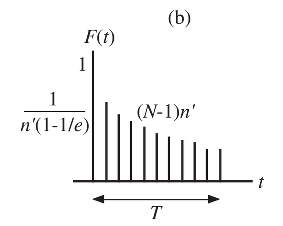
Filtering function to correct the slip-velocity

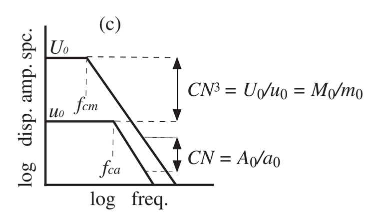
$$F(t)=\delta(t-t_{ij})+\frac{1}{n'(1-\exp(-1))}\sum_{k=1}^{(N-1)n'}\left[\exp\left(-\frac{k-1}{(N-1)n'}\right)\delta\left(t-t_{ij}-\frac{(K-1)\tau}{(N-1)n'}\right)\right]$$

Travel time difference between r_{ij} and r_0

$$t_{ij}=(T_{ij}-T_0)+\frac{\xi_{ij}}{V_R}$$

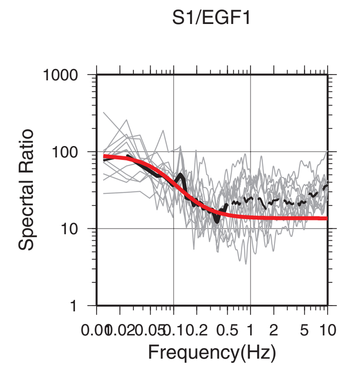
Rupture time at ξ_{ij}

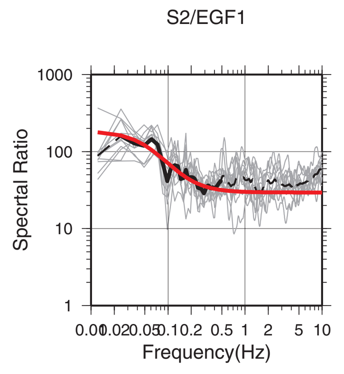


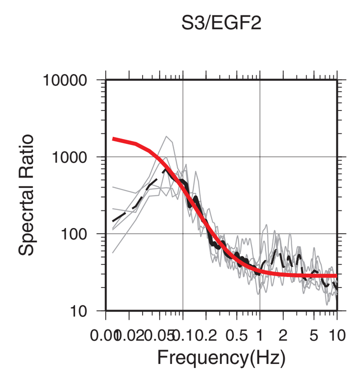


After Miyake *et al.* (2003)

Source Spectral Ratios



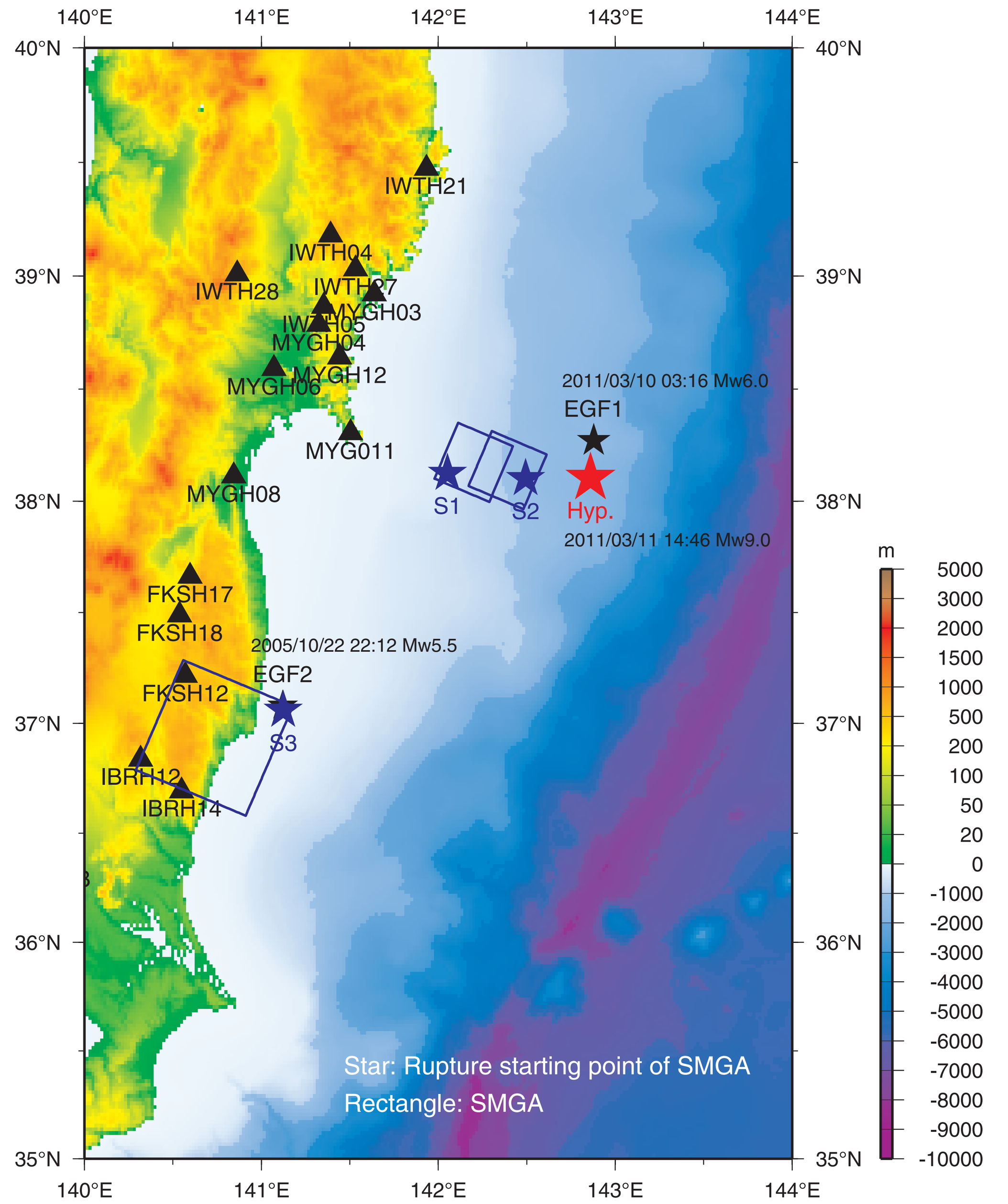




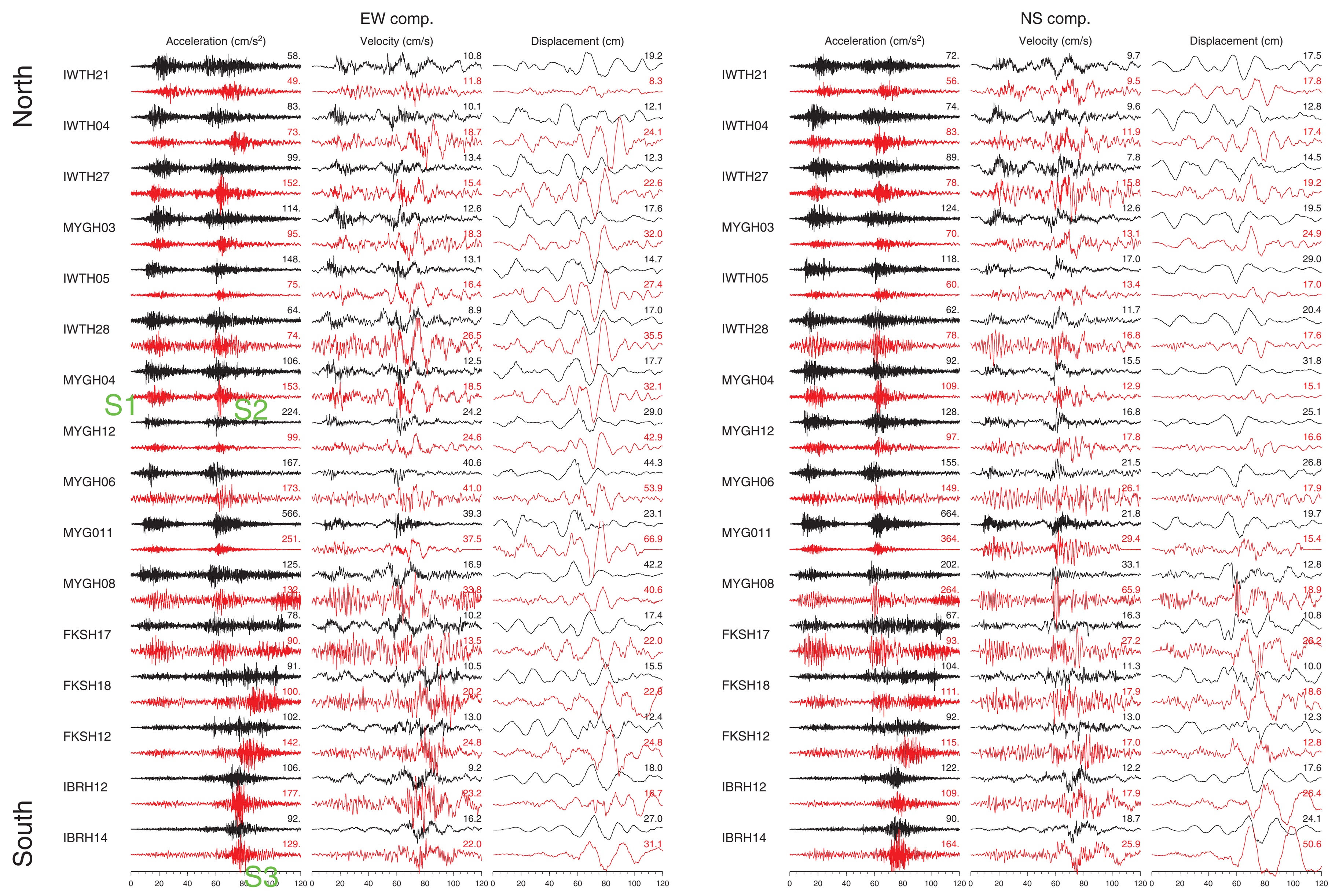
Each portion seems to follow ω^{-2} model.
N = 3 for S1 and S2
N = 8 for S3

EGF1: 2011/03/10 03:16 Mw6.0
EGF2: 2005/10/22 22:12 Mw5.5
(JST = UT + 9)

Strong Motion Stations and SMGAs



Waveform Fitting (Black: Obs., Red: Syn., 0.05-5Hz)



Estimation of Source Pramaters for SMGAs

The rupture starting point of each SMGA is determined by the travel time analysis picking up the S-wave onset of each pulse (S1~S3). EGF1 is used as the master event to correct the error in travel time. Strike and dip angles for the fault plane are fixed at 203 deg. and 10 deg. from Global CMT. The best set of parameters for each SMGA, length (=width), rise time, rupture starting point inside the SMGA, and stress drop are determined by the grid search apporach to minimize the following residual function (Miyake et al., 2003).

$$Residual=\sum_{sta}\sum_{comp}\frac{\sum_t (u_{obs}-u_{syn})^2}{\sqrt{\left(\sum_t u_{obs}^{\ 2}\right)}\sqrt{\left(\sum_t u_{syn}^{\ 2}\right)}}+\sum_{sta}\sum_{comp}\frac{\sum_t (a_{env,obs}-a_{envsyn})^2}{\sqrt{\left(\sum_t a_{env,obs}^{\ 2}\right)}\sqrt{\left(\sum_t a_{env,syn}^{\ 2}\right)}}$$

	Length (km)	Width (km)	Area (km^2)	Rise Time (s)	M_0 (Nm)	Δσ (MPa)	Rupture Starting Point of SMGA			Delay Time from Origin Time (s)
							Latitude (deg)	Longitude (deg)	Depth (km)	
S1	30	30	900	0.60	3.05×10^{20}	27.5	38.125	142.052	35.4	25.0
S2	30	30	900	0.60	4.57×10^{20}	41.2	38.102	142.494	29.0	67.2
S3	60	60	3600	1.36	4.20×10^{20}	4.7	37.059	141.123	40.5	114.3

Conclusions

We modeled the observed strong ground motions by the empirical Green's function method (Irikura, 1986) which allow us to simulate ground motions in broadband frequency range. Followings remarks are worth to be noted.

* The source model composed of three Strong Motion Generation Area (SMGA, S1~S3) could explain the observed broadband strong ground motion along the east coast of Japan.
* The first (S1) and second (S2) SMGA are located west of the epicenter, and S1 and S2 are located close to each other. Those are consistent with observed wave propagation characterisitics.
* S1 might overlap the asperity of the Mw7.1 event on August 16, 2005 in this area.
* The third SMGA (S3) is located far south of the epicenter, and it ruptured 2min after the origin time.
* Those SMGAs are not overlap the large slip area estimated by teleseismic, geodetic, and tsunami inversion. Its suggests that this event is complex of multiple usual events for srong motion generation and shallow long-duration slip event for tsunami generation.
* The summed seismic moment of S1, S2, and S3 is only 2~3% of total moment release of this Mw9.0 event.