After the unexpected extreme event, the Off the Pacific Coast of Tohoku Earthquake of M9.0, are we all guilty for not including this kind of event in our probabilistic seismic risk estimate?

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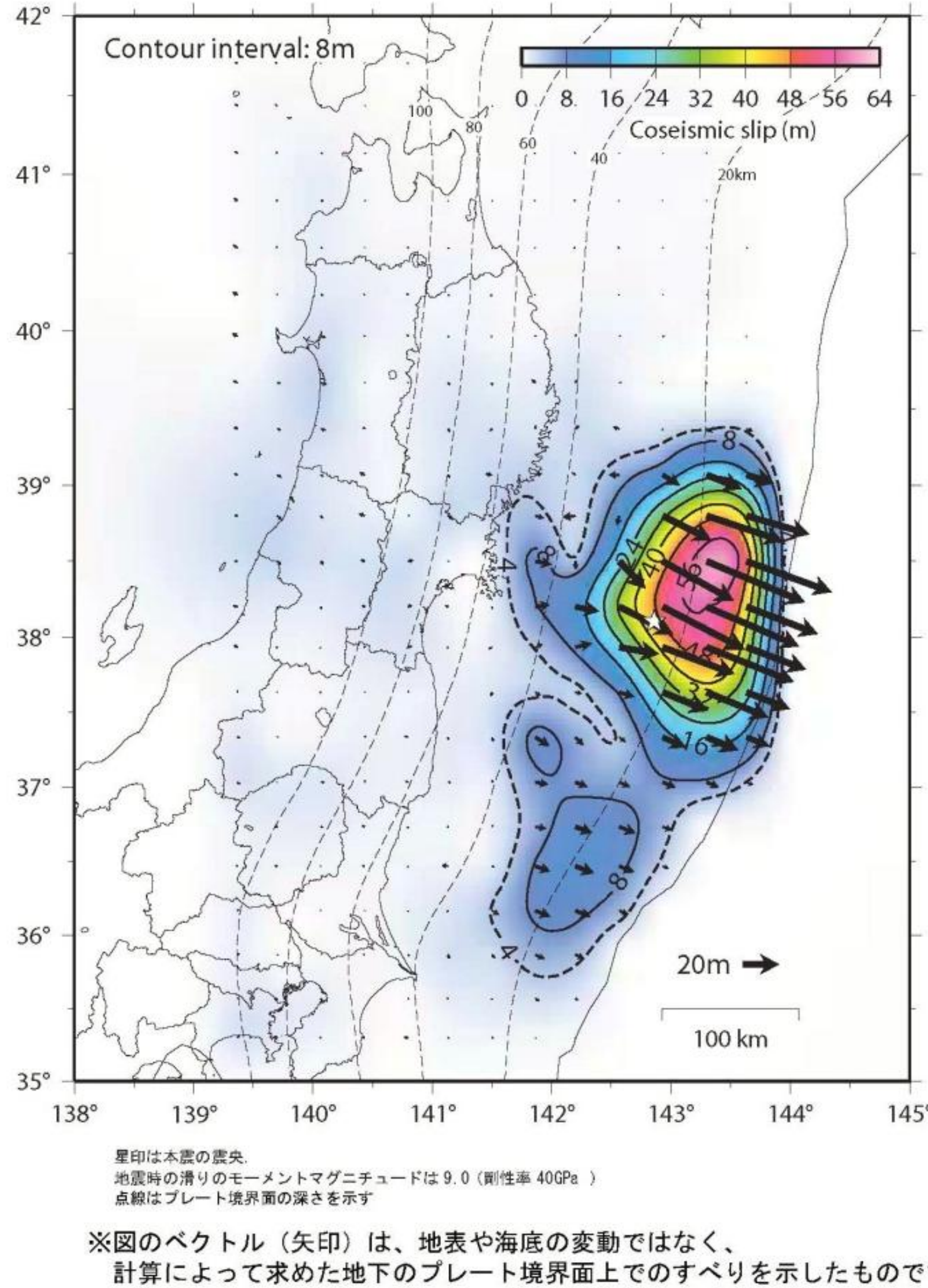
What kind of the earthquake?

- A typical “plate boundary (subduction-zone) earthquake” between the Pacific plate and the North American plate.
- It started from the Miyagi-ken Oki area, where the highest probability of occurrence (99% in 30 years) was predicted.
- No historical corresponding earthquake of this size was recorded (except for 893 Jogan).

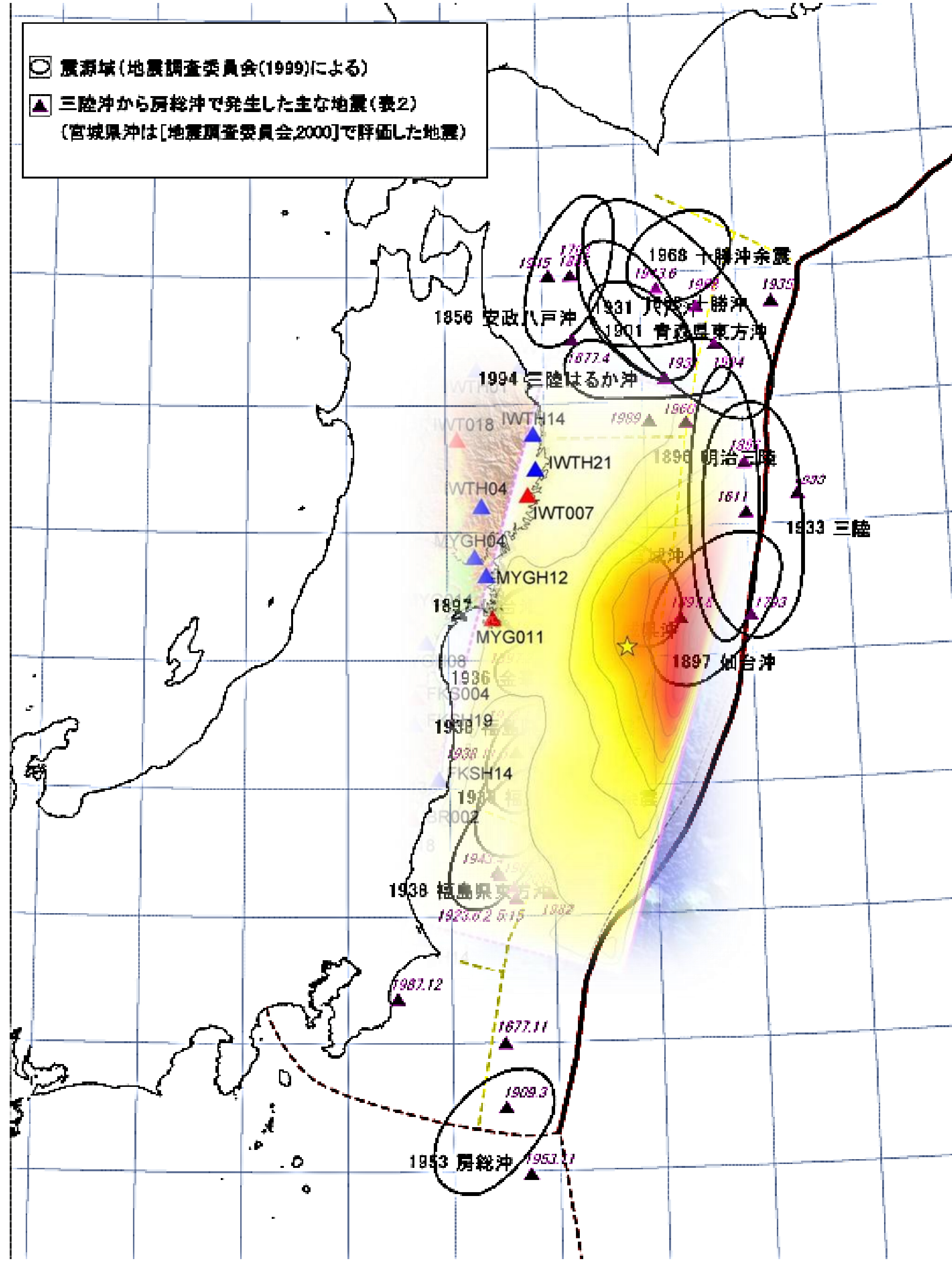
Slip distribution along the fault inverted by GSJ from GPS crustal deformation and ocean bottom deformation sensors.

Near the hypocenter they obtained 60 m slip in a relatively compact area of 100km x 200km.



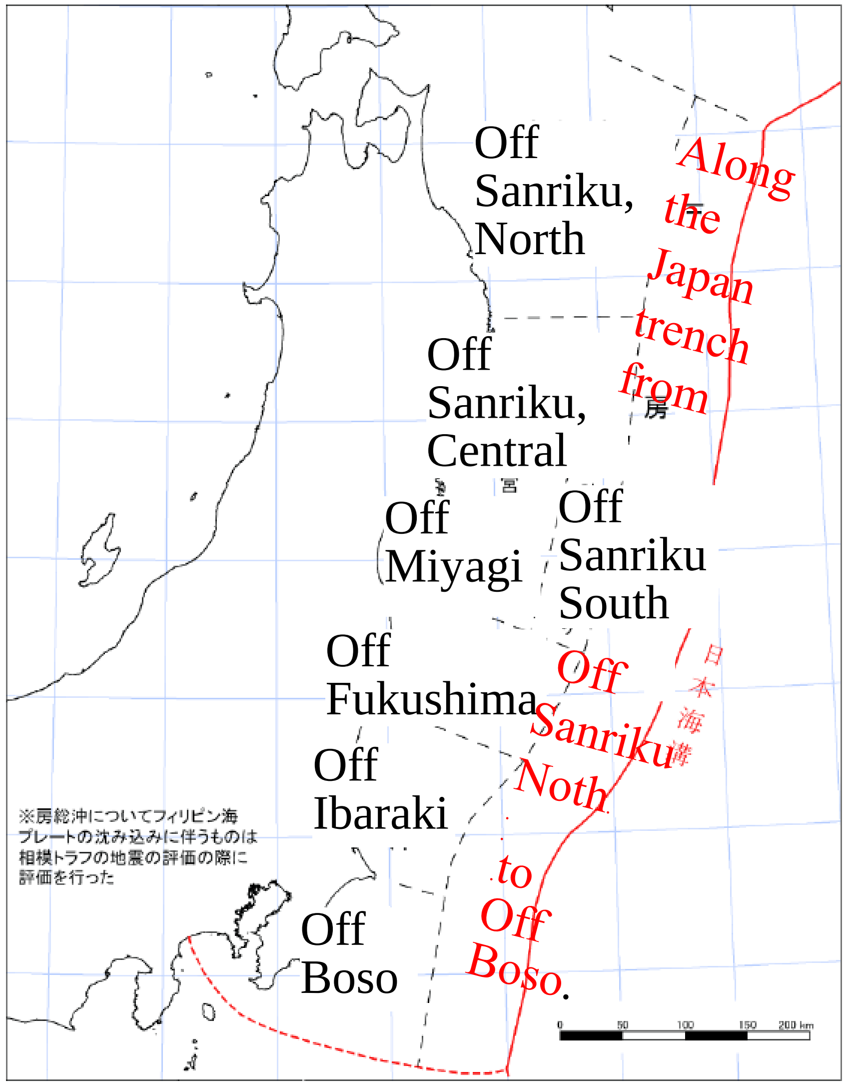
From GSJ site

Source areas of past major earthquakes in the Tohoku region from 1923 to 2008 are not coincide with the largest slip area west of the hypocenter (inverted by NIED).

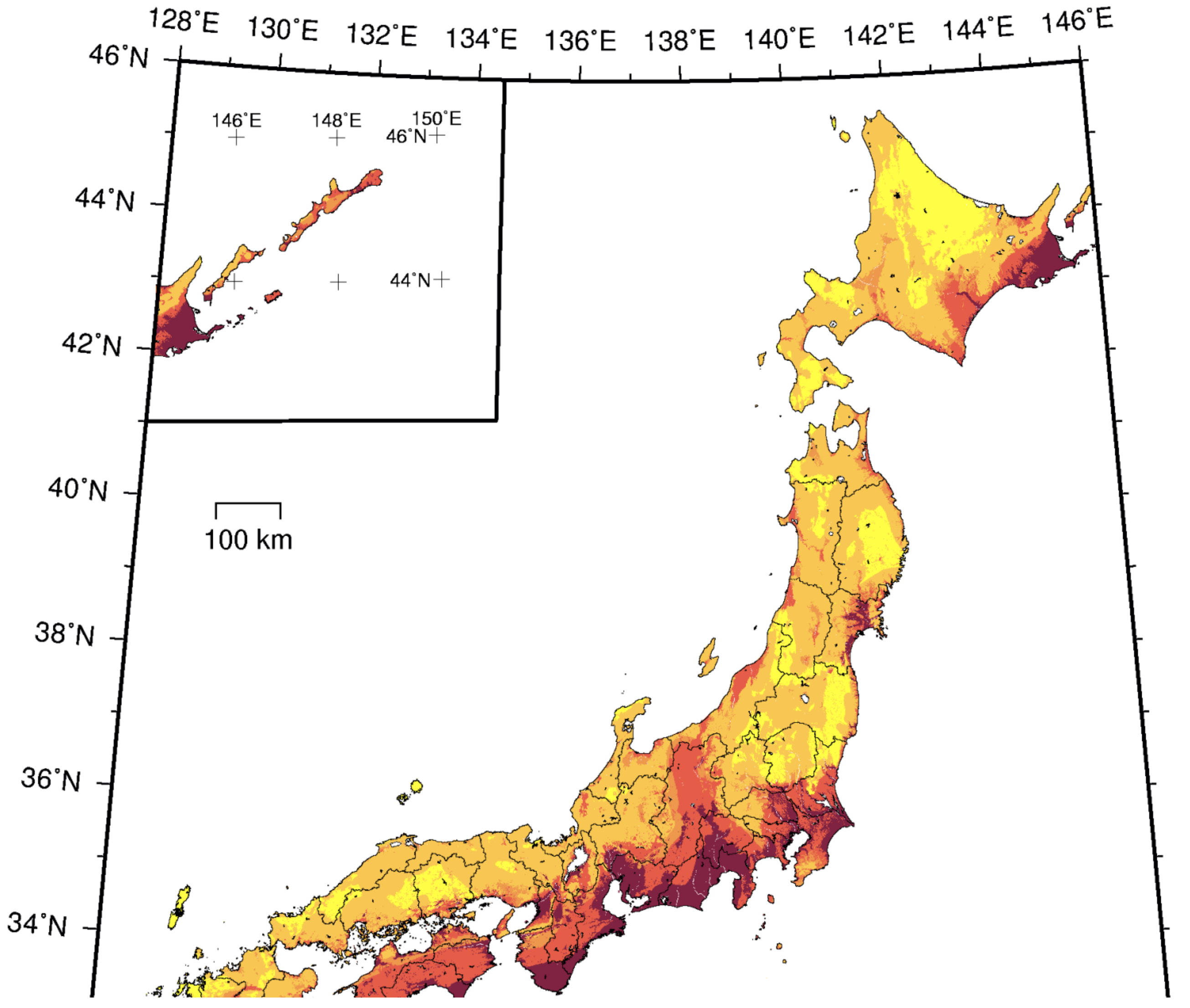


From http://www.jishin.go.jp/main/chousa/ 09mar_sanriku/f01.htm

Assumed segments of earthquake occurrence along the Pacific Coast of the Tohoku Region. Each region has assigned expected maximum magnitude M≦8.3



Probabilistic seismic hazard map for JMA intensity 6- or larger. Average case as of 2010/1/1.



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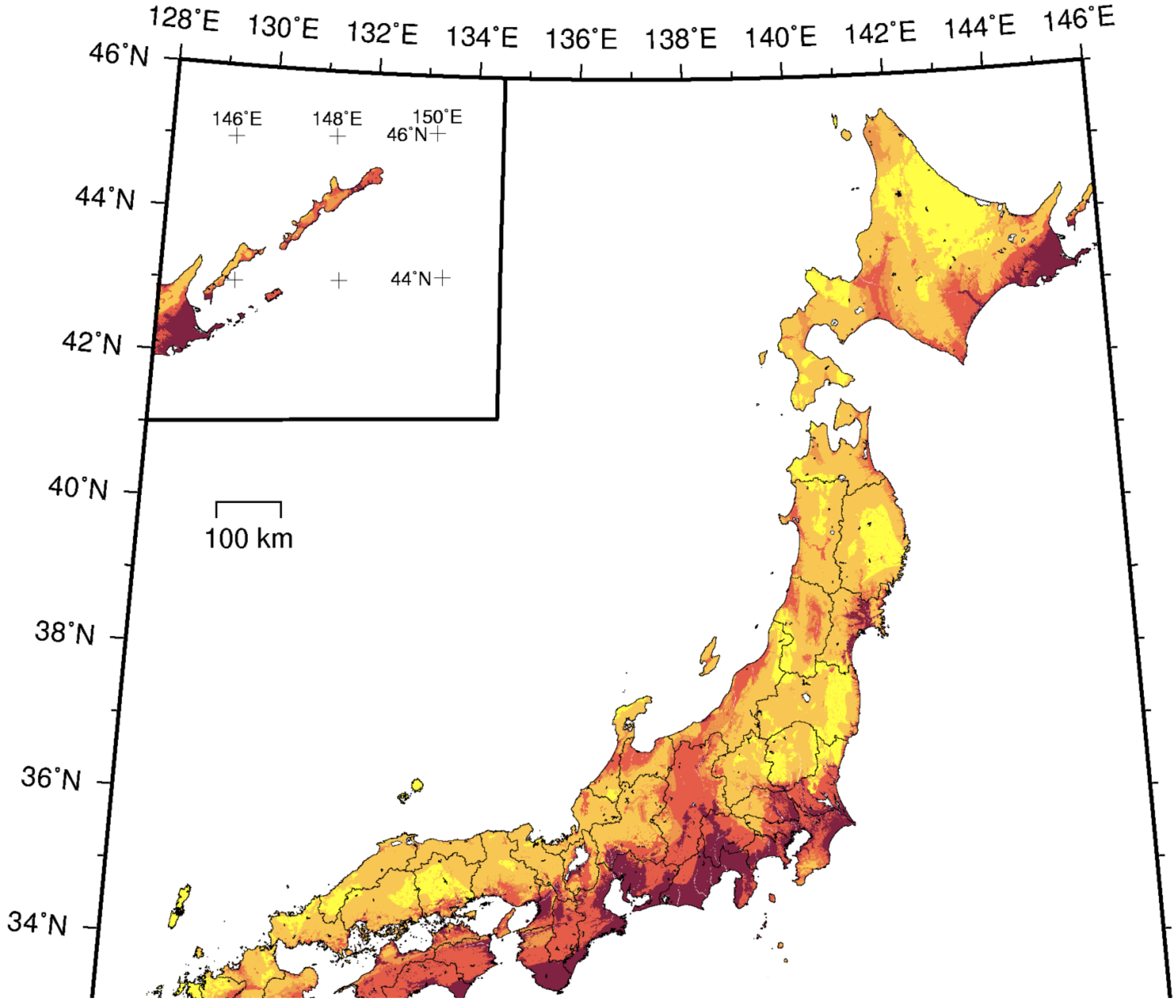
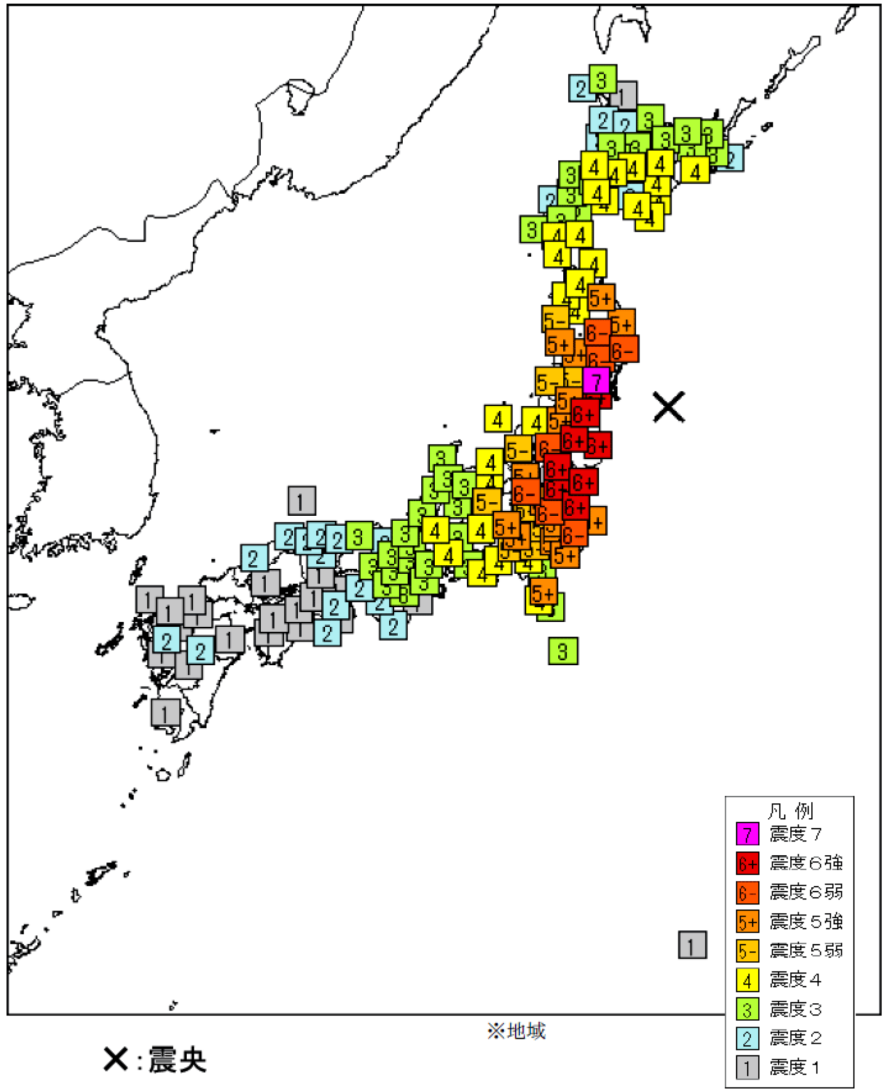


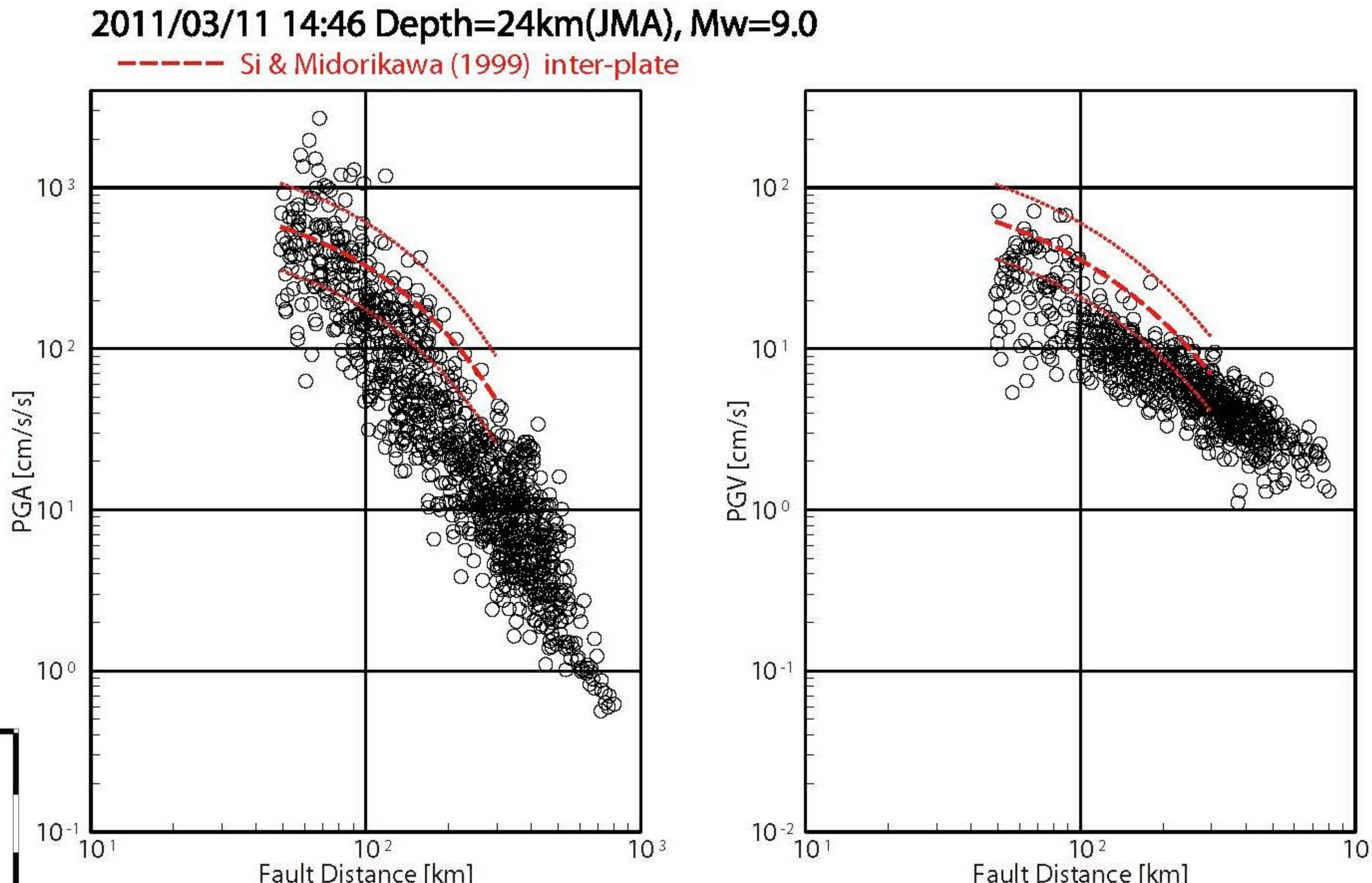
Seismic Intensity broadcasted by JMA



By JMA

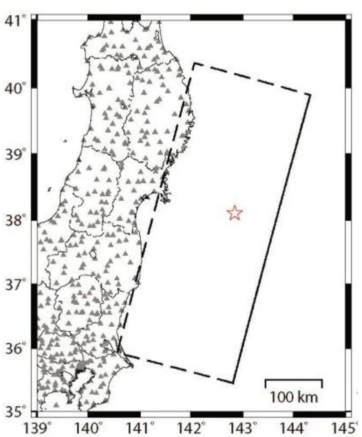
Attenuation relationship by K-NET & KiK-net

If we use shortest distance to the fault (below), PGAs in the far field look small



Peak Ground Acceleration cm/s^2

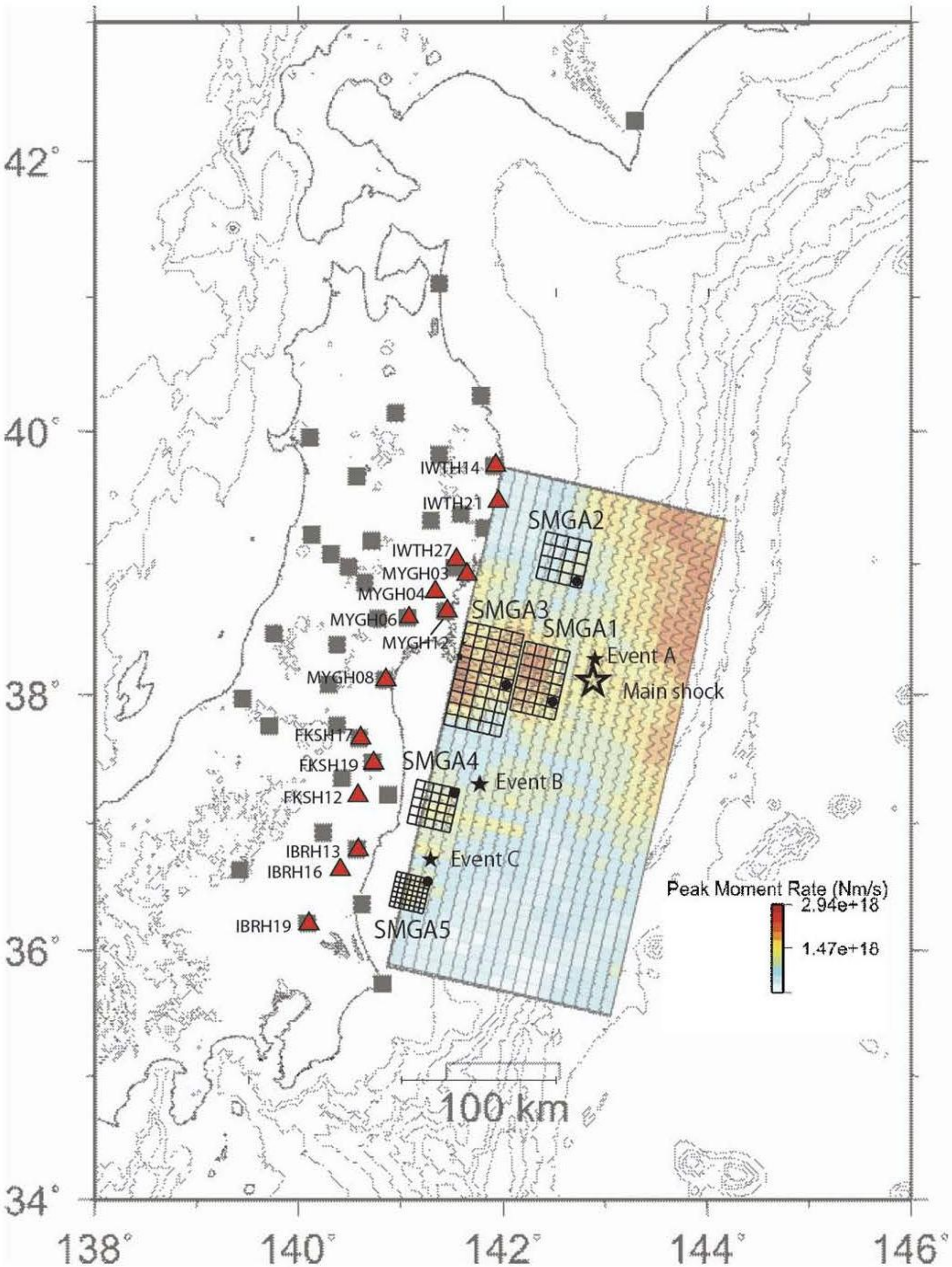
Peak Ground Velocity cm/s



By NIED

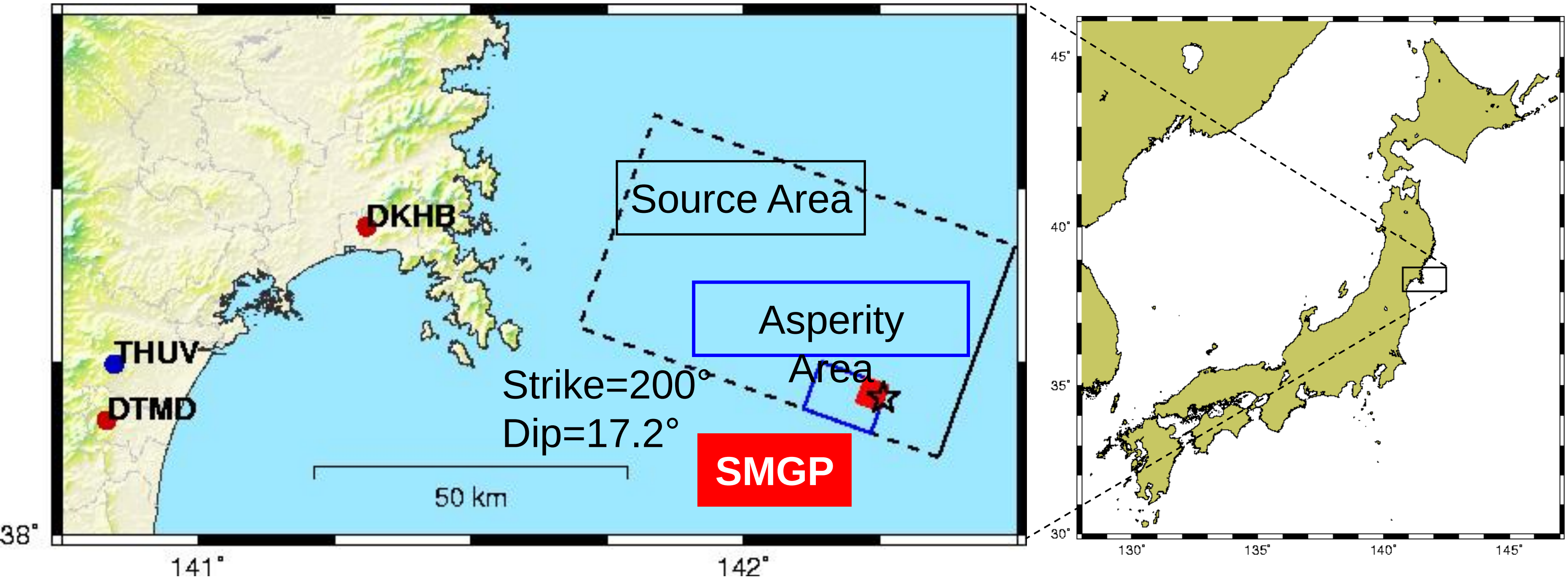
Very high PGAs are observed.

Site code	Name	PGA NS	PGA EW	PGA UD	Vector
MYG004	Tukidate	2,700	1,268	1,880	2,933
MYG012	Shiogama	758	1,969	501	2,019
IBR003	Hitachi	1,598	1,186	1,166	1,845
MYG013	Sendai	1,517	982	290	1,808
IBR013	Hokota	1,355	1,070	811	1,762
TCG009	Imaichi	1,017	1,186	493	1,444
FKS016	Shirakawa	1,295	949	441	1,425
FKSH10	Saigo	1,062	768	1,016	1,335
IBR004	Oomiya	1,283	1,007	775	1,312
TCGH16	Haga	799	1,197	808	1,305
TCG014	Mogi	711	1,205	494	1,291
IWT010	Ichinoseki	998	852	353	1,226
IBRH11	Iwase	815	827	815	1,224
MYGH10	Yamamoto	871	853	622	1,137
FKS018	Kooriyama	745	1,069	457	1,110
FKS008	Funabiki	1,012	736	327	1,069
IBRH15	Omaeyama	606	781	640	1,062
CHB007	Sakura	1,036	491	200	1,054



SMGAs obtained by Kurahashi and Irikura (2011). They found two SMGAs west of the hypocenter★ and another one in the north and two SMGAs in Fukushima. Each corresponds to be M8 class events and the total moment of these SMGAs corresponds to Mw8.5. Stress drop of them are equally high, ~30MPa.

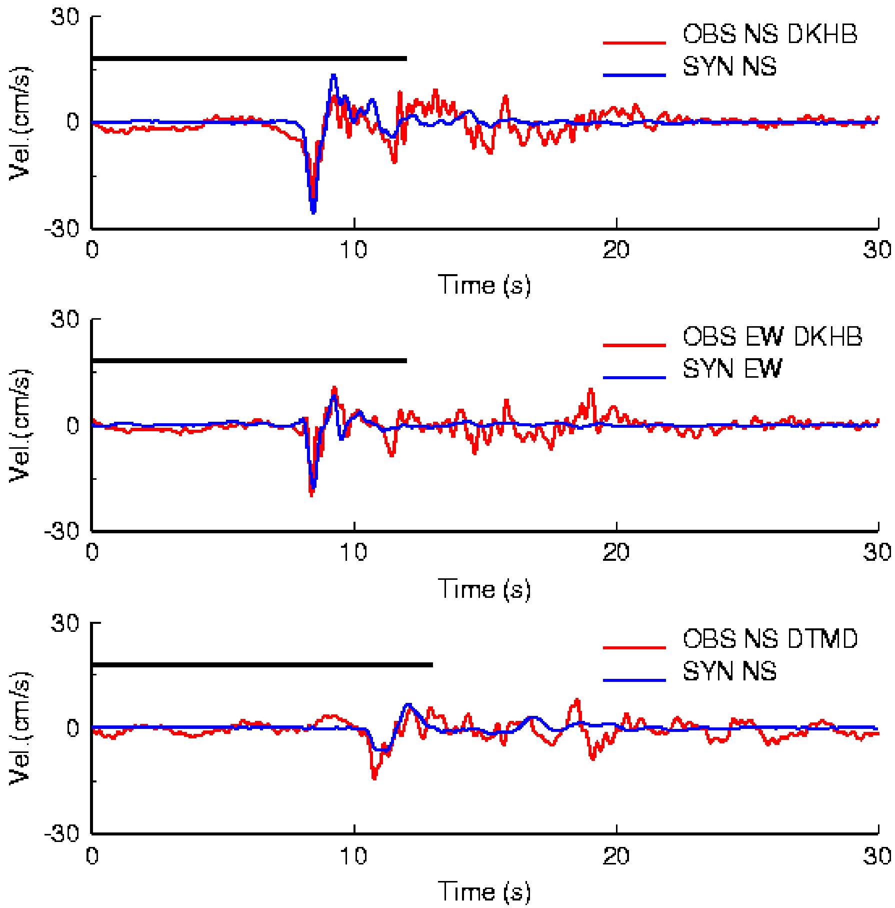
Historically Tohoku is high stress region. E.g., Miyagi-Oki Earthquake of 1978.



☆Start of Rupture
●Strong Motion Stations

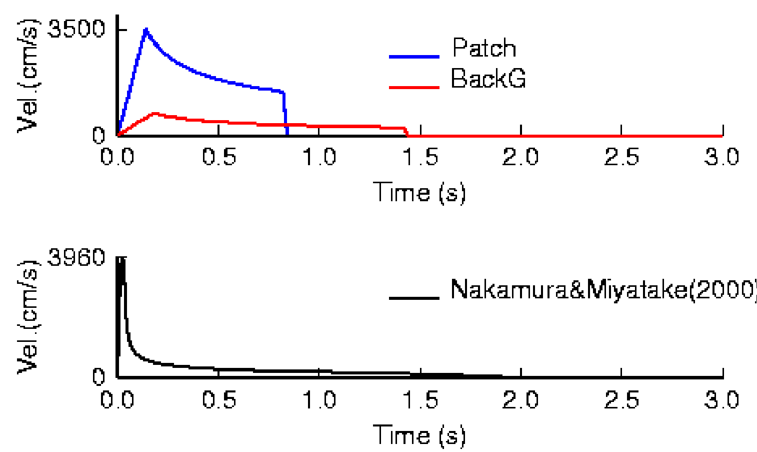
- Consider only the asperity area close to the start of rupture
- Source location is based on report by Headquarters for Earthquake Research Promotion (2003)

Best Fit Case with super-patch



Velocity waveform (f < 4.0Hz)

		Best Case			Nakamura&Miyatake(2000)
		Patch	Back	total	HERP (2003)
size	km^2	16	80	96	96
time to max. vel.	sec	0.14	0.18	-	0.024
duration	sec	0.84	1.44	-	1.333
coefficient		1	1	-	-
max. vel.	cm/s	3500	750	-	3956
rake	deg	15	15	-	90
slip	m	16.5	5.59	7.408	5.9
M_0	10^{19}Nm			3.3	2.6



Slip velocity time function

- The slip velocity time function of the smaller patch has a larger amplitude and shorter duration
- The slip velocity time function by Namakura&Miyatake is derived from parameters in the report by HERP

Structural damage by seismic motion

Virtually no severe damage
around MYG004, 2.7g site.

Several wooden houses collapsed
around MYG006, JMA intensity 6+ site.

Photo by Prof. Goto of Kyoto Univ.(on the left) and by Prof. Morikawa of Tokyo Inst.

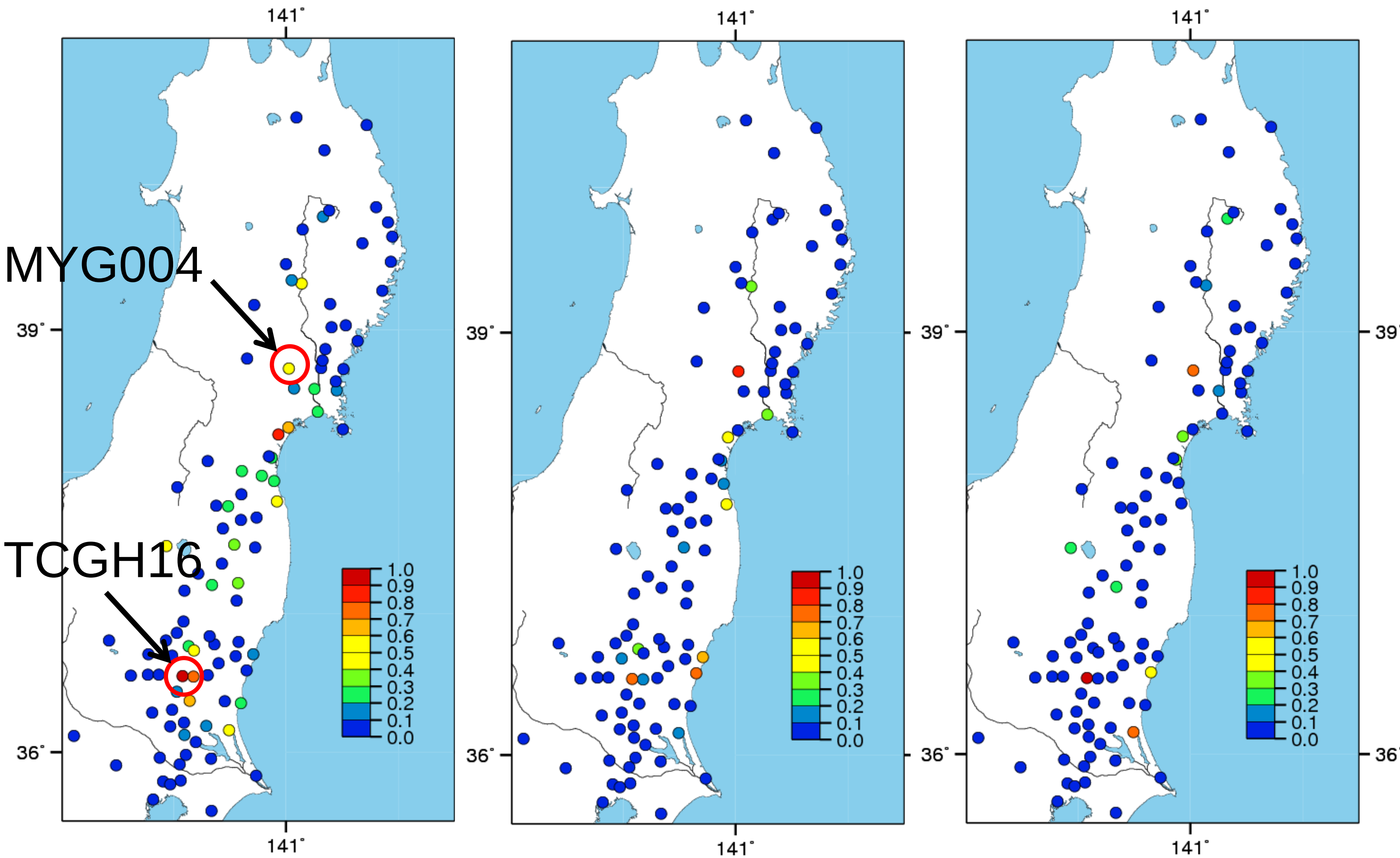
Structural damage by seismic motion

Virtually no severe damage around IBR003, 1.6g site.

Several houses have damage in the roof around TCGH16, 1.2g site.

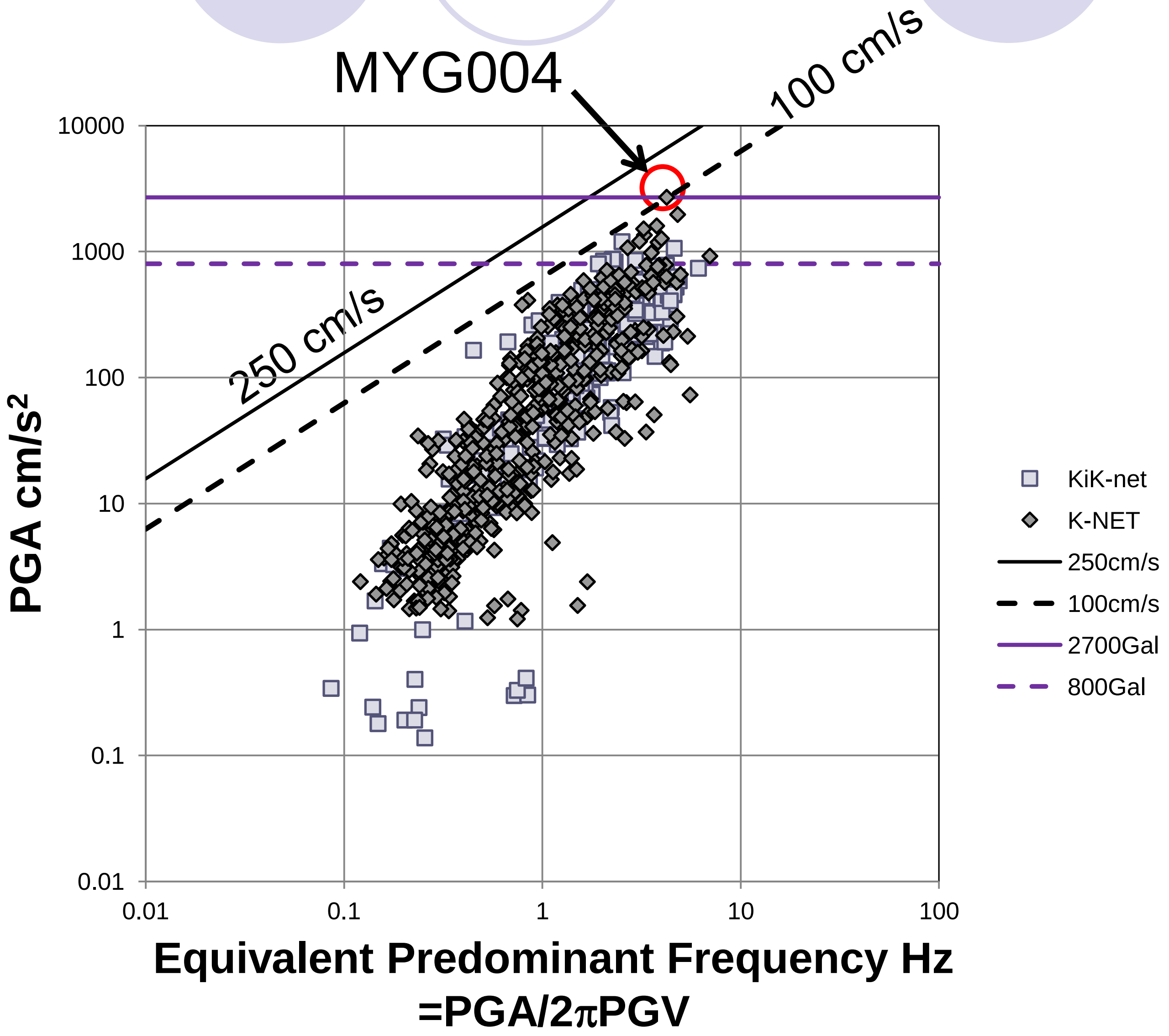
Photo by Prof. Sakai of Tsukuba University (See http://www.kz.tsukuba.ac.jp/

Building damage potential by simulation



Wooden, 2st st.（Old） **RC, 9 st.（Old）** **Steel, 5 st.（Old）**

PGA and Equivalent Predominant Frequency



At many sites PGAs exceed 1,000 Gal (1g) but PGVs did not exceed 100cm/s ➔explain why structural damage was not so intense.

What was the consequence?

- Why we cannot include this kind of event?

➔Based on the previous history of 110 years, we cannot account for the occurrence of this kind of rare event.

- Is the probabilistic long term prediction total failure?

➔At least the hypocenter was successfully predicted since we have M7.3 event in 2005 and we judged that this event is too small as the main one.

- Did we fail to predict strong motions for this kind of event?

➔Strong motions can be interpreted as the successive generation of waves from ordinary (M8!) sized SMGAs. Then this was just a multi-segment rupture.

What should we learn?

- From short duration of reference data we need to accept rational risks for failure to predict next event.
- Any kind of a priori assumptions we are implicitly introducing could be a source of failure of prediction.
- From probabilistic approach we have to prepare for the response from the public that we fail to tell them the truth, either if we predict high probability and no occurrence or if we predict low probability and actual occurrence. Truth is nobody knows the real truth (but unfortunately we cannot say that).
- As for the strong motion prediction empirical formula works more or less in a reasonable manner so that we can proceed in the current line of research, I guess.

Concluding agenda:

We really would like to know how to let the public accept (and appreciate) the probabilistic seismic risk estimate.

Note that the Central Disaster Management Council, Cabinet Office, Government of Japan, strongly inclined to increase the parameters of the expected mega-thrust event beyond the rational level to M9.