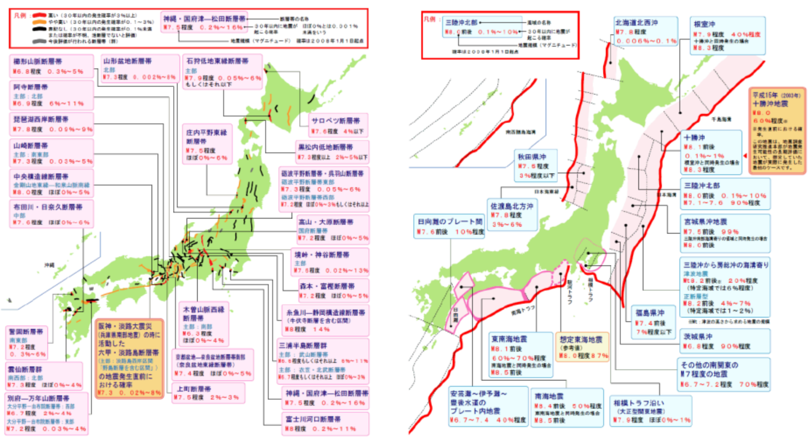
Seismic hazard assessment for Japan after the 2011 Great East Japan Earthquake

Hiroyuki Fujiwara

National Research Institute for Earth Science and Disaster Prevention

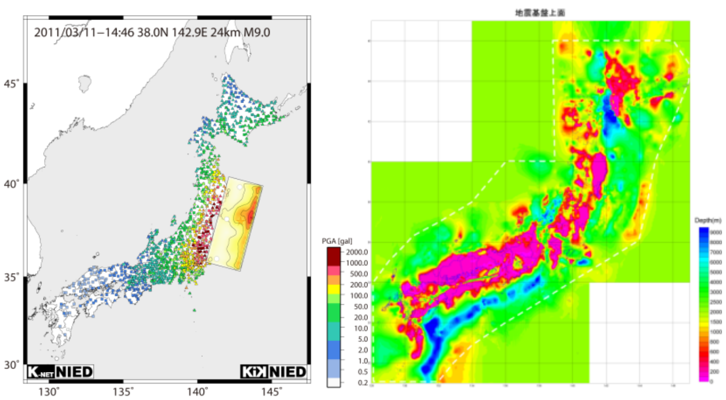
National seismic hazard maps for Japan

Long term evaluation



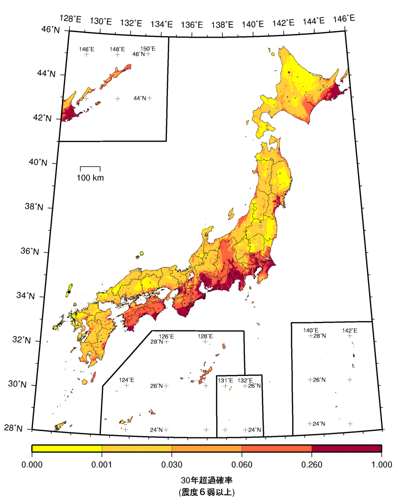
Probability of occurrence, magnitude, location

Strong-motion evaluation



Strong-motion, underground structure

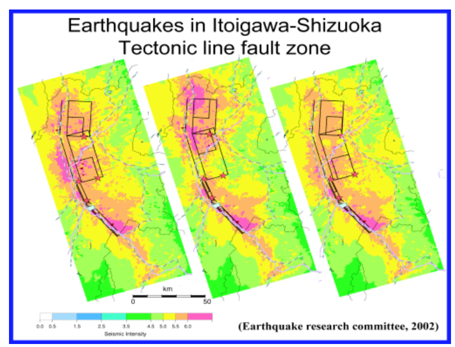
Probabilistic Seismic Hazard Maps



・Showing the strong-motion intensity with a given probability, or the probability with a given intensity.

・Considering all possible earthquakes.

Scenario Earthquake Shaking Maps



・Showing the strong-motion intensity around the fault for a specified earthquake.

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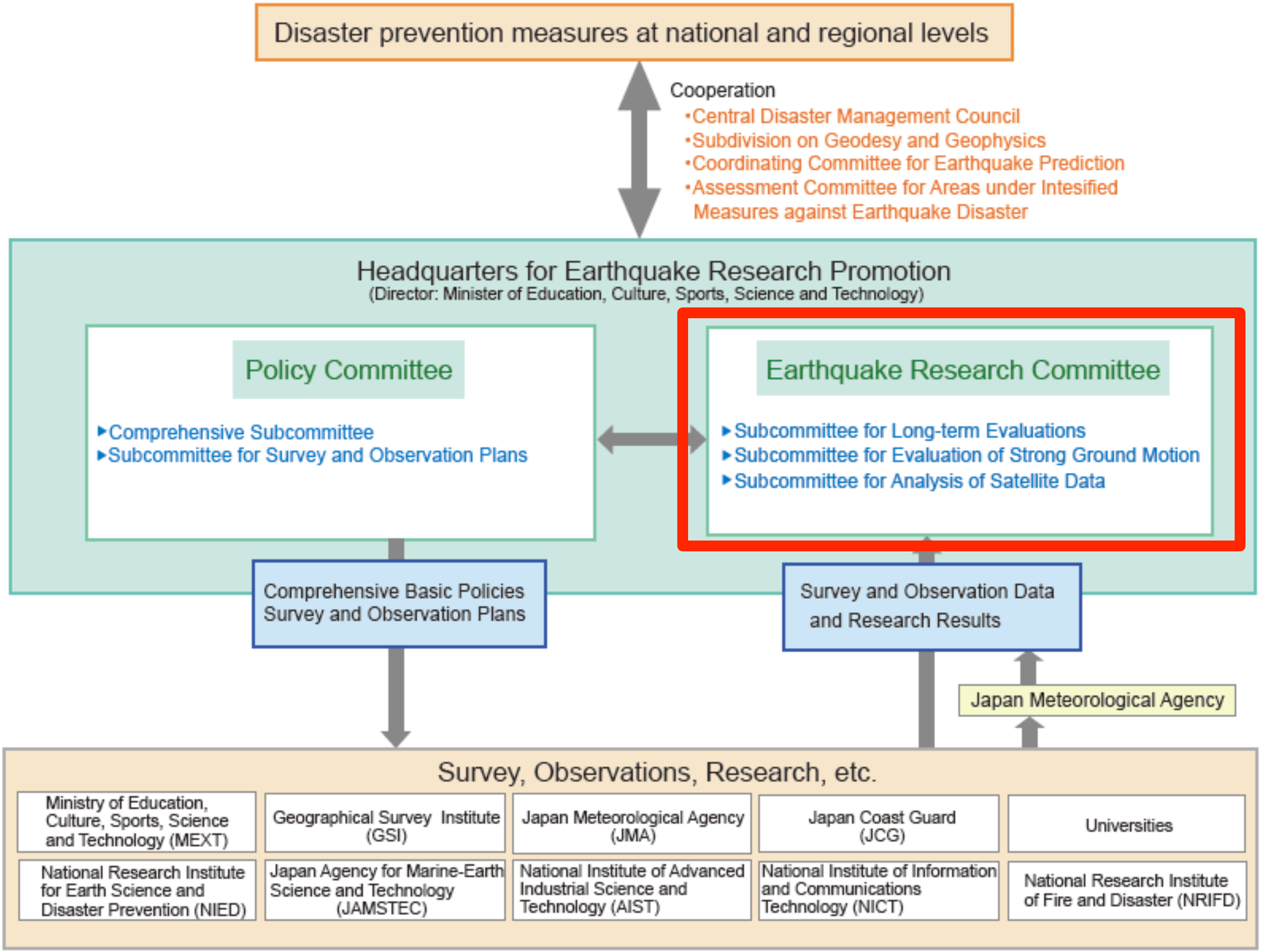
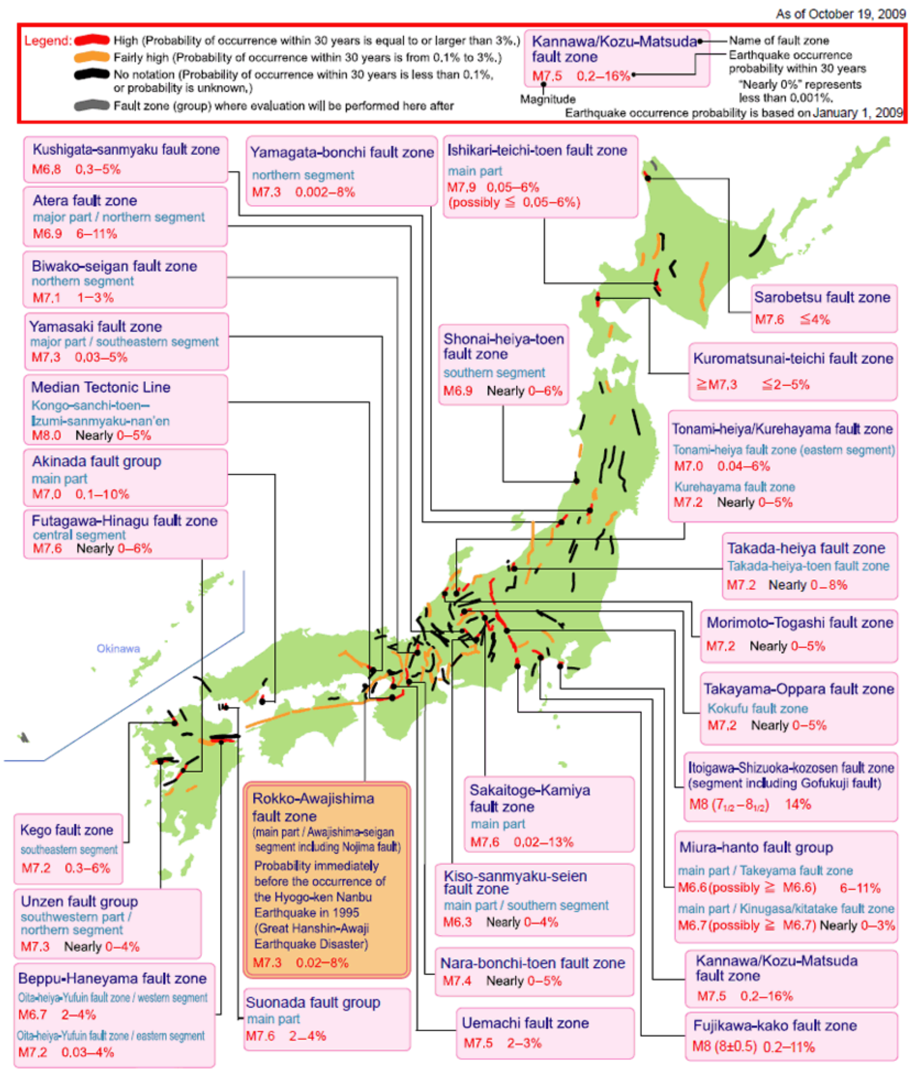
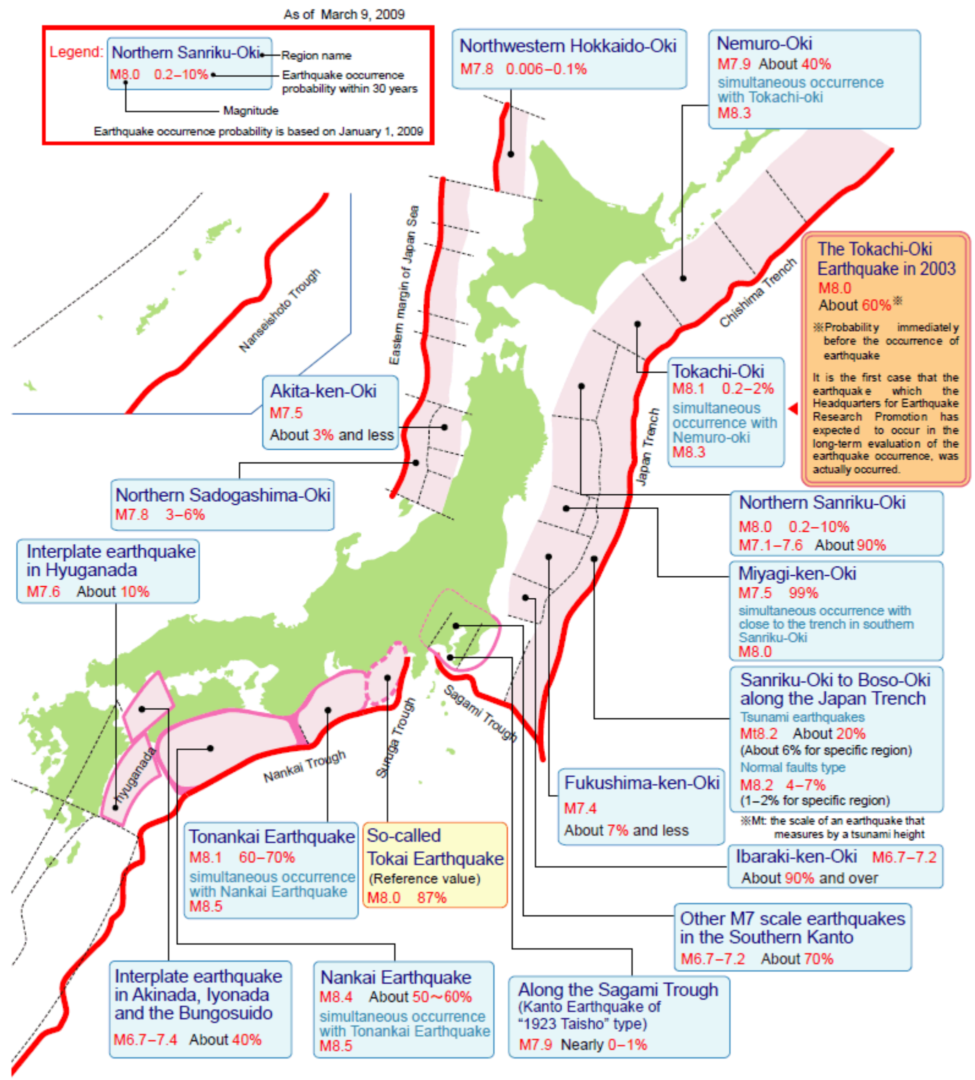

Disaster prevention measures at national and regional levels
Cooperation
•Central Disaster Management Council
•Subdivision on Geodesy and Geophysics
•Coordinating Committee for Earthquake Prediction
•Assessment Committee for Areas under Intesified Measures against Earthquake Disaster
Headquarters for Earthquake Research Promotion
(Director: Minister of Education, Culture, Sports, Science and Technology)
Policy Committee
▸Comprehensive Subcommittee
▸Subcommittee for Survey and Observation Plans
Earthquake Research Committee
▸Subcommittee for Long-term Evaluations
▸Subcommittee for Evaluation of Strong Ground Motion
▸Subcommittee for Analysis of Satellite Data
Comprehensive Basic Policies
Survey and Observation Plans
Survey and Observation Data and Research Results
Japan Meteorological Agency
Survey, Observations, Research, etc.
Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Geographical Survey Institute (GSI)
Japan Meteorological Agency (JMA)
Japan Coast Guard (JCG)
Universities
National Research Institute for Earth Science and Disaster Prevention (NIED)
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
National Institute of Advanced Industrial Science and Technology (AIST)
National Institute of Information and Communications Technology (NICT)
National Research Institute of Fire and Disaster (NRIFD)

Evaluation of occurrence probability of earthquakes by ERCJ





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Flowchart of PSHA

Modeling of seismic activity

↓

Evaluation of an EQ occurrence probability **$P(E_i)$**

↓

Probabilistic evaluation of an intensity level **$P(Y_i > y|E_i)$**

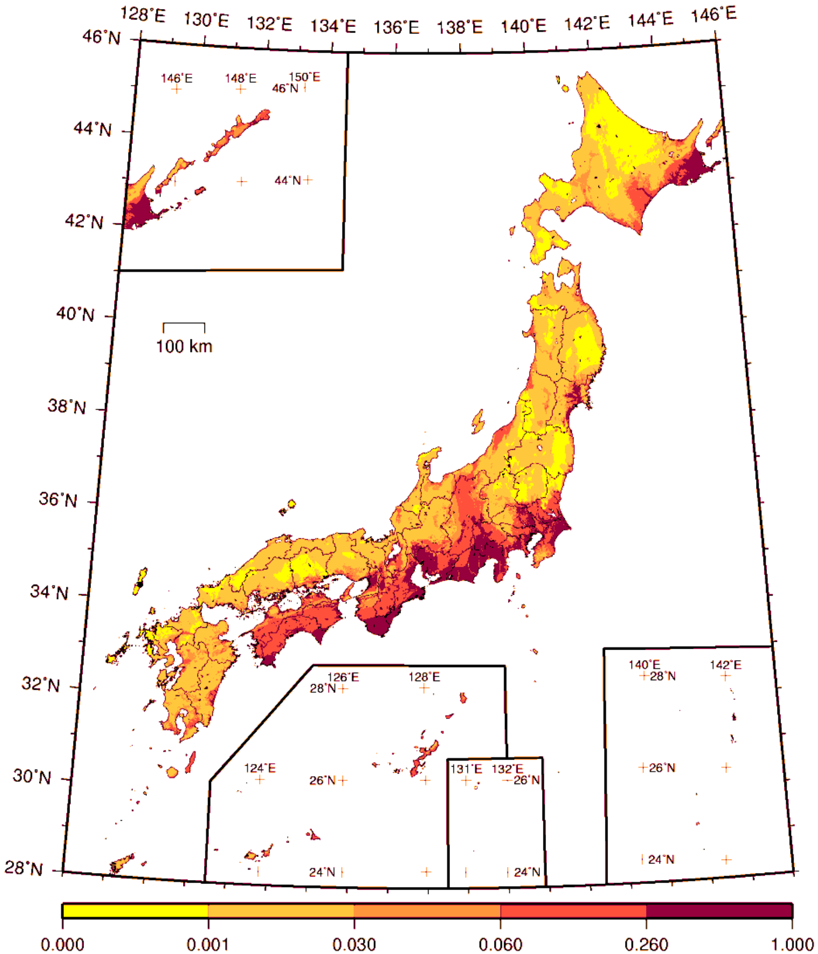
↓

Evaluation of probabilistic seismic hazard
for each earthquake **$P(Y_i > y) = P(E_i)\,P(Y_i > y|E_i)$**

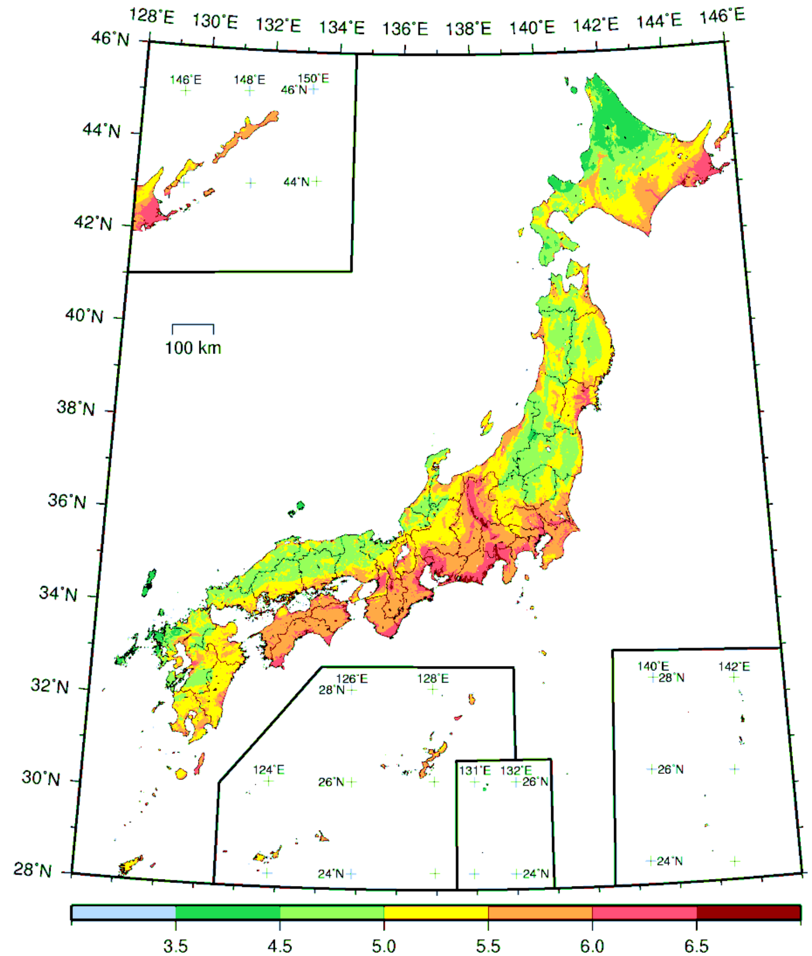
↓

Evaluation of probabilistic seismic hazard
for all earthquakes **$P(Y > y) = 1 - \Pi[1 - P(Y_i > y)]$**

Probabilistic Seismic Hazard Maps



Probability in 30 years.
(≧JMA Seismic Intensity 6-)



Seismic Intensity with 3% probability of exceedance in 30 year.

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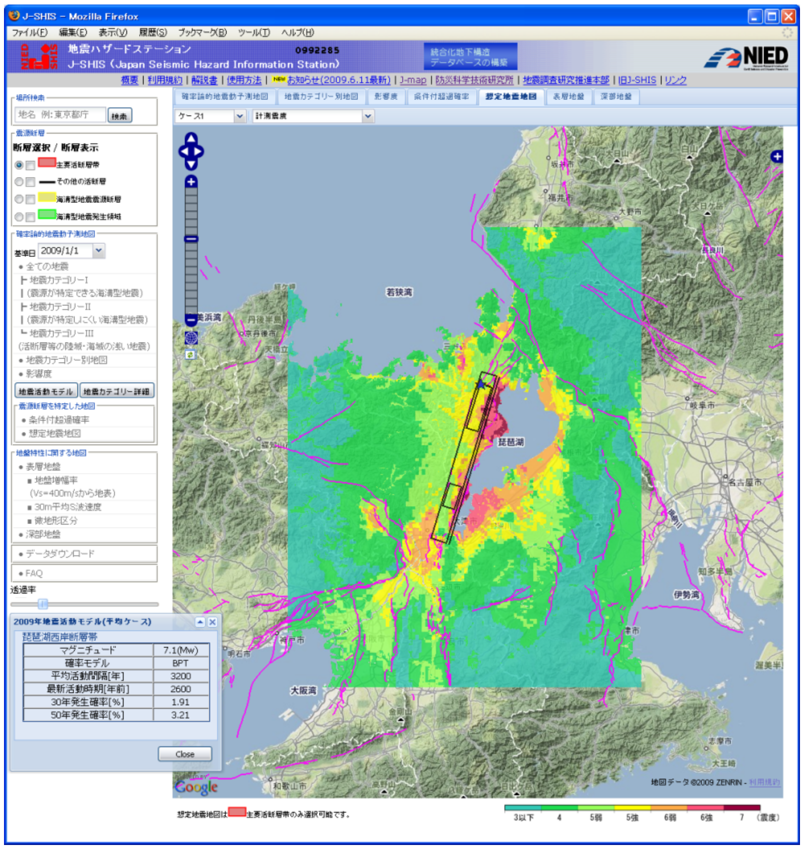
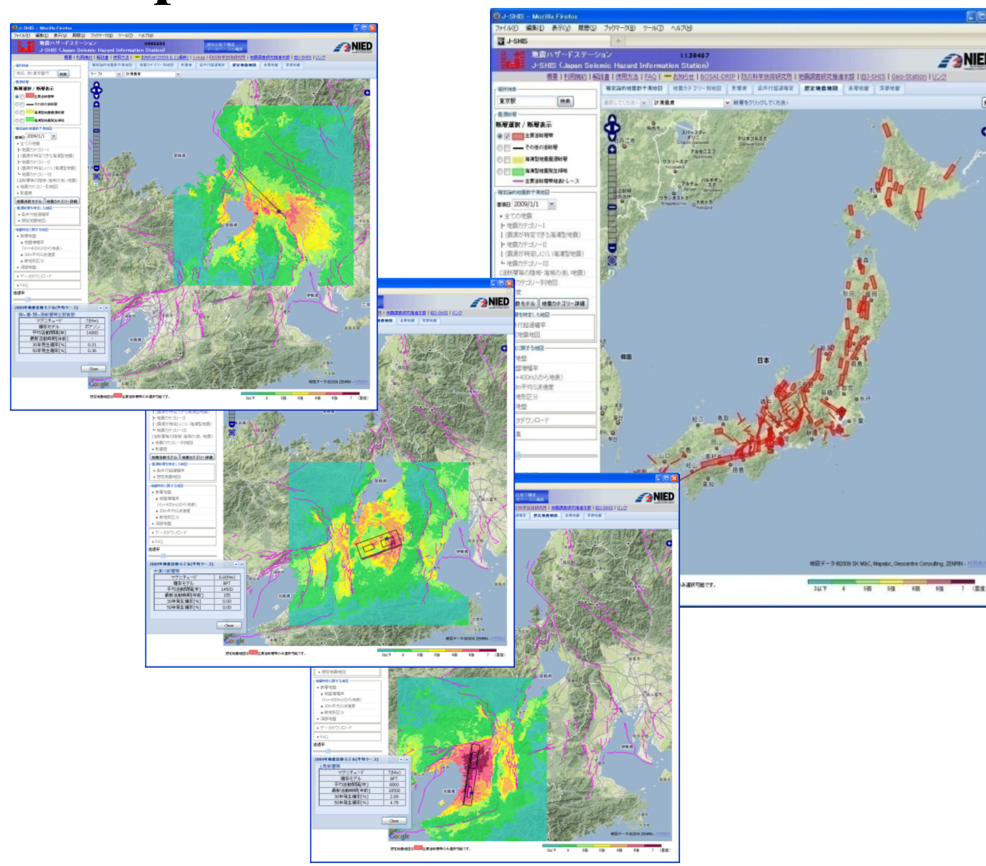
Scenario Earthquake Shaking Maps

The shaking maps are evaluated for 490 scenario earthquakes of almost all of major faults in Japan.





Selection of a specified scenario is essential to make a shaking map. The basic policy of the selection of a scenario earthquake is that we choose the most probable case.

For treatment of uncertainties, we assume several cases of source model and compare the results of them to show deviation of strong-motion evaluation due to uncertainties.

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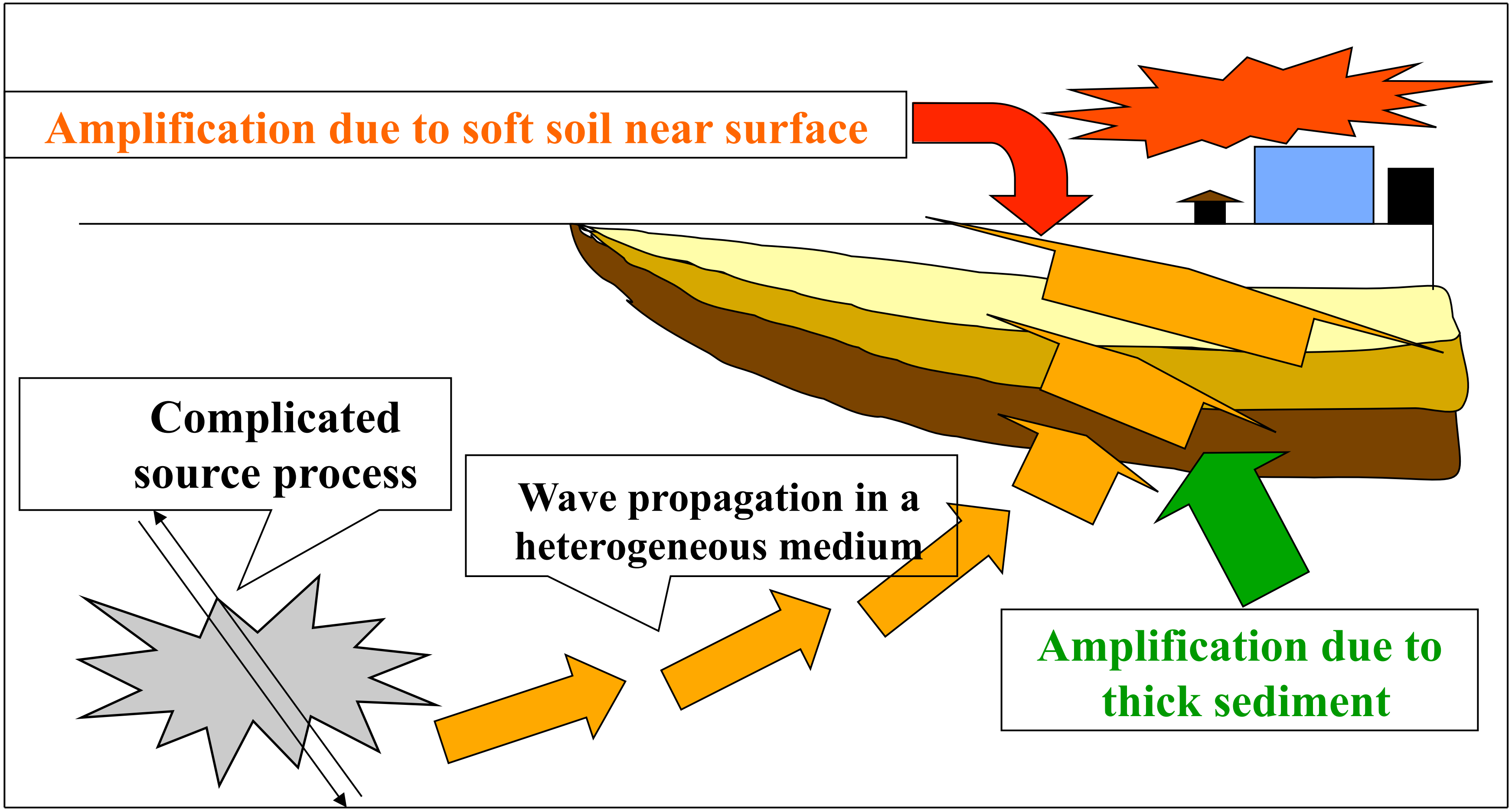
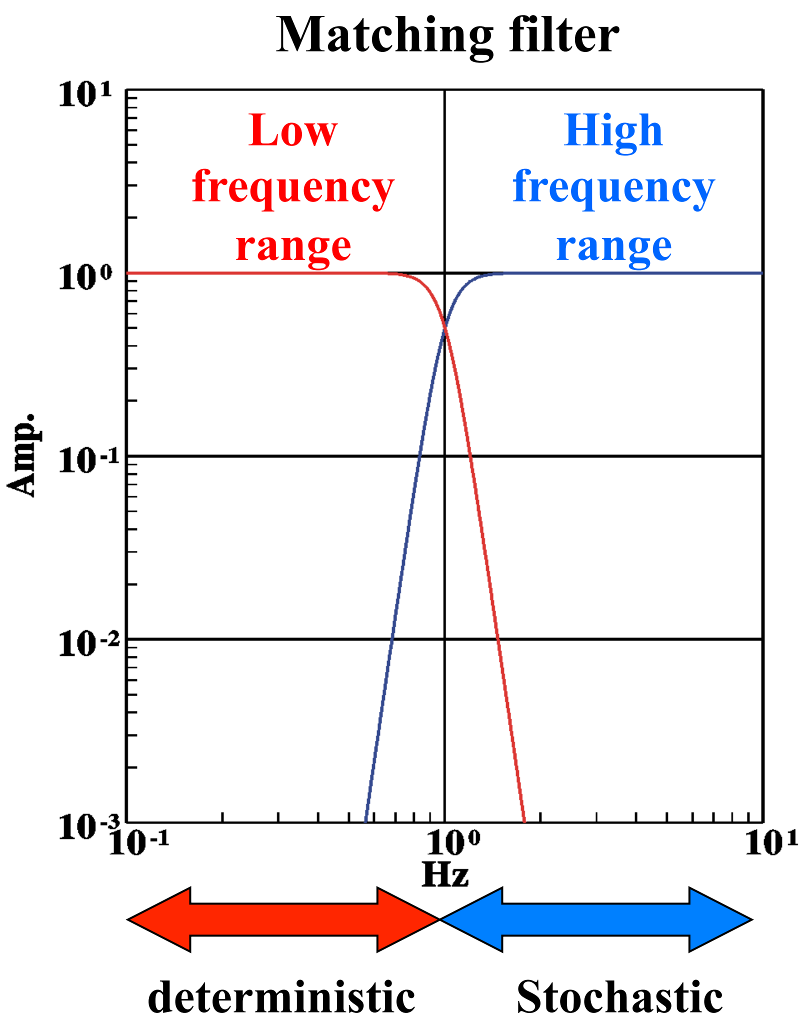
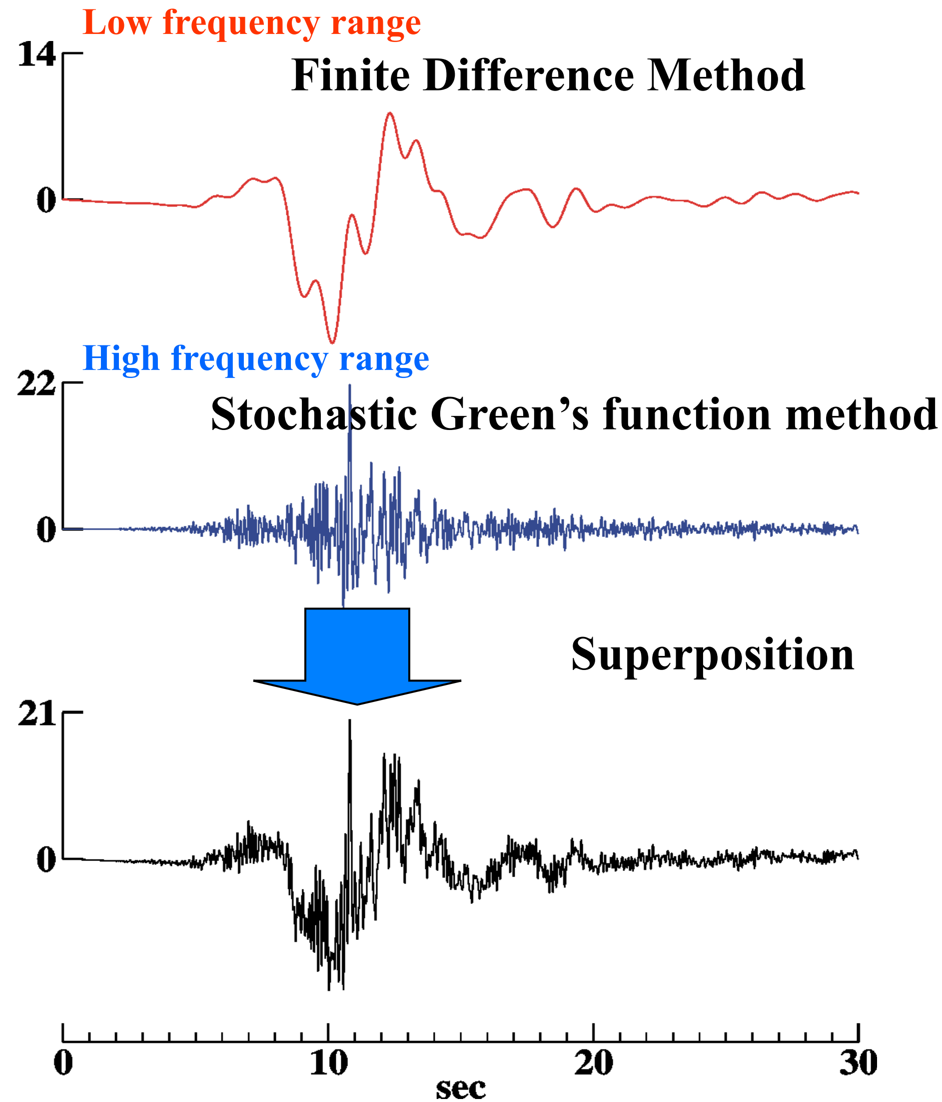
Theoretical approach for evaluation of strong-motion



Hybrid method for evaluation of strong-motion





The technical details on the hybrid method are summarized as the 'Recipe for strong-motion evaluation', which are published by the earthquake research committee of Japan.

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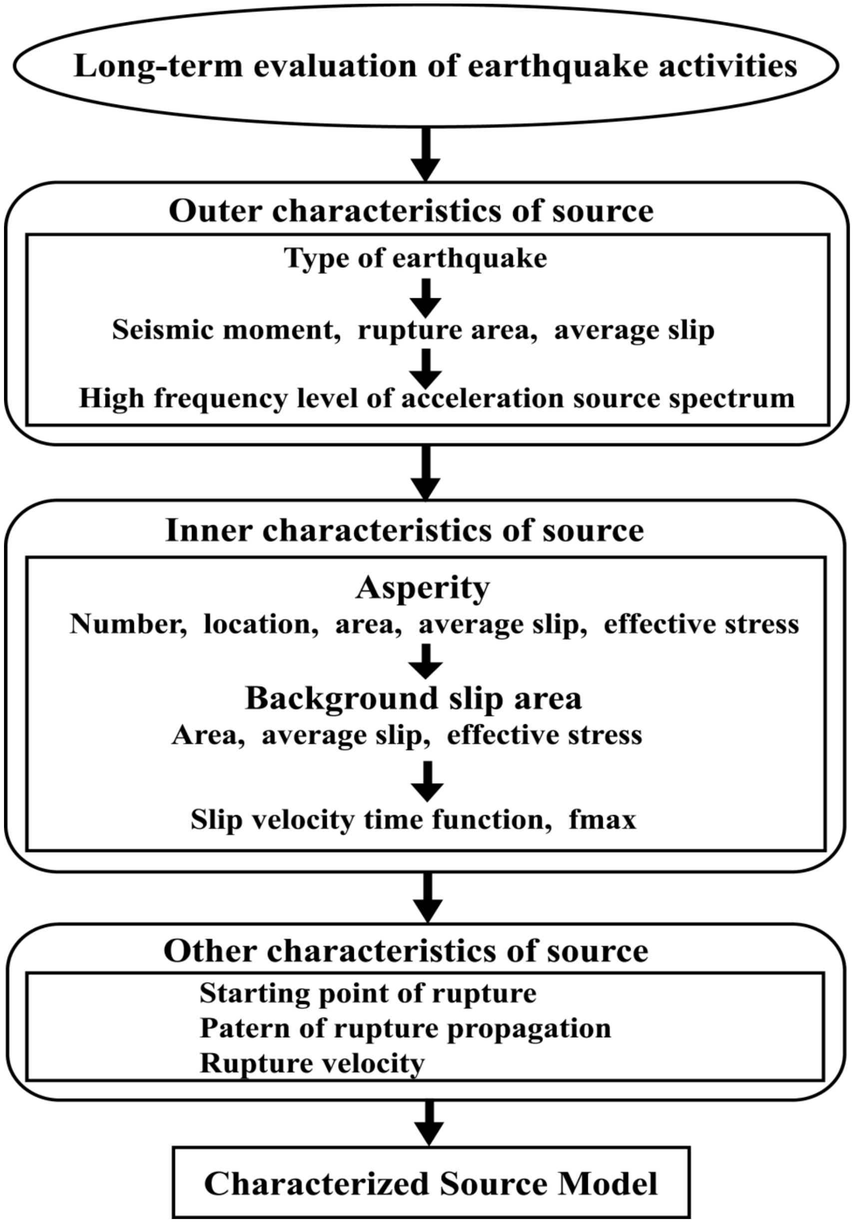
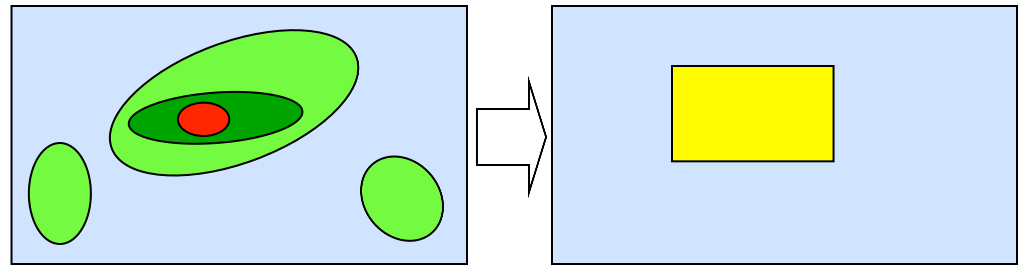
Characterized Source Model



Complicated source model



The complicated source model is simplified by the characteristic source model for strong-motion prediction.

Characterized source models are composed of asperities and a background slip area surrounding the asperities. Asperities are the main rupture areas in the fault zone.

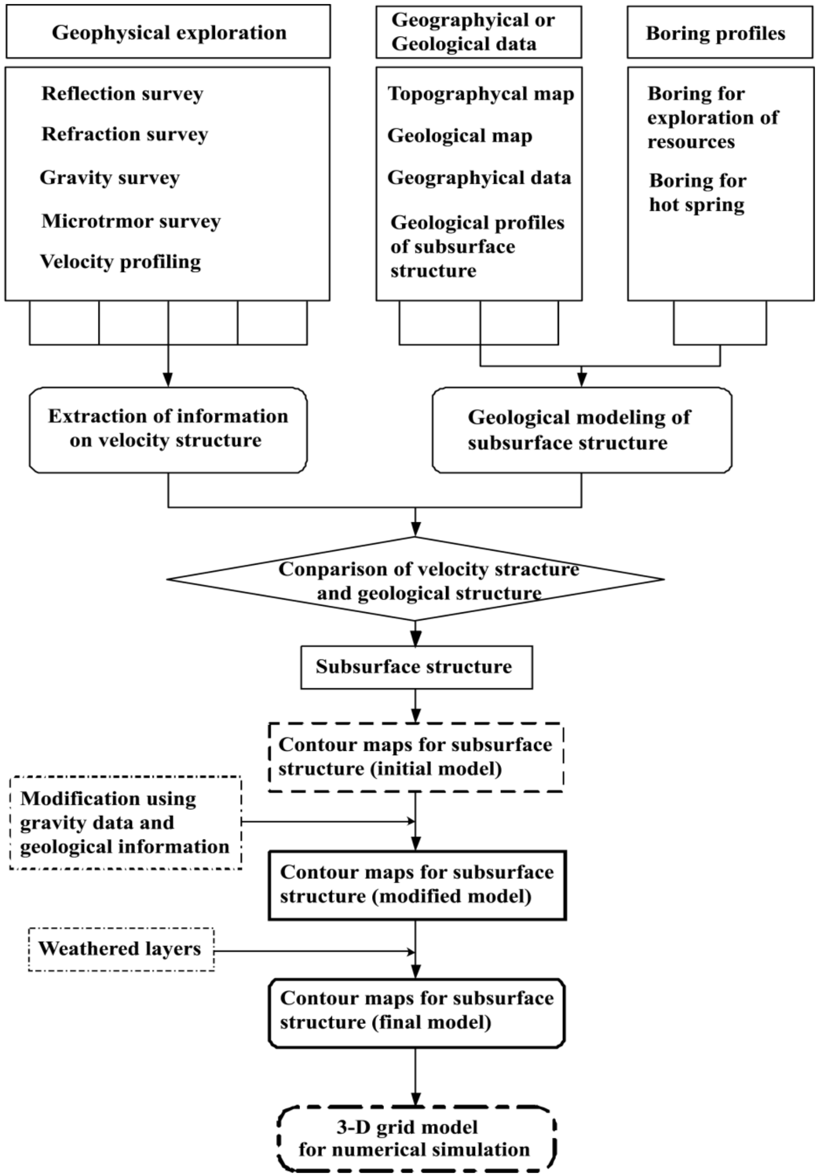
Source parameters required to evaluate strong-motions by using the characterized source model are classified into three parts.

The first part is the set of outer parameters that show the magnitude and the fault shape of the earthquake.

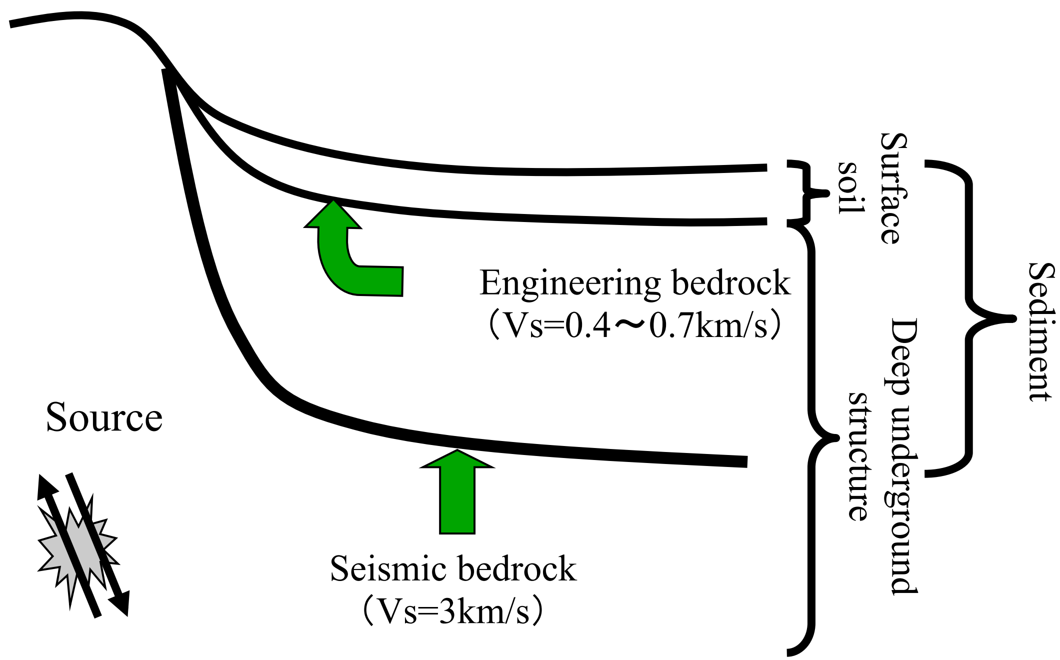
The second part is the set of the parameters that describe the degree of fault heterogeneity.

The third part is the set of the parameters to define the characteristics of the rupture propagation.

Modeling of underground structure



Flowchart of structure modeling



•The deep underground structure from the crust and plates up to seismic bedrock;

•The structure of sediments from the seismic bedrock up to engineering bedrock (Vs=400m/s～700m/s);

•The structure of surface soils from the engineering bedrock up to the ground surface.

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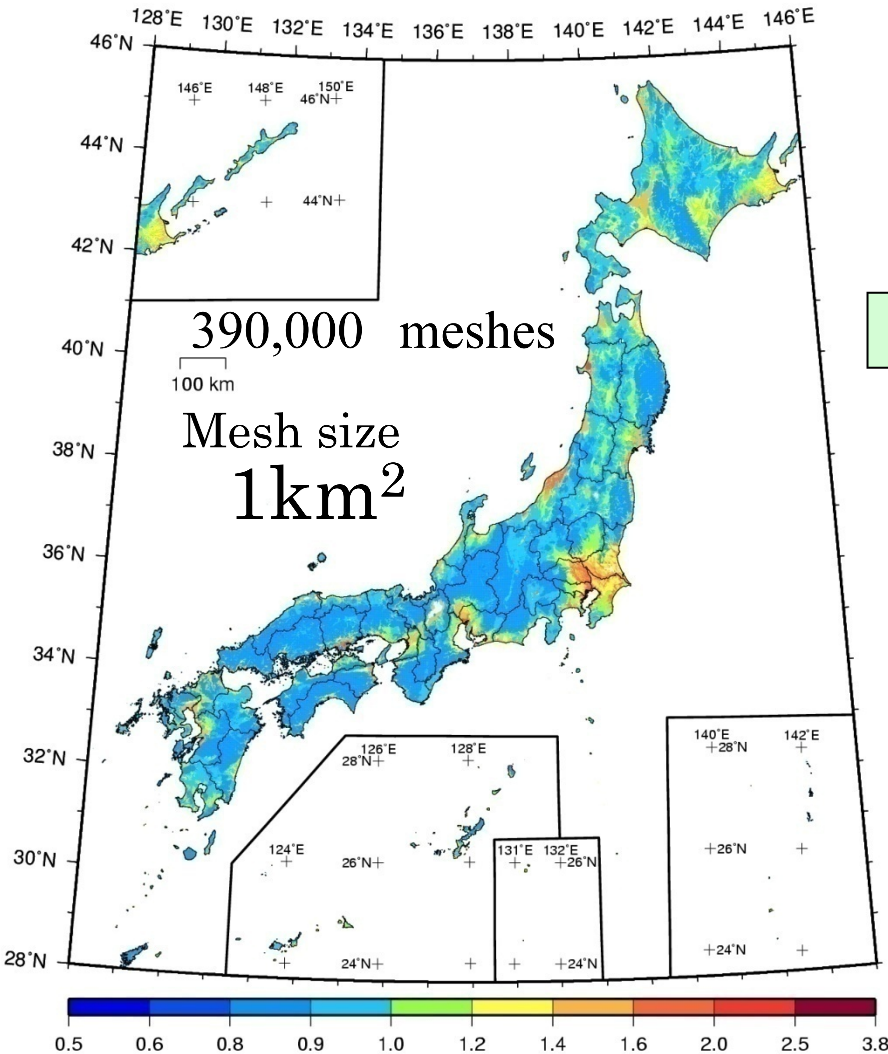
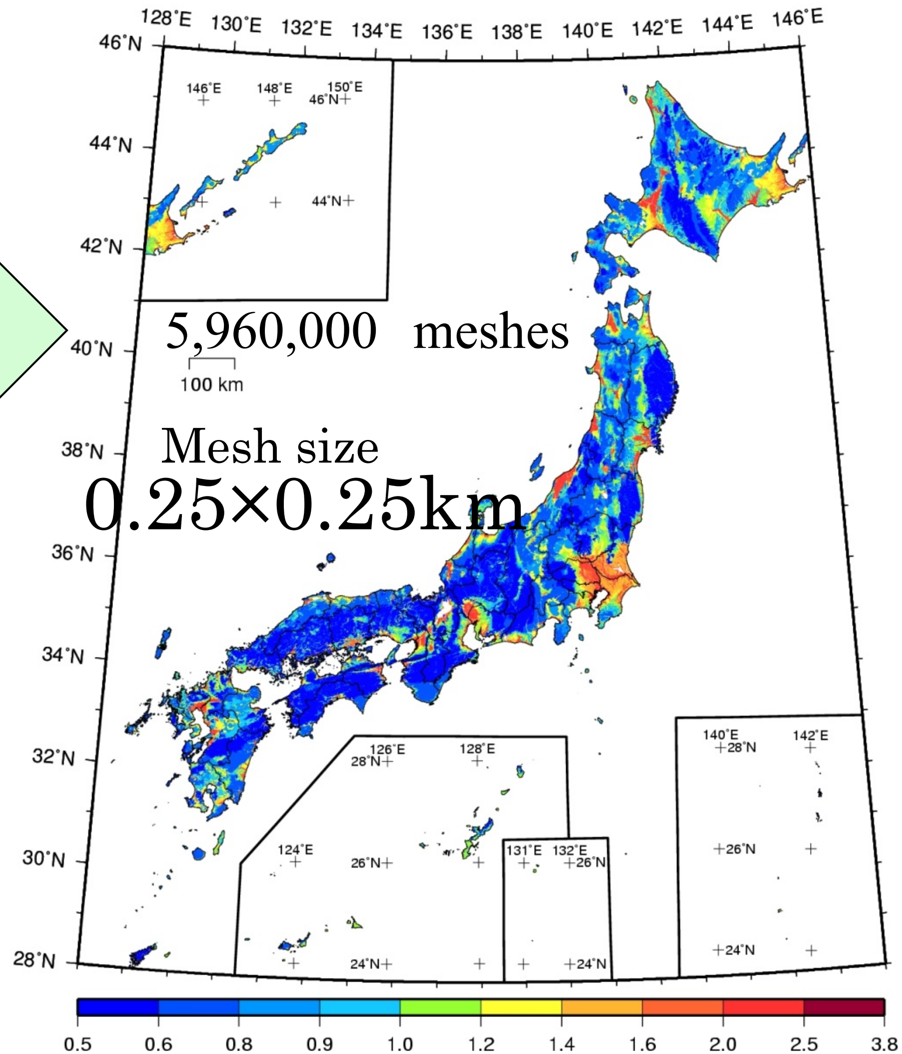
Site Amplification

2005～2008



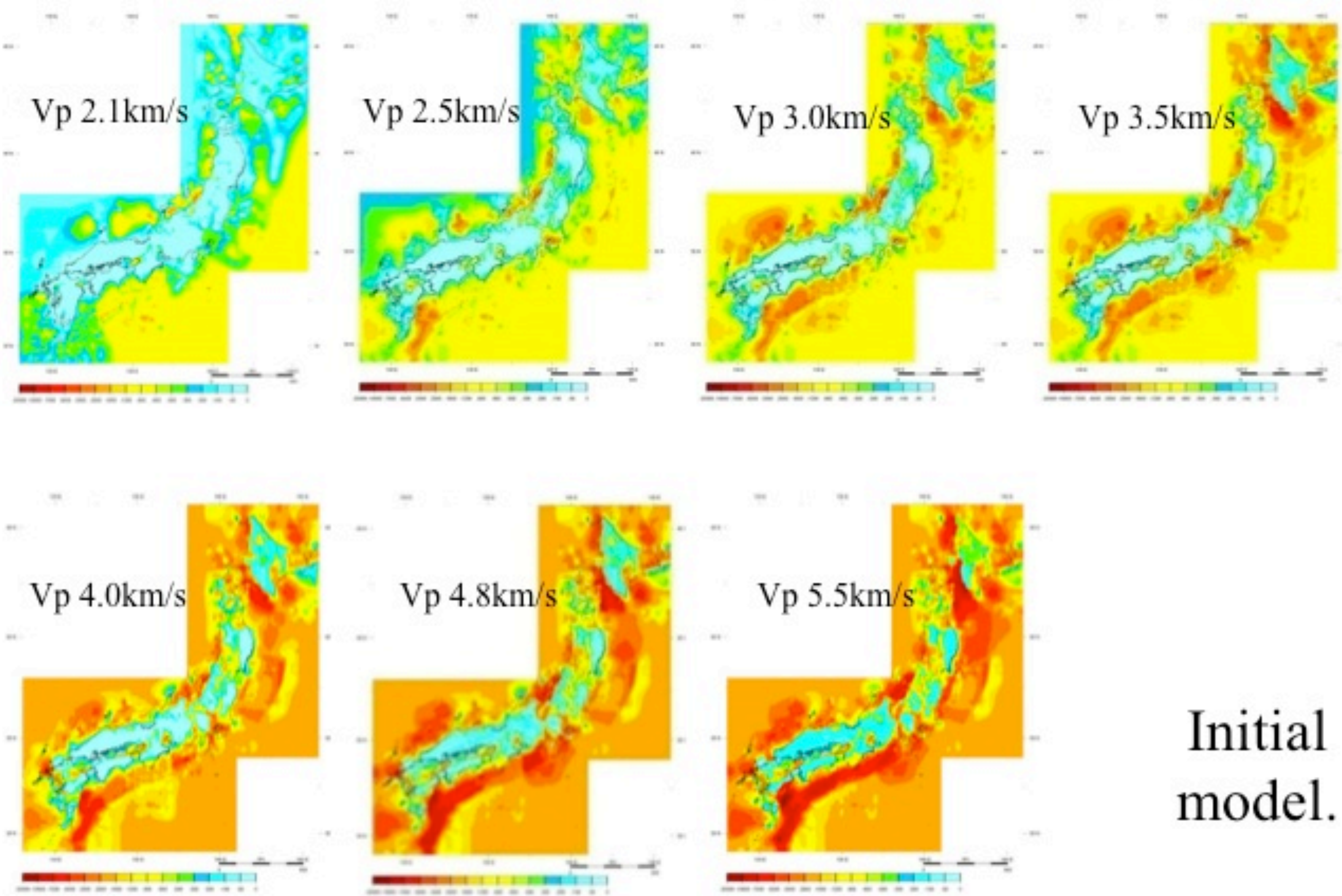
Site Amplification

2009



Site Amplification

Subsurface modeling of deep sedimentary layers



Velocity-structure of deep sedimentary layers from the seismic bedrock to the engineering bedrock greatly affects the characteristics of relatively long period strong-motion.

We developed a velocity structure model of deep sedimentary layers of the whole of Japan for evaluation of strong motion.

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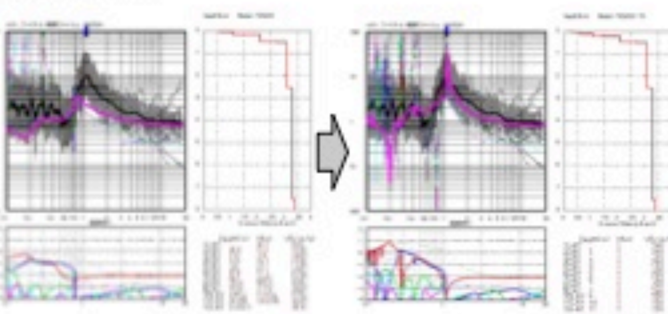
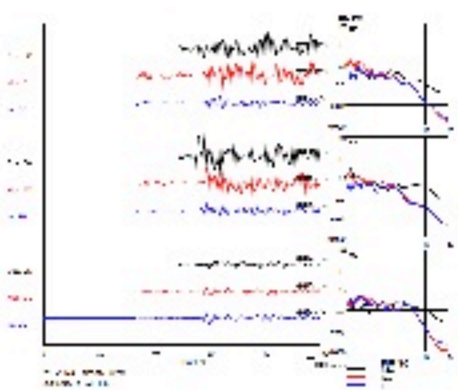
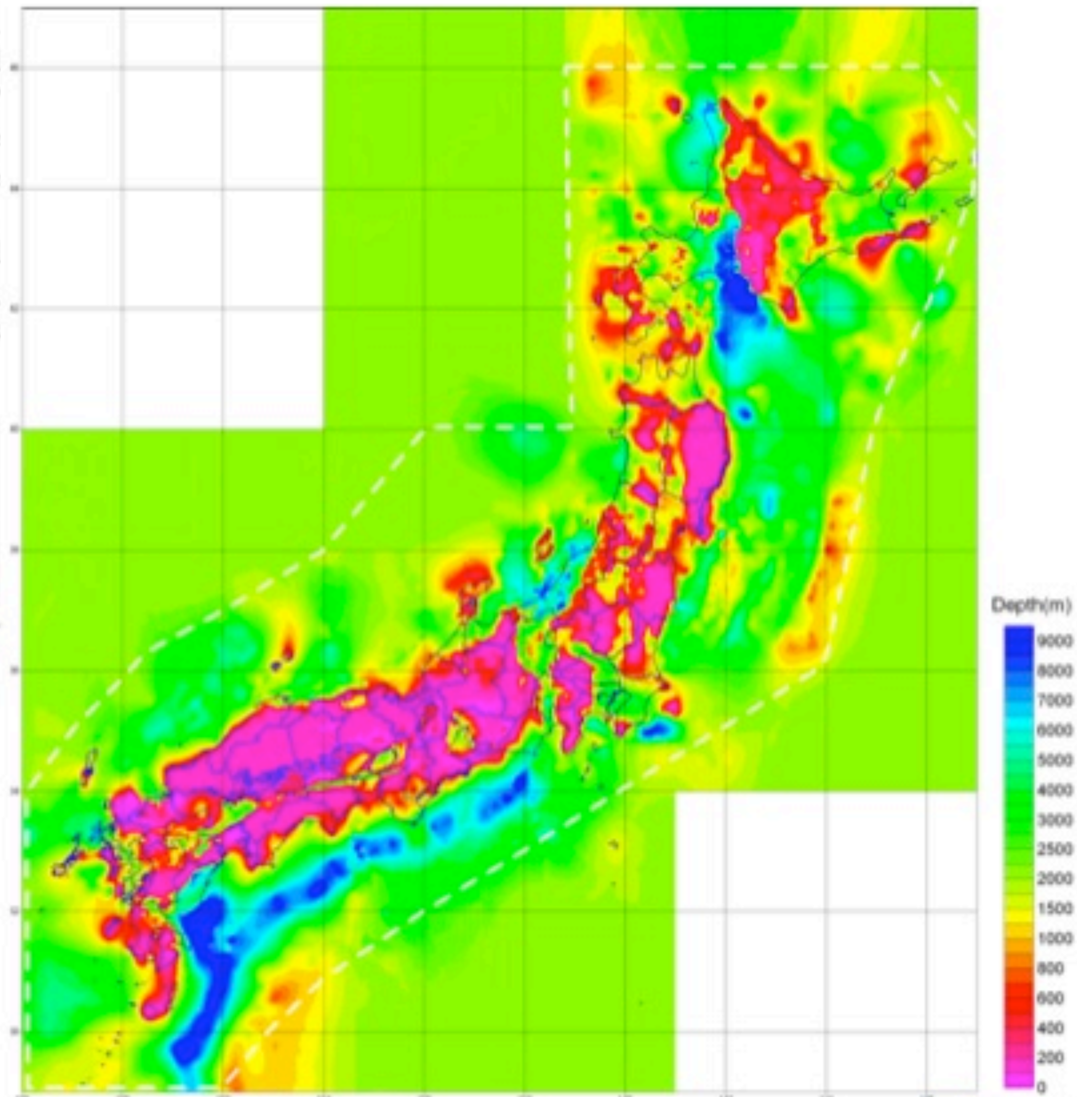
Velocity structure model for deep sedimentary layers

To improve the initial model, with a focus on predominant periods, by comparing the H/V spectral ratio of seismic records (for M5.5 or greater) obtained by the Kyoshin Network (K-NET, KiK-net) and the H/V spectral ratio of fundamental to 4th higher-mode Rayleigh waves obtained from velocity structure models.

Comparing calculated waveforms with observed waveforms for middle-scale earthquakes (around M5), the validity of adjustments using H/V spectral ratios was reviewed.







Depth contour of seismic bedrock

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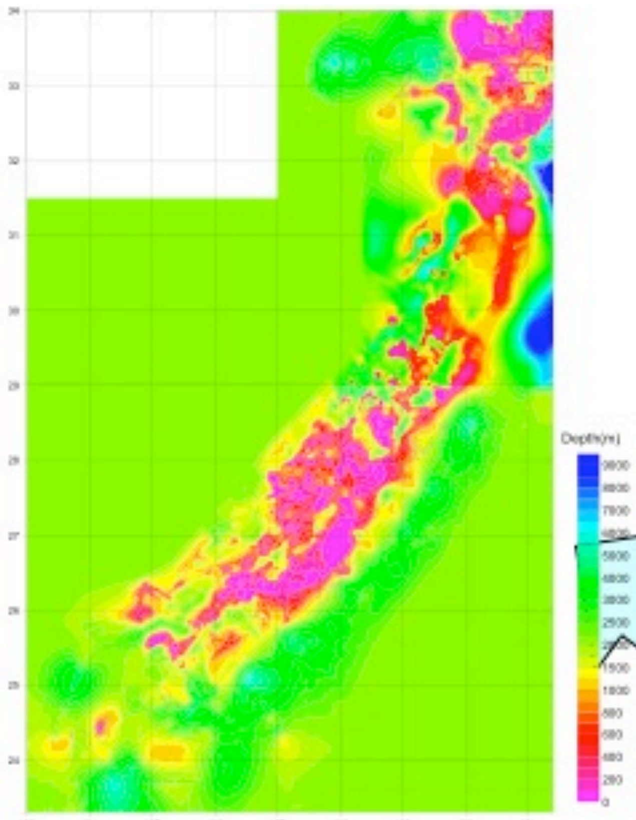
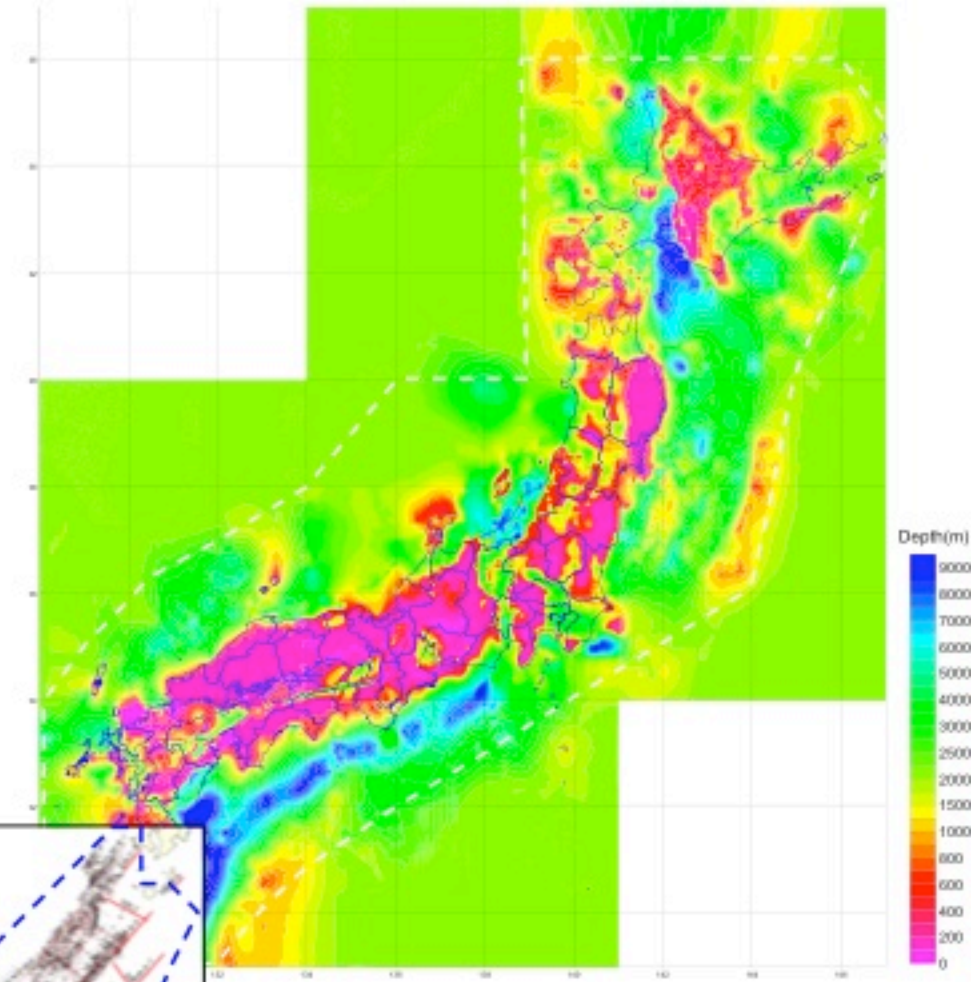
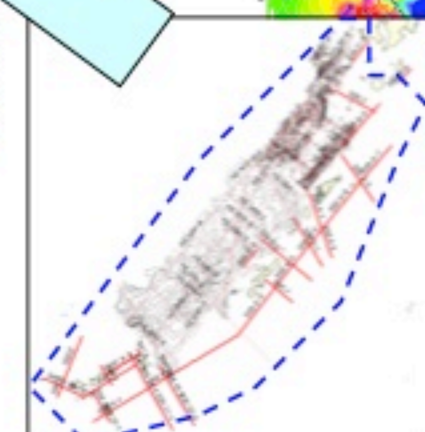
Nansei-shoto (southwestern islands off Kyushu and in the Okinawan archipelago)

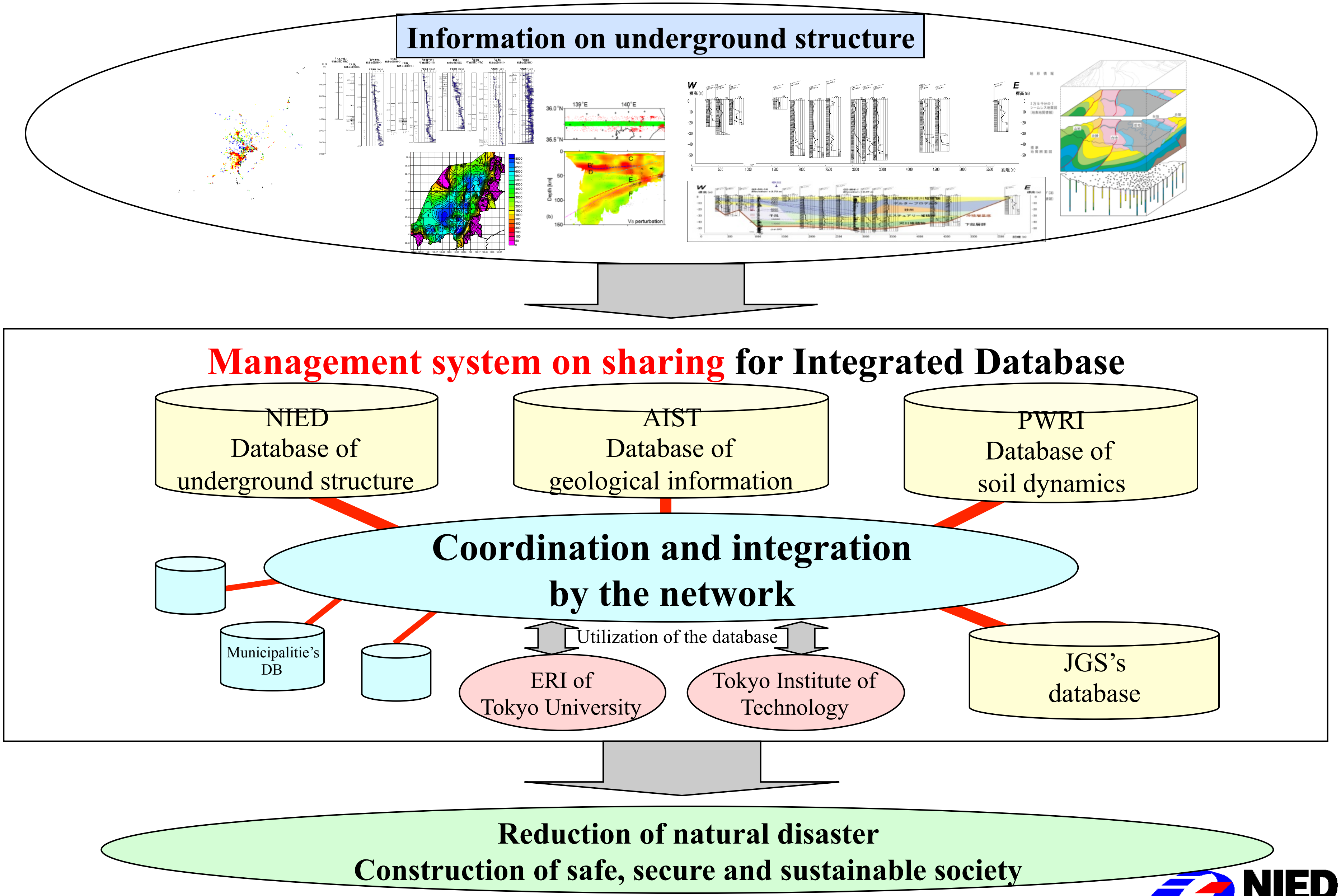






Depth contour of seismic bedrock

Development of Integrated Geophysical and Geological Information Database



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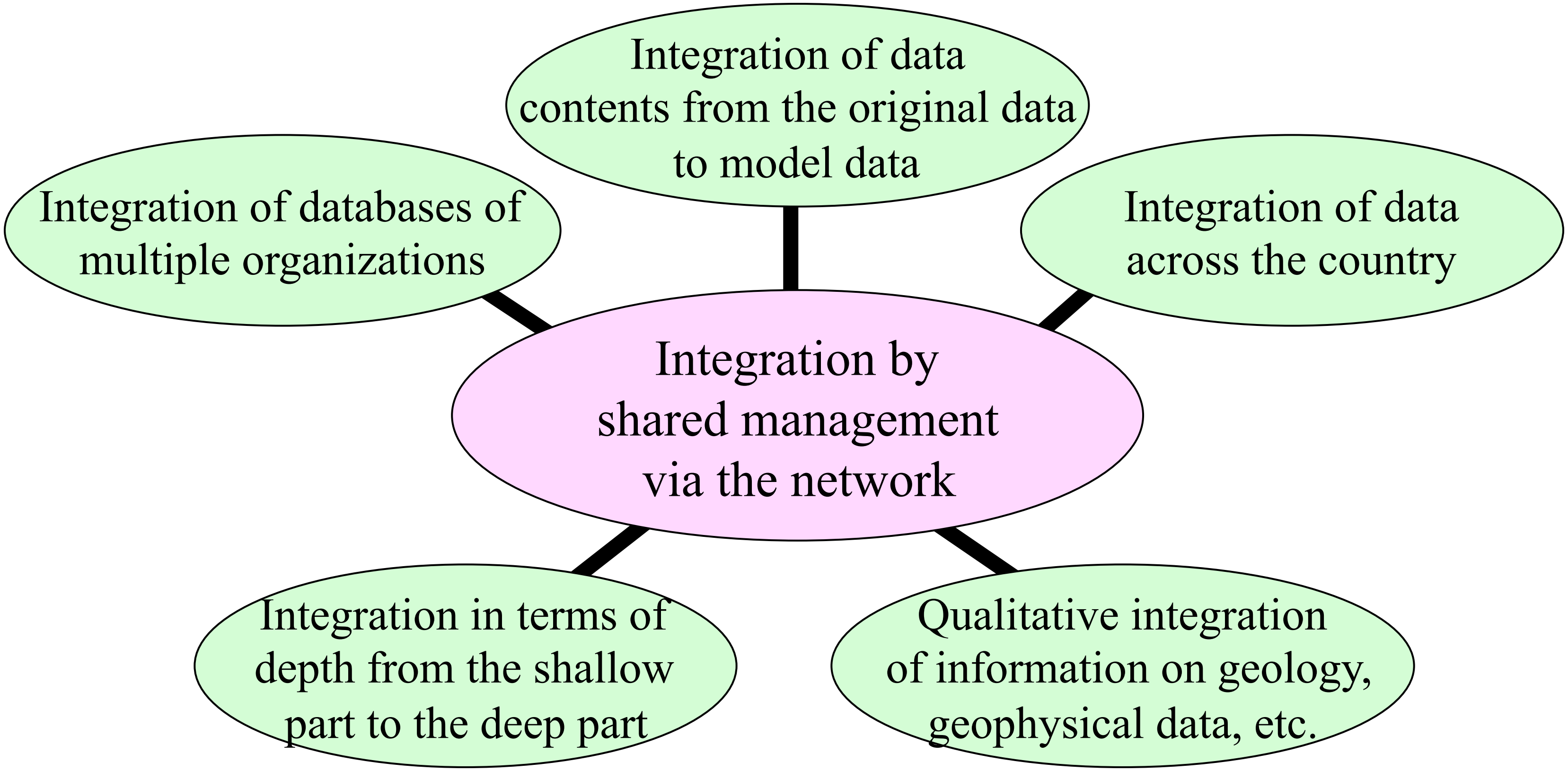
The concept of Integrated Database

Image of Integration



As we regards information on underground structure as 'public assets of the nation', we develop a database that allows for mutual utilization and publication of data through a network of each organization's databases. The keyword of this research project is 'Integration'. The word 'Integration' implies several meanings, as shown in this figure, the process of integration is to be carried out following these six principles.

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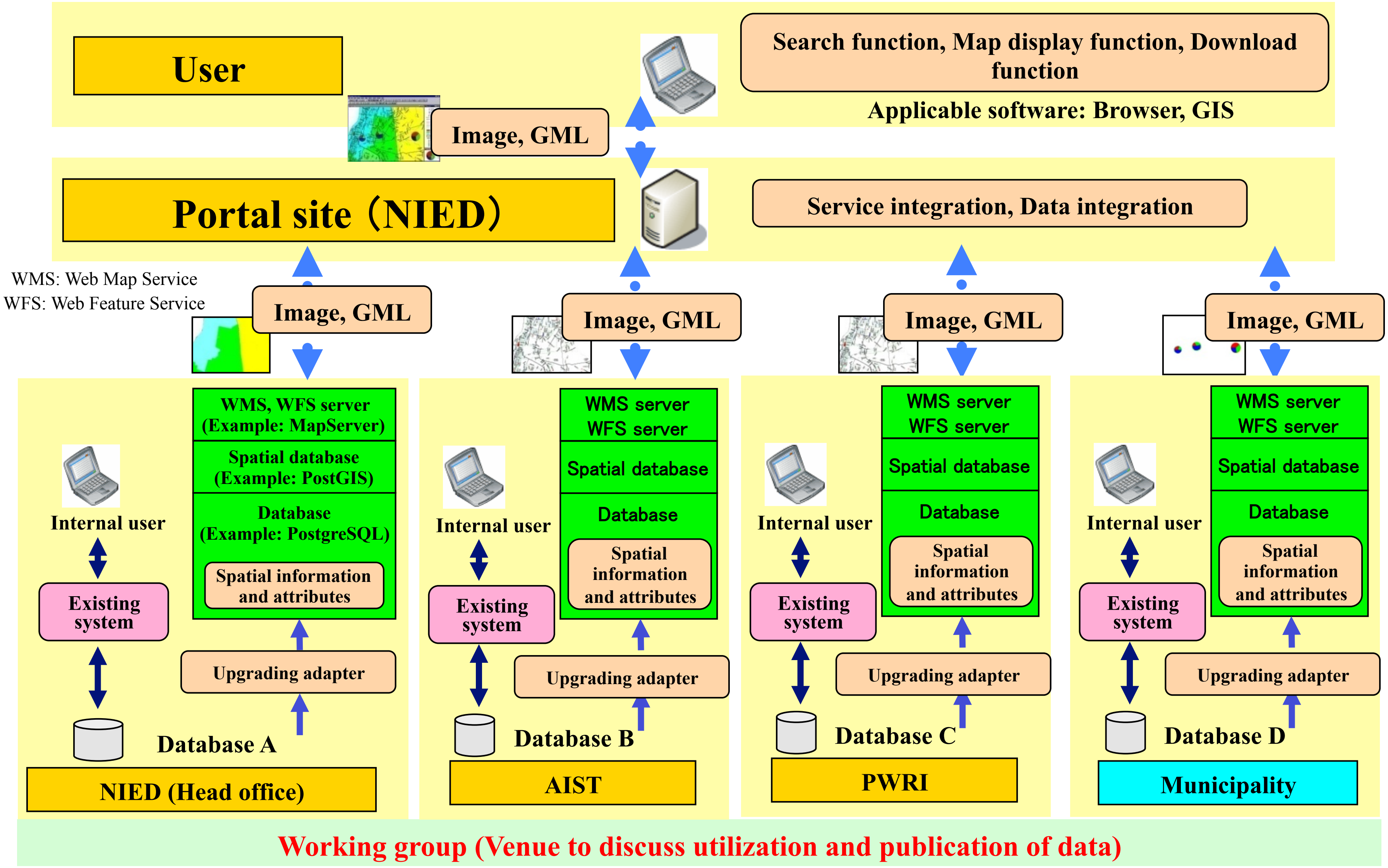
Diagram showing the concept of the management system on sharing

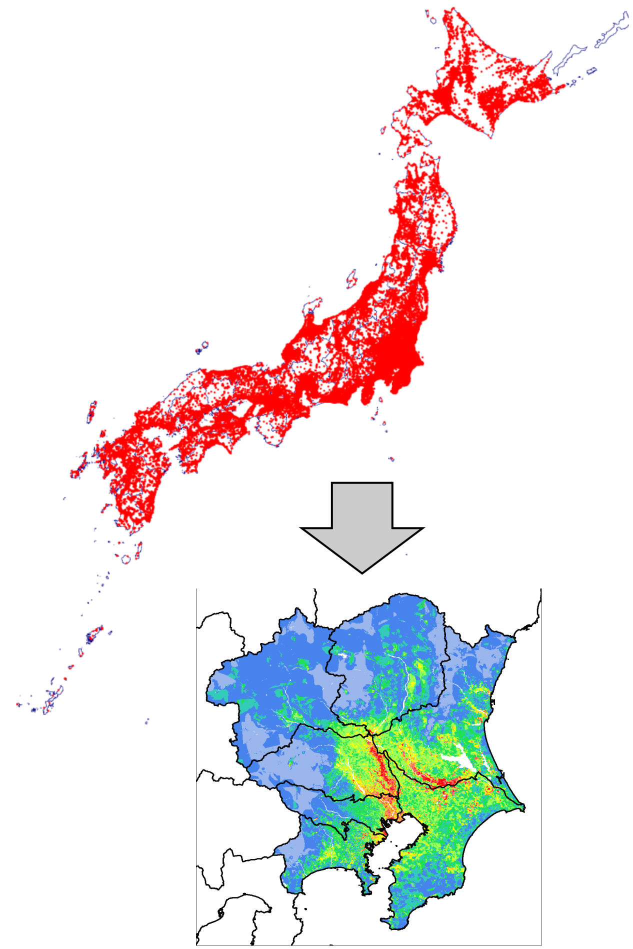


The configuration of the data sharing management system consists of database management servers for individual organizations and a portal site.

Boring data collected and registered into database

機関	本数	機関内訳	本数内訳
国	142, 492	国土交通省	90, 542
		文部科学省 (防災科研を含む)	51, 950
都道府県	169, 647	北海道地方	11, 242
		東北地方	9, 397
		関東地方	87, 511
		北陸地方	8, 359
		中部地方	23, 475
		近畿地方	15, 580
		中国地方	12, 637
		九州地方	1, 446
市町村	44, 075	北海道内	315
		青森県内	268
		岩手県内	493
		秋田県内	179
		山形県内	741
		福島県内	340
		茨城県内	24
		栃木県内	777
		埼玉県内	1, 560
		千葉県内	2, 196
		神奈川県内	28, 857
		新潟県内	1, 020
		富山県内	199
		石川県内	4, 201
		福井県内	342
		静岡県内	830
		岡山県内	218
		広島県内	194
		山口県内	585
		徳島県内	128
		香川県内	595
		福岡県内	13
その他	122, 007	学会・協議会関係	107, 511
		旧公団・公社等	3, 652
		地盤図等	10, 844
合計	478, 221		

The number of boring data that have been registered in the database is approximately 480,000 across the country.

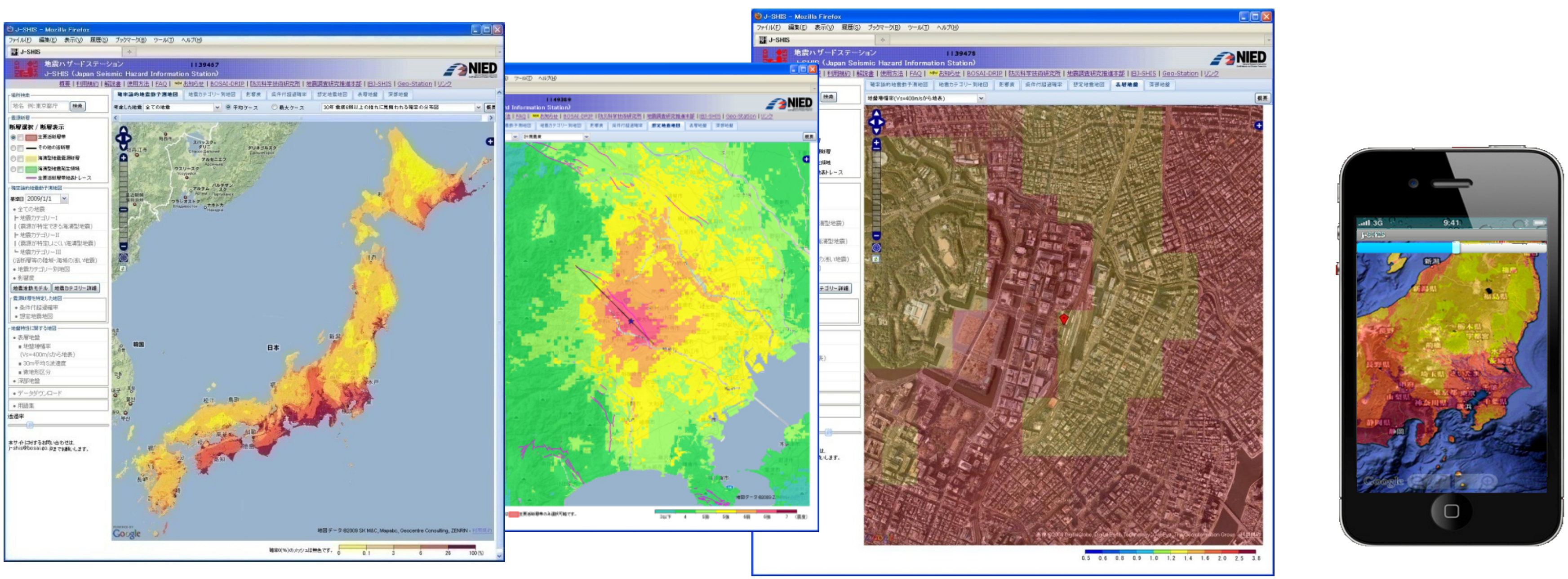


Japan Seismic Hazard Information Station

http://www.j-shis.bosai.go.jp

In order to promote the use of the national seismic hazard maps, an engineering application committee (Chairman: Prof. H. Kameda) was established by NIED. Under the committee guidance, we developed an open web system to provide information interactively, and named this system as Japan Seismic Hazard Information Station, J-SHIS.

Our products are aimed to meet multi-purpose needs in engineering fields by providing information of the probabilistic seismic hazard analysis.



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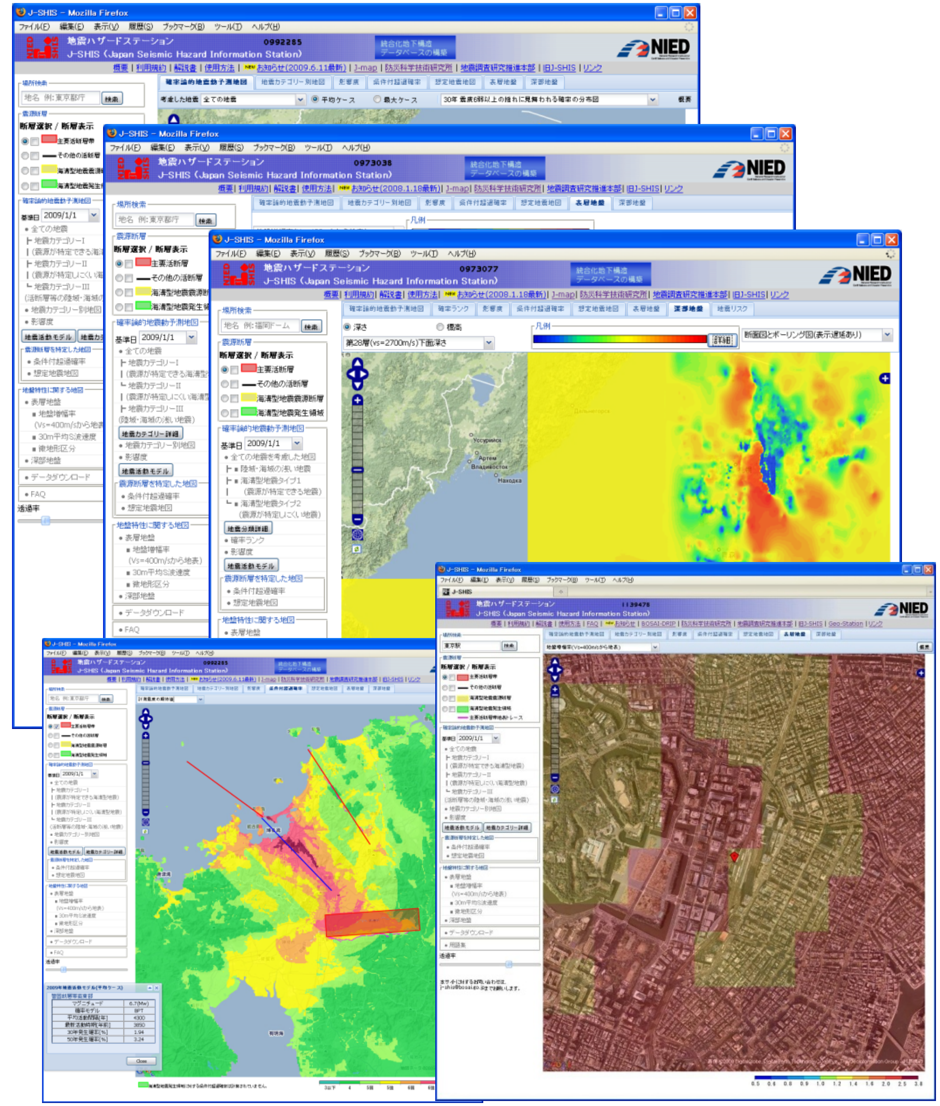
Japan Seismic Hazard Information Station



http://www.j-shis.bosai.go.jp

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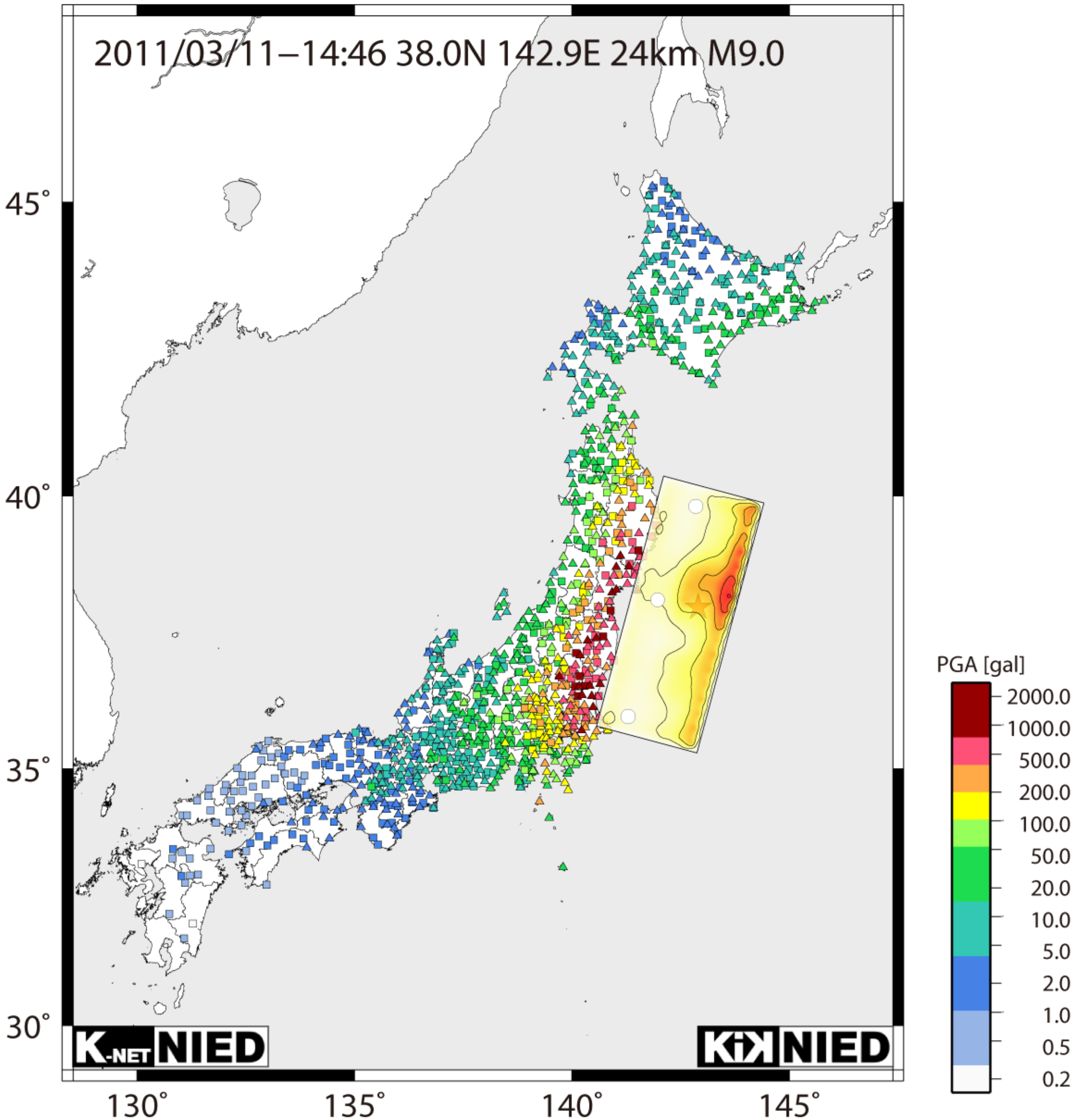
The 2011 Tohoku-oki earthquake



This magnitude 9.0 megathrust earthquake initiated approximately 100 km off-shore of Miyagi prefecture and the rupture extended 500 km along the subducting Pacific plate.

Due to the large ground motions and tsunami associated by this event, approximately 20,000 people were killed or missing and more than 220,000 houses and buildings were totally or partially destroyed.

The Tohoku-oki earthquake was the first M9-class earthquake that is closely recorded by dense seismograph network.

The ground motions were recorded at more than 1200 K-NET and KiK-net.

The peak ground accelerations (PGA) exceeded 1g at 20 sites and the largest PGA, 2933 gal was observed at the K-NET Tsukidate station (MYG004).

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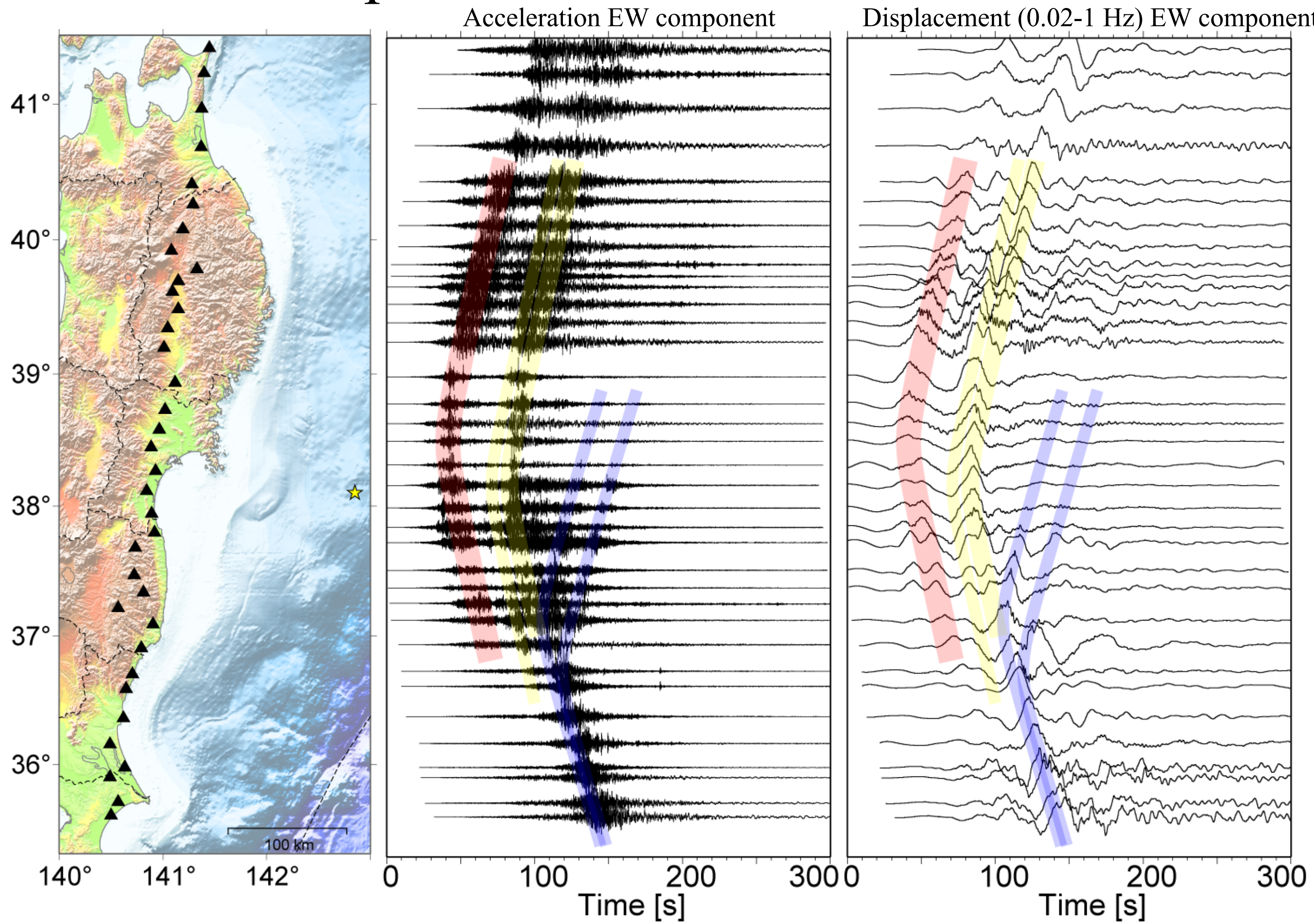
Paste-up of the observed waveforms



Normalized acceleration and displacement (0.02 - 1.0 Hz) paste-up of the waveforms observed by K-NET and KiK-net ordered by latitude which reveal a very complex source process; An initial strong phase originating near the hypocenter is clearly observed. A subsequent seismic phase uniformly delayed by approximately 40s suggests a second event at nearly the same location. A later seismic phase is strongly observed to the south 50 - 60 s after the initial phase. This phase suggests that a third strong event took place off-shore of Fukushima-Ibaraki.

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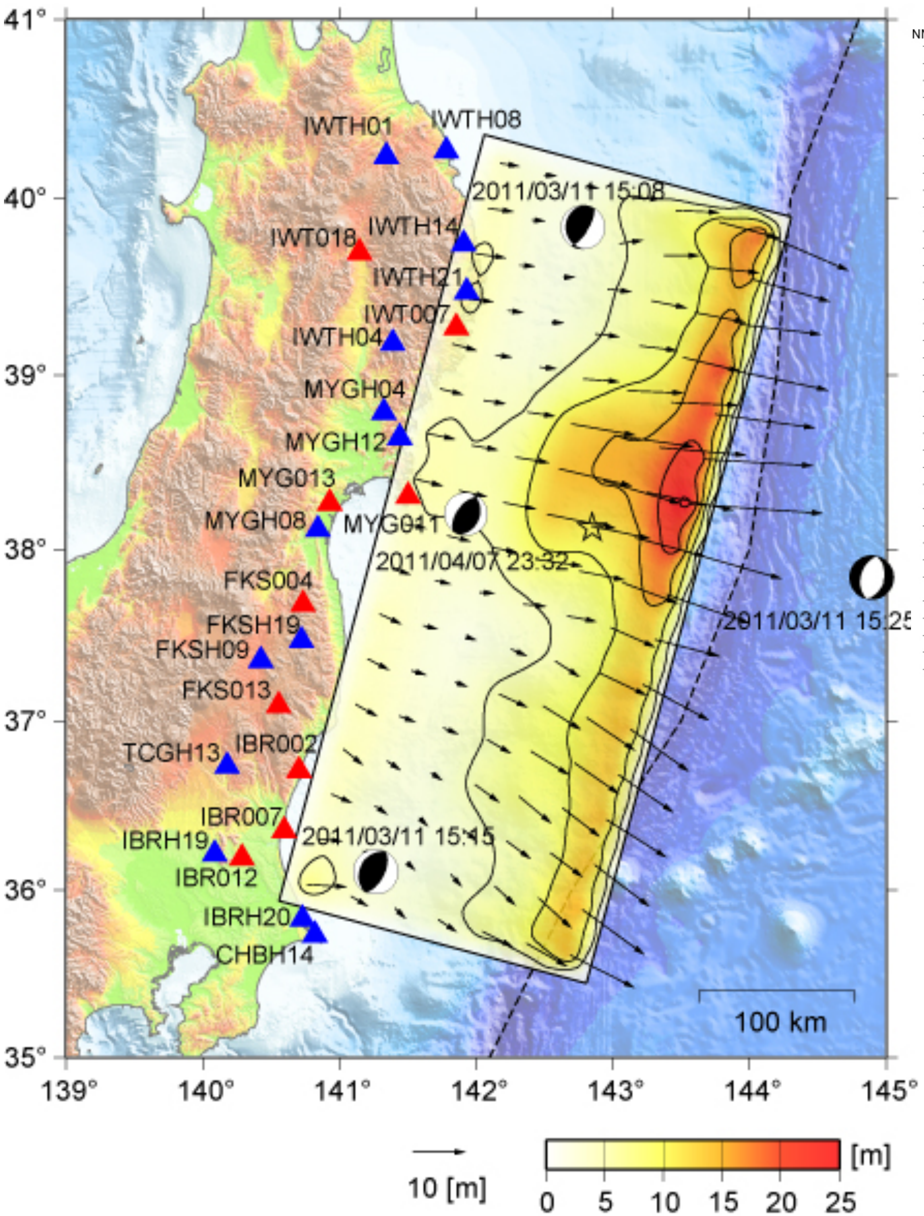
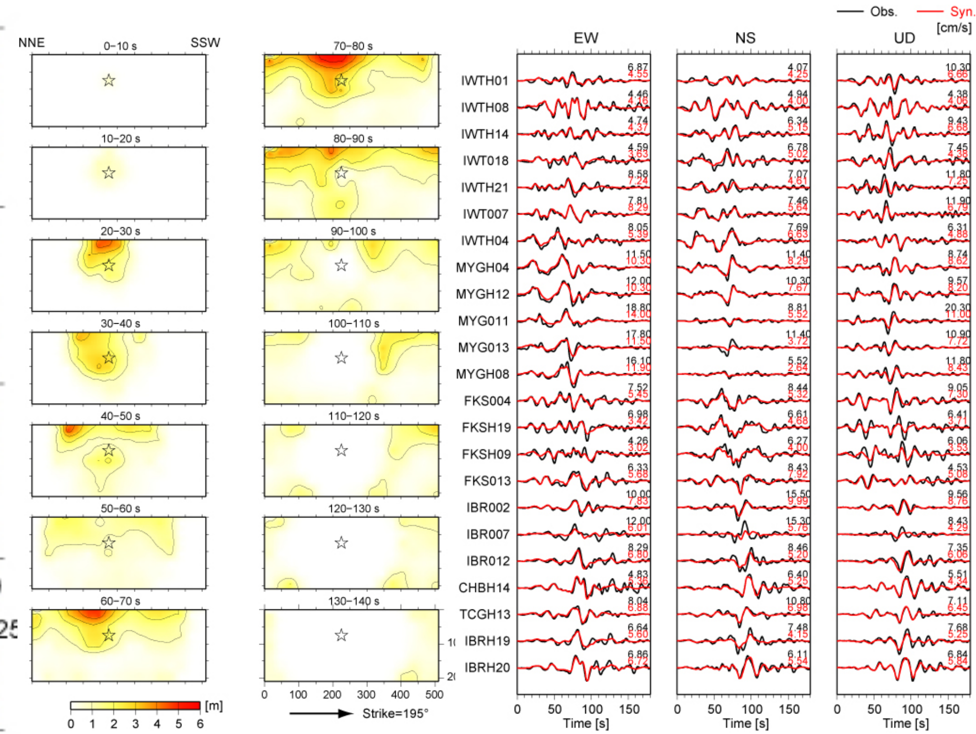
Source rupture process estimated from strong-motion records





○ Results

- Large slip area extends from a region around the hypocenter to the shallower part of the fault plane.
- The largest total slip of 25 m is estimated near the trench of far off the coast of Miyagi prefecture.
- The main rupture started 20 seconds after the initial rupture at the area situated up-dip from the hypocenter and propagated to the north for 30 seconds. Large slip occurred again near the area where the main rupture started after 60 to 80 seconds.
- Seismic moment is 3.43×1022 Nm (Mw9.0)

Suzuki et al. (2011)

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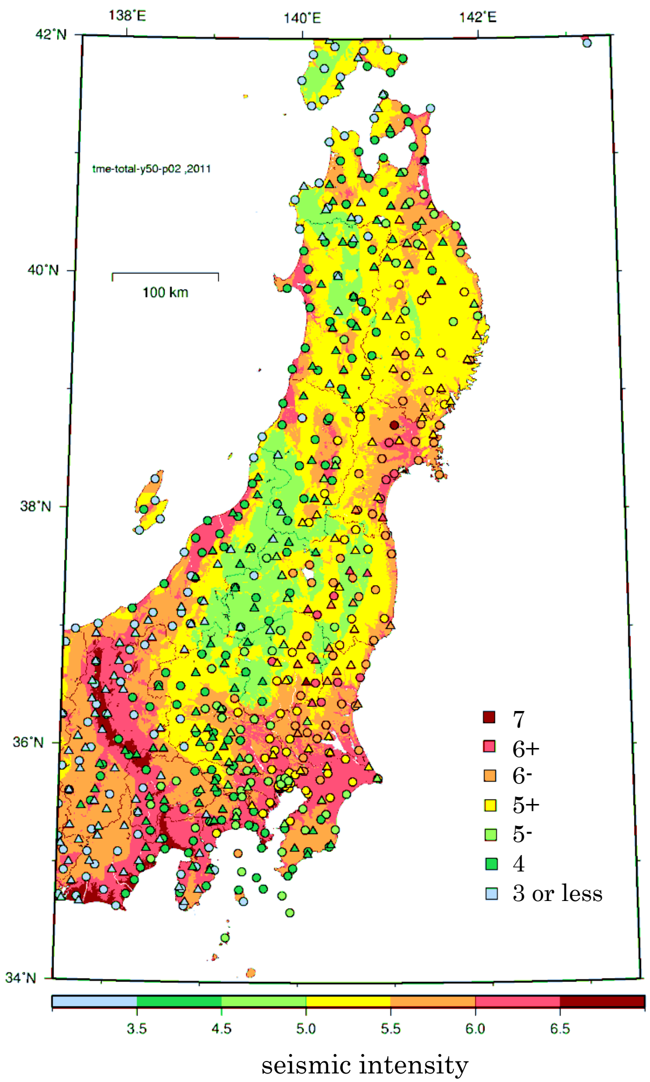
Comparison between the hazard maps and observed strong motions



Seismic Intensity with 2% probability of exceedance in 50 year.

Comparison between the observed seismic intensities (○ : K-NET, △ : KiK-net) of the Tohoku earthquake and seismic intensity distribution for 2% probability of exceedance in 50 years, which is one of the probabilistic seismic hazard map.

As you can see from this comparison, predicted ground motion level in the probabilistic seismic hazard map was clearly underestimated in Fukushima Prefecture and the northern part of Ibaraki Prefecture for the Tohoku-oki earthquake (M9.0).

This is primarily because, in the long-term evaluation that has been the basis of the seismicity model for the probabilistic seismic hazard map, the occurrence of great earthquakes M9.0 has not been evaluated.

On the other hand, the cause of underestimate also lies in the inability to function well the whole framework of probabilistic seismic hazard assessment methods under the circumstances that many issues are left unresolved in seismology.

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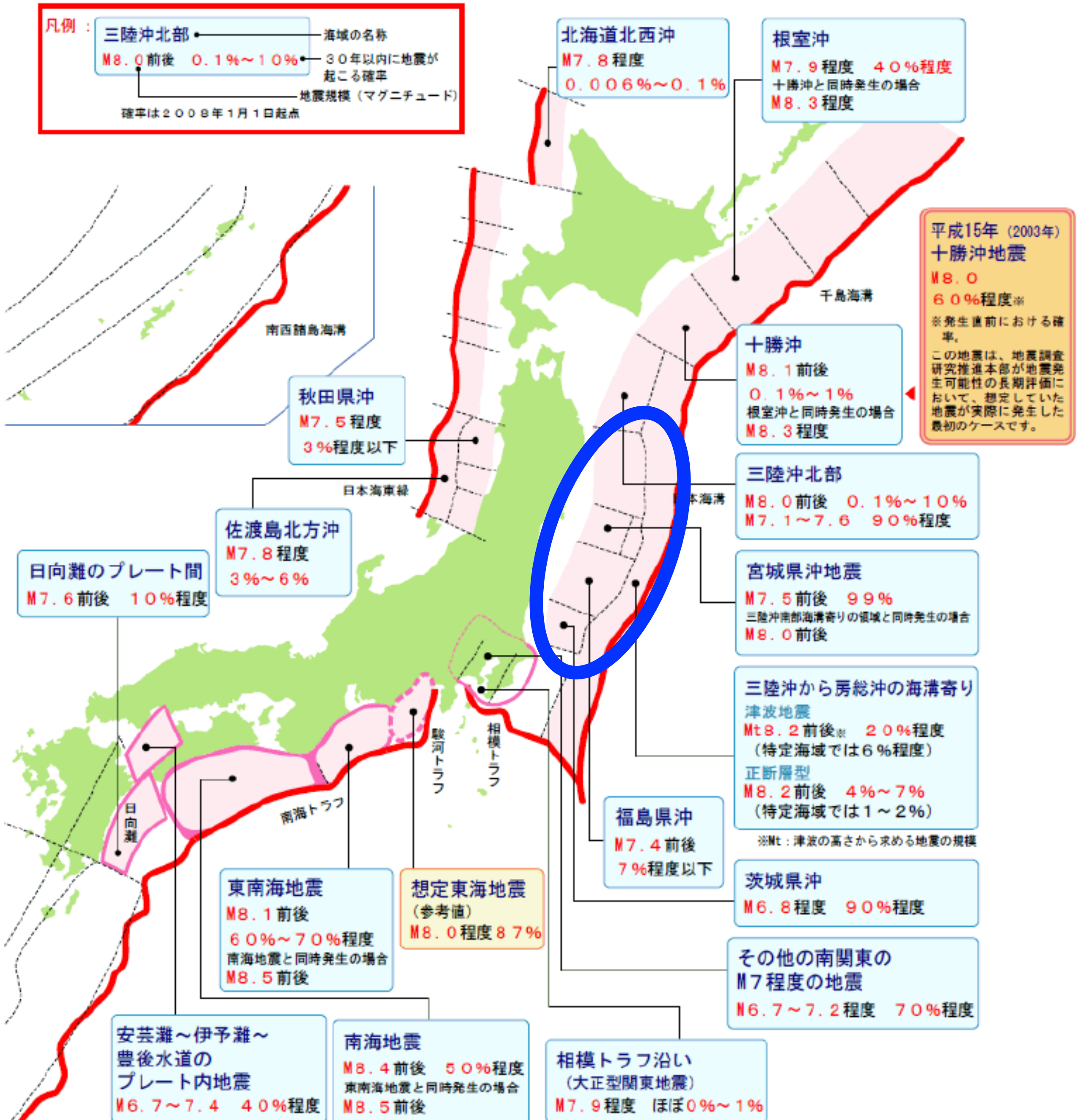

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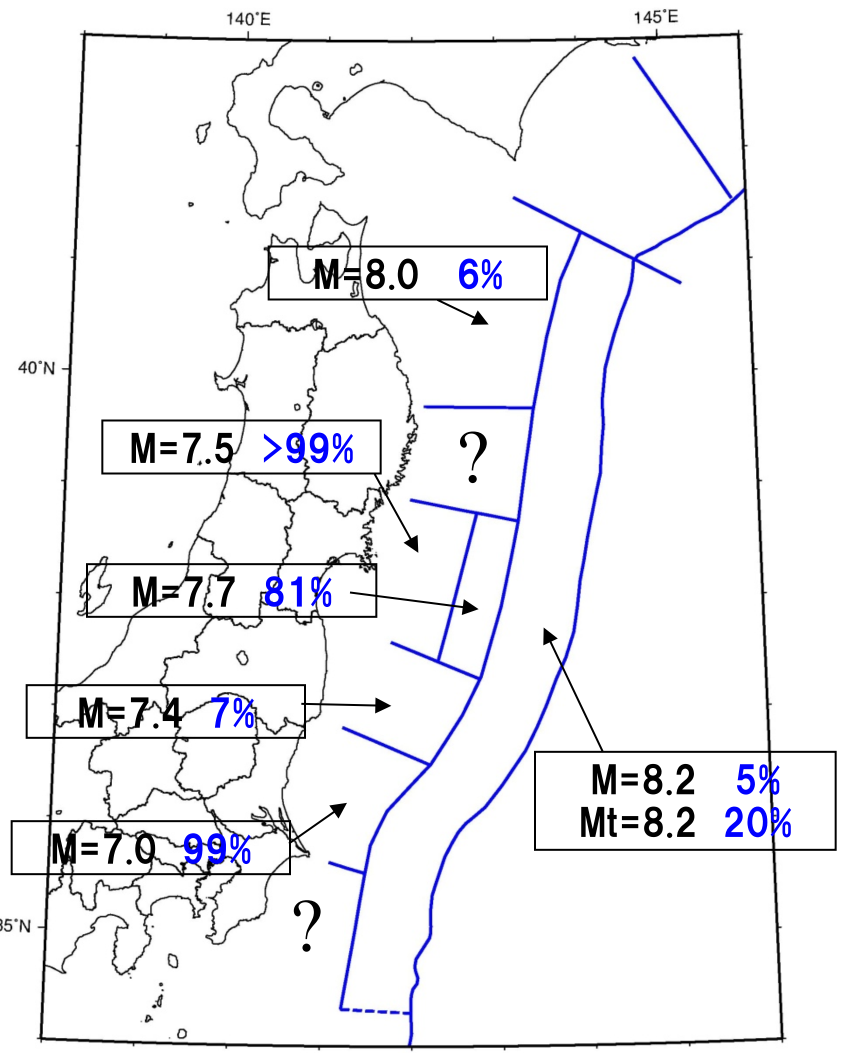
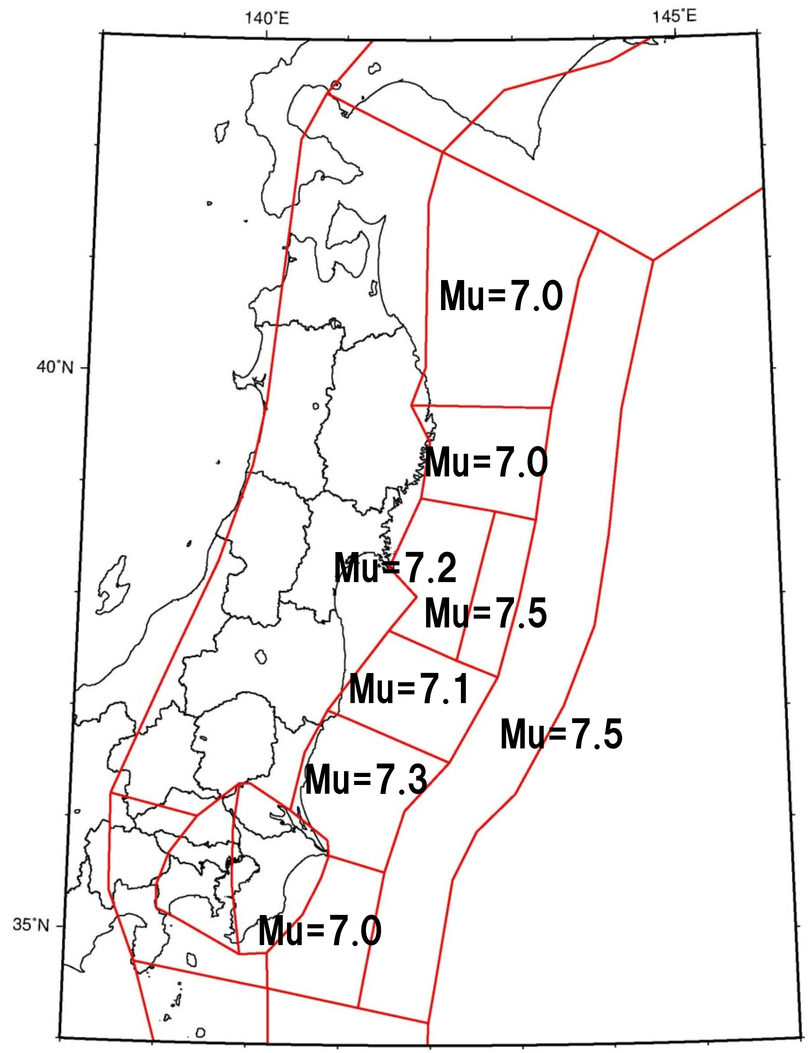
Modeling of seismic activity in the Pacific plate before the 311 Tohoku earthquake



M for characteristic earthquakes



Max M for background earthquakes

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Seismic activity model for hazard assessment

Earthquakes with specified fault

Earthquakes in major or other fault zones

Earthquakes in subduction zones
(Interplate or intraplate)

Background earthquakes

Inland earthquakes

Earthquakes in subduction zones
(Interplate or intraplate)

In order to construct a probabilistic seismic activity model that encompasses the seismic activity of all possible earthquakes, it is necessary for the complement the long-term evaluation to use a different methodology.

It may be necessary to promote proper modeling of background earthquakes that encompasses all earthquakes without long-term evaluation.

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Classification of uncertainty factors

● Aleatory Uncertainty

- Intrinsic uncertainty.
- It is represented by a random variable in the prediction model.
- Uncertainty caused by a limitation of model to explain phenomena.
- Uncertainty used to calculate a hazard curve.

● Epistemic Uncertainty

- Uncertainty due to a lack of knowledge and data.
- Uncertainty due to differences in judgment for modeling
- It is evaluated by using a logic tree.
- Represented by more than one hazard curve.

Problems that must be overcome for improvement of seismic hazard assessment

1) Modeling of seismic activity with no oversight to low-probability earthquakes.
2) Preparation of strong ground motion maps considering low-probability earthquakes.
3) Development of methodology for selecting appropriate scenario earthquakes from probabilistic seismicity model.
4) Development of methodology for prediction of strong ground motions for mega-thrust earthquakes.

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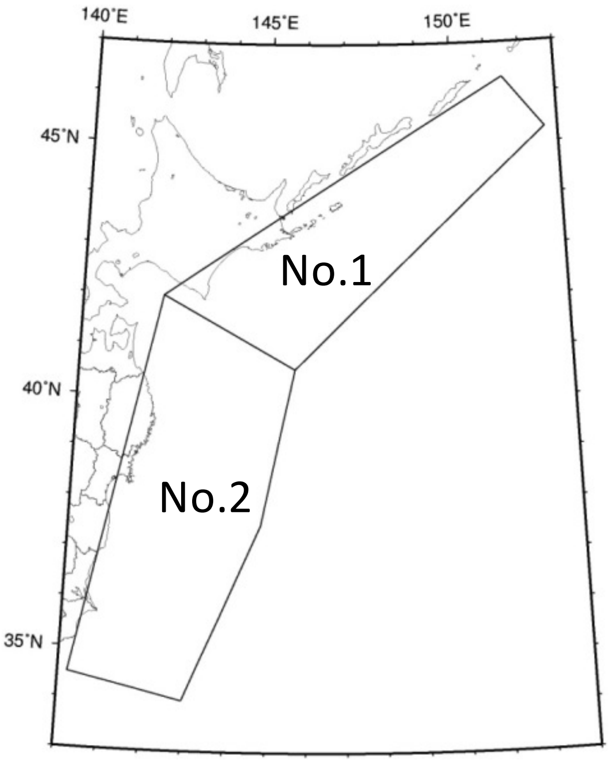
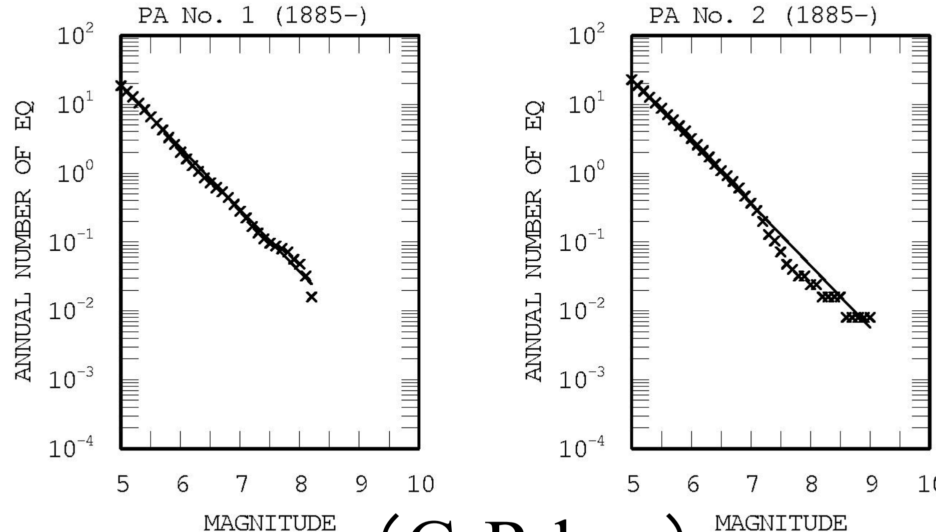
Seismic activities in the Pacific plate





(G-R law)

It may be necessary to promote proper modeling of background earthquakes that encompasses all earthquakes without long-term evaluation.

For example, it may be possible to evaluate the magnitude of earthquakes from the area of the plate boundary that can be considered to cause earthquakes, and to assess the frequency of occurrence of earthquakes by using the Gutenberg-Richter formula that shows the relationship between the number of earthquakes and their magnitude.

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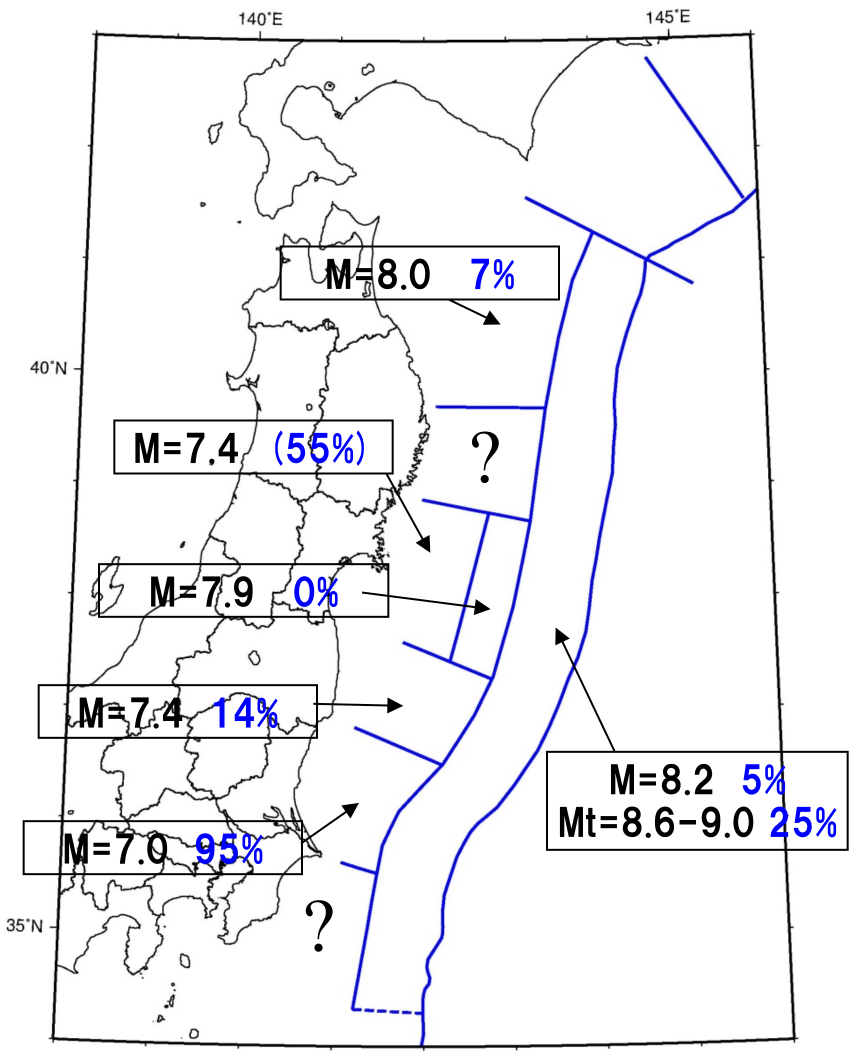
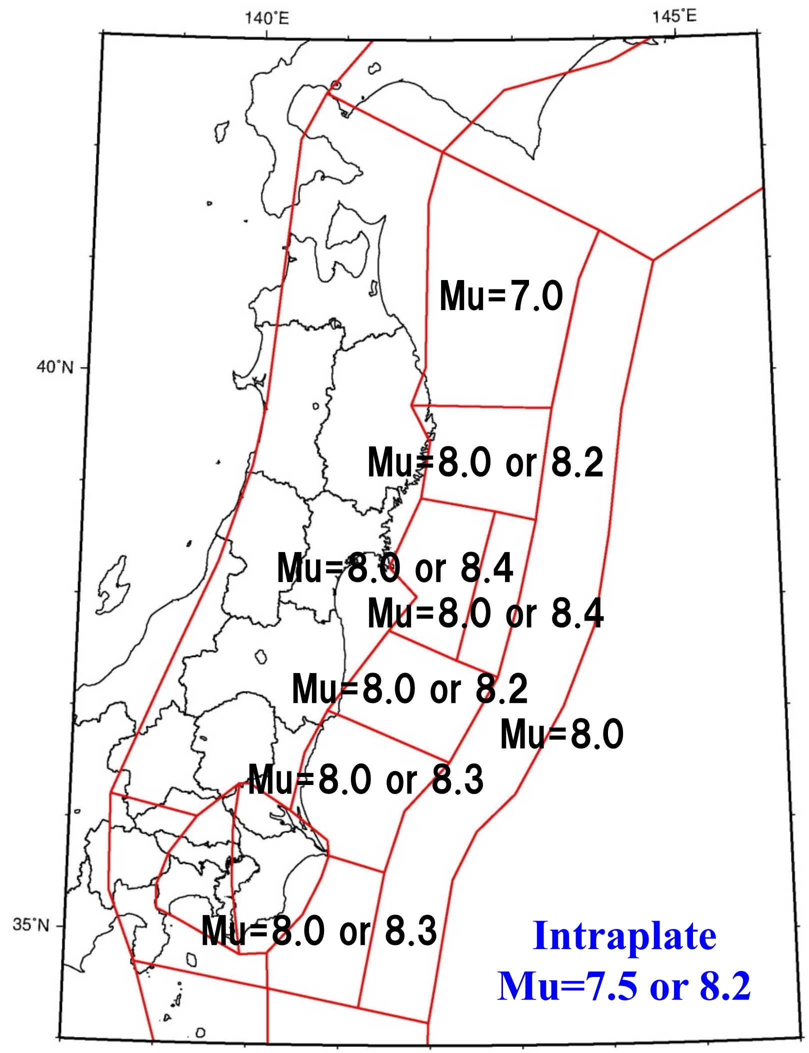
Modeling of seismic activity in the Pacific plate after the 311 Tohoku earthquake



M for characteristic earthquakes



Max M for background earthquakes

(Model 1 or Model 2)

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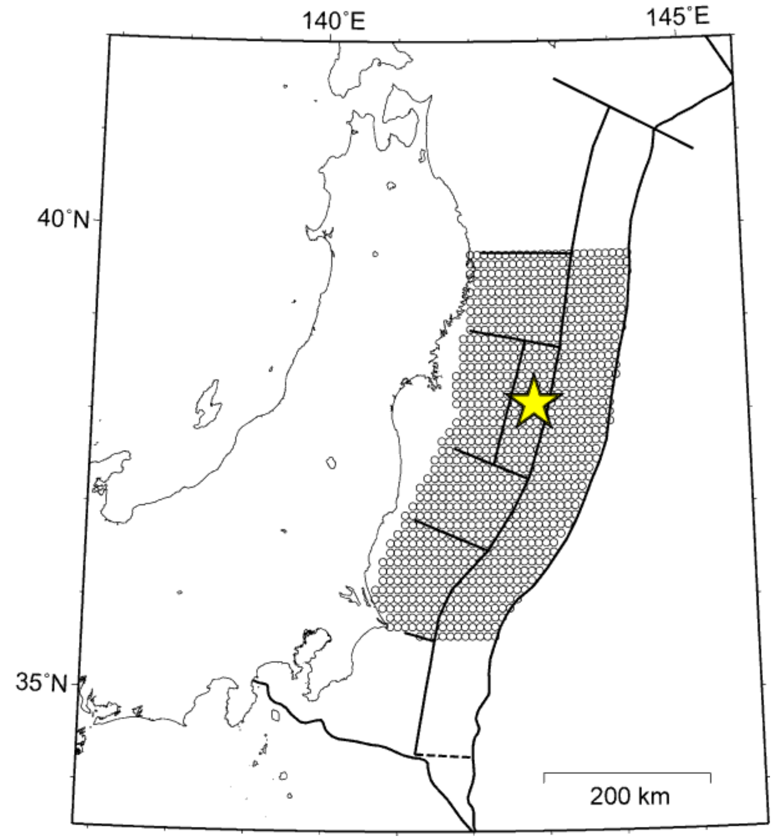
PSHM taking into account the Tohoku earthquake (M9)

■Setting conditions for the Tohoku EQ

- Source area: Aftershock area
- The origin of the time: 2011/1/1
- Average interval: 600 years
- Latest activity period: 15th century
- Occurrence probability in 30 years: 15.4%
- Ground-motion equation: Si and Midorikawa(1999) (Saturated with Mw8.3)



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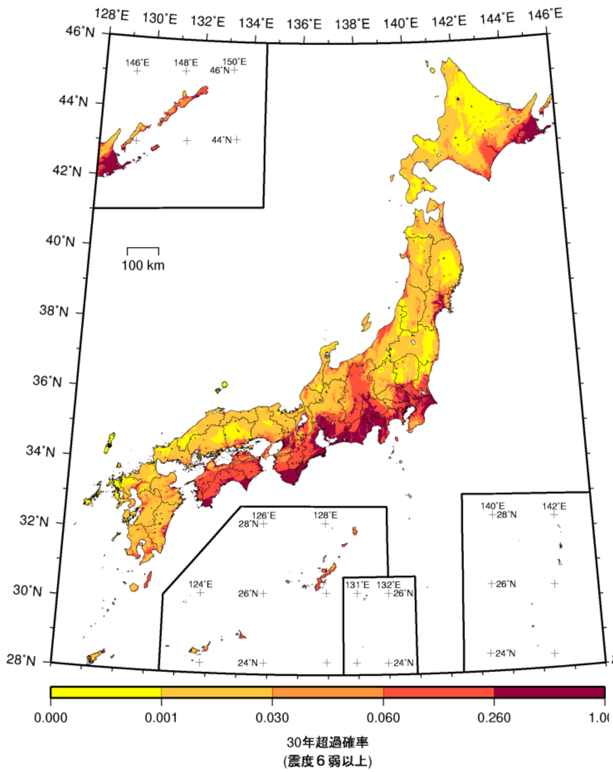
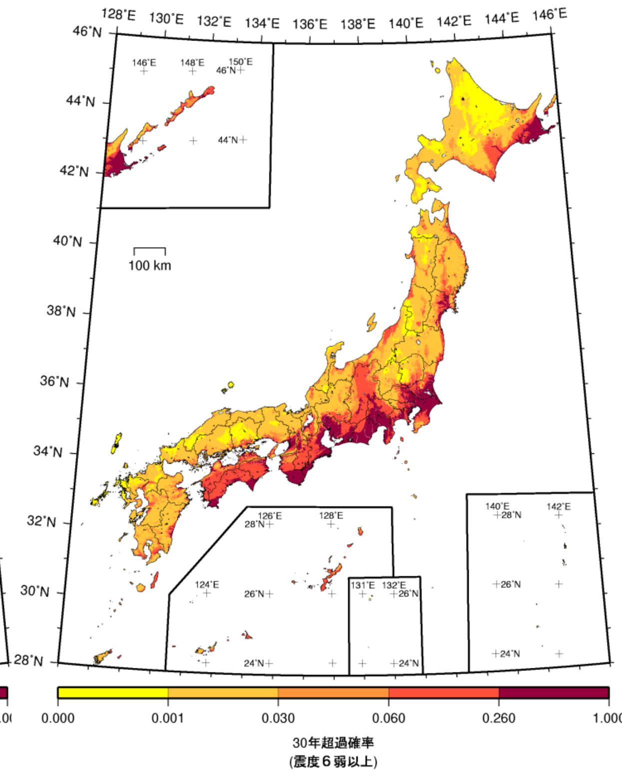
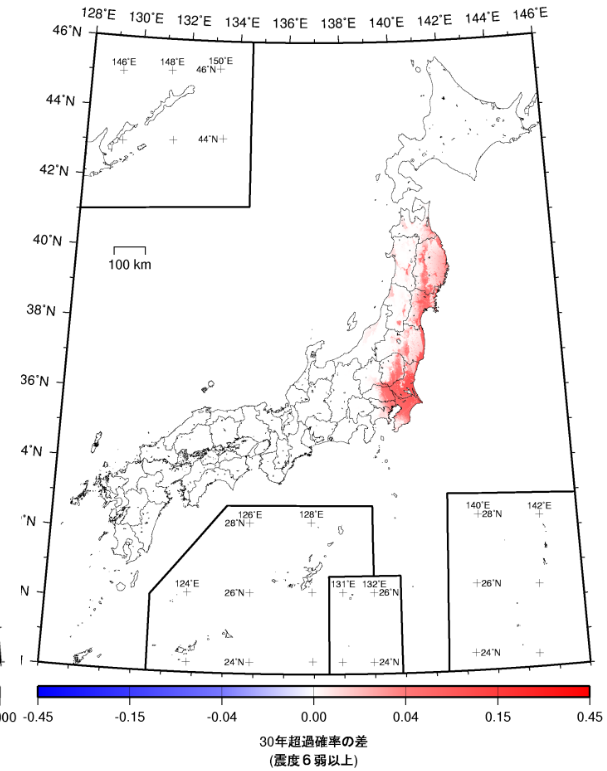
PSHMs considering the Tohoku type earthquake

(a) PSHM2011　(b) PSHM2011＋TohokuM9







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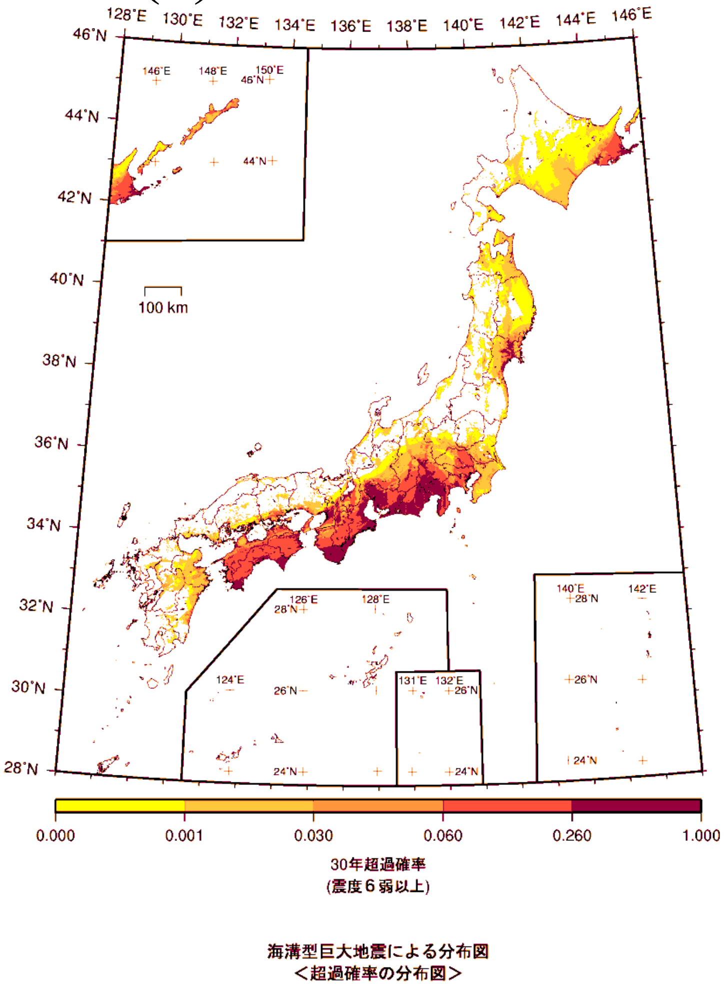
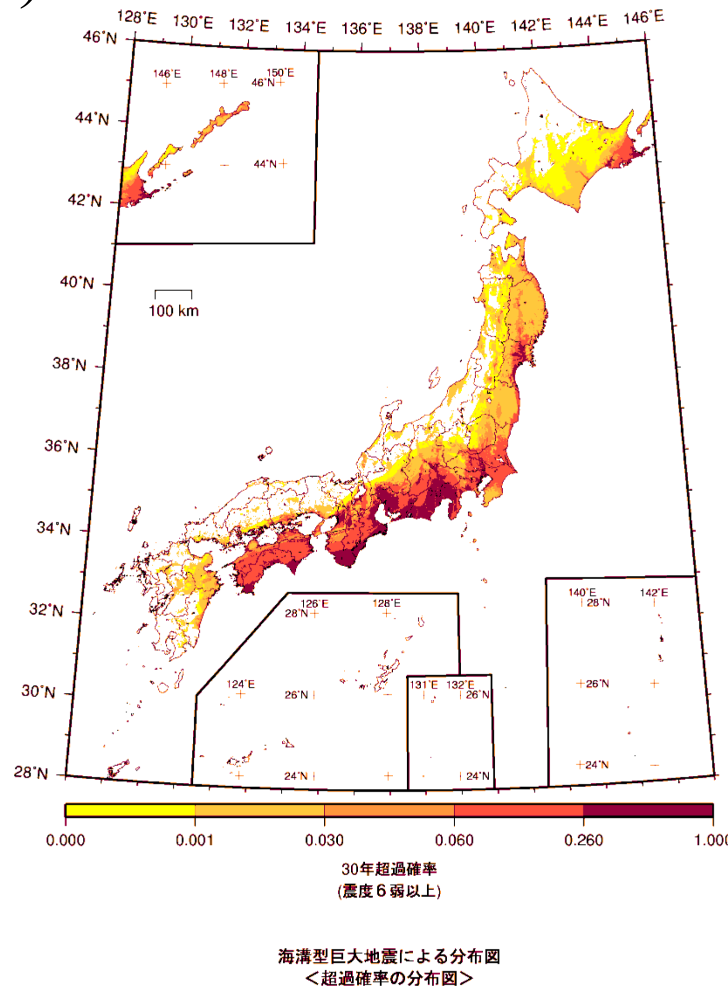
PSHMs for Earthquake Category Ⅰ

(a) PSHM2011



(b) PSHM2011＋TohokuM9



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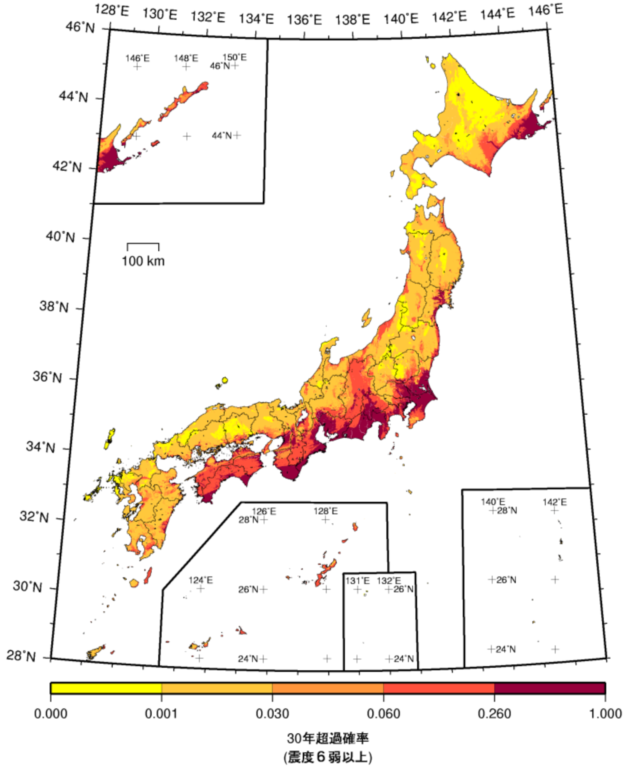
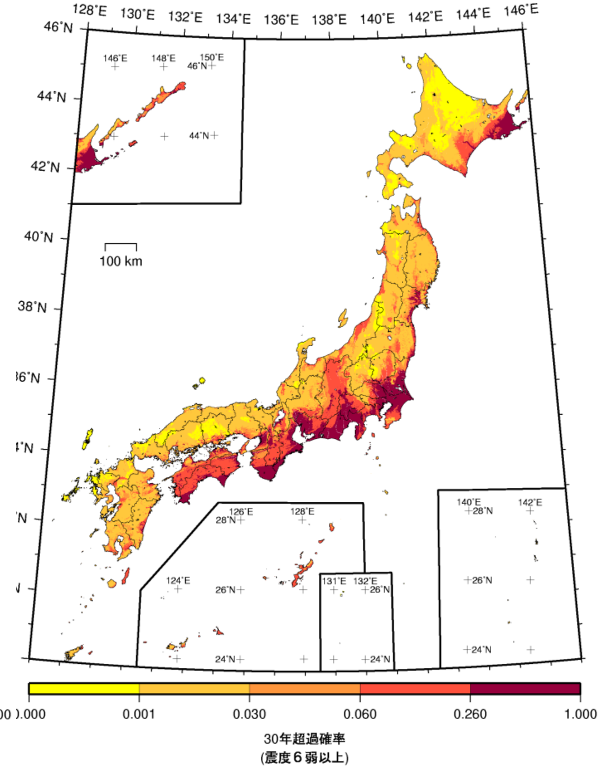
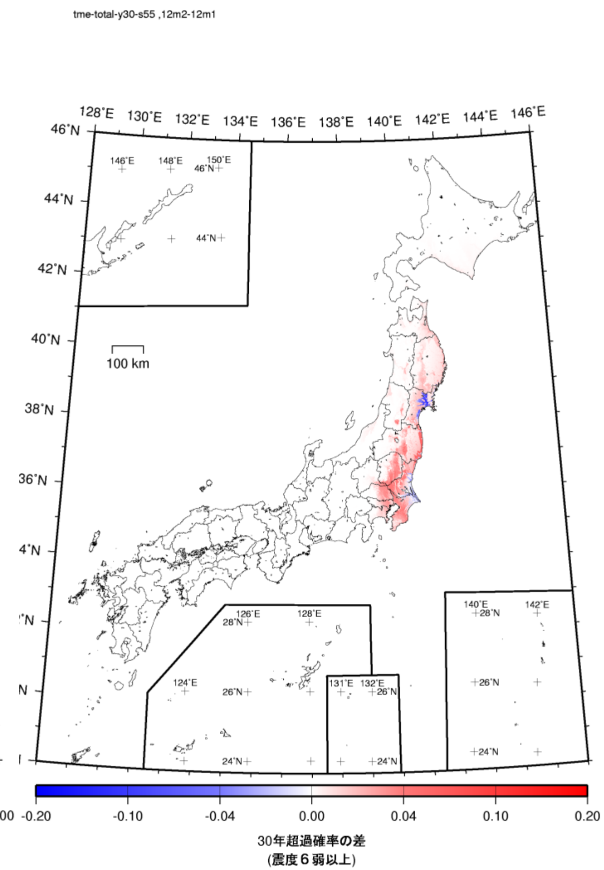
PSHMs for 2012

Model 1



Model 2





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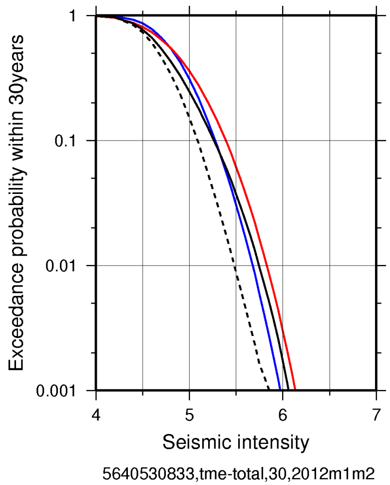
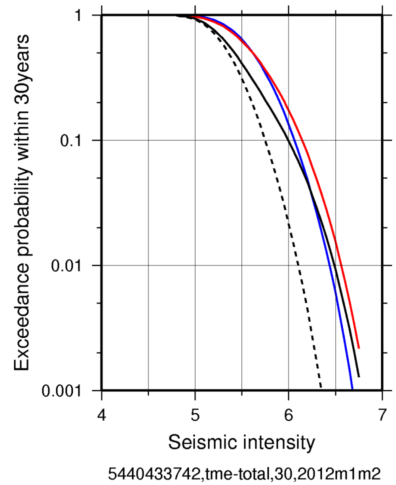
Comparison of hazard curves

Black dashed curve：PSHM2011, Black curve：PSHM2011 with M9

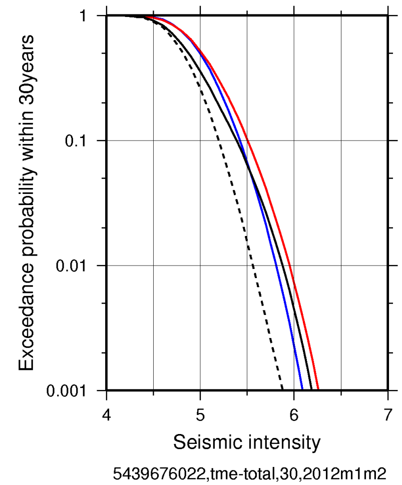
Blue line：PSHM2012(Model1), Red curve：PSHM2012(Model2)



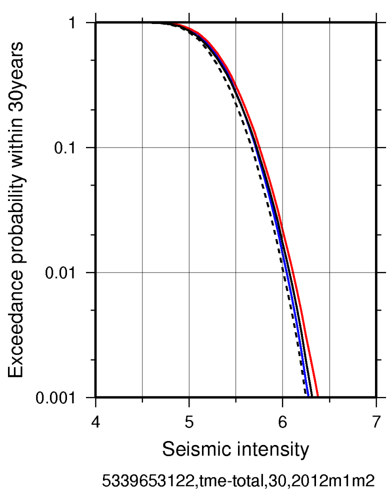
(a) Fukushima



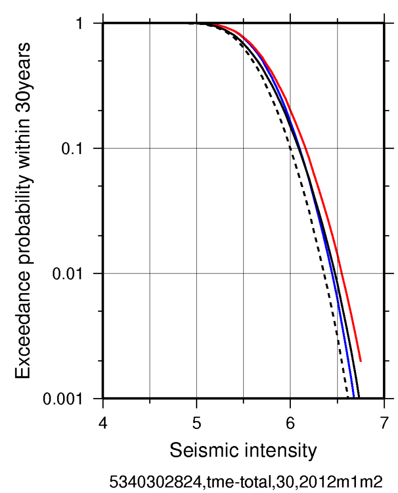
(b) Mito



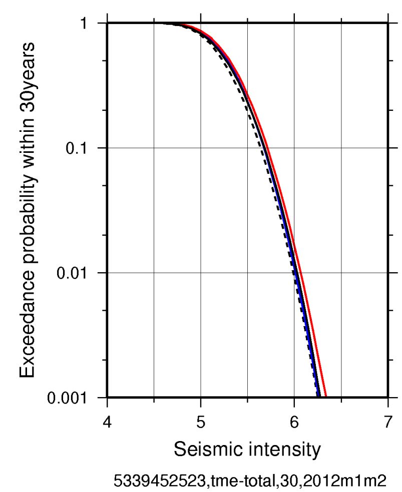
(c) Utsunomiya



(d) Saitama



(e) Chiba



(f) Tokyo

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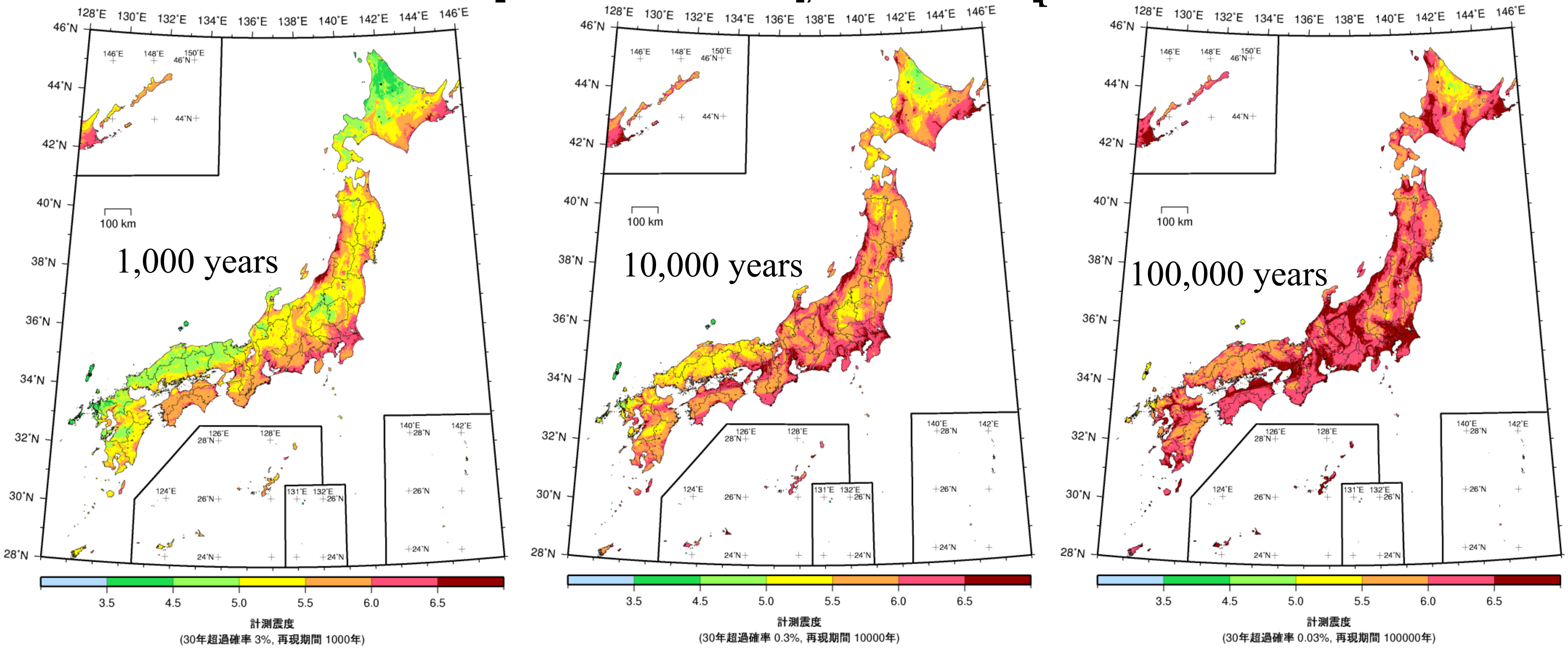
Strong-motion maps considering low-probability earthquakes



Based on the averaged long-term seismic hazard assessment, evaluating strong-motion level for 10,000 ~100,000 years return period, we should prepare the maps that show the distribution of strong-motion level, which represent effect of major earthquakes on active faults and subduction zone earthquakes with low-probability.

Regarding the seismic hazard assessment for low probability, at present, it is insufficient to evaluate the uncertainty for low probability M8 class earthquakes and it is necessary to improve techniques for them.

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Japanese-Chinese-Korean cooperative joint research collaboration program

Title of cooperative research project (2010-2013)

Seismic Hazard Assessment for the Next Generation Map

Research Leaders

Hiroyuki Fujiwara (Japan, NIED)

Tao Xiaxin (China, Harbin Institute of Technology)

Myung-Soon Jun (Korea, KIGAM)

Cooperative joint research

1. To review the data and methodologies adopted in SHA maps of the three countries, and re-evaluate and improve the SHA in each of the countries.
2. To compare the data and the methodologies with the state of the art, and see if there anything could be accepted for the next generation maps.
3. To develop a procedure to establish ground motion equations for maps.
4. To combine the probabilistic seismic hazard assessment and the scenario seismic approach, the latter is especially for near field of potential large earthquake.

The 1st Annual Meeting of the Strategic Chinese-Korean-Japanese Cooperative Program: Seismic Hazard Assessment for the Next Generation Map, November 25~30, 2011, Harbin, China

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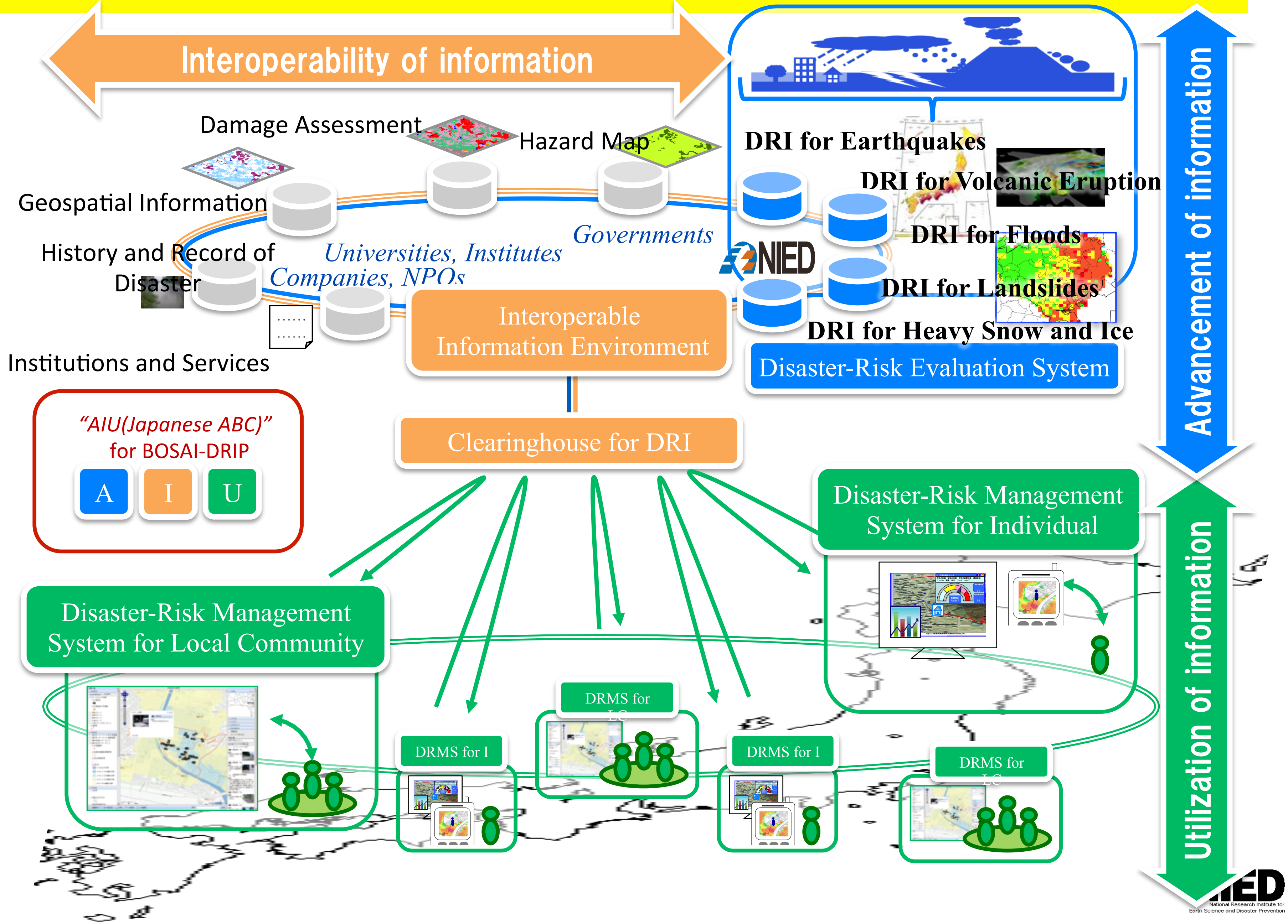
Disaster-Risk Information Platform (BOSAI-DRIP)



Thank you for attention.