Overview and Recent Progress in Earthquake Prediction Research in Japan

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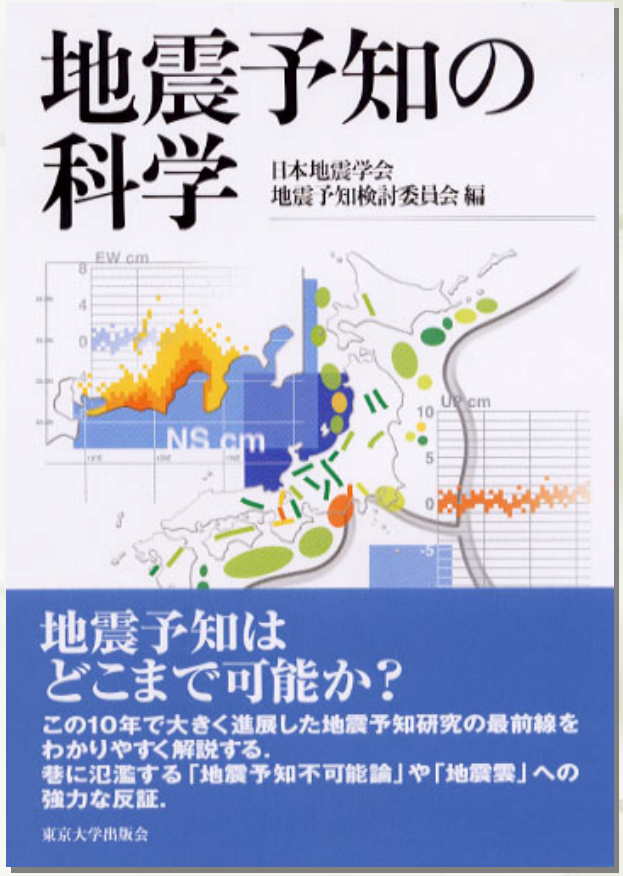

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Systematization (1)
Requirements in earthquake prediction

- *WHEN* (Time)
- *WHERE* (Place)
- *HOW BIG* (Magnitude)

Earthquake prediction is to know these components with practical accuracy before an earthquake.

Systematization(2)
Classification of earthquake prediction in terms of time accuracy.

- Long-term prediction
  - Statistical prediction using time history of earthquake occurrence.
- Mid-term prediction
  - Computer simulation based on physical model using monitoring data.
- Short-term prediction
  - Prediction using precursory phenomena of earthquakes.

Present State of earthquake prediction (in Japan)

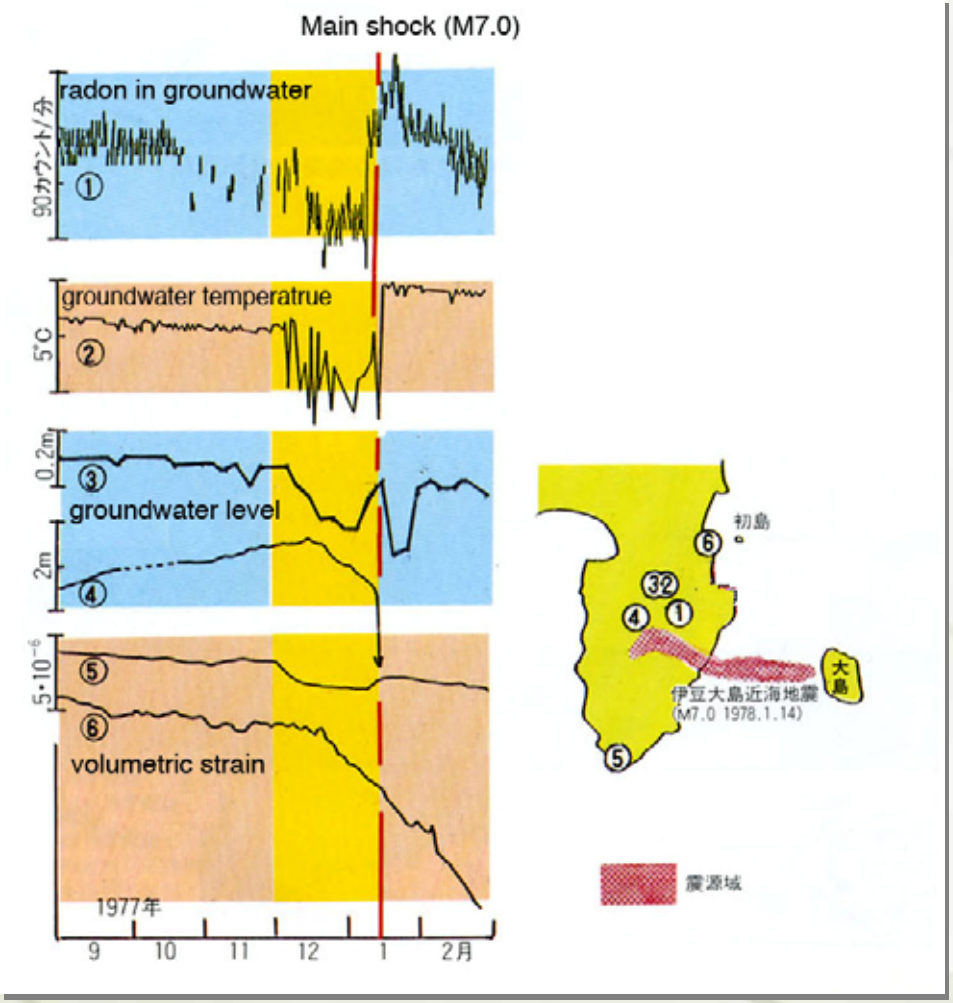
	Long-term (tens to hundreds years)	Mid-term (years to months)	Short-term (Days to hours)
Place	Almost established for inter-plate and active faults	Same as left	Same as left
Magnitude	Almost established for inter-plate and active faults	Same as left	Same as left
Time	Issued by the government	Under development	Under development

National earthquake prediction program (Old program) 1965-1998

1. Establishment of nationwide observation network
   - Seismic observation network
     - Telemetry network
     - Deep borehole measurement in Tokyo metropolitan area
   - Strain observation network
     - Bury-in type volumetric strainmeters in Kanto-Tokai
2. Detection of precursors for long-term and short-term prediction of earthquakes
   - Seismic gap, for long-term precursor
   - Seismicity, crustal deformation etc…
   - Basic research

Short-term precursors before 1978 Izu-Oshima Kinkai Earthquake.

-One of the very few examples.



From the Brochure of Earthquake prediction program (1991)

New national program for earthquake prediction research

1. Study of the process in the earth's crust leading to major earthquakes.
2. Development of predictive simulation models and monitoring system for the crustal activity
3. Development of new observational and experimental technology

Earthquake Disaster reduction and Earthquake Research in Japan.

Prediction of earthquake hazards → Countermeasure for disaster mitigation

The Headquarter of Earthquake Research Promotion
地震調査推進本部

Comprehensive and basic policy
1.Probabilistic earthquake hazard map of Japan
2.Real-time earthquake information
3.Observation and Research of Tokai earthquake
4. Earthquake prediction research.

Policy driven research based on the methodology that is already established

← Scientific research oriented

1. Long-term earthquake prediction

- Stochastic estimate of earthquake occurrence based on earthquake history
- Time predictable model

  ‘The probability of the occurrence of Tonankai earthquake in the next 30 years is 50%.’

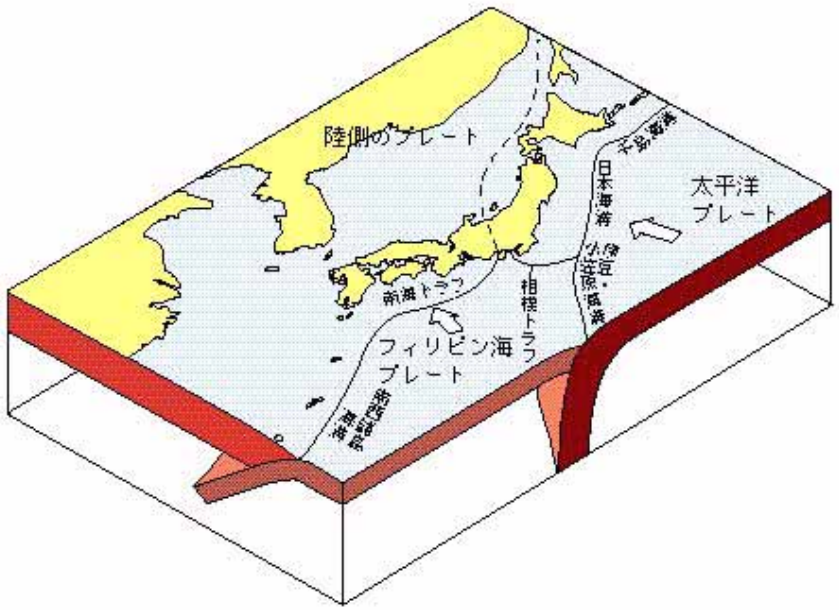
North-American plate

Eurasian Plate

Pacific Plate

Philippine Sea Plate

Plate configuration around Japan



Historical earthquakes

Historical earthquakes repeatedly occurred in the southern part of Japan with various combinations of three ‘asperity’ patches.

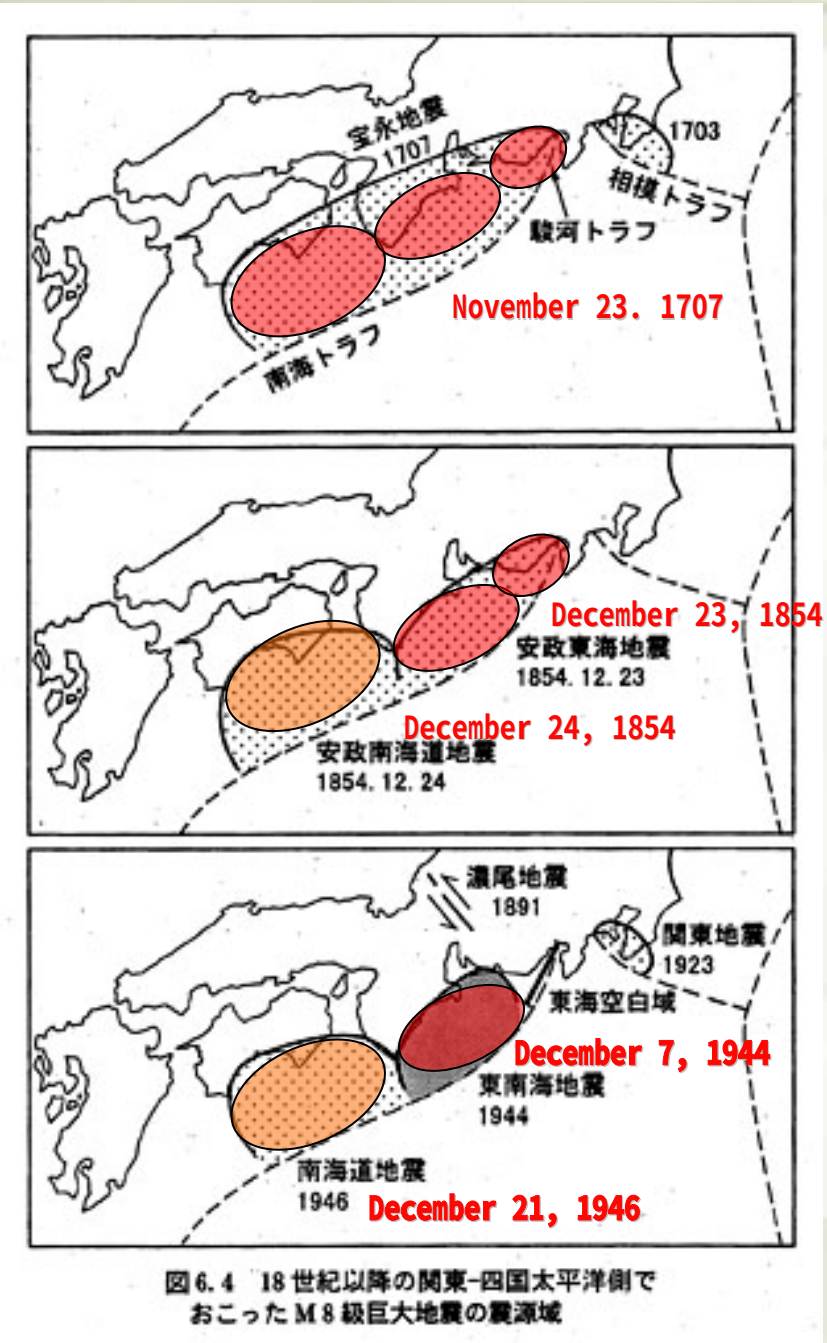
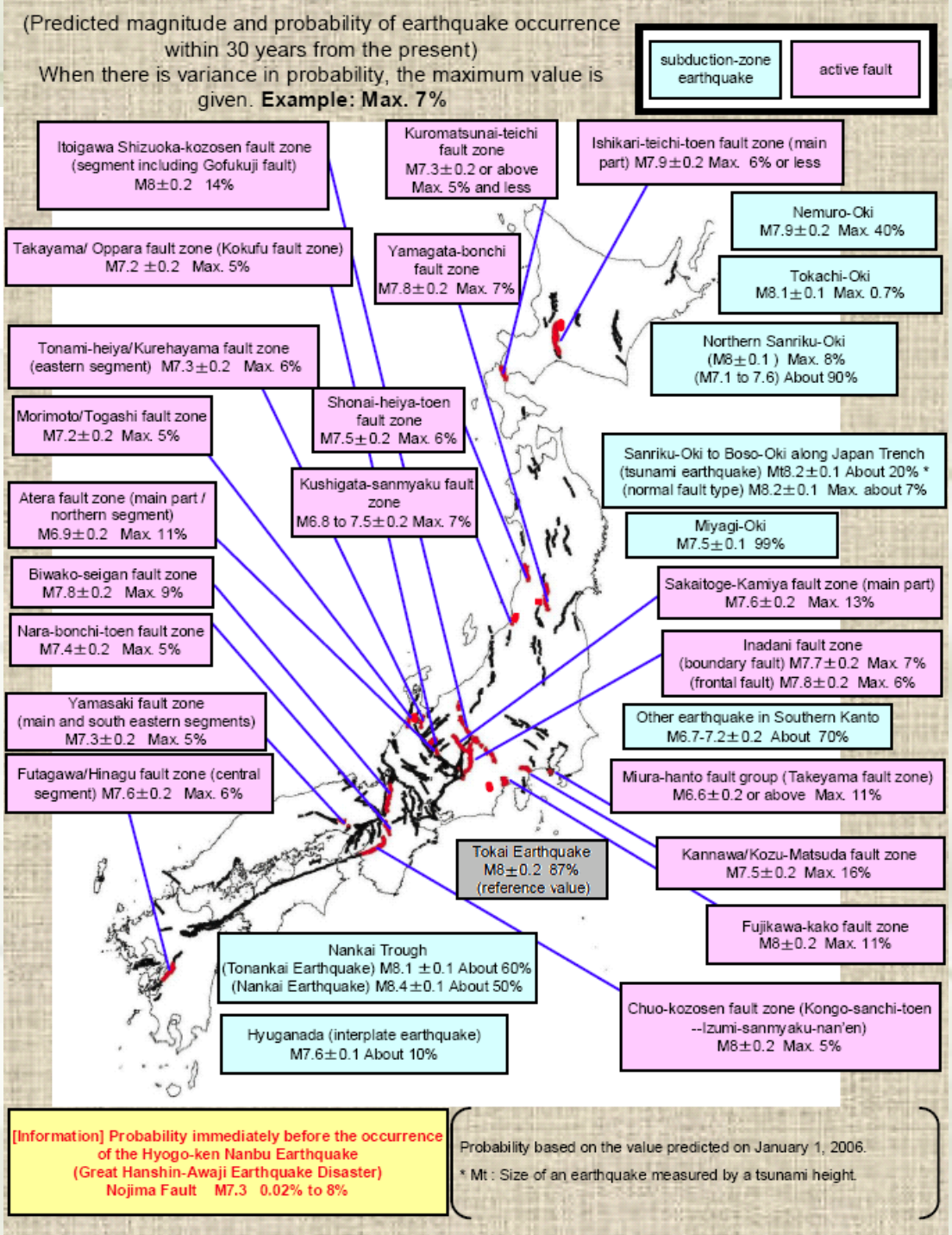


図 6. 4　18 世紀以降の関東-四国太平洋側で
おこった M 8 級巨大地震の震源域

Long-term probability of earthquake occurrence in the next 30 years.



地震の長期評価：
Long-term prediction of earthquake occurrence

uake occurrence
t)
ximum value is

subduction-zone earthquake | active fault

資料： 地震調査研究推進本部

３０年以内に
震度６弱以上の揺れに見舞われる確率
Probability of strong ground motion with Shindo >6- in the next 30 years.

(segment including Gofukuji fault)
M8±0.2 14%

tsunai-teichi fault zone
M7.3±0.2 or above
Max. 5% and less

Ishikari-teichi-toen fault zone (main part) M7.9±0.2 Max. 6% or less

Nemuro-Oki
M7.9±0.2 Max. 40%

Tokachi-Oki
M8.1±0.1 Max. 0.7%

Takayama/ Oppara fault zone (Kokufu fault zone)
M7.2 ±0.2 Max. 5%

Yamagata-bonchi fault zone
M7.8±0.2 Max. 7%

Tonami-heiya/Kurehayama fault zone (eastern segment) M7.3±0.2 Max. 6%

Northern Sanriku-Oki
(M8±0.1) Max. 8%
(M7.1 to 7.6) About 90%

Morimoto/Togashi fault zone
M7.2±0.2 Max. 5%

Shonai-heiya-toen fault zone
M7.5±0.2 Max. 6%

Sanriku-Oki to Boso-Oki along Japan Trench (tsunami earthquake) Mt8.2±0.1 About 20% *
(normal fault type) M8.2±0.1 Max. about 7%

Kushigata-sanmyaku fault zone
M6.8 to 7.5±0.2 Max. 7%

Atera fault zone (main part / northern segment)
M6.9±0.2 Max. 11%

Miyagi-Oki
M7.5±0.1 99%

Biwako-seigan fault zone
M7.8±0.2 Max. 9%

Sakaitoge-Kamiya fault zone (main part)
M7.6±0.2 Max. 13%

Nara-bonchi-toen fault zone
M7.4±0.2 Max. 5%

Inadani fault zone
(boundary fault) M7.7±0.2 Max. 7%
(frontal fault) M7.8±0.2 Max. 6%

Yamasaki fault zone (main and south eastern segments)
M7.3±0.2 Max. 5%

Other earthquake in Southern Kanto
M6.7-7.2±0.2 About 70%

Futagawa/Hinagu fault zone (central segment) M7.6±0.2 Max. 6%

Miura-hanto fault group (Takeyama fault zone)
M6.6±0.2 or above Max. 11%

Tokai Earthquake
M8±0.2 87%
(reference value)

Kannawa/Kozu-Matsuda fault zone
M7.5±0.2 Max. 16%

Fujikawa-kako fault zone
M8±0.2 Max. 11%

Nankai Trough
(Tonankai Earthquake) M8.1 ±0.1 About 60%
(Nankai Earthquake) M8.4±0.1 About 50%

Chuo-kozosen fault zone (K
--Izumi-sanmya
M8±0.2

Hyuganada (interplate earthquake)
M7.6±0.1 About 10%

0% 0.1% 3% 6% 26% 100%

[Information] Probability immediately before the occurrence of the Hyogo-ken Nanbu Earthquake (Great Hanshin-Awaji Earthquake Disaster)
Nojima Fault M7.3 0.02% to 8%

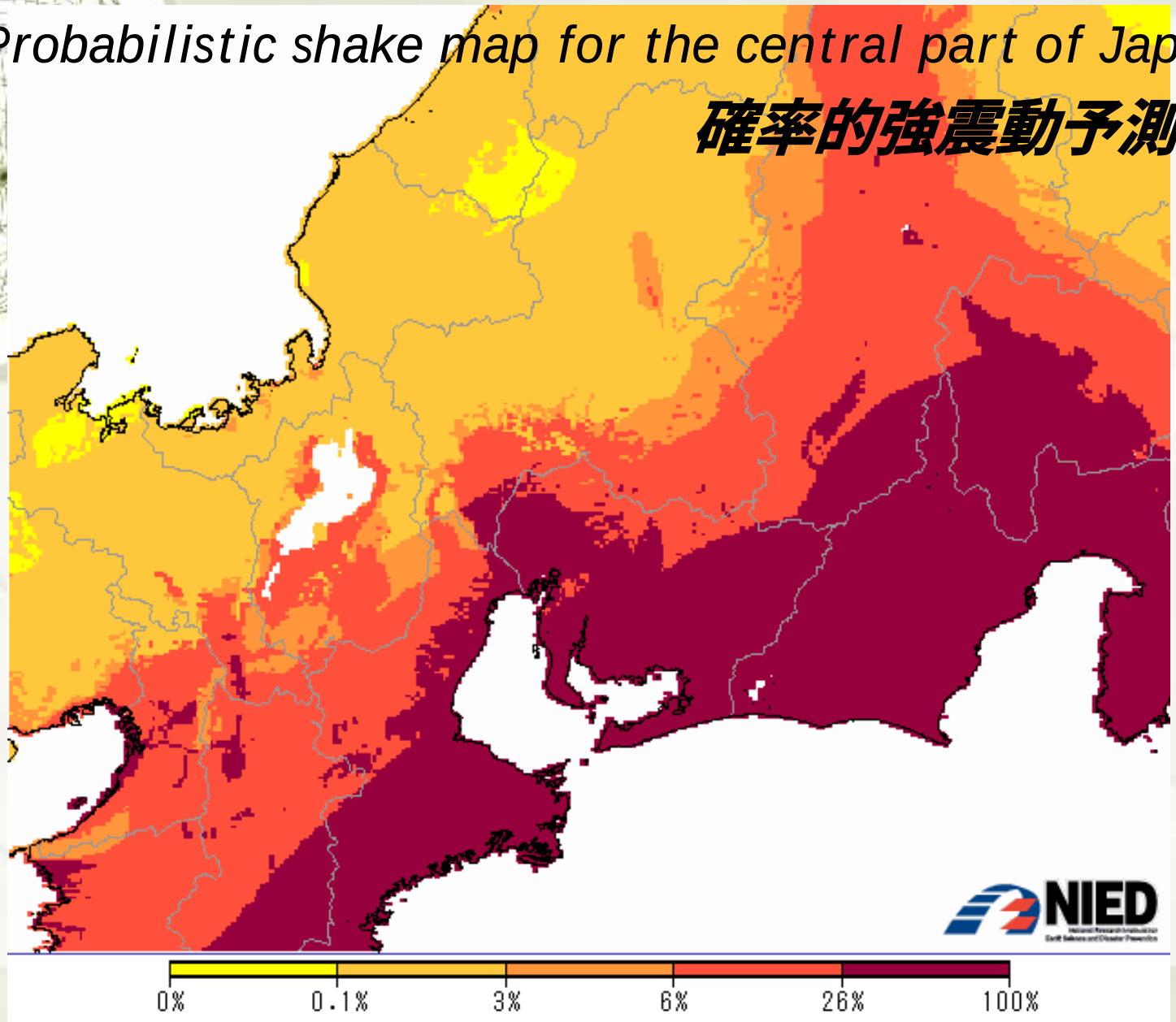
Probability based on the value predicted on January 1, 2006.
* Mt : Si

今後３０年以内に発生する確率

Probability within the next 30 years

Probabilistic shake map for the central part of Japan

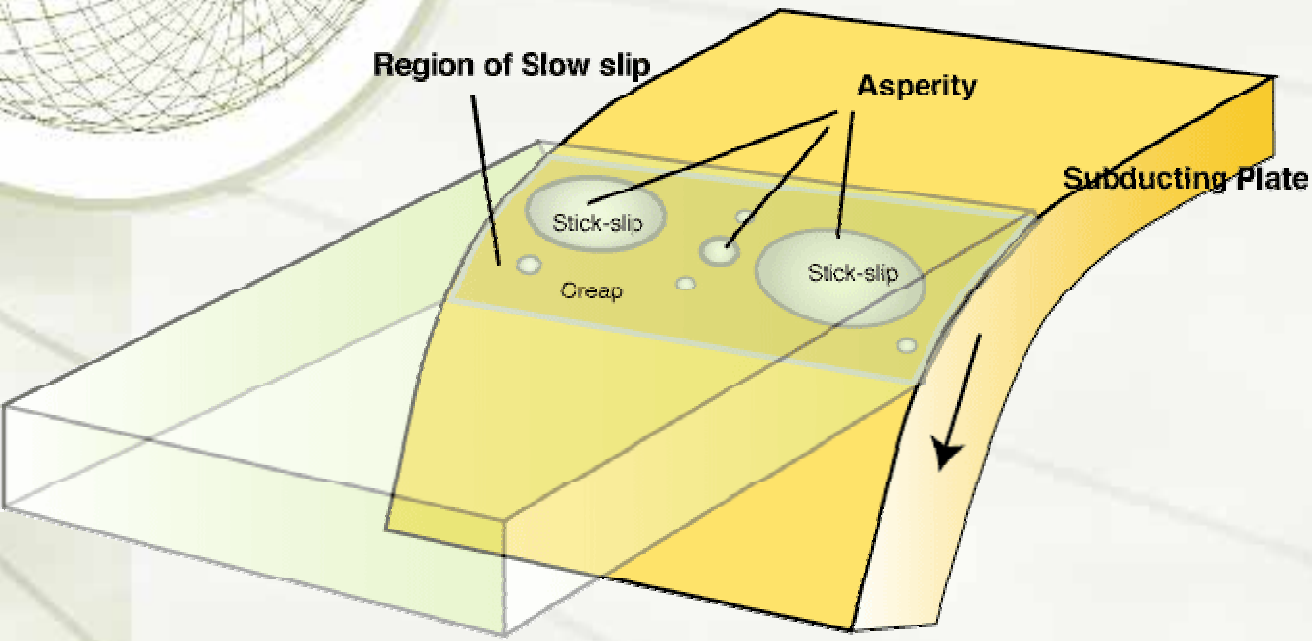
確率的強震動予測図



2. Mid-term earthquake prediction

- Computer simulation based on physical model using monitoring data.
  - Mathematical formulation is necessary
- Do we have Differential Equation for Earthquake prediction ?
  - YES
    - Media : elasticity or visco-elasticity
    - Faulting: rate- and state- dependent friction law
      - Stable sliding and Stick Slip are produced.

Establishment of Asperity model



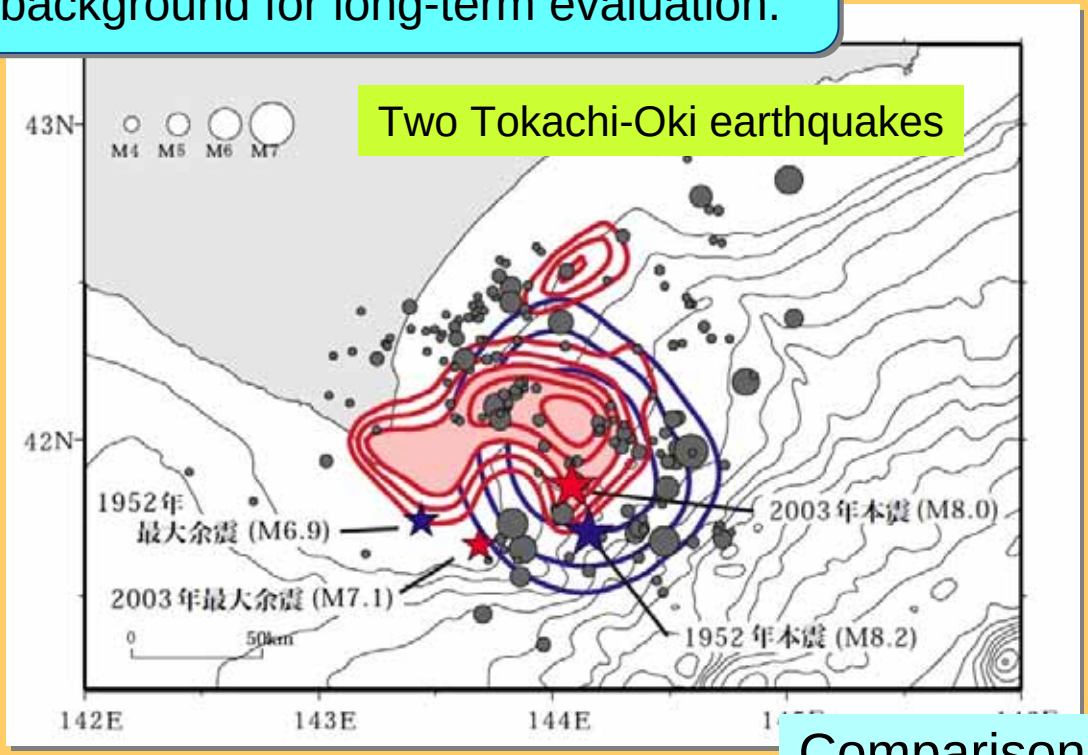
Schematic illustration on interface at subduction plate boundary

for Large Earthquakes on Plate Boundary

- Distribution of asperity do not change through earthquakes.
- Stress concentrate at asperities due to slow slip and stable sliding around them
- Large slip occur at asperities at earthquakes.

Observational results supporting asperity model.

Asperity model also gives scientific background for long-term evaluation.

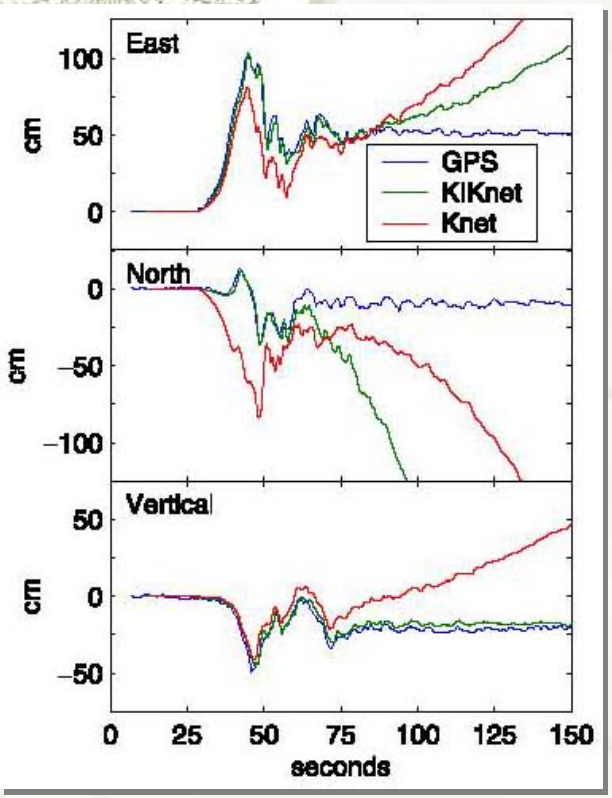


Comparison between slips of 1952 and 2003 earthquakes.

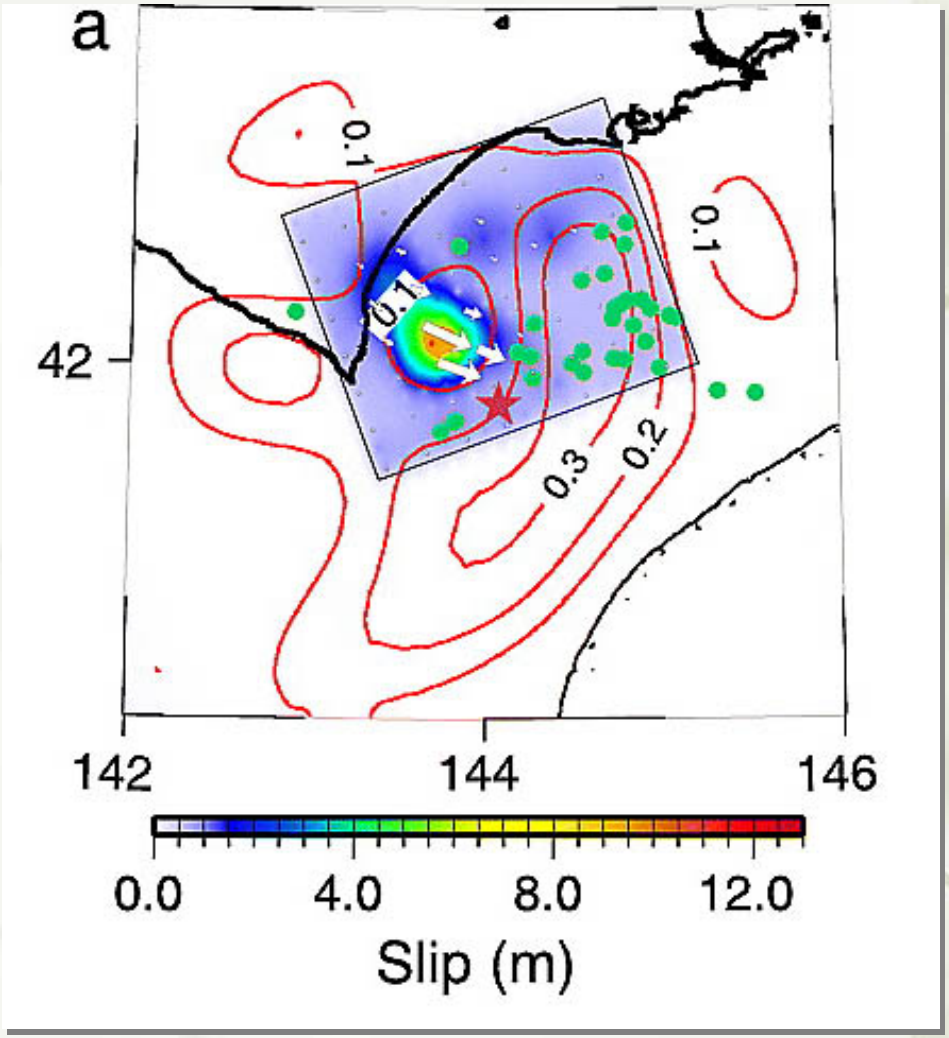
- Blue contour: slip at 1952 earthquake
- Red contour: slip at 2003 earthquake
- Similar slip distribution with similar magnitude.

Yamanaka and Kikuchi (2003)

Coseismic and after slip at 2003 Tokachi-oki earthquake using 1 sps GPS data

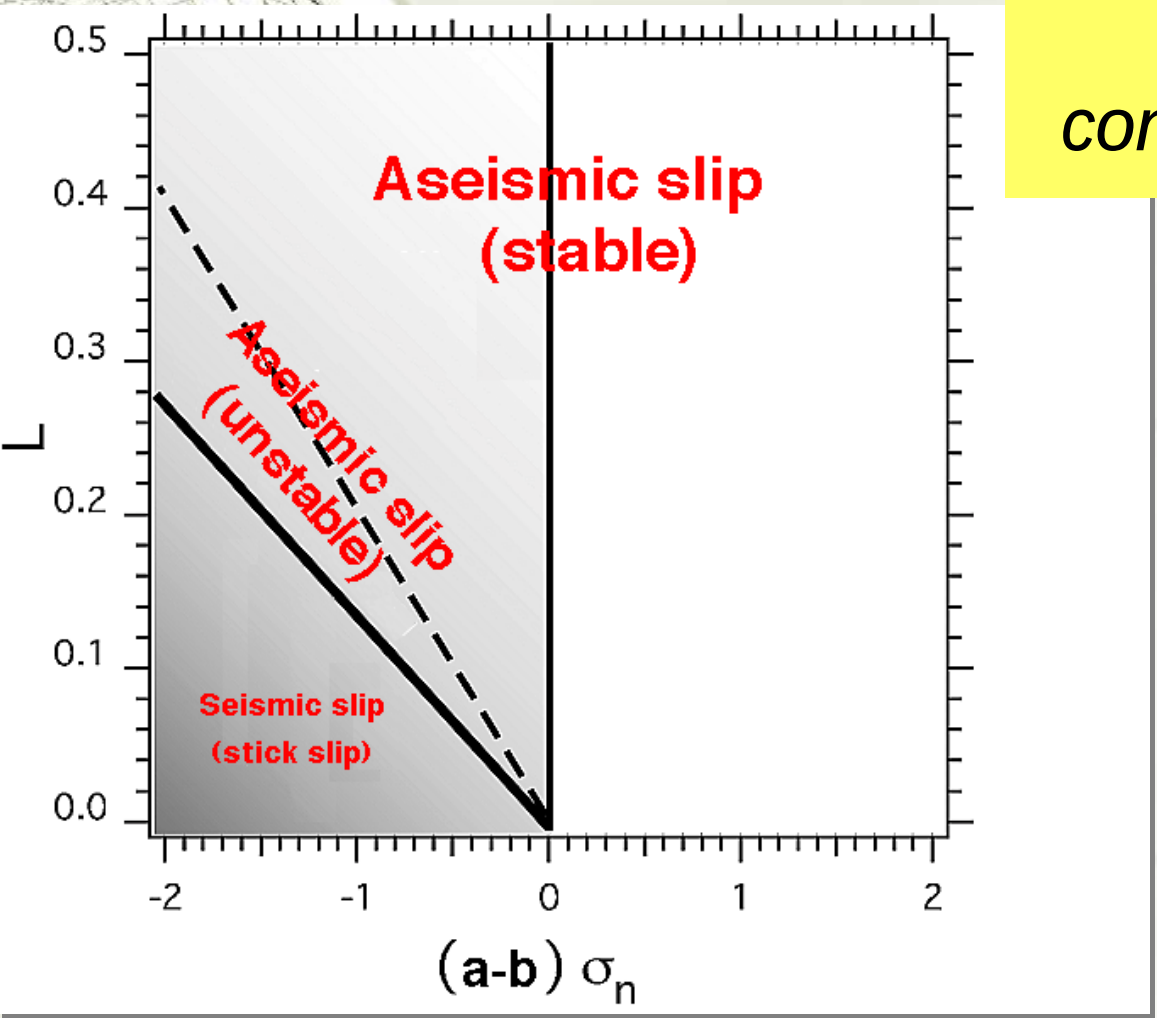


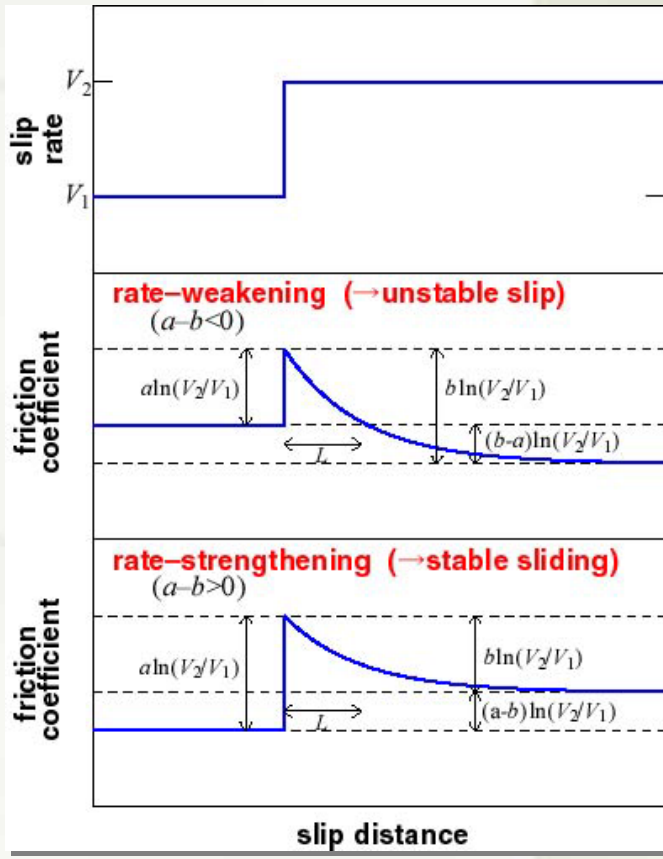
Miyazaki et al. (2004)



Area of co- and after-seismic slip are spatially compensative.

Seismic or Aseismic controlled by (a-b) and L

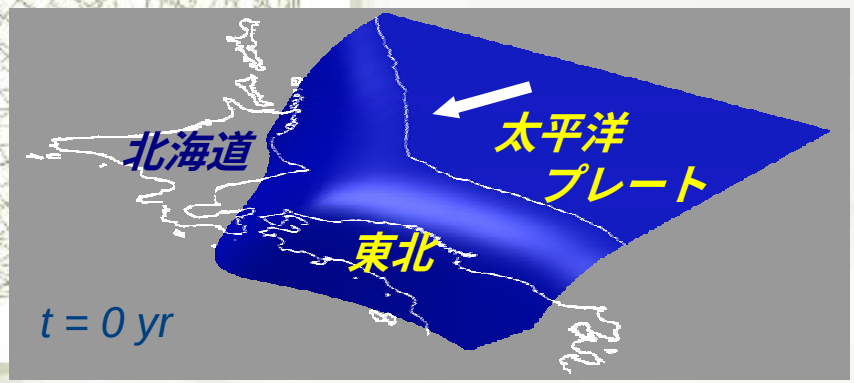


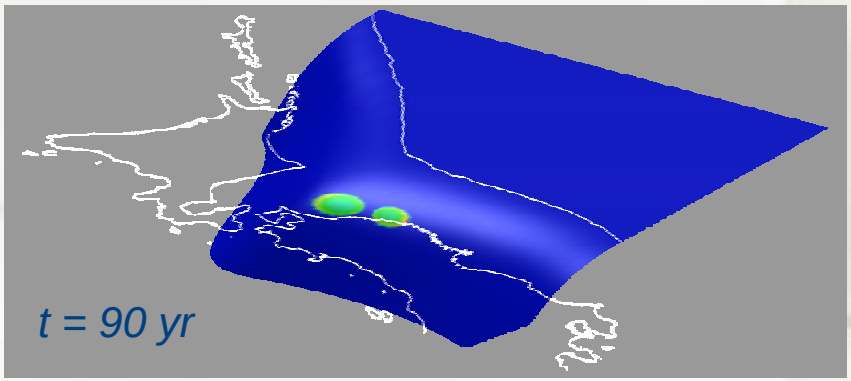


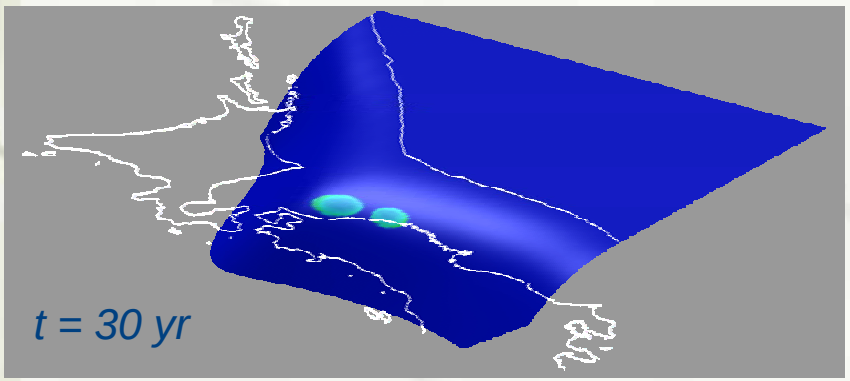
$$\tau_i = \sigma_n(\mu^*_i + a_i \ln(V_i/V^*) + b_i \ln(\theta_i/\theta^*))$$

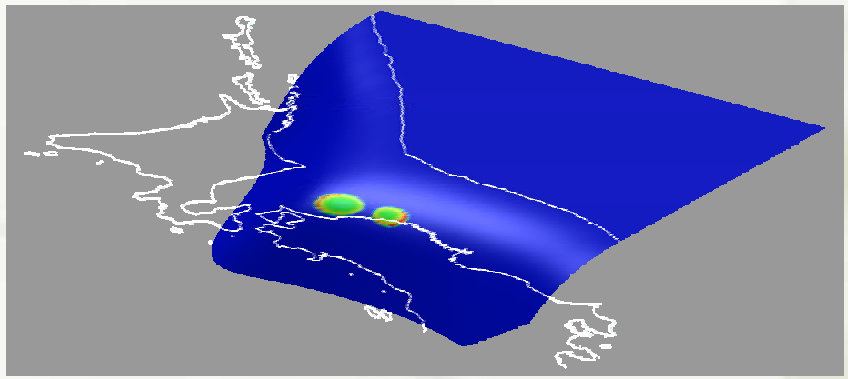
$$\dot{\theta}_i = -\frac{V\theta_i}{L_i}\ln\left(\frac{V\theta_i}{L_i}\right)$$

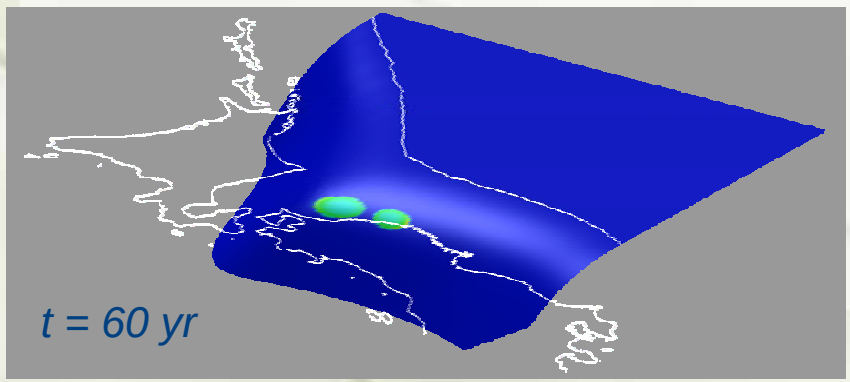
Predictive Simulation - 1
Interplate earthquake in Tohoku-Hokkaido region





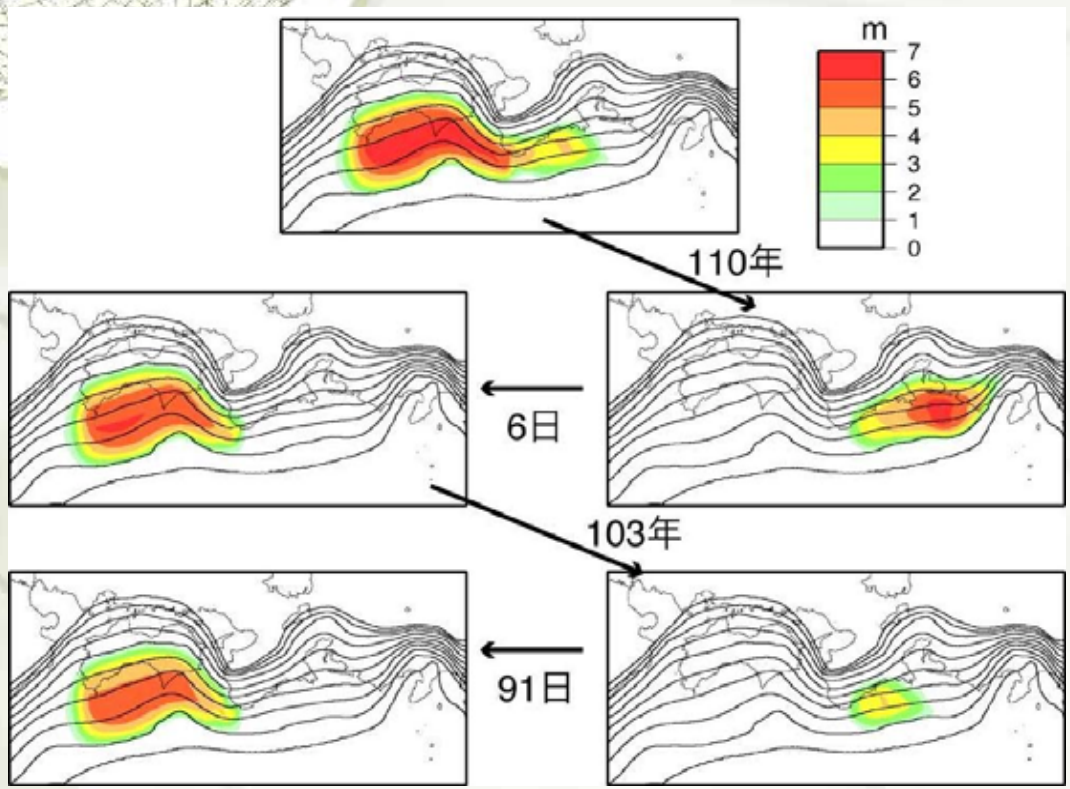






(Matsu'ura, 2004)

Predictive Simulation - 2 great earthquakes along the Nankai Trough

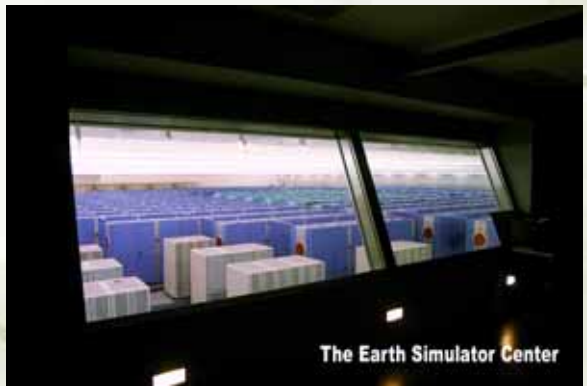


Hori et al. 2005

宝永 1707

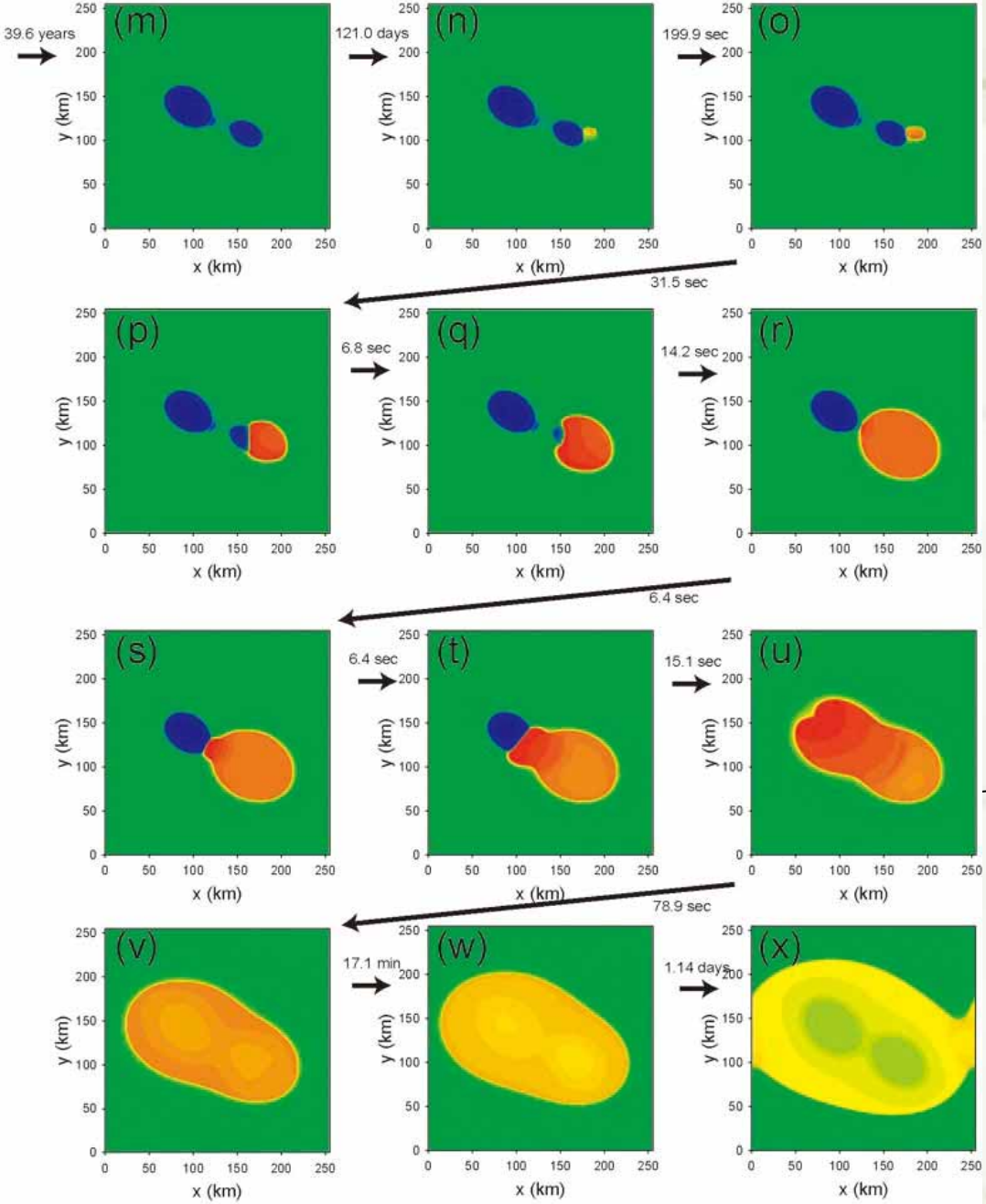
安政 1854 1854

昭和 1946 1944



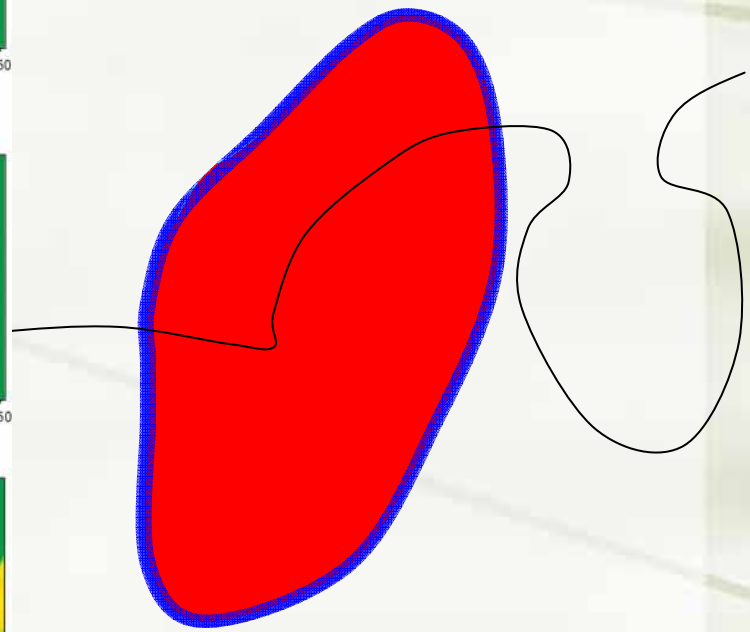
3. Short-term prediction

- Need to detect phenomena that is uniquely appears immediately before earthquake occurrence
- Pre-slip is an only possible candidate
- Little progress for short-term prediction



(Naoyuki Kato 2004)

Pre-slip



TOKAI EARTHQUAKE!

Quantitative earthquake prediction

Is earthquake impending?

Monitoring
strain
Seismic activity
slip on earthquake fault
……

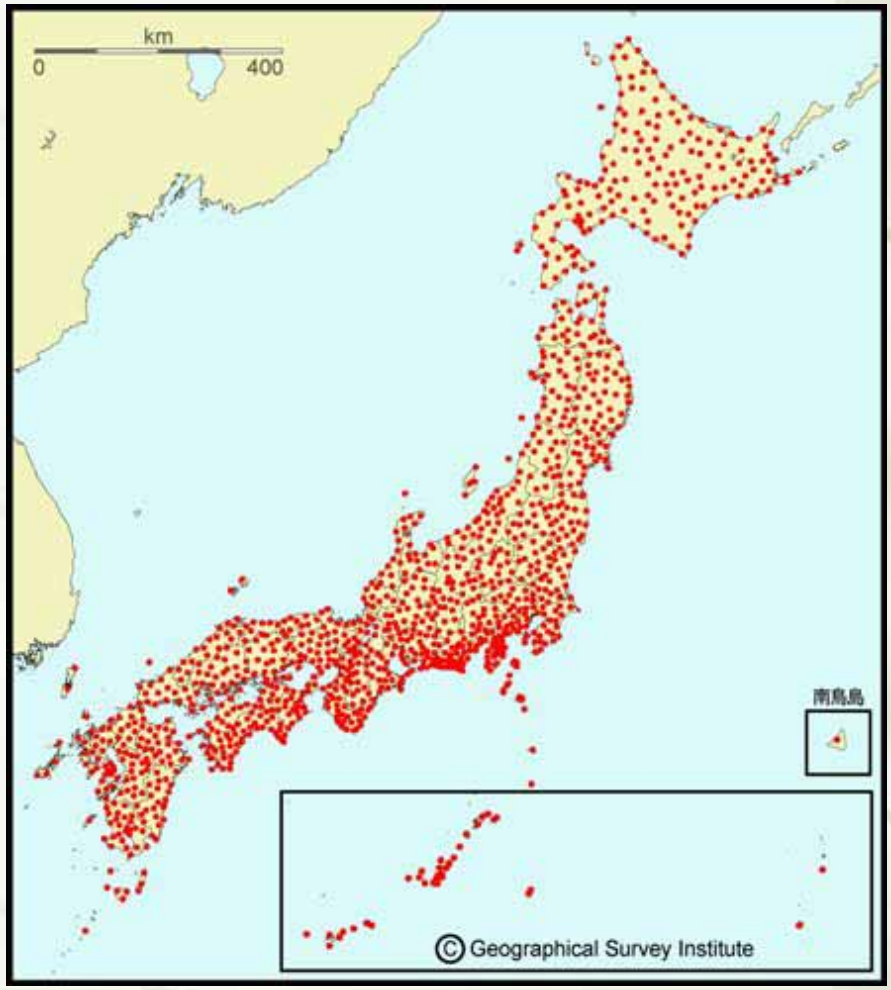
Computer simulation
for stress state on earthquake fault.

Physical model based on research on earthquake process ***throughout earthquake cycle***

Monitoring is essential

Traditional leveling survey

GPS observation stations

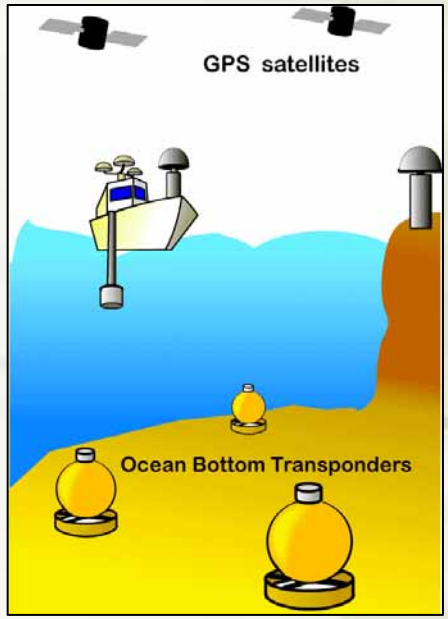


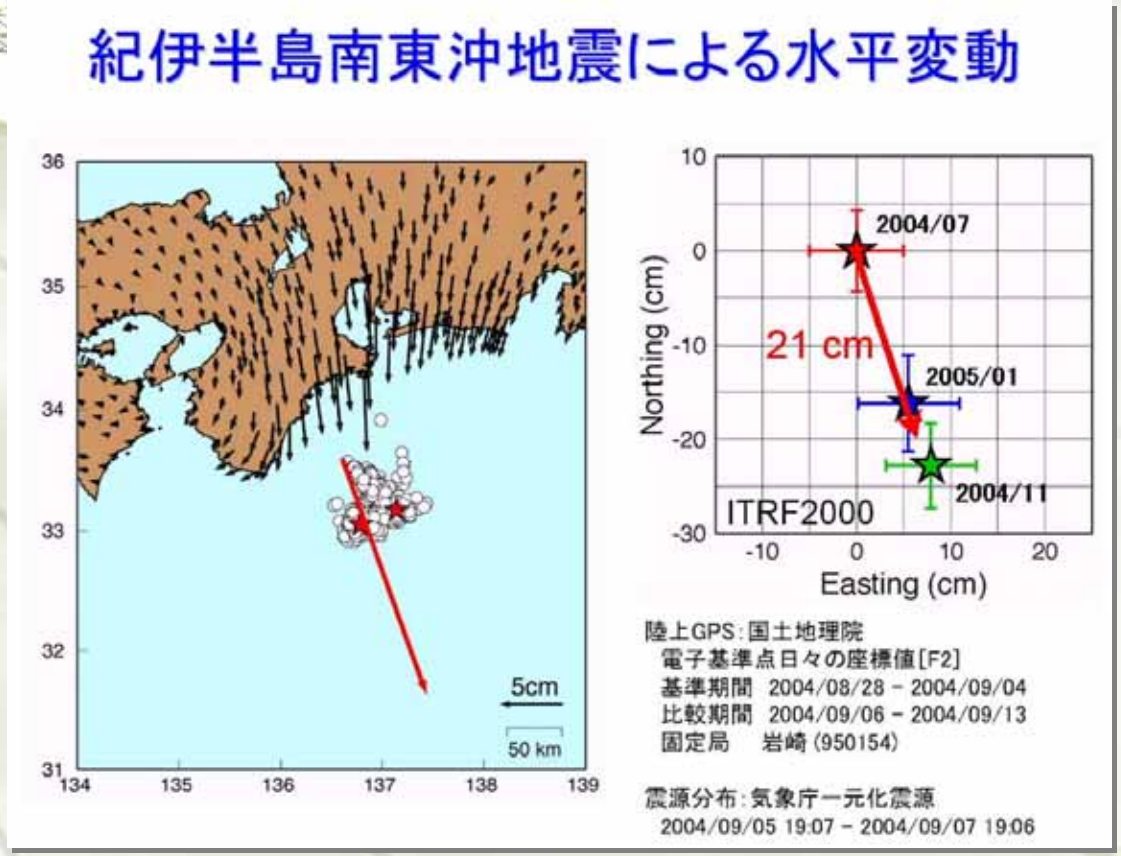
More than 1300 stations

Monitoring example - 1

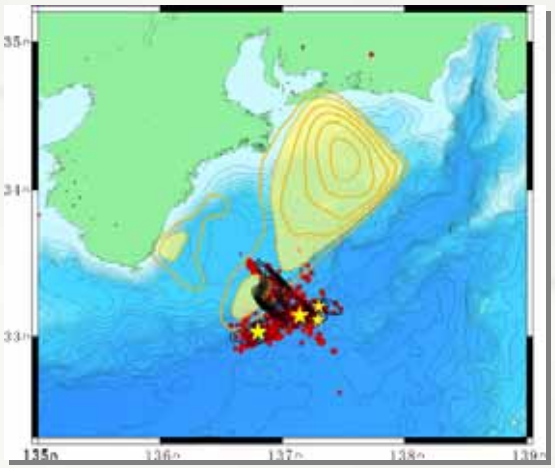
Geodetic monitoring at Ocean Bottom

Displacement at 2004 Off-Kii peninsula earthquake





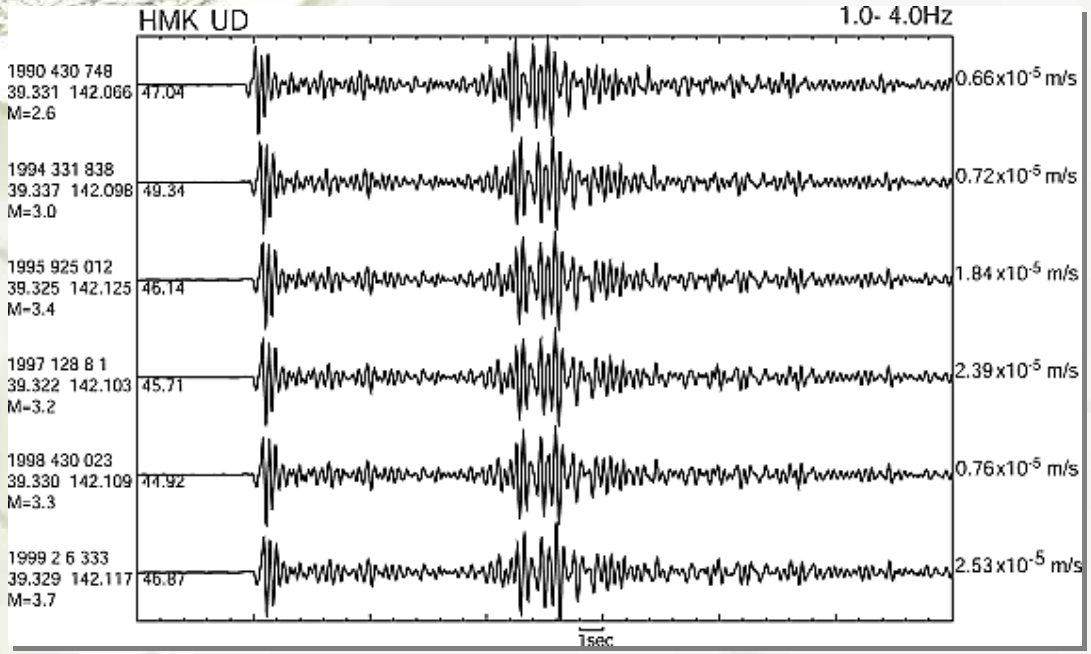
GPS-acoustic seafloor positioning (Nagoya Univ.)

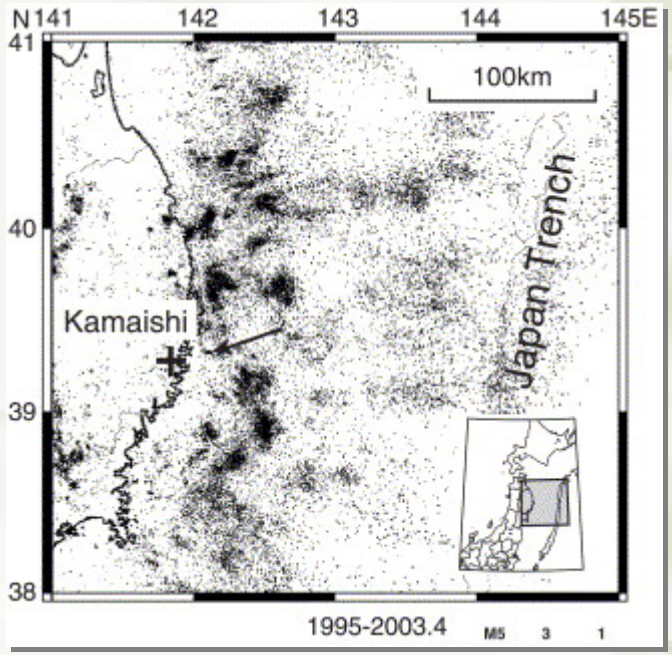


Slip distribution of 2004 Off-Kii peninsula earthquake (Yamanaka 2005)

Monitoring example -2
Interplate slip monitoring using repeating earthquakes

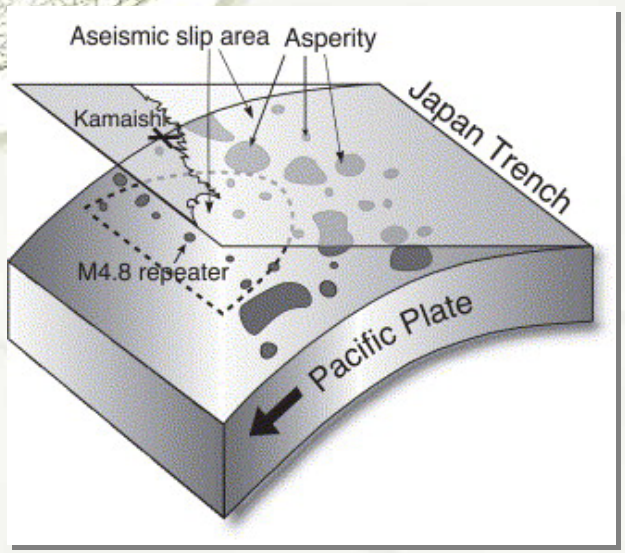
Examples of repeating earthquake

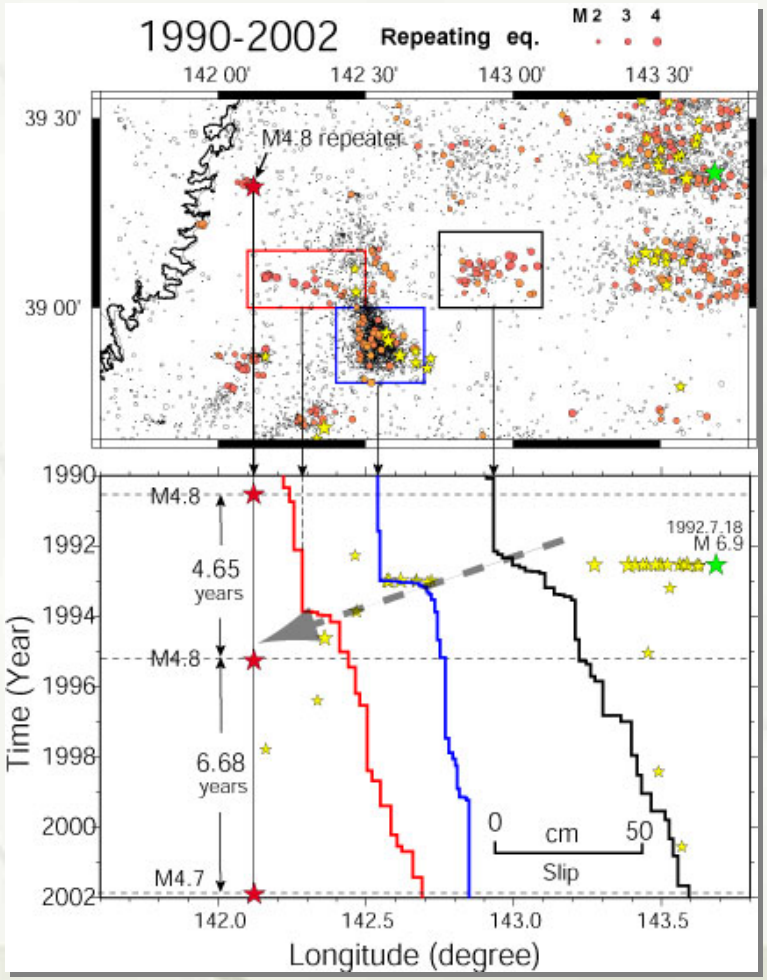




Uchida et al. (2005)

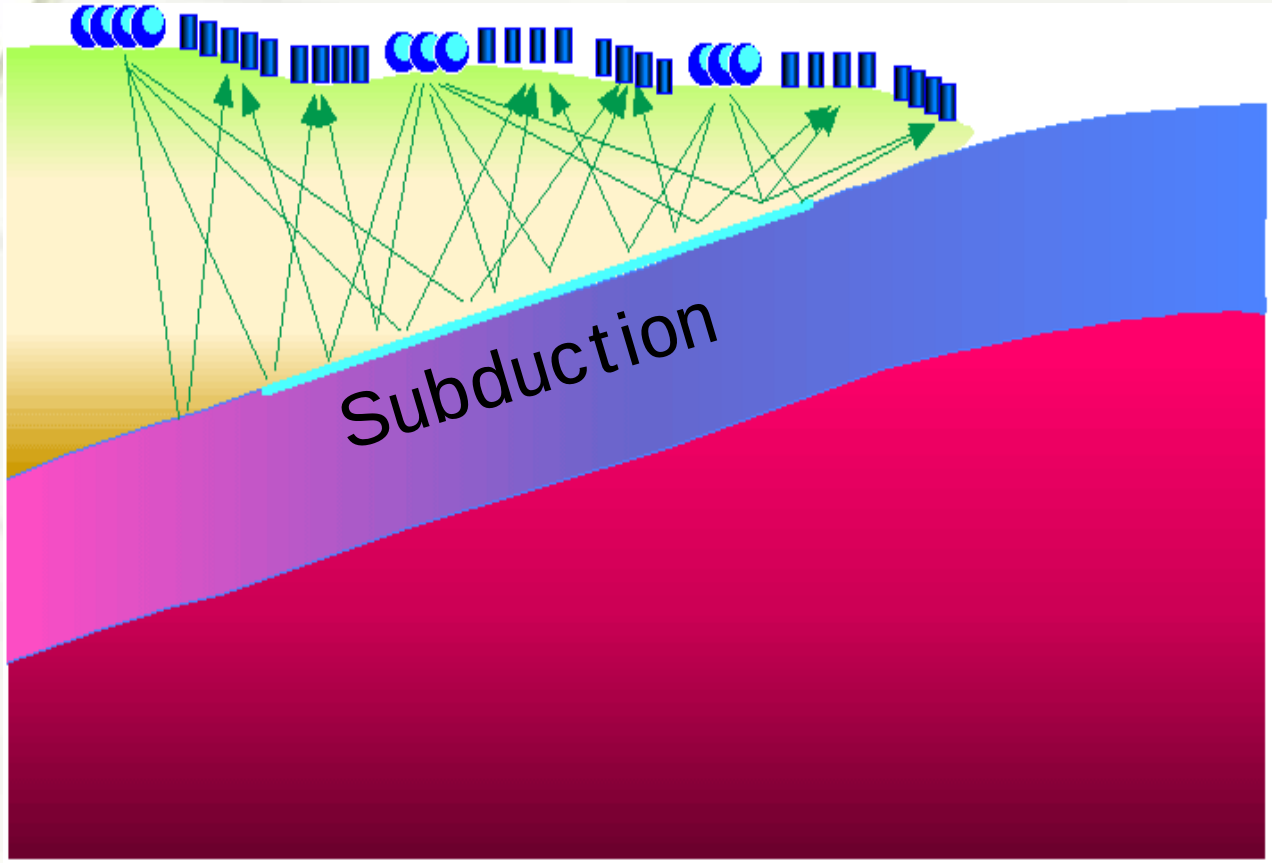
Monitoring example -2-1 Interplate slip monitoring using repeating earthquakes





Uchida et al. (2005)

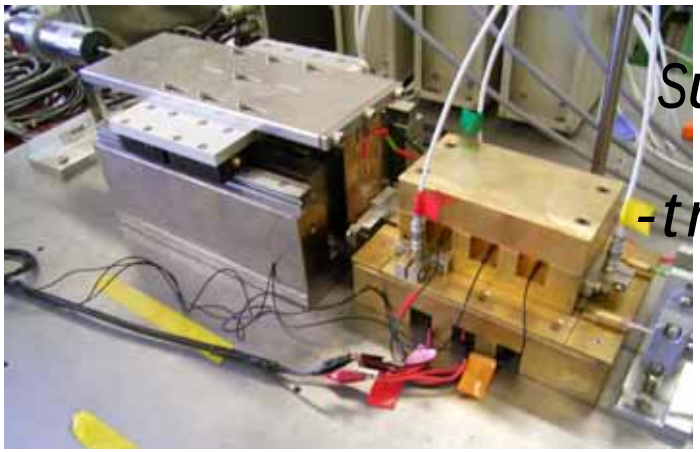
Monitoring example -3
ACTIVE monitoring for the coupling

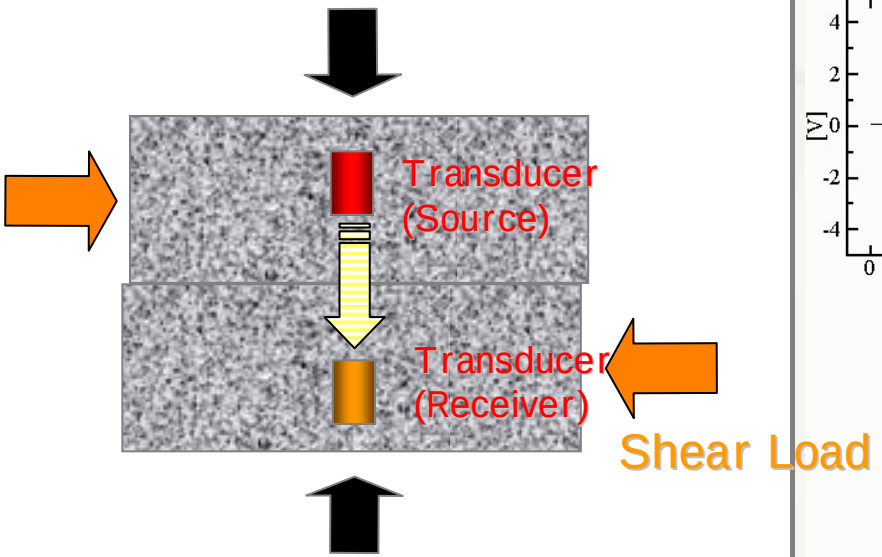


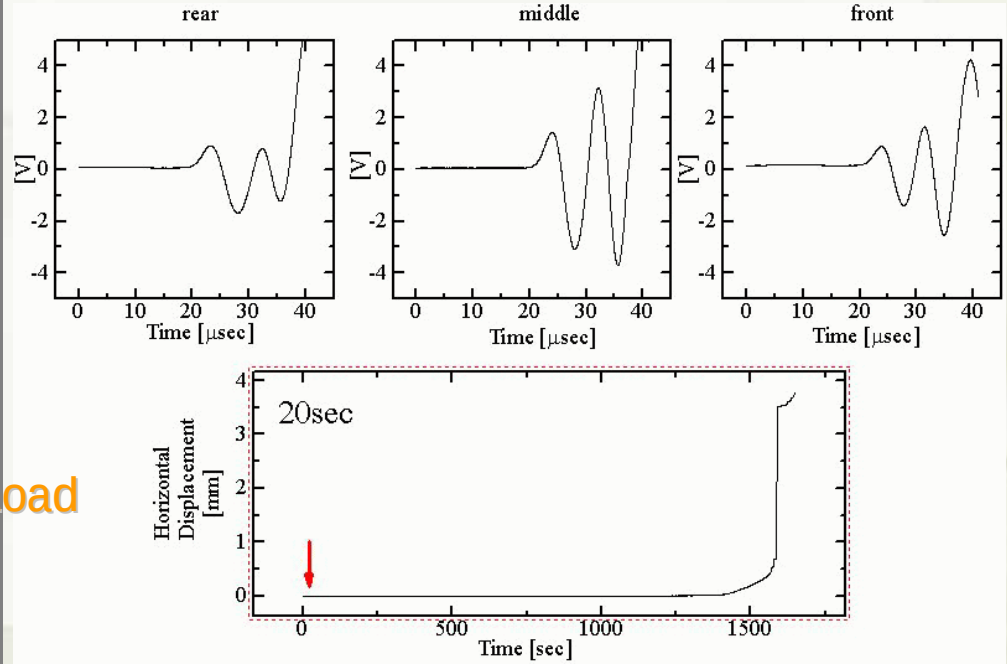
What do we monitor with continuous active source.

Suggestion from Laboratory experiment

-transimissive wave across fault surface



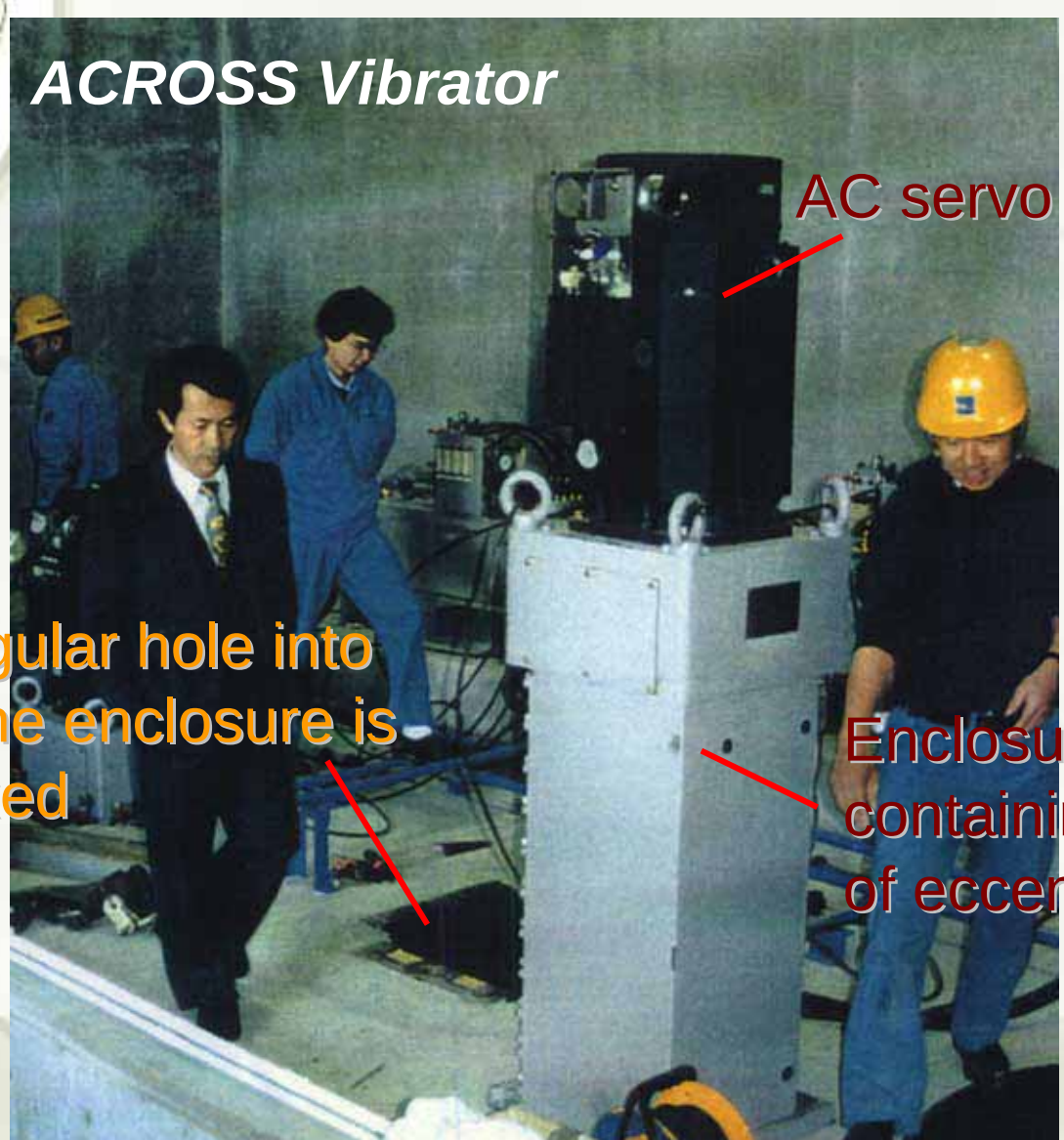




Yoshioka et al. (2004)

Monitoring example -3-2

ACTIVE Monitoring



Summary

- New program of earthquake prediction research in Japan emphasizes the importance of

1. Modeling of process in the Earth's crust leading to earthquakes
2. Monitoring the state of crust

   Important Role of Active Monitoring
3. Predictive simulation
4. Basic research for Short-term is necessary