Seafloor Geodesy

A New Challenge for Approaching Great Earthquakes around Japan

Masayuki FUJITA

Hydrographic and Oceanographic Department
Japan Coast Guard
(JCG)

18th International Workshop on Laser Ranging

Fujiyoshida, Japan

11 November 2013

The Great East Japan Earthquake (M9.0)

By Japan Coast Guard

The Great East Japan Earthquake (M9.0)

14:46
11 March 2011

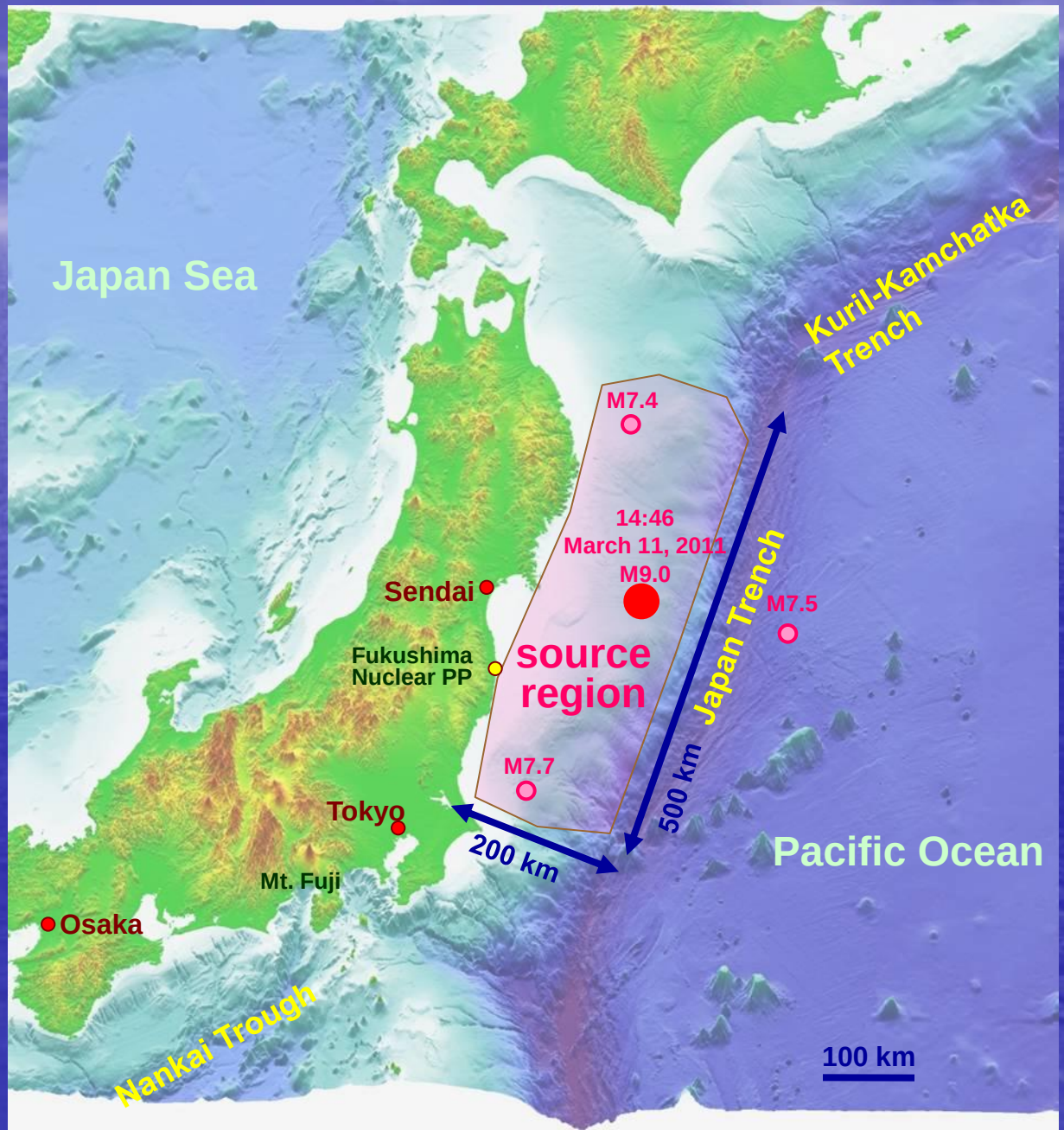
Personnel damages (persons)

Killed	:	15,883
Missing	:	2,652
Injured	:	6,149

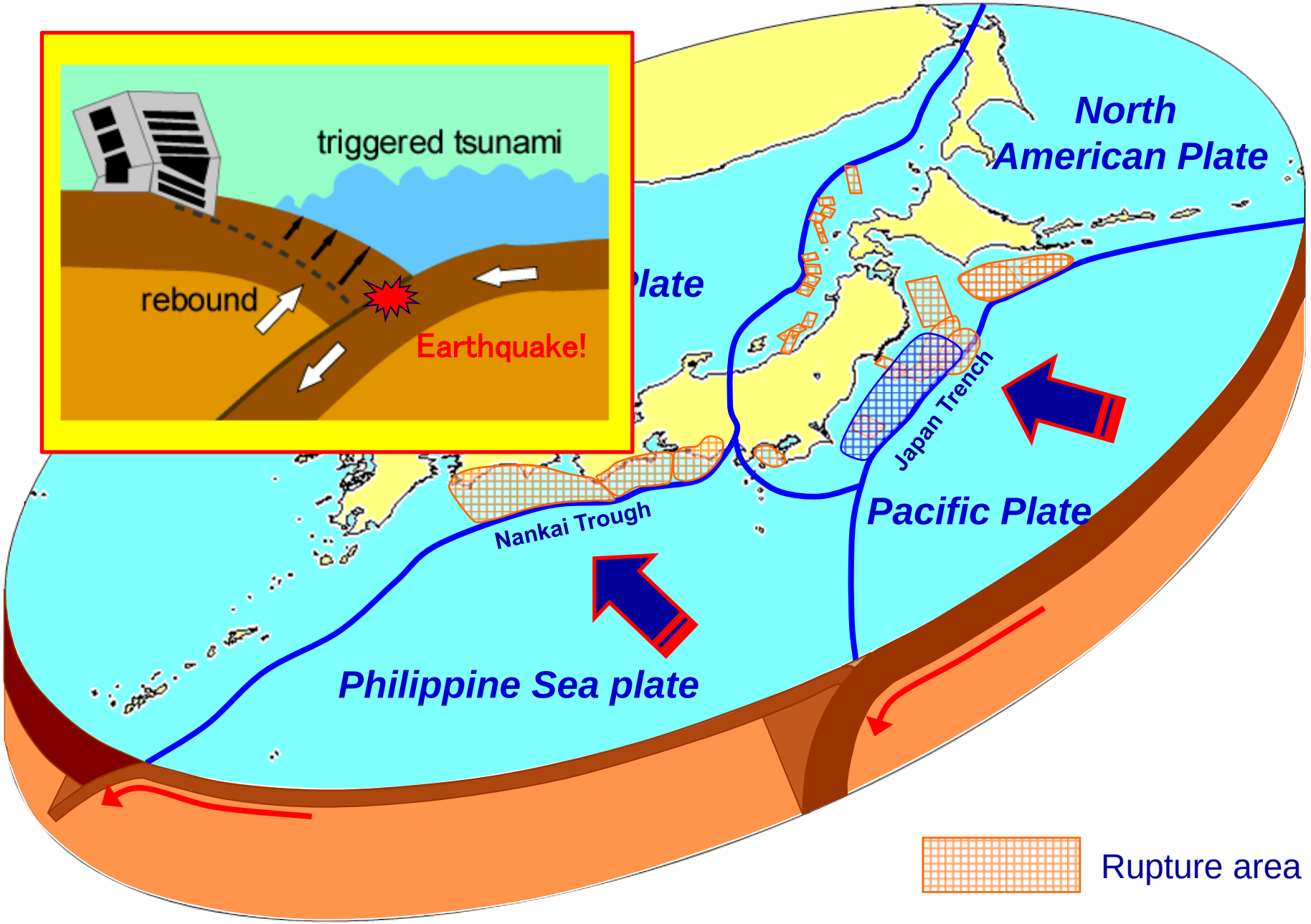
Property damages (doors)

Total Collapse	: 126,583
Half Collapse	: 272,315
Partially Damaged	: 742,867

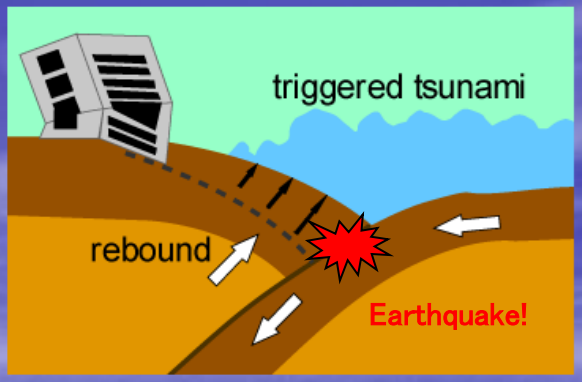
(ref. National Police Agency of Japan, Oct. 10, 2013)



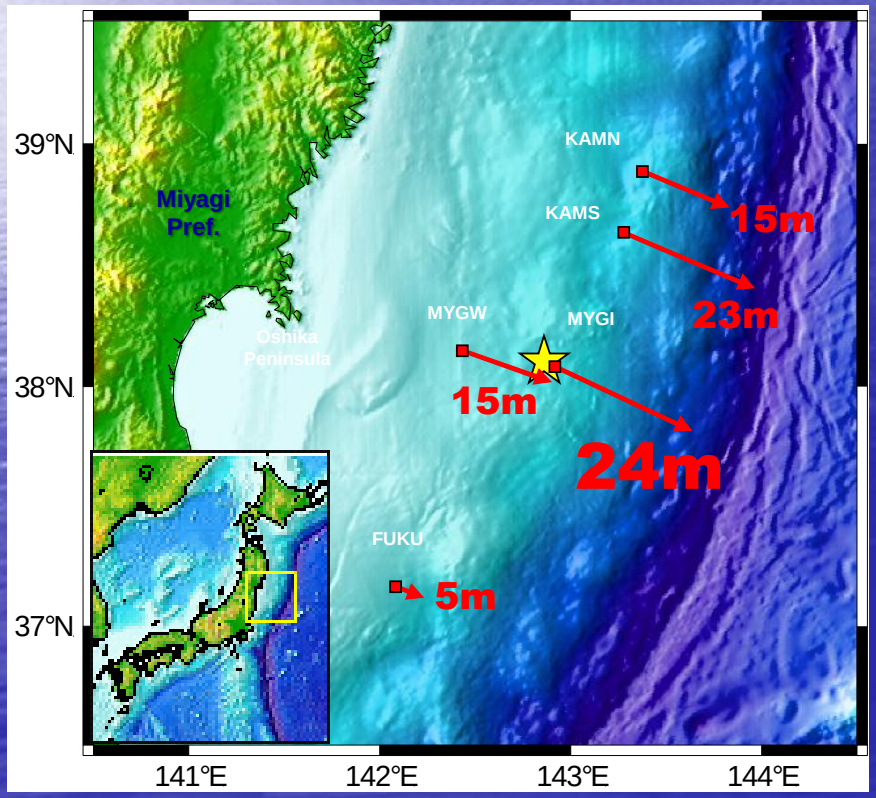
Tectonic Overview around Japan



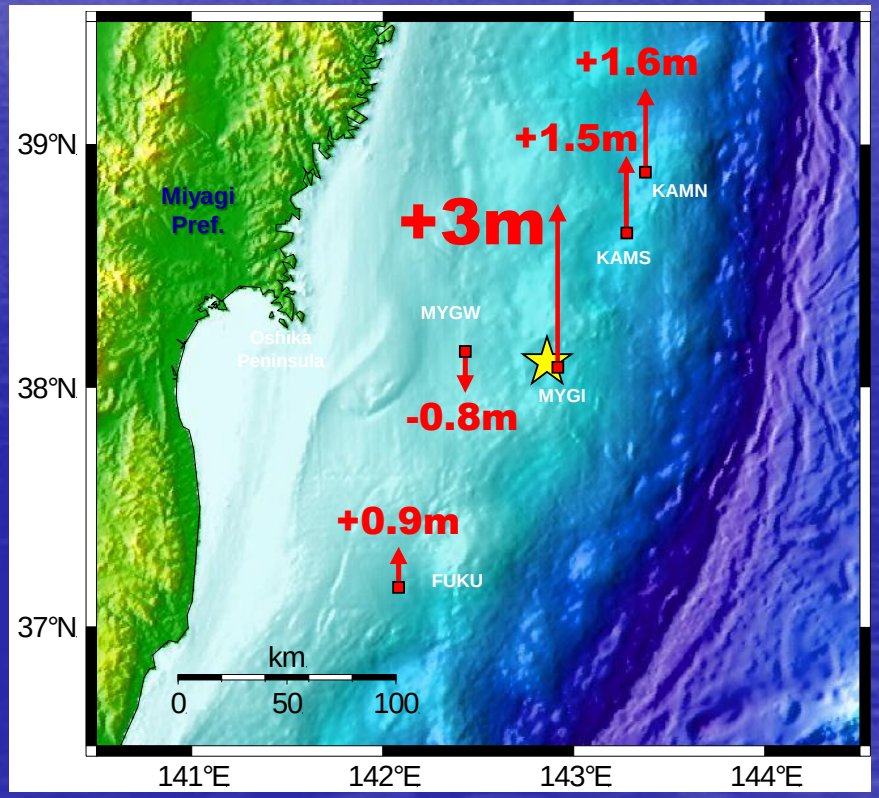
Seafloor Geodesy has found huge offshore displacements !!



Horizontal



Vertical



Sato et al. (2011) reported in Science Magazine

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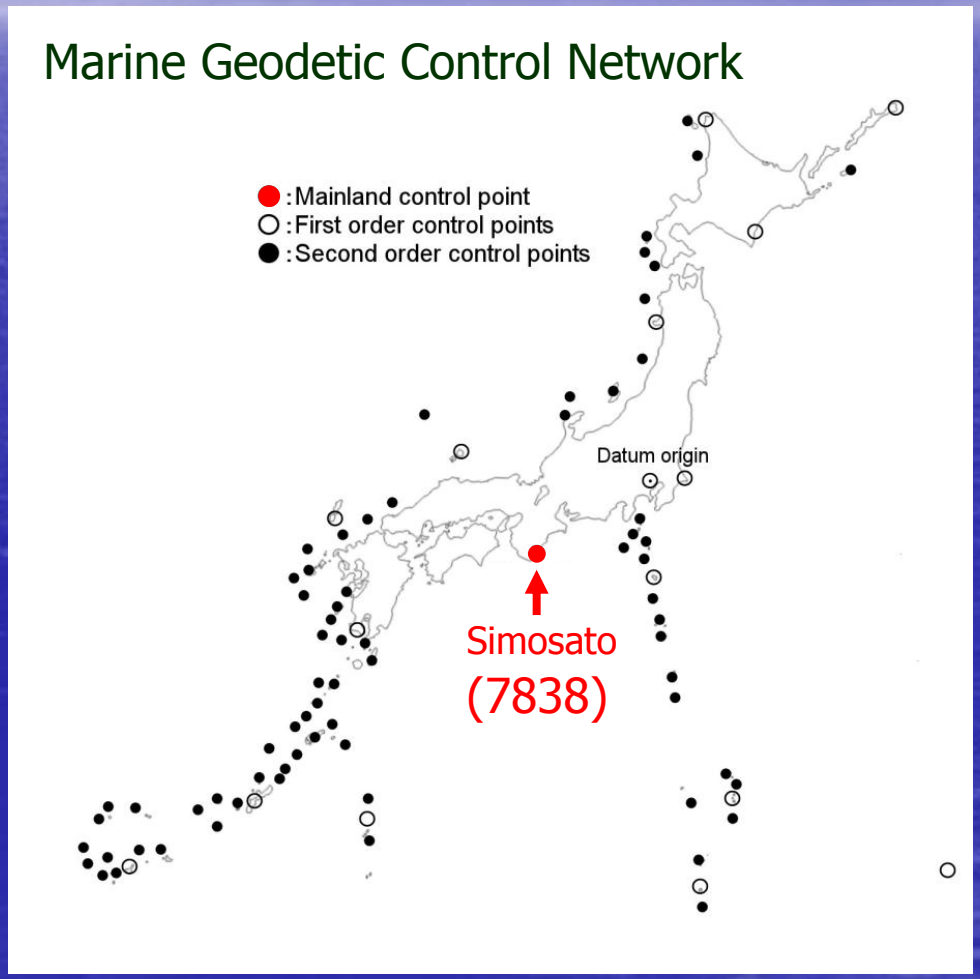
JCG operating SLR at Simosato

- **Operated more than 30 years since 1982**
- Core site of the Marine Geodetic Control project in Japan



Poster Presentation

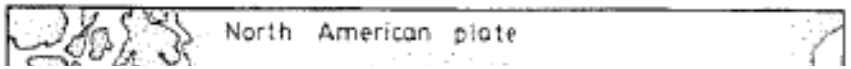
Po35: "Satellite Laser Ranging at Shimosato Hydrographic Observatory"

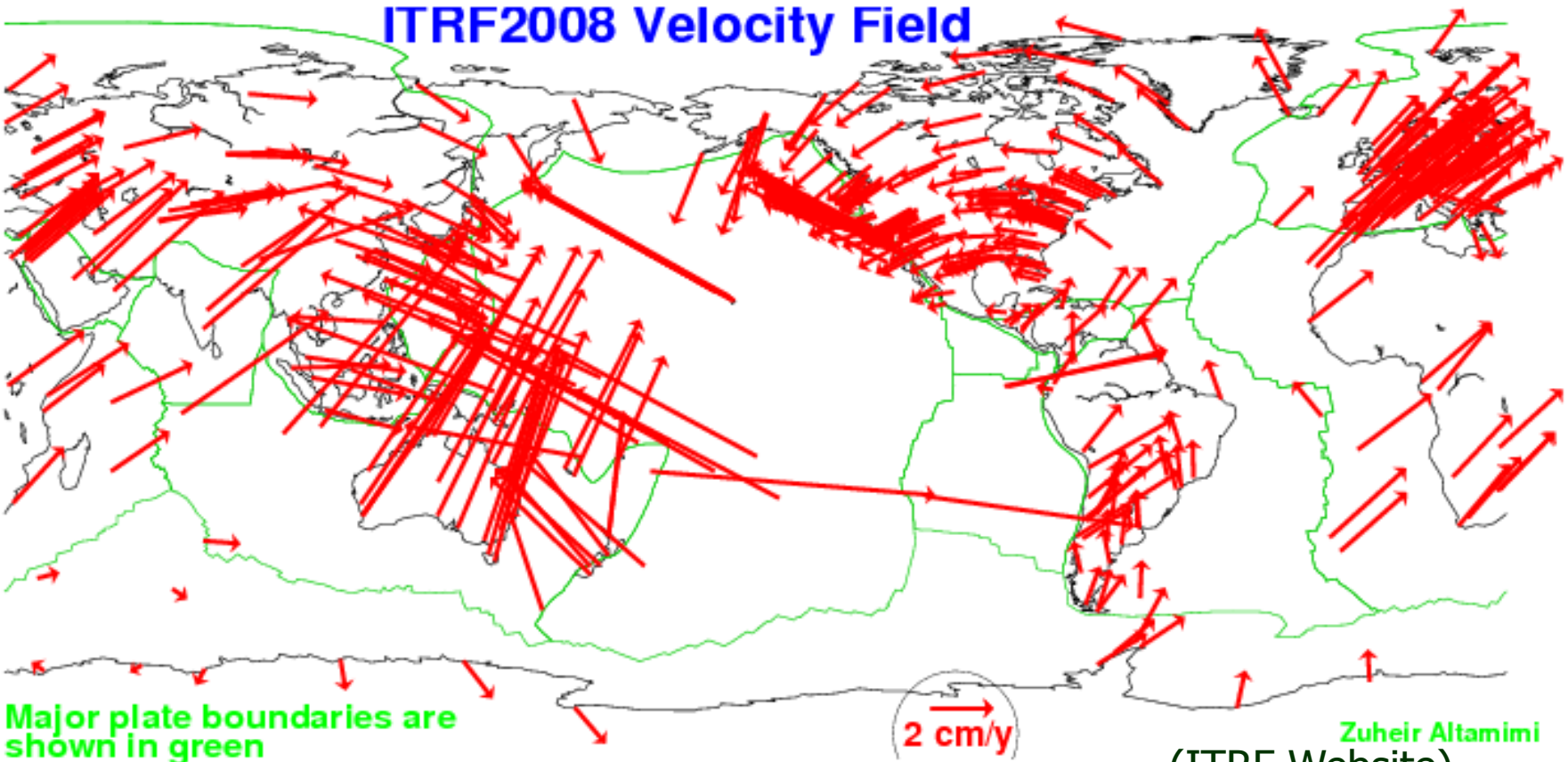
Role of Space Geodesy

for earthquake research

Geodesy

Early **VLBI** results by Heki et al. (1987)





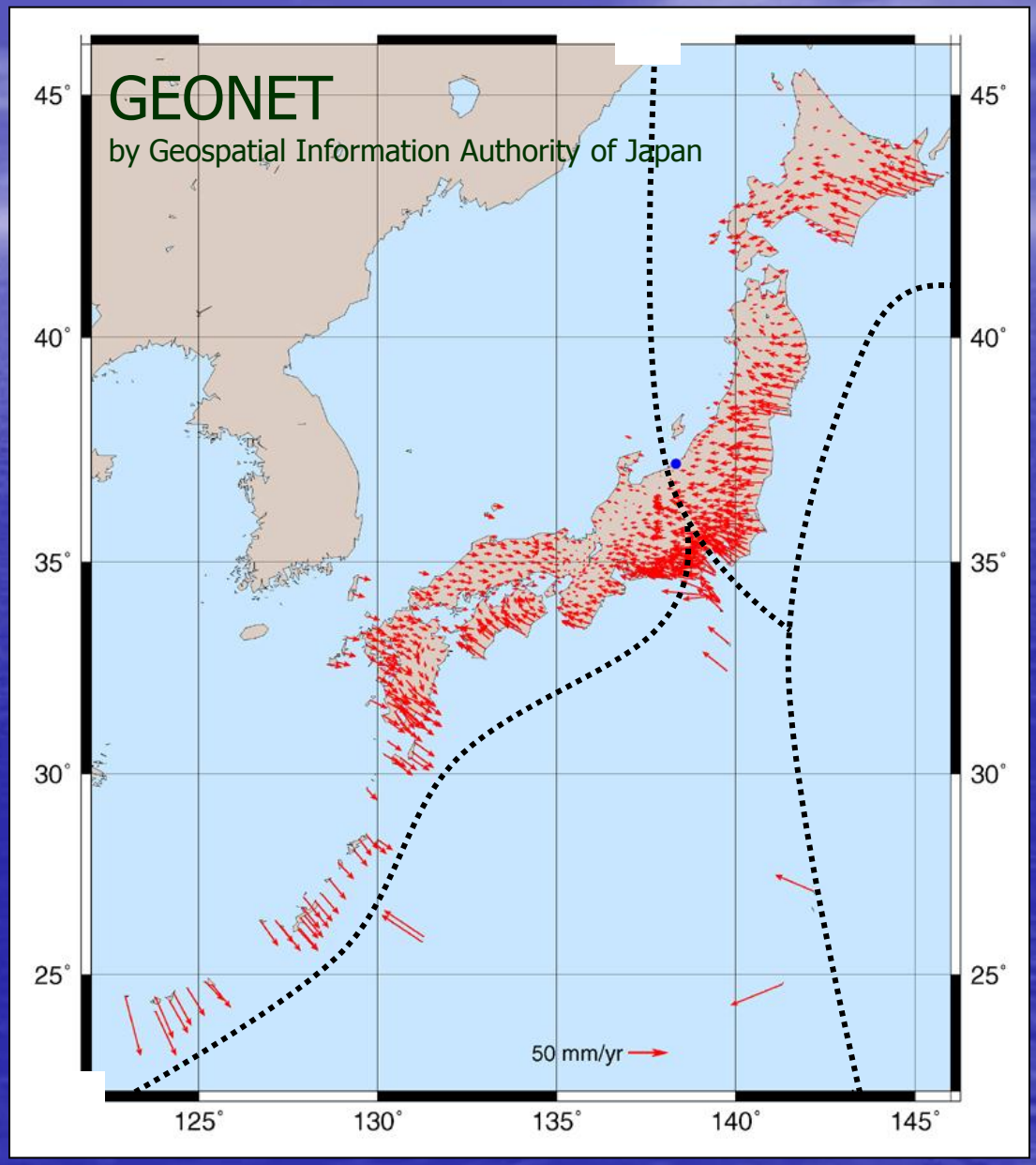
Role of Space Geodesy
for earthquake research

- Verifying and understanding plate tectonics
  - Measurement of present-day long-range movement
    ~Success in SLR & VLBI
- Monitoring crustal deformation
  - Real-time measurement
  - Contribution to modeling
    ~Development of high-density GPS network

Dense GPS network in Japan

- 1200 reference points
- Real time operation

Intraplate movement for interseismic period



(Modification to the figure produced by the Geodetic Society of Japan)

Role of Space Geodesy
for earthquake research

- Verifying and understanding plate tectonics
  - Measurement of present-day long-range movement
    ～Success in SLR & VLBI
- Monitoring crustal deformation
  - Real-time measurement
  - Contribution to modeling
    ～Development of high-density GPS network

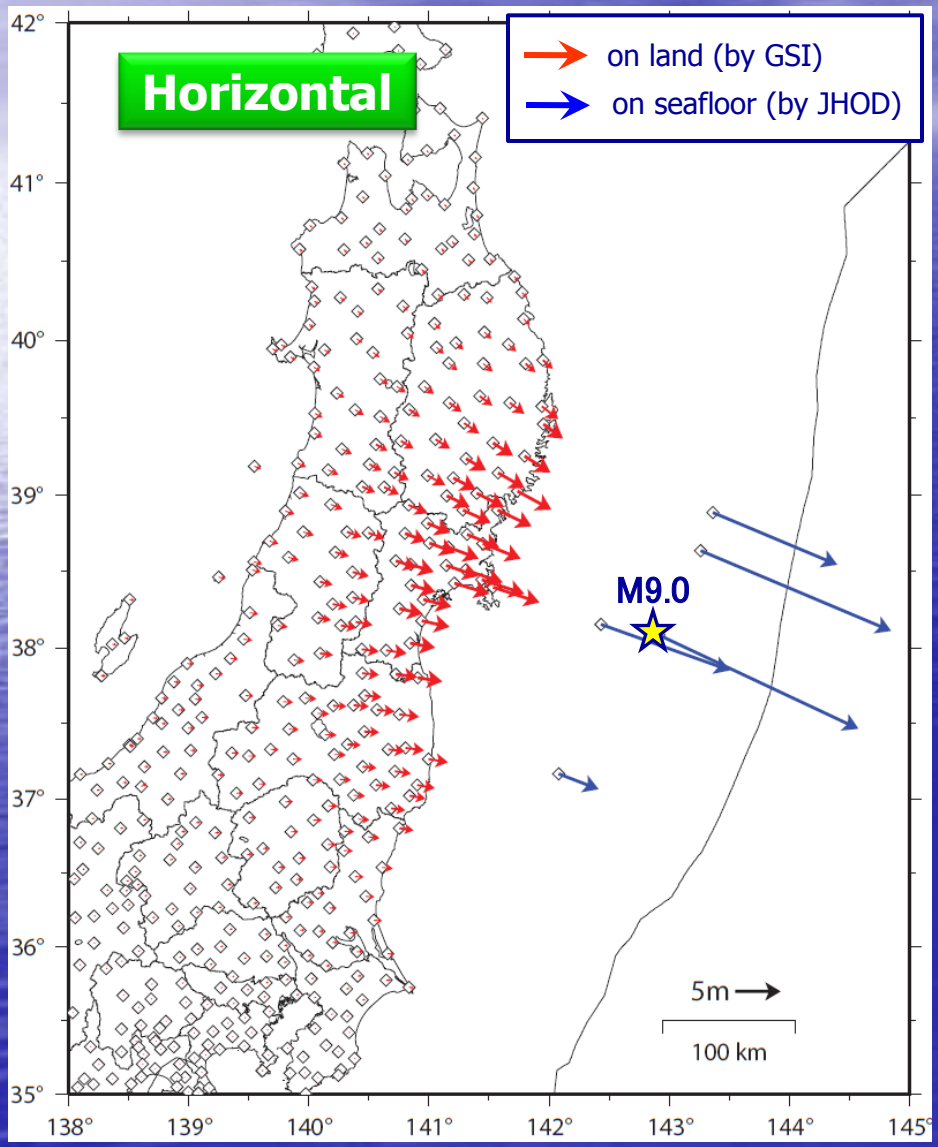
Seafloor Geodesy ～ Open a new window in this field

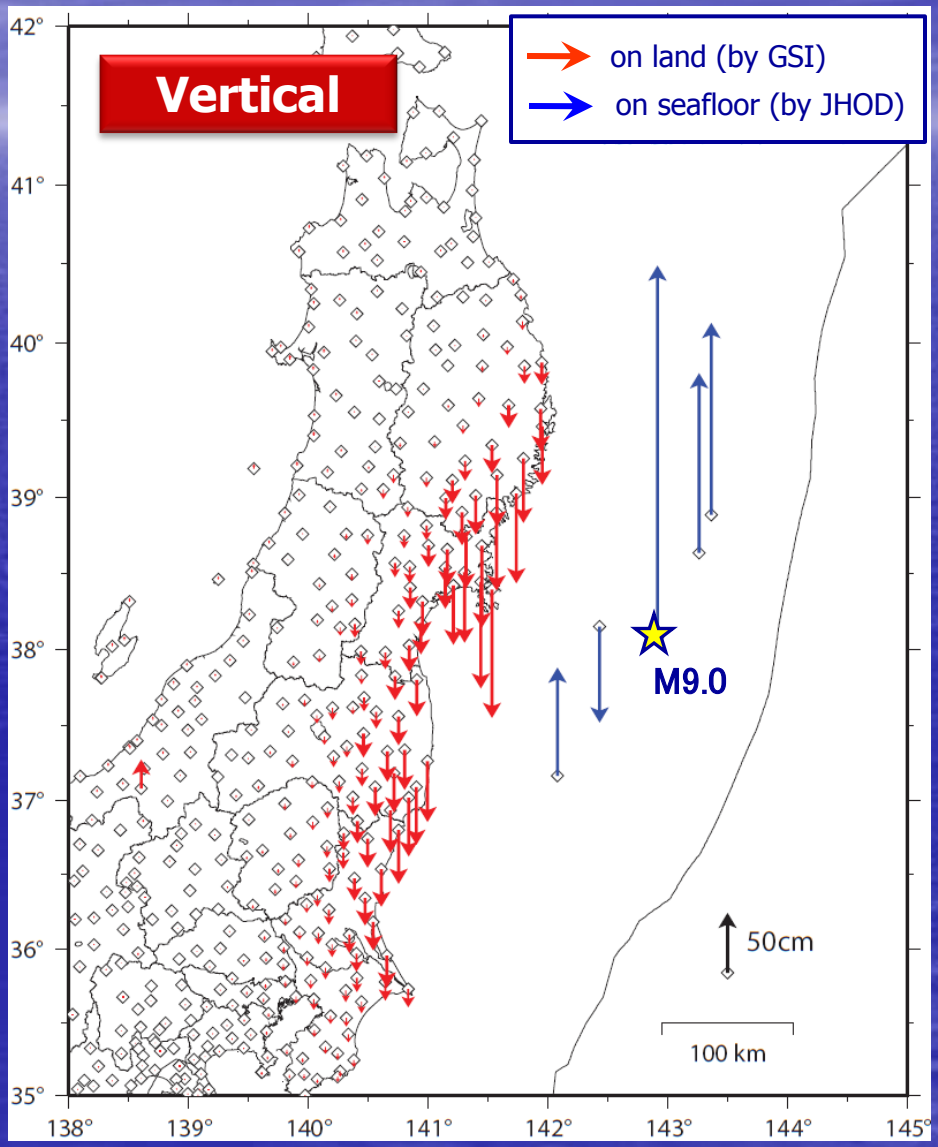
Seafloor Geodesy ~ Open a new window in this field

How it works?

In the coseismic case for the 2011 event (M9.0)

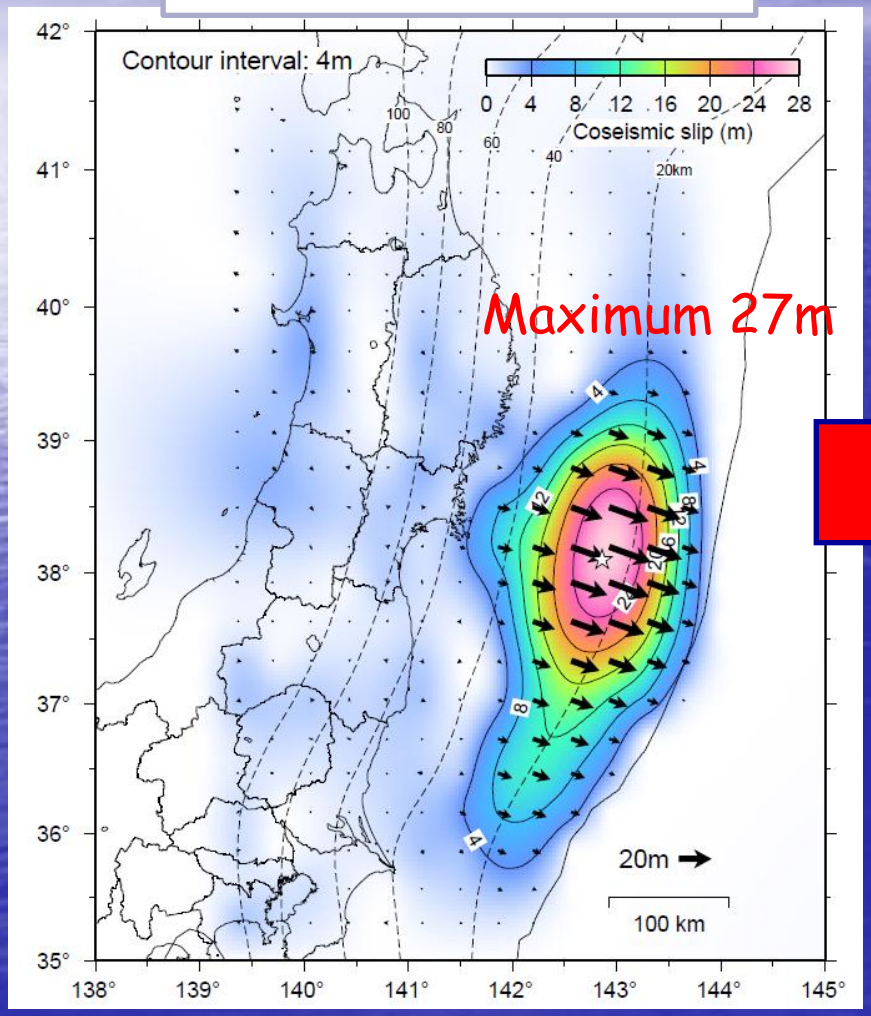
Coseismic movement (onland+seafloor)
associated with the 2011 event



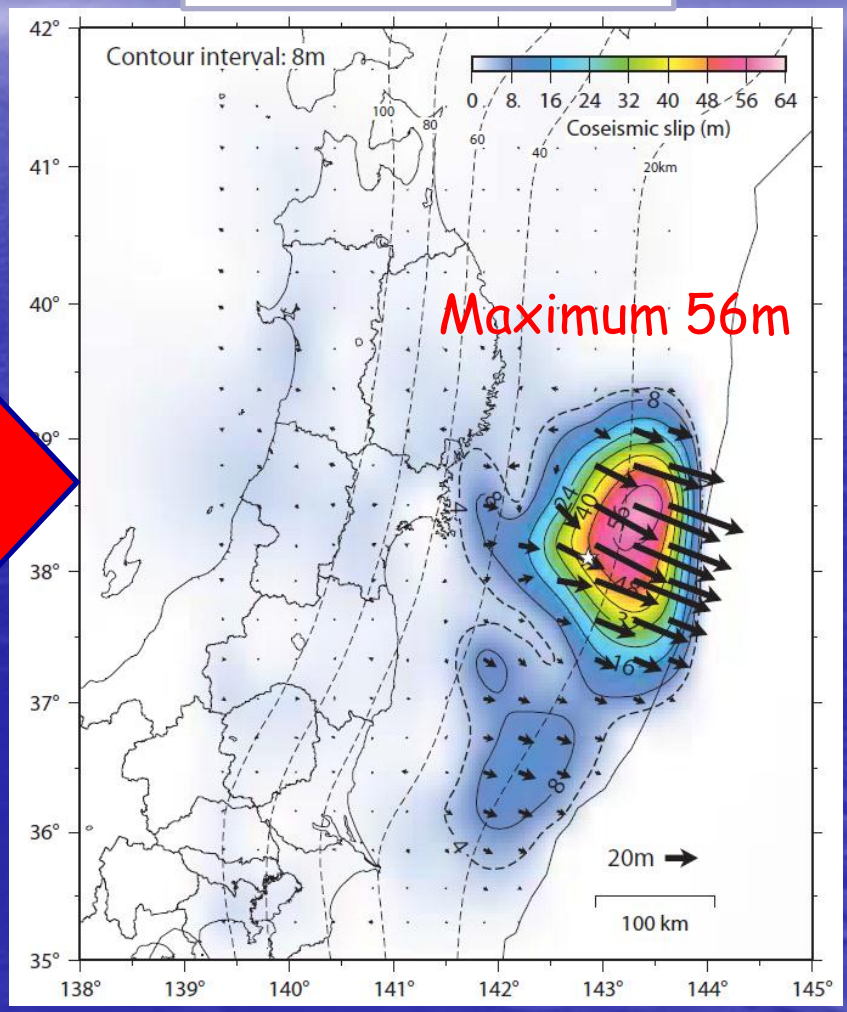


Slip distribution model
with and without seafloor data

Without Seafloor data

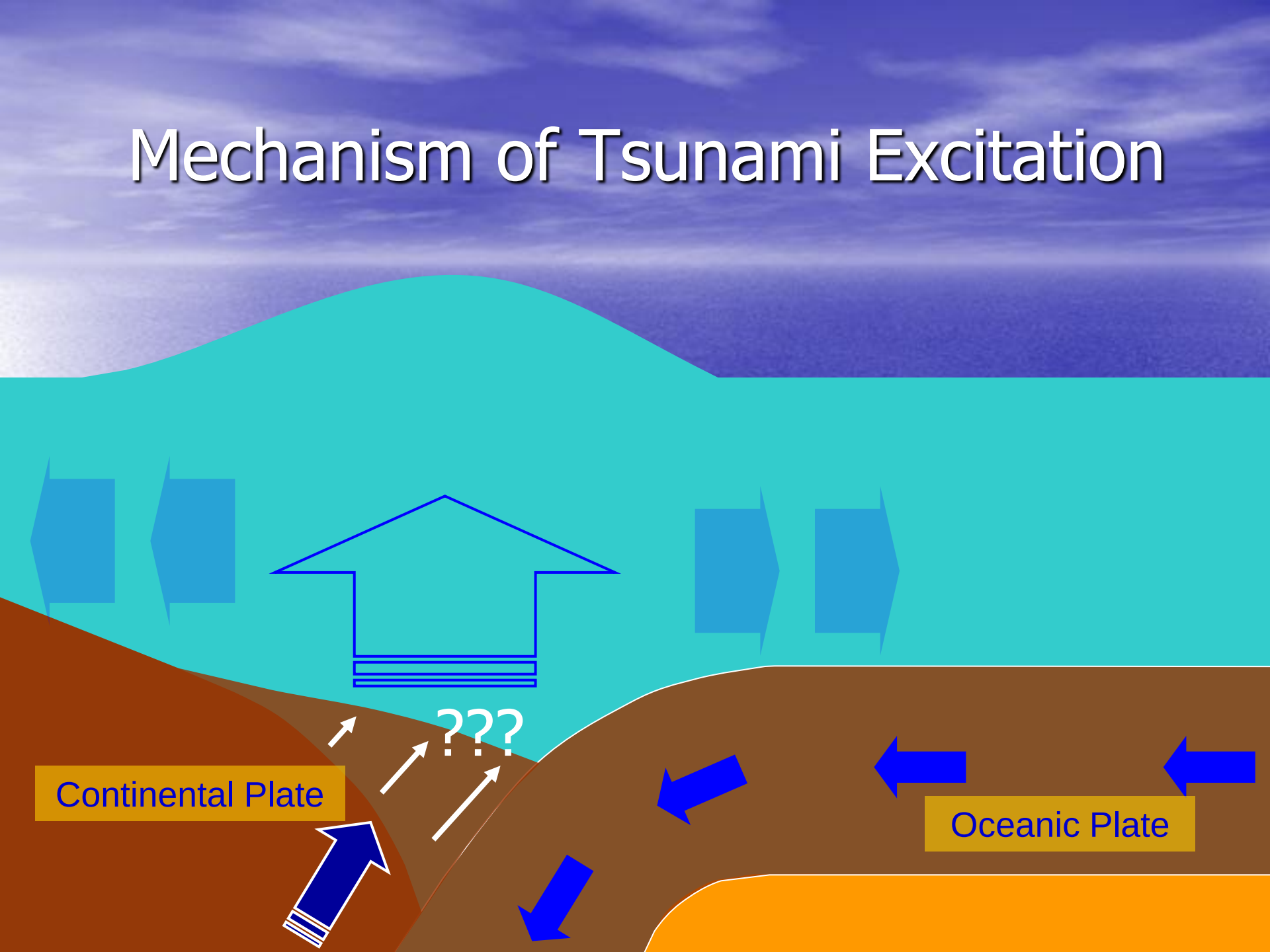


With seafloor data



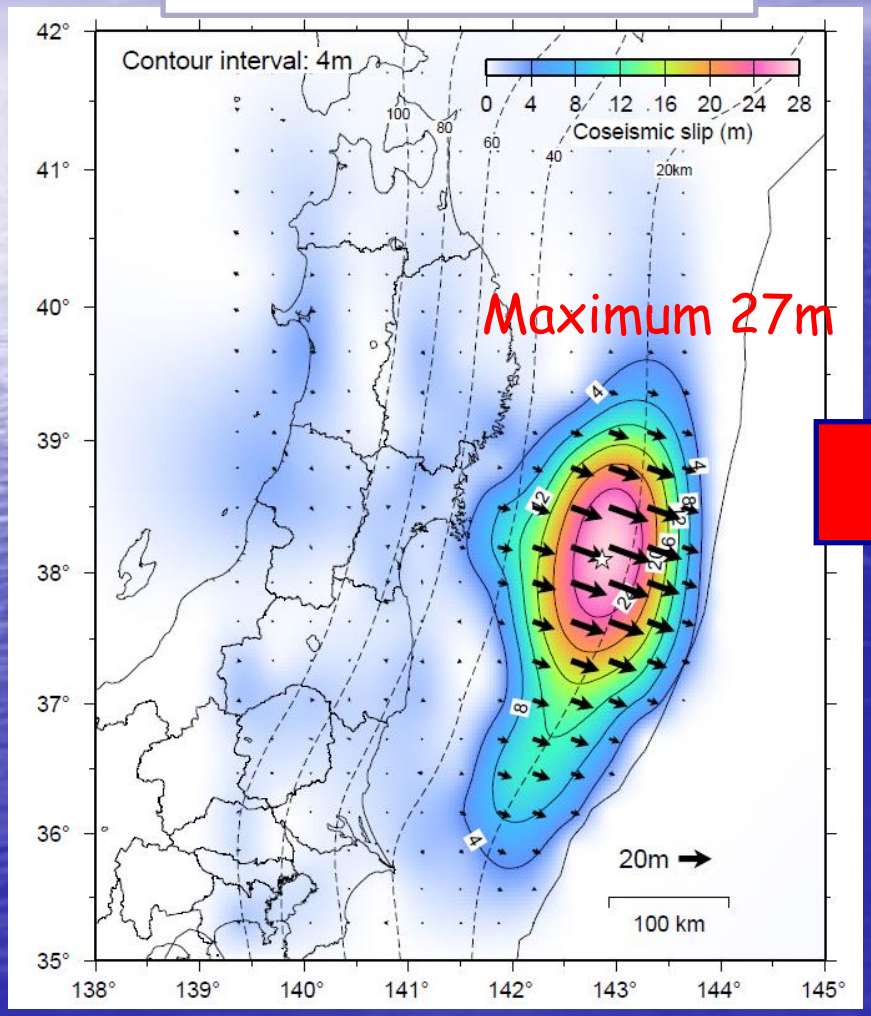
from GSI web page

Mechanism of Tsunami Excitation

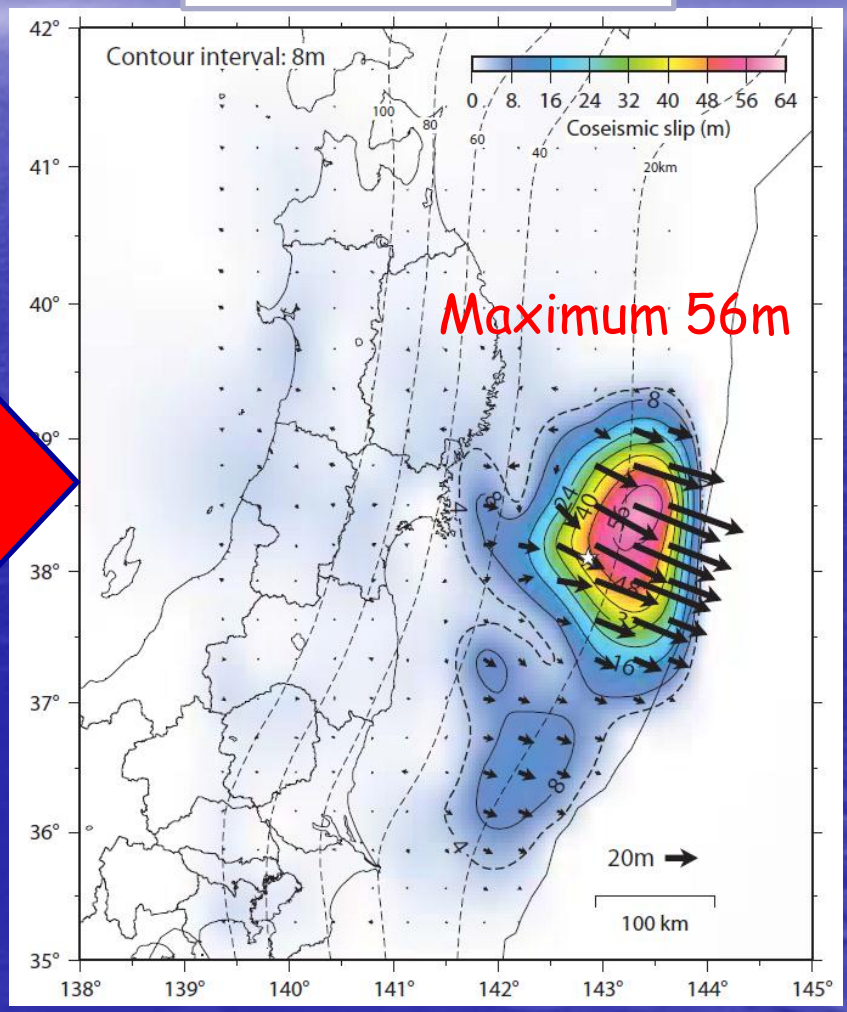


Slip distribution model
with and without seafloor data

Without Seafloor data



With seafloor data



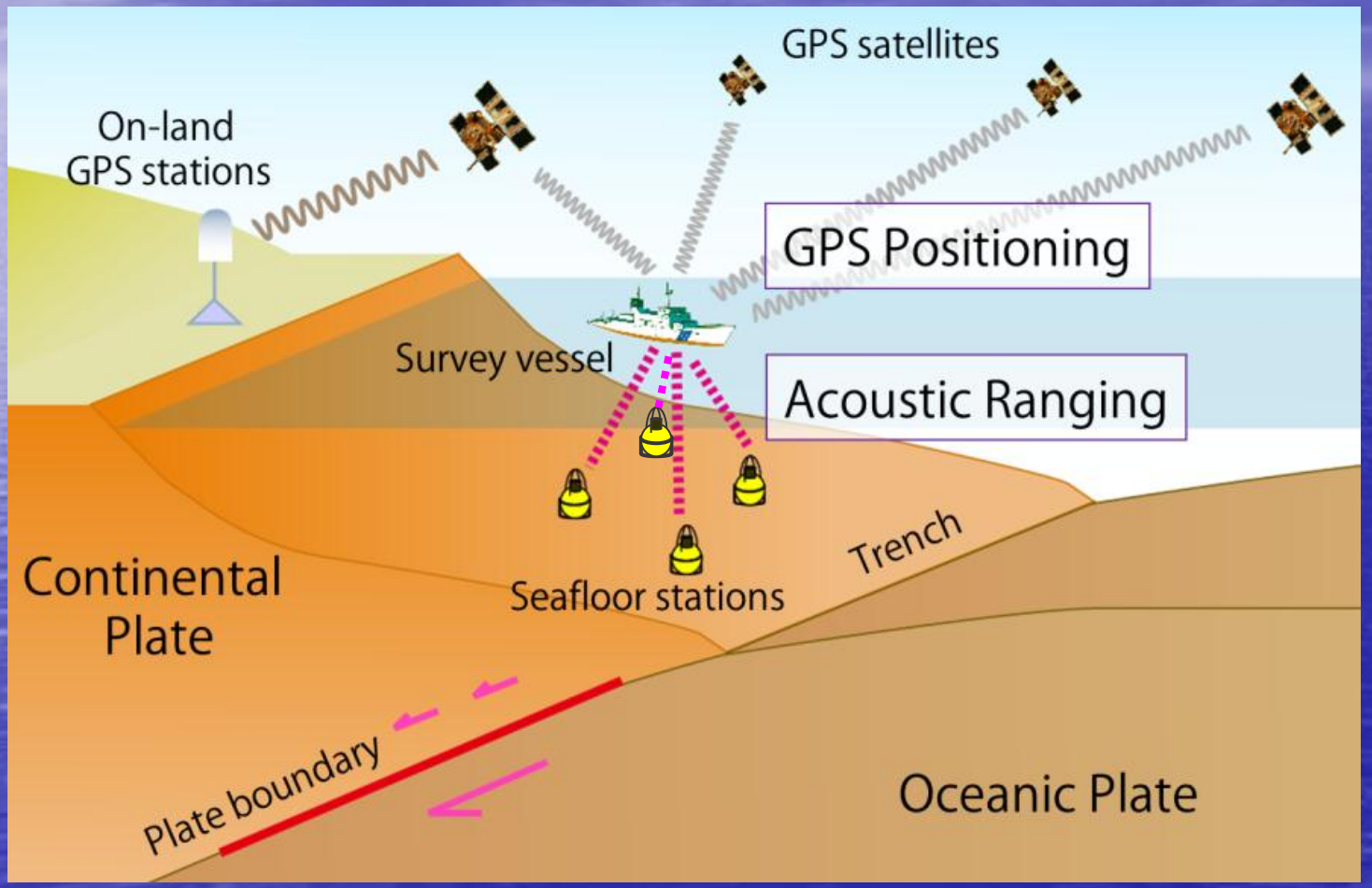
from GSI web page

Seafloor Geodesy

How & what to measure ?

General aspects

How to measure ?



GPS/Acoustic combination technique

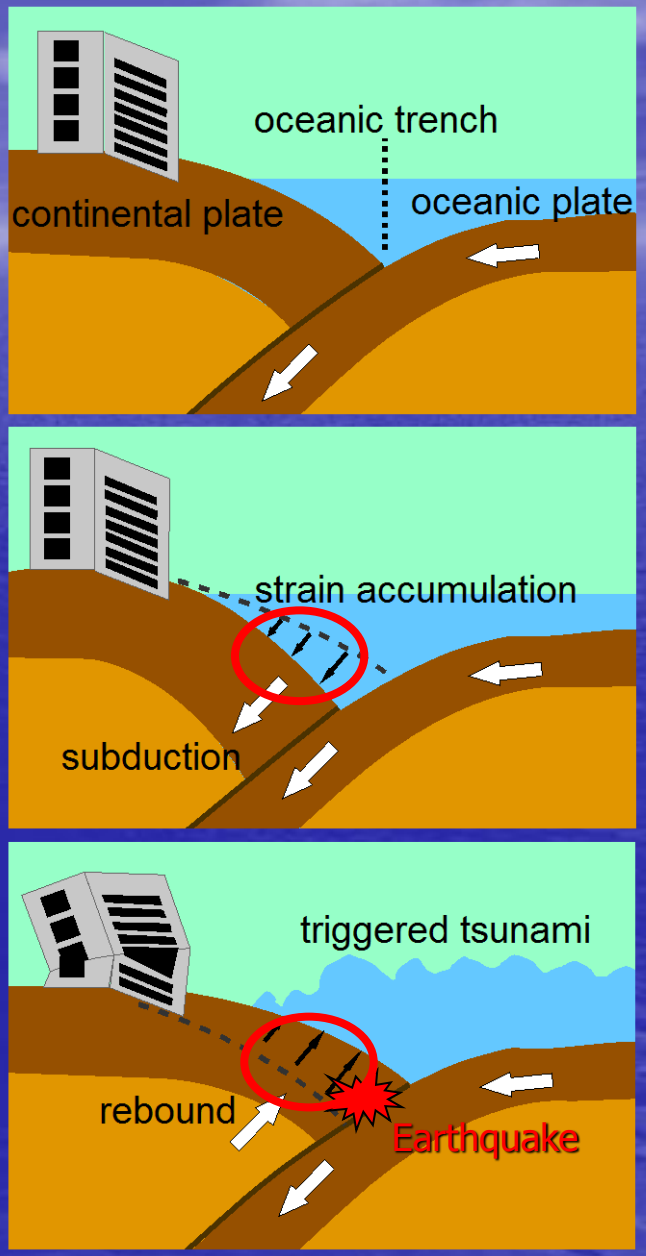
What is a target ?

Interseismic movement

at centimeters level !!

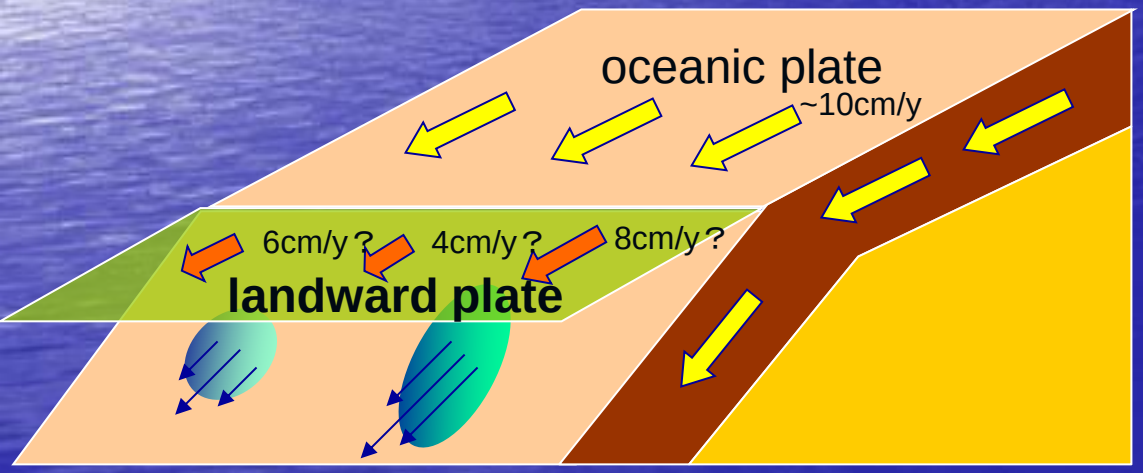
Coseismic movement

could be at meters level



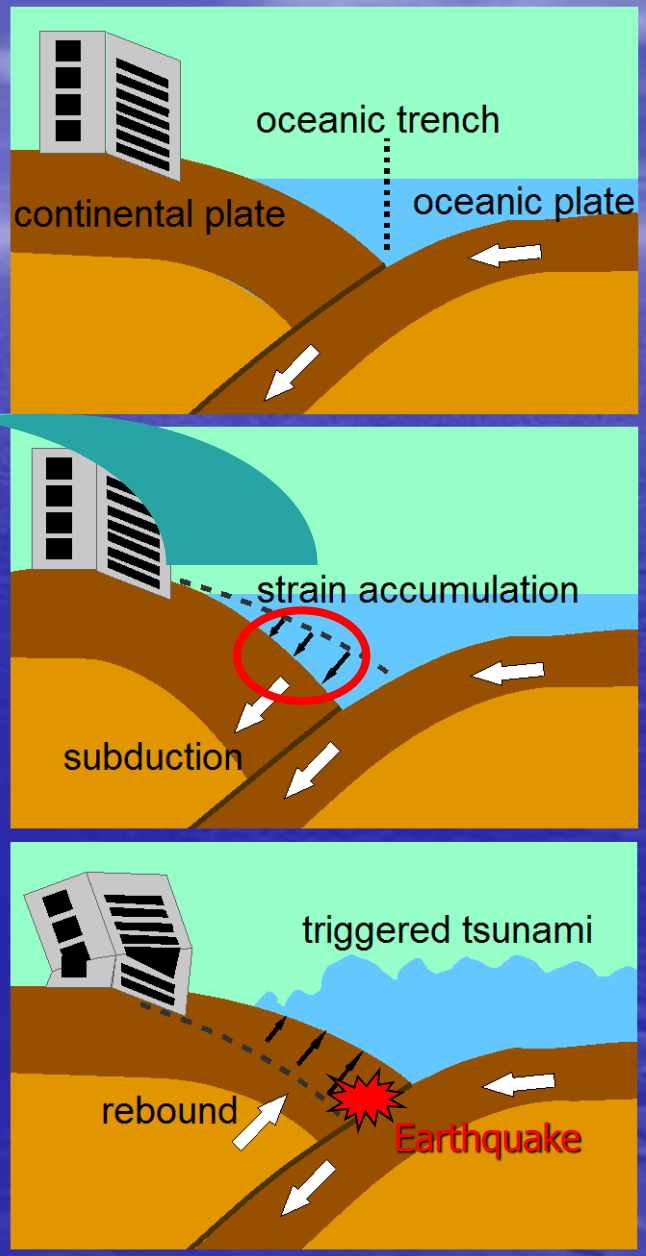
What is a target？

Seafloor movement
at centimeters level



coupled area (asperity)

where landward plate is dragged down together



Seafloor Geodesy

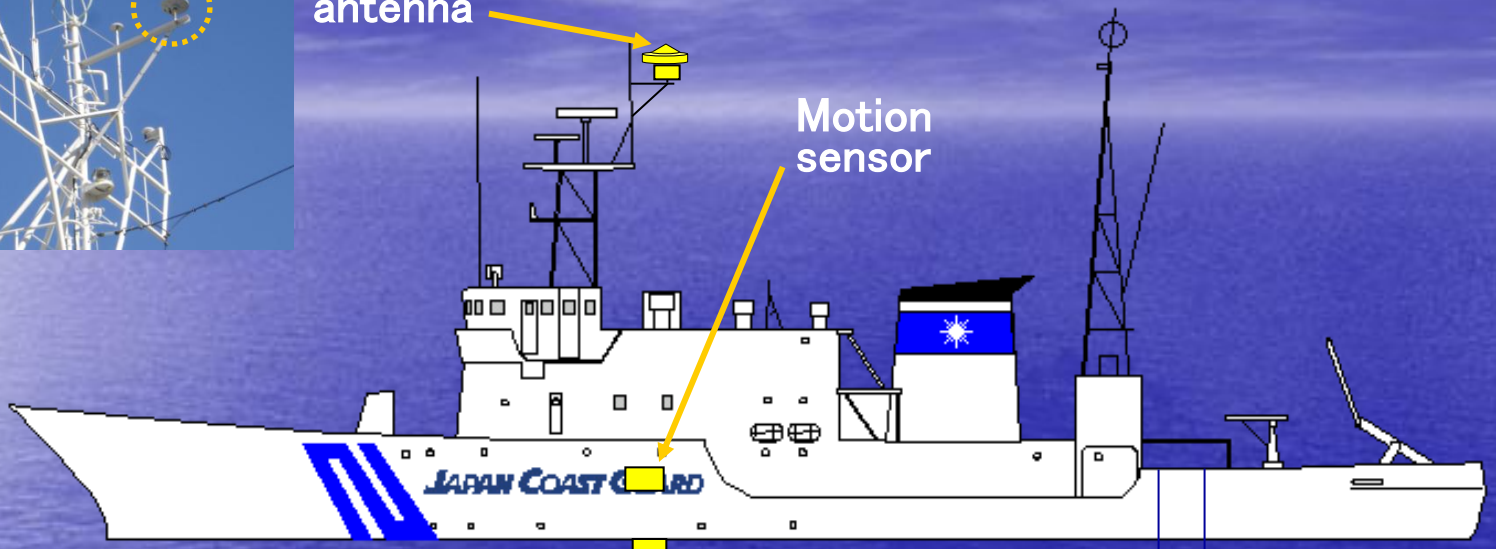
Observation by JCG

GPS/A Observation system with S/V

(Hull-mounted system)

GPS antenna

Motion sensor



Acoustic transducer

XBT
XCTD

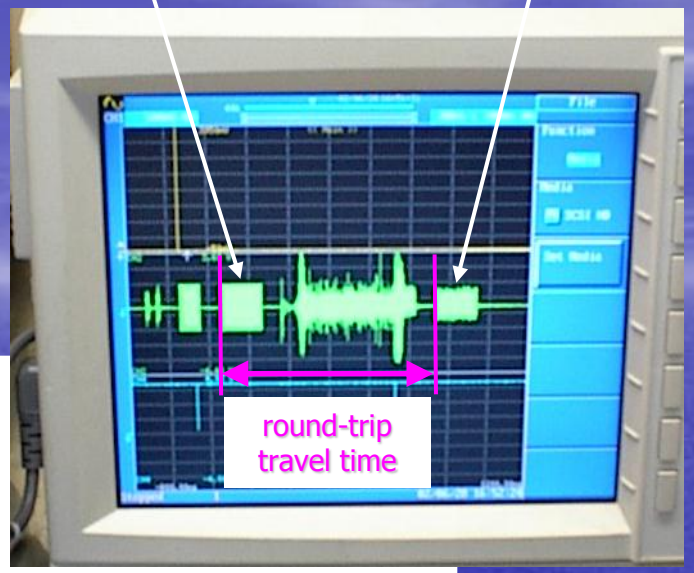
CTD

Seafloor

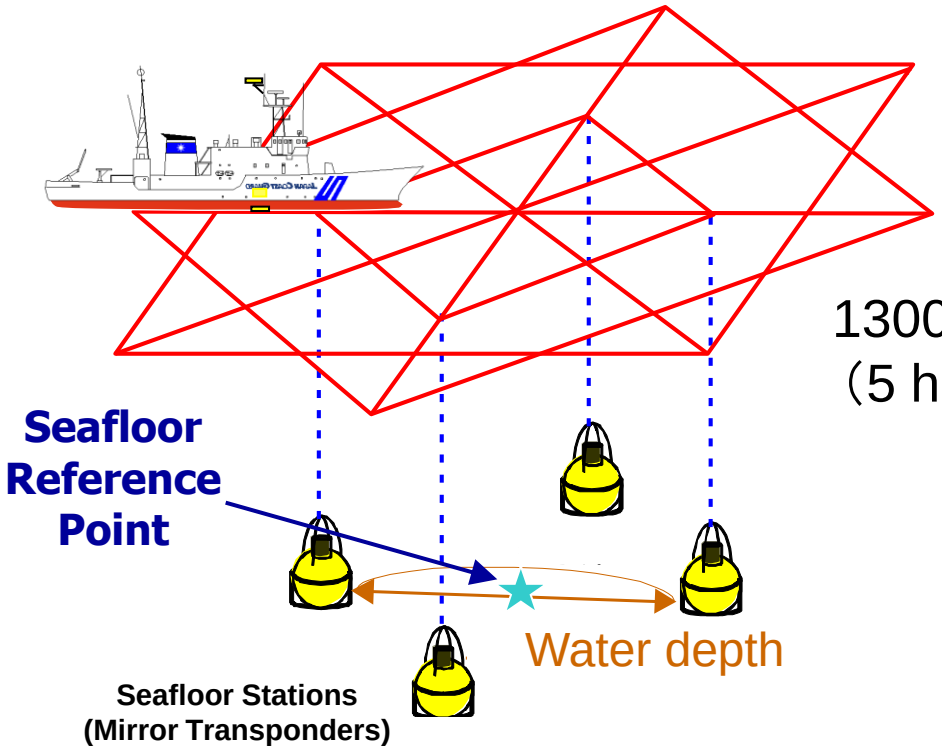
Seafloor stations
(Mirror-type transponders)

Photo by JAMSTEC

Onsite operation



The vessel runs at a speed of 5-8 knots.



1300shots
（5 hours）

×4 times

Ranging data of about 5200 shots

Seafloor Geodesy

Data analysis

Flow of data analysis

(1) Acoustic wave analysis

Acoustic Wave Data

Round-trip travel time b/w vessel and transponder

(3) Underwater positioning

Sound Speed Data

GPS Data

(2) Kinematic GPS analysis

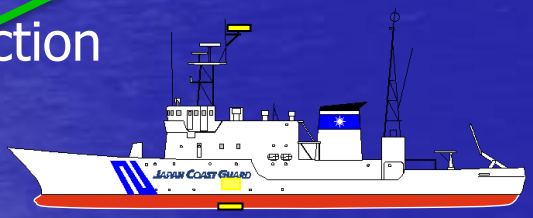
Antenna position

Transducer position

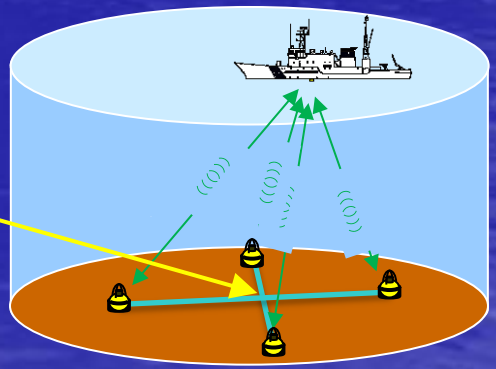
Seafloor station position

Correction

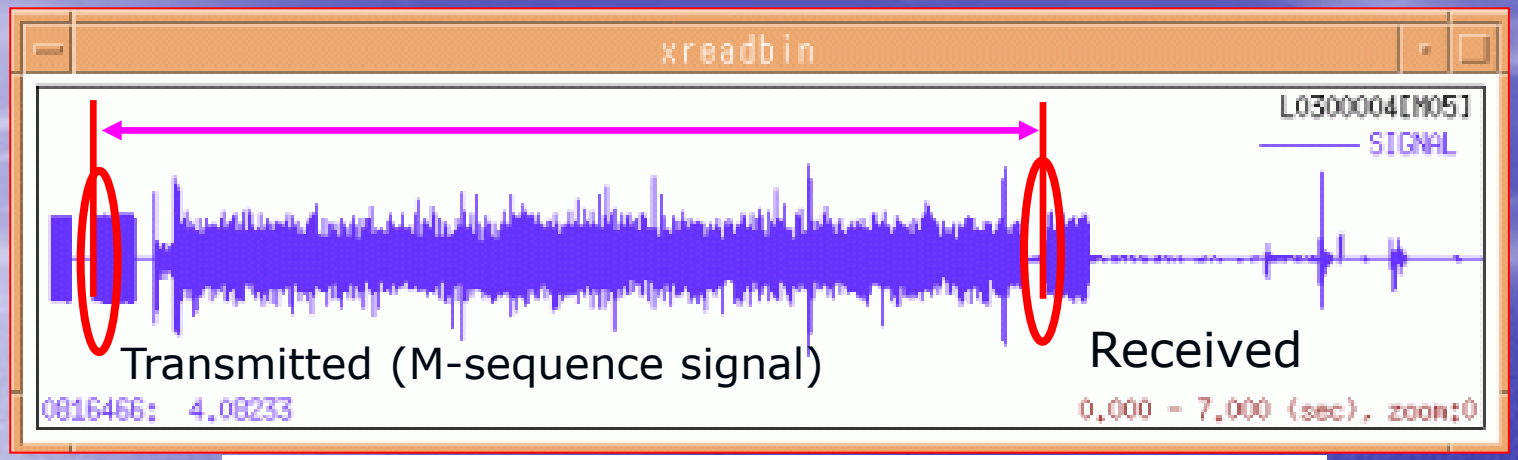
Attitude Data

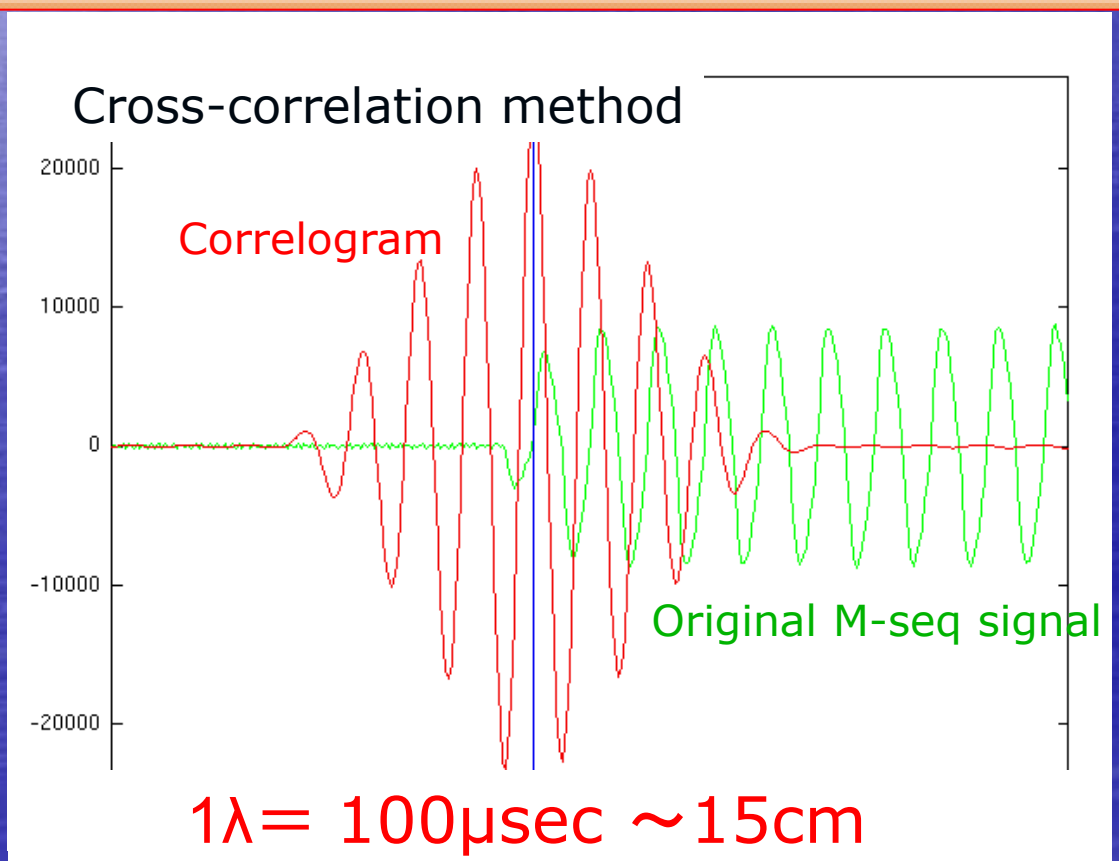


Seafloor Reference Point



(1) Acoustic wave analysis





Flow of data analysis

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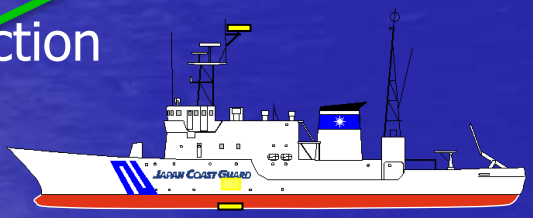
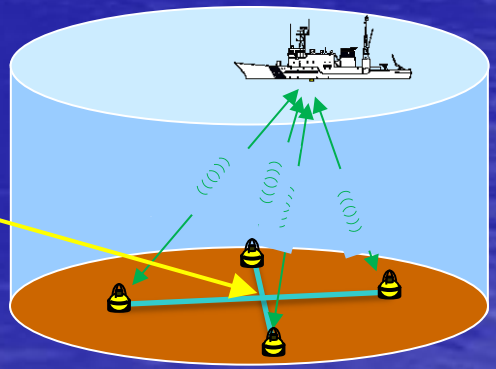
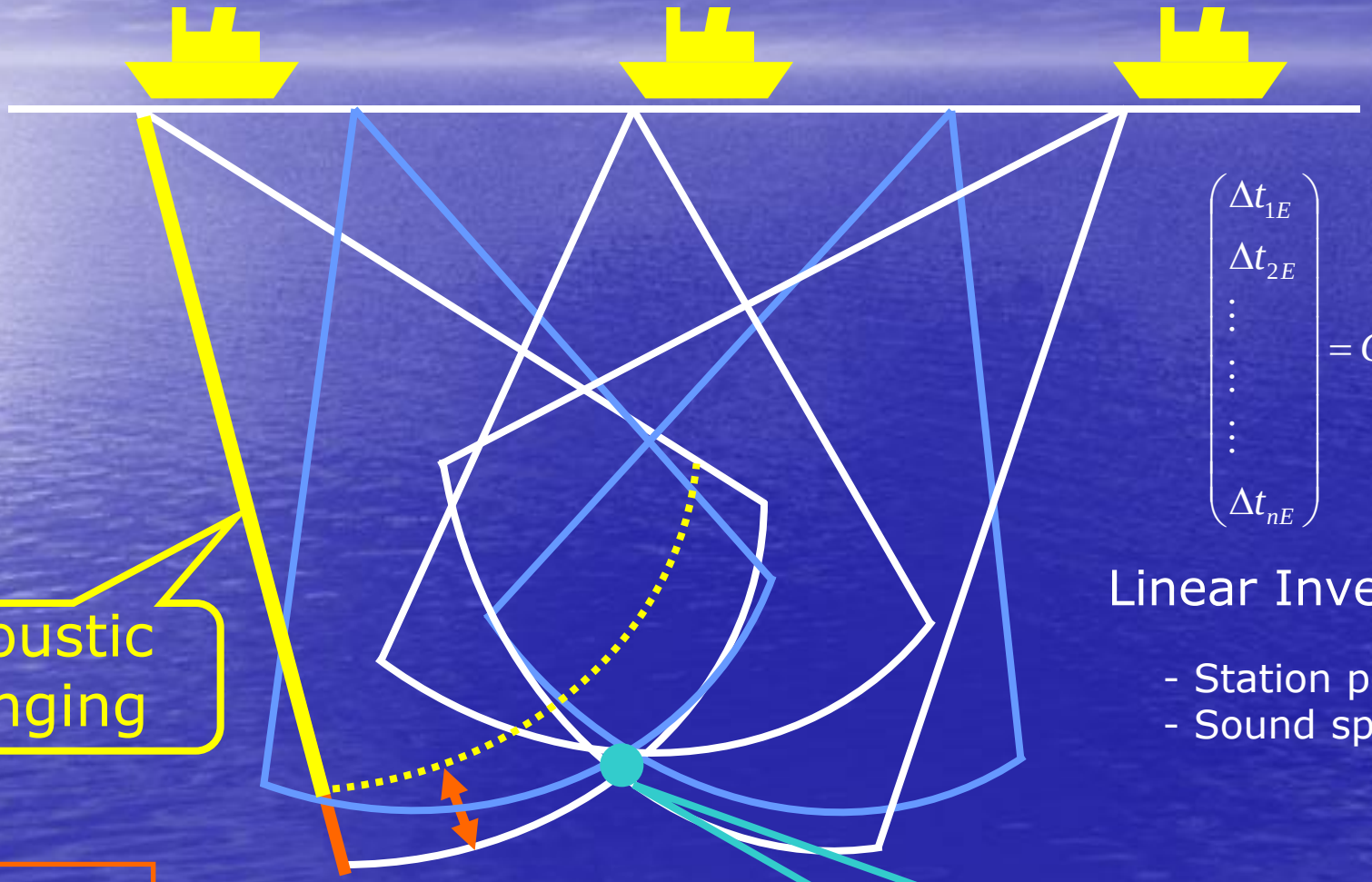


Seafloor Reference Point



(3) Underwater positioning



$$\begin{pmatrix} \Delta t_{1E} \\ \Delta t_{2E} \\ \vdots \\ \Delta t_{nE} \end{pmatrix} = G_E \cdot \begin{pmatrix} \Delta x_E \\ \Delta y_E \\ \Delta z_E \end{pmatrix}$$

Linear Inversion

- Station position
- Sound speed

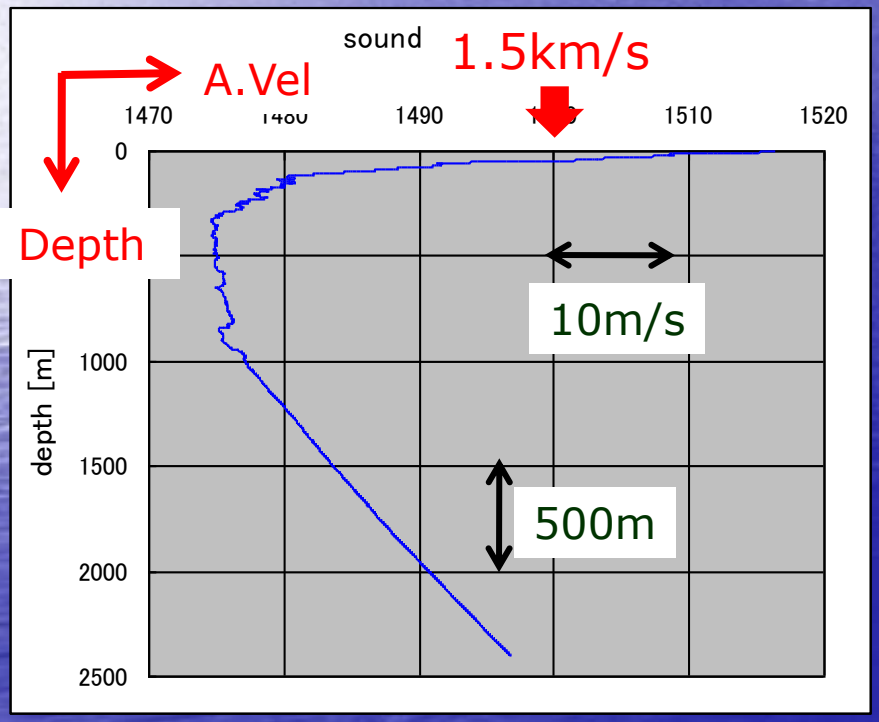
Acoustic Ranging

Sound speed error → Ranging error

Seafloor station

Major error source

- Errors included in the sound speed



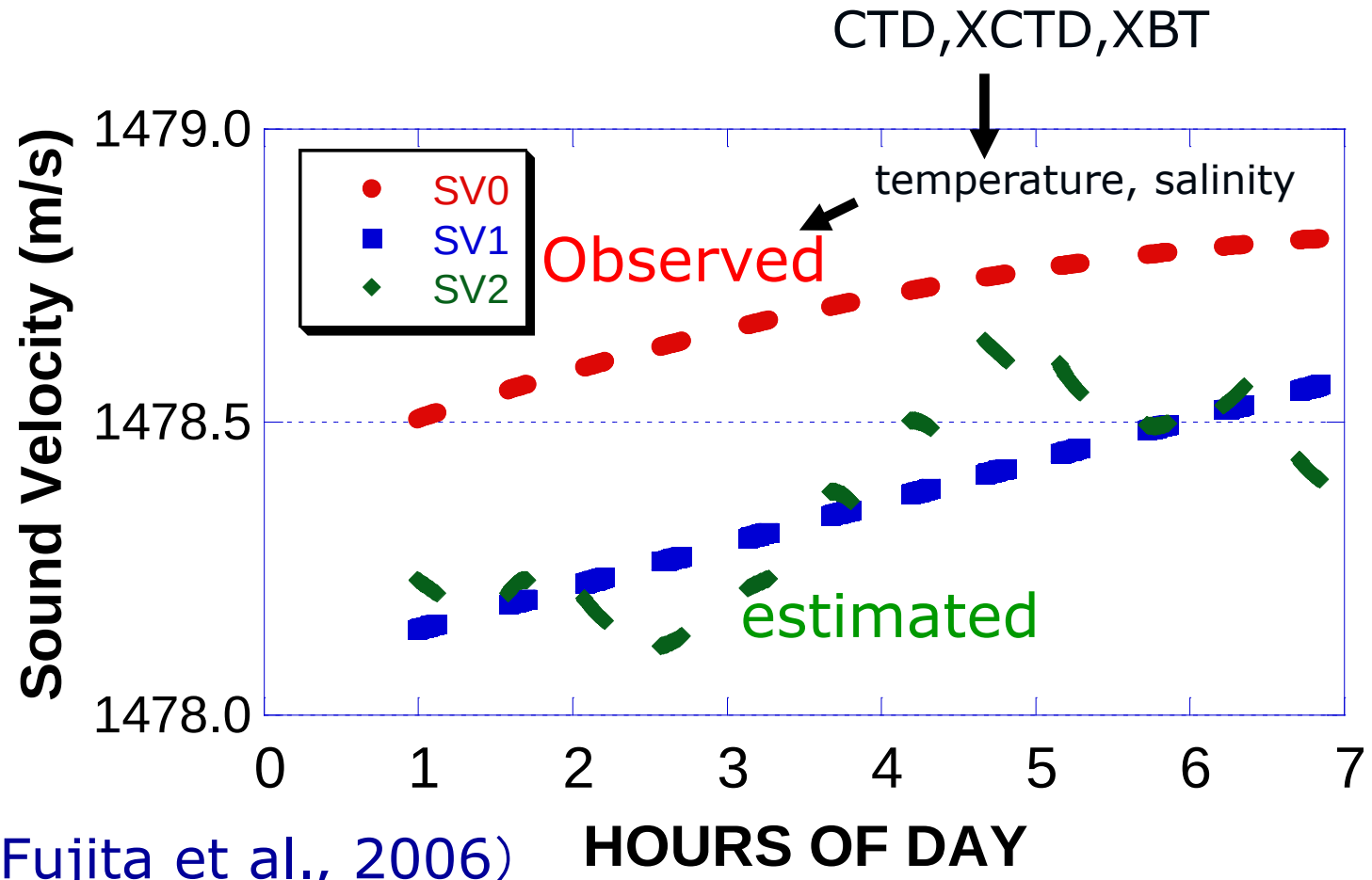
- Sound speed in water ～1.5km/s
- Temporal & Spatial variation
- 0.1% ～ 15cm/s

  → D=2000m ～20cm difference

Error reduction through estimation of sound speed

Sound speed estimation

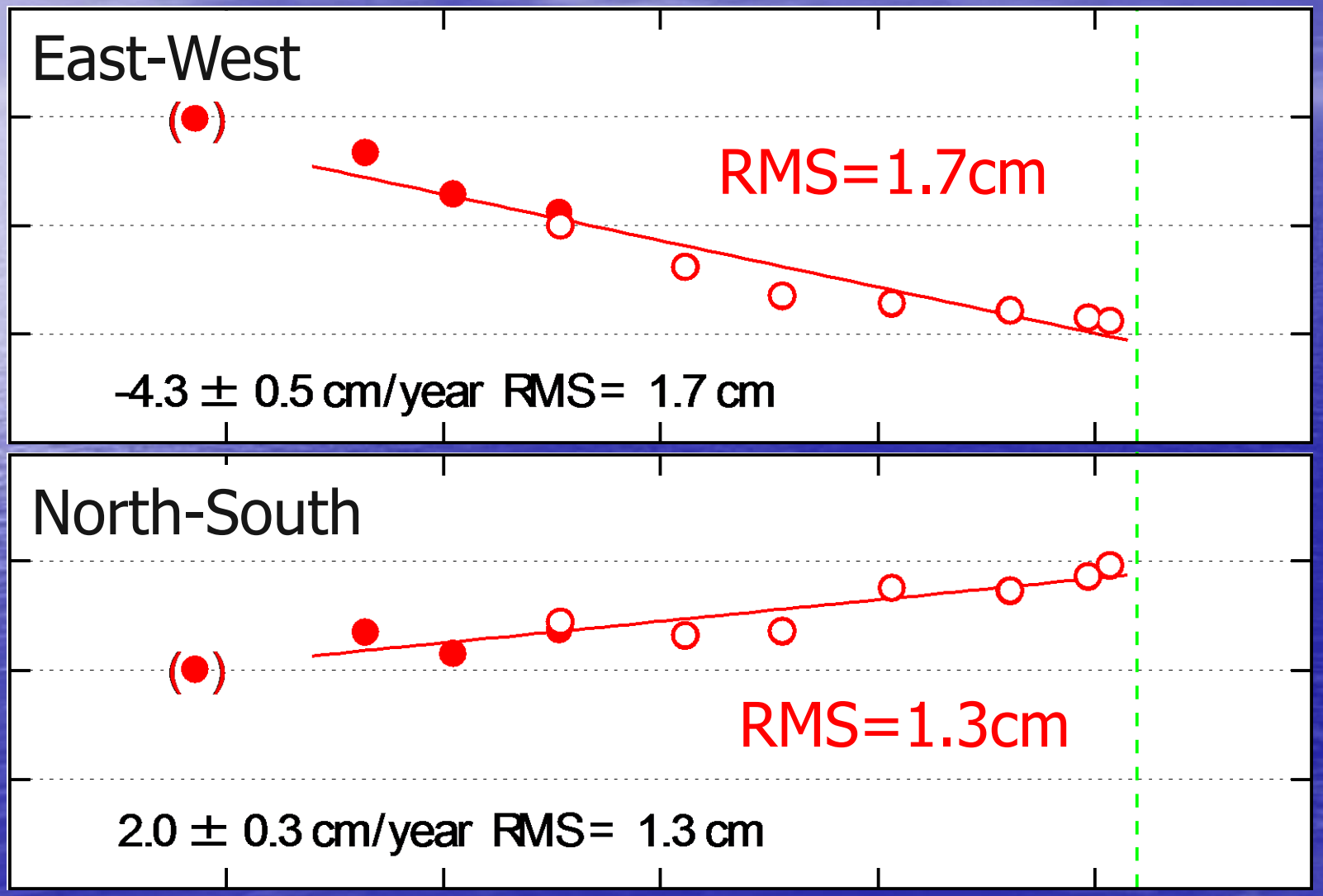
Estimation condition
- horizontally layered
- 2nd polynomial approximation in time



(Fujita et al., 2006)

Precision of seafloor positioning

～Example of time series at TOKW～



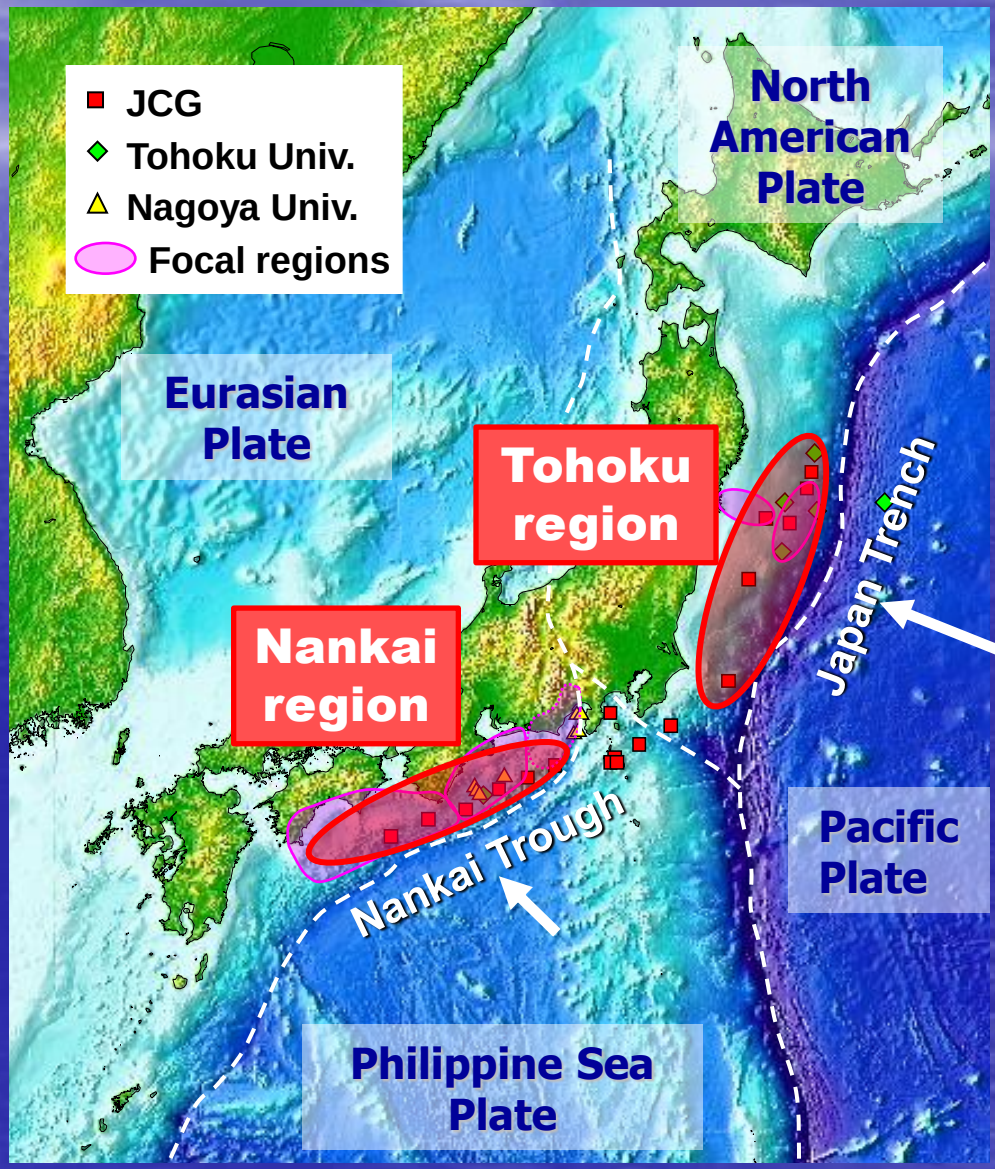
Seafloor Geodesy

Major Results

for the interseismic period

Distribution of Seafloor Reference Points
(before the 2011 Great East Japan Earthquake)

- Landward slope of the Major trench
  - **Japan Coast Guard：18 about 100km interval**
  - Tohoku Univ. : 6 mainly off Miyagi Pref.
  - Nagoya Univ. : 8 Suruga bay, Kumano basin
- Water depth mostly **1500 - 2500m (JCG)**



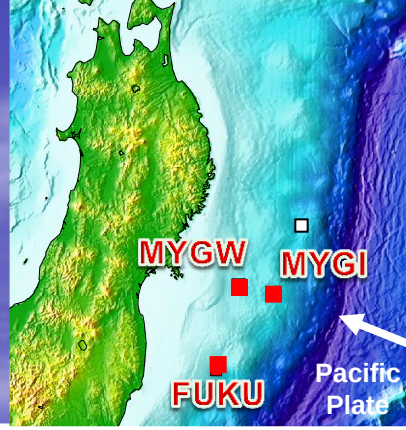
Seafloor Geodesy ~ Major Results

Tohoku region

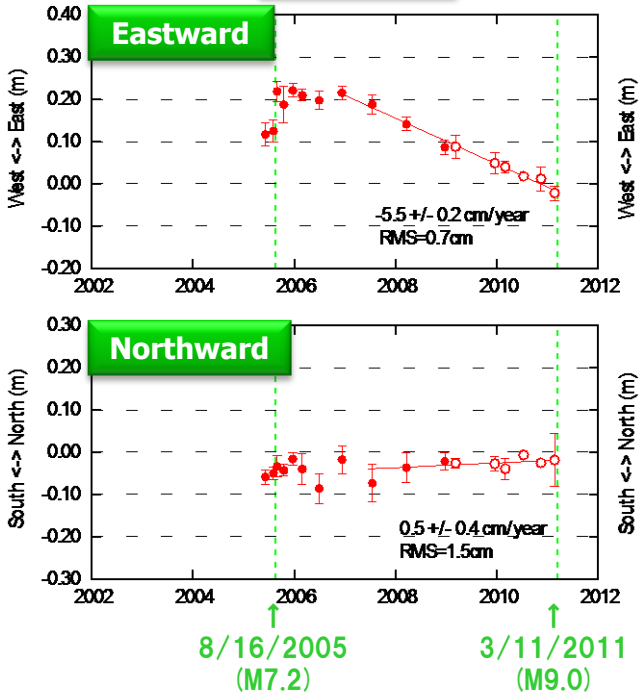
where the huge earthquake has just occurred

Time series of the estimated positions

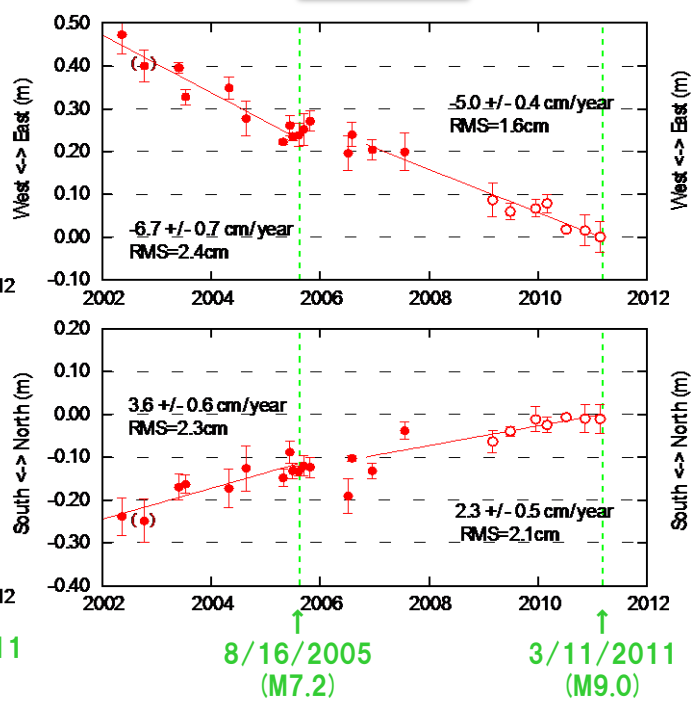
before the 2011 earthquake (2002-2011.2, vs EU)



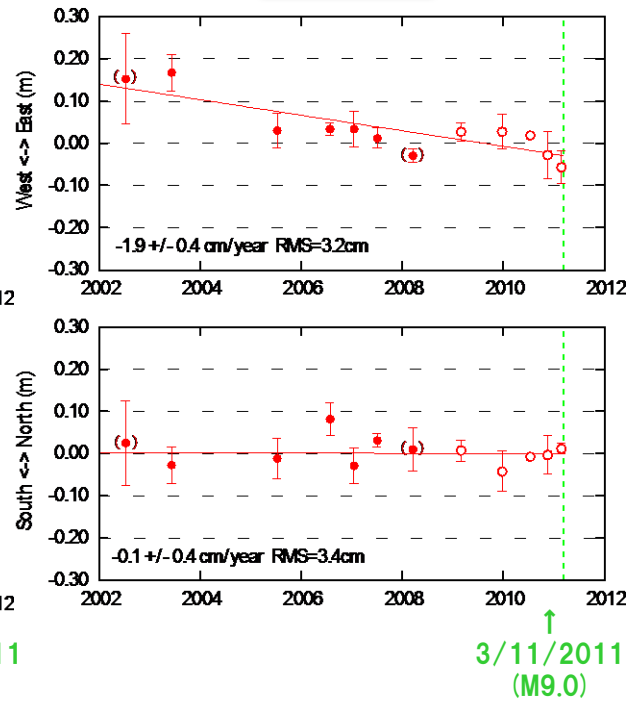
MYGW



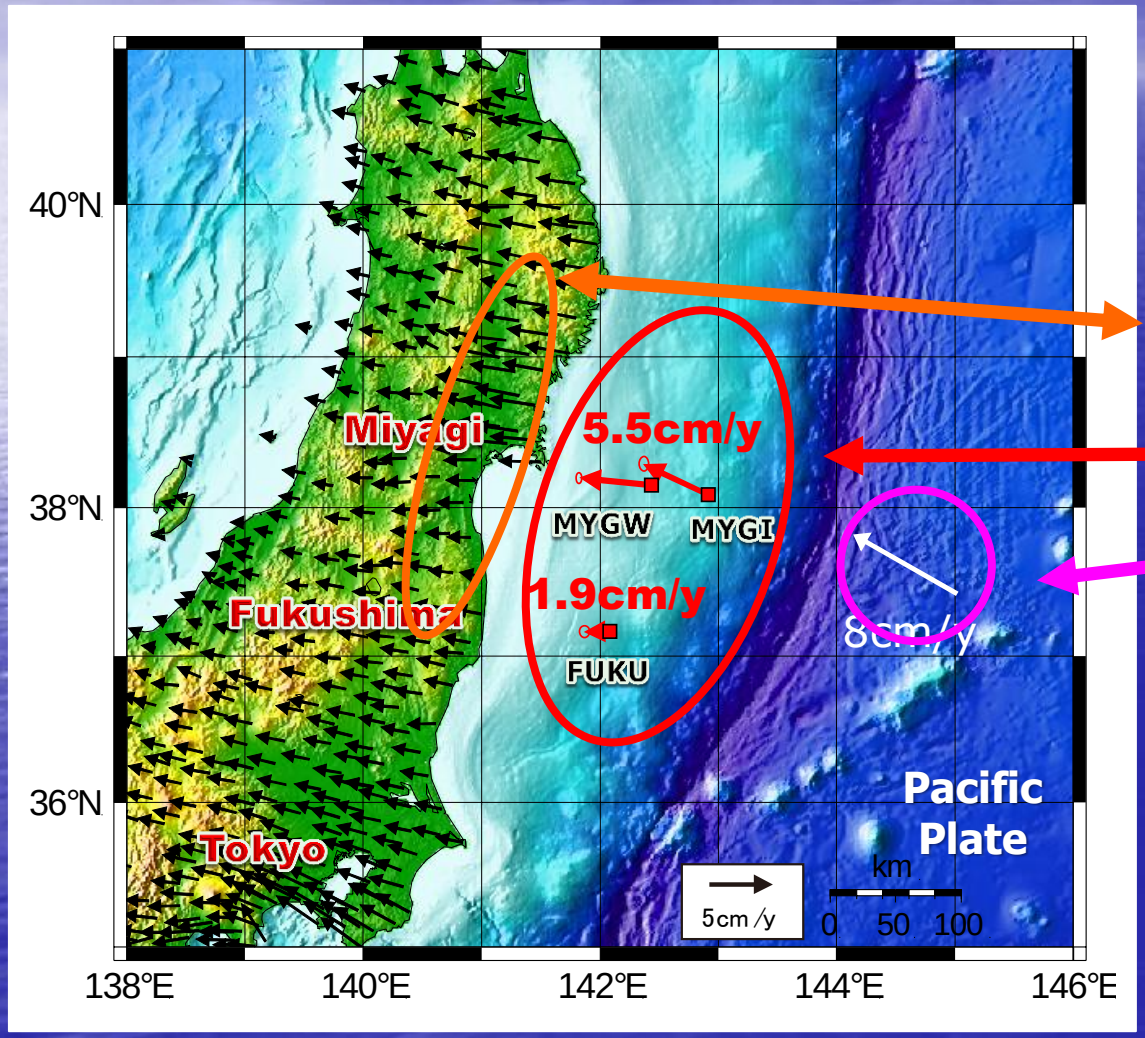
MYGI

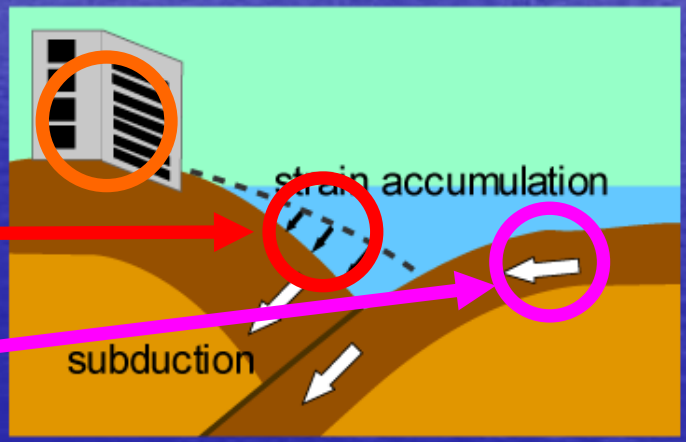


FUKU

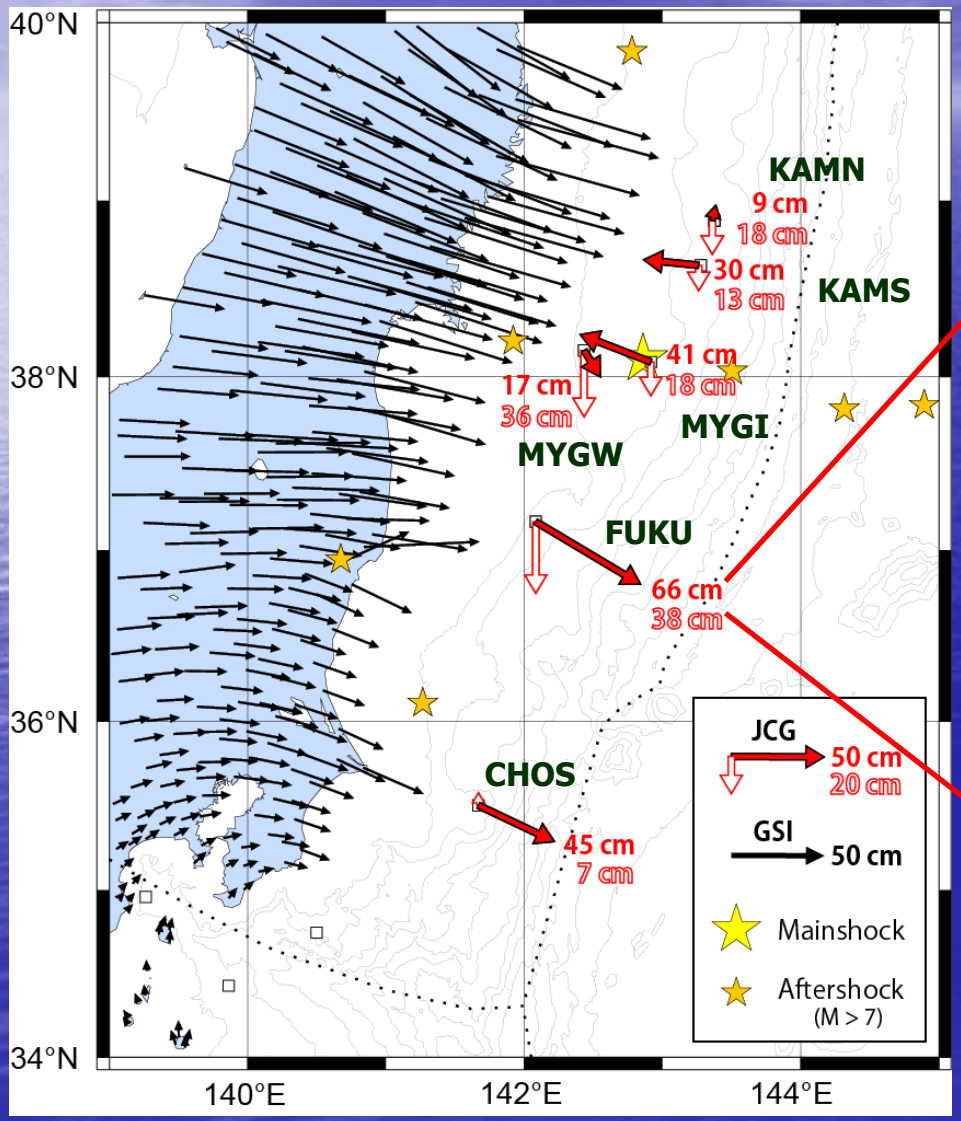


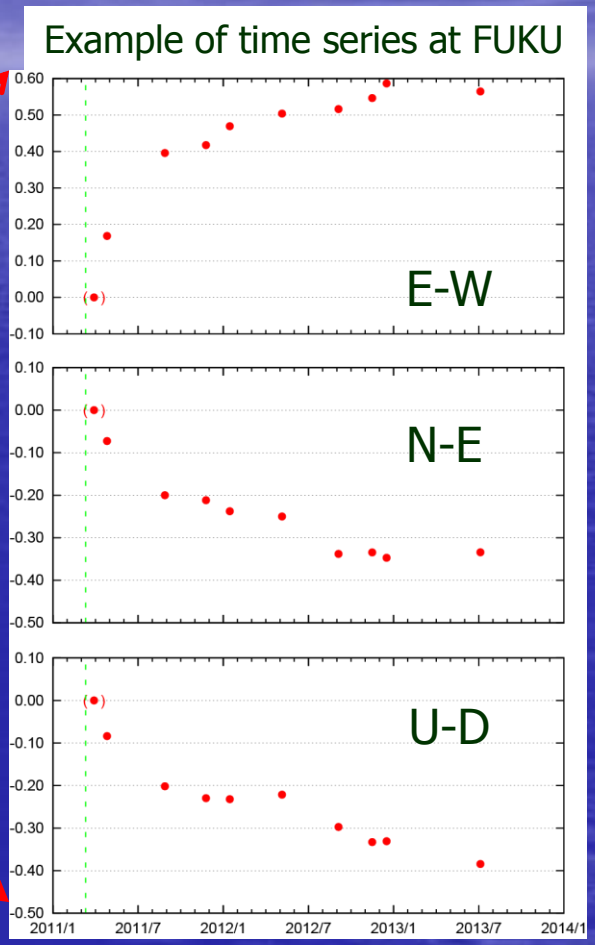
Interseismic crustal velocities
(before the 2011 earthquake)





Postseismic movements
(Mar.2011-Jul.2013)





2011 event

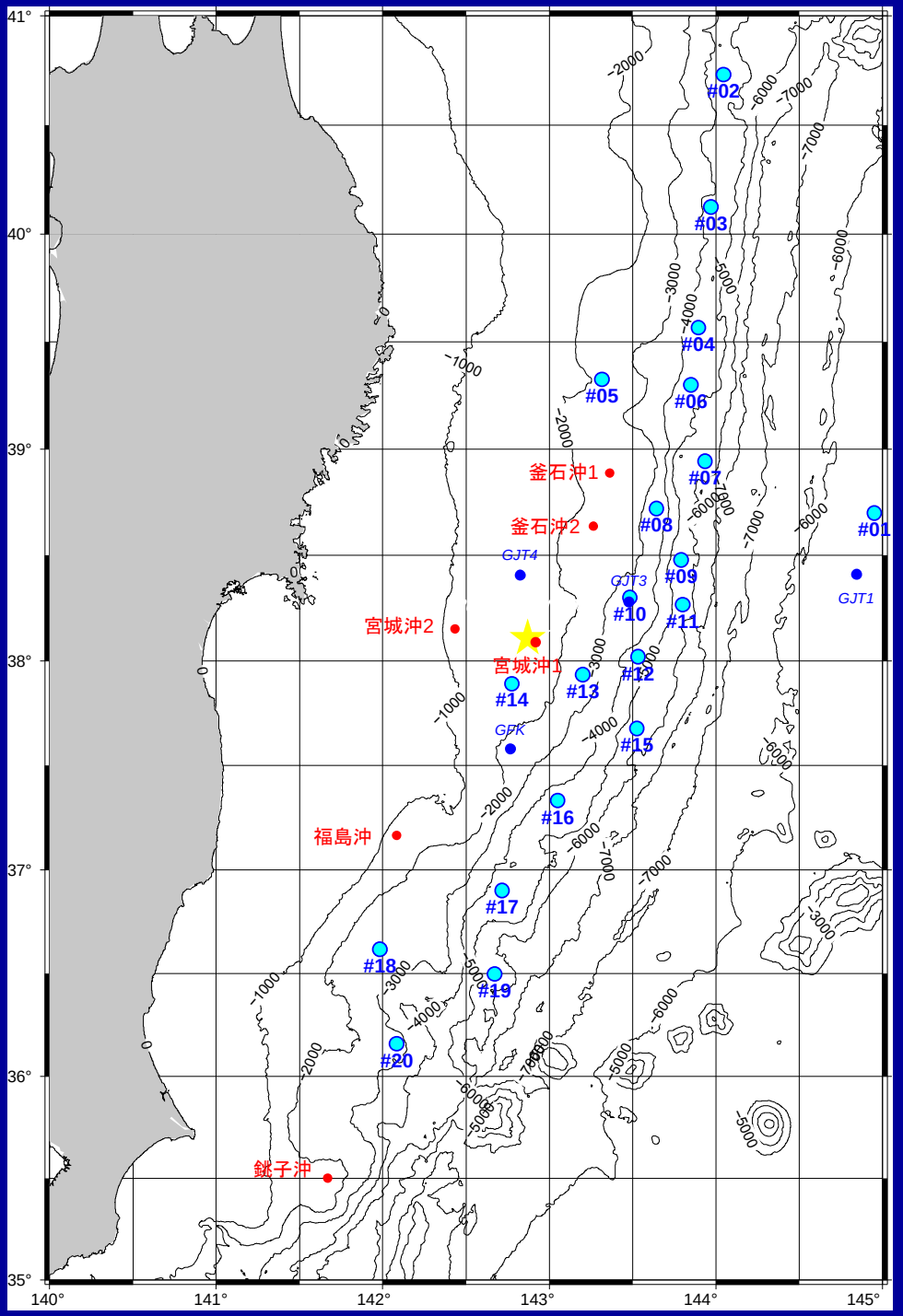
Expansion of Seafloor Network

By Tohoku University

- 20 more sites in 2012

・1000～2000m ・・・ 1
・2000～3000m ・・・ 4
・3000～4000m ・・・ 2
・4000～5000m ・・・ 7
・5000m以深 ・・・ 6

1-D to 2-D

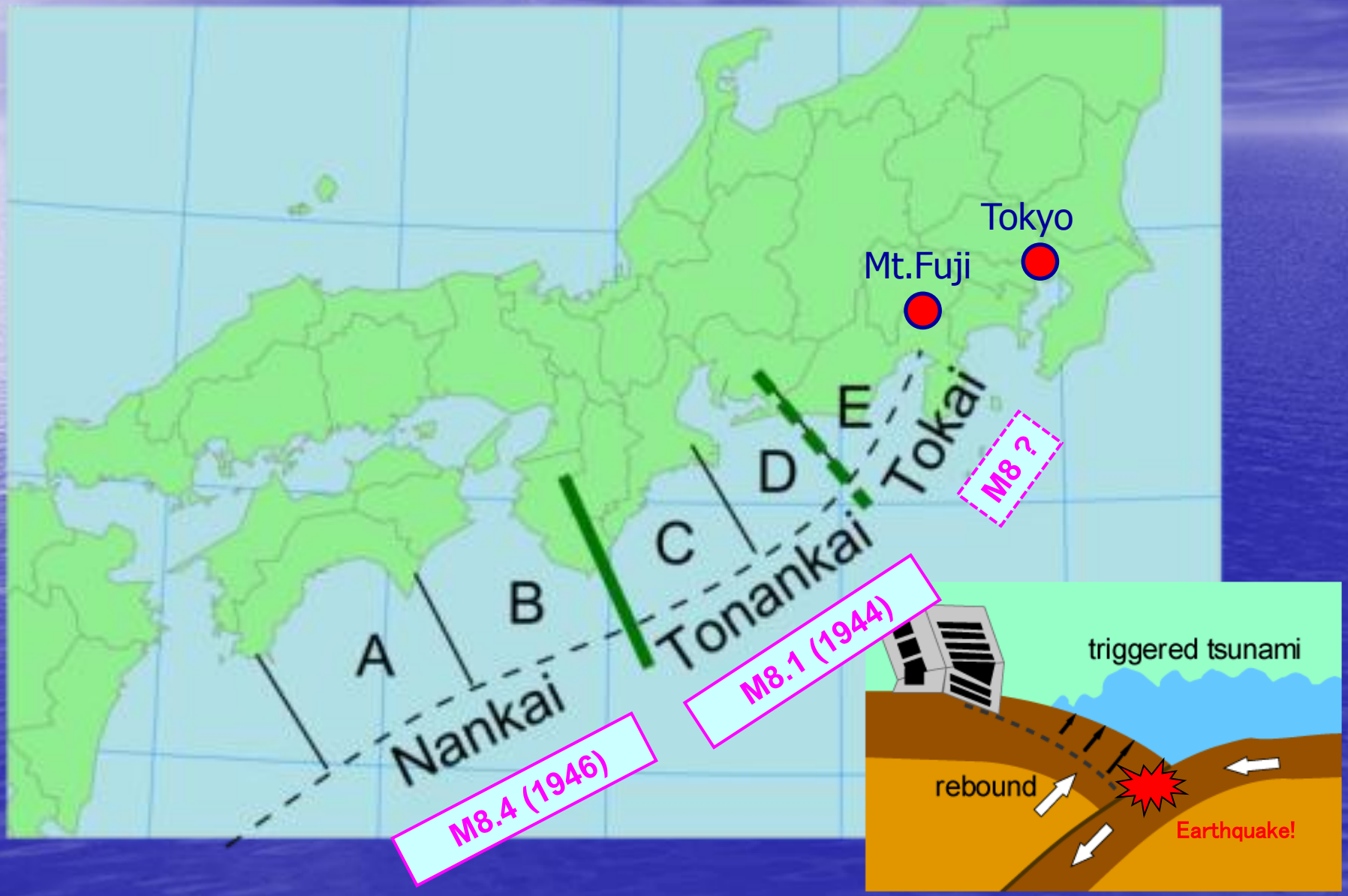


Seafloor Geodesy ~ Major Results

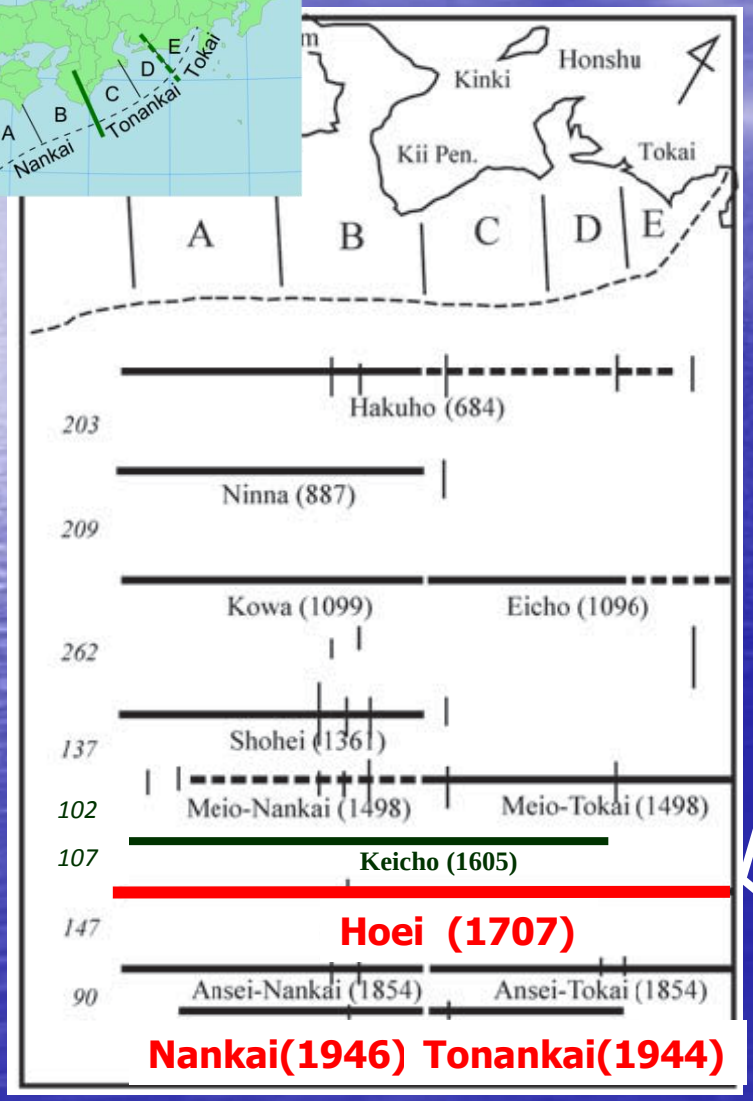
Nankai region

where huge earthquakes were repeated
and are expected in the future

Nankai Megathrust earthquakes



Nankai Megathrust earthquakes



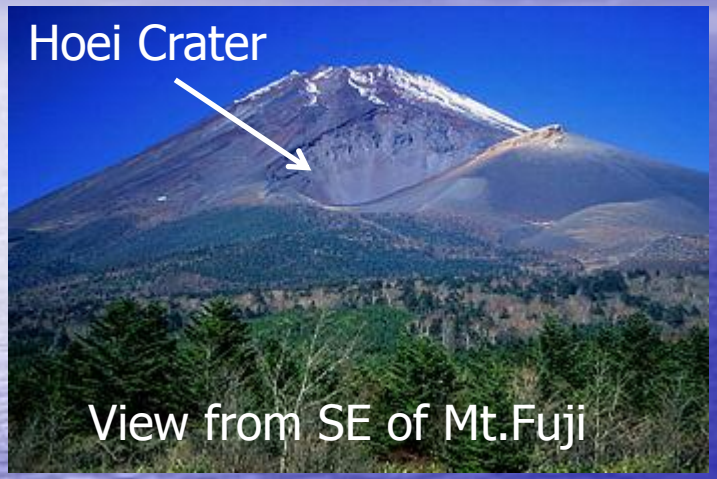
Recent

Modified from Seno (2012)

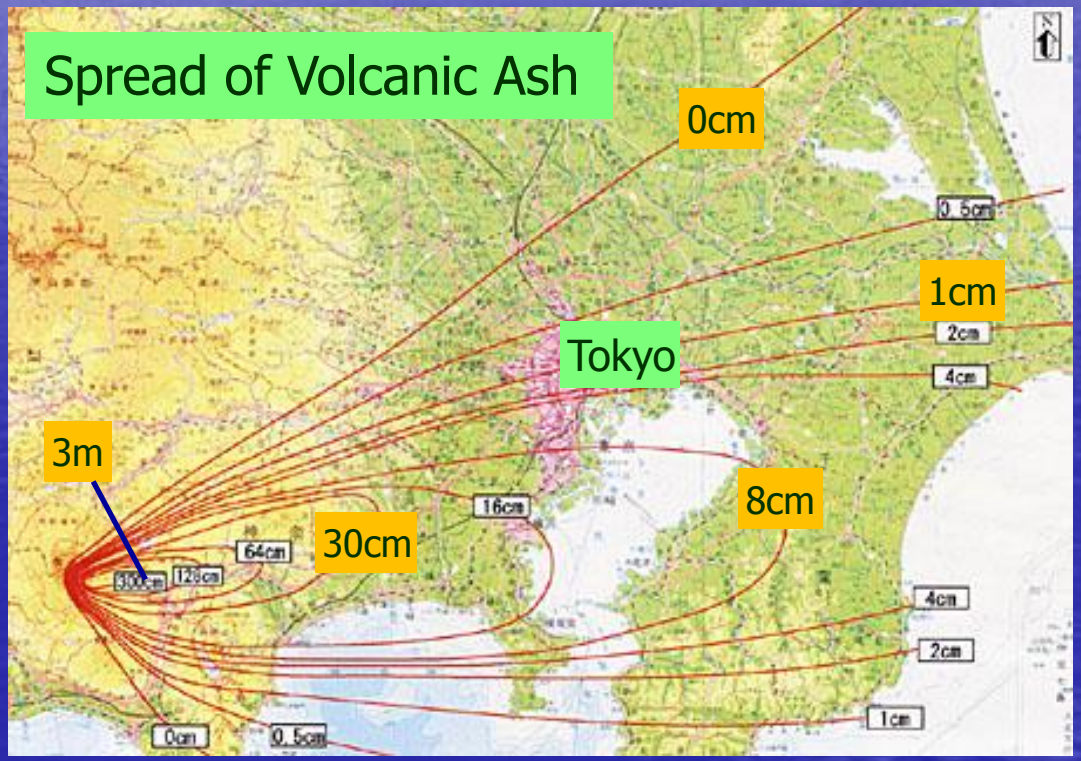
- Repeated every 100-150 yrs

Hoei Eruption of Mt.Fuji (1707)
49 days after the earthquake

Hoei eruption (1707) of Mt.Fuji



Aerial photo (Hoei Crater)

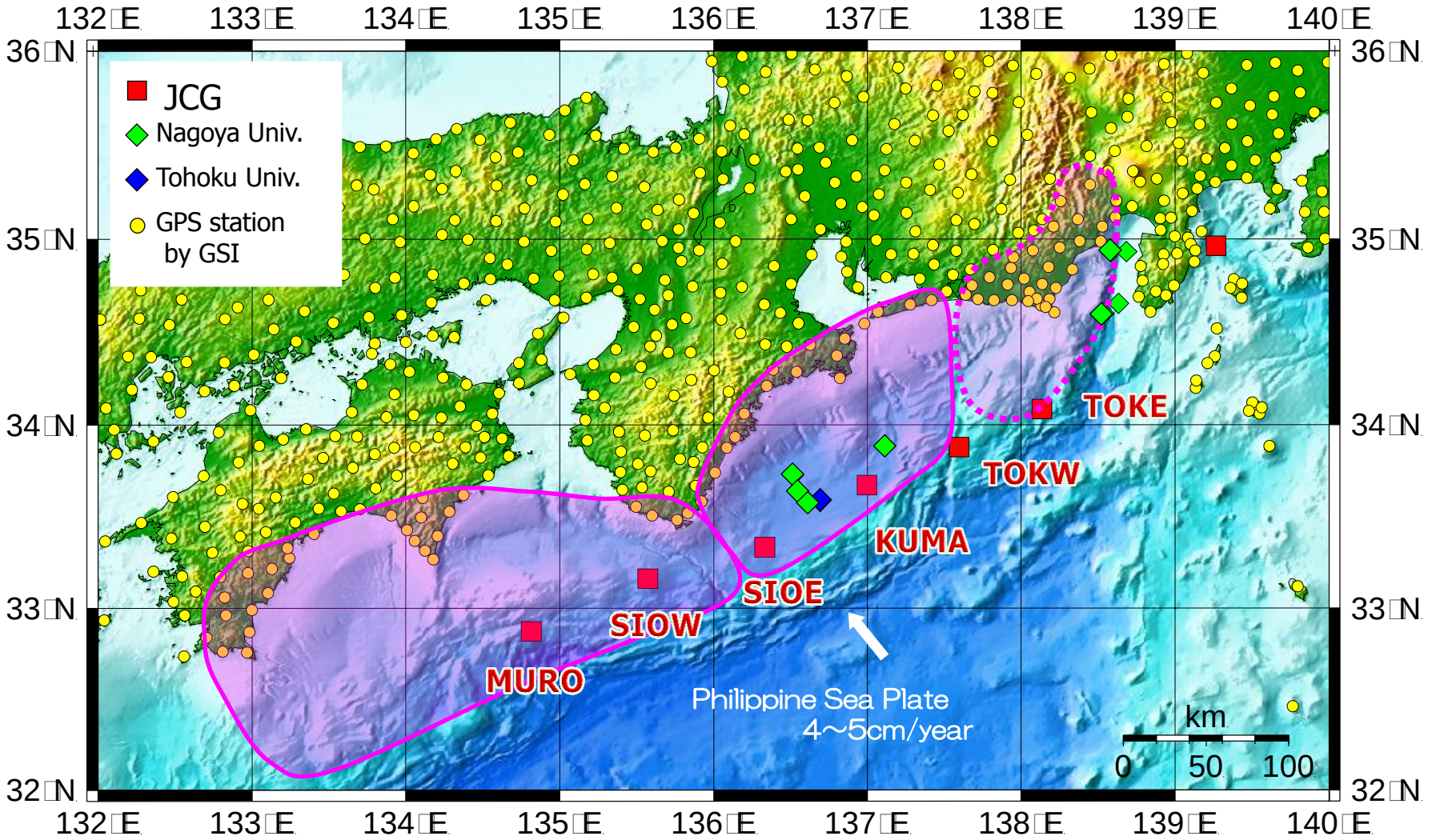


Report by the Committee under the Cabinet Office

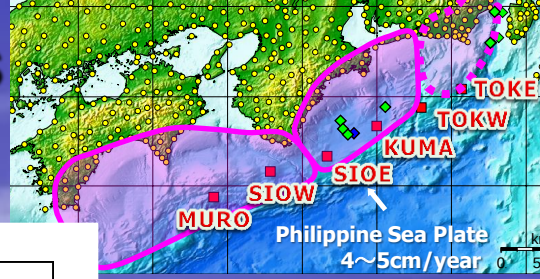
※Photos are taken from Wikipedia

Seafloor reference points along the Nankai Trough

(before the 2011 Tohoku earthquake)



Time series of the estimated positions along the Nankai Trough



East

West

Eastward **Northward**

10cm

March 11, 2011
Tohoku-oki earthquake
(M9.0)

TOKE
4.4 years
-3.8 ± 0.4 cm/year RMS= 1.8 cm
1.5 ± 0.2 cm/year RMS= 0.9 cm

TOKW
3.4 years
-4.3 ± 0.5 cm/year RMS= 1.7 cm
2.0 ± 0.3 cm/year RMS= 1.3 cm

KUMA
3.4 years
-1.9 ± 0.7 cm/year RMS= 1.9 cm
1.0 ± 0.5 cm/year RMS= 1.6 cm

SIOE
4.6 years
-2.5 ± 0.4 cm/year RMS= 1.7 cm
1.9 ± 0.5 cm/year RMS= 2.0 cm

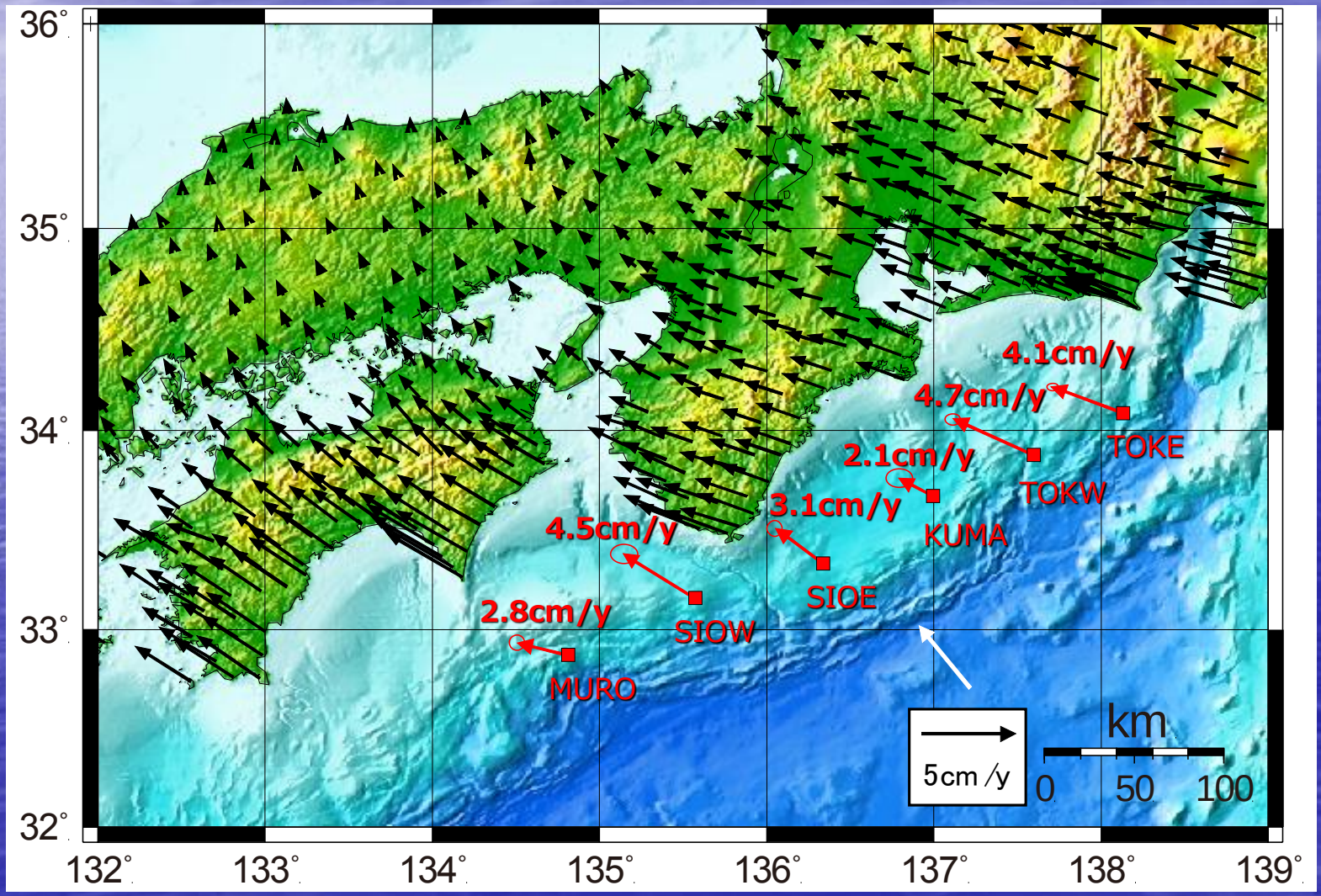
SIOW
3.4 years
-3.8 ± 0.9 cm/year RMS= 2.7 cm
2.3 ± 0.6 cm/year RMS= 1.8 cm

MURO
4.3 years
-2.6 ± 0.4 cm/year RMS= 1.6 cm
0.7 ± 0.4 cm/year RMS= 1.7 cm

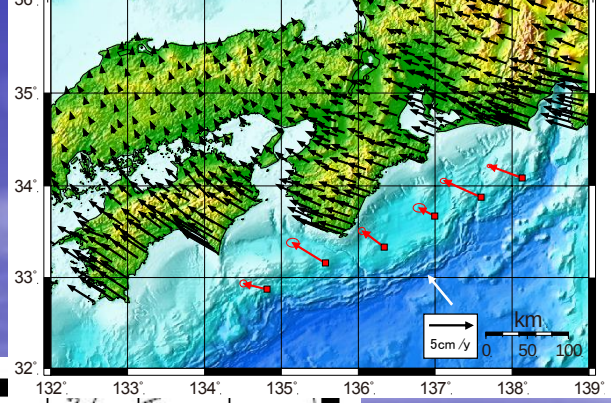
2006 2007 2008 2009 2010 2011 2012

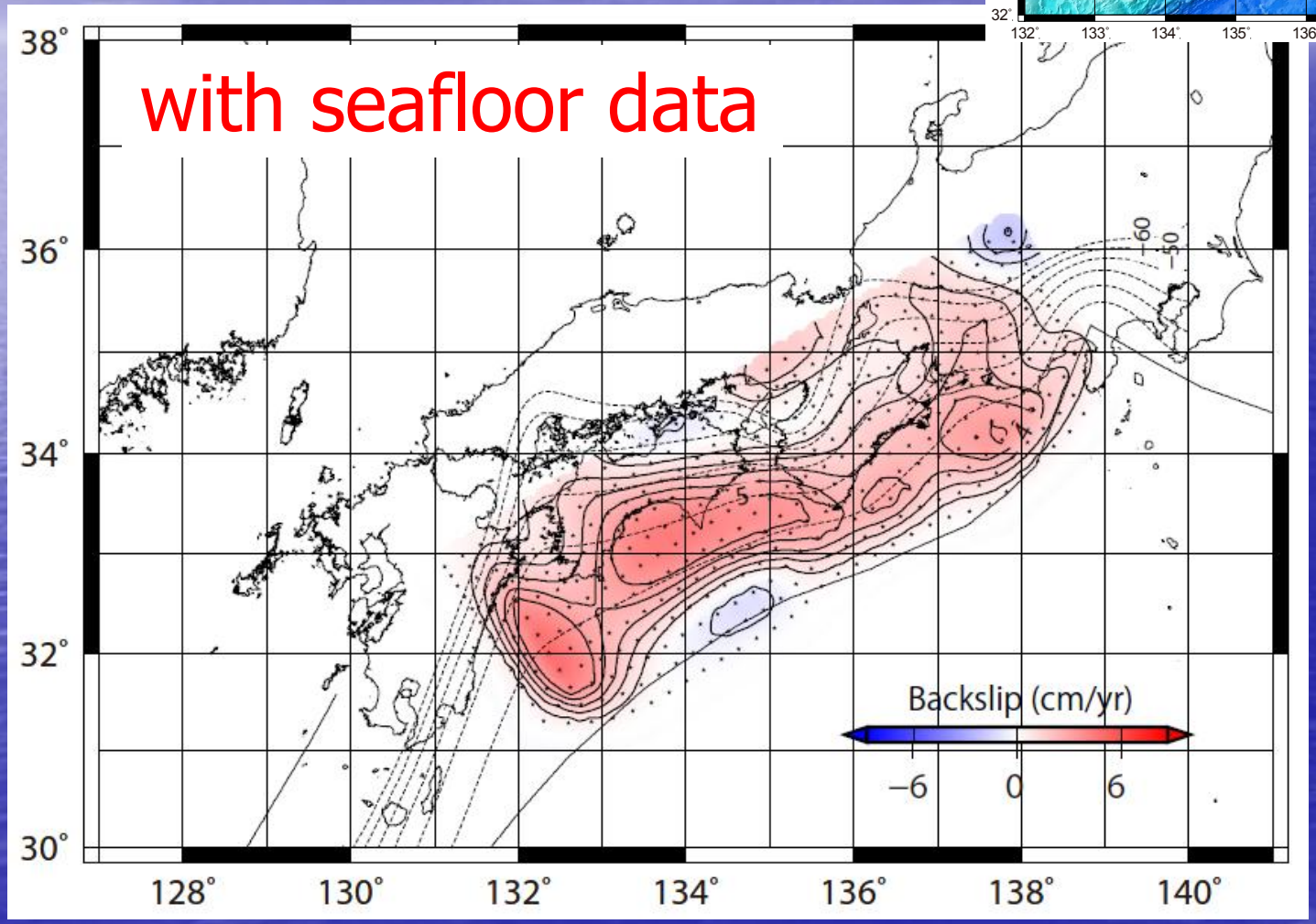
Position reference:
EU plate

Velocity vectors on the seafloor
along the Nankai Trough (~2011)



Back slip estimation
with and without seafloor data

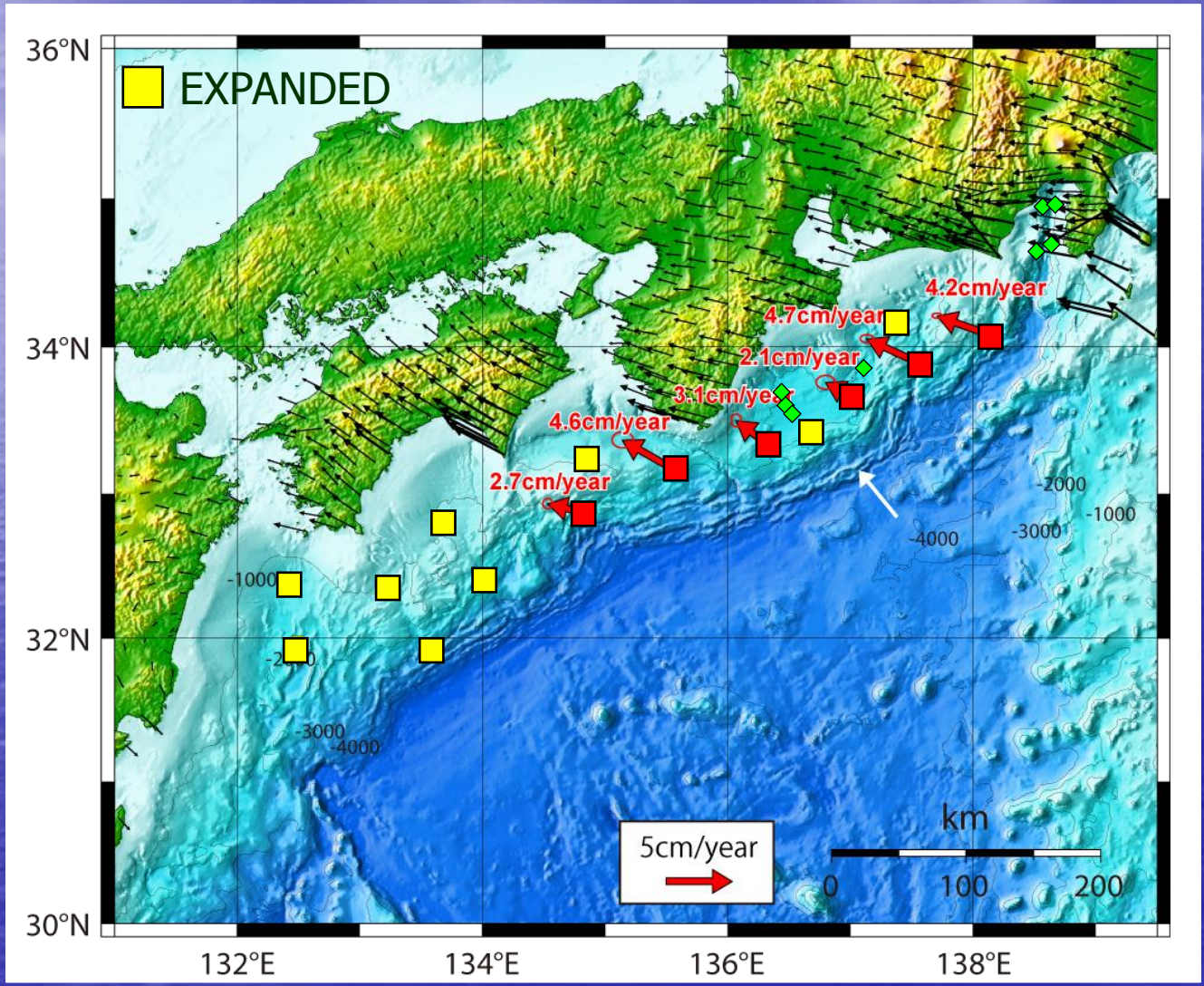




Preliminary results by Yokota et al. (2013)

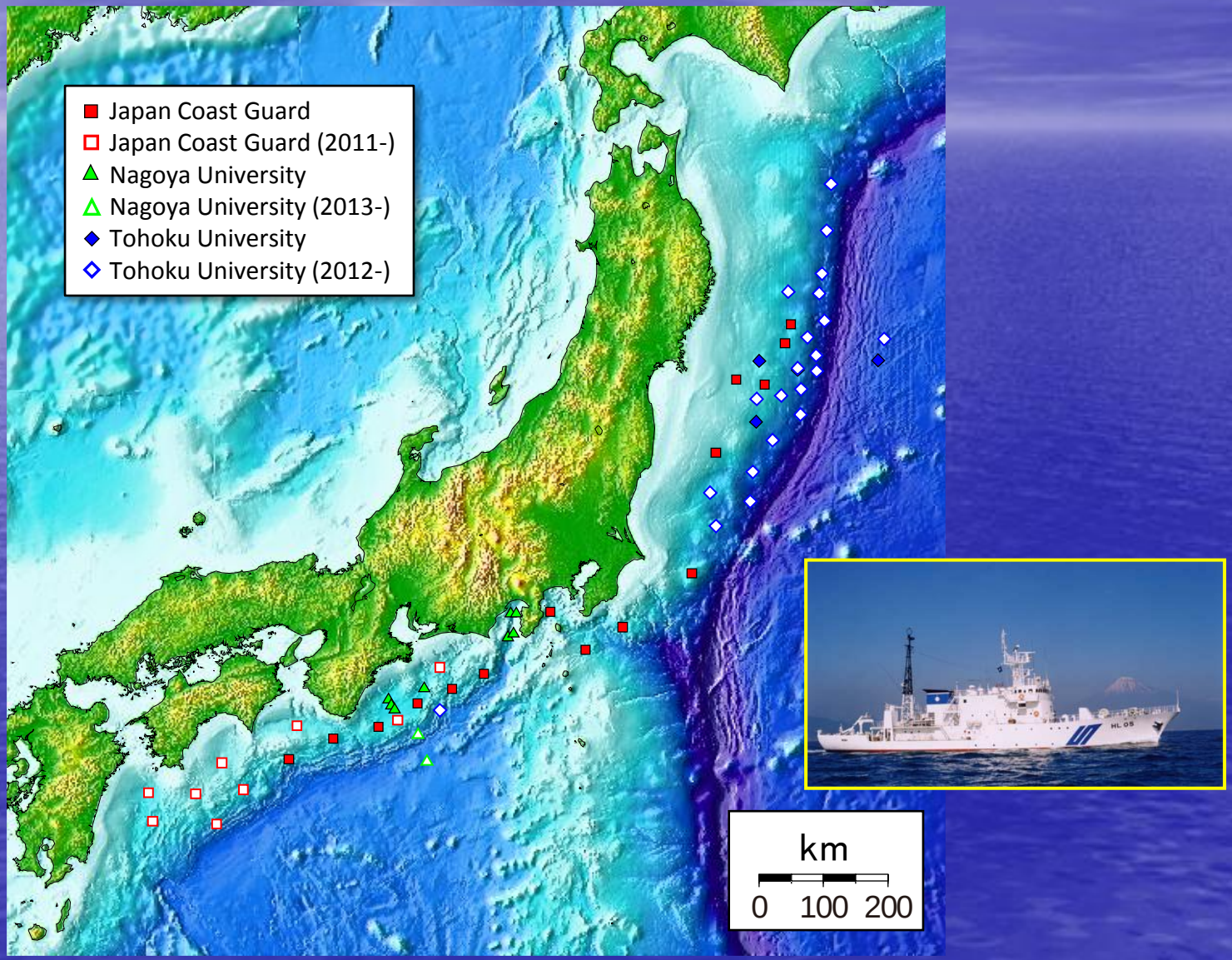
Expansion of Seafloor Reference Points

along the Nankai Trough (2011～)



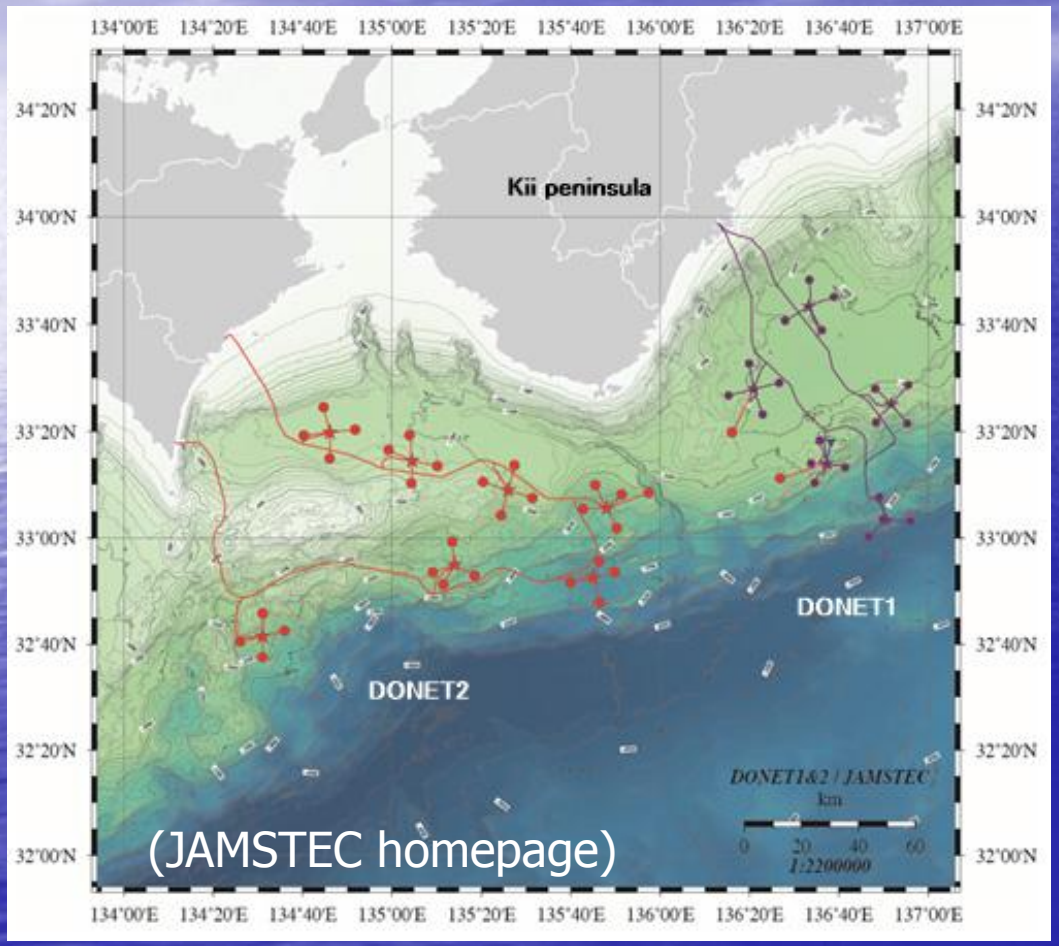
6 pts to 15 pts ➡ 1-D to 2-D

Expanded Seafloor Geodetic Network in Japan



Another Seafloor Network in Nankai region

DONET* by JAMSTEC



- Seafloor cable network
  - DONET1 : 20 pts, completed in Aug.2011
  - DONET2 : 30 pts, started in 2010
- Seismometer, Water-pressure gauge, Hydrophone …

* DONET = Dense Oceanfloor Network system for Earthquakes and Tsunamis

Thank you for your attention!