Geodesy application for disasters (GNSS tsunami early warning system): Case in Japan

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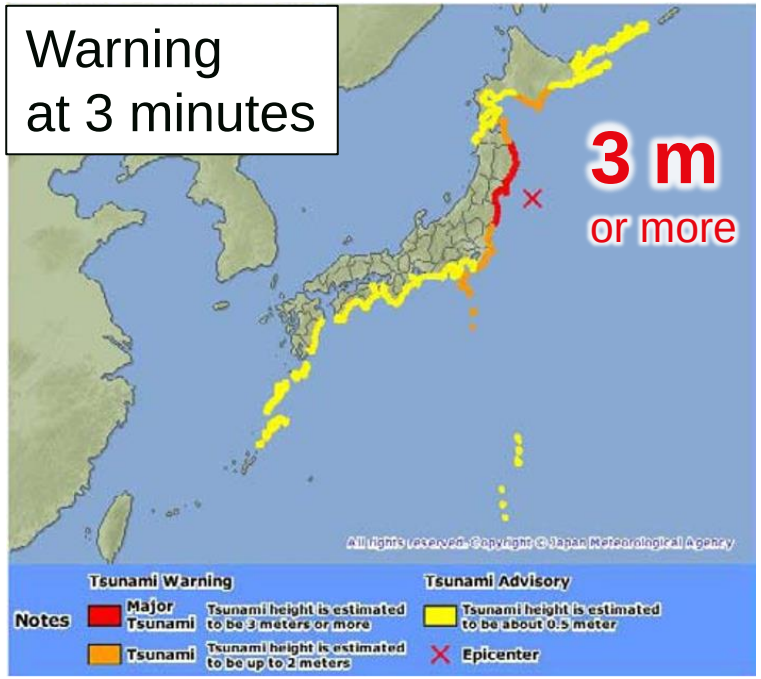
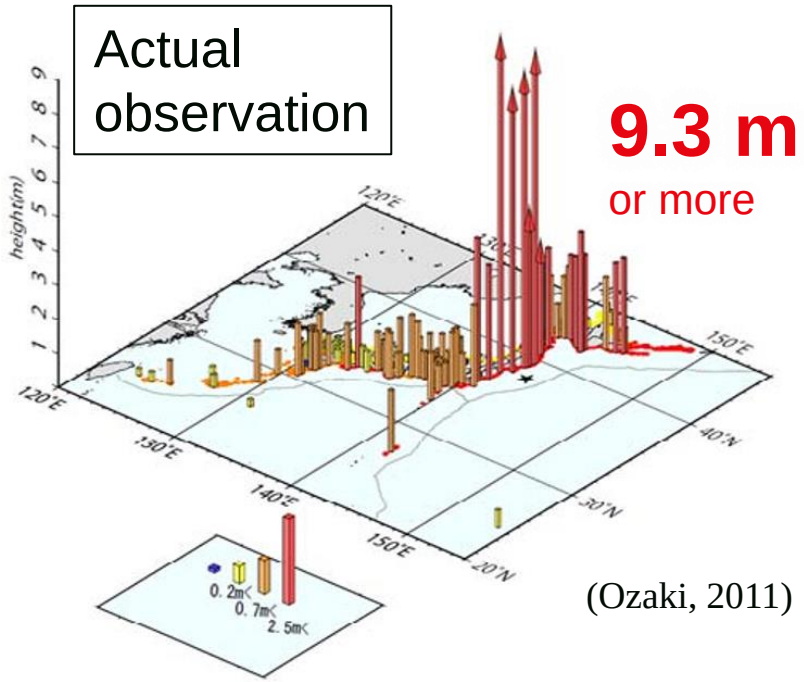
Contents

Background

Underestimation of Tsunami warning for 2011 Tohoku-Oki earthquake (Mw 9.0)





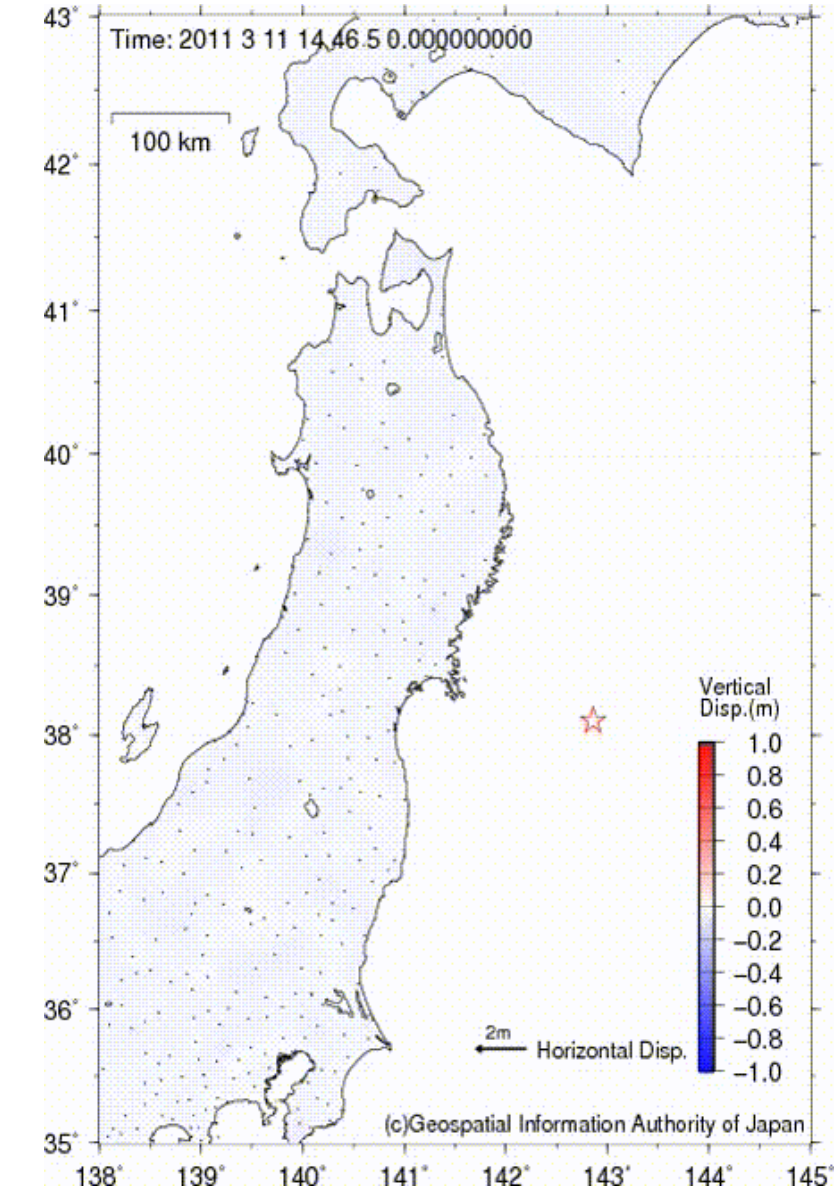
(Ozaki, 2011)

What makes this gap:

- Saturation of Earthquake Early Warning (**M7.9**) based on seismometers
- Tsunami warning based on the EEW

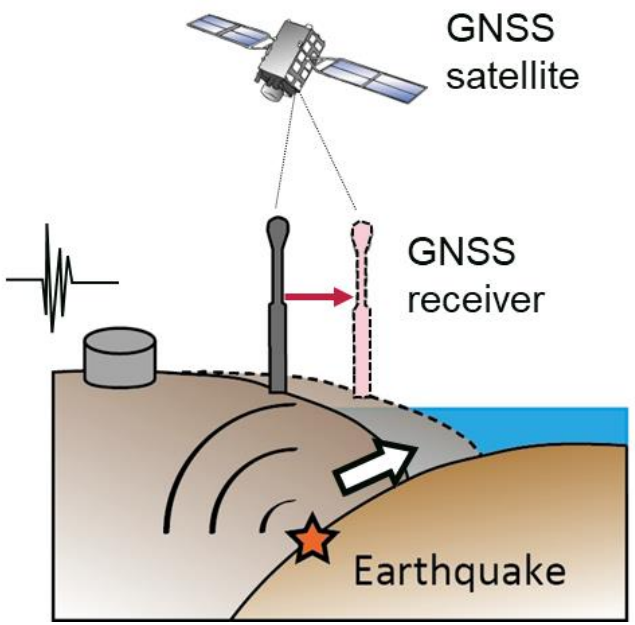
➡ **How to prevent Mw saturation in real-time estimation?**

Utilization of Real-time GNSS data



(www.gsi.go.jp/cais/chikakuhendo40010.html)

Real-time GNSS positioning can provide Mw without saturation problem



- ✓ The observation is not velocity or acceleration but displacement itself
- ✓ Using crustal deformation data, we can estimate finite fault model

Japanese nationwide GNSS CORS network

- ✓ approx. 1,300 stations
- ✓ Distributed with 20 km intervals
- ✓ 1 Hz continuous observation
- ✓ Real-time communication

➡ GEONET enables
"real-time finite fault estimations based on GNSS data"

Motivation & Goal

Motivation:

How to prevent Mw saturation in real-time estimation?

Goal:

Provision of finite fault models using real-time GNSS data within several minutes

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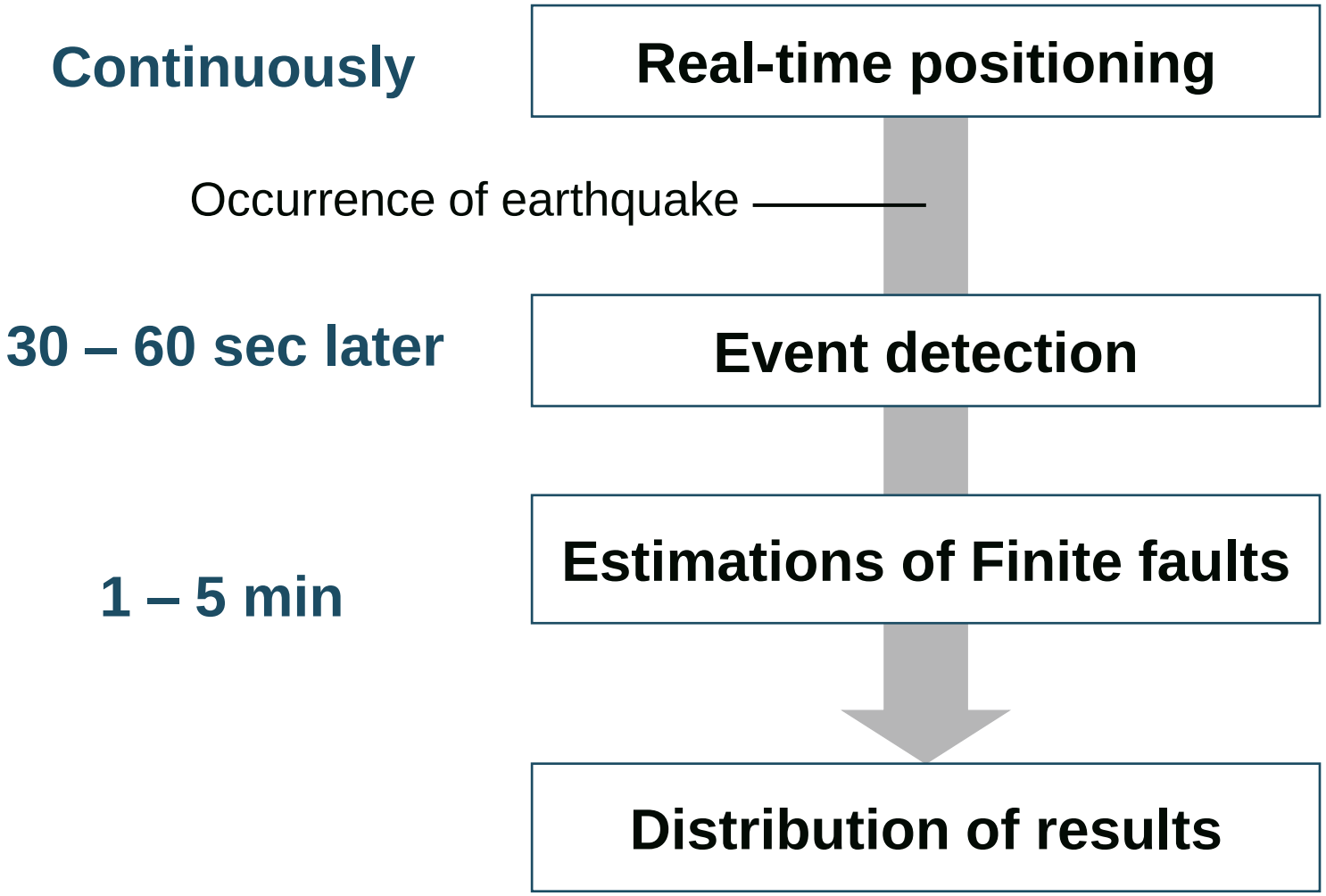
Basic concept of the system



Continuously …

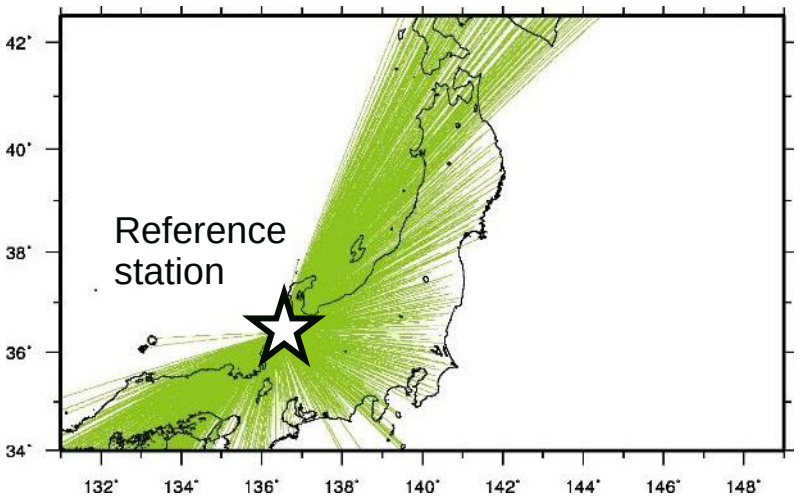
When an earthquake occurs …

Kawamoto *et al*. (2016, 2017)

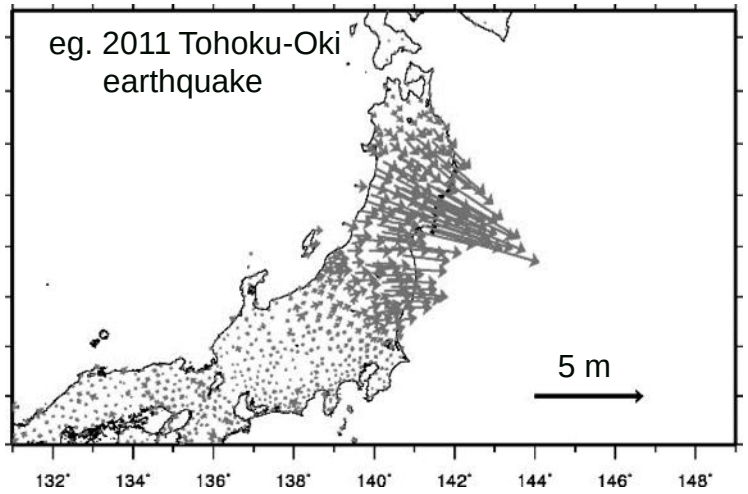
① Positioning (1 Hz)

② Event detection

③ Fault models inversion

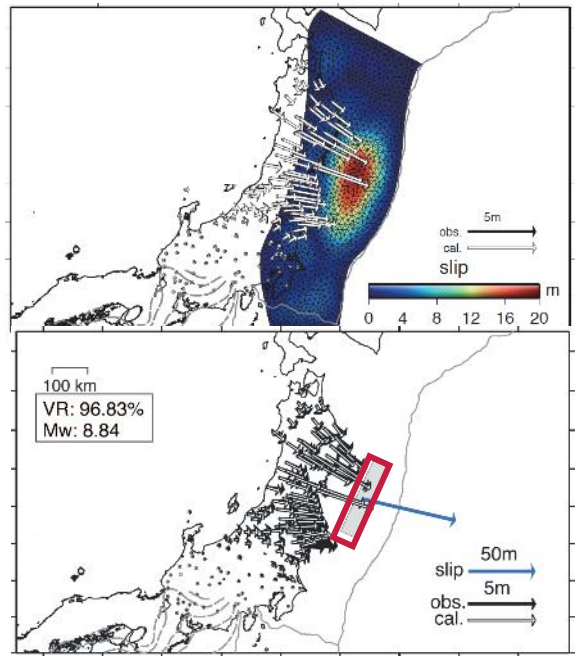


Real-time Kinematic (RTK) positioning



Detection with
EEW & RAPiD (Ohta et al., 2012)

Calculation of displacement using specific time span



1. Slip distribution model on the plate interface
2. Single rectangular model without location constraints

Products

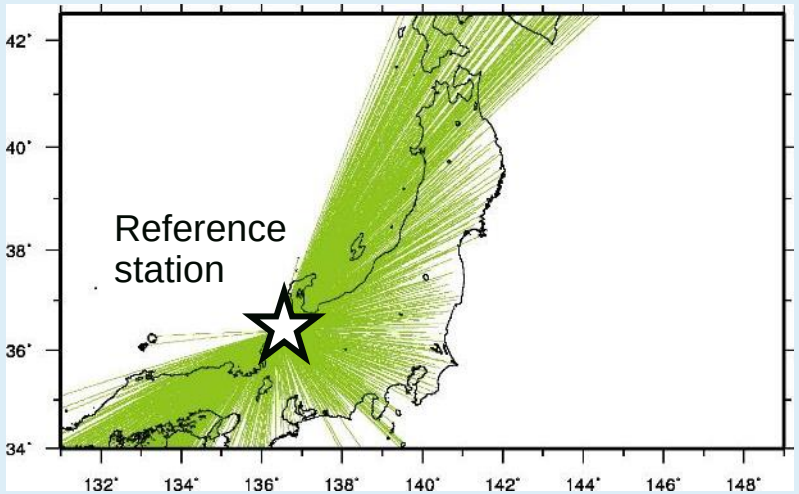
Continuously …

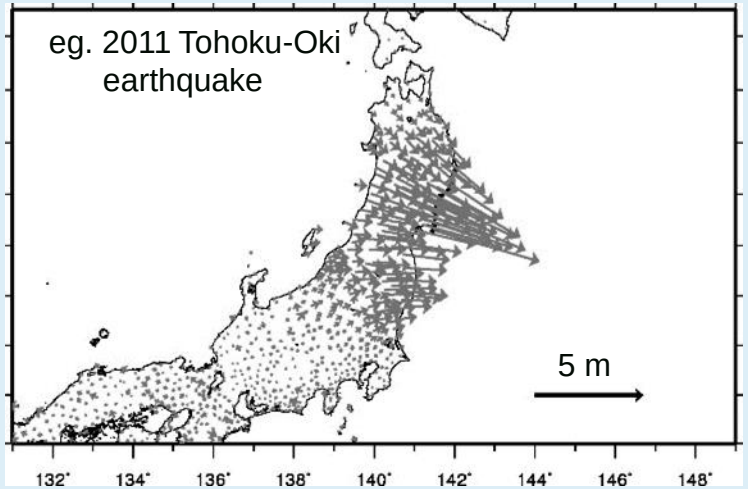
When an earthquake occurs …

① Positioning (1 Hz)

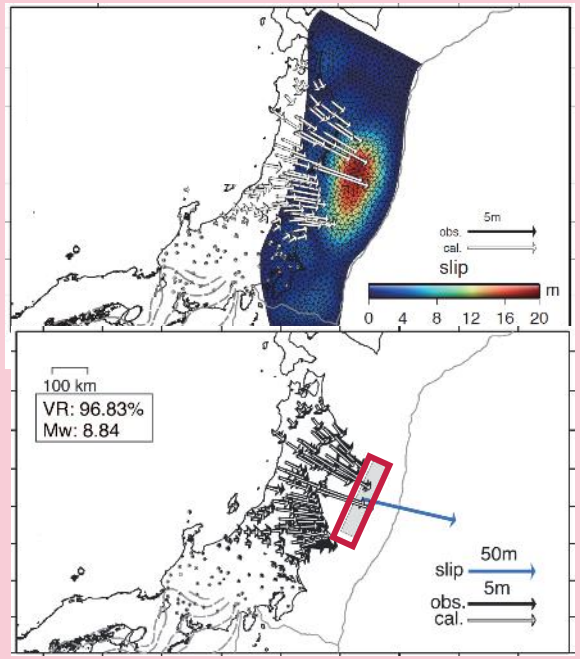
② Event detection

③ Fault models inversion





Crustal deformation

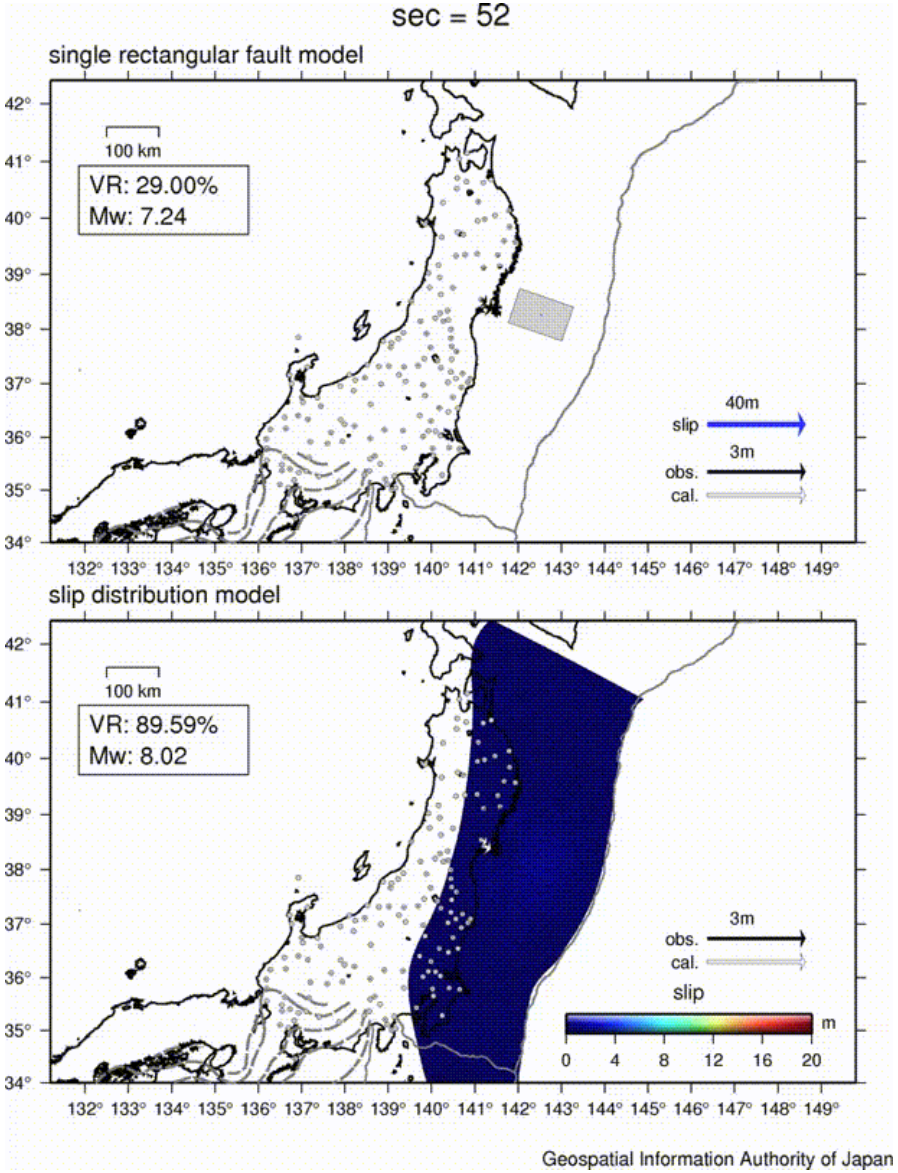


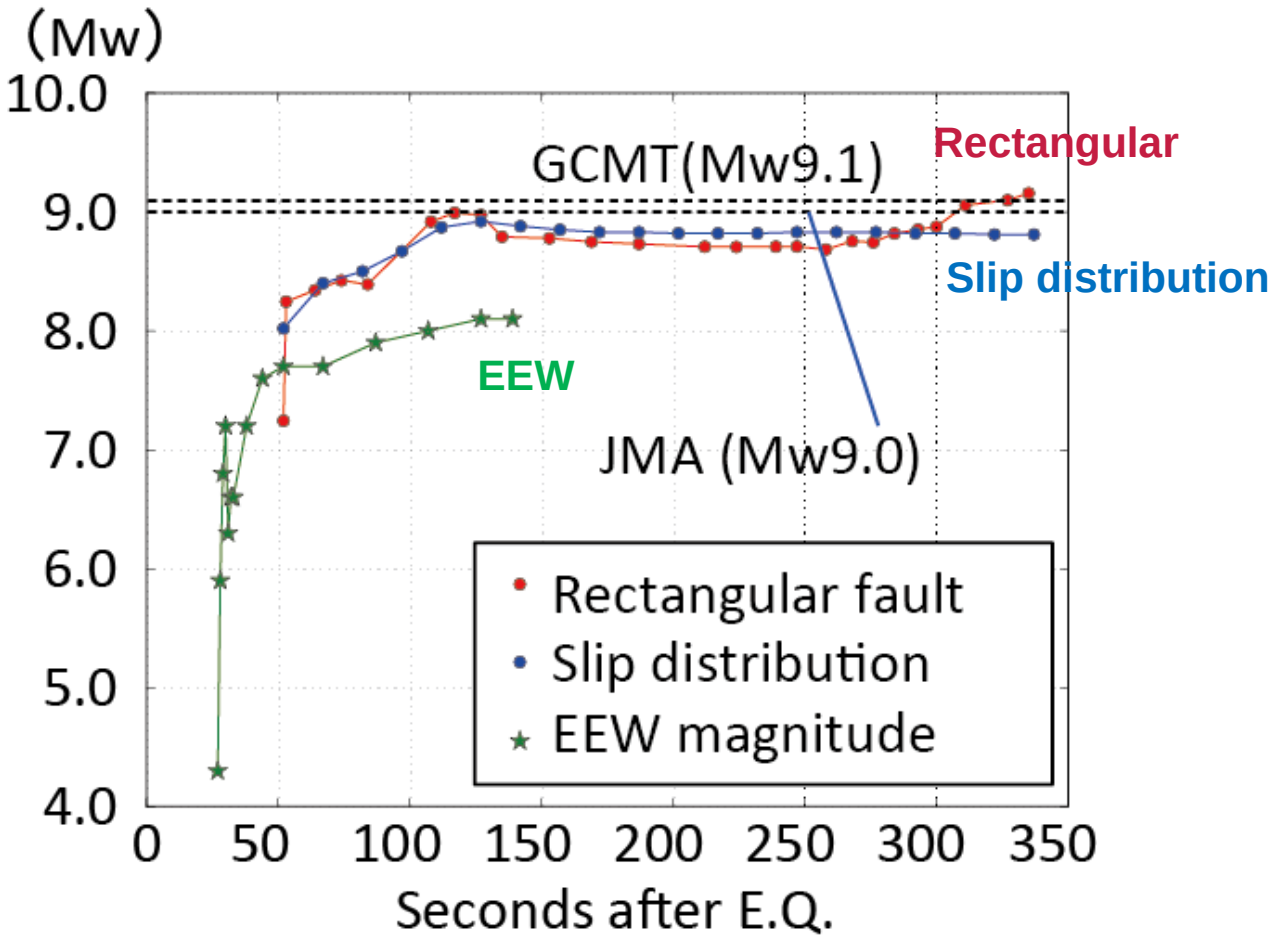
Fault models, Mw

Within several minutes…

these products are automatically sent to the relevant agencies and organizations

Data: Actual GNSS observation

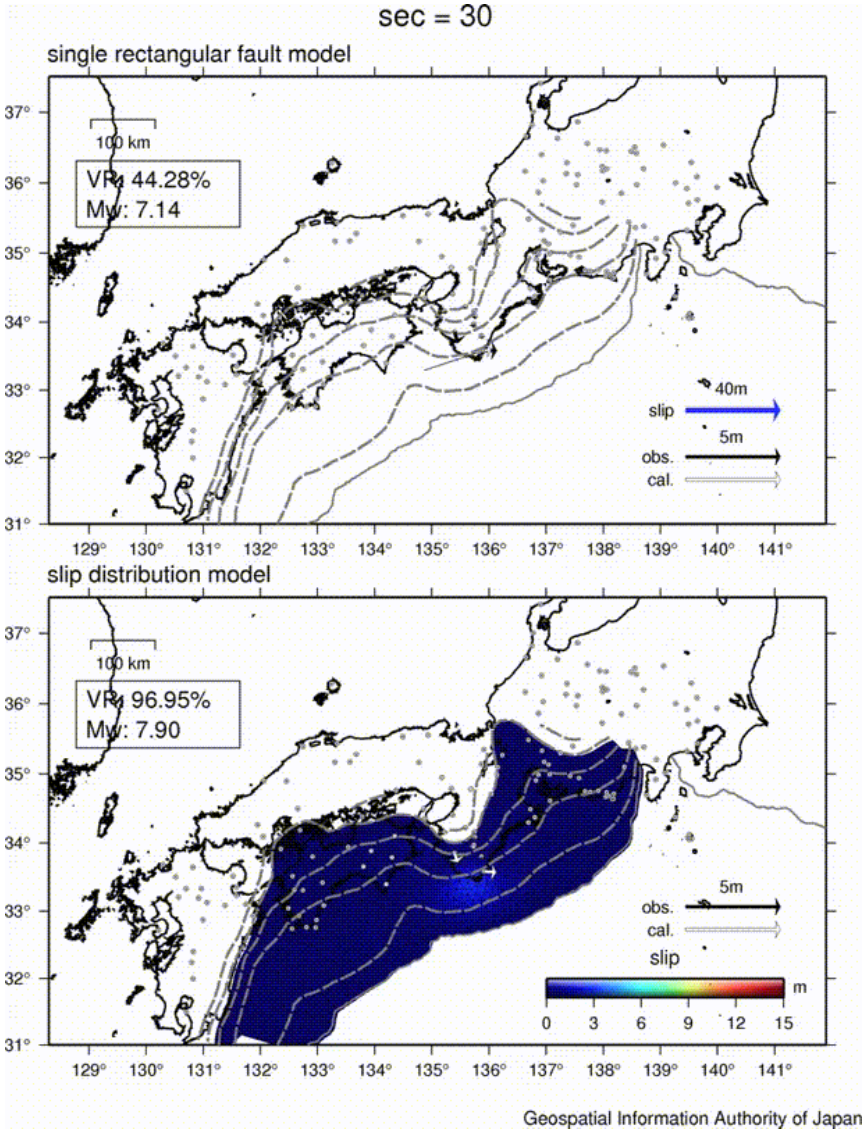


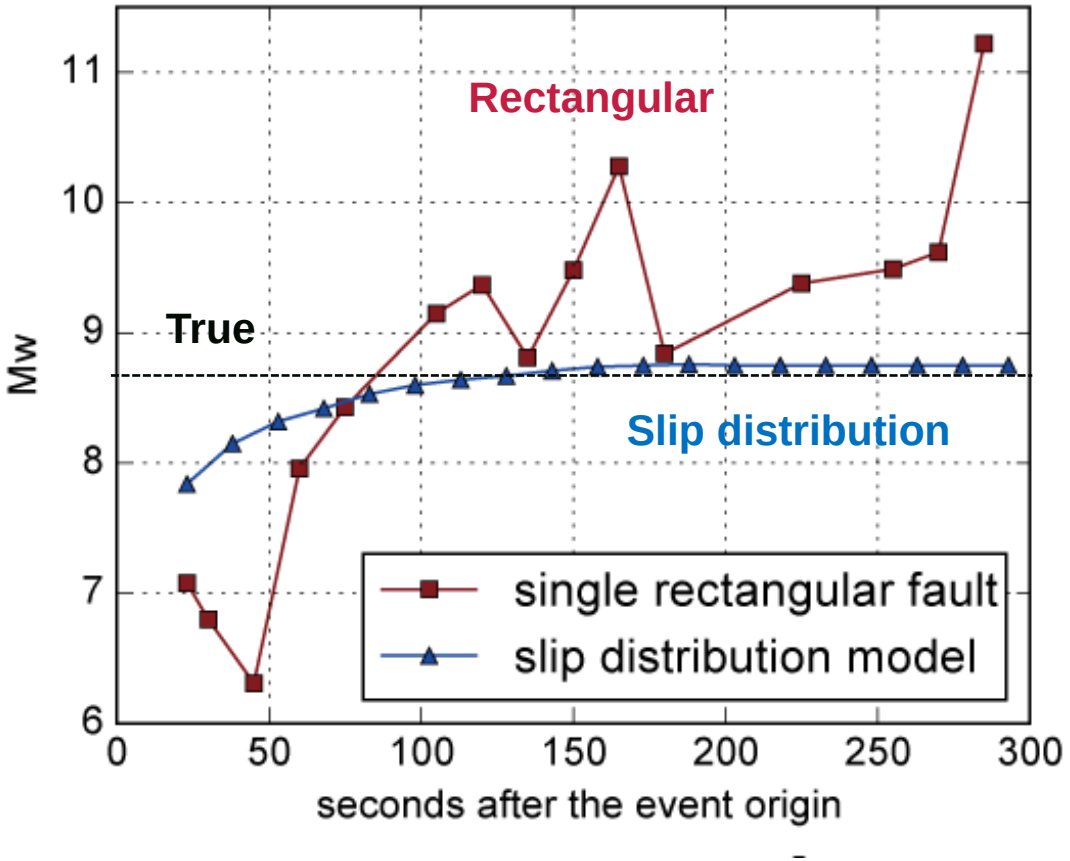


- ✓ The estimation became stable within 120 seconds
- ✓ Mw of REGARD is consistent with post-analysis values

Data: Simulated GNSS observation

- Assumed slip distribution (Todoriki *et al.*, 2013)





- ✓ Slip distribution model provided accurate Mw
- ✓ Single rectangular fault was unstable because it cannot reflect complex plate geometry and inhomogeneous slip

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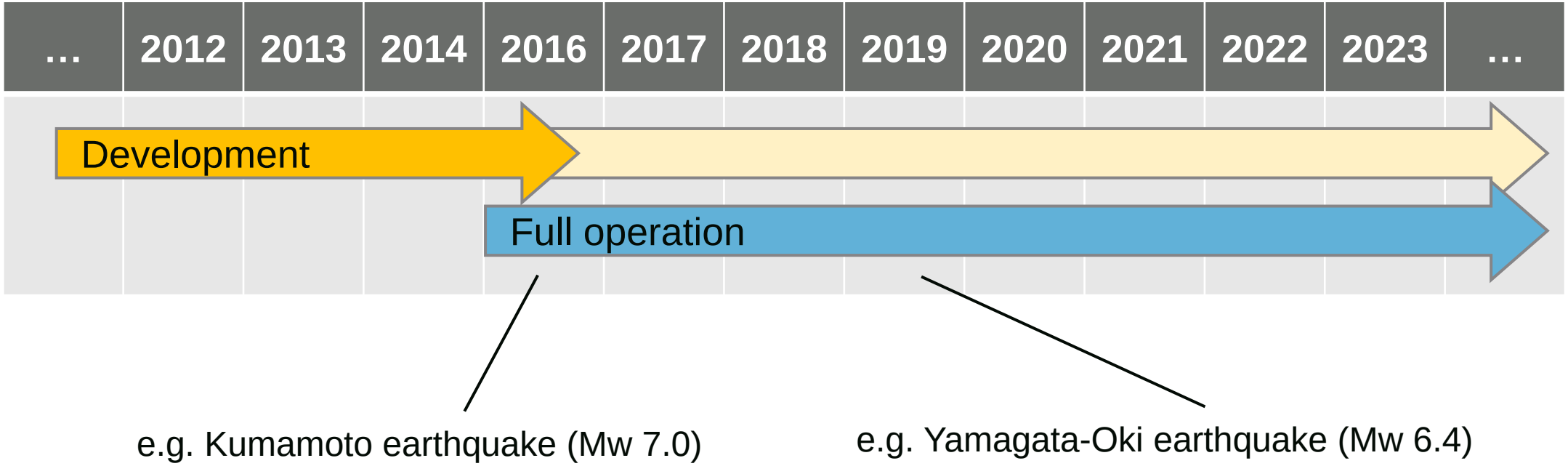
Operational history

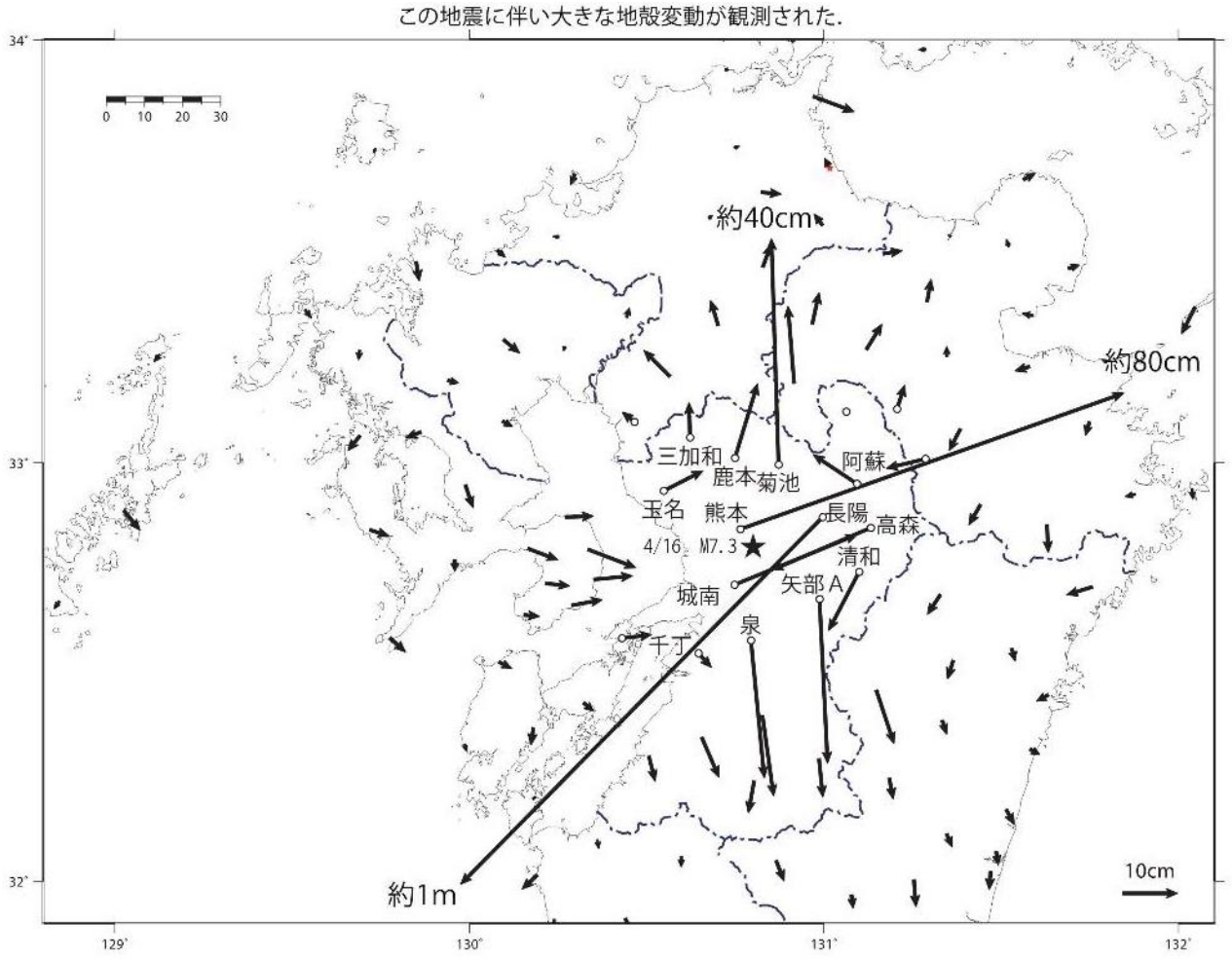
- ✓ GSI has started collaboration on REGARD with Tohoku University since 2012
- ✓ Full operation since 2016

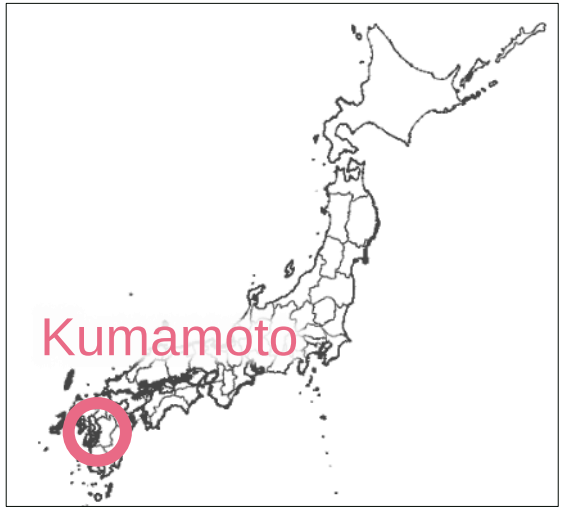


- ✓ There are approx. 400 detections (> M4) per year → vigorous system tuning
- ✓ REGARD was originally designed to focus on large earthquakes, but has worked well for M6-7 earthquakes

Example | **2016 Kumamoto earthquake (Mw 7.0)**

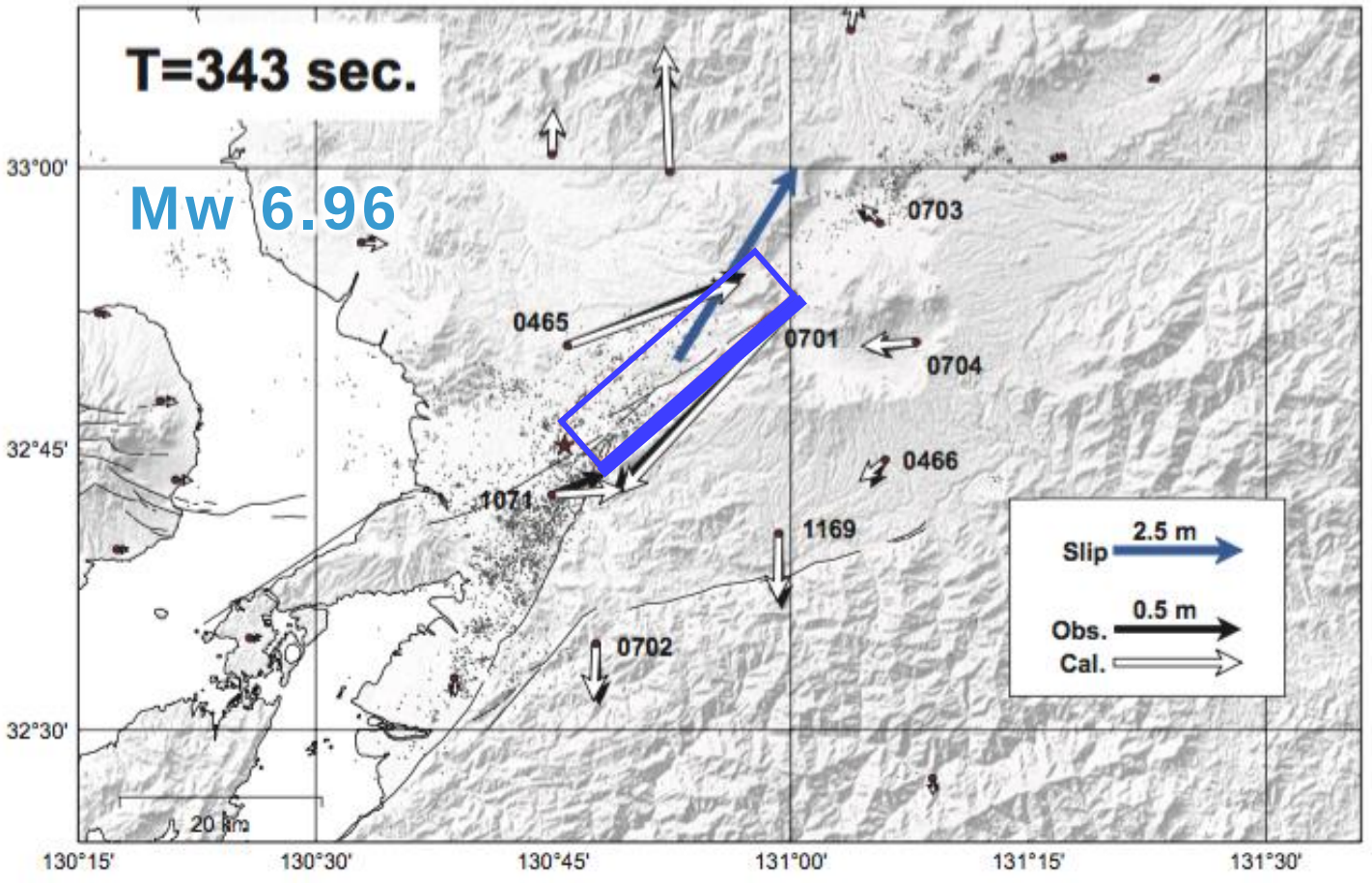
Crustal deformation





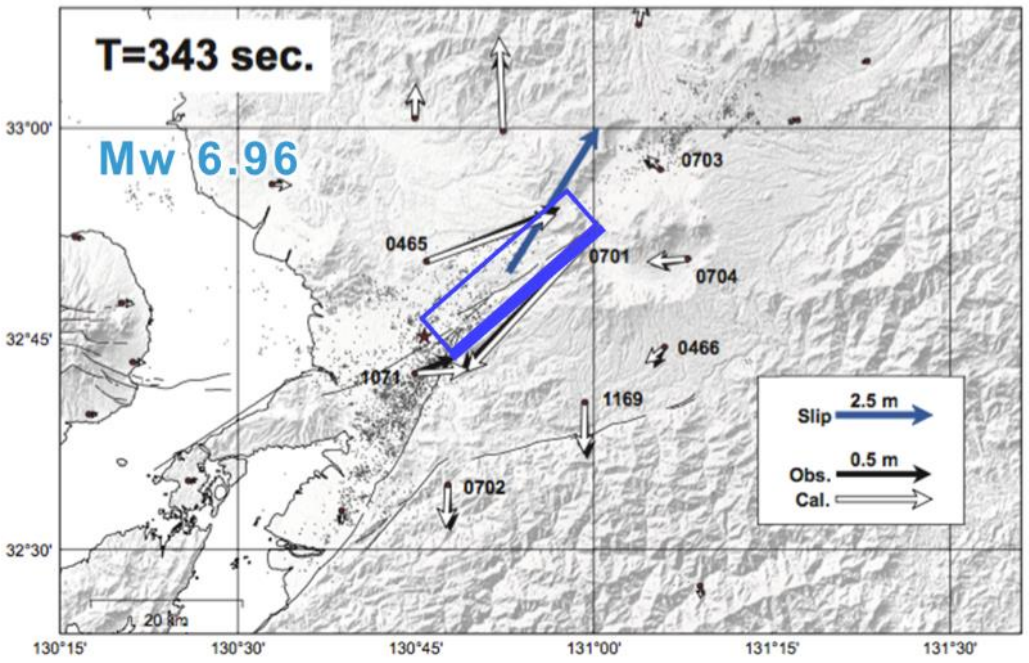
✓ REGARD detected significant horizontal displacements of maximum 1m

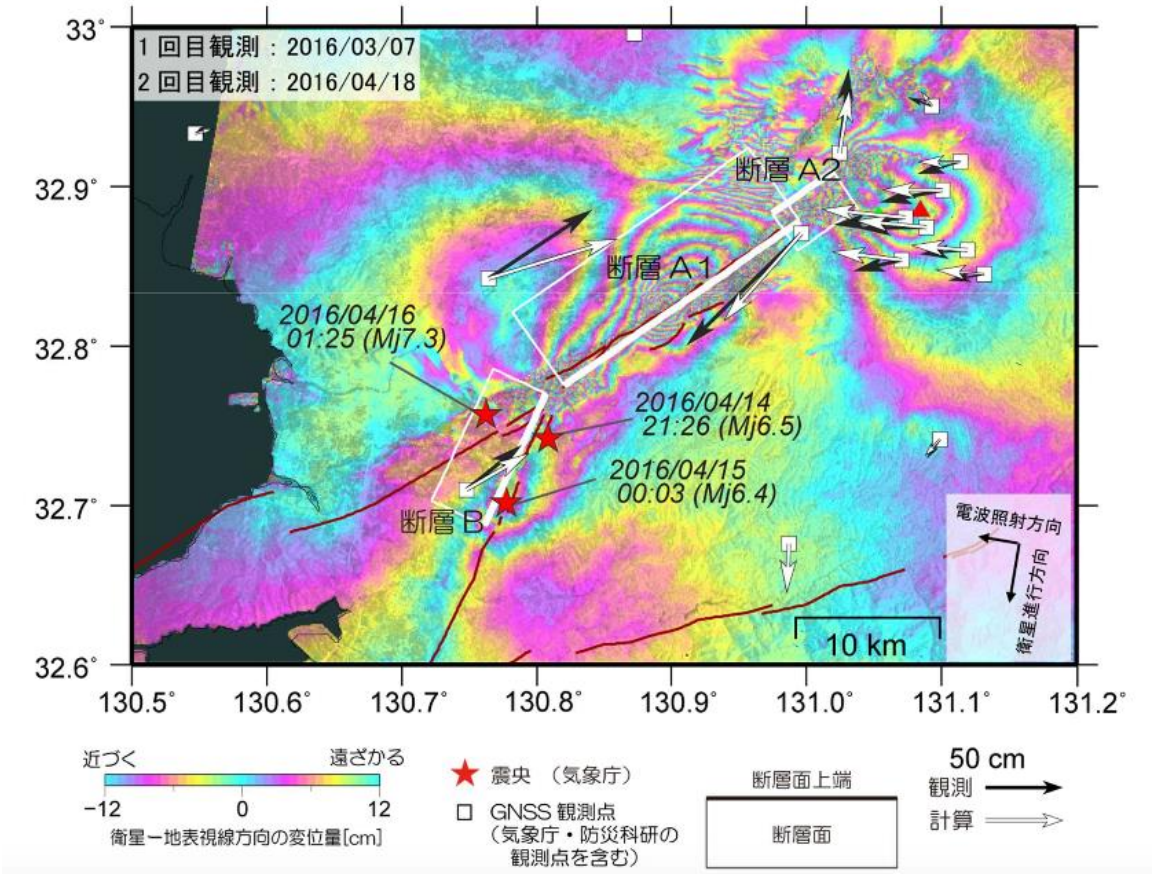
Fault model



✓ REGARD estimated fault model and Mw within several minutes

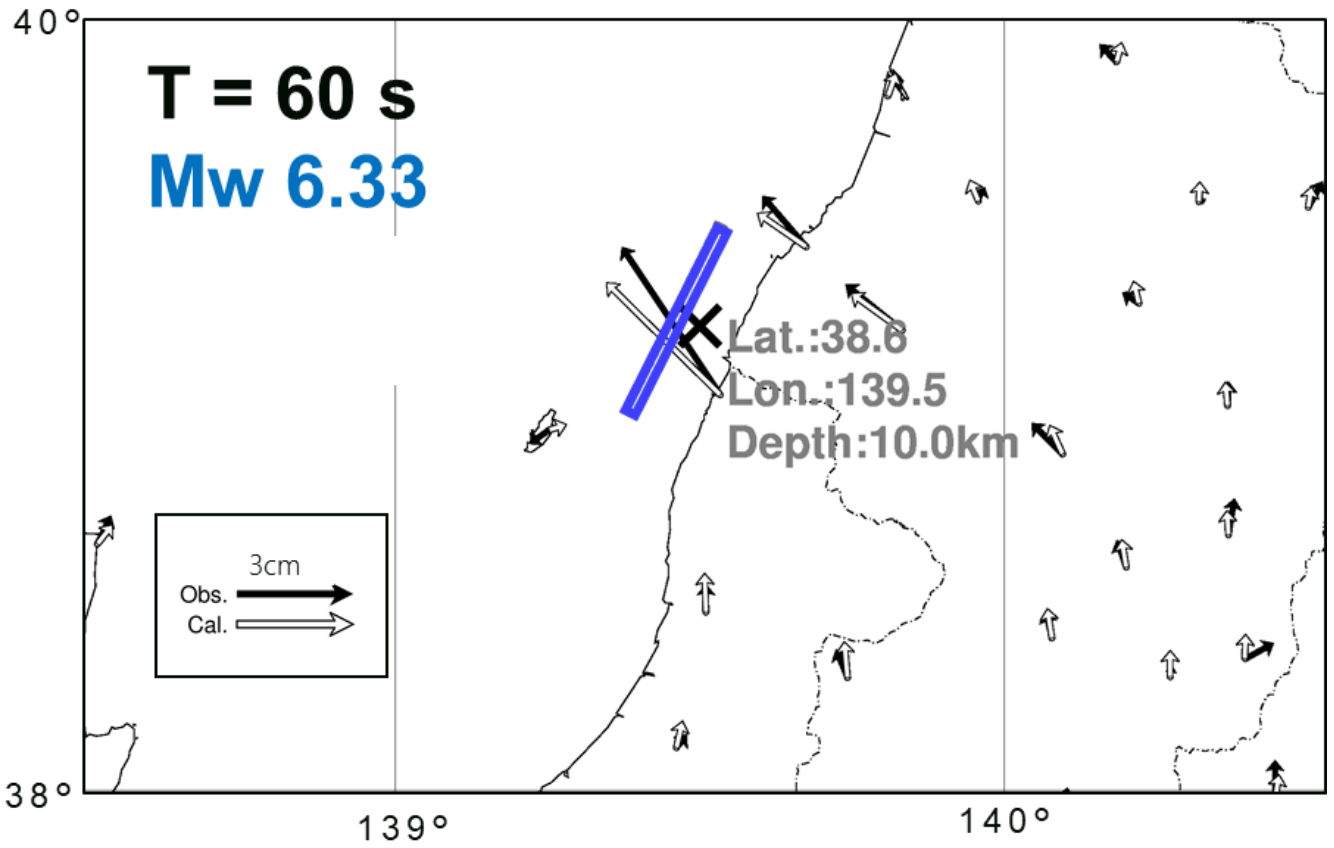
Fault model





- ✓ The estimated fault model was consistent with the post-processed fault model estimated from GNSS and InSAR data

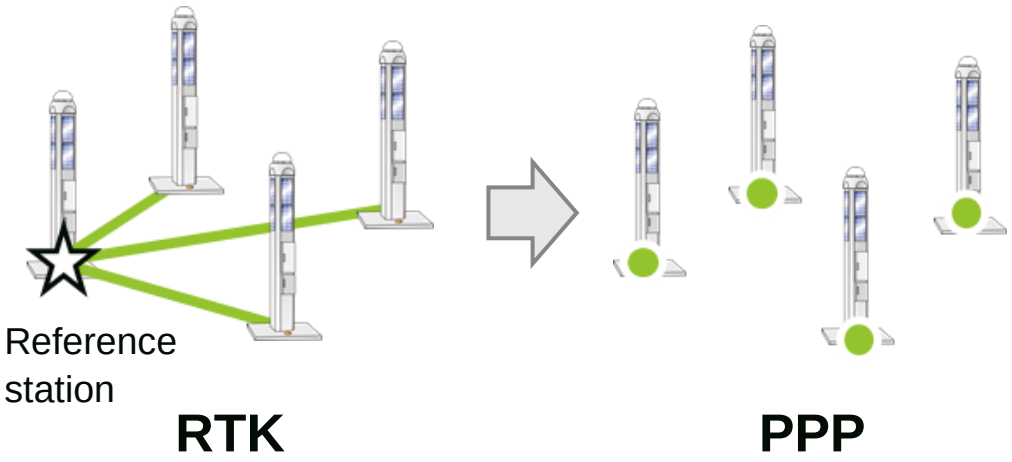
Crustal deformation & Fault model



✓ REGARD worked well even for small displacement events of up to 5 cm

Two recent topics under development

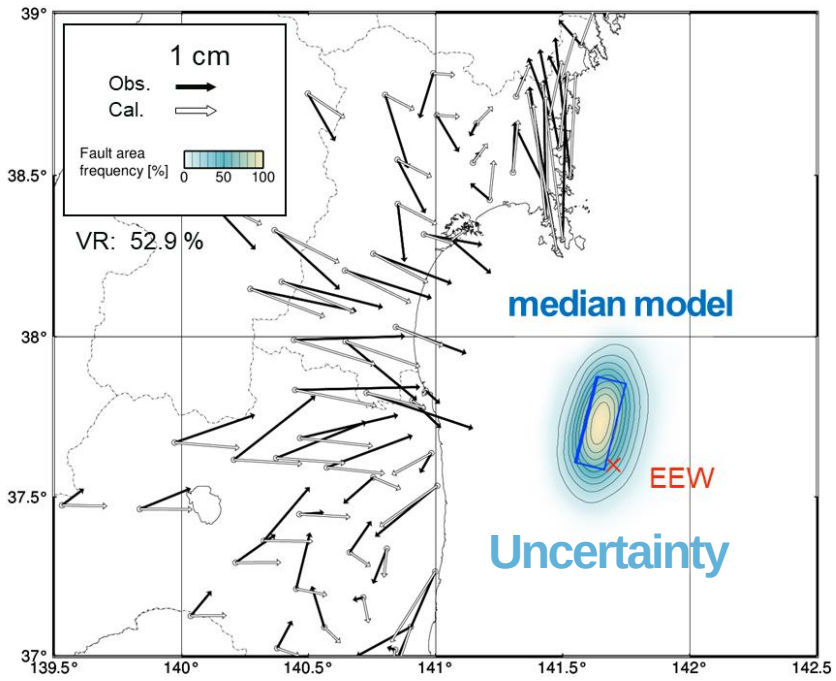
① More robust positioning



- ✓ **PPP** (Precise Point Positioning) can provide equivalent results as RTK, without the influence of reference station's observation error

② New fault model estimation method

(Ohno *et al.*, 2021)



e.g. Fukushima-Oki earthquake (Mw 7.4)

- ✓ **MCMC** (Markov Chain Monte Carlo method) can provide stable estimation and quantitative uncertainty information regarding for Mw and fault parameters

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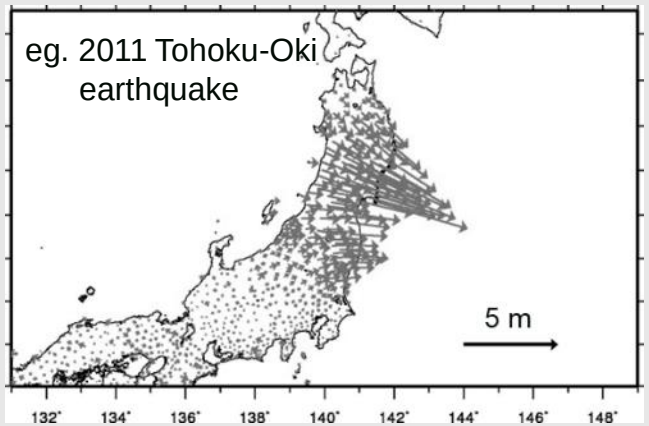
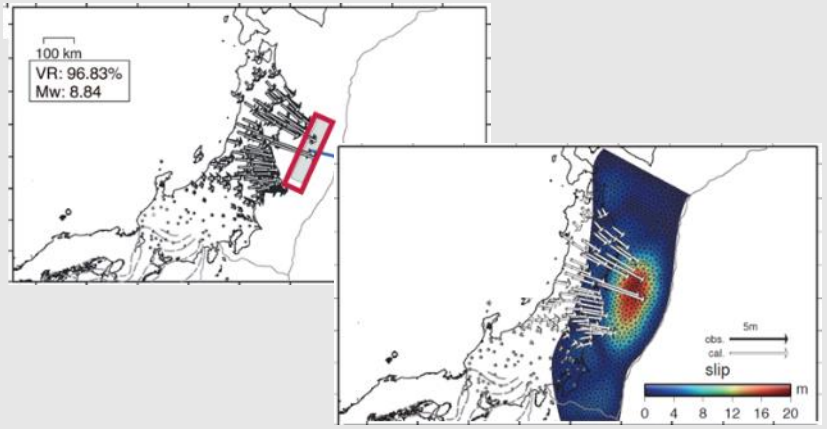
Utilization of REGARD results



Crustal deformation



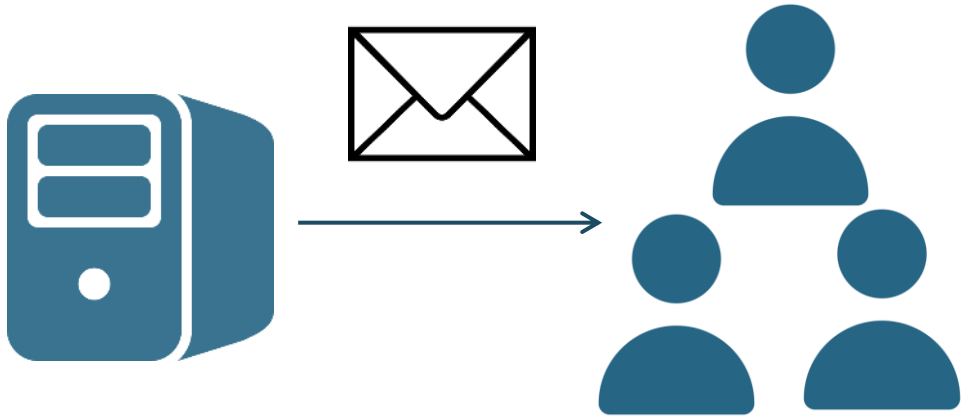
Fault models, Mw

Within several minutes…

These products are automatically sent to :

- ✓ GSI's staff
- ✓ the relevant agencies and organizations

- ✓ Early situation is reported by automated REGARD system via Email
- ✓ Reference information for disaster assessment



within several minutes

Disaster management using REGARD **outside GSI**

- ✓ Initial response of government
- ✓ Supporting information for Tsunami warning update
- ✓ Input model of tsunami inundation calculation system
- ✓ Railway emergency operation plan

(https://ggos.org/about/org/fa/geohazards/)

Summary

Development of REGARD system

- ✓ GSI has operated a real-time GNSS analysis system named “REGARD”, which estimates coseismic fault models and Mw using the Japanese nationwide GNSS network “GEONET”
- ✓ Estimated results are used to support initial response for earthquakes and rapid tsunami prediction
- ✓ For more reliability and robustness, two improvements are ongoing: PPP and MCMC

Performance

- ✓ Past large earthquakes were well simulated
- ✓ REGARD has successfully provided accurate fault models in real-time