Real-time coseismic fault model estimation based on RTK-GNSS analysis in Japan

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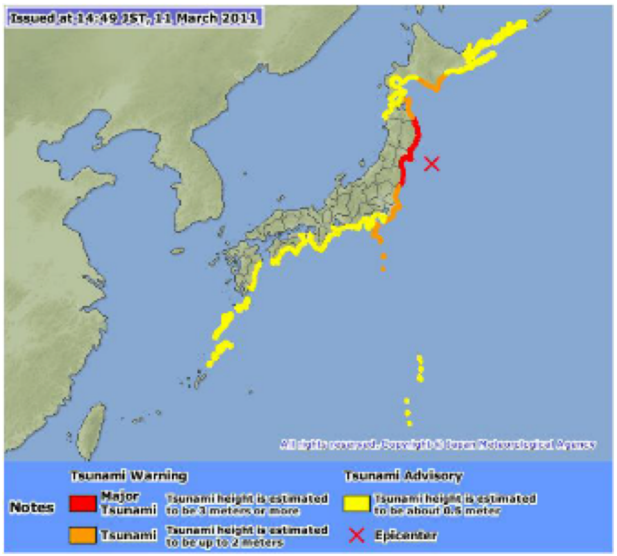
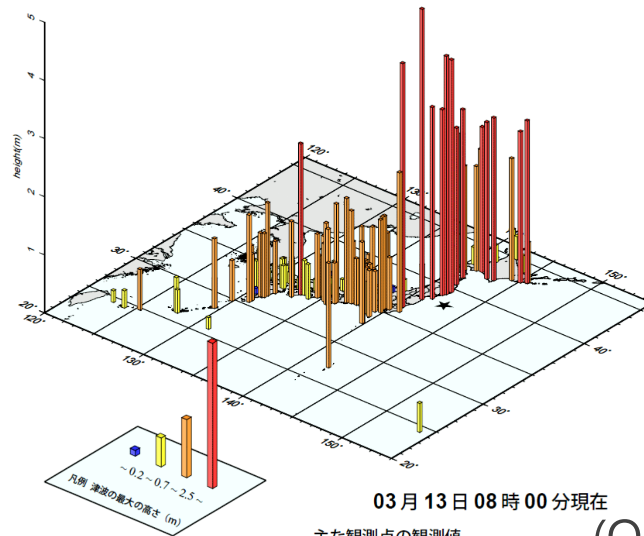
Contents

Underestimation of Tsunami warning for the 2011 Tohoku Earthquake (Mw 9.0)

Warning at 3 minutes



Observed



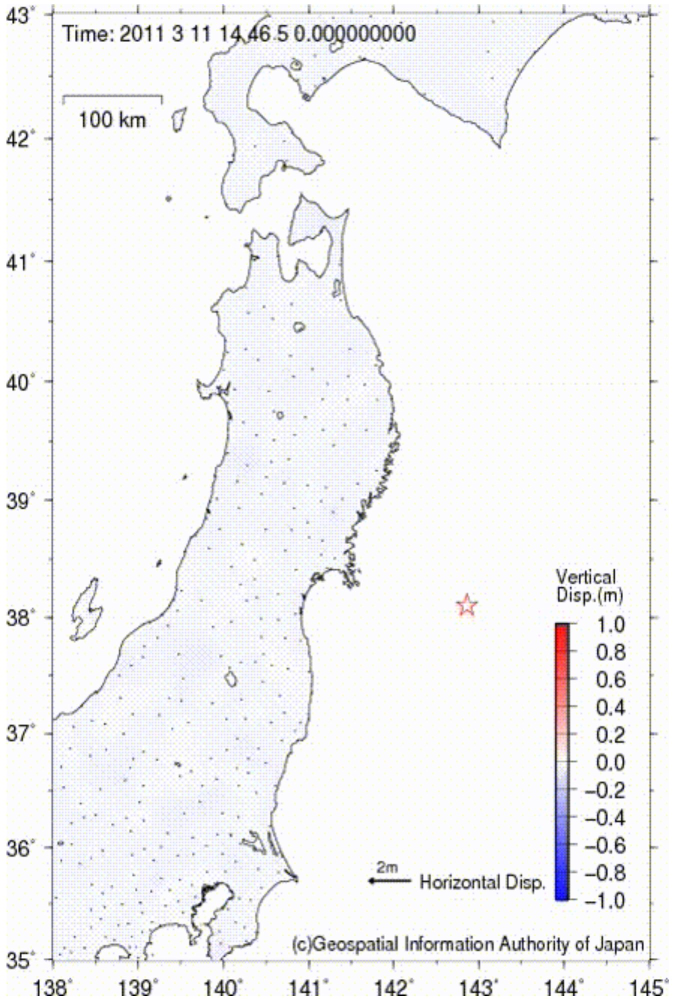
(Ozaki, 2011)

Reasons:

- tsunami warning depended on magnitude based on **short period seismometers**
- Used a saturated magnitude (**M7.9**)

How to prevent the saturation problem?

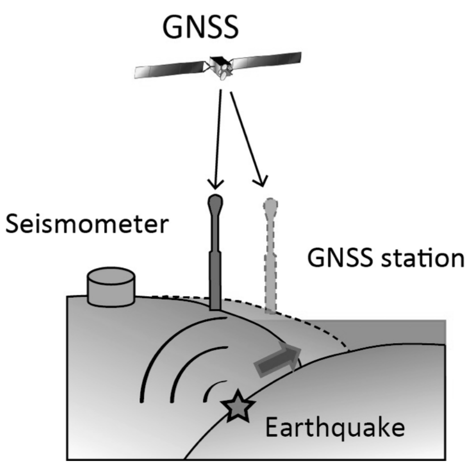
Prevention of the Magnitude Saturation



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

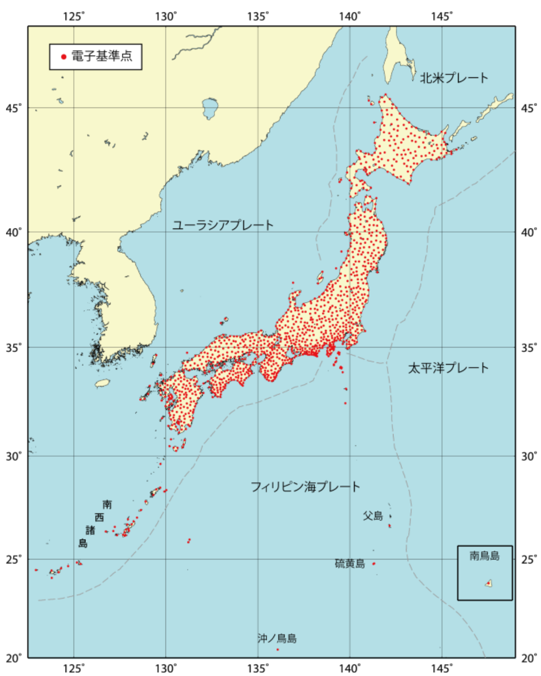
Real-time Kinematic GNSS provides:

- Real-time displacement
- Finite fault model
- Mw **free from saturation problem**



GEONET

Japan's official CORS (GNSS) network



- 1,318 stations
- Distributed at 20 km intervals
- Continuous observation
- Real-time communication

Enables **real-time finite fault estimations** based on GNSS data

GOAL

Provision of

finite fault model within 3 minutes

to improve tsunami warning

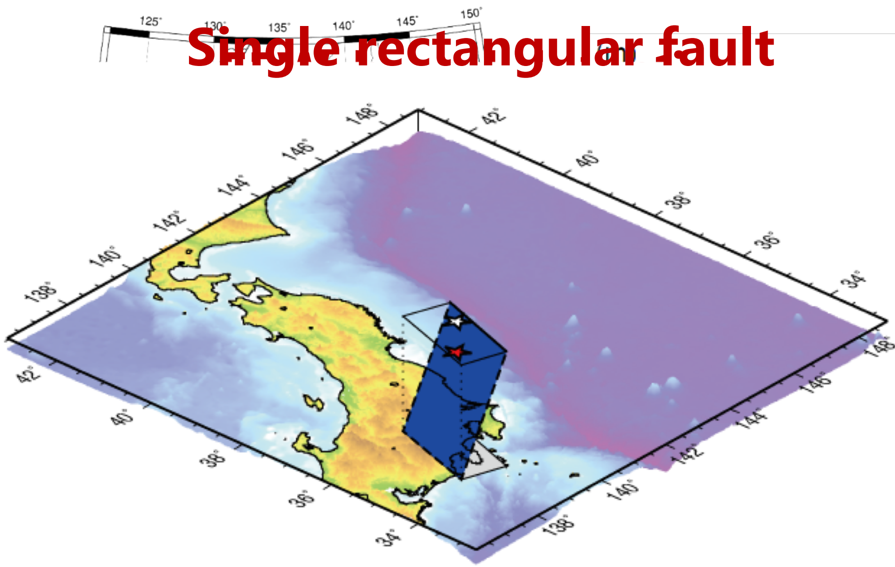
Contents

Development of REGARD system

Provides Mw within 3 minutes

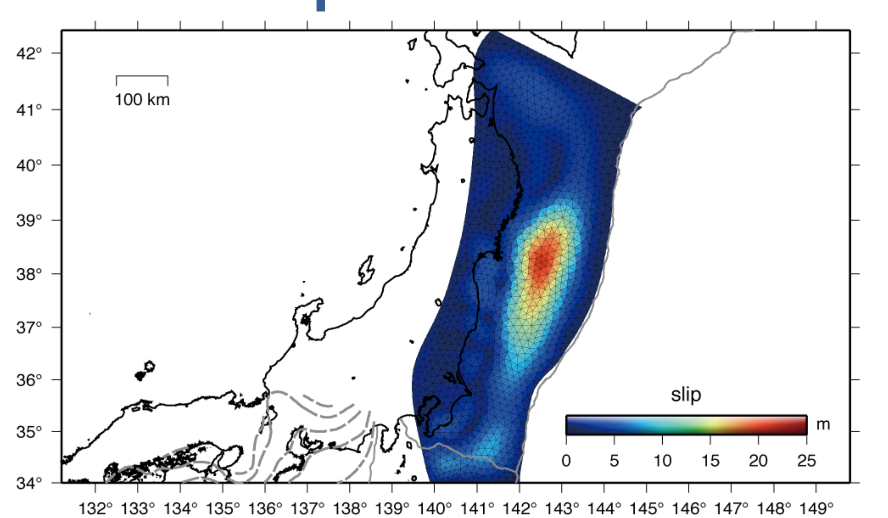
- Calculates 1Hz displacement by RTK
- Detects earthquake events
- Estimates fault model automatically

Single rectangular fault



GNSS-based detection

Slip distribution



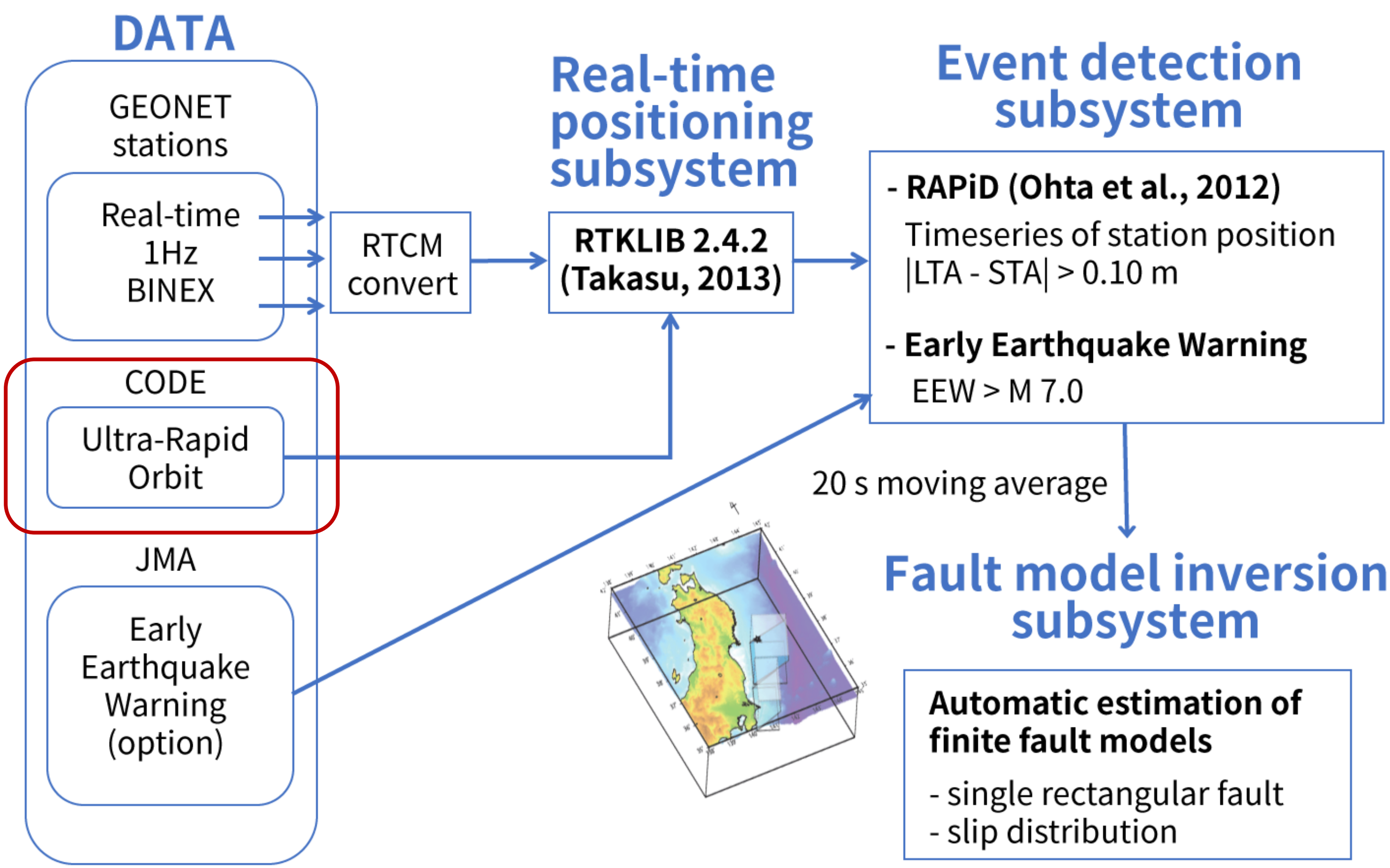
Threshold: **10 cm**

Basic concept of the system

Continuously	RTK-GNSS analysis
30 – 40 sec	Event detection
1 – 3 min	Estimations of Finite faults
3 min ~	Results distribution

Importance of ultra-rapid orbit

REGARD system depends on **ultra-rapid orbit (predicted part)** for precise positioning

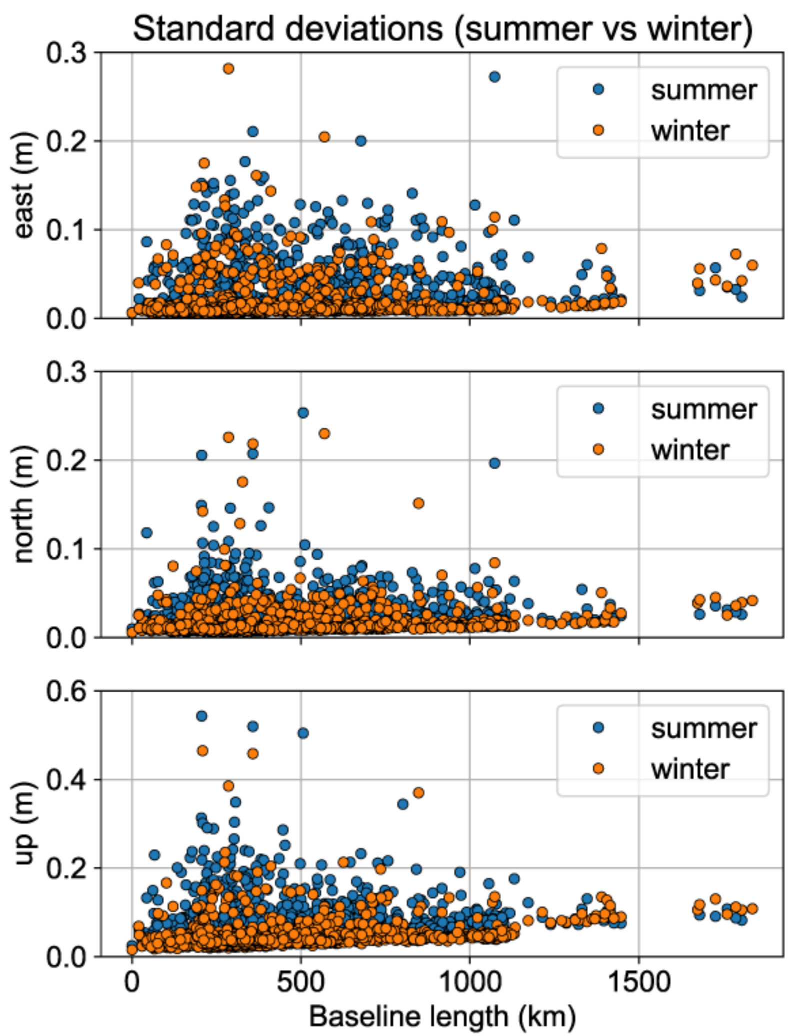


Positioning precision of REGARD

E

N

U



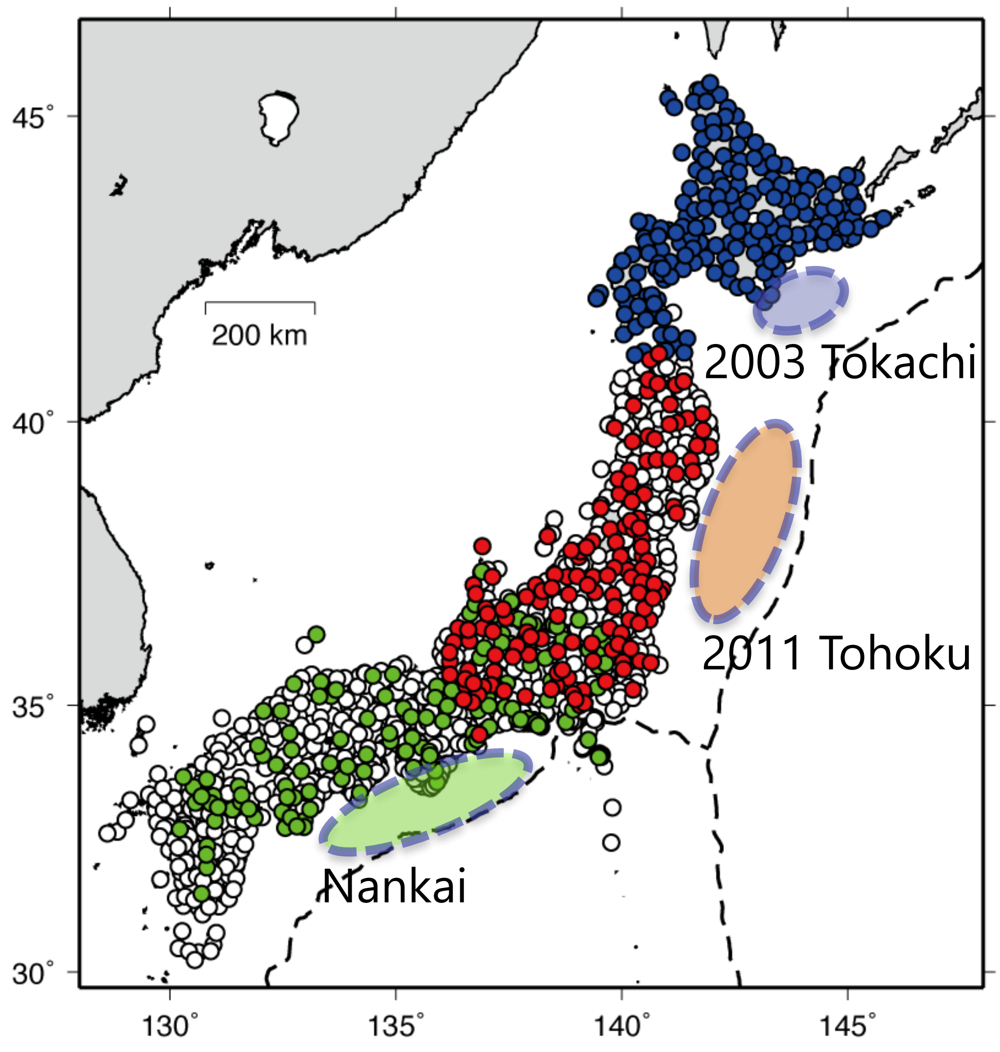
Mean Std: 2.4cm

Mean Std: 2.2cm

Mean Std: 6.1cm

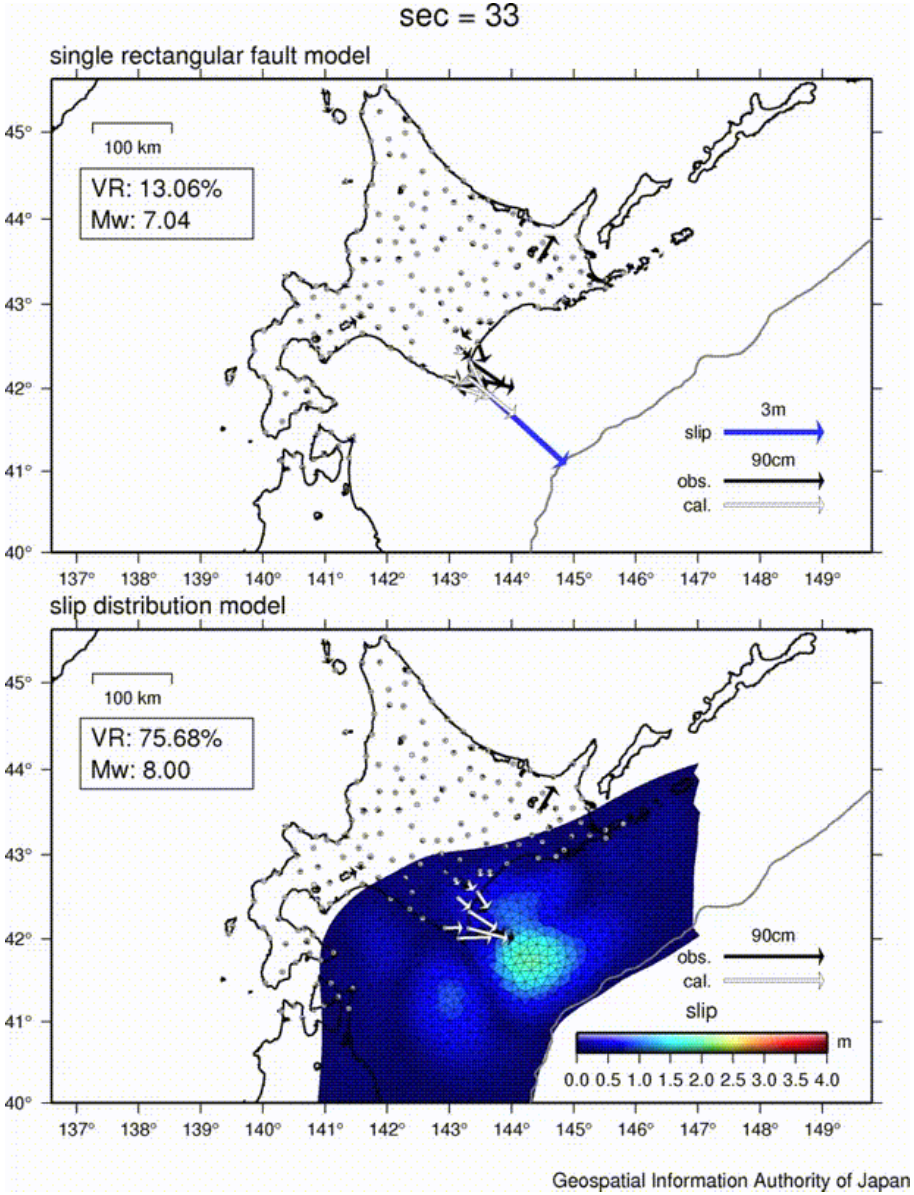
Contents

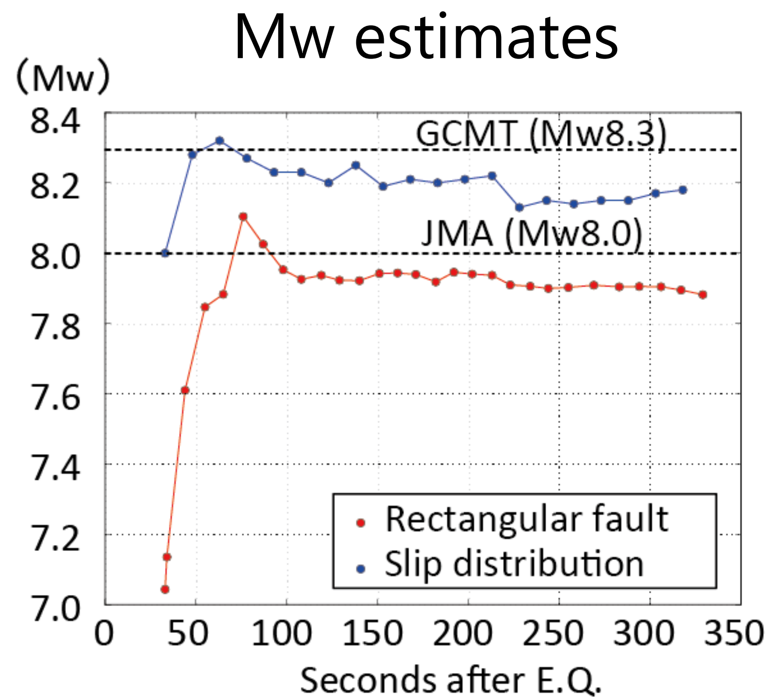
Tests for past large earthquakes



- 2003 Tokachi-oki earthquake (Mw 8.3)
- 2011 Tohoku earthquake (Mw 9.0)
- Nankai Trough earthquake (Mw 8.7; simulation data)

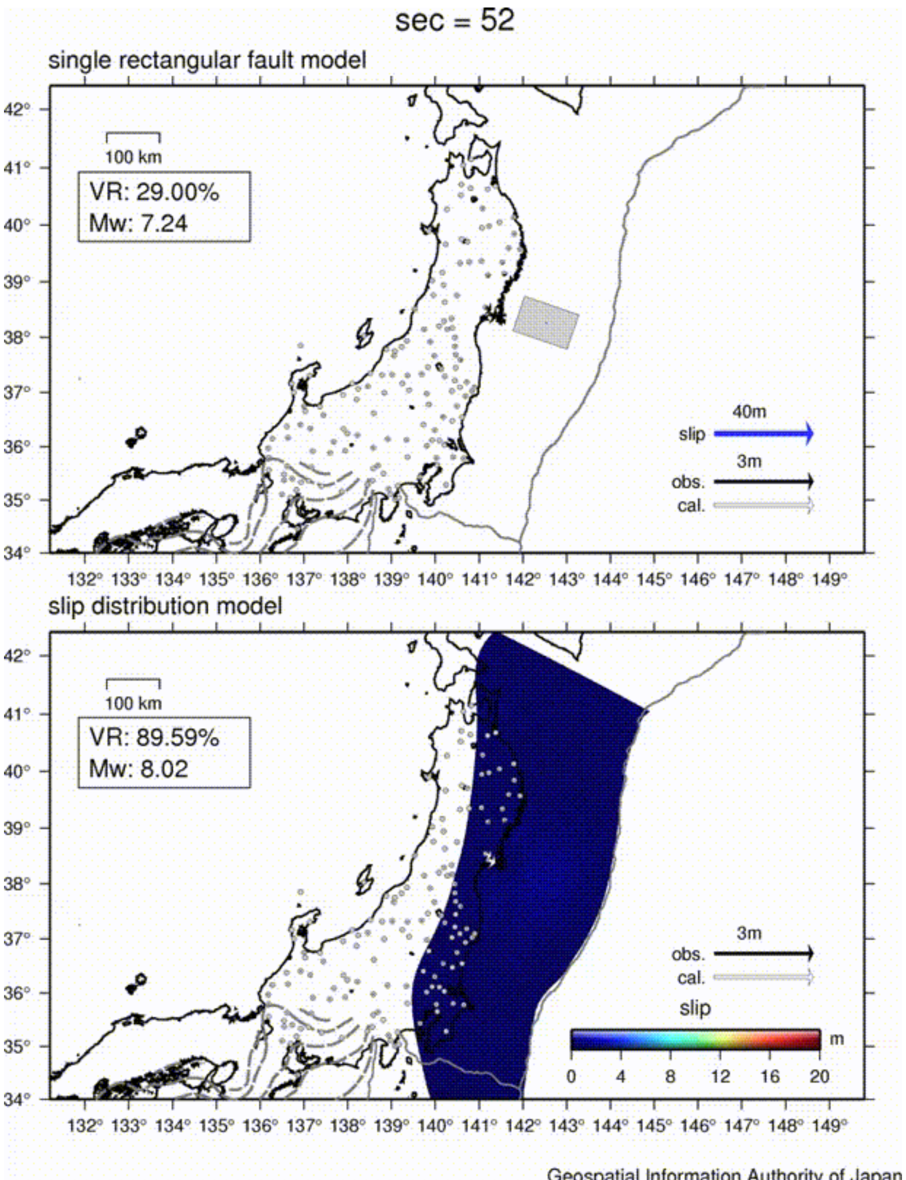
2003 Tokachi-oki earthquake (Mw 8.3)

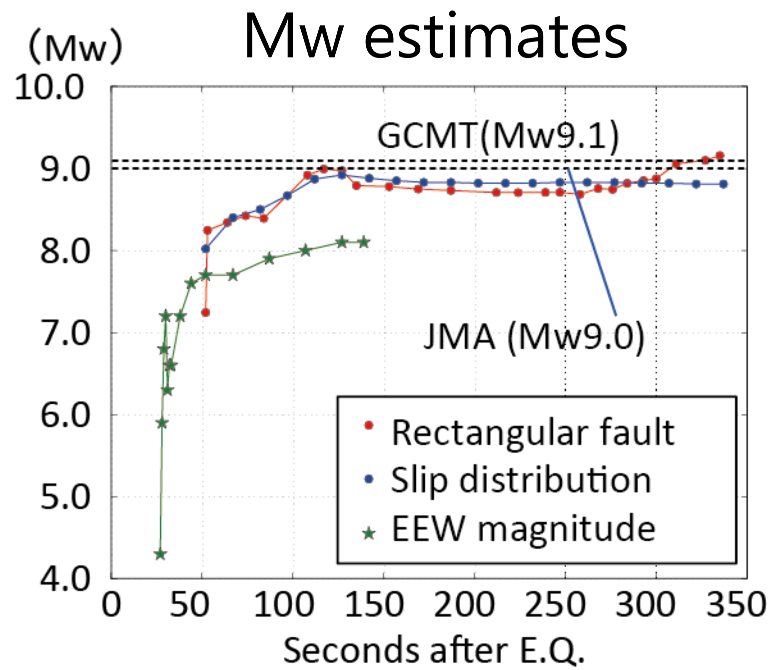




- **Both models were stable** with high VRs
- Single rectangular fault was smaller because it converged to a shallower depth

2011 Tohoku earthquake (Mw 9.0)

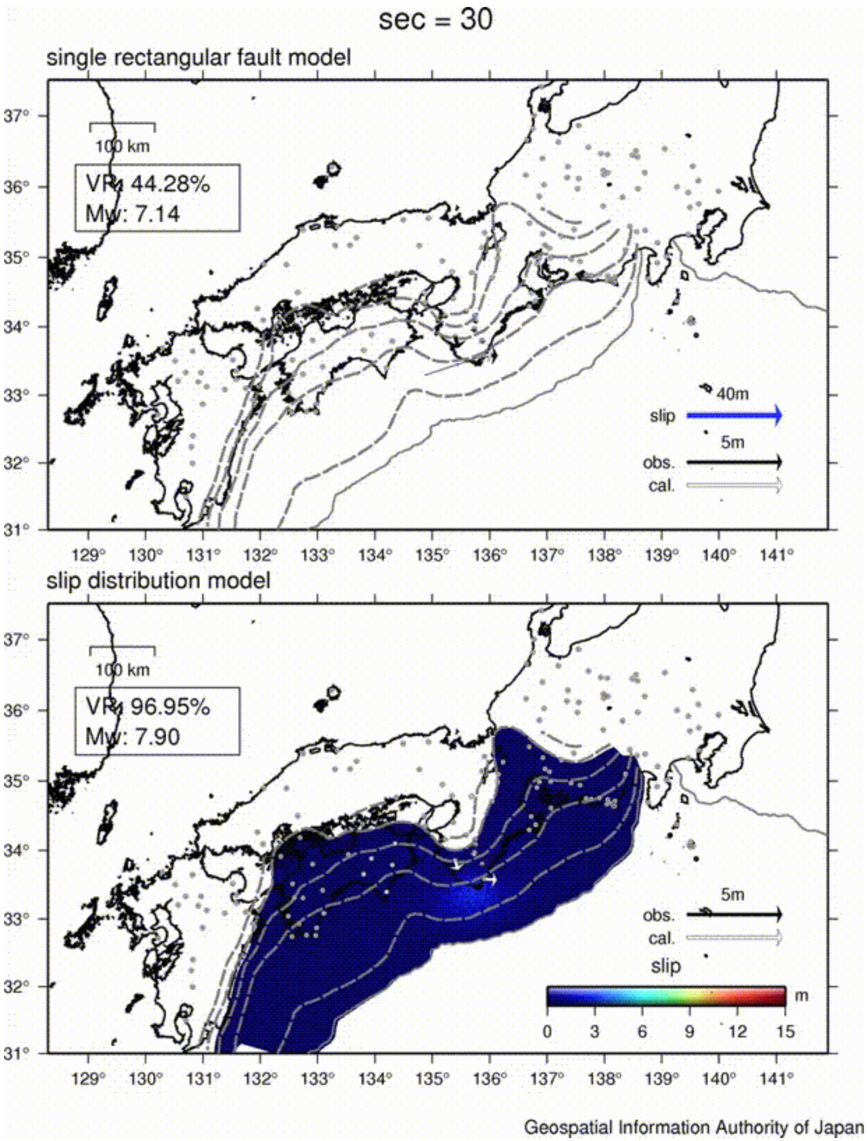


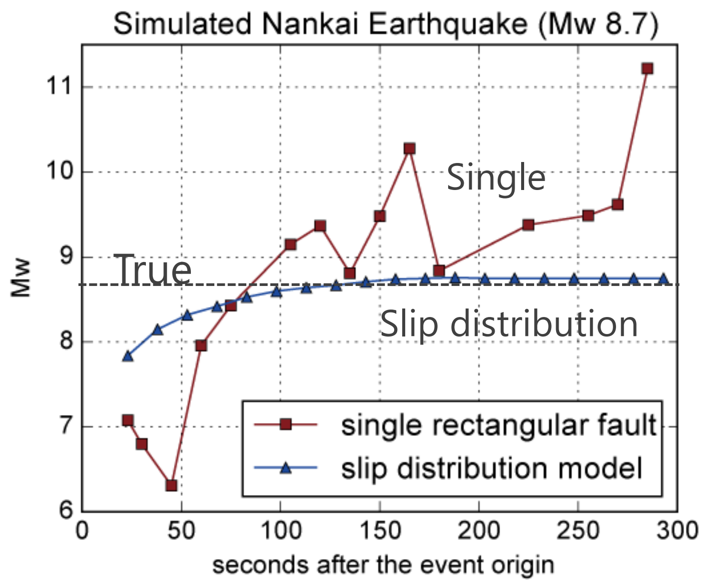


- **Stable after 120 seconds**

Single fault: Mw 9.03 (VR 96%)
Slip distribution: Mw 8.83 (VR 99%)

Nankai Trough earthquake（Mw8.7）

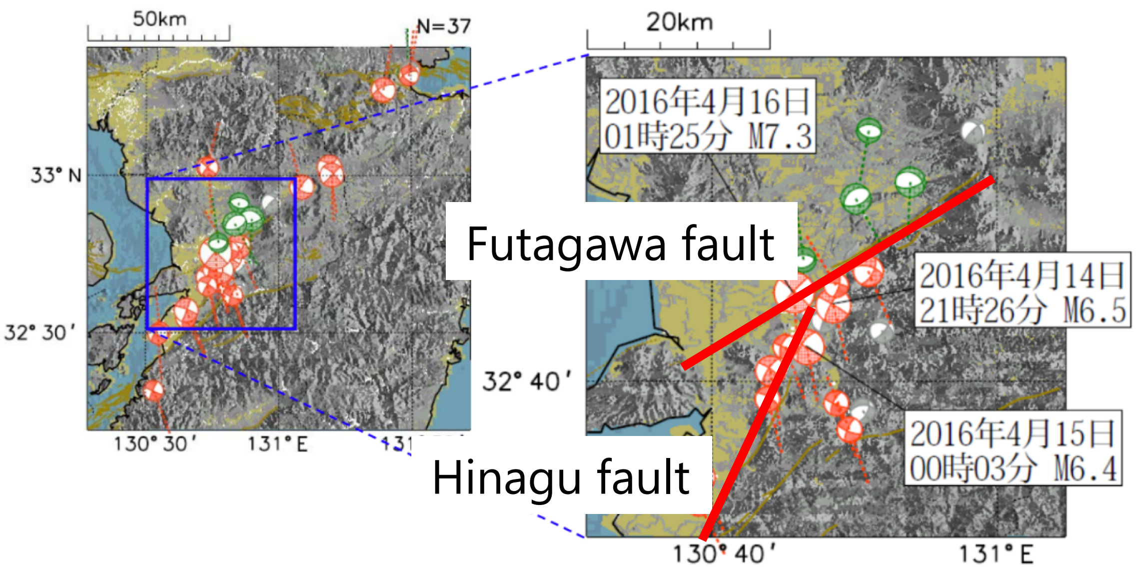




- **Slip distribution model provided accurate Mw**
- Single rectangular fault was unstable due to the complex plate boundary and slip

Contents

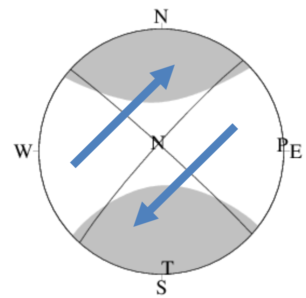
The 2016 Kumamoto earthquake (M7.3; Mw7.0)



（Japan Meteorological Agency）

図２－４　発震機構（CMT 解）分布図
（1997 年 10 月 1 日～2016 年 4 月 30 日、
深さ０～30km、M≧4.0）
シンボルから伸びる点線は張力軸の方位を示す。
橙色は横ずれ断層型、緑色は正断層型の発震機構を示す。
震央分布図中の細線は、地震調査研究推進本部の長期評価による活断層を示す。

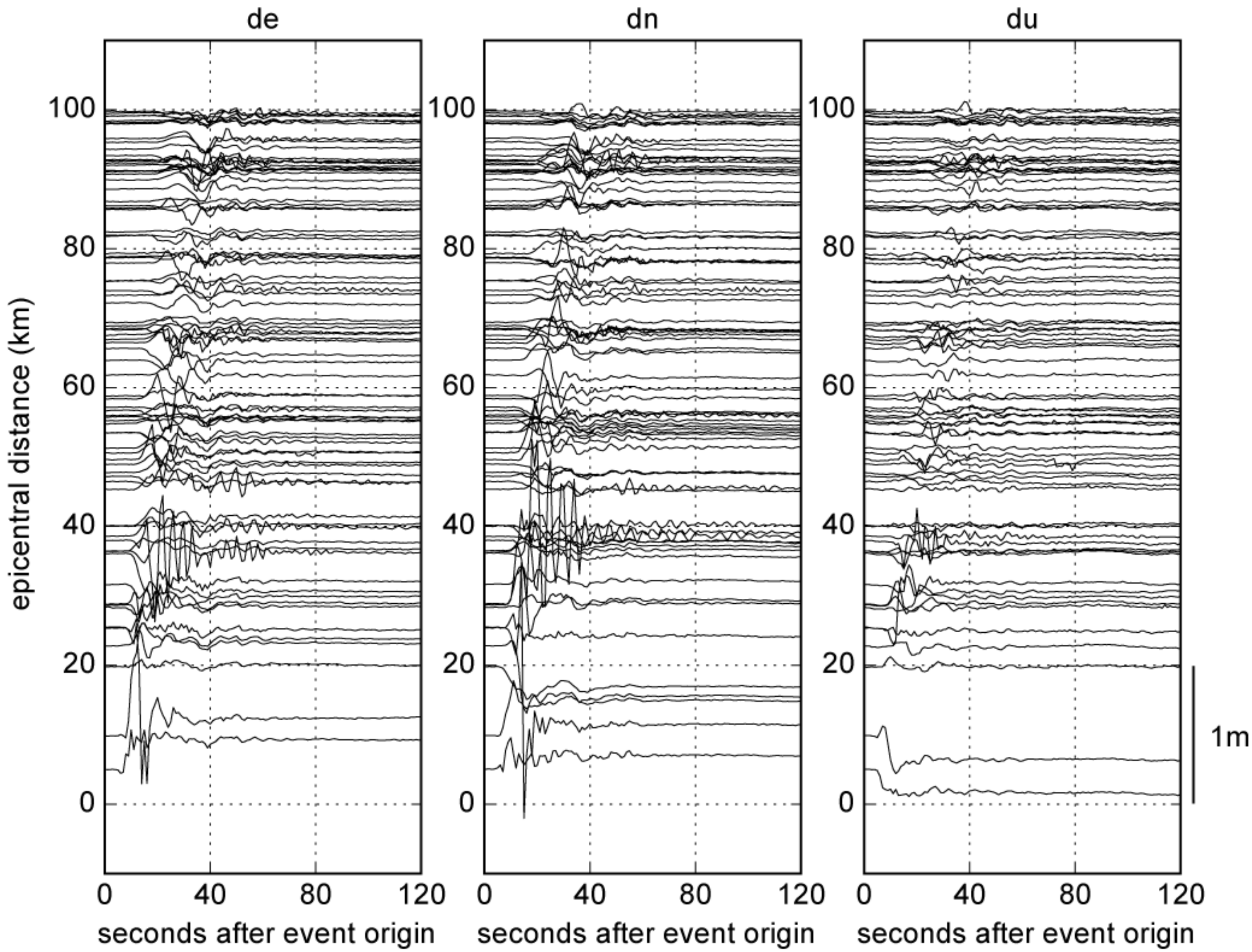
Massive landslide



4/16 Mw7.0

- Two large foreshocks（M6.5 on April 14, M6.4 on April 15）
- **The mainshock (M7.3)** caused significant damage
- NE-SW right lateral strike slip along the Futagawa-Hinagu fault zone

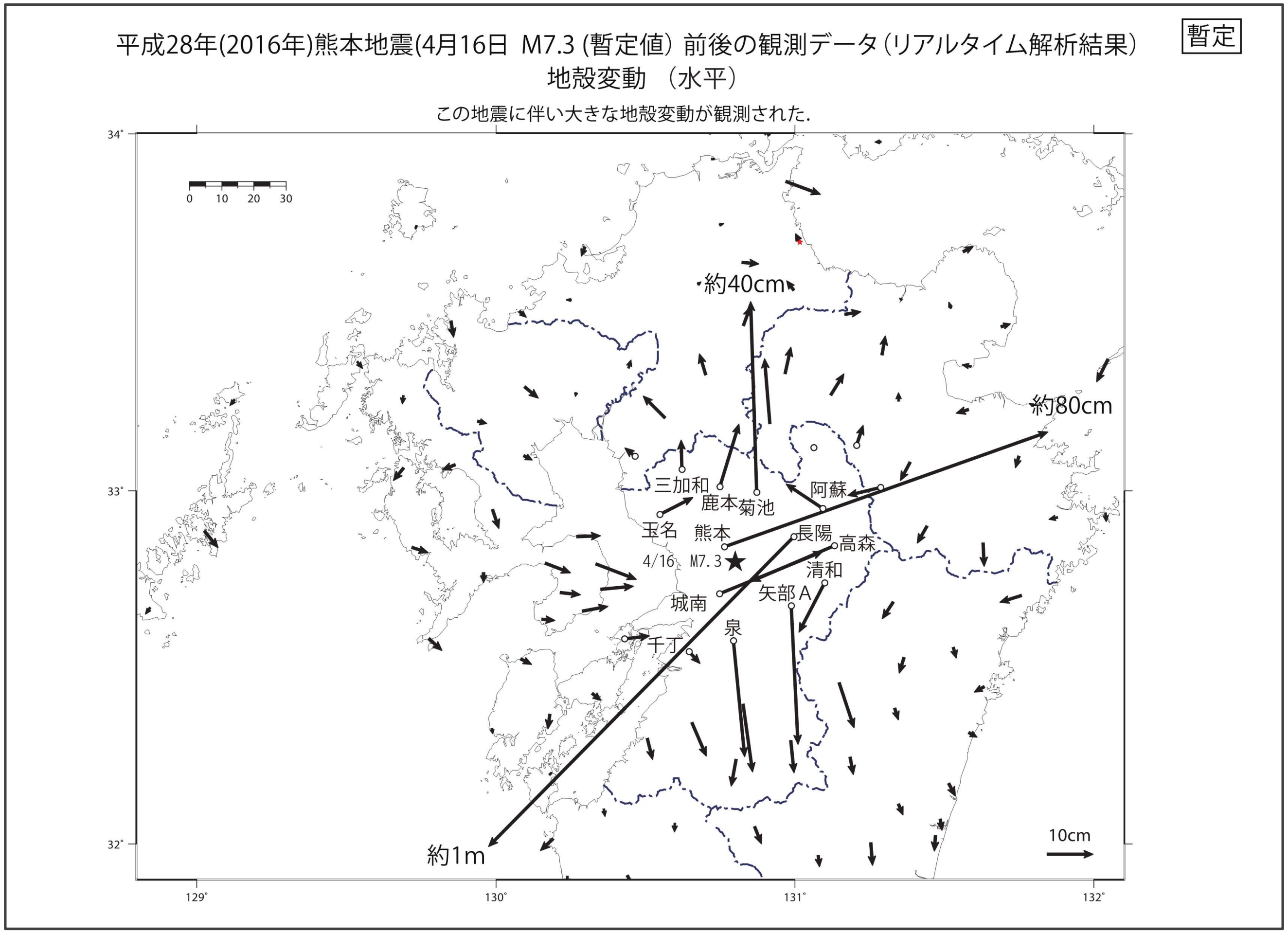
Coseismic displacements by GNSS



t0=01:25:05

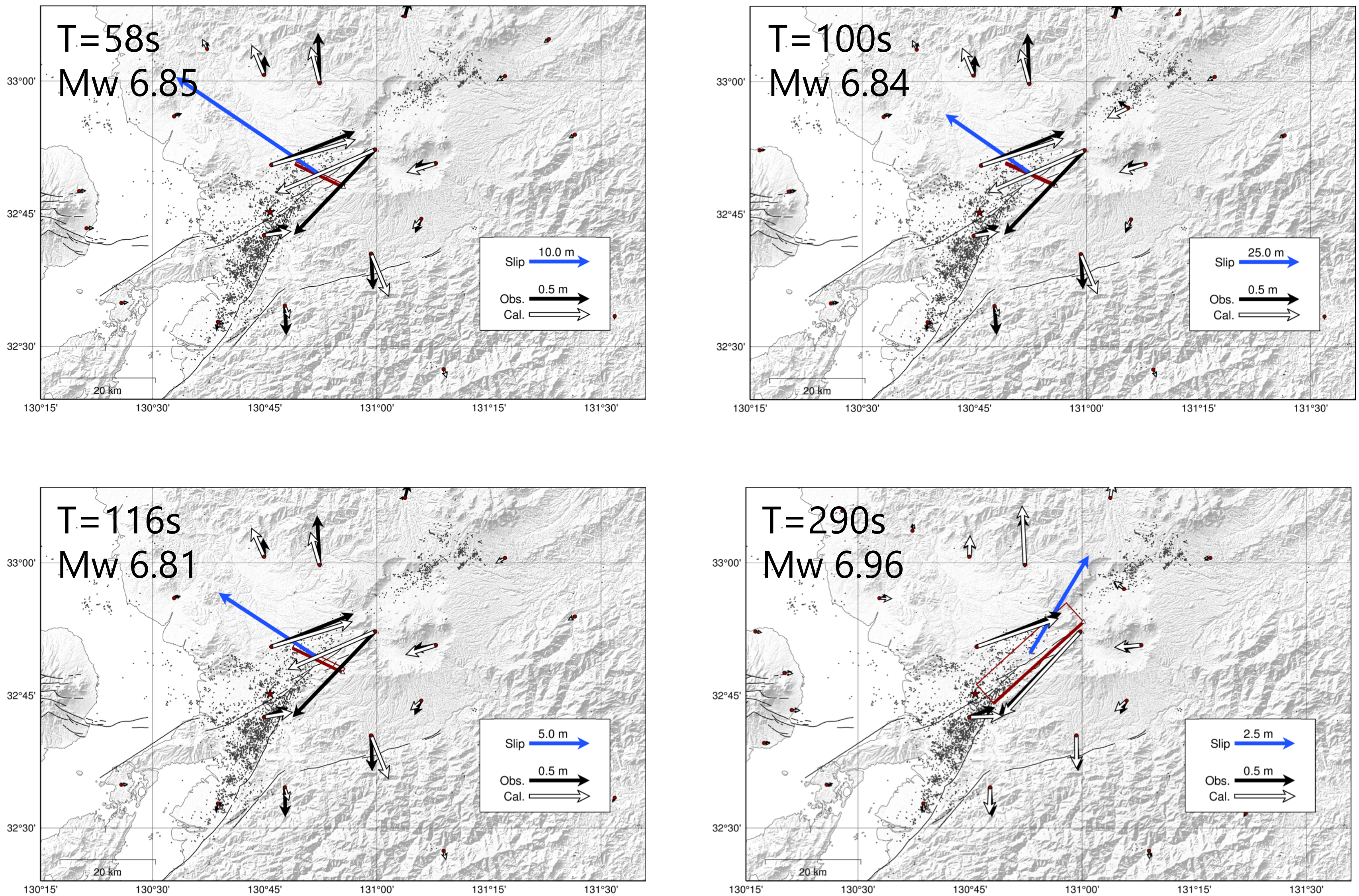
Coseismic displacements due to the mainshock

Significant horizontal displacements of up to 1m

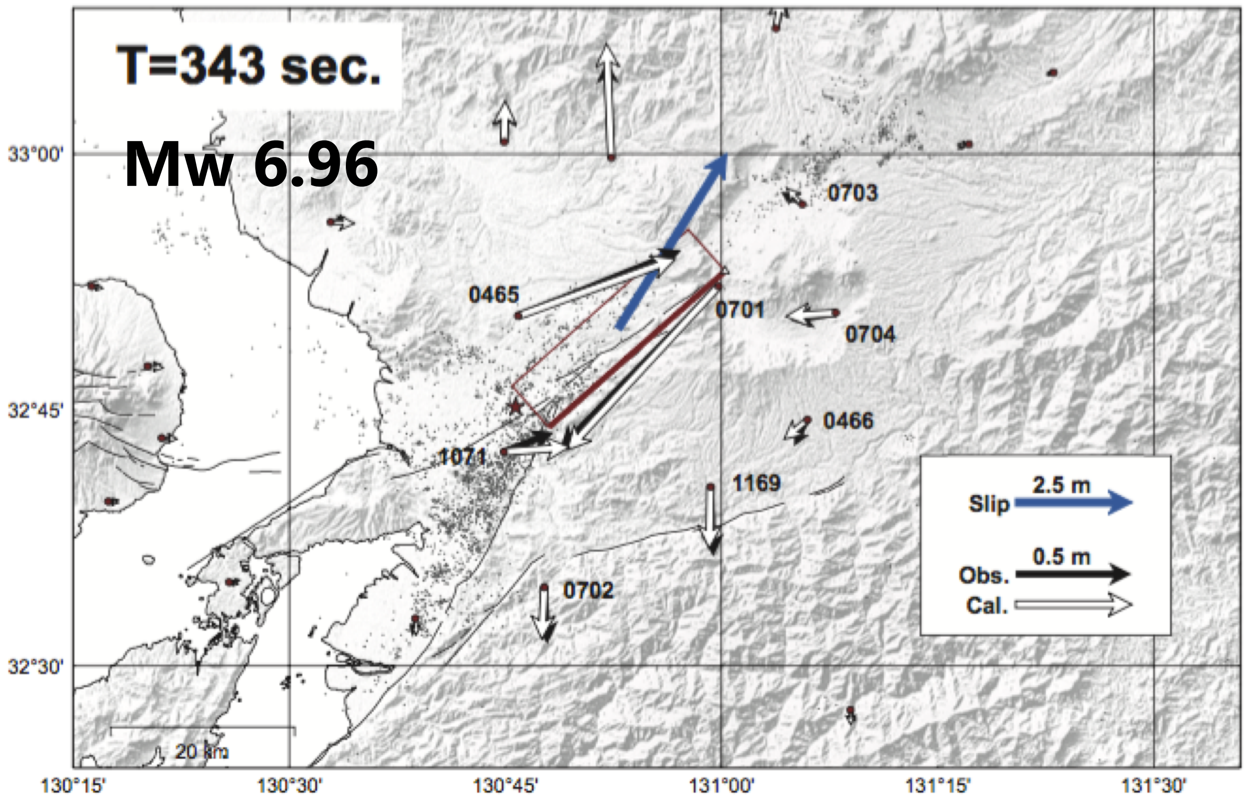


Observed displacements published on the GSI website

Real-time inversion results

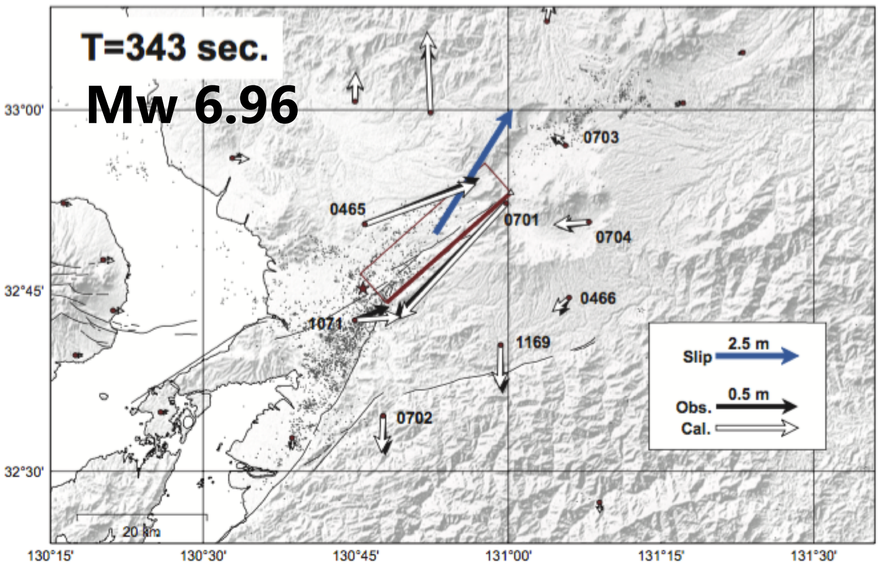


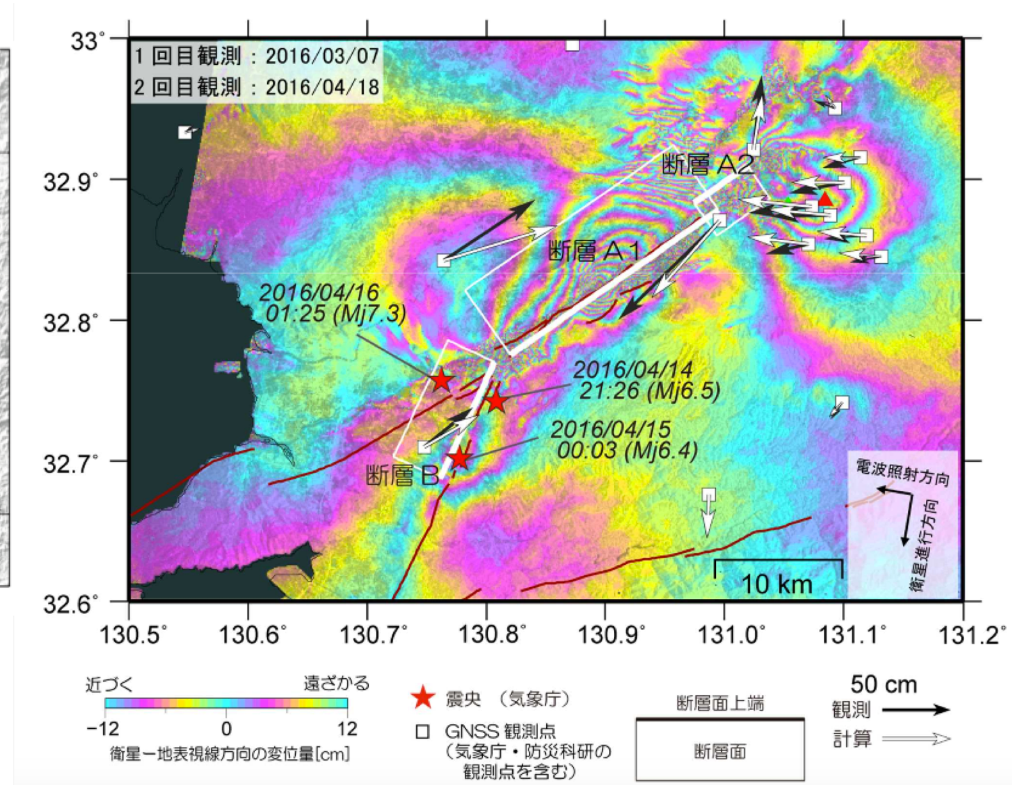
Final model for Kumamoto EQ (Mw 7.0)



Provided right-lateral slip fault model along the Futagawa fault segment **within ~5 minutes**

Final model vs post-processed model





http://www.gsi.go.jp/common/000140781.pdf

Consistent with the post-processed fault model inferred from GNSS and InSAR data

Contents

Conclusion

Development of REGARD system

- Implements RTK-GNSS at 1,200+ sites
- Provides finite fault estimates within **3 minutes**
- successfully **provided accurate fault model for the 2016 Kumamoto earthquake in real-time**

For more robust system…

- **Multi-GNSS products** (ultra-rapid or real-time orbit) are important for more accurate positioning
- Implementation of PPP for redundancy

Related works:

- Ohta et al. (2012), Quasi real-time fault model estimation for near-field tsunami forecasting based on RTK-GPS analysis: Application to the 2011 Tohoku-Oki earthquake (Mw9.0), JGR.
- Kawamoto et al. (2016), First result from the GEONET real-time analysis system (REGARD): the case of the 2016 Kumamoto Earthquake, Earth, Planets and Space.
- Kawamoto et al. (2017), REGARD: A new GNSS-based real-time finite fault modeling system for GEONET, JGR.