ICG Working Group D

Reference Frames, Timing and Applications

How GNSS CORS in Japan works for geodetic control and disaster mitigations

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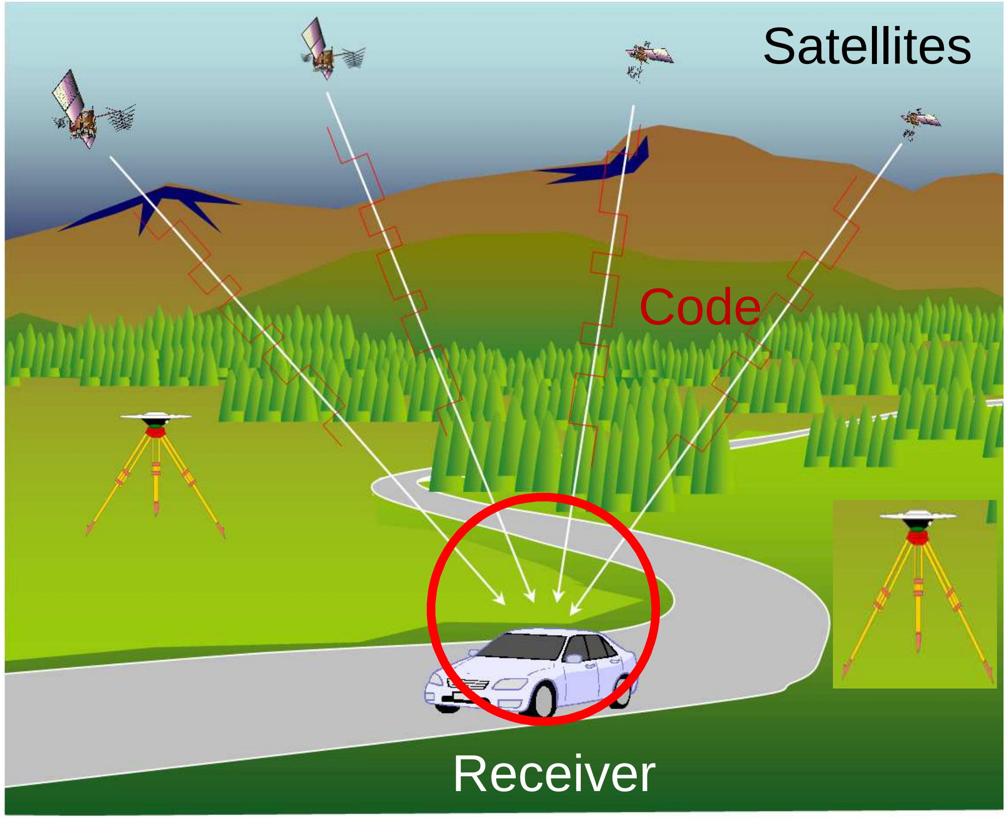
   - Disaster mitigations
     - Real-time GNSS analysis system for rapid earthquake fault estimations

Introduction to GEONET

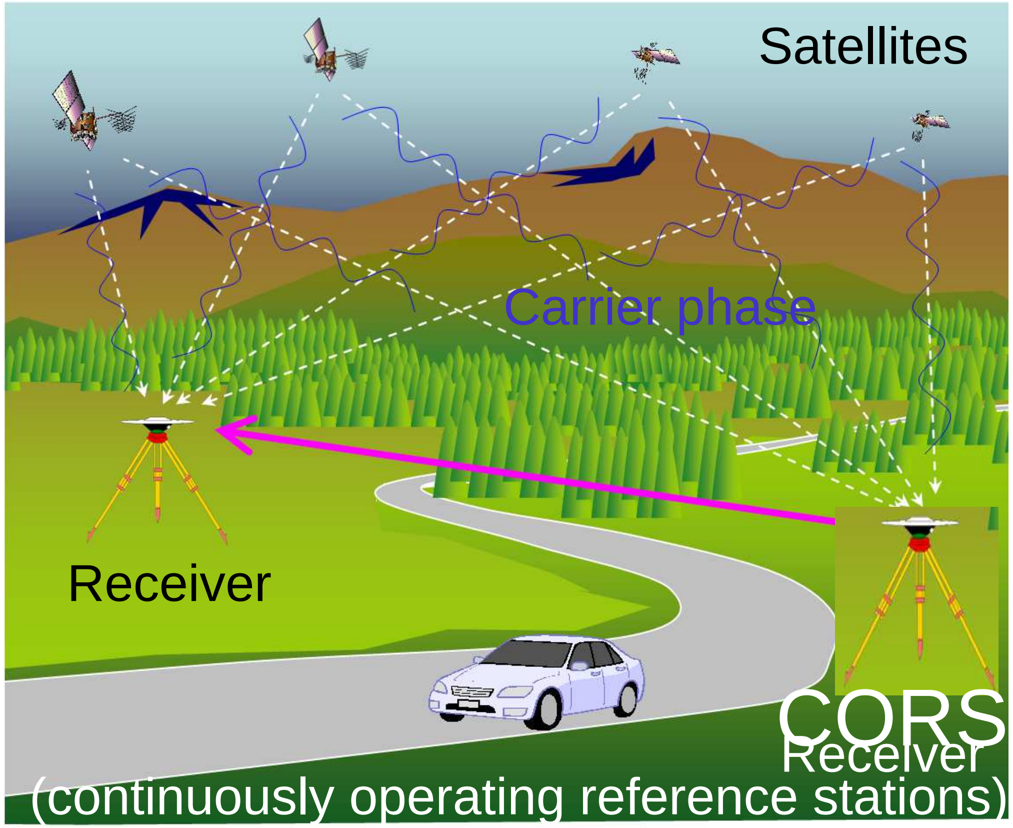
Positioning with GNSS

Car Navigation



- ✓ Point positioning (XYZ) or (Lon, Lat, H)
- ✓ Precision ～ 10 m

Land Surveying

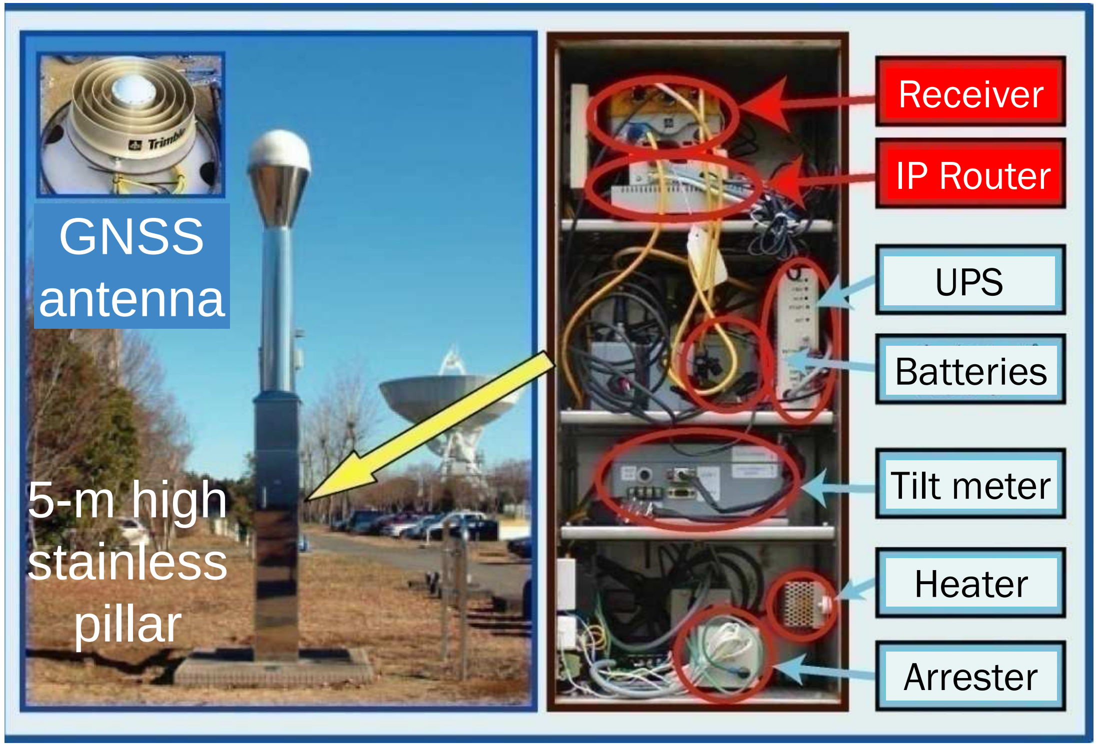


- ✓ Relative positioning between 2 receivers
- ✓ Precision ～ 1 cm

What is GEONET ?

- One of the Largest Continuously Operating Reference Stations networks
  - 1,300 permanent stations with 20km spacing in Japan
  - Collects GNSS data every seconds, and provides data / products to users
  - Includes 7 IGS stations
- Infrastructure for surveying and precise positioning in Japan since 1994

GEONET Stations
(GNSS-based control points)

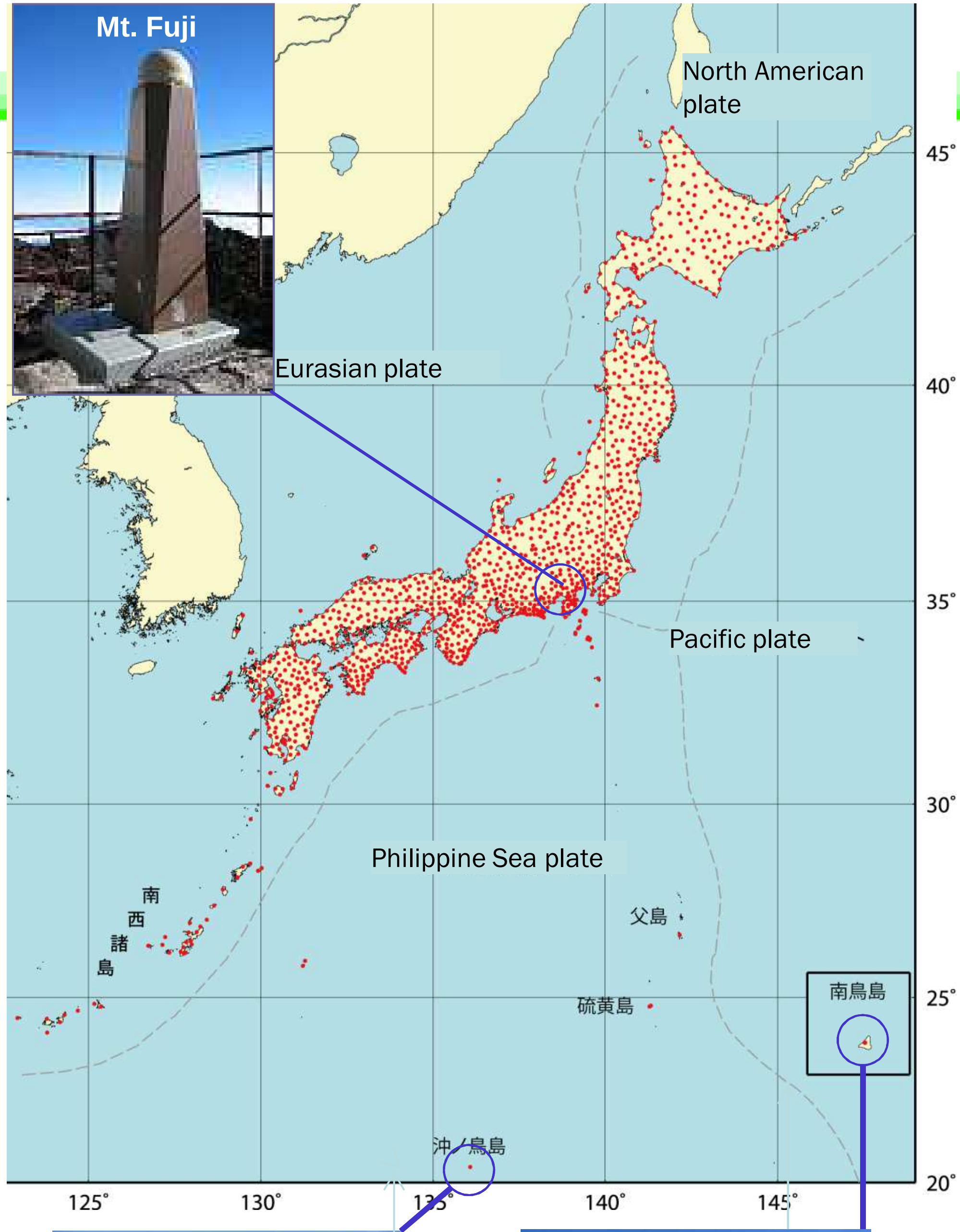


Model 93
1993

Model 94
1994

Model 95
1995-1997

Model 02
2002-



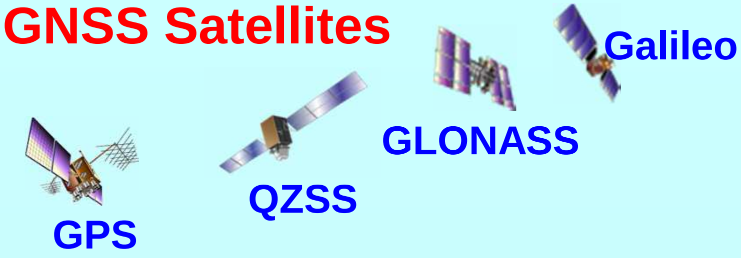
Okino Tori island

Minami Tori island

GEONET data / outcomes

Geospatial Information Authority of Japan (GSI)

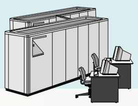
GNSS Satellites



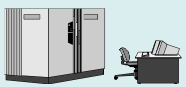
GNSS-based control points

- 20 km spacing
- Operated 24/7
- Transferring real-time 1 Hz observation data

Analysis Center in Tsukuba

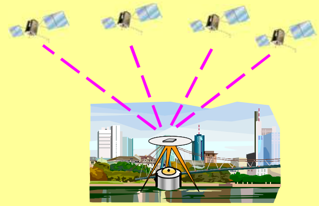


Data Collection



Data Analysis

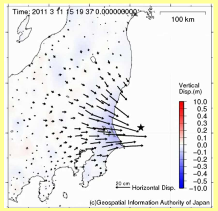
Observed data (every 30 sec)



Survey & Mapping

- Data open to the public via web page, free of charge, with official site coordinates

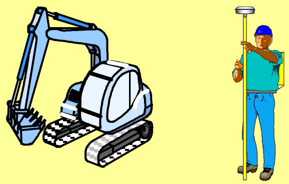
Analyzed data (coordinates)



Crustal deformation Monitor

- Monitoring of Earthquakes and Volcanic activities
- (new) Tsunami early warning

Real-time data

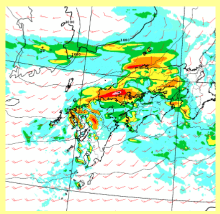


Provided to the Industry

Precise real-time positioning

- ICT construction
- precision farming
- Source of QZSS augmentation

Other data



Applications

- Weather forecast using watervapor info from GNSS
- Ionosphere studies

How GEONET works for geodetic control

- Realization of ITRF in tectonically active regions

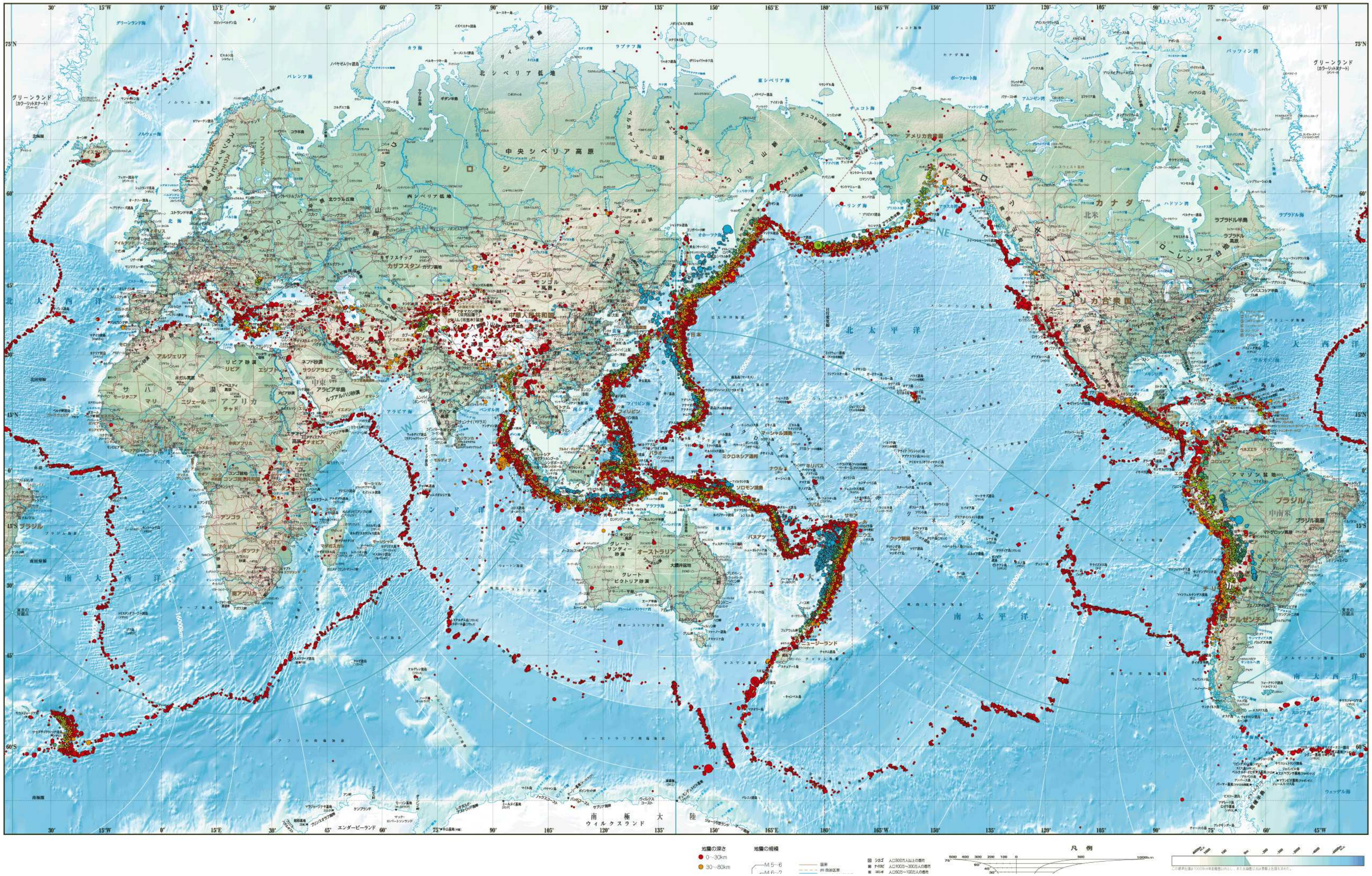
Seismicity map of the world

Geospatial Information Authority of Japan (GSI)

Earthquakes > M5.0 in 1977-2014

世界の震源分布

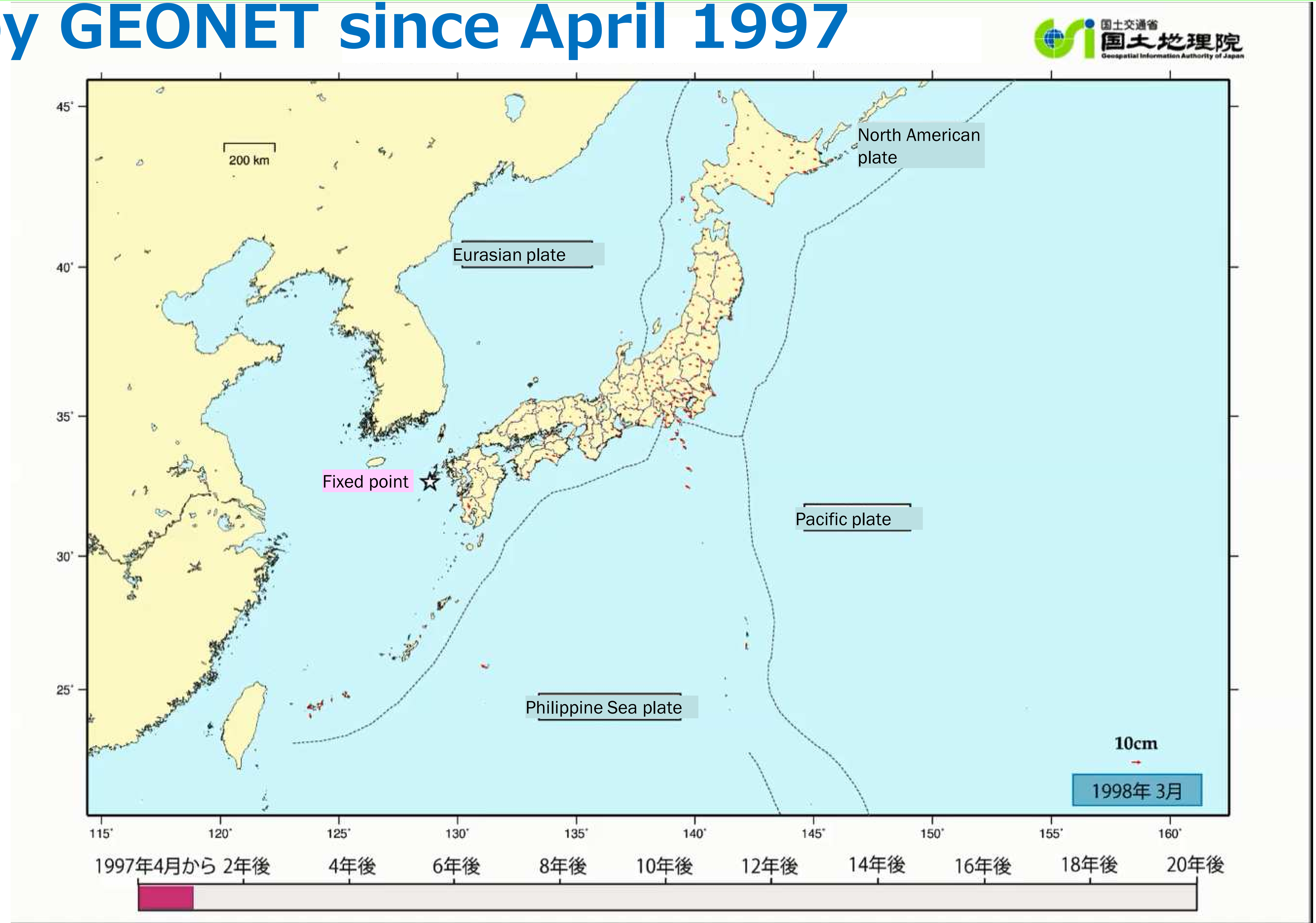
東京大学 地震研究所



Earthquake Research Institute, University of Tokyo, http://www.eri.u-tokyo.ac.jp

Crustal deformation observed by GEONET since April 1997

Geospatial Information Authority of Japan (GSI)

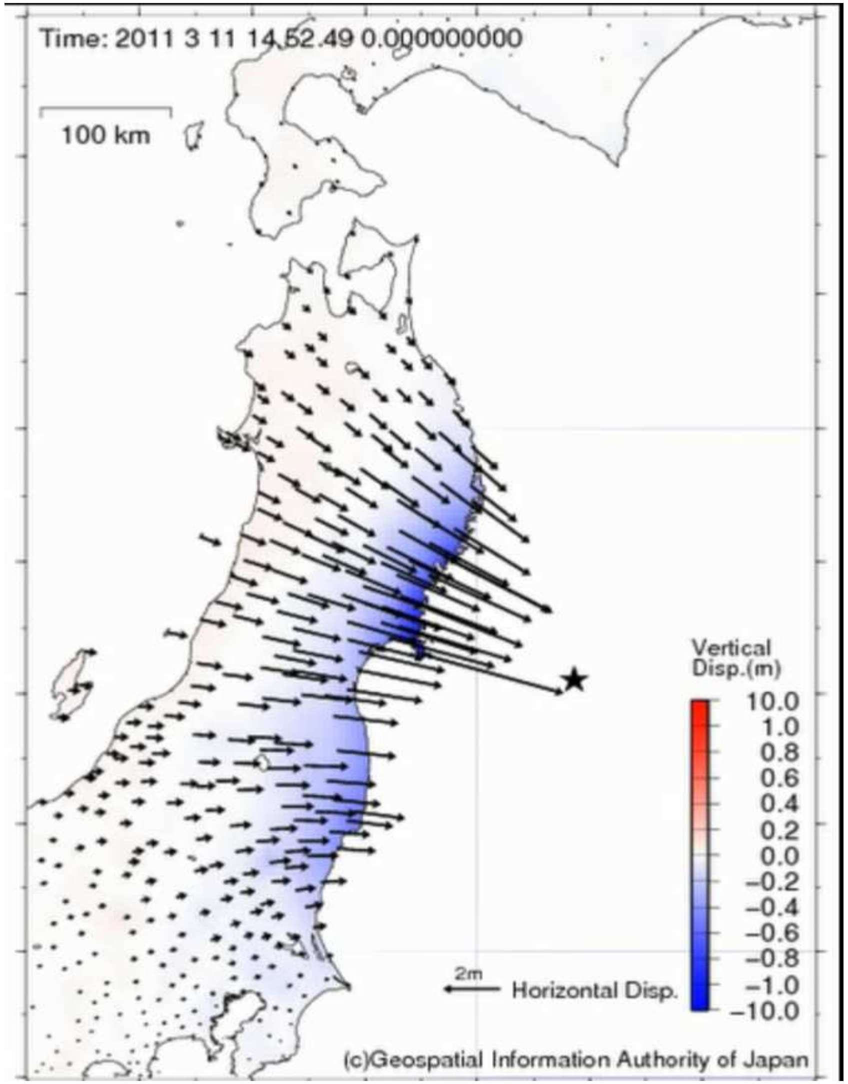


Tohoku EQ (M9.0)
March 11, 2011

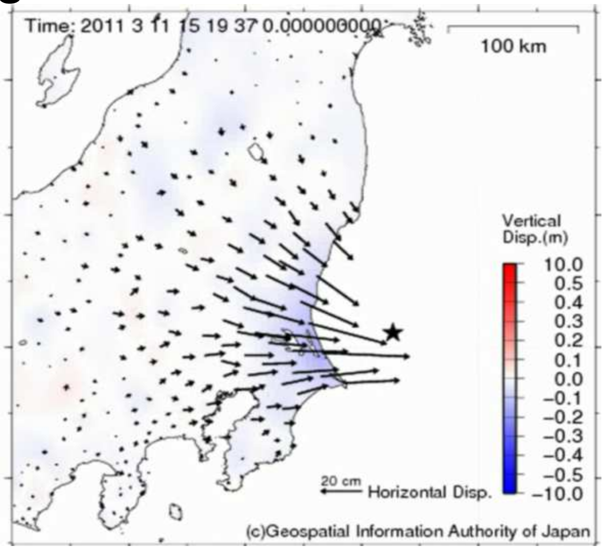
Coseismic deformation field observed by GEONET with 1Hz

Geospatial Information Authority of Japan (GSI)

14:46, March 11, 2011
Main shock M9.0



15:15, March 11, 2011
Largest after shock M7.7

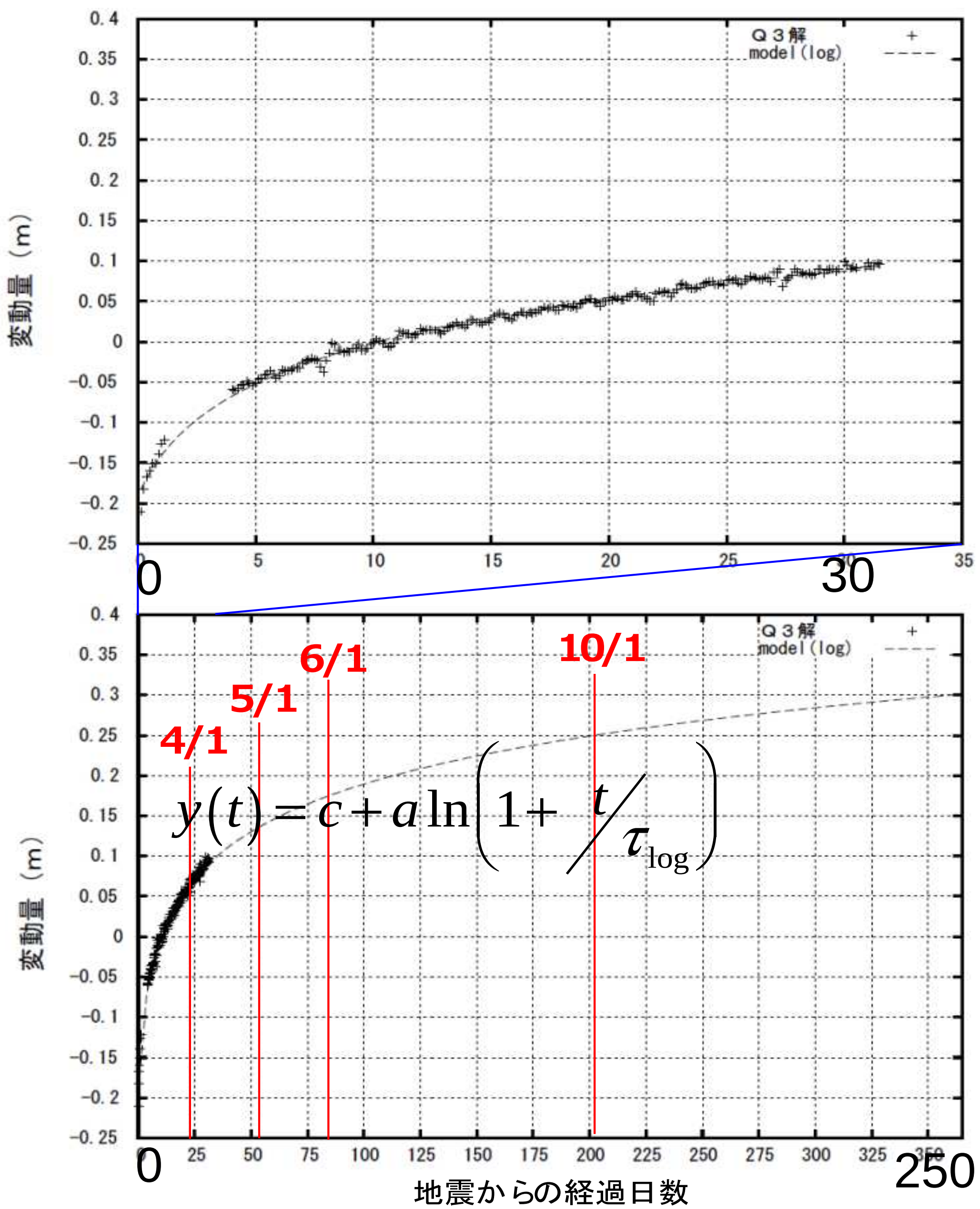


Post processed 1 Hz PPP kinematic solutions with GIPSY 6.1 (Nishimura, 2011)
www.gsi.go.jp/cais/chikakuhendo40010.html

Vectors whose error exceeds 0.1m are not plotted.

Site Coordinates of GEONET

Geospatial Information Authority of Japan (GSI)



Days after the mainchock

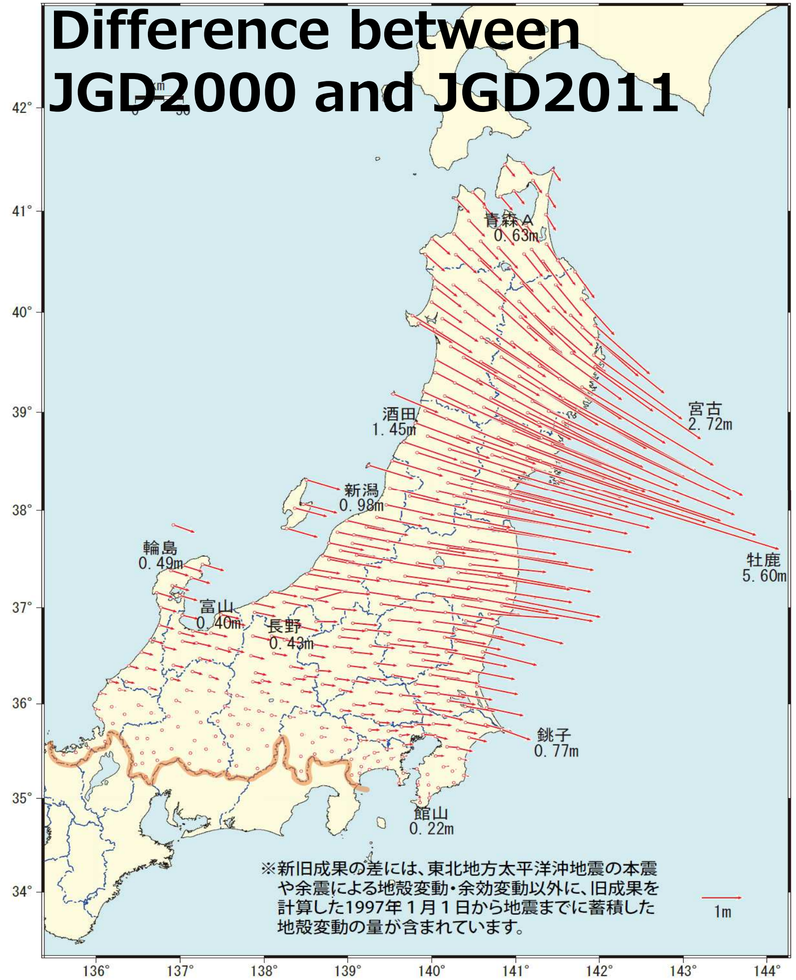
Japanese Geodetic Datum (JGD) 2000

- **Official coordinates for surveyors in Japan**
- **Static datum: Realization of ITRF94 with the epoch 1997.0**
- **Obsolete in east Japan after 2011 Tohoku EQ**

⇩

- **Should be updated using VLBI and GEONET results**
- **The timing was decided by the predicted post-seismic deformation.**

Update of official site coordinates (JGD2011)



- New official coordinates of GEONET form JGD2011 (ITRF2008) with the epoch May 24, 2011 for eastern Japan

⇩

- Accelerated infrastructure reconstruction in Tohoku area.
- This quick response was achieved by the continuous observation of GEONET.

Although JGD2011 is a static datum whose epoch is fixed, we also provide daily site coordinates aligned with ITRF and <u>semi-dynamic correction parameters</u>.

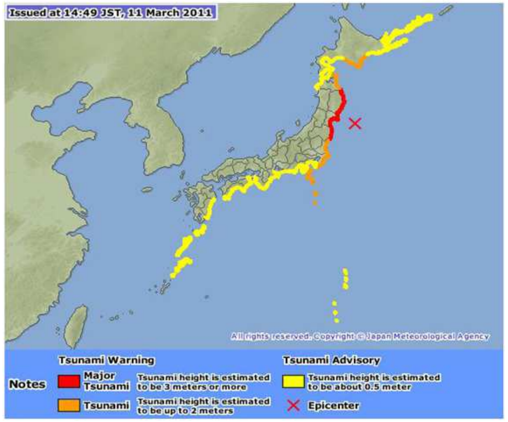
How GEONET works for disaster mitigations

- Real-time GNSS analysis system for rapid earthquake fault estimations (REGARD)

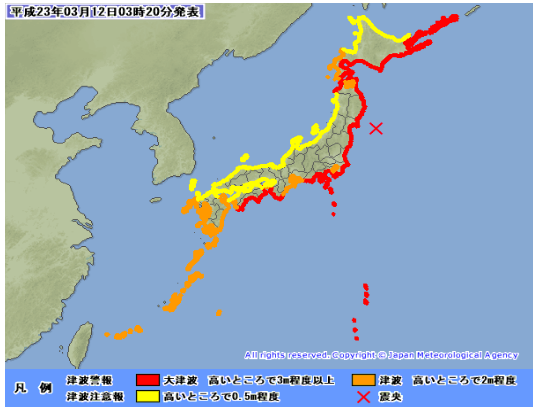
The following slides are prepared by Mr. Satoshi Kawamoto, GSI.
Development of REGARD is the joint effort with Tohoku University.

Motivation: improvement of tsunami warning in Japan

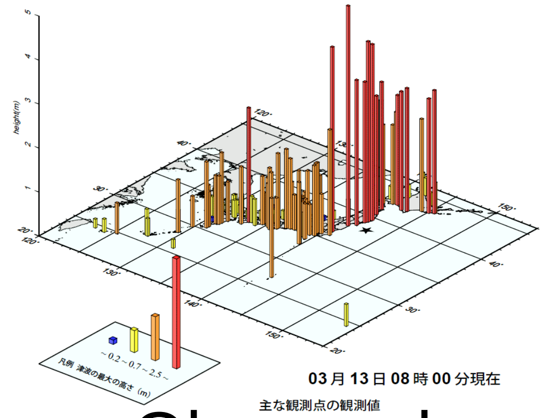
Tsunami Warning after the 2011 Tohoku Earthquake (Mw 9.0)



3 minutes



12 hours



Observed

(Ozaki, 2011)

- Early Earthquake Warning: 30 sec.
- Tsunami Warning: 3 min.

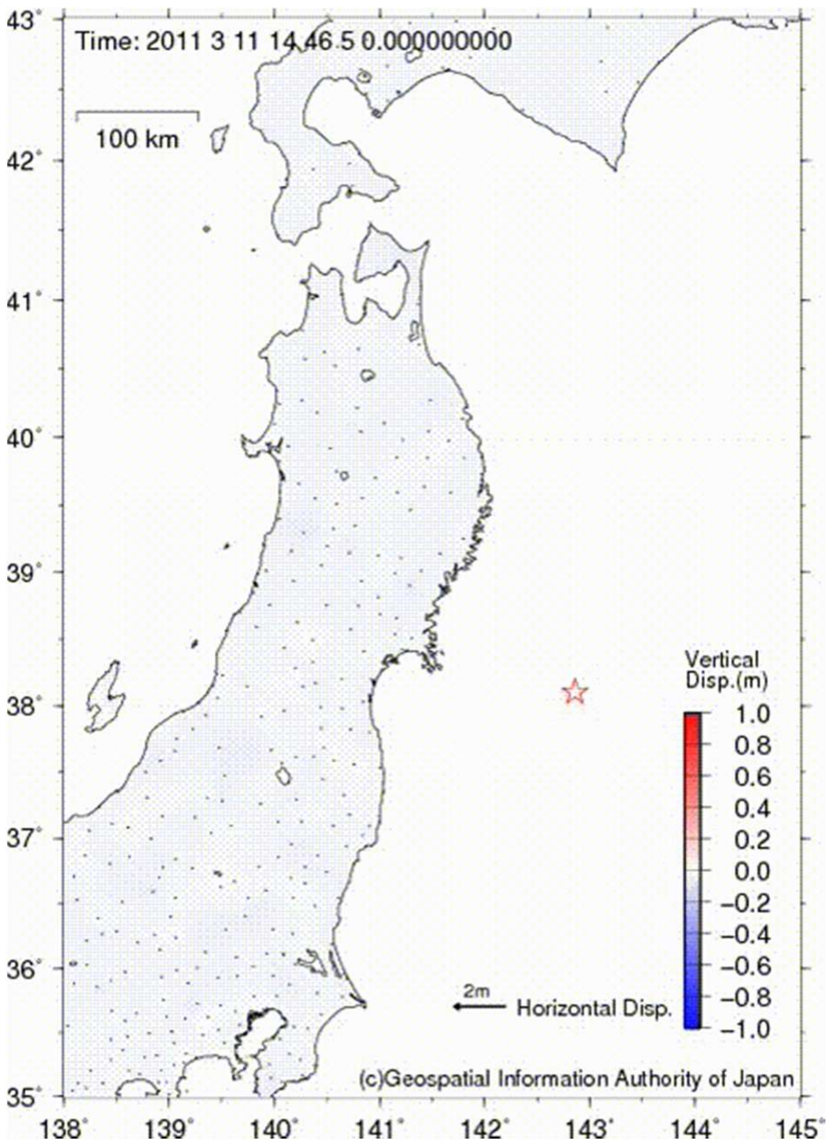
➡ Initial magnitude (EEW) was **Saturated at M7.9**

➡ **Underestimating tsunami heights**

➡ **How to prevent saturations?**

Kinematic GNSS analysis

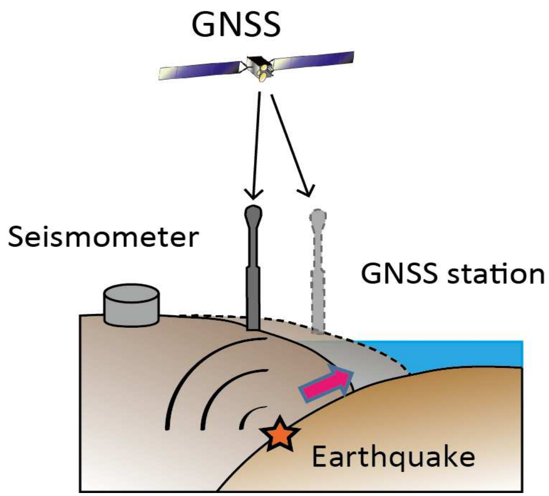
Geospatial Information Authority of Japan (GSI)



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

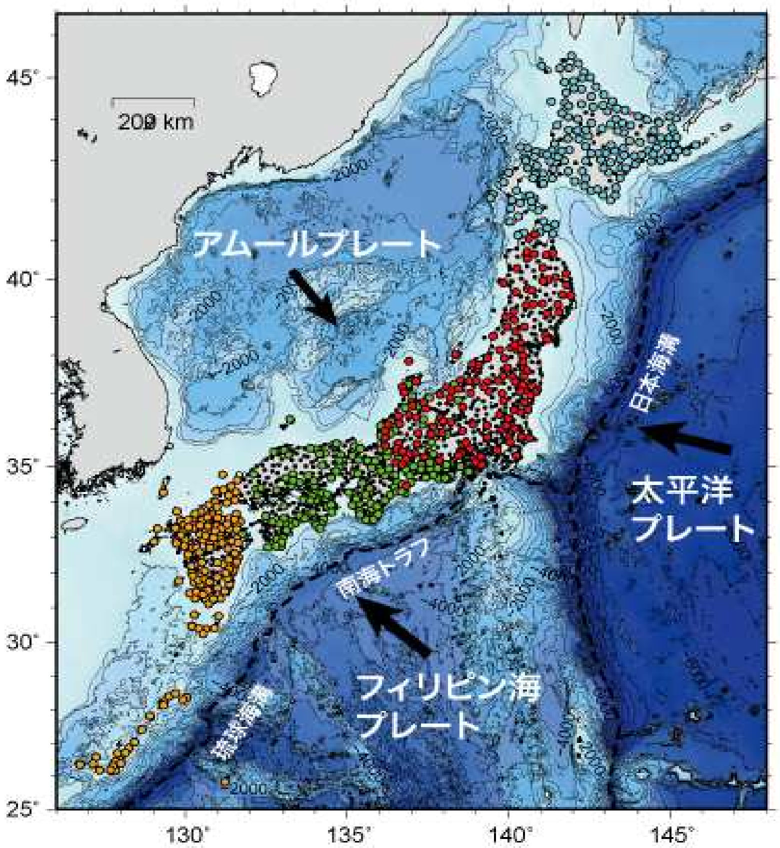
Provides:

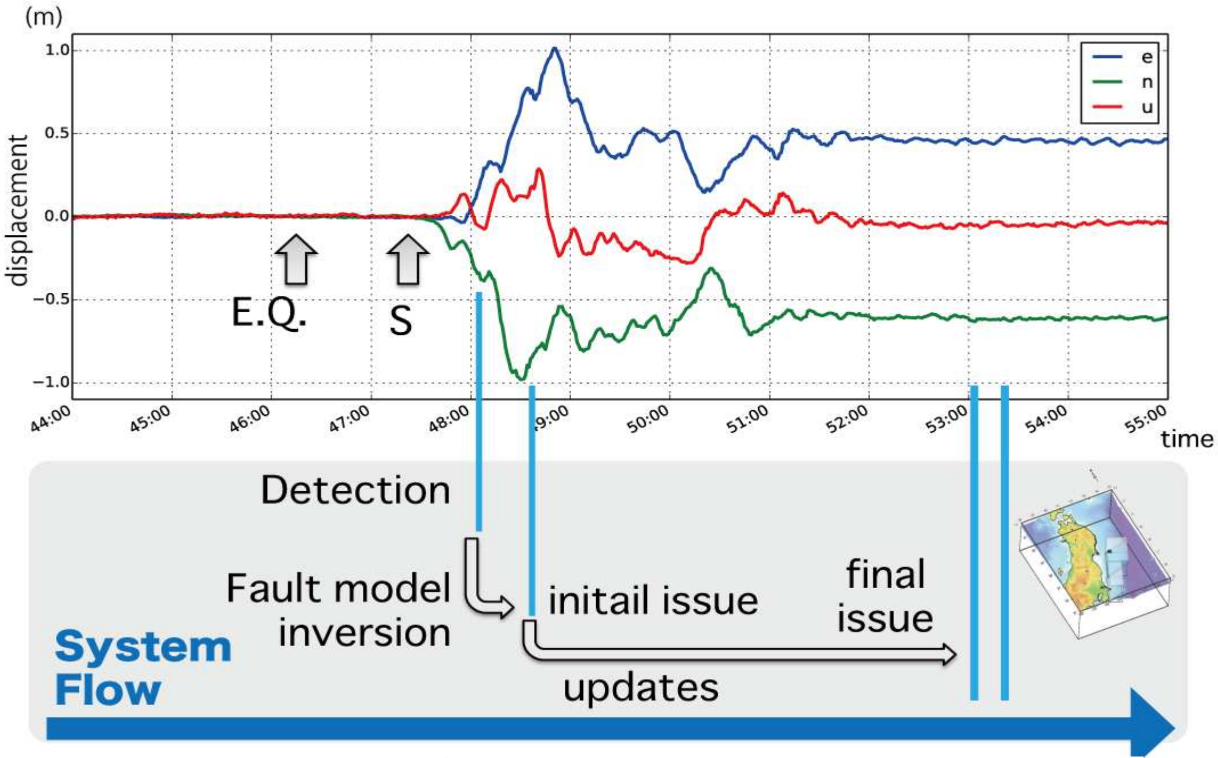
- **Displacement wave-form**
- **Mw free from the saturation problems**
- **Rupture length and width**
- **Size of a potential subsequent tsunami**

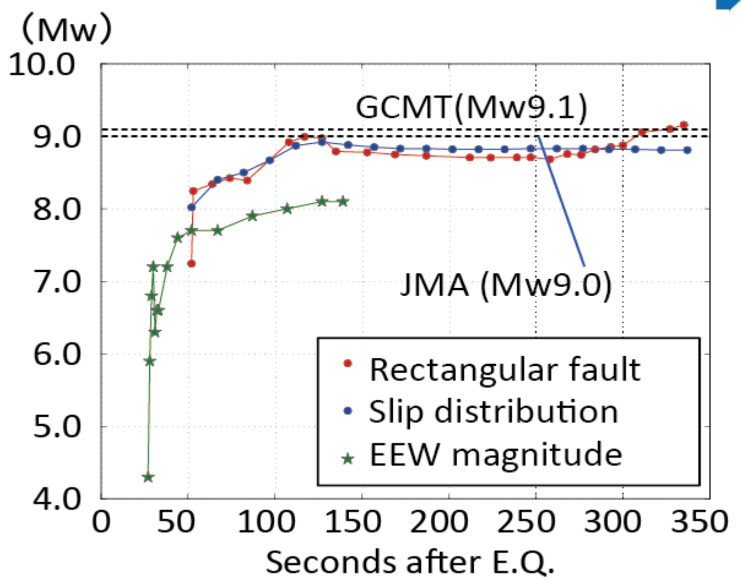


GEONET real-time analysis system（REGARD）

Geonet stations







GEONET real-time analysis system:

– Calculates 1Hz displacement
– Detects earthquake event
– Automated fault model inversion

GOAL: Provides Mw < 3minutes

Flow diagram of REGARD

Geospatial Information Authority of Japan (GSI)

DATA

GEONET stations

Real-time 1Hz BINEX

IGS

Ultra-Rapid orbit

JMA

Early Earthquake Warning (option)

RTCM convert

RTCM

1. Real-time Positioning subsystem

RTKLIB 2.4.1 (Takasu, 2011)

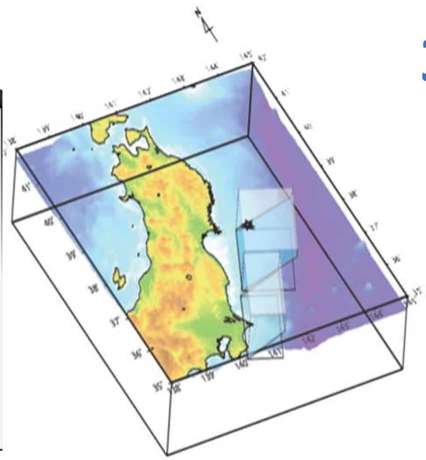
2. Event detection subsystem

- **RAPiD (Ohta et al., 2012)** Station position time-series' |LTA-STA| > 0.03m
- **Early Earthquake Warning** EEW > M7.0

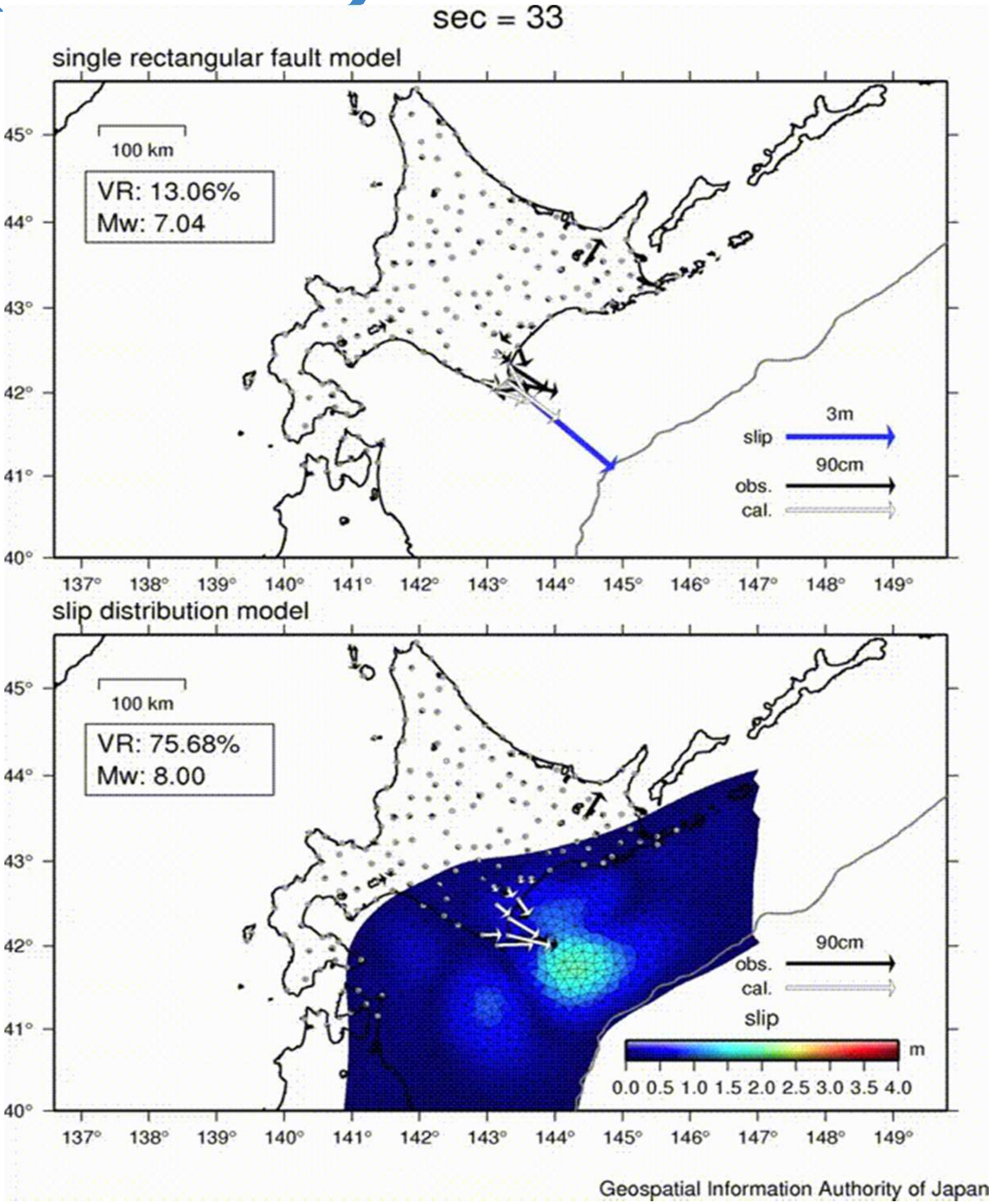
Low-pass filter (20s moving average)

3. Fault model inversion subsystem

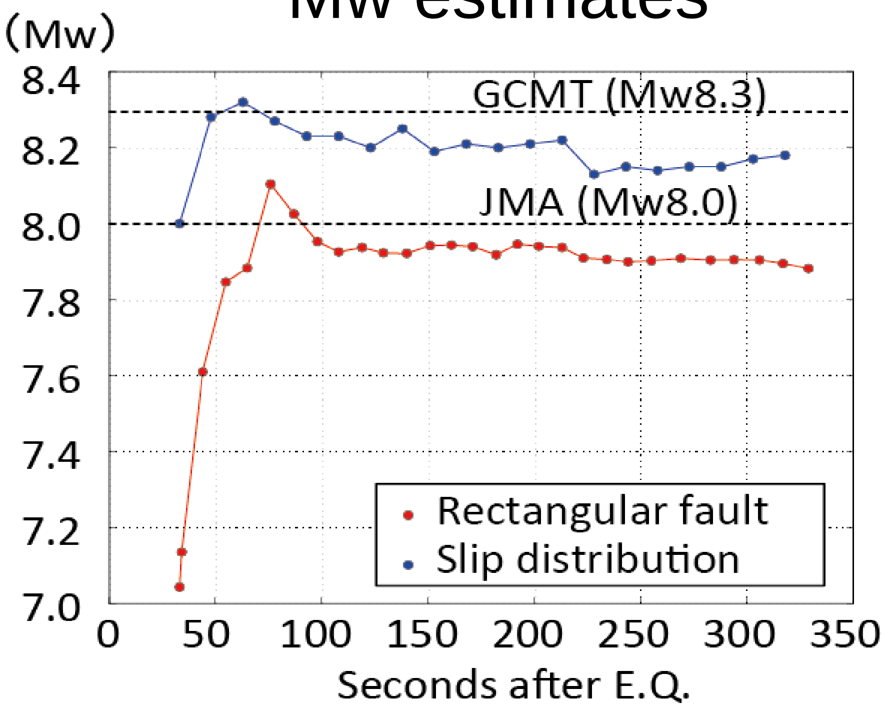
Automatic estimation of finite fault model



2003 Tokachi-oki Earthquake (Mw 8.0)



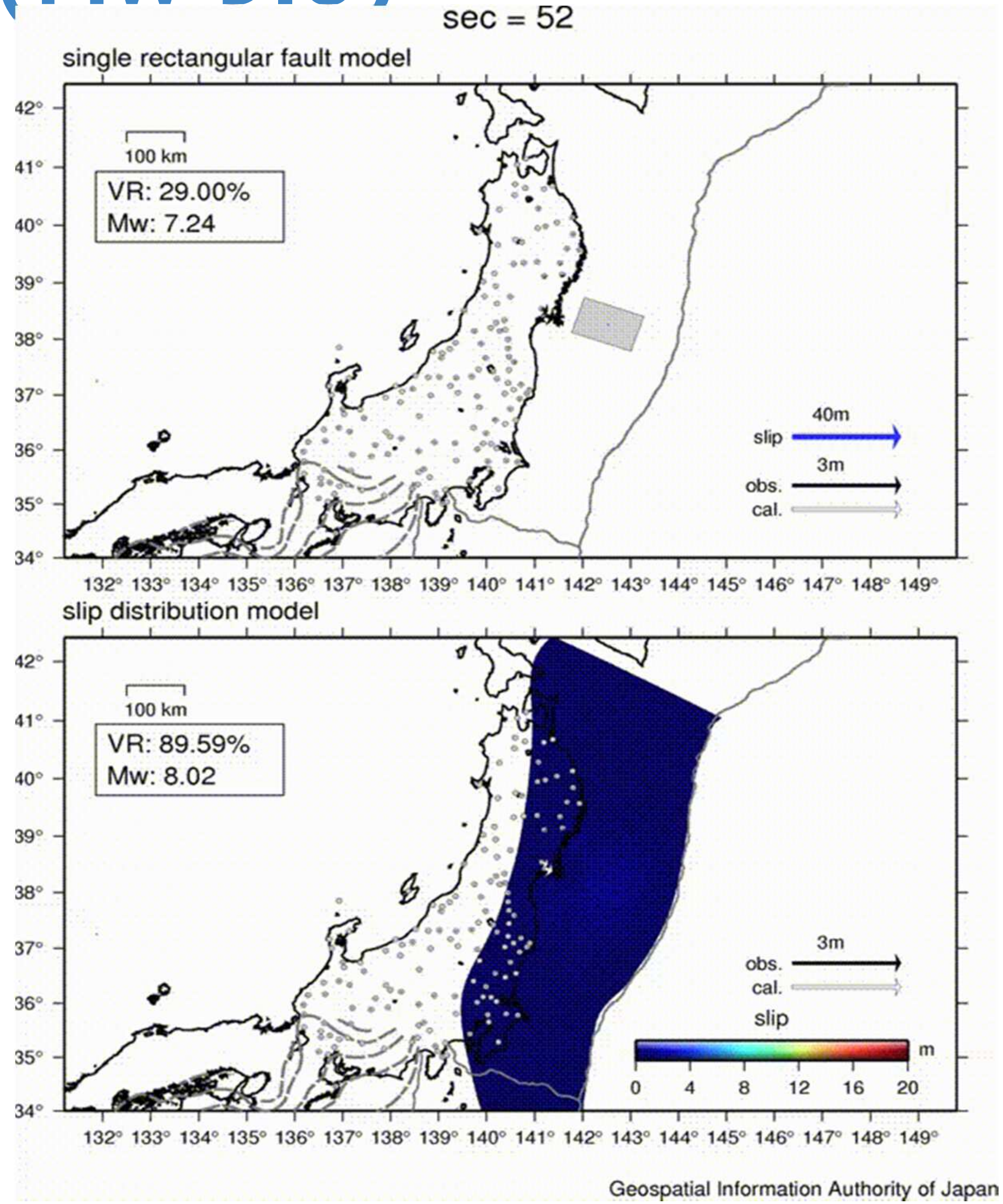
Mw estimates

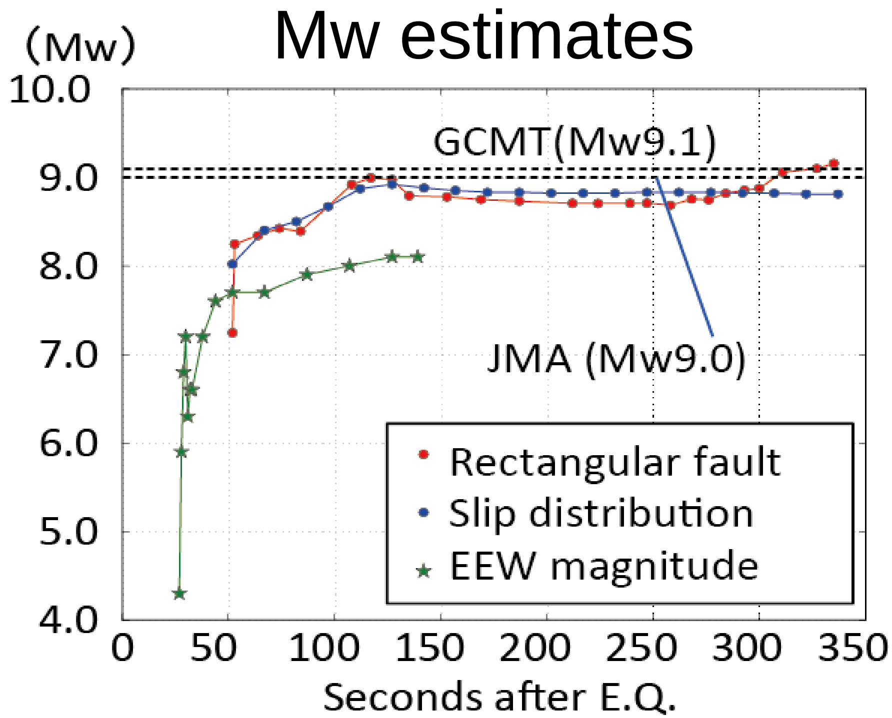


- Stable magnitudes were derived within 100 sec by both modeling routines

2011 Tohoku Earthquake (Mw 9.0)

Geospatial Information Authority of Japan (GSI)



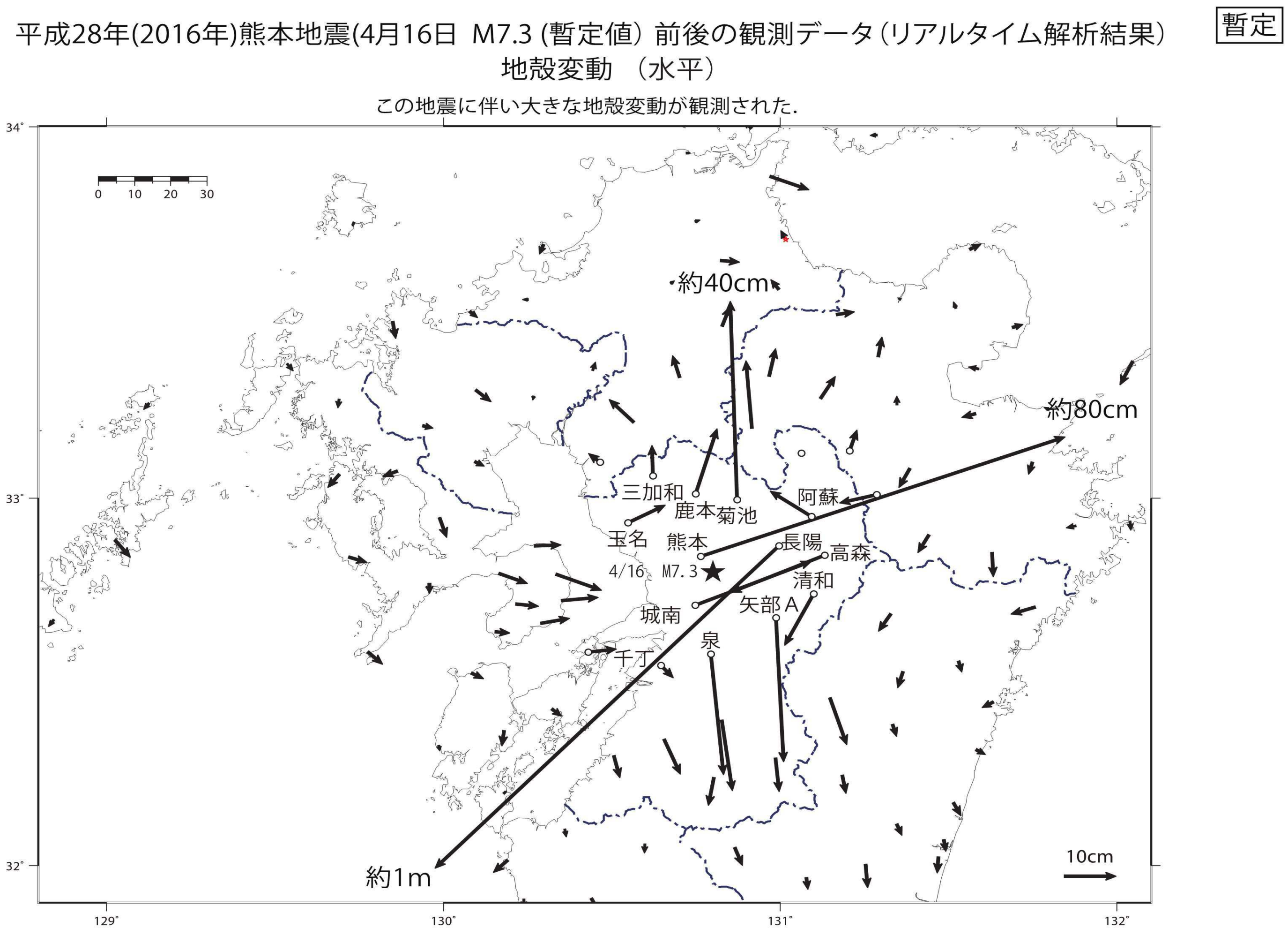


- Stable after 120 seconds
- No saturation occurred for magnitude estimates using GPS real-time positionings

2016 Kumamoto EQ (M7.3)

Geospatial Information Authority of Japan (GSI)

Horizontal Crustal deformation from REGARD



- Observed significant horizontal displacements of up to 1 m

Real-time earthquake fault estimates at Kumamoto EQ

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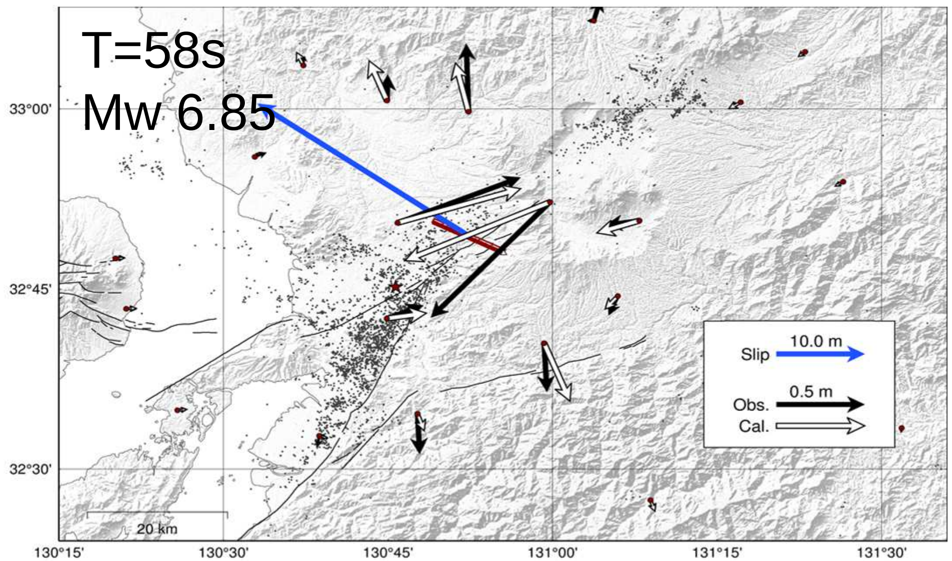
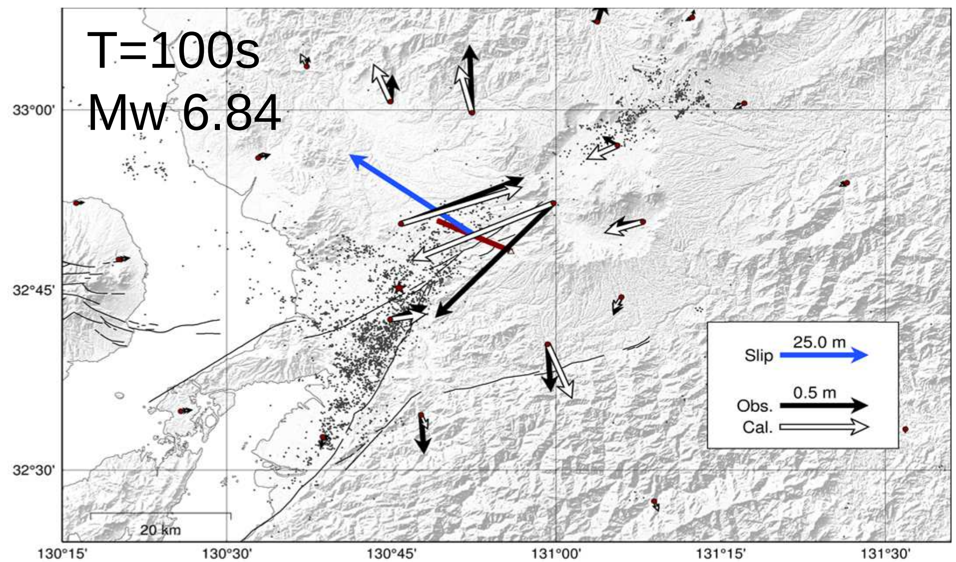
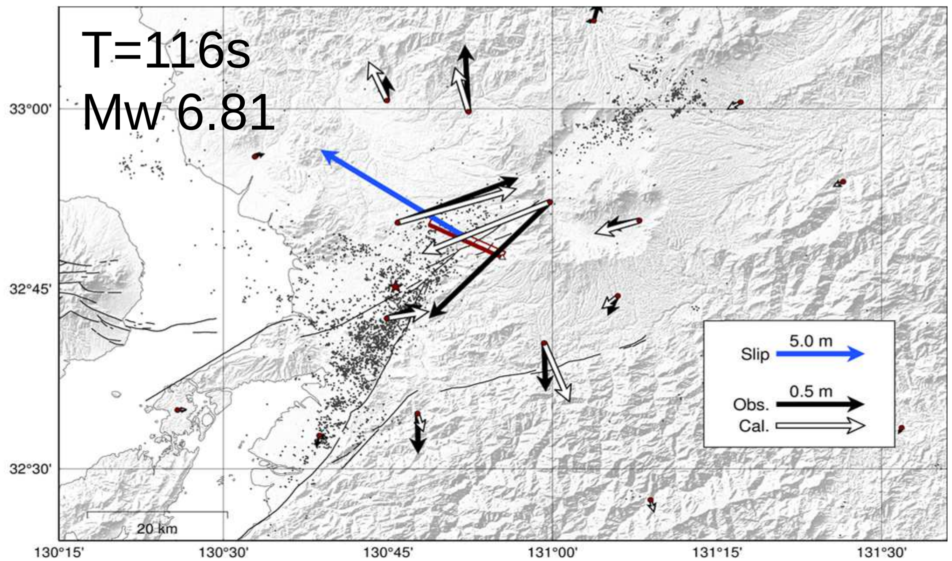
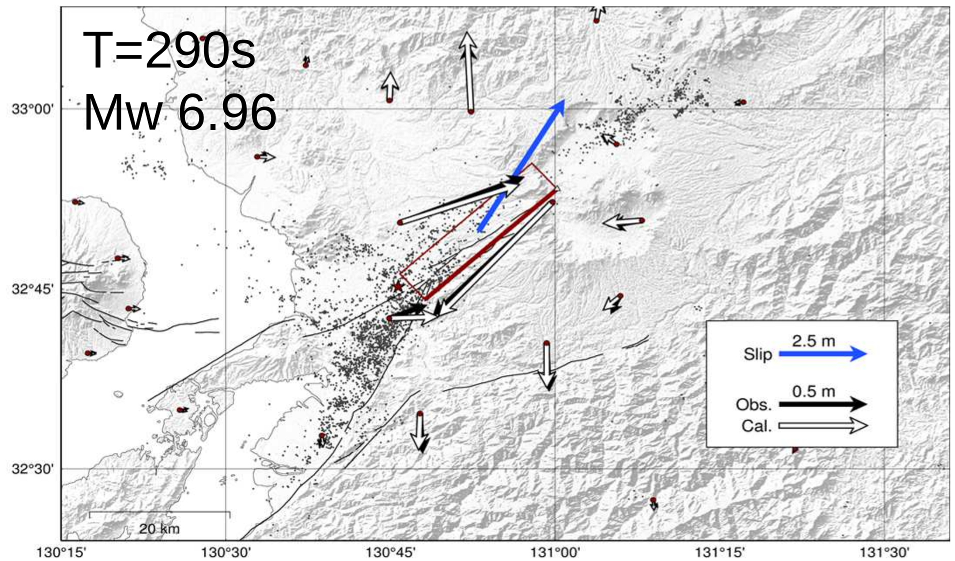
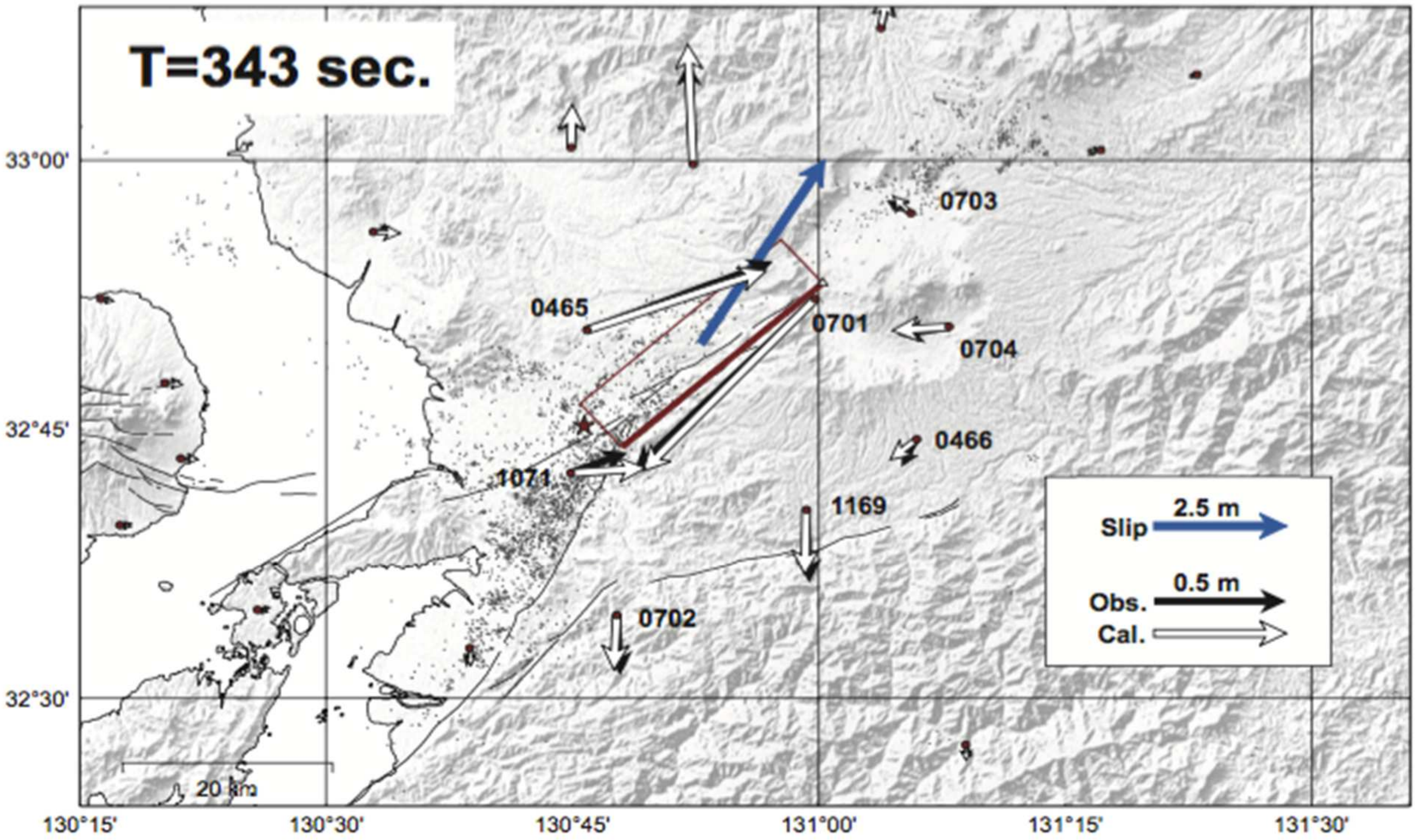








The fault model (final) Kumamoto EQ



- Earthquake fault with right-lateral slip along the Futagawa fault segment

Conclusions

- GSI has been operating GEONET in Japan for the past two decades
  - to establish a regional reference frame consistent with the ITRF, and
  - to monitor crustal deformations for disaster mitigations.
- GNSS is a great tool for society !
- Geodetic reference frame (i.e. ITRF) is necessary to connect GNSS and society.