The 7th Multi-GNSS Asia (MGA) conference

"Geospatial Challenges in the Asia-Pacific Region"

How GNSS CORS in Japan (GEONET) works for disaster mitigations

9th December 2015, Brunei Darussalam

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国土地理院

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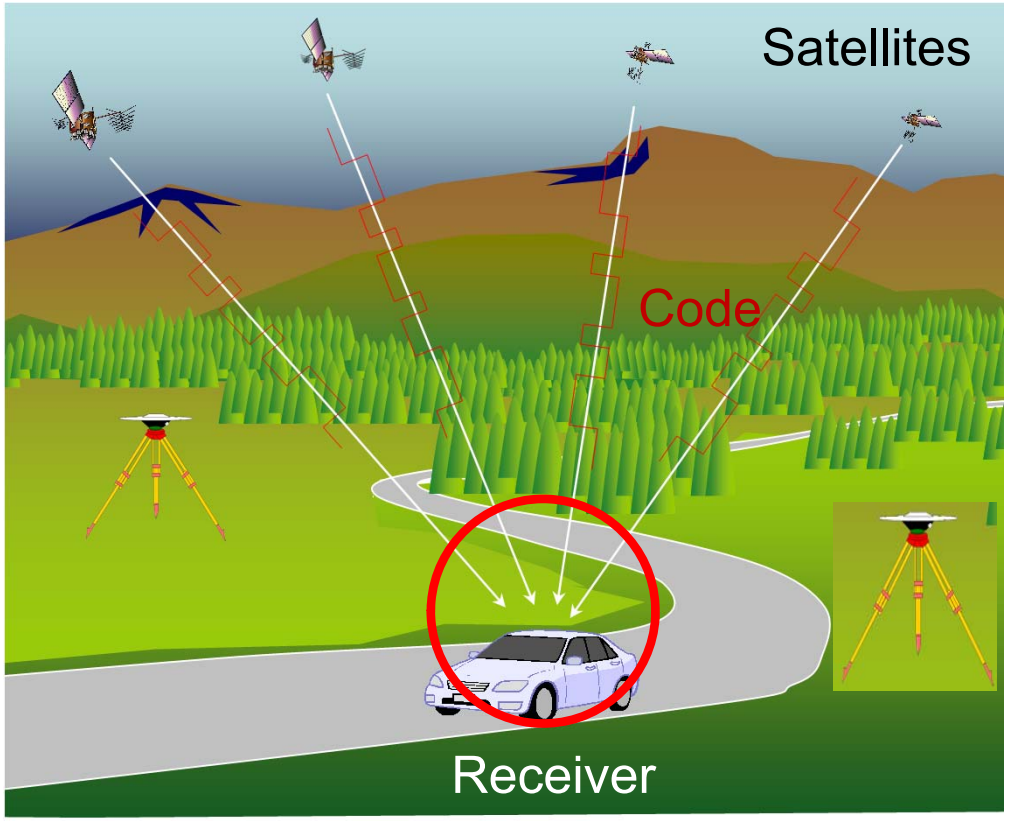
   - Monitoring of active volcanoes
   - Weather forecast using GEONET data by Japan Meteorological Agency (2009～)
   - UAV to monitor flooded area (2015)

Introduction to GEONET

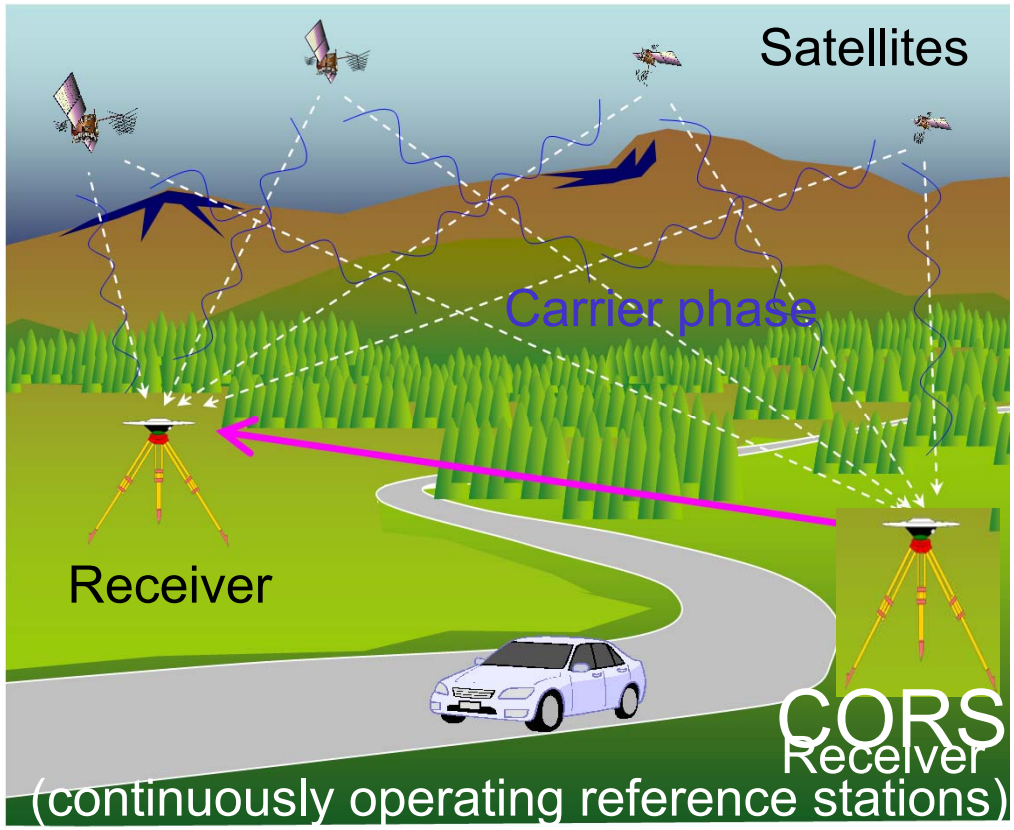
Positioning with GPS

Car Navigation



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

Land Surveying



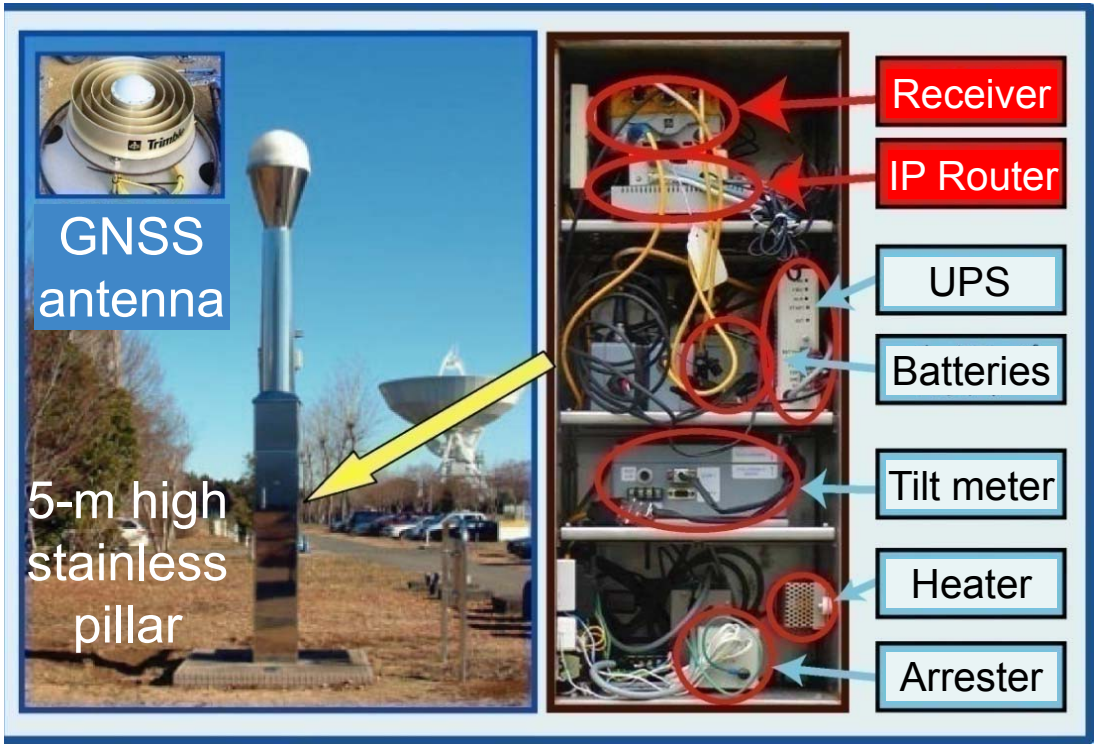
- ✓ Relative positioning between 2 receivers
- ✓ Precision ~ 1 cm

What is GEONET ?

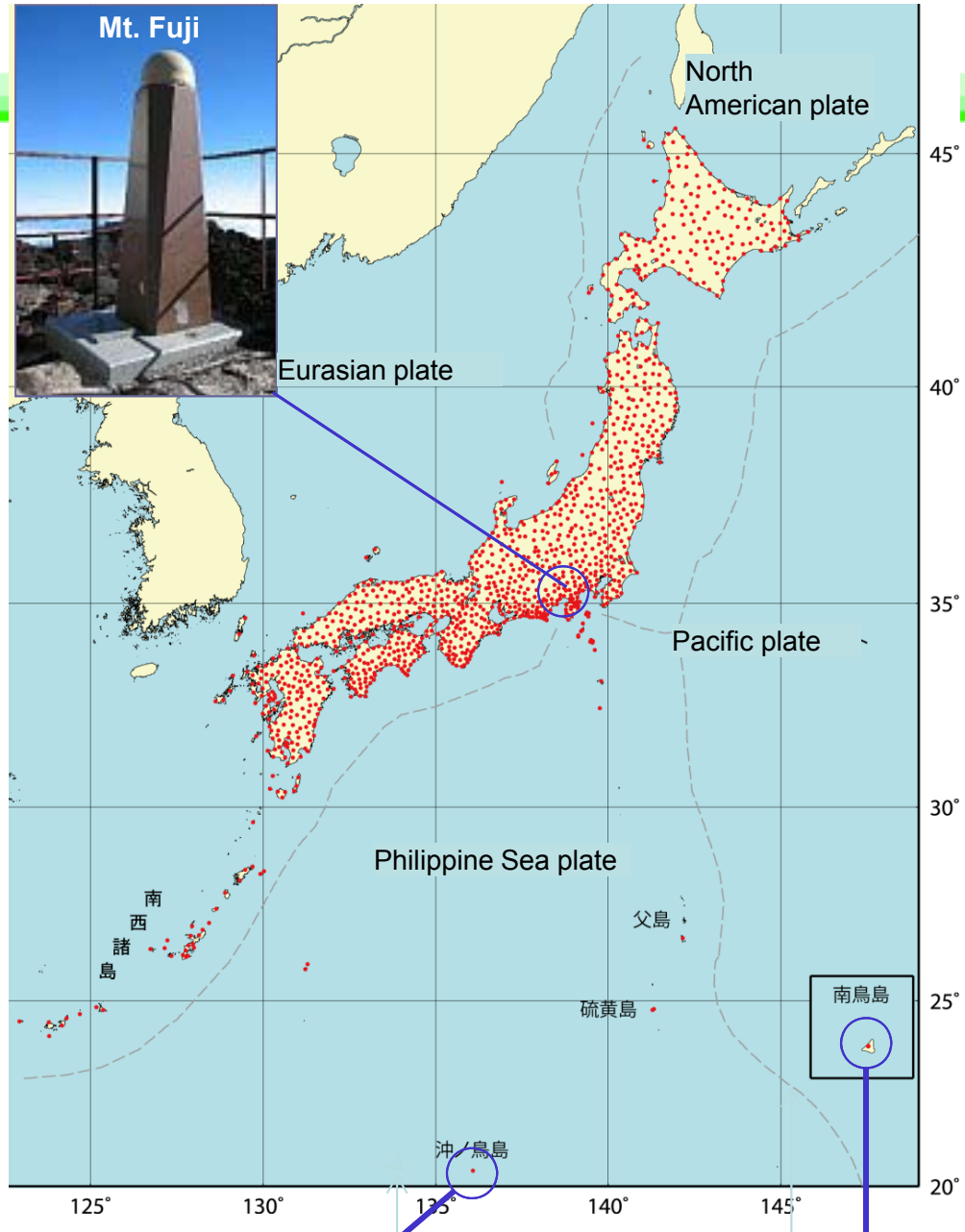
- One of the Largest Continuously Operating Reference Stations networks in the world
  - 1,300 permanent stations with 20km spacing in Japan
    + processing center in Tsukuba
  - Collects GNSS data every seconds, and provides data / products to users
  - Includes 7 IGS stations
- Infrastructure for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

GEONET Stations

(GNSS-based control points)



Model 93	Model 94	Model 95	Model 02
1993	1994	1995-1997	2002-



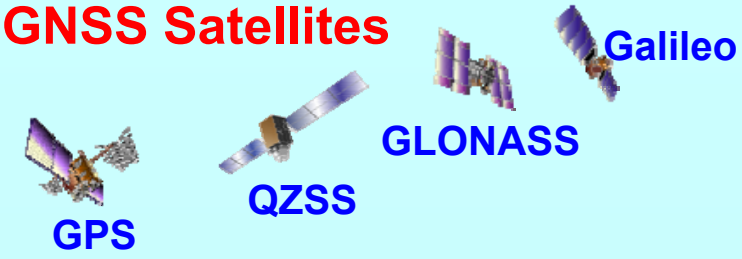

Okino Tori island


Minami Tori island

GEONET data / outcomes

Geospatial Information Authority of Japan (GSI)

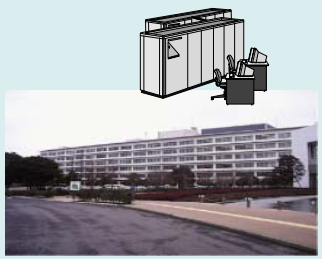
GNSS Satellites



GNSS-based control points

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

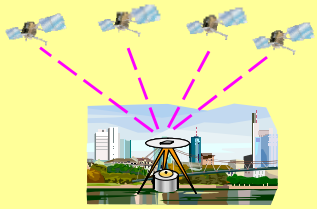
Analysis Center in Tsukuba



Data Collection

Data Analysis

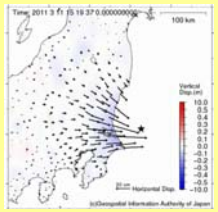
Observed data (every 30 sec)



Survey & Mapping

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

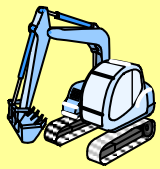
Analyzed data (coordinates)



Crustal deformation Monitor

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

Real-time data

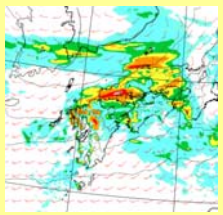


Provided to the Industry

Precise real-time positioning

- ICT construction
- precision farming
- Source of QZSS augmentation

Other data



Applications

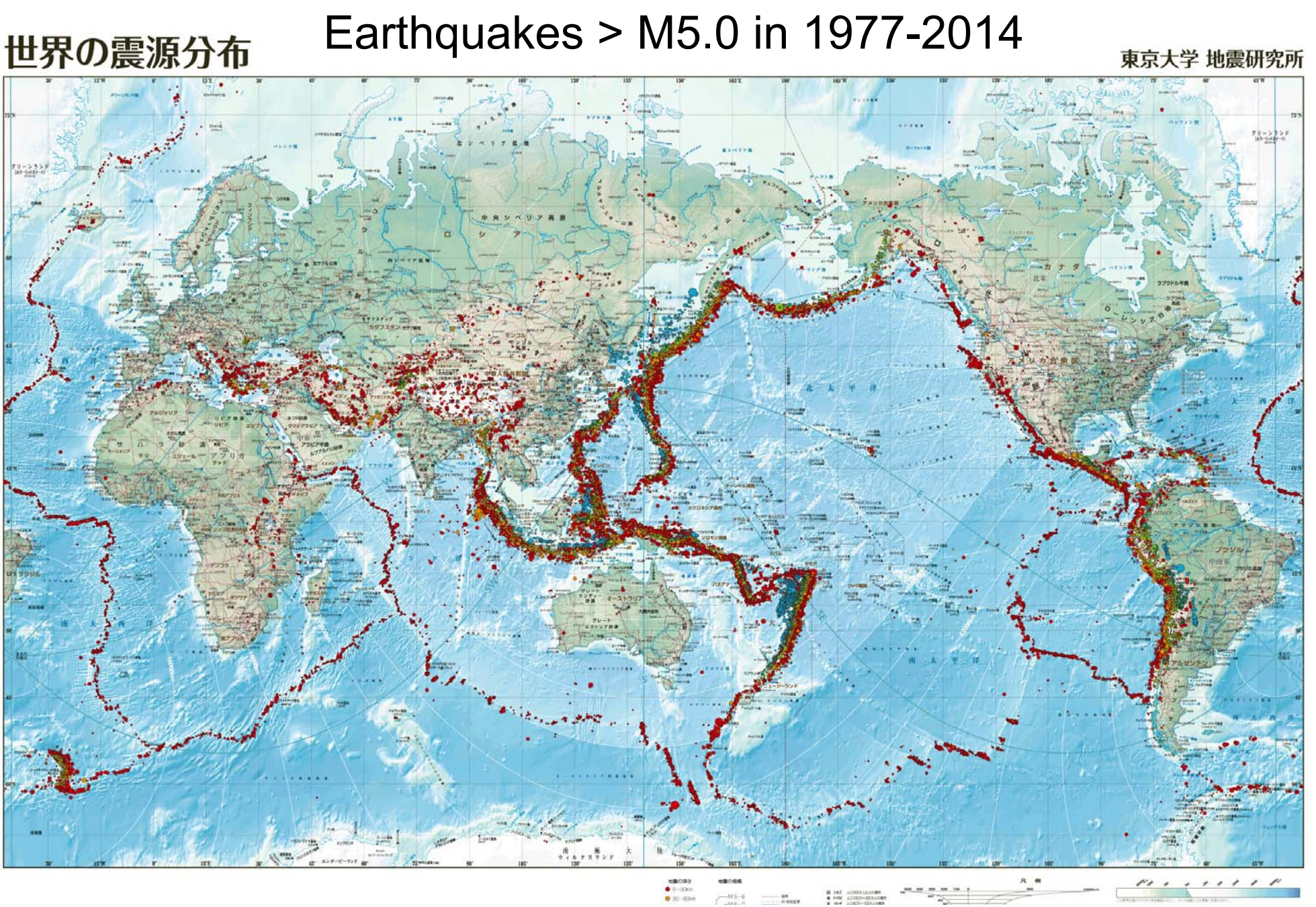
- Weather forecast using watervapor info from GNSS
- Ionosphere studies

How GEONET works for disaster mitigations

Case 1: Earthquakes

Seismicity map of the world

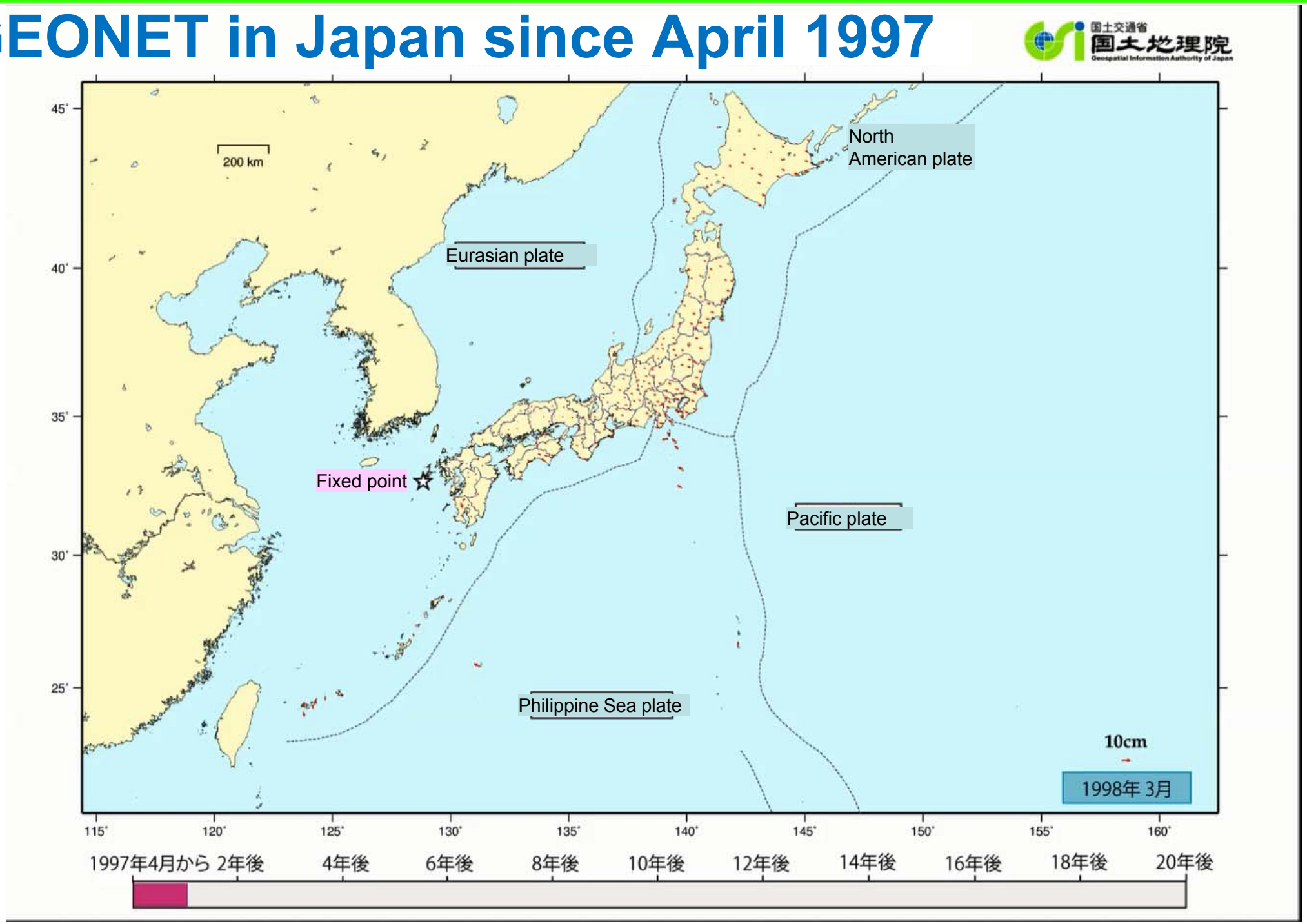
Geospatial Information Authority of Japan (GSI)



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

Crustal deformation observed by GEONET in Japan since April 1997

Geospatial Information Authority of Japan (GSI)

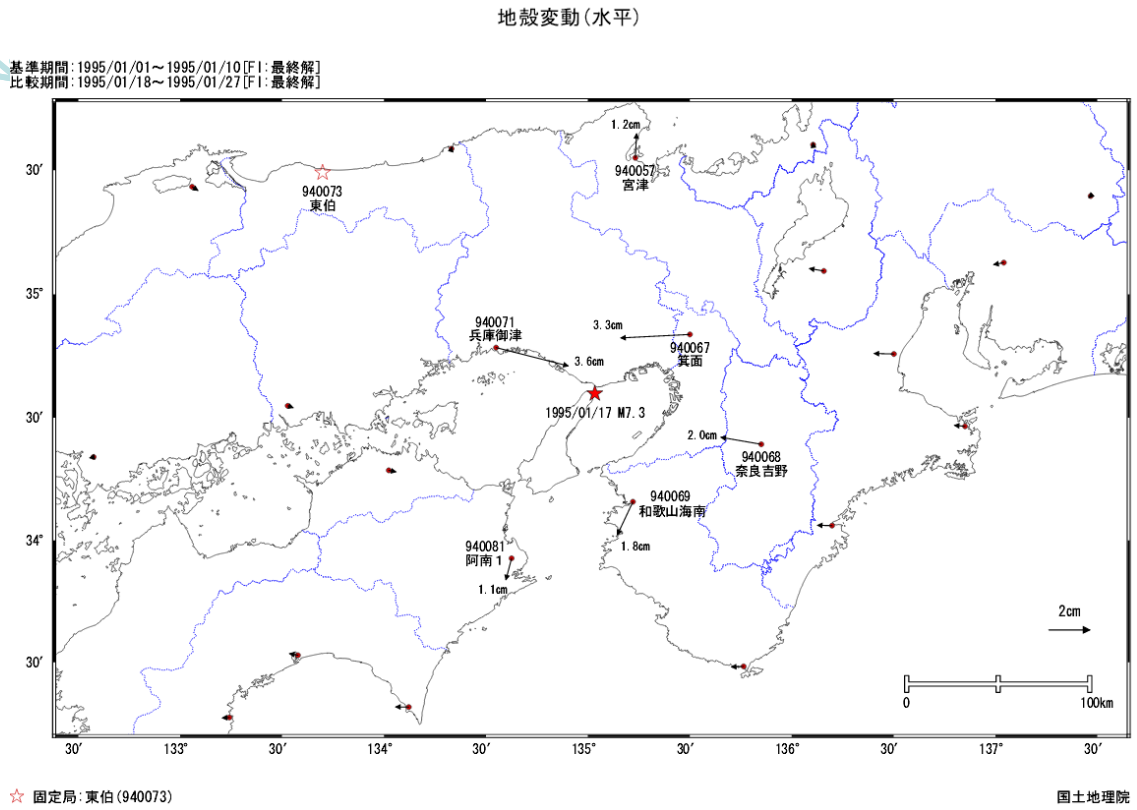


Major earthquakes recorded by GEONET

Geospatial Information Authority of Japan (GSI)

Full list is available in “Index of Earthquake-derived Crustal Deformations detected by GEONET” (http://mekira.gsi.go.jp/catalogue/index.html)

1994/10/04 M8.1 Hokkaido toho oki
1994/12/28 M7.6 Sanriku haruka oki
1995/01/17 M7.3 Kobe EQ
2000/07/30 M6.5 Miyakeiima kinkai
2000/10/06 M7.3 Tottoriken seibu
2001/03/24 M6.7 Geiyo
2003/09/26 M8.0 Tokachi oki
2004/10/23 M6.8 Chuetsu
2005/03/20 M7.0 Fukuokaken seihouoki
2007/03/25 M6.9 Noto hanto
2007/07/16 M6.8 Chuetsu oki
2008/06/14 M7.2 Iwate Miyagi nairiku
2009/08/11 M6.5 Surugawan
2011/03/11 M9.0 Tohoku EQ
2011/03/11 M7.6 Ibaraki oki
2011/04/11 M7.0 Fukushima hamadoori
2013/04/13 M6.3 Awaji shima
2014/11/22 M6.7 Naganoken hokubu
・・・

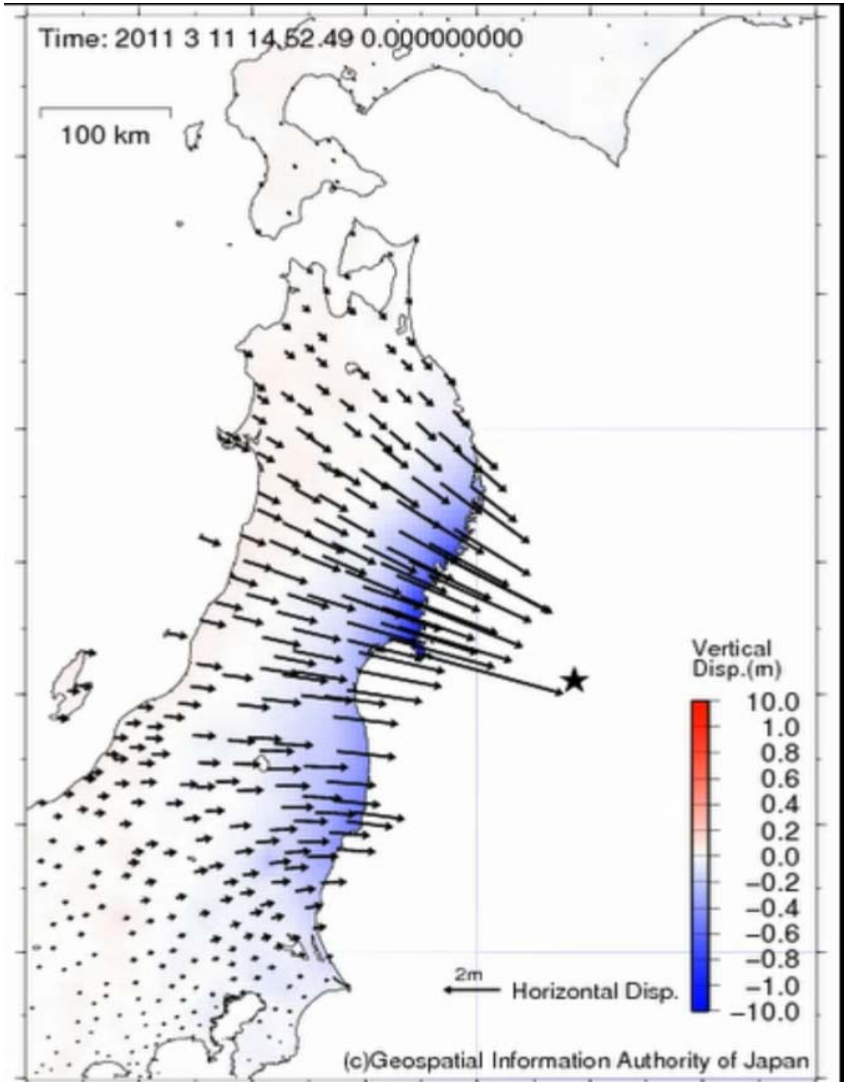


Tohoku EQ (M9.0)
March 11, 2011

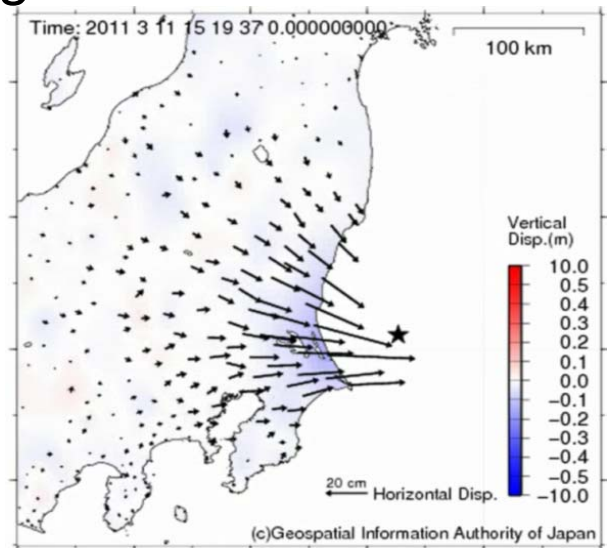
Coseismic deformation field observed by GEONET with 1Hz

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.

GEONET operation on March 11

- 14:46 The 2011 Tohoku EQ (M9.0)
  - Due to blackout in Tsukuba, emergency generator of GEONET HQ activated.
- 15:45 No data from 37 stations via IP-VPN
- 16:15 No data from 358 stations via IP-VPN
  - Data from 196 stations retrieved by backup mobile phone lines (packet communication)
- 18:50 Coseismic deformation field using 3 hour data after EQ obtained; H: 4.0m, V: 0.7m
- 21:00 The result reported at Earthquake Research Committee of the Government

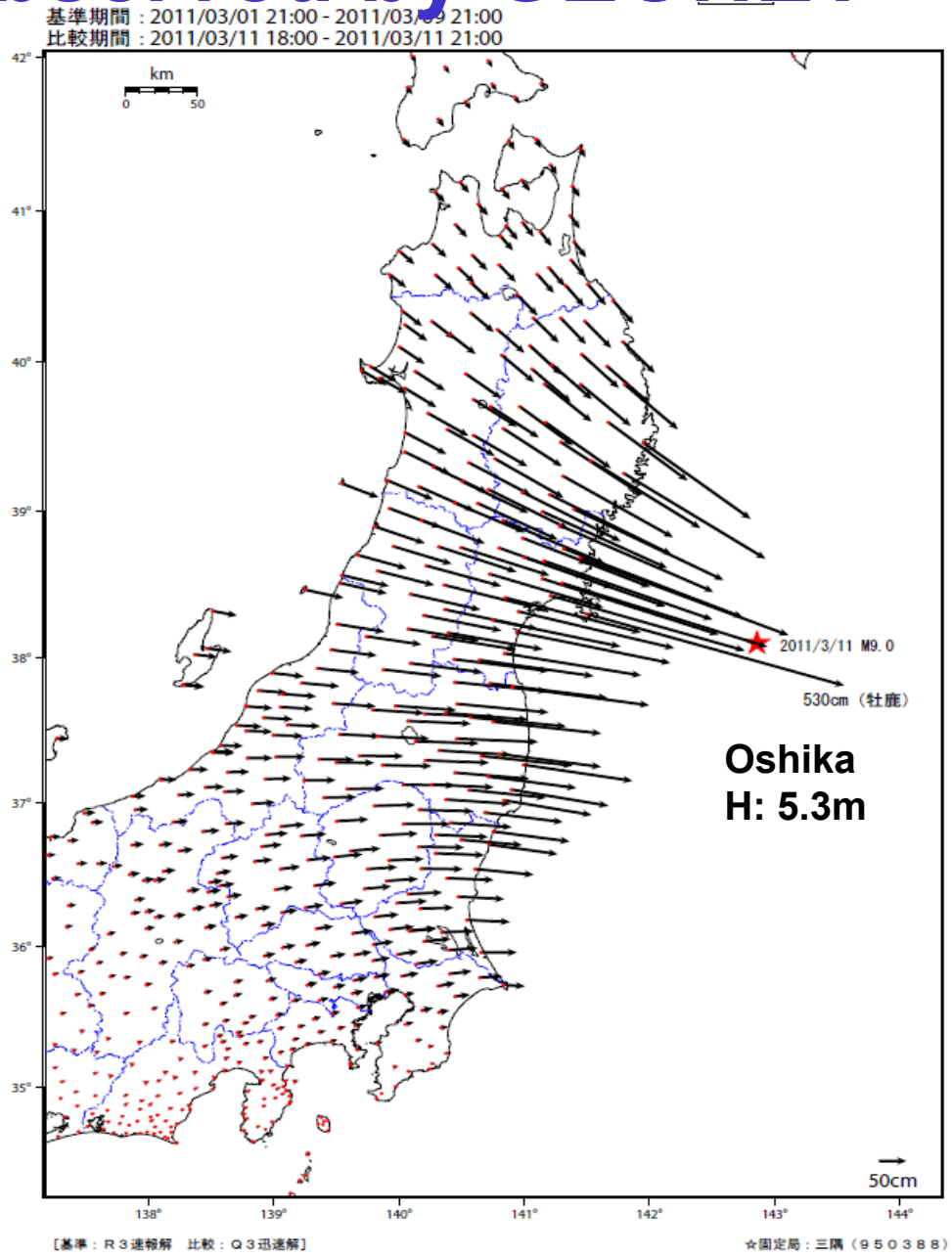
How GEONET mitigated Tohoku EQ disaster

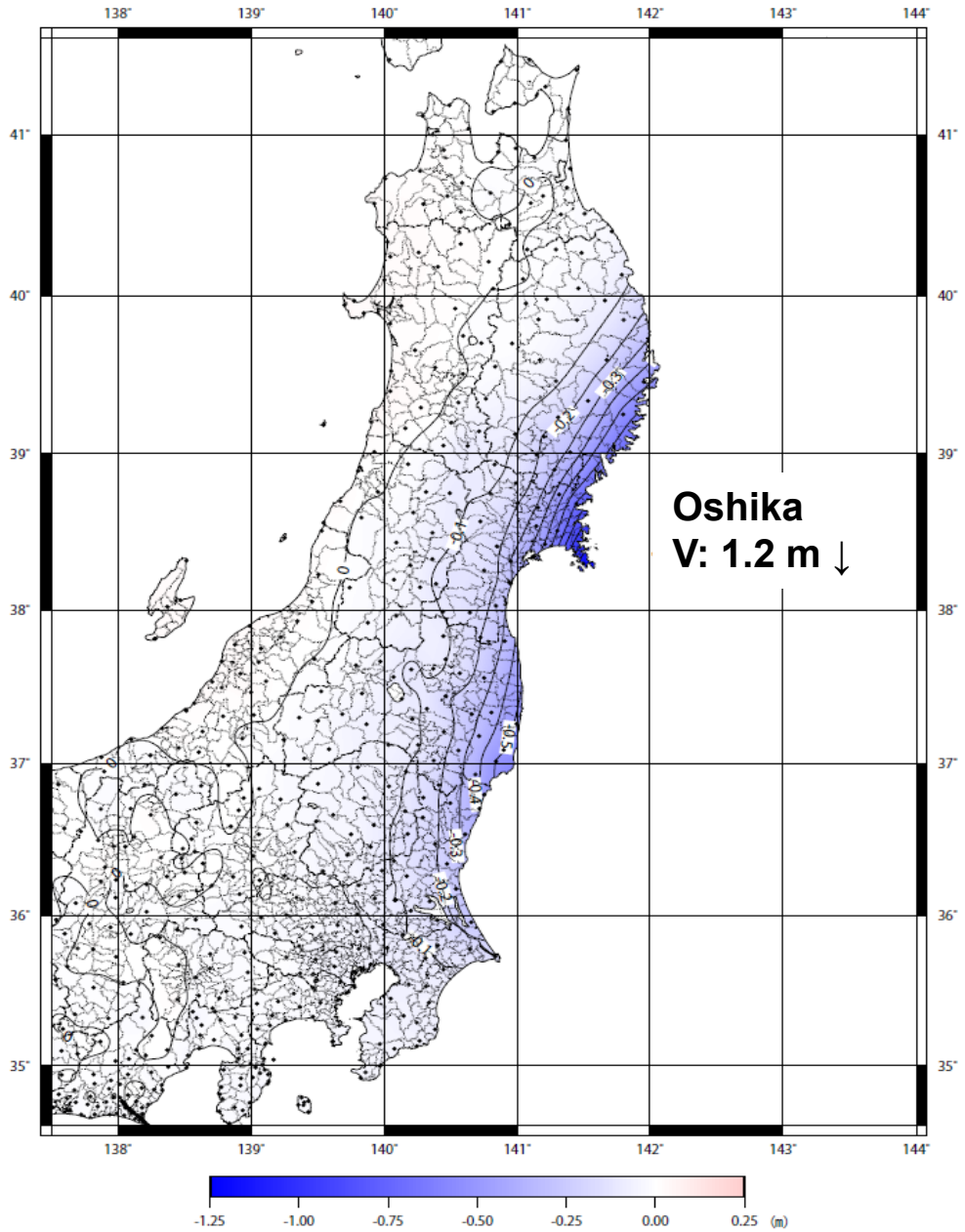
- Observation of coseismic crustal deformations
  - Better modeling of EQ for predicting aftershocks
- Confirmation of large ground subsidence (～1m)
  - Warning to high tide along the Pacific coast
- Supporting aerial photogrammetry of flooded area
- Enabling efficient reconstruction surveys
  - Quick revision of the official site coordinates
  - ICT construction using multi-GNSS
- Monitoring of post seismic deformations
  - Important for facility management (port)

× No real-time deformation info at the time of EQ

Coseismic deformation field observed by GEONET

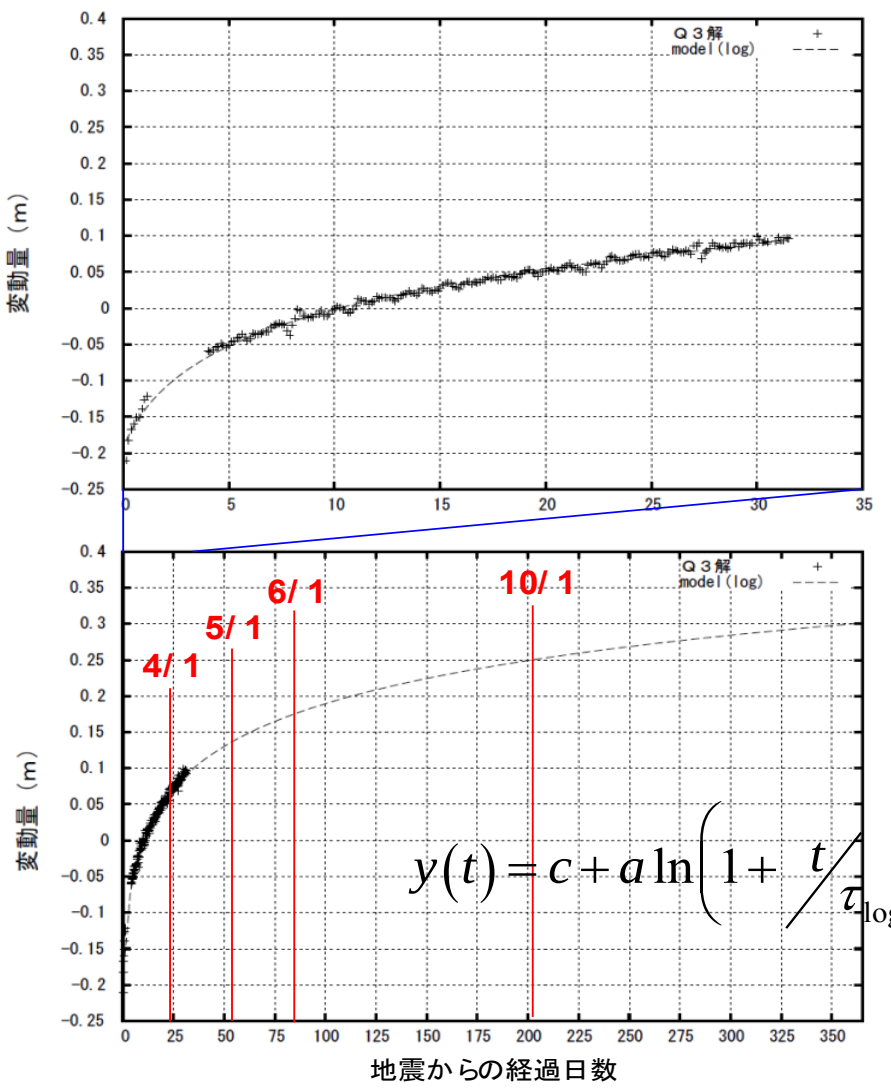
Geospatial Information Authority of Japan (GSI)





Site Coordinates of GEONET

Geospatial Information Authority of Japan (GSI)



$$y(t) = c + a\ln\left(1 + \frac{t}{\tau_{\log}}\right)$$

Japan Geodetic Datum (JGD) 2000

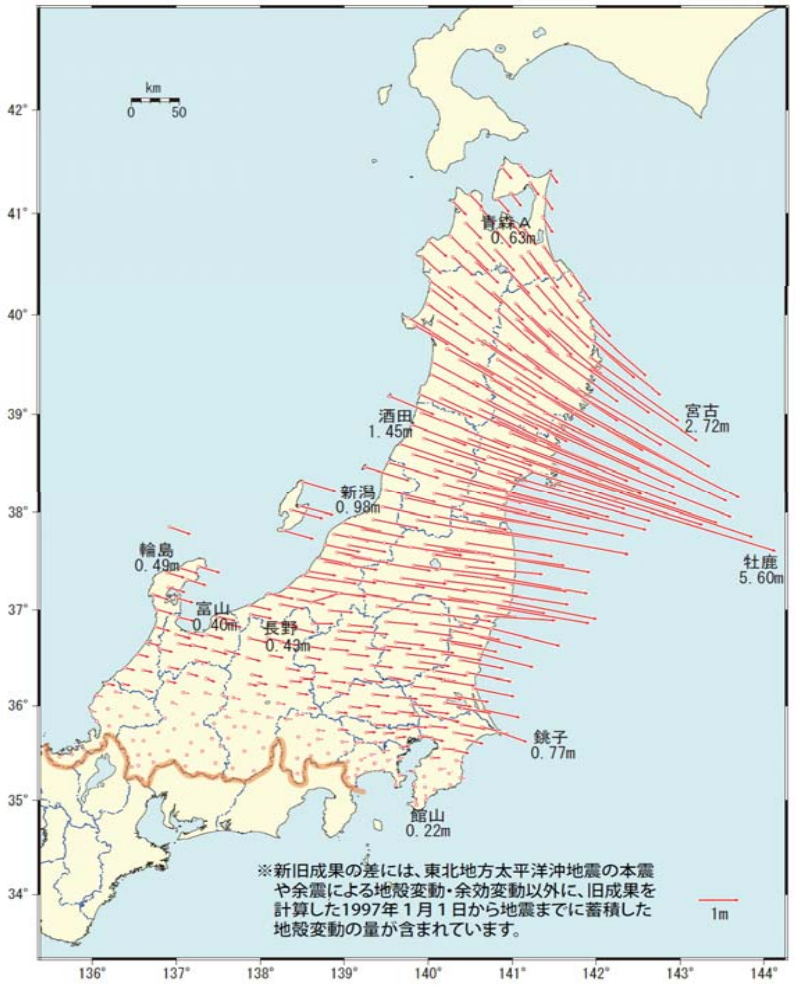
- Official coordinates for surveyors in Japan
- A Realization of ITRF94 with the epoch 1997.0
- Obsolete in east Japan after the 2011 Tohoku EQ

Updated to a new Japan Geodetic Datum;
Realization of ITRF2008 using VLBI and GEONET results with the epoch 2011.4.

The update timing was determined considering the predicted decay curve of post-seismic deformation.

Update of official site coordinates (JGD2011)

Geospatial Information Authority of Japan (GSI)



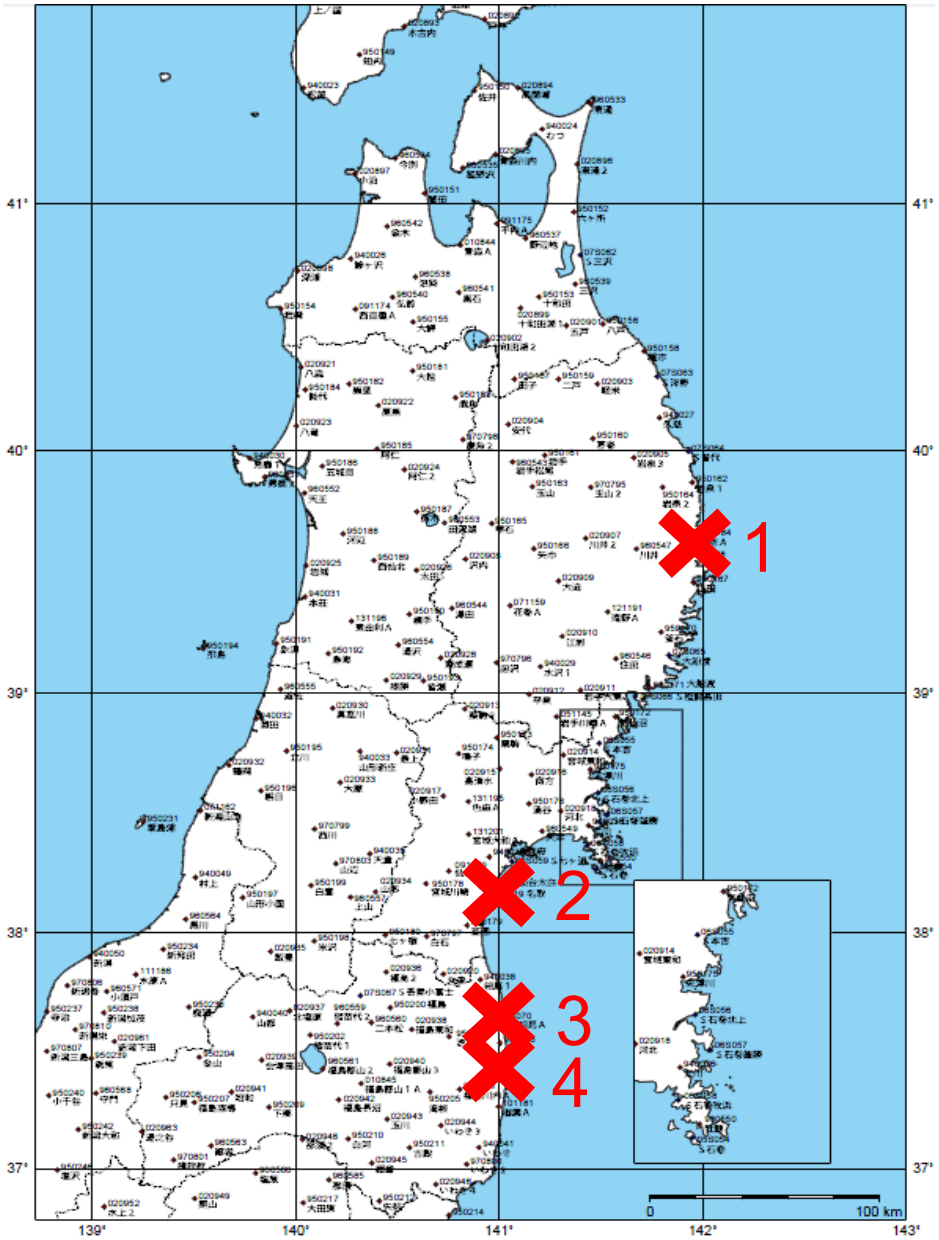
Difference between JGD2000 and JGD2011

- New official coordinates of GEONET and **JGD2011** (ITRF2008) released on May 31

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

Damage to GEONET

Geospatial Information Authority of Japan (GSI)



- Tsunami washed 4 GEONET stations.

1) Taro, Iwate pref.
2) Natori, Miyagi pref.
3) Minami Souma, Fukushima pref.
4) S Namie, Fukushima pref.

Natori (Miyagi Pref.)

Geospatial Information Authority of Japan (GSI)

Before EQ (2007~2009)

Natori (Miyagi Pref.)

Geospatial Information Authority of Japan (GSI)

After EQ (March 12-13, 2011)

Natori (Miyagi Pref.)

Geospatial Information Authority of Japan (GSI)

Natori (Miyagi Pref.)

GSI team visited the site on March 16, 2011

Minami Souma (Fukushima Pref.)

Geospatial Information Authority of Japan (GSI)

April 19, 2011

Recovery from 2011 Tohoku EQ

Geospatial Information Authority of Japan (GSI)

With Solar Panel
and mobile phone

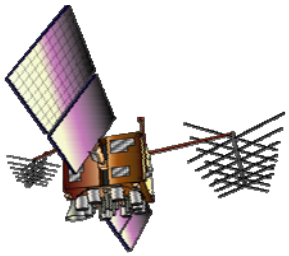
Evolution of GEONET

1) Real-time deformation monitoring

– For quick estimation of magnitude of mega EQ to assist early Tsunami warning

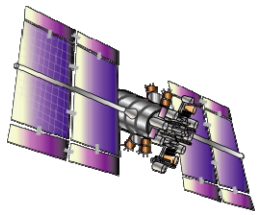
2) Multi-GNSS support

– For more efficient GNSS surveys in urban areas

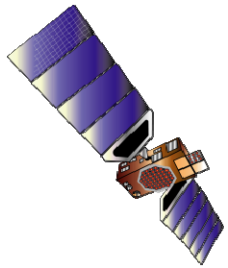


GPS（US）

QZSS（Japan）



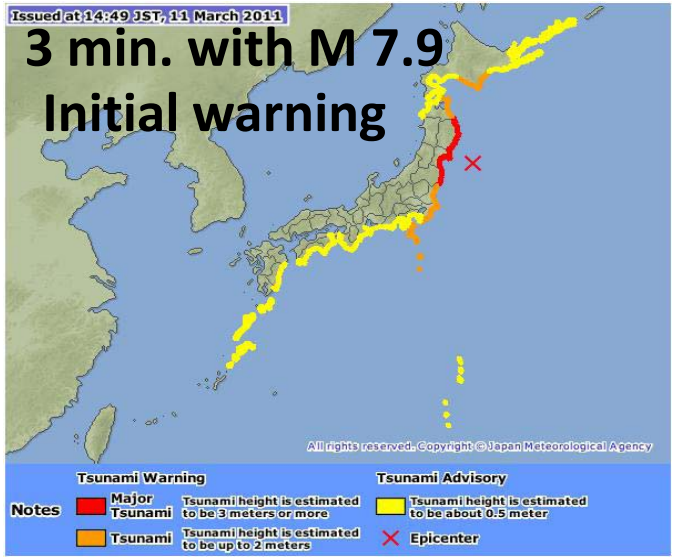
GLONASS（Russia）

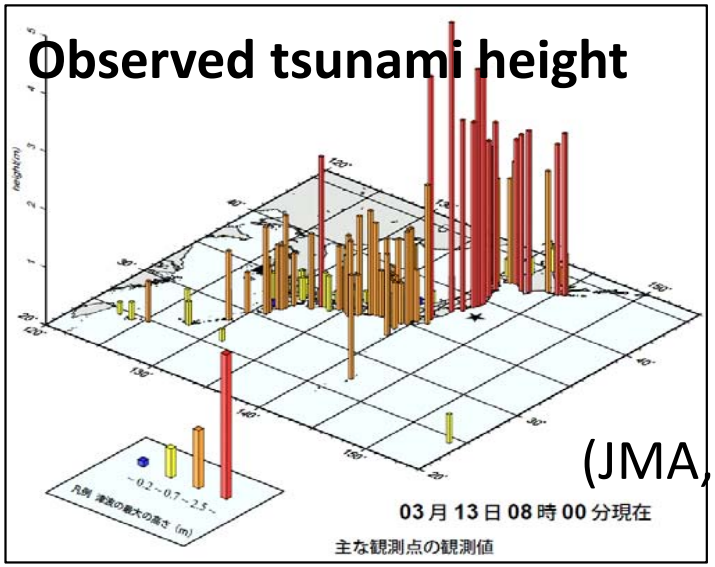


Galileo（EU）

GNSS: Global Navigation Satellite System(s)

Motivation: Improvement of the tsunami warning





(JMA, 2011)

Tsunami warning issued after the 2011 Tohoku earthquake (Mw9.0)

1. Determination of the initial magnitude based on seismic wave data
   → Saturation problem occurred (M7.9)
2. Tsunami database search: based on the saturated magnitude
3. The first tsunami warning: Underestimated tsunami height

Development of the real-time analysis system of GEONET (REGARD)

- GNSS data will never saturate for large earthquakes, should improve the tsunami warning in Japan.

Flow diagram of REGARD

Geospatial Information Authority of Japan (GSI)

DATA

GEONET stations

Real-time 1Hz BINEX

RTCM convert

RTCM

IGS

Ultra-Rapid orbit

JMA

Early Earthquake Warning (option)

1. Real-time Positioning subsystem

RTKLIB 2.4.1 (Takasu, 2011)

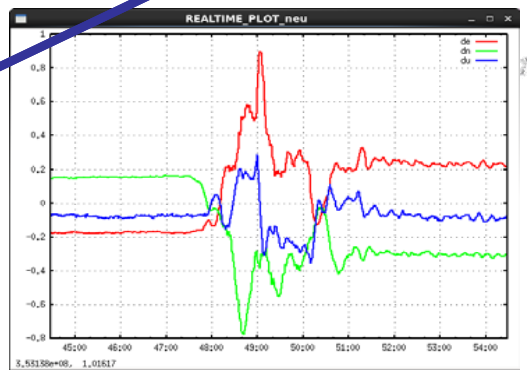
2. Event detection subsystem

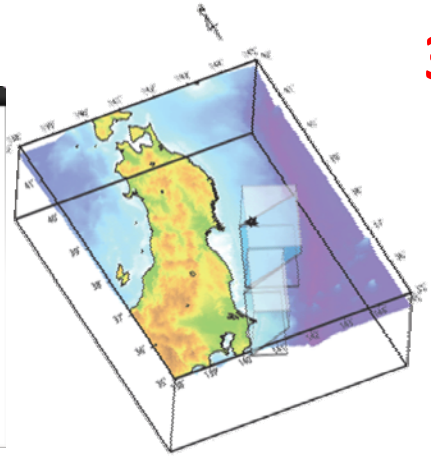
Check for event detections:

- **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)



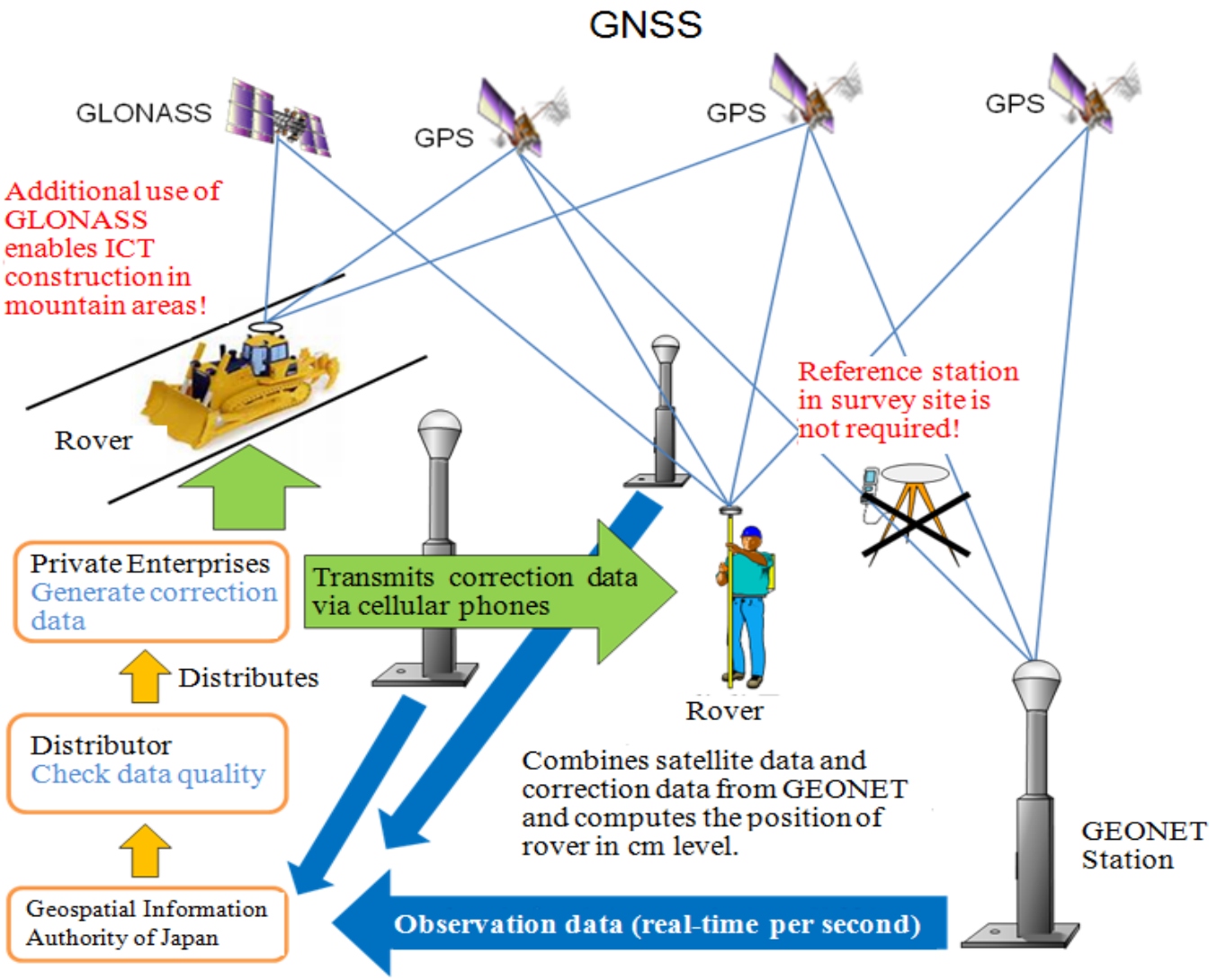


3. Fault model inversion subsystem

Automatic estimation of finite fault model

2) GNSS support for Real-time kinematic positioning (RTK)

- GEONET 1 Hz data are provided to real-time users by private sector
- Widely used in RTK positioning for
  - public surveys
  - aerial photogrammetry
  - mobile Mapping
  - ICT construction
- GLONASS and QZSS data are available from May 10, 2013 in addition to GPS



RTK positioning with GEONET real-time 1-Hz data

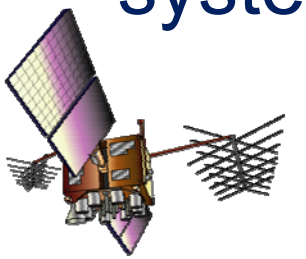
ICT construction with GPS+GLONASS

RTK positioning in Tohoku area

Source: http://www.jenoba.jp/case/case_h04_satoukoumu.html

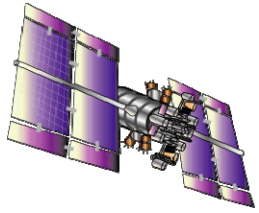
GEONET today

- ~ 1,300 stations with 20km spacing
- 72 hour backup battery
- IP-VPN + backup mobile line (packet communication)
- Modernized for GNSS at all stations !
  - Ready for GPS, QZSS, GLONASS, and Galileo
  - Trimble NetR9 / Topcon NET-G3 (5) and their antennas
- Real-time data delay ~ 0.2 sec
- Growing needs in ICT construction, mobile mapping system, aerial photogrammetry, etc.

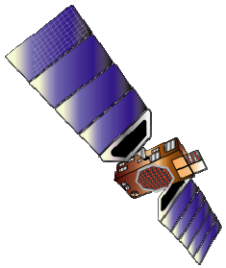


GPS（US）

QZSS（Japan）



GLONASS（Russia）



Galileo（EU）

Case 2 : Volcanic Activities

Active Volcanos in Japan

Mt. Usu

Mt. Hokkaido Komagatake

Mt. Iwate

Mt.Yakedake

Mt. Unzen

Mt. Kusatsu Shirane

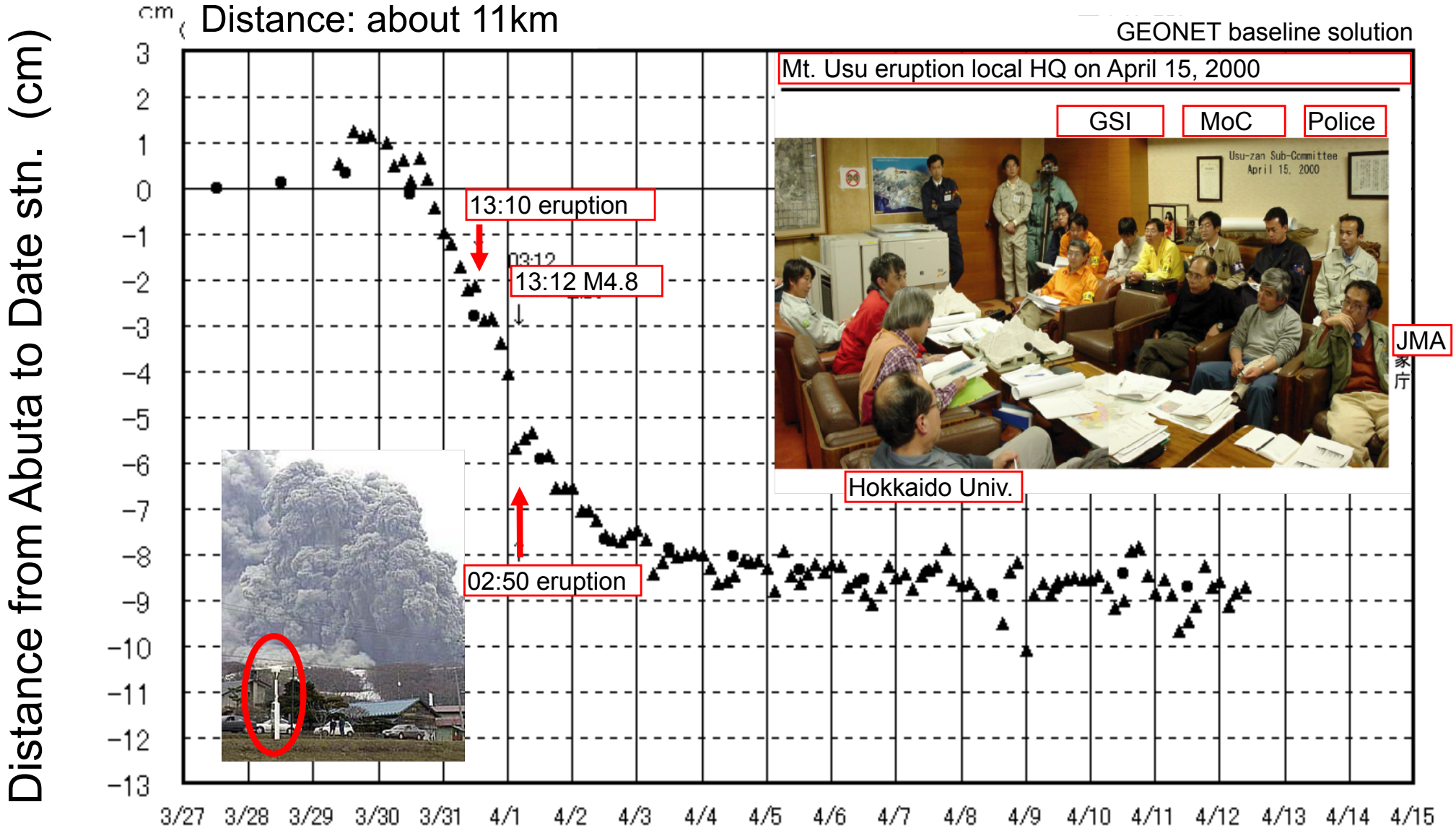
Mt. Kirishima

Mt. Miyake

Mt. Hakone

Detecting magma movement before Mt.Usu eruption in 2000

Geospatial Information Authority of Japan (GSI)



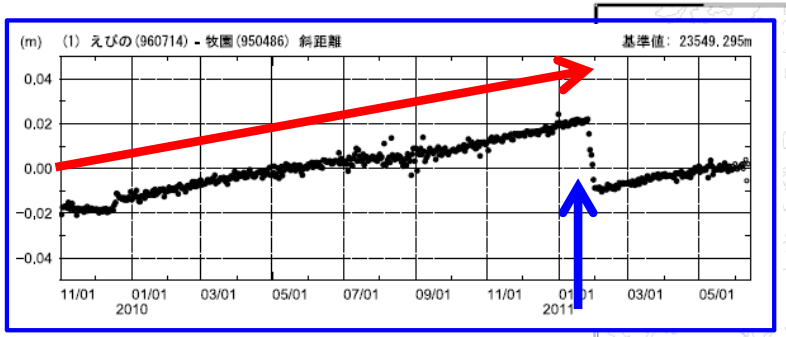
Mt. Kirishima eruption in 2011

Mt. Kirishima eruption in 2011

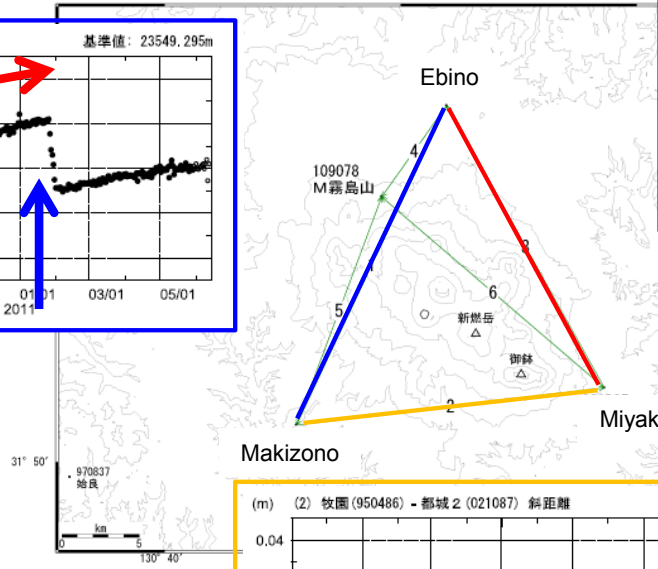
Geospatial Information Authority (GSI)

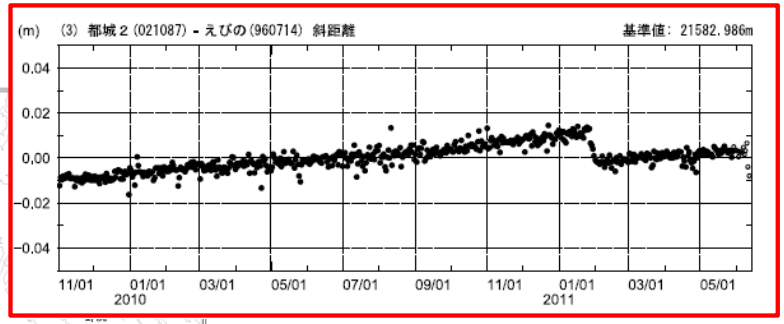
1. Distance increased gradually before eruption
2. After eruption distance decreased

Ebino – Makizono

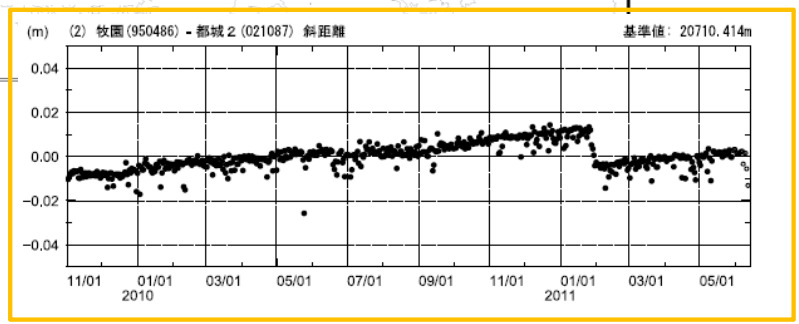


GPS stations around Mt. Kirishima





Miyakonojo-2 - Ebino



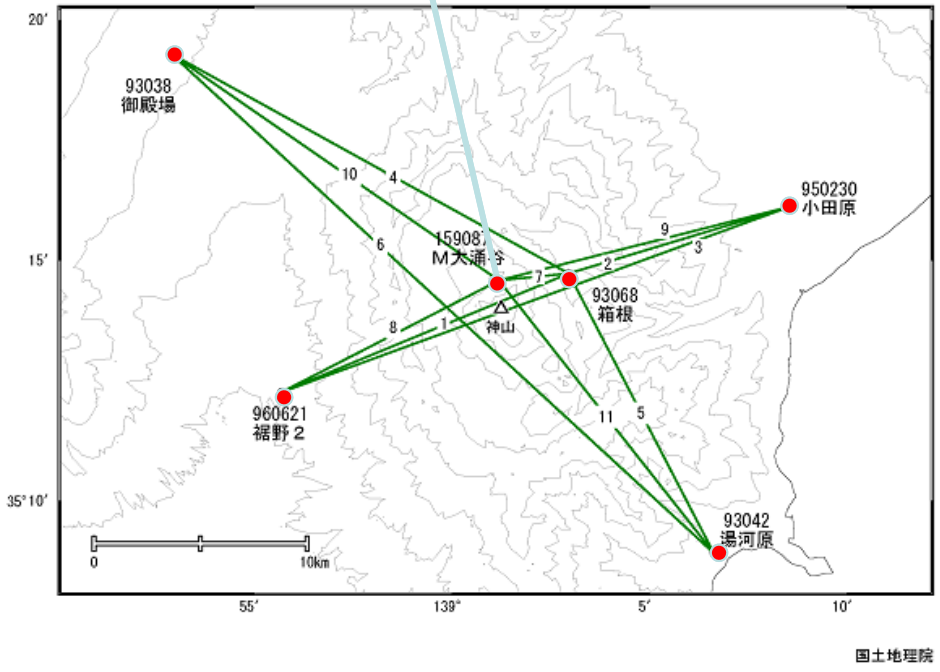
Makizono – Miyakonojo-2

Mt. Hakone eruption in 2015

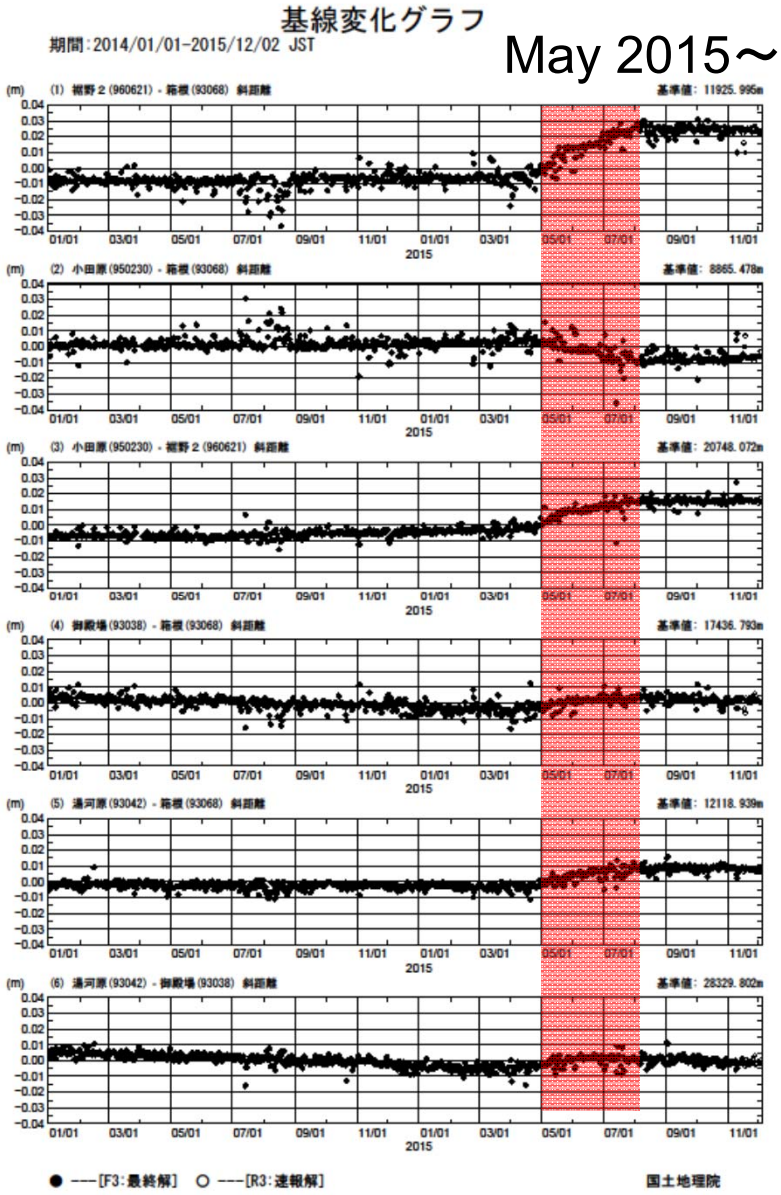
Geospatial Information Authority of Japan (GSI)

- GEONET+REGMOS (Remote GNSS Monitoring System)

May 8, 2015



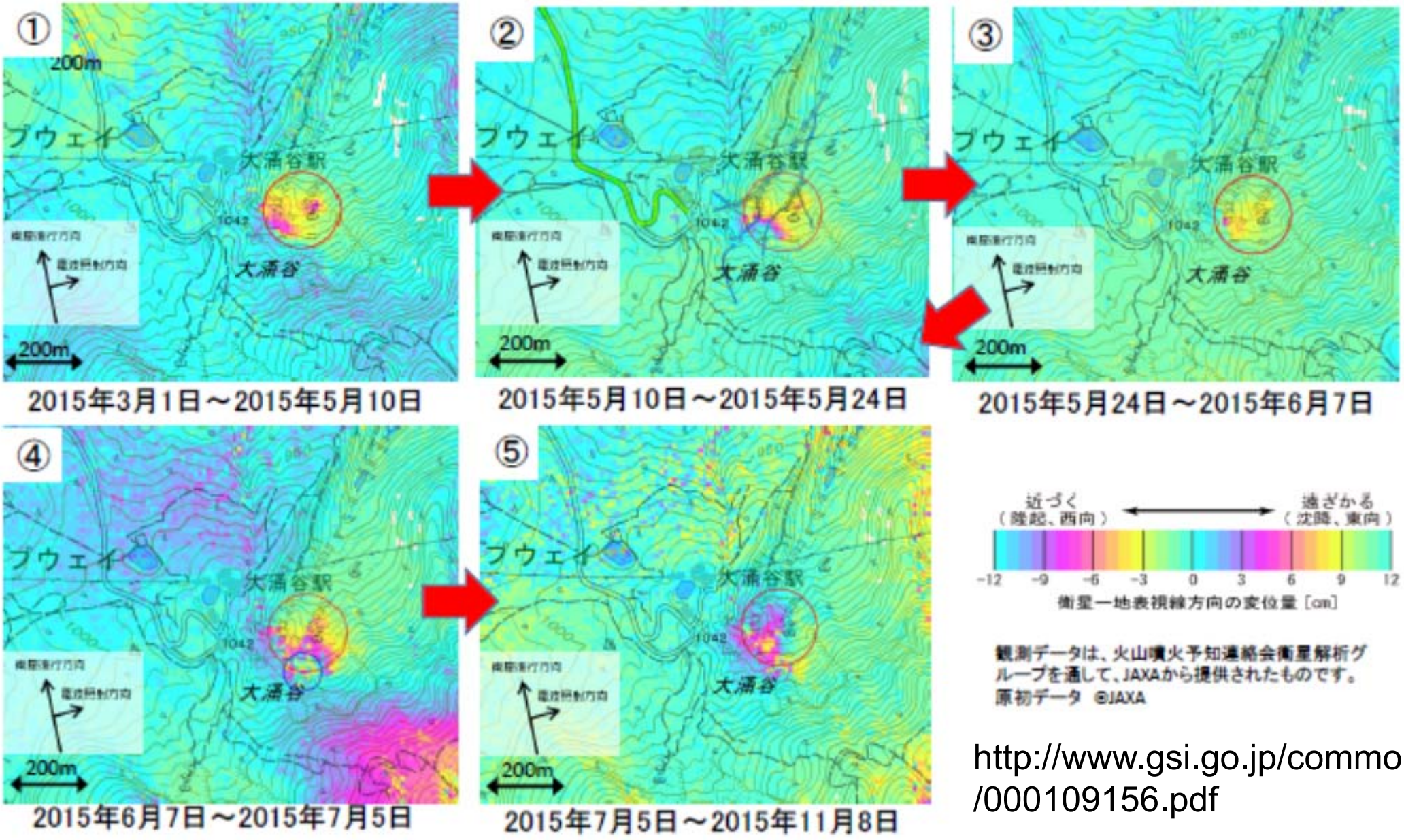
May 2015～



Mt. Hakone eruption in 2015

Geospatial Information Authority of Japan (GSI)

- **Interferometric SAR using ALOS-2 of JAXA**



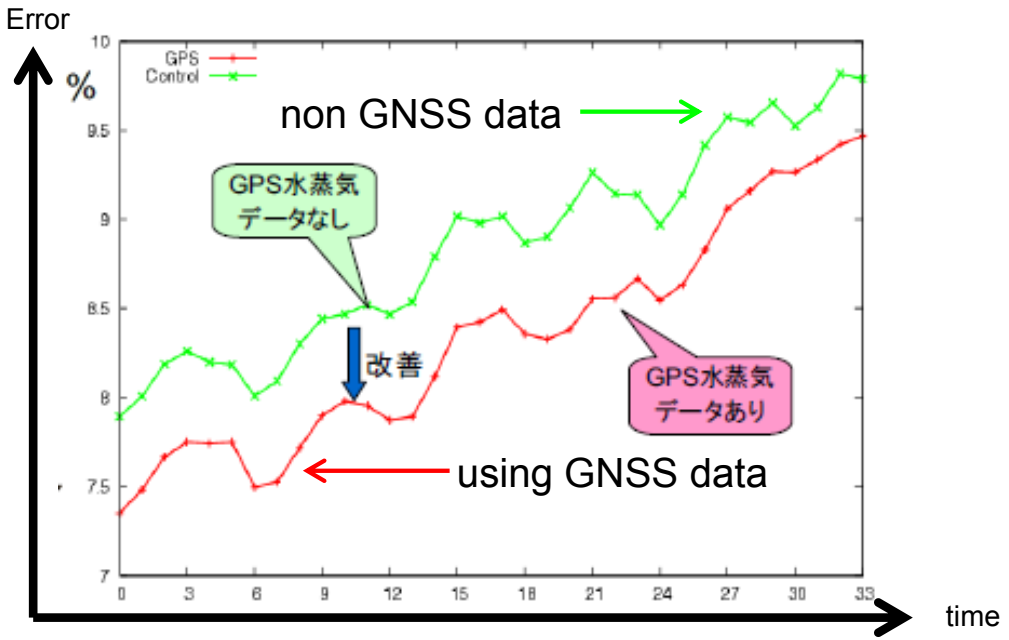
http://www.gsi.go.jp/common/000109156.pdf

Case 3 : Rain Fall Prediction

GPS meteorology

- Watervapor in the atmosphere delays GNSS signals.
- Using GNSS signals in turn, we can estimate zenith tropospheric delays, which can be used for data assimilation of numerical weather prediction.

- After joint study on GPS meteorology with GSI, JMA introduced GPS precipitable water from 2009 for their routine analysis.
- This is effective to the prediction of torrential rains.



Predict error of humidity decrease
(Meso Scale Model)

http://www.jma.go.jp/jma/press/0910/27a/MSM_GPS.htm

Score of JMA rain fall prediction

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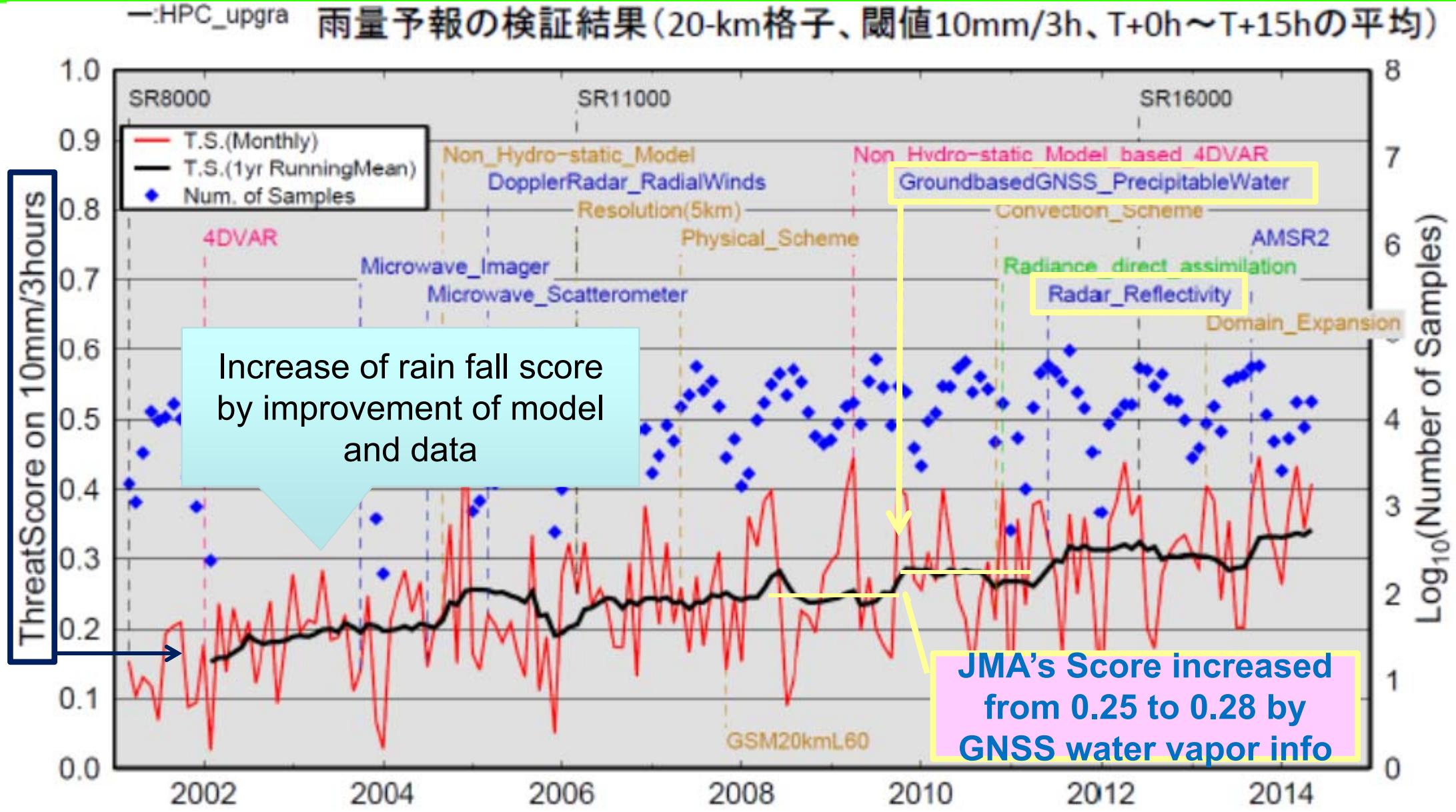

Source: Masashi Nagata, 2015
http://www2.jpgu.org/meeting/2015/session /PDF/U-07/U07-07_E.pdf

UAV in action at flooded areas

- Due to the Kanto and Tohoku heavy rain fall on September 10, 2015, “Kinugawa river” was flooded.
- Being quite near to GSI’s HQ in Tsukuba, a UAV team was sent there on the same day.
- UAV shoots flooded area from 10m height.
  - Youtube (search with “kinugawa” and “uav”)

https://www.youtube.com/watch?v=WFtpyGXyDFg&feature=youtu.be

Conclusions

- GSI has been operating GEONET in Japan for the past two decades
  - to establish a regional reference frame consistent with the Global Geodetic Reference Frame (GGRF), and
  - to monitor crustal deformations associated with EQ and volcanic activities for disaster mitigations.
- We can not stop natural hazards, but can mitigate disasters by making full and smart use of Geospatial Information.

Appendix: Open source GNSS analysis software: GSILIB

- GSI developed GNSS analysis software named GSILIB (GNSS Surveying Implementation Library) to support multi-GNSS surveys, based on RTKLIB （Takasu,T., 2011, http://www.rtklib.com/ rtklib.htm)
- GSILIB enables the correction of several biases of multi-GNSS receivers (i.e. L2C quarter-cycle bias, Inter Frequency Bias, and Inter System Bias) for using single/double differences between GPS and other GNSS.
- Please visit our web site at http://datahouse1.gsi.go.jp/gsilib/gsilib.html.