ICG Working Group D

Reference Frames, Timing and Applications

Application of GNSS CORS for precise positioning and earthquake research in Japan

GEONET

ICG-13, Nov.4-9, 2018 @ Xi’an, China

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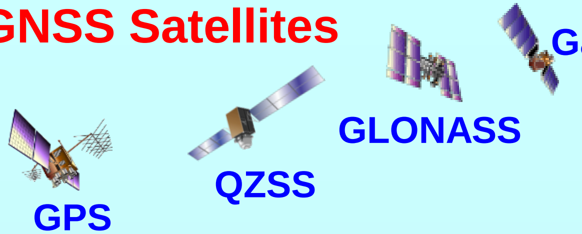
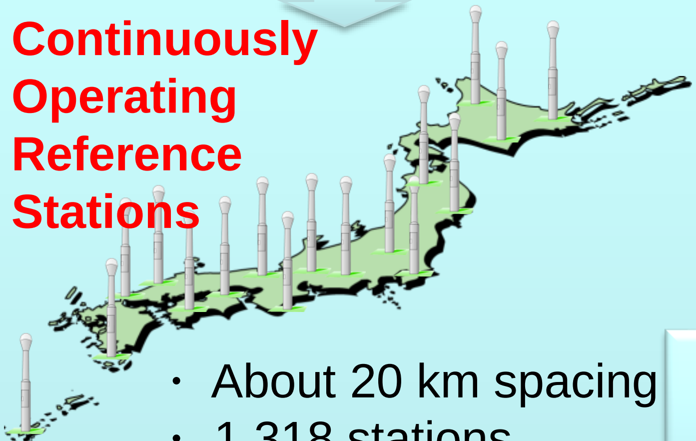
GNSS CORS in Japan *GEONET*

Geospatial Information Authority of Japan (GSI)

GNSS Satellites

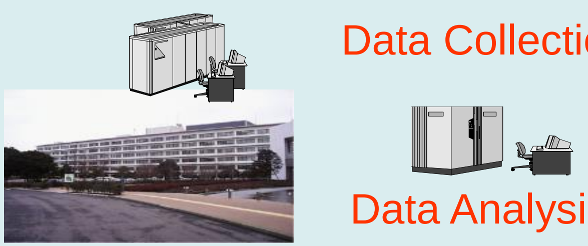


Continuously Operating Reference Stations

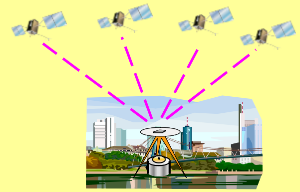


- About 20 km spacing
- 1,318 stations
- Operated 24/7
- Transferring real-time 1 Hz observation data

Analysis Center in Tsukuba



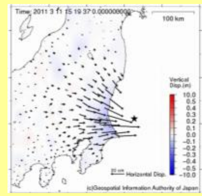
RINEX data (every 30 sec)



Survey & Mapping

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

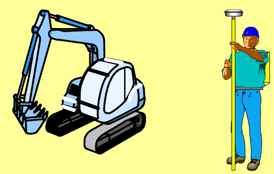
Site Coordinates (ITRF)



Crustal deformation Monitoring

- Monitoring of Earthquakes and Volcanic activities
- Tsunami early warning
- Monitoring of ground water

Real-time data

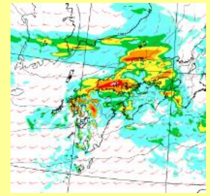


Provided to the Industry

Precise real-time positioning

- ICT construction
- Precision farming
- QZSS Centimeter Level Augmentation（CLAS）

Other data

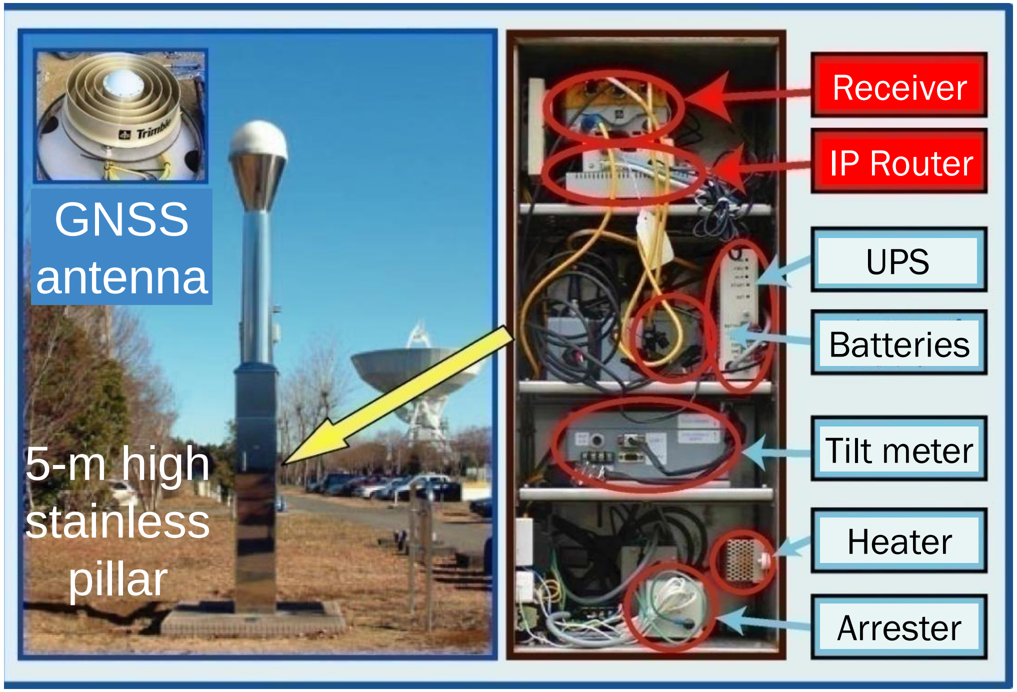


Other Applications

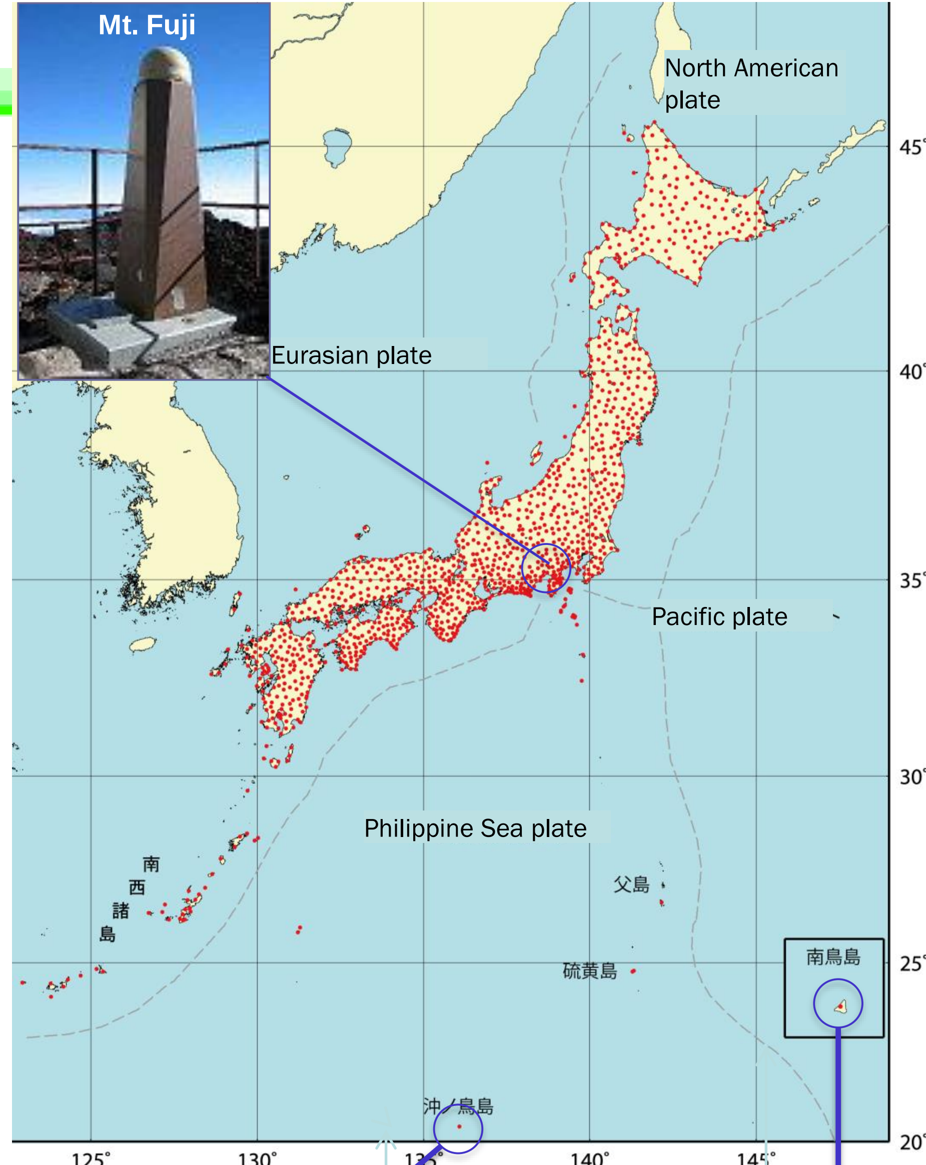
- Weather forecast using watervapor info from GNSS
- Ionosphere studies

GEONET stations

1,318 stations with 20 – 25 km spacing



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




Okino Tori island


Minami Tori island

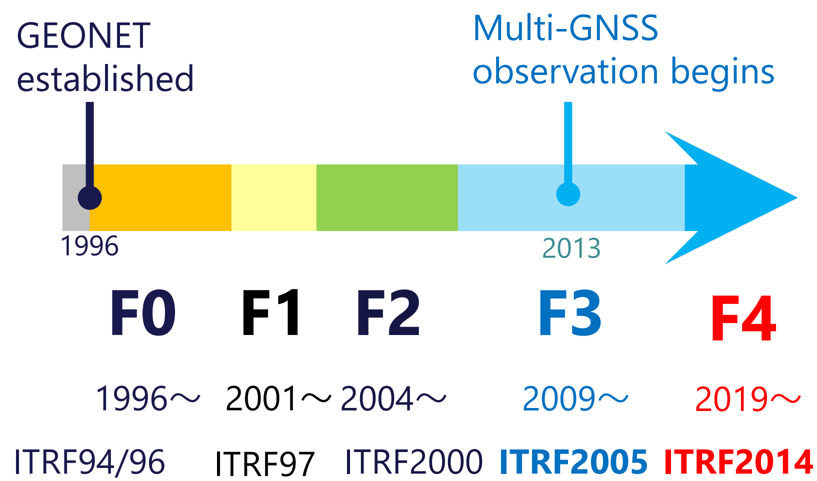
Realization of ITRF2014 in Japan

These slides are based on the presentation on “Development of new GEONET analysis strategy” by S.Kawamoto, S.Abe, Y.Hatanaka, and N.Takamatsu read at the 130th meeting of the geodetic society of Japan in Oct. 2018.

Daily Site Coordinates of GEONET

- GSI provides daily site coordinates of GEONET
  - Widely used for crustal deformation monitoring and precise positioning including CLAS, which are dynamic.
  - Current version is “F3”, soon to be replaced by “F4”.
  - Note that coordinates at the reference epoch derived from GNSS & VLBI observations define the Japanese Geodetic Datum for survey and mapping, which are static.

Name of analysis strategies and solutions

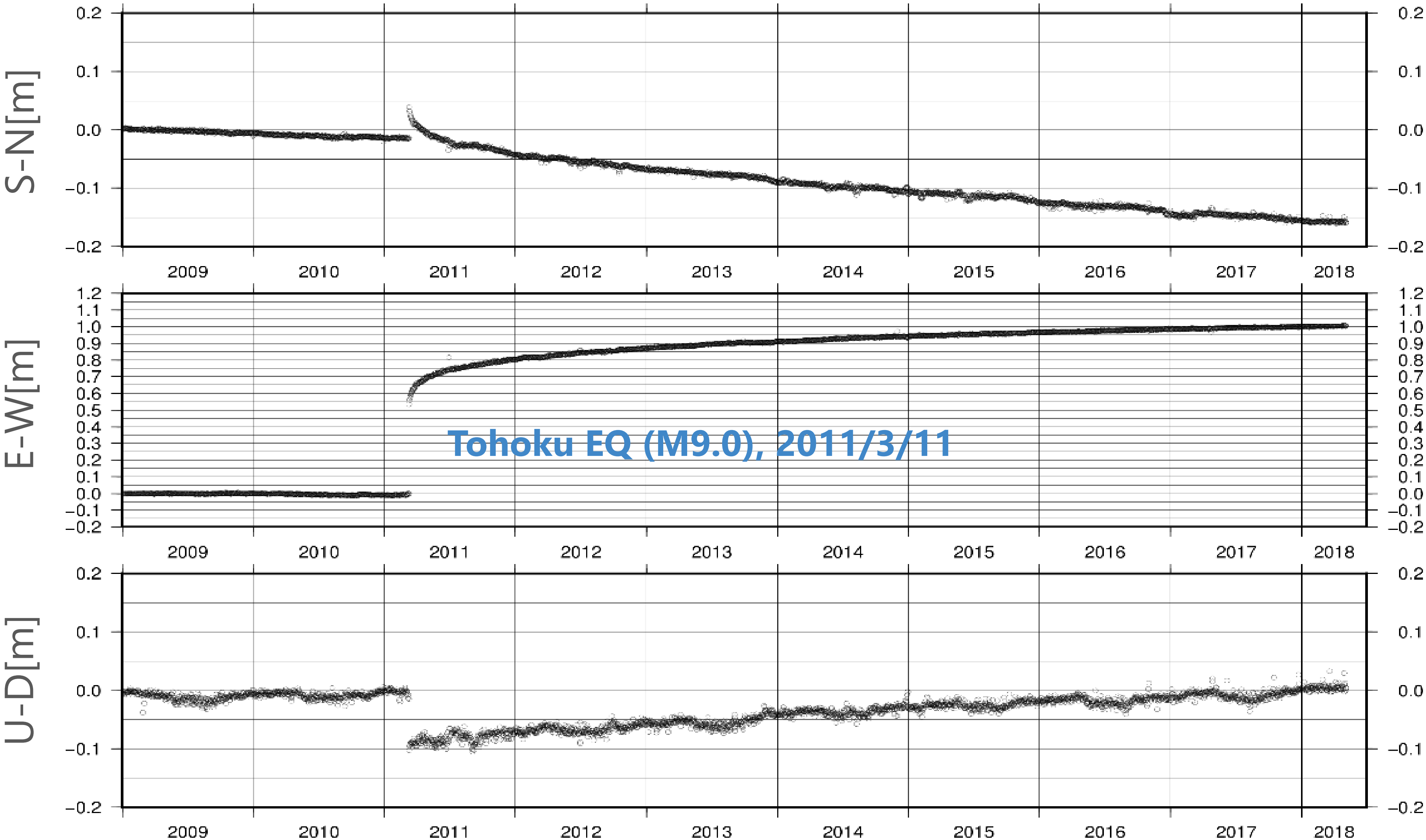


Daily Site Coordinates of GEONET

Geospatial Information Authority of Japan (GSI)

Daily coordinates (F3) at TSKB (Tsukuba)

2009-Jan-01 to 2018-May-05

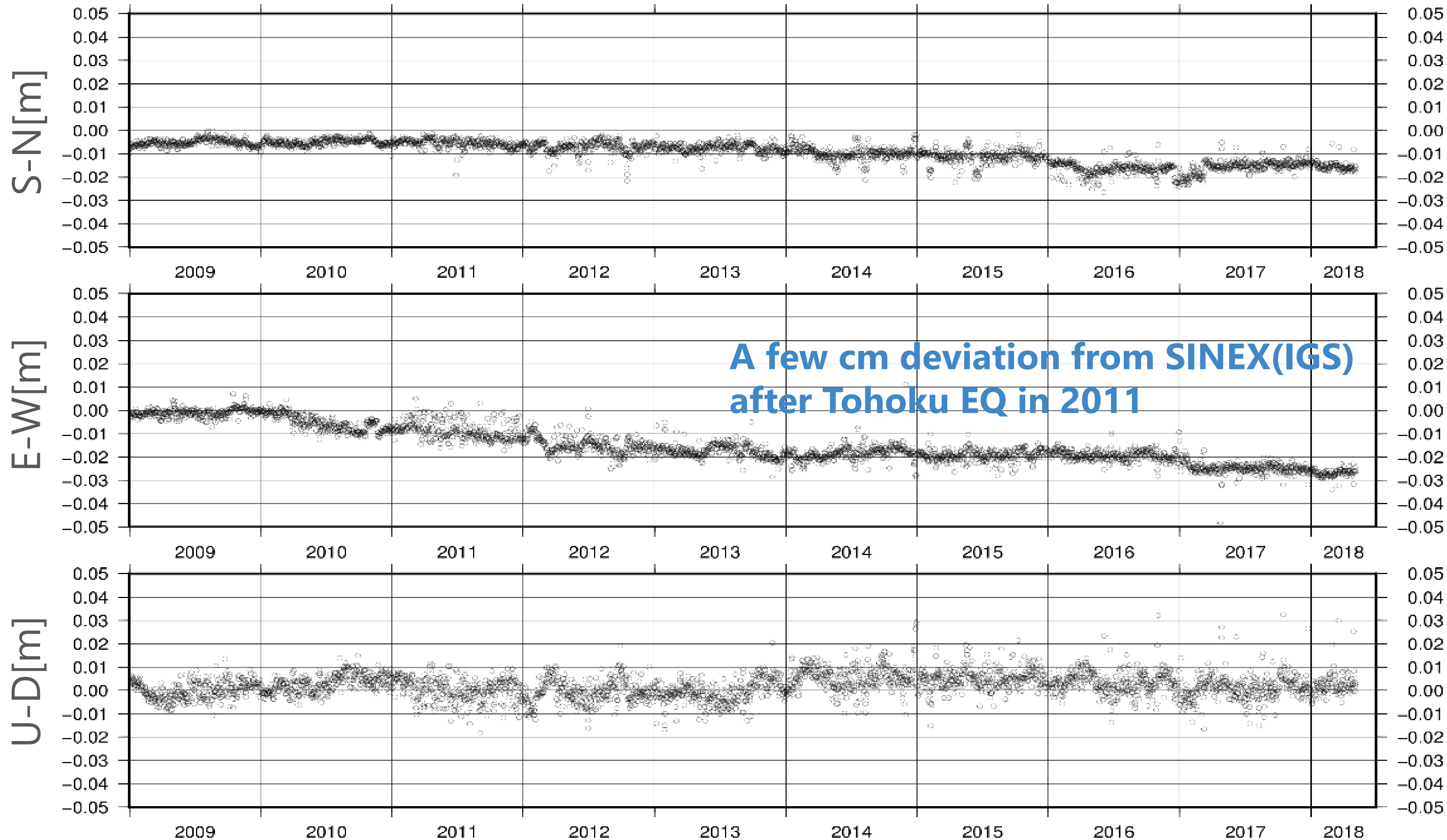


Daily Site Coordinates of GEONET

Geospatial Information Authority of Japan (GSI)

Differences between F3 and SINEX(IGS) at TSKB

2009-Jan-01 to 2018-May-05



Analysis strategy for “F4”

	F3	F4
Software	Bernese ver.5.0	Bernese ver.5.2
Satellite type	GPS only	GPS and GLONASS
Coordinates	ITRF2005	ITRF2014
Mapping function	NIELL	GMF/VMF1
ZTD space	3h	1h (GPS) 2h (GLONASS)
Grd space	24h	3h (GPS) 6h (GLONASS)

Newest version

Multi-GNSS

Newest RF

More localities

More time resolution for tropospheric delay parameters

To remove periodic noises (~8 days) in GLONASS time series, Helmert transformation 7 parameters are also estimated when normal equations are combined.
For details, see our presentation at WG-D, ICG-12.

Comparison of time series

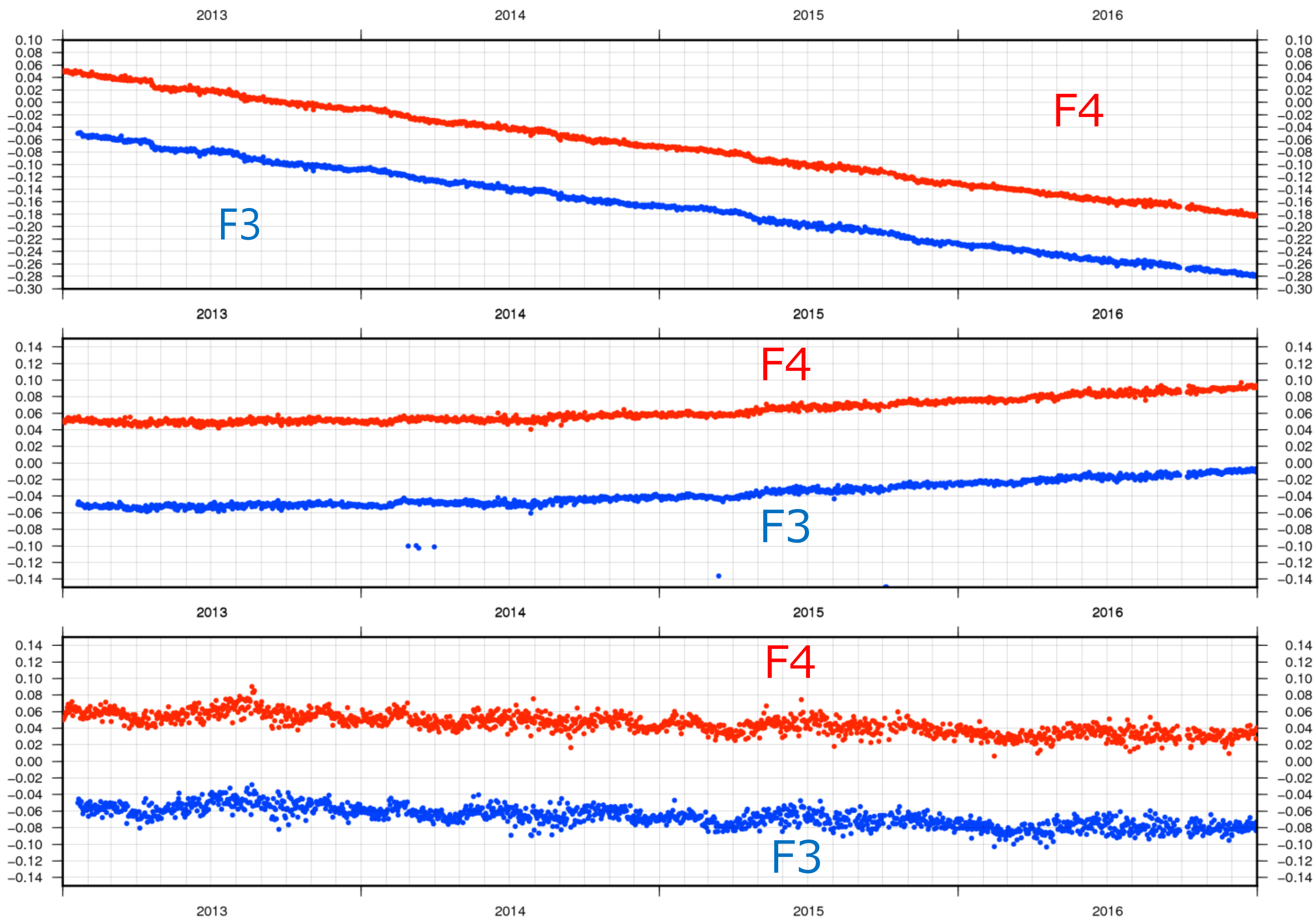
Geospatial Information Authority of Japan (GSI)

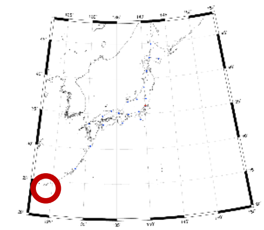
Time series at “Hateruma” station Jan. 1st 2014 – Dec. 31st 2016

NS

EW

UD





"Hateruma"

±5 cm offsets are given

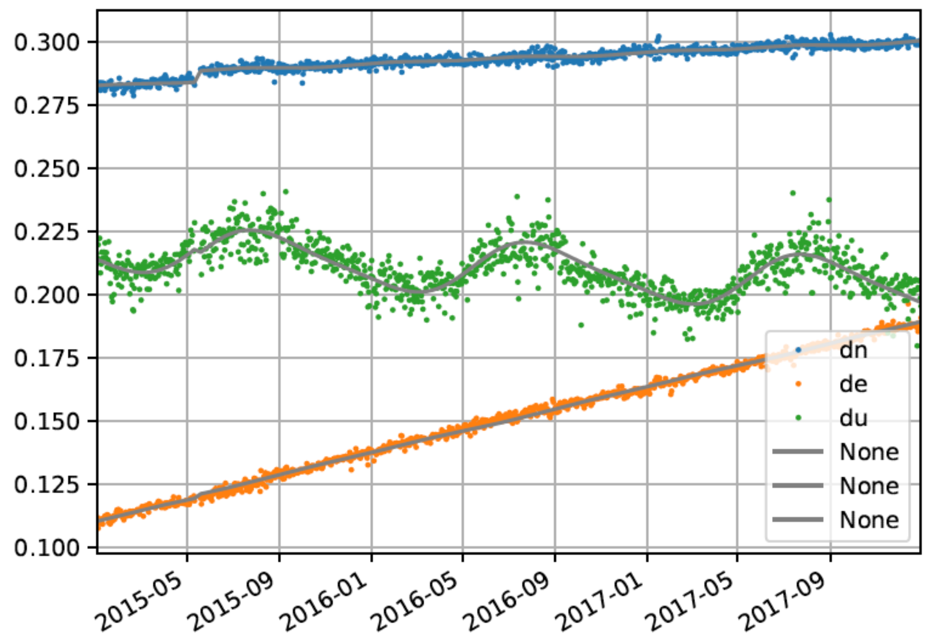
Evaluation of precision

Residual RMS of 20 baseline vectors from Tsukuba1 are examined after removing linear trends and seasonal variations with the cycles of 1-year and a half-year.

Period : 2015/1/1～2017/12/31

Sites : Backbone stations (20)

Function : $Y = y_0 + \mathrm{trend} + \mathrm{year} + \mathrm{half\ year}$



The offsets from antenna exchanges are estimated from time series.

Comparison of precision

Mean RMS at 20 Backbone stations

	N	E	U
GPS solution (F3)	2.04 mm	2.16 mm	6.52 mm
(F4)	**2.01** mm	**2.10** mm	6.21 mm
GLO sol. (F4)	2.51 mm	3.68 mm	8.71 mm
Comb. sol. (F4)	**2.00** mm	**2.11** mm	**5.76** mm

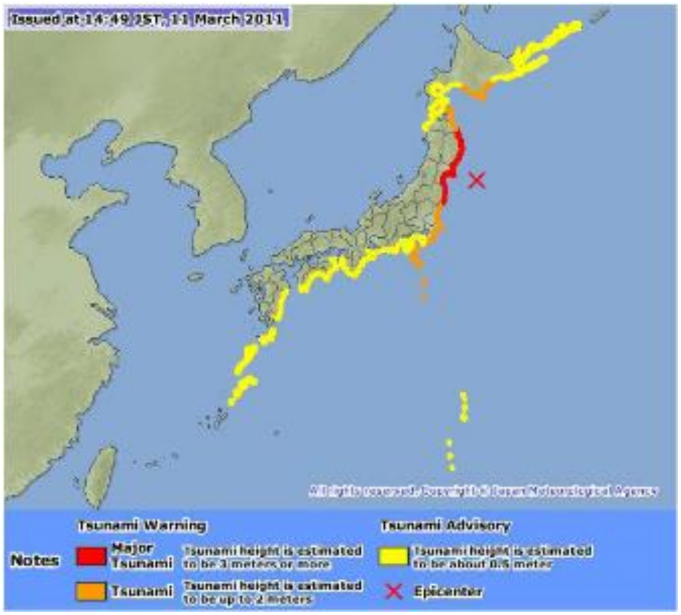
- Reduction of RMS in F4 analysis by
  N, E: **0.03 - 0.05** mm
  U : **0.3 - 0.7** mm
- Significant improvement in vertical component for combined solutions (F4)

Real-time coseismic fault model estimation system "REGARD" based on RTK-GNSS analysis

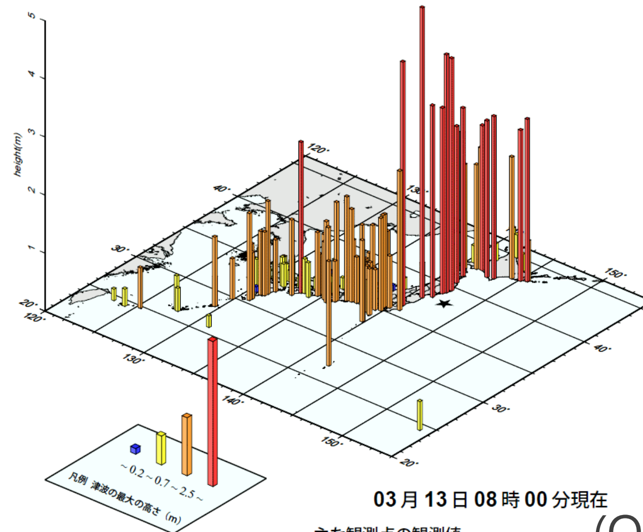
These slides are prepared by S. Kawamoto[1], S. Abe[1], K. Ohashi[1] , Y. Ohta[2], M. Todoriki[3], and T. Nishimura[4] for the 12th Joint Meeting of the UJNR Panel on Earthquake Research in Oct. 2018.
1) GSI, 2)Tohoku Univ., 3)Fujitsu laboratories Ltd., 4)Kyoto Univ.

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

Warning at 3 minutes



Observed



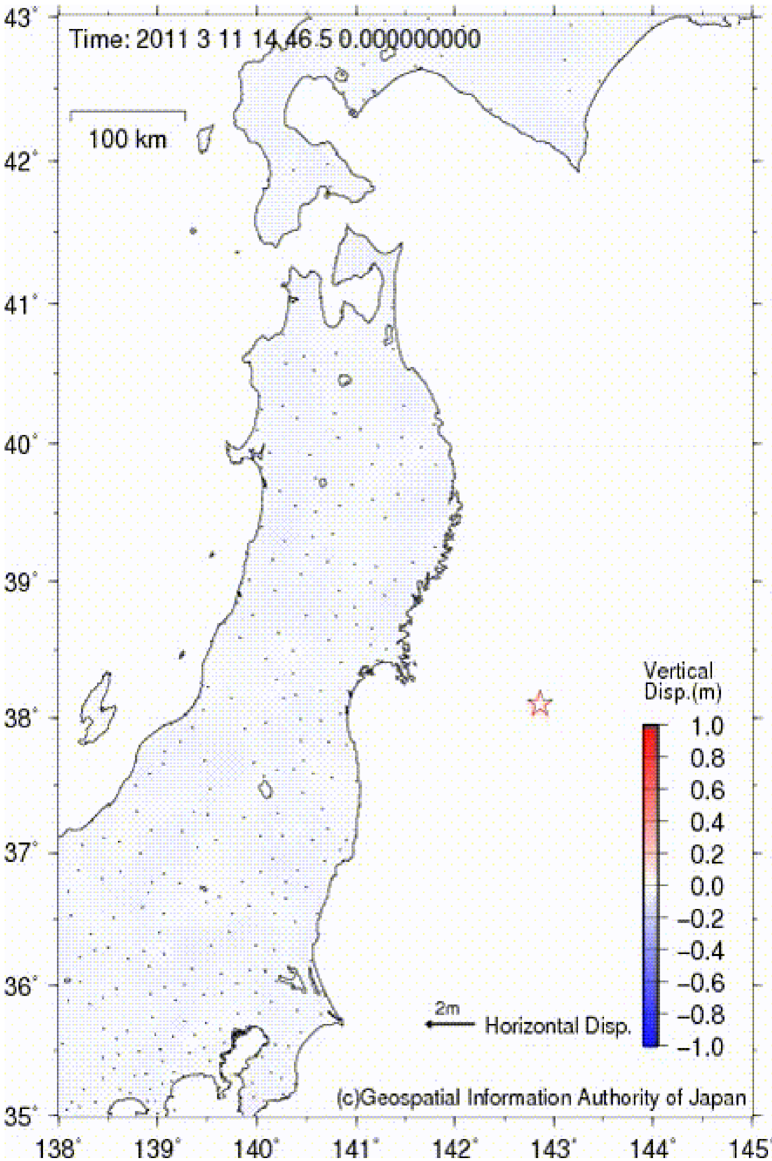
(Ozaki, 2011)

Reasons:

- Saturated earthquake early warning (**M7.9**)
- Tsunami warning **depended on short-period magnitude**

How to prevent the saturation problem?

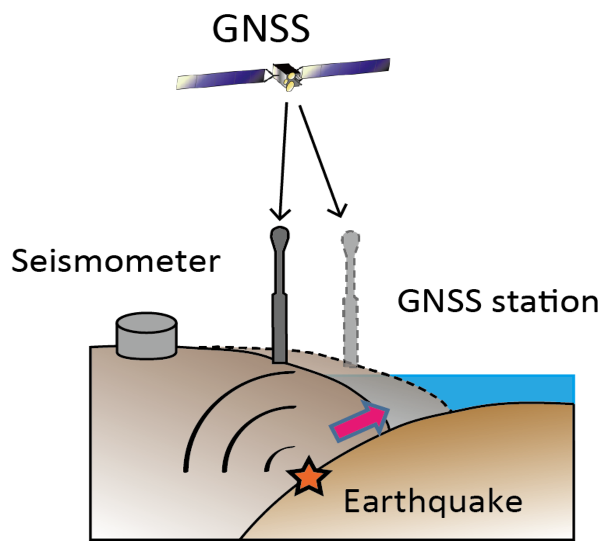
Prevention of the M Saturation



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

Real-time Kinematic GNSS provides:

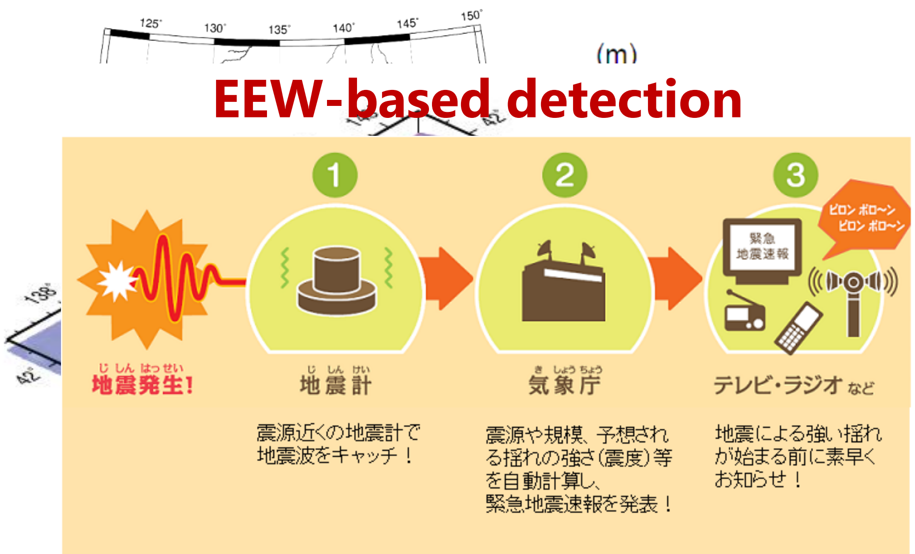
- **Real-time displacement**
- **Finite fault model**
- **Mw free from saturation problem**



Provides Mw within 3 minutes

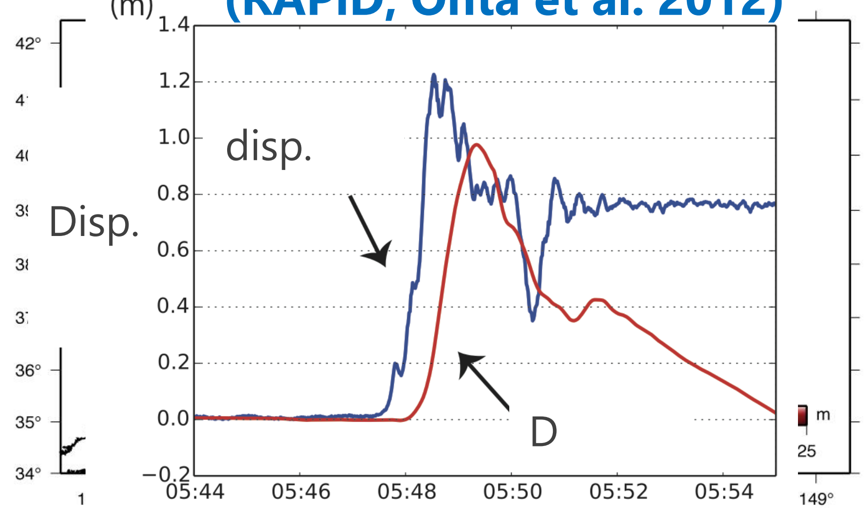
- Calculates 1Hz displacement
- Detects earthquake events
- Estimates fault model automatically

EEW-based detection



Threshold: M>7

GNSS-based detection (RAPiD; Ohta et al. 2012)



Threshold: 10 cm

History of the REGARD system

Geospatial Information Authority of Japan (GSI)

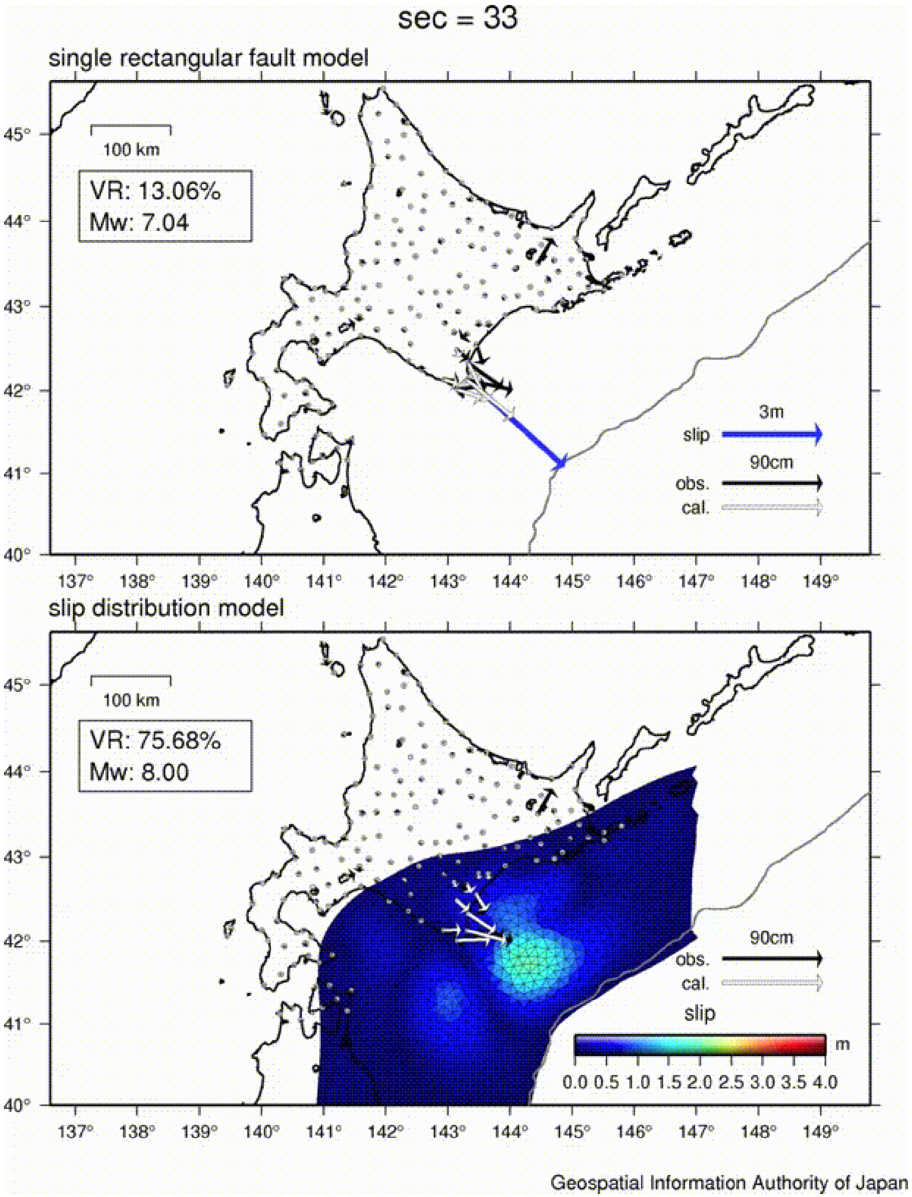
	2012	2013	2014	2015	2016
# of sites	160	600			1200+
satellites	GPS			GPS+GLO	
inversions	･Single rectangular fault			･Slip distribution	

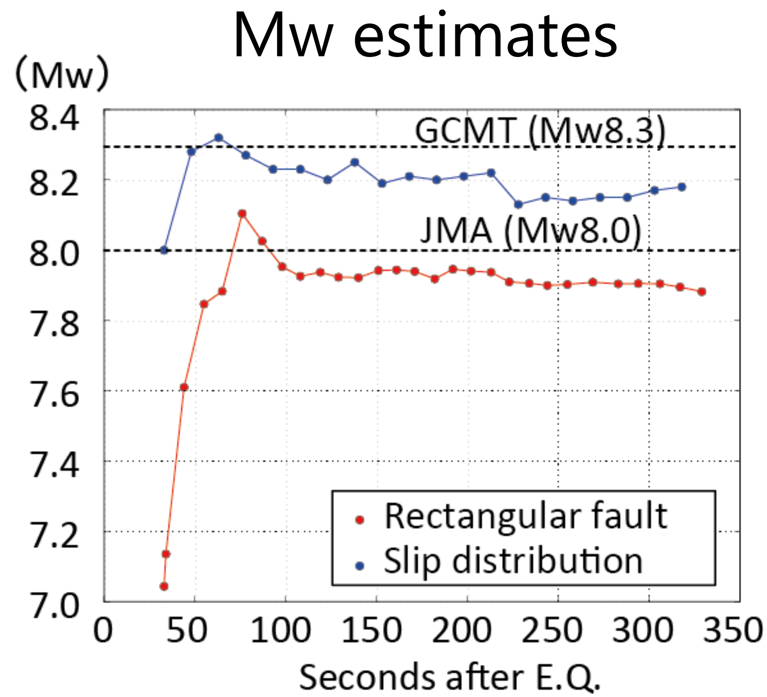
Project launch (2012)

Full operation (2016)

- **Full operation after Apr. 2016**
- Real-time positioning at 1200+ stations (GPS+GLO)
- Two fault model inversion routines

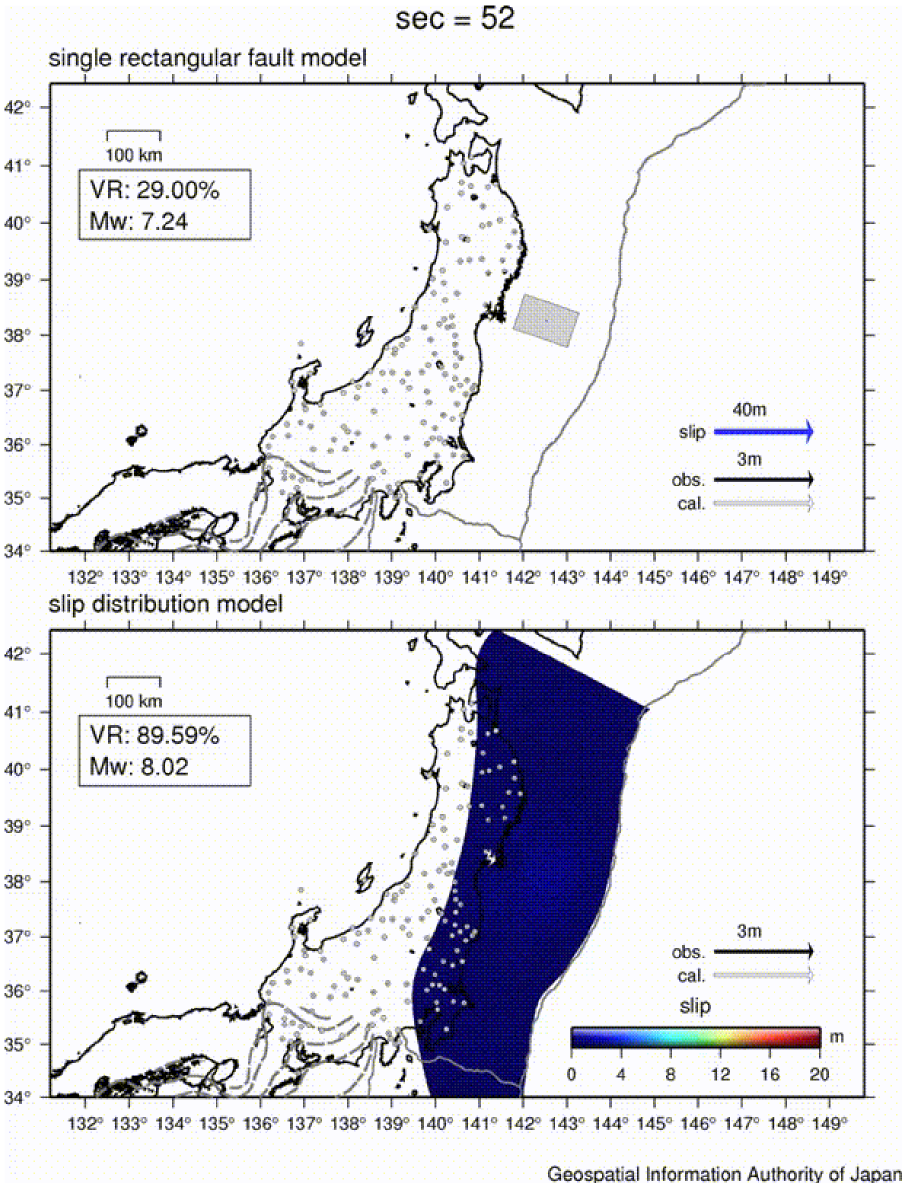
2003 Tokachi-oki earthquake (Mw 8.3)

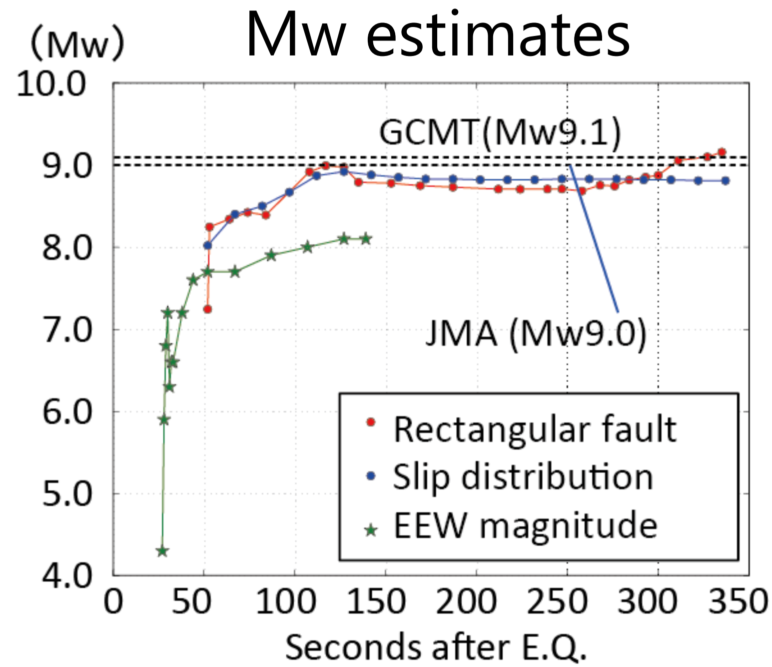




- **Both models were stable** with high VRs
- Single rectangular fault was a little small because of shallower pos estimate

2011 Tohoku earthquake (Mw 9.0)





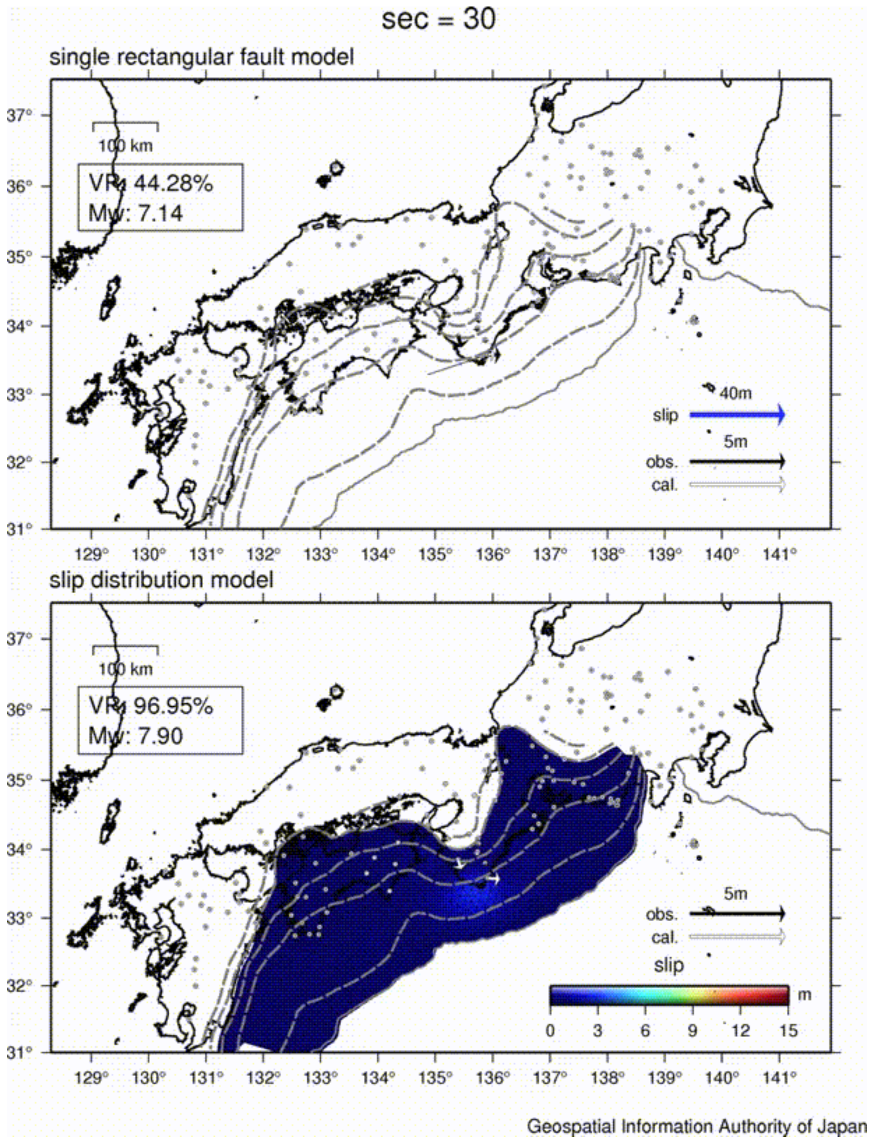
- **Stable after 120 seconds**

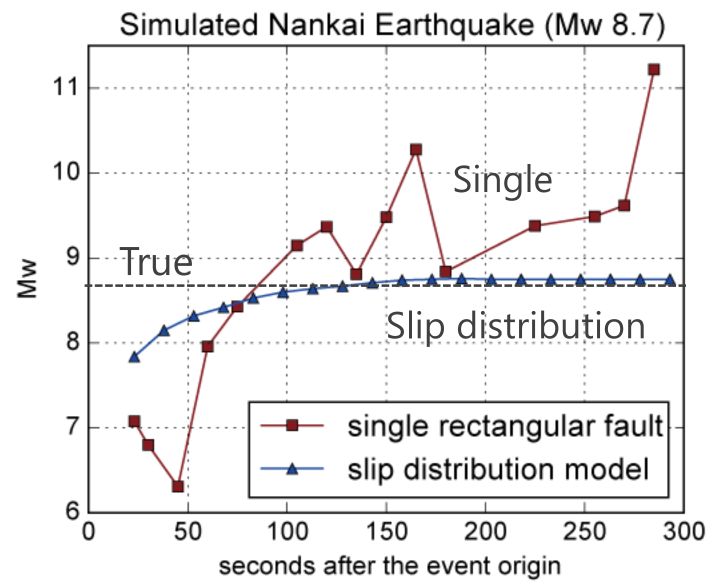
Single fault: Mw 9.03 (VR 96%)
Slip distribution: Mw 8.83 (VR 99%)

Test for future large earthquake

Geospatial Information Authority of Japan (GSI)

Nankai Trough earthquake (Mw8.7)

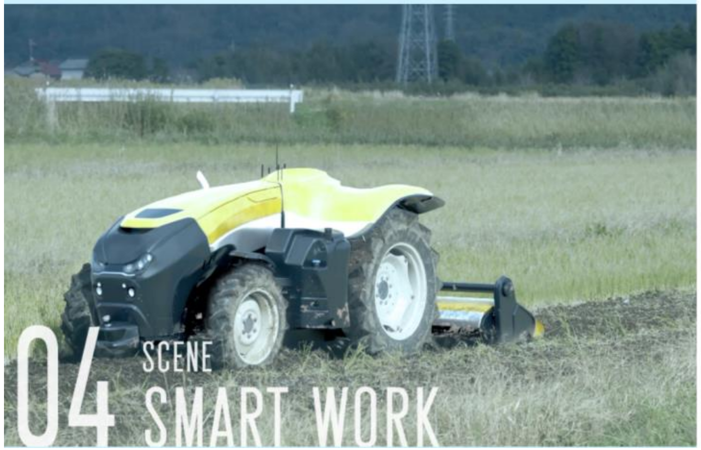




- **Slip distribution model provided accurate Mw**
- Single rectangular fault was unstable due to the complex plate boundary and slip

Towards the "Society 5.0“

"Society 5.0"



https://www.gov-online.go.jp/cam/s5/eng/

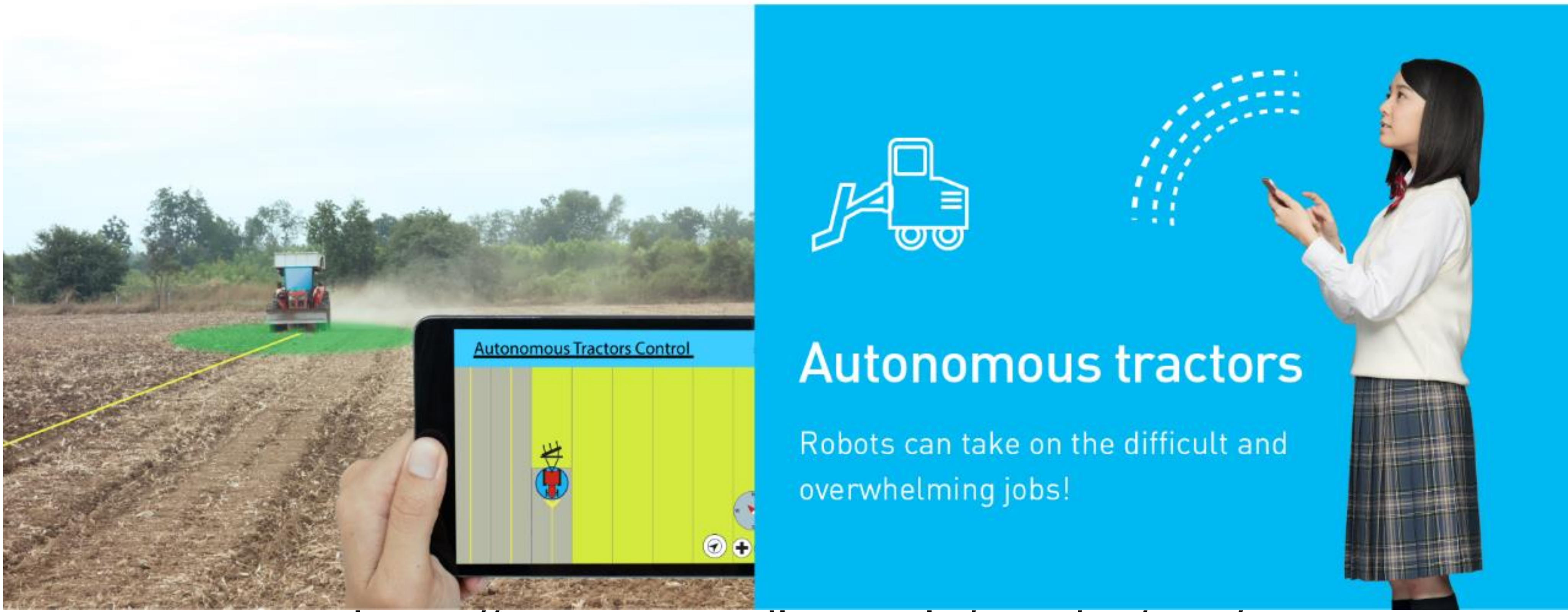
“Society 5.0” with QZSS

Daily life | Work

Work will change.

Autonomous tractors ending the labor shortage?

GPS is used for car navigation and other purposes. "Michibiki," Japan's Quasi-Zenith Satellite System (QZSS), will reduce GPS calculation errors down to units of a few centimeters. These will, for example, result in autonomous tractors helping end labor shortages for farmers needing to plow and seed a field.



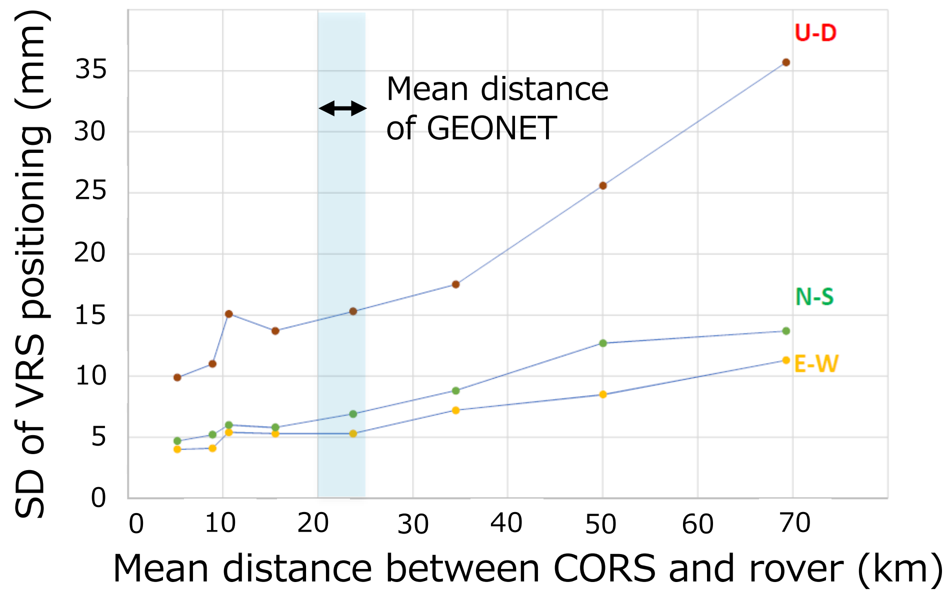
https://www.gov-online.go.jp/cam/s5/eng/

Importance of dense CORS

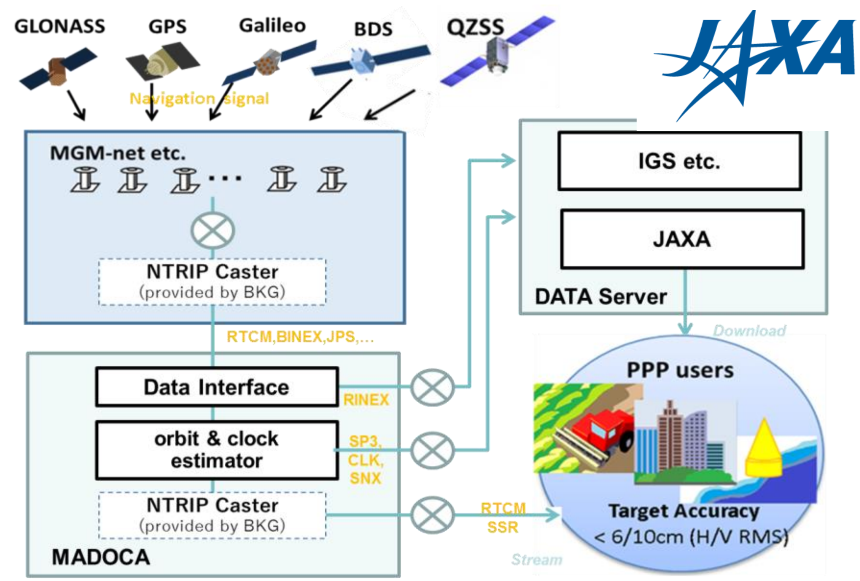
Dense GNSS CORS can

- **improve precision of network RTK-GNSS**

T.Imakiire and M.Hosoya, Density of CORS and positioning accuracy, presented at the 130th Meeting of Geodetic Society of Japan, Oct. 2018



- **boost performance of PPP with local correction**
  - Target for moving platform
    - Horizontal 3 cm (RMS)
    - Vertical 6 cm (RMS)
    - Quick initialization with local correction from nearby GEONET (30 minutes ⇒ 1 min)



Based on the presentation by Dr. Hideki Yamada of JAXA at the 1st JAXA-GSI GNSS WG on June 21, 2017.

Conclusions

- Introduction to GNSS CORS in Japan: GEONET
- New daily coordinates of GEONET (“F4”) aligned to ITRF2014 will be published soon.
- Real-time analysis of GEONET for disaster mitigation (“REGARD”) is now operational.
- Dense CORS can boost performance of RTK and PPP.

- Thank you for providing the state of the art GNSS services and IGS products, which enable the realization of “Society 5.0”

How to get GEONET Data

- RINEX 30 sec, daily solutions F3, R3 (cc-by)
  - GSI web page http://terras.gsi.go.jp
  - To access from non-jp domain, see http://datahouse1.gsi.go.jp/terras/terras_english.html
  - Old RINEX before April 2010 (marginal cost)
    ⇒ Contact data@geo.or.jp
    (Japan Association of Surveyors)
- RINEX/BINEX 1 sec at events (marginal cost, cc-by)
  ⇒ See http://www.jsurvey.jp/eng-data_rinex-1sec.htm, Contact data@geo.or.jp
- Real-time stream 1 sec (commercial)
  ⇒ Contact Network RTK providers
  https://www.jenoba.jp/support/contact/
  https://www.gpsdata.co.jp/contact_us/
  https://www.terasat.co.jp/contact.html