IAG / FIG / UNGGIM / UNICG / PhilGEGS
Reference Frame in Practice
Manila, Philippines 21-22 June 2013

GNSS CORS and Reference Frame
(GEONET by GSI : part1)

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（Geospatial Information Authority of Japan)

Contents

1. Introduction

- The Geospatial Information Authority of Japan (GSI) is the unique governmental organization that conducts basic survey and mapping.
  - Formerly known as *Geographical Survey Institute*
- GSI is responsible to provide the “standard” for the survey and mapping in Japan, including the geodetic reference frame for surveyors and other users of geodetic coordinates .
- GEONET is the essential infrastructure to realize the geodetic reference frame of Japan.

Survey Act and GSI

Survey Act (Japanese law for the survey and mapping)claims that all the survey data should be referred to the origins of horizontal and vertical control networks.

- Origin of Horizontal Control Network for geographical latitude and longitude

Origin of horizontal control network
(Azabudai, Minato-ku, Tokyo)

- Origin of Vertical Control Network for height

Origin of vertical control network
(Nagatacho, Chiyoda-ku, Tokyo)

GSI is responsible to establish the geodetic control network of Japan, regarding to the Survey Act, as the governmental organization.

Control Points in Japan (maintained by GSI)

to provide the reference positions for Basic Survey and Public Survey

Category	# of stations	Sub-category		Average Interval
GNSS-based control stations **(GEONET)** 	1,240			20 km
Triangulation stations 	109,074	First order triangulation stations	975	25 km
		Second order triangulation stations	5,060	8 km
		Third order triangulation stations	32,326	4 km
		Fourth order triangulation stations	70,713	1.5 km
Bench marks 	18,239	Fundamental bench marks	86	150km
		First order bench marks	14,682	2 km
		Second order bench marks	3,471	2 km
Total	128,553			

GEONET is the most fundamental facilities for Survey

(as of March 31, 2011)

2. GEONET

GNSS based control station in Tsukuba (GSI headquarters)

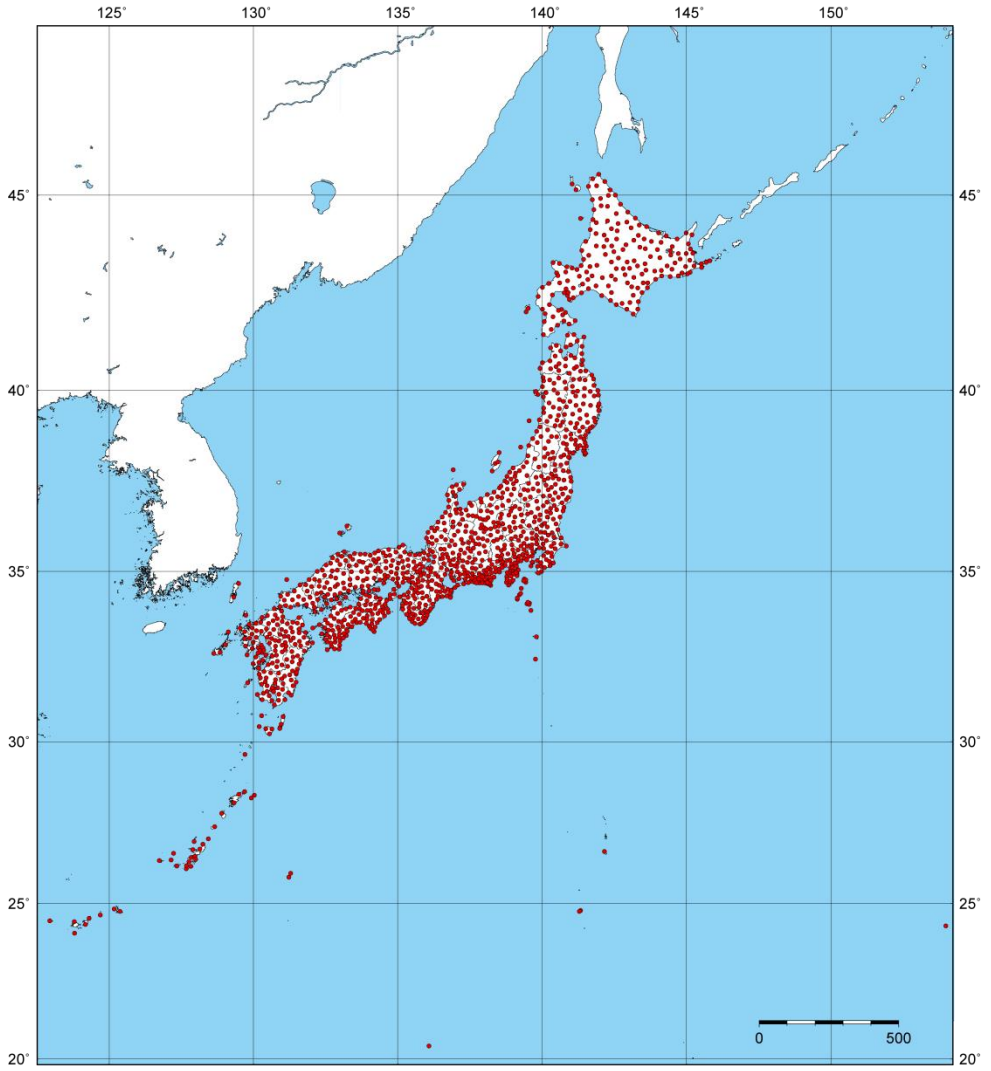
GEONET

- *GNSS Earth Observation Network System*

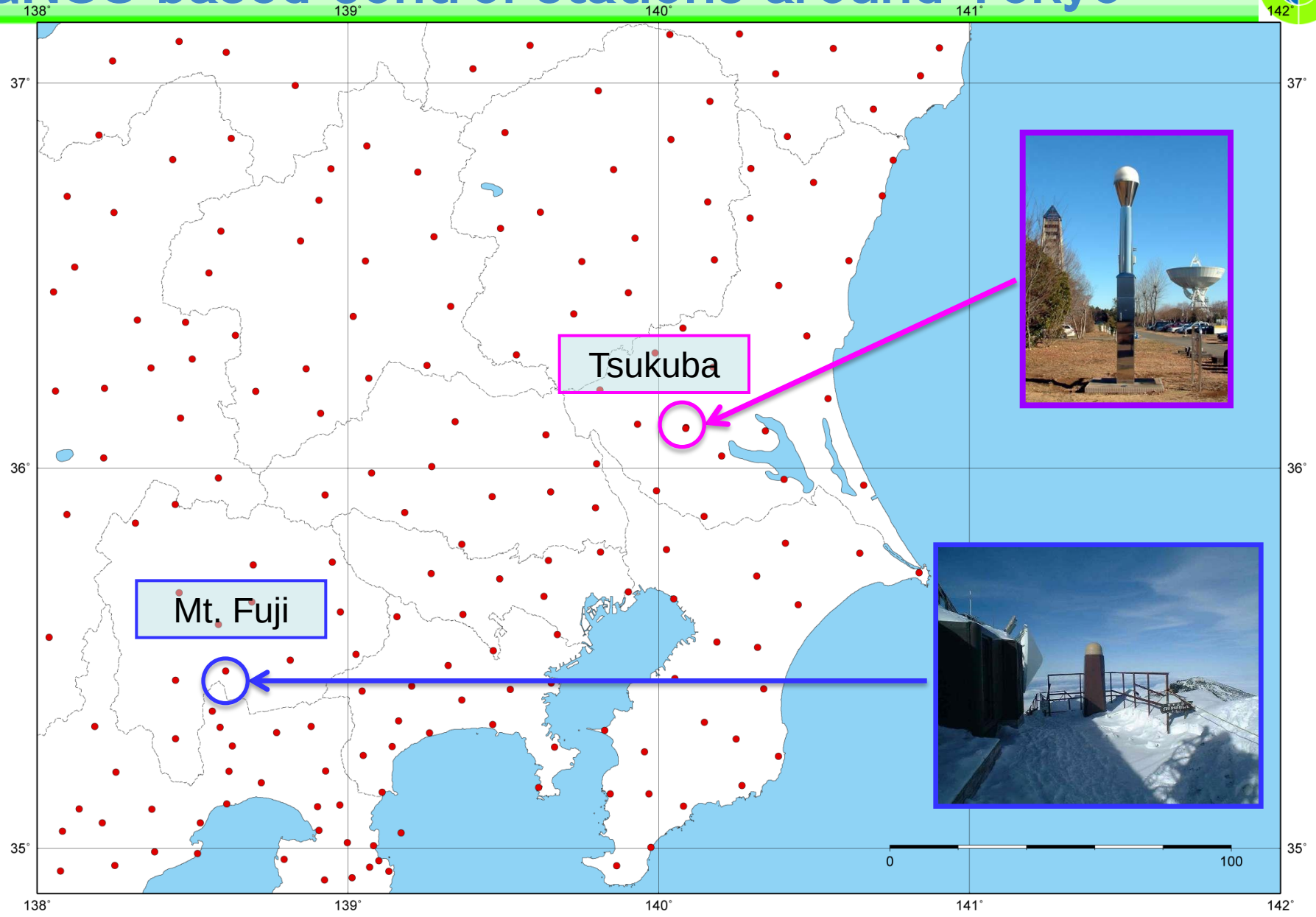
- GNSS continuously operating reference stations (CORS) covering Japanese archipelago for surveying and crustal deformation monitoring

2.1 Facilities and Operation

- The backbone of geodetic reference frame in Japan
- 1271 stations *(April, 2013)*
  - Average spacing between stations **About 20 km**
- Monitoring crustal deformation by real-time data

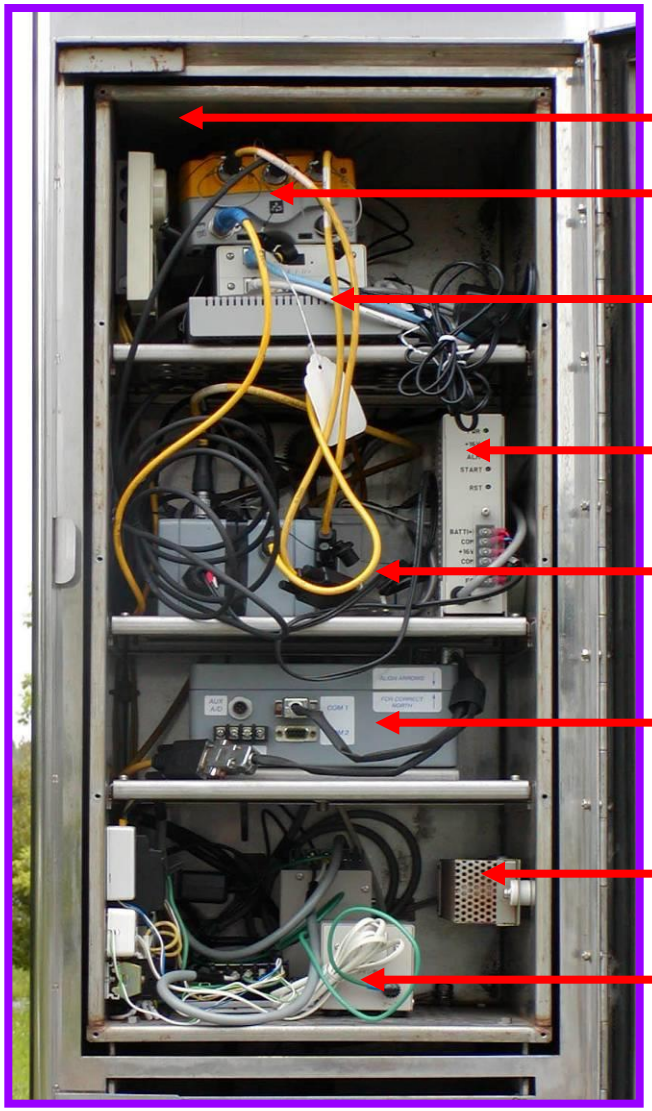


GNSS based control stations around Tokyo



Equipments inside a pillar

Standard type of the stations keep all equipments within the container box in the middle of the pillar.



- Cooling Fan
- GNSS Receiver
- Communication device
- UPS
- Battery
- Tilt meter
- Heater
- Lightning Arrester

GNSS Receivers

Triple frequency (L1 L2 L5)

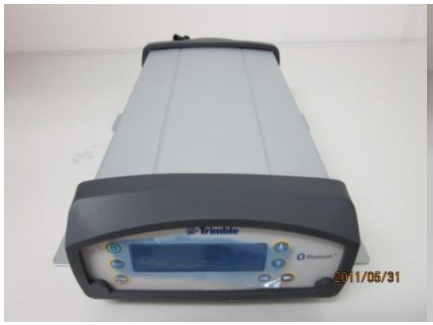
Receiving GPS, GLONASS and QZSS signal every 1 second

Transferring 1 sec. data to Tsukuba via IP-VPN

Remote Control from Tsukuba (configuration, download)

Storing 30 sec. sampling data locally for back-up

Receiver models installed in GEONET sites



NetR9

Net-G3

Trimble NetR9: 800

TOPCON NET-G3(A): 469

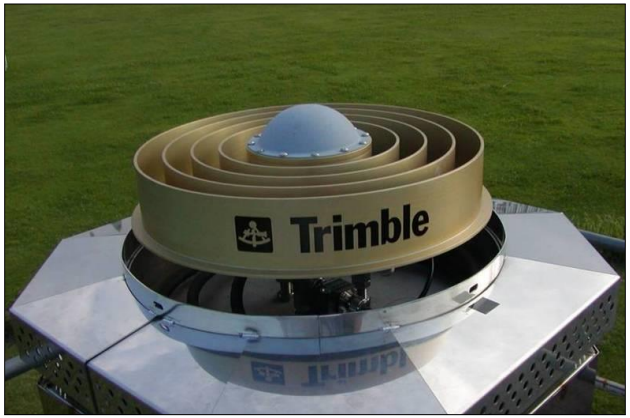
Trimble NetRS: 1

Trimble 5700RC: 1

↑Older type receivers remaining

GNSS Antenna

Most of the antennas installed at GEONET sites are choke ring type adapted for triple frequency. (exception; Okinotori island, three stations around Fukushima)



TRM59800.80(Trimble)

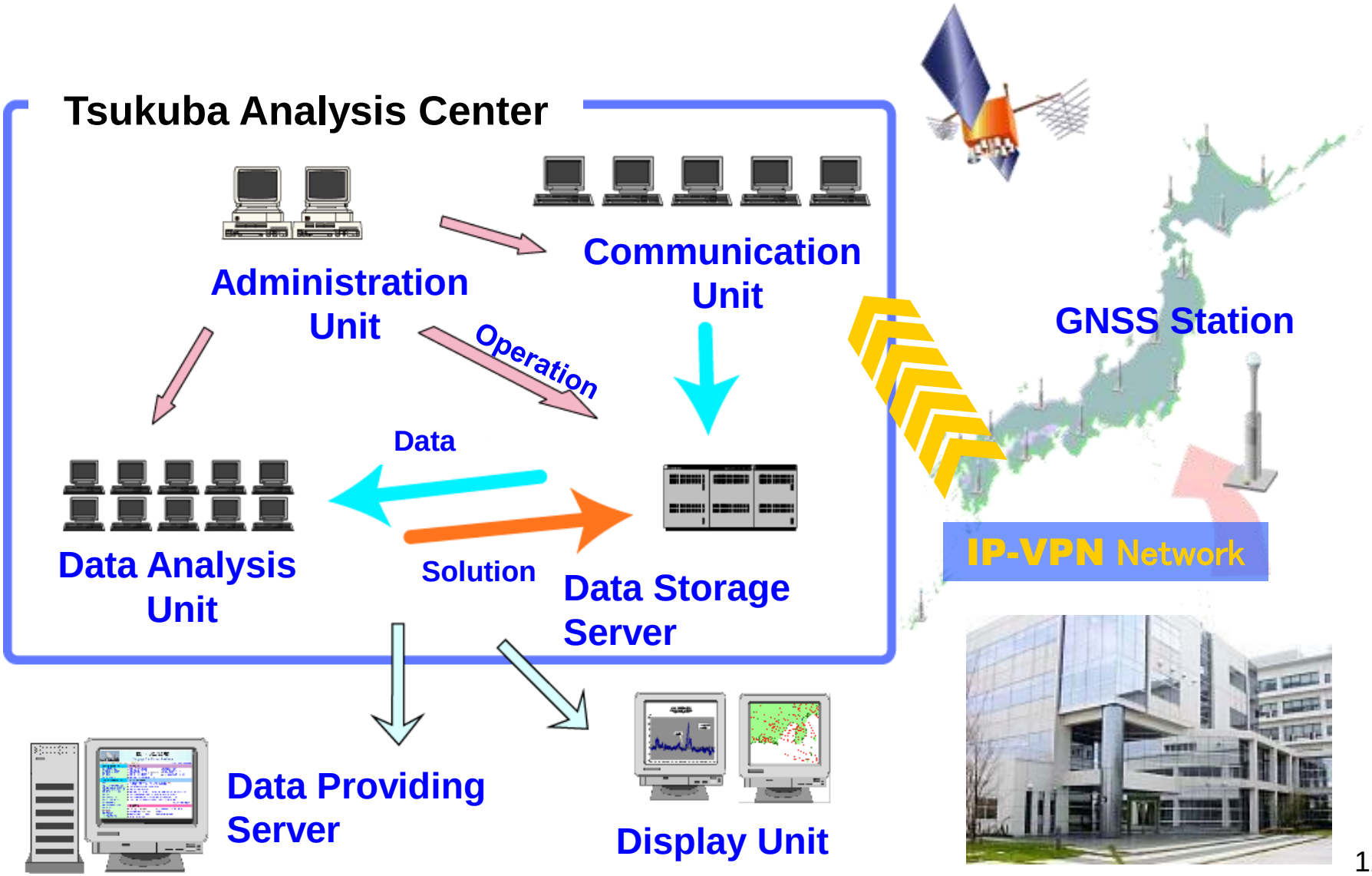
TPSCR.G5 : 448

TRM59800.80 : 819

TRM29659.00 : 3

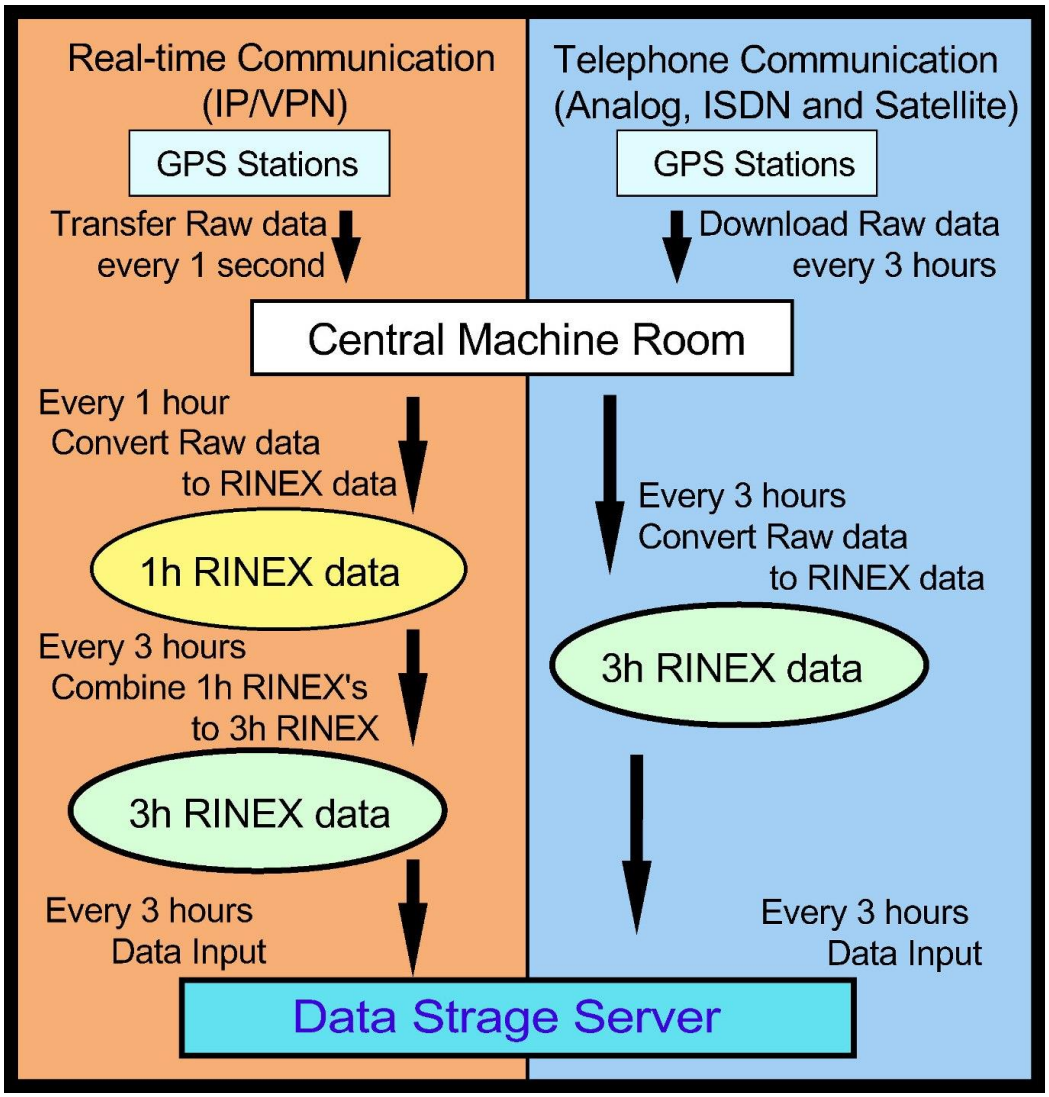
TRM39105.00 : 1

GEONET analysis facilities



Data Flow

- Observation Data is transferred via two routes: IP/VPN and Telephone line.
- About 1250 stations transfer GNSS data via IP-VPN every second.
- About 20 stations transfer data via telephone every 3 hours.
- 3h RINEX data are formed every 3 hours, and input to Data Storage Server.
- 24h RINEX data are created from eight 3h data sets.

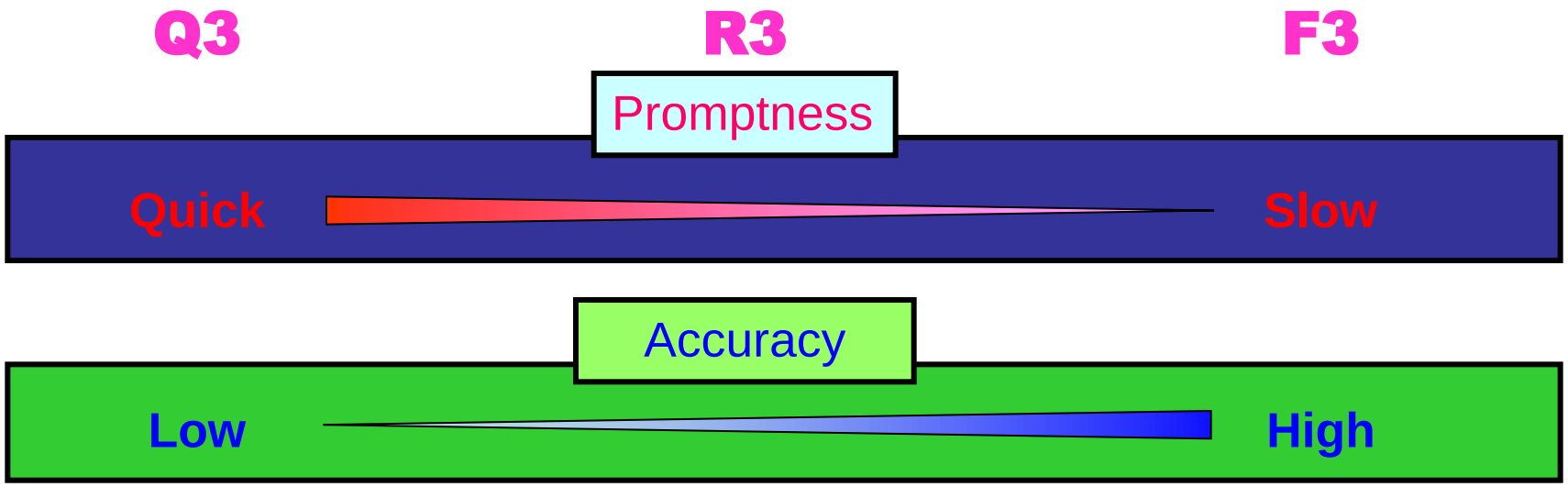


GEONET analysis

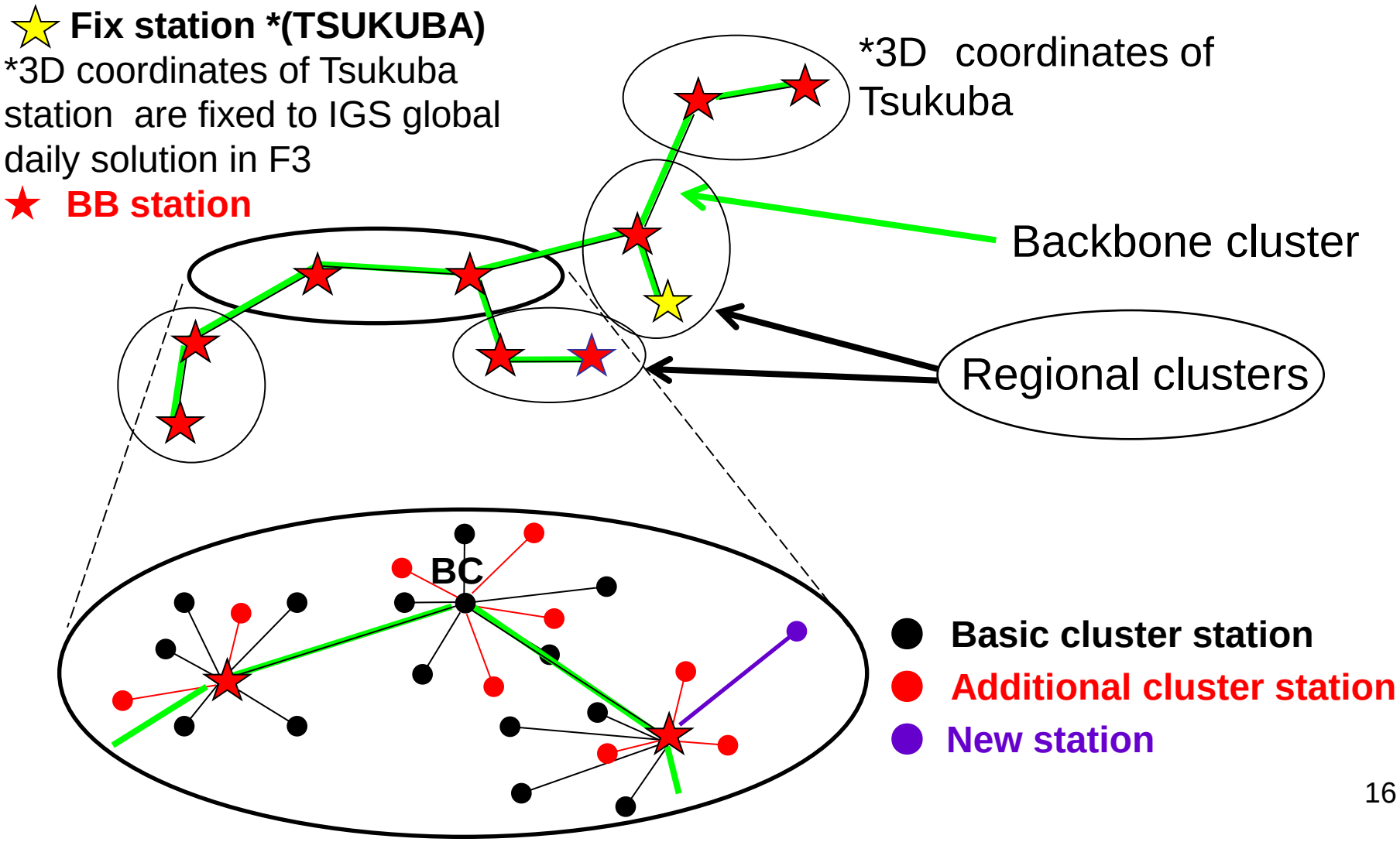
- Hardware: **HP HPProLiant DL380 G5 Quad Core** (x6)
  - CPU(Xeon X5355 2.66GHz) , L2 Cache (2x4GB), Memory (2GB) , HDD (146GB, 10krpm 2.5',(x2))
- Software: BERNESE Ver.5.0
- Coordinate: ITRF2005
- Ellipsoid: GRS80
- PCV model: GSI original absolute
- Three types of routine analyses : F3,R3,Q3
  - Using 30 seconds epoch data
- Higher frequency analyses : *(not for all sites)*
  - real-time and post-processing by 1 sec. data

Three routine analysis strategies

	Q3(*Quick*)	R3(*Rapid*)	F3(*Final*)
Data	6-hours	24-hours	24-hours
orbit	IGS ultra-rapid	IGS rapid	IGS final
Schedule	Every 3 hours	Everyday	Every Sunday



2.2 Connection to the global frame



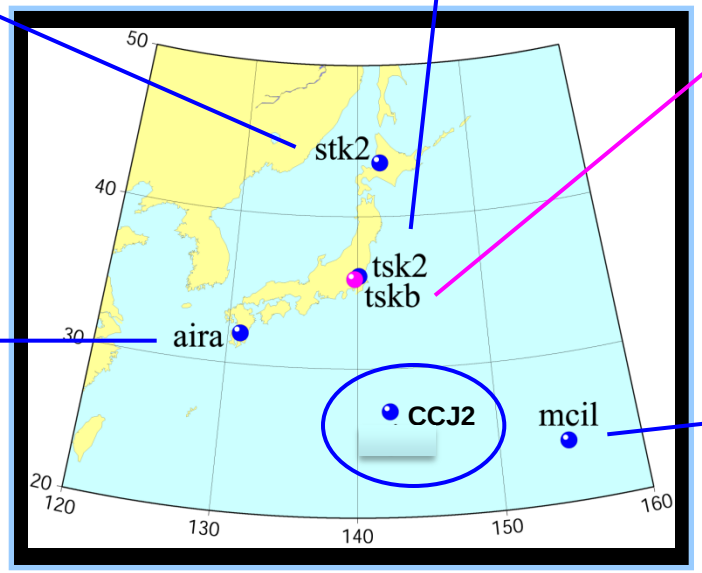
IGS sites operated by GSI

tsk2

tskb

stk2

aira



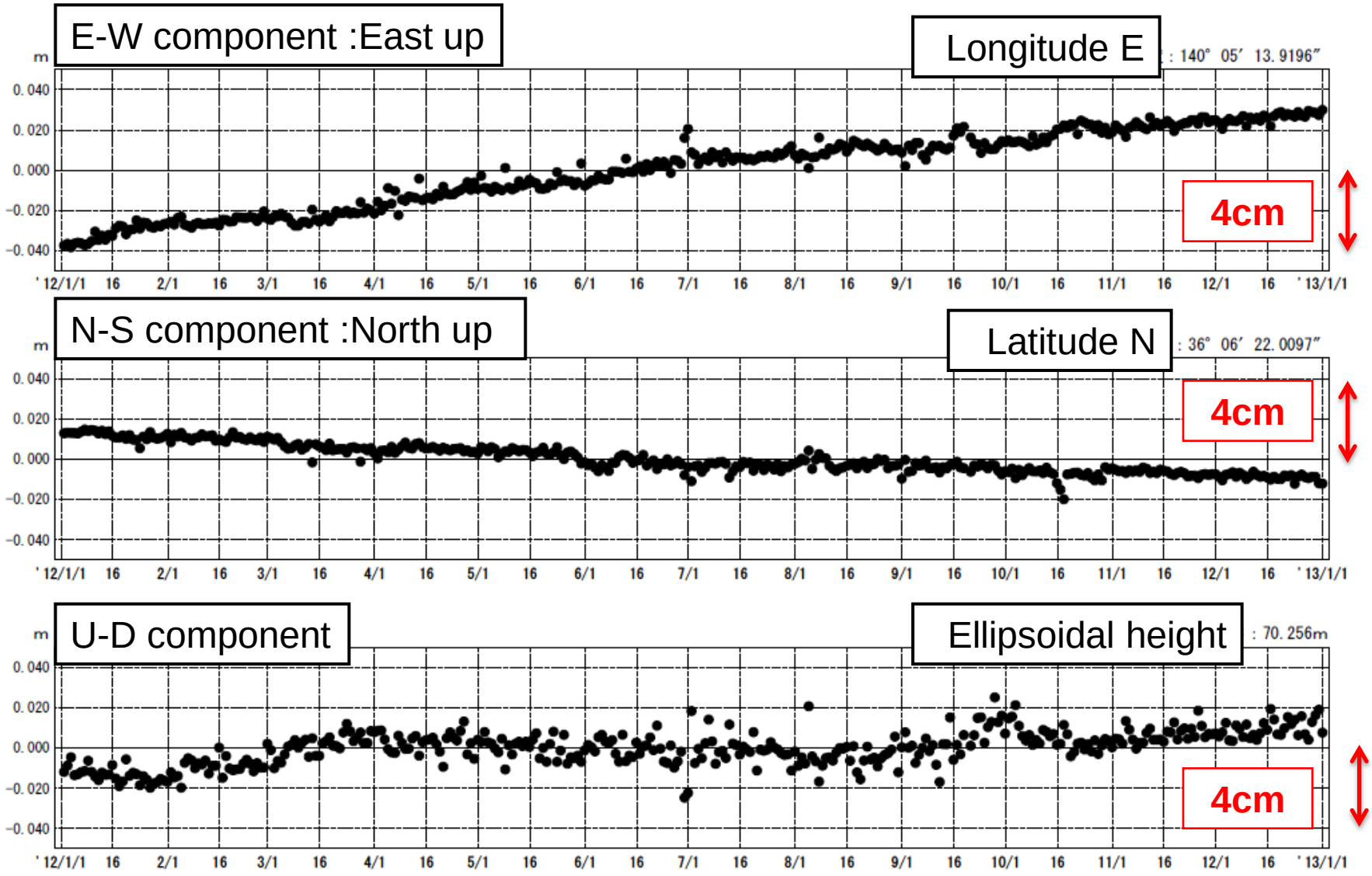
mcil

ccj2

syog

- aira, ccj2, stk2 and tsk2 provide GLONASS data, as well as GPS
- aira, ccj2, stk2, tskb and tsk2 locate near VLBI observation sites for co-location
- syog locates in Antarctic area

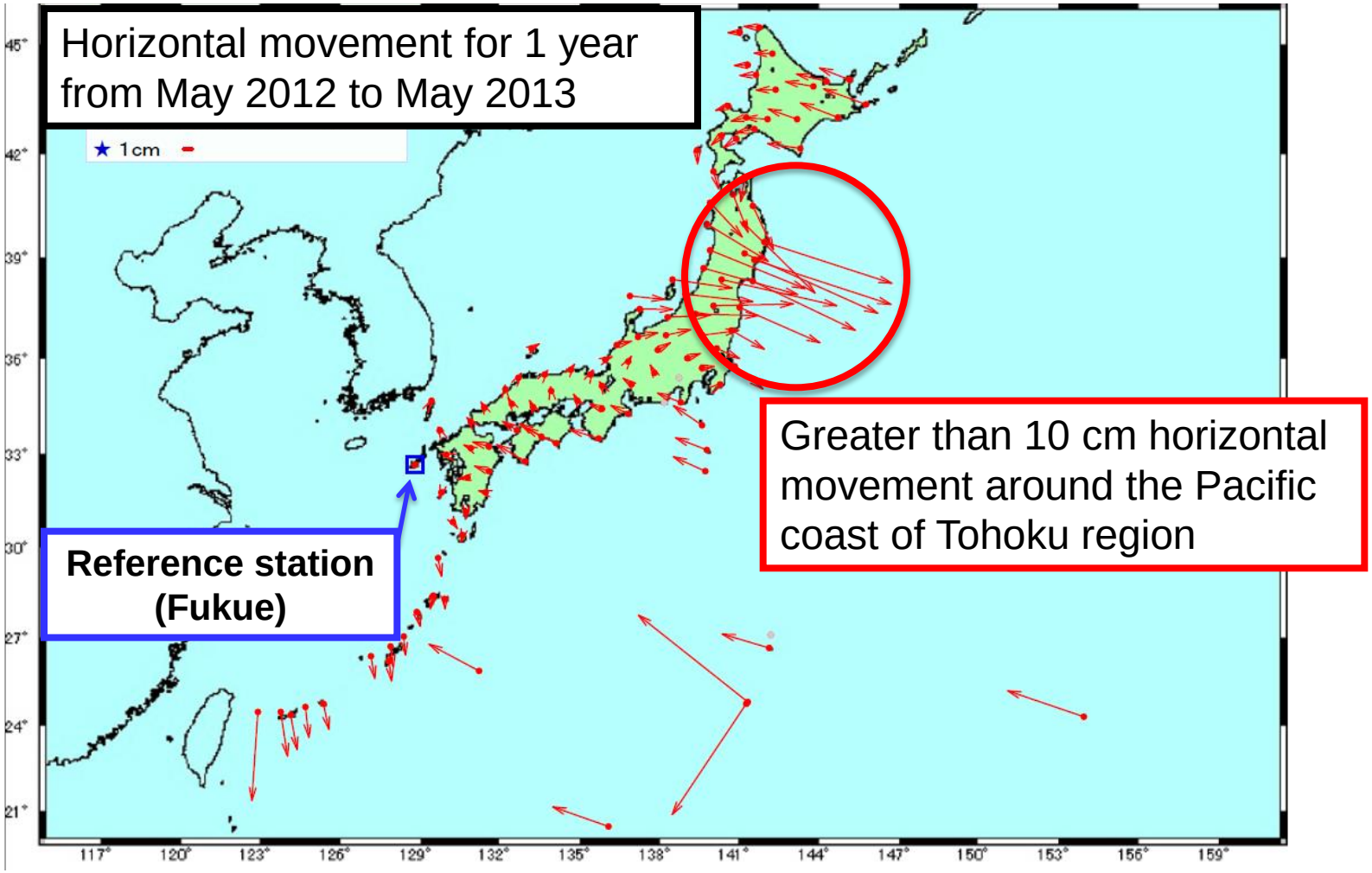
Movement of TSUKUBA site within the global frame



Tsukuba is moving toward ESE referred to global frame by 7cm/yr.

Tectonic movement of Japanese islands

The effect (post-seismic crustal deformation) of the Great East Japan (Tohoku) Earthquake is notable around northeast Japan, even in 2012-2013.



3. Effects of crustal deformation

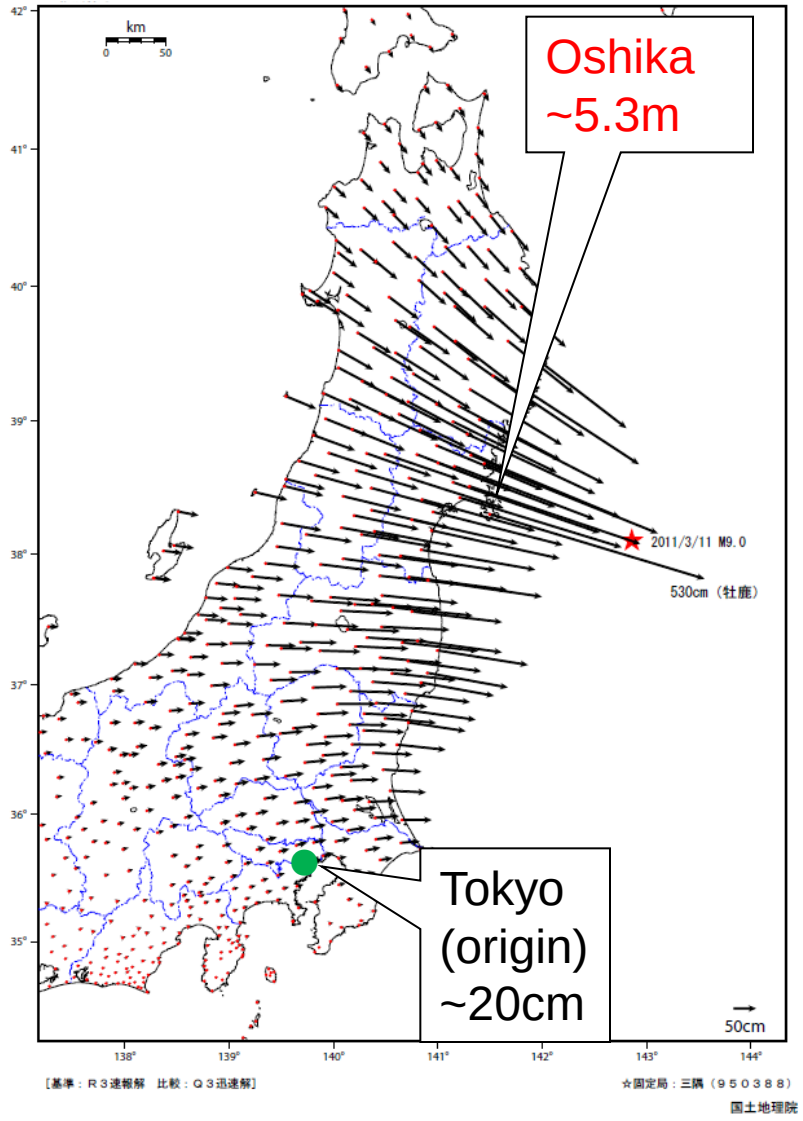
- Geodetic reference system of Japan (JGD2000) is designed, considering the provision for the secular crustal deformation.
- ”Semi-dynamic Correction” method is used, in order that frequent revision of the coordinates would not be necessary.

- **However, the Great East Japan earthquake (March 11, 2011) caused far larger deformation that was supposed.**

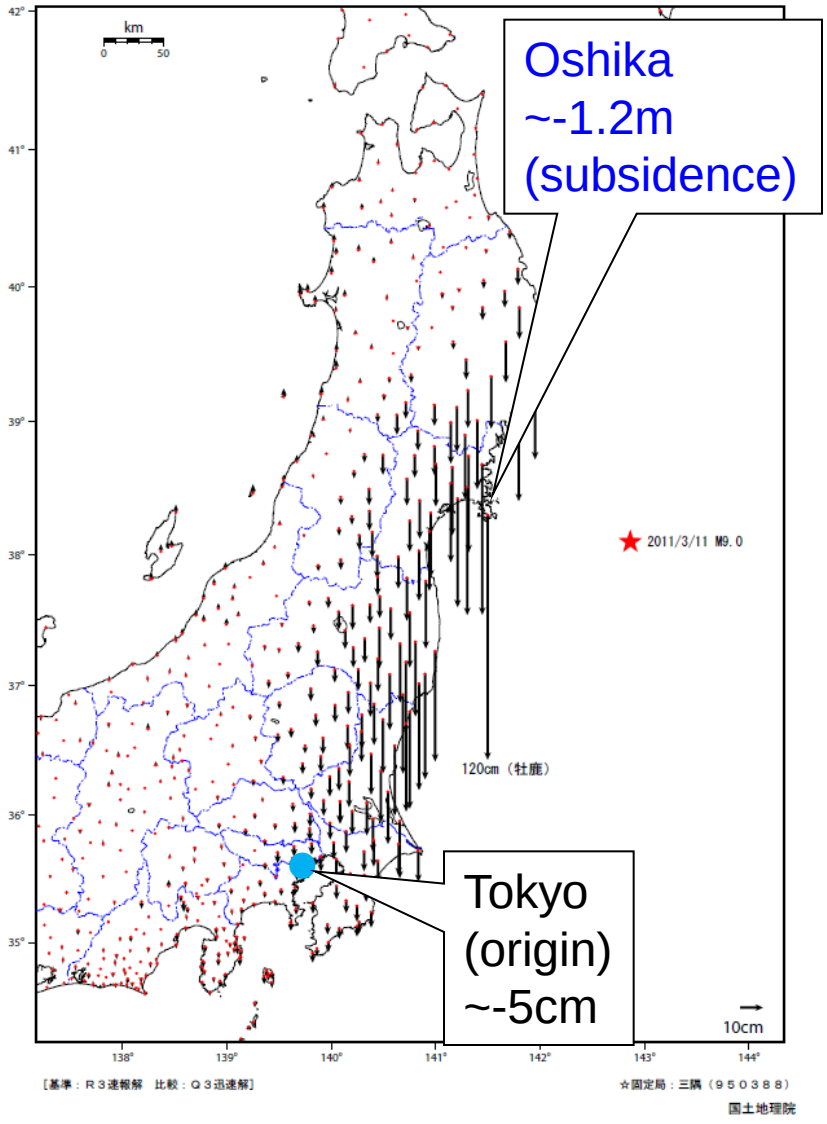
3.1 Monitoring the crustal deformation

Co-seismic Movement by Great East Japan EQ

Horizontal



Vertical



Monitoring high by frequency data

GEONET reveals the seismic motion of the Great East Japan EQ

$$STA(t)=\frac{\sum_{i=t-\alpha+1}^{t} p_i x_i}{\sum_{i=t-\alpha+1}^{t} p_i} \quad (\alpha=60\text{sec.})$$

$$LTA(t)=\frac{\sum_{i=t-\beta+1}^{t} p_i x_i}{\sum_{i=t-\beta+1}^{t} p_i} \quad (\beta=600\text{sec.})$$

$$p_i = R_i/\rho_i^2$$

(Weighting parameter)

$$D=\left|(STA(t)-LTA(t))\right|-SD(LTA(t))$$

- "RAPiD" (Ohta et al., 2012) as the automatic detection method

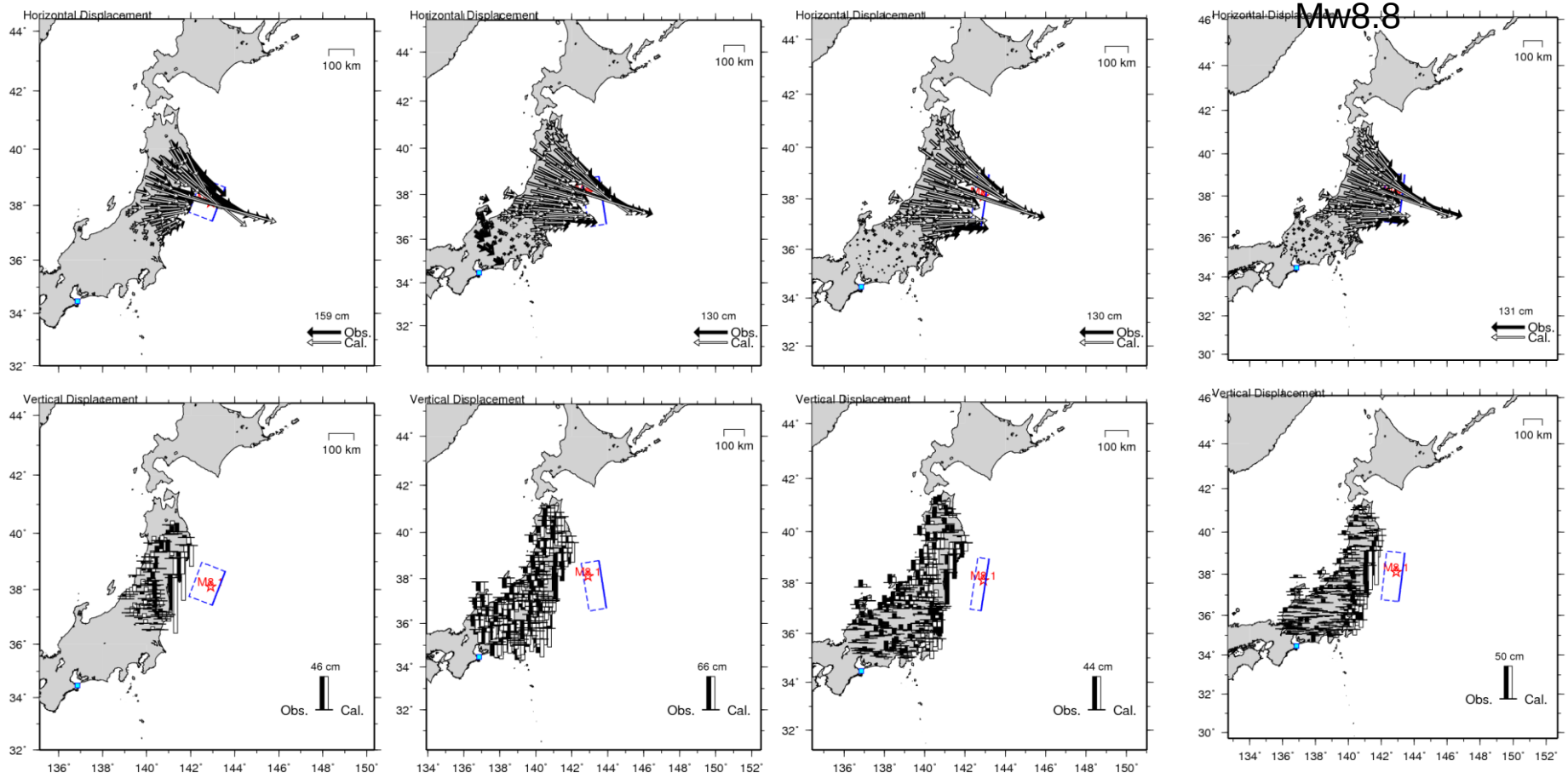
	"Rapid" detection parameters
α	60s
β	600s
K(>D)	D>0.1m for detection
Disp.	Difference between positions now and 5 min. before the detection

Difference of short term average (STA) & long term average (LTA) "D" increases just after the station records permanent displacement (seismic wave).

Real time estimation of the fault model

New real time analysis strategy shows the possibility to estimate the scale of the Great East japan Earthquake within a few minute

14:48:14(116s) Mw8.9 | 14:50:14(236s) Mw9.0 | 14:51:14(296s) Mw8.8 | Final Mw8.8



- Mw8.9 is estimated within 2 min. after the earthquake, but the result is unstable.
- It takes about 5 min. to derive appropriate fault model.

Affected area where the survey data are closed (GNSS-based control stations & triangulation control stations)

Criterion for suspension: prefecture including the area where estimated strain will be over 2ppm

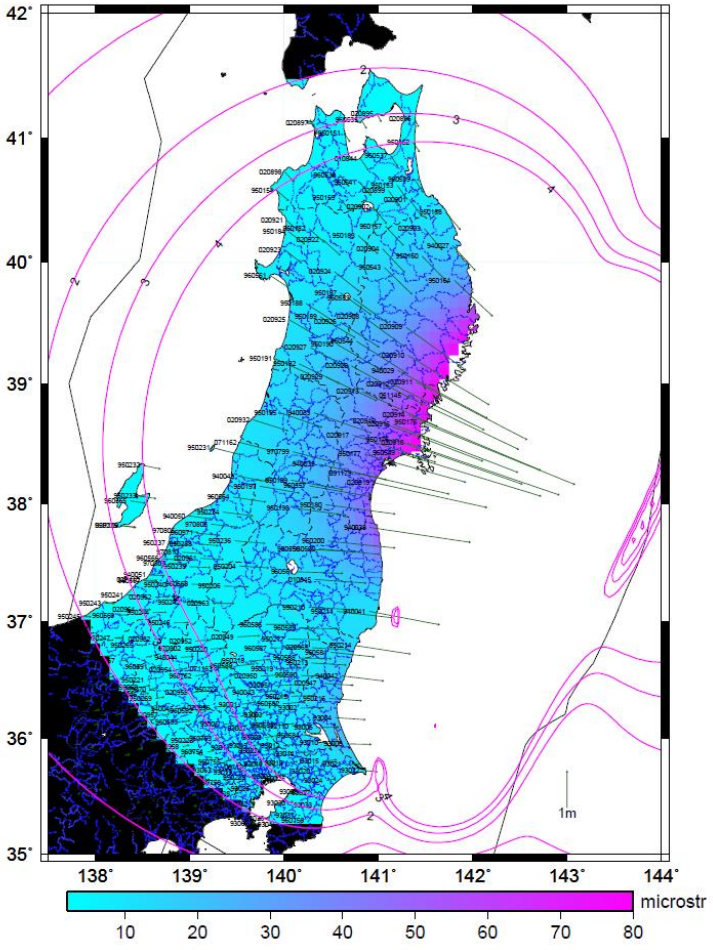
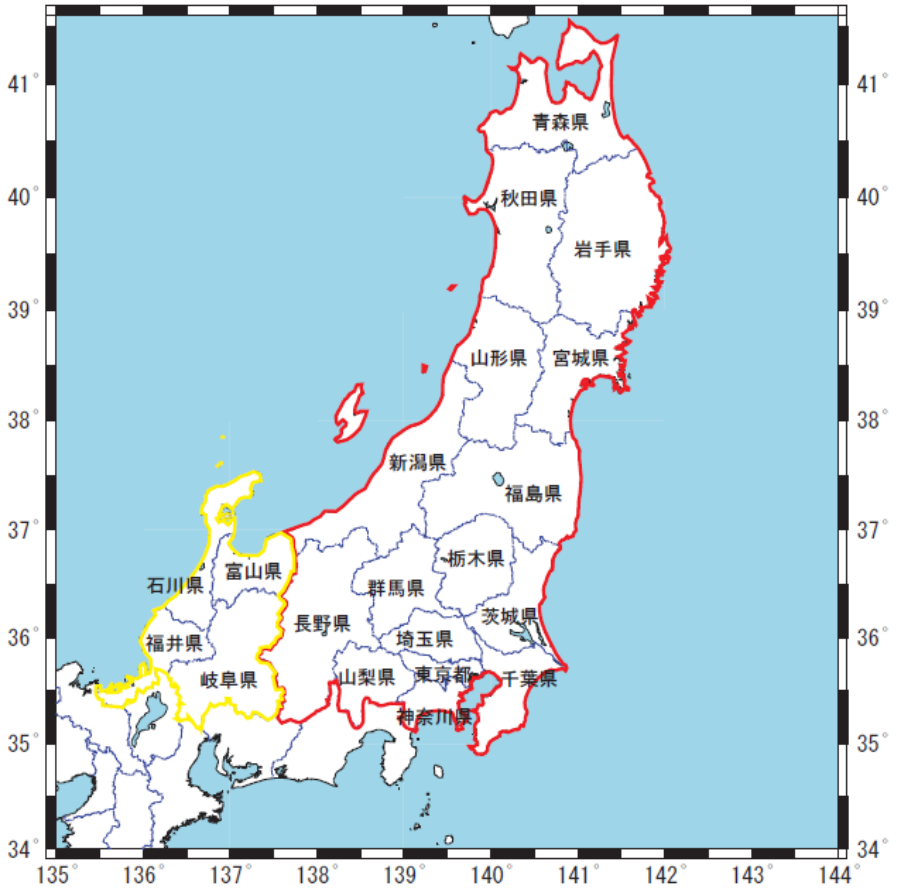


Fig: strain map estimated from a fault model

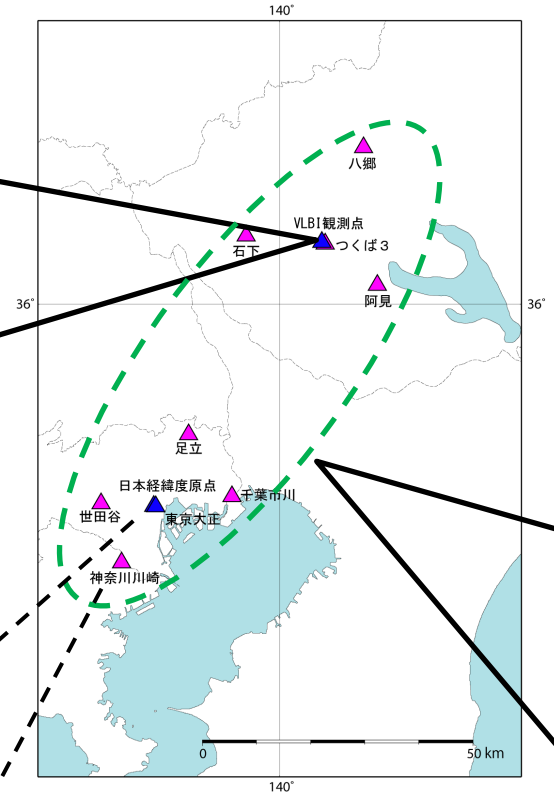
Survey data of 438 GNSS-based control stations had been closed until May 31, when new survey data was opened.

Survey data of ~44,000 triangulation points became closed.



3.2 Revision of the datum

1. Determine the coordinate of VLBI station “Tsukuba” as of May 24, 2011.



2. GPS observation* was carried out around VLBI station “Tsukuba” and the Origin, respectively.

The metal marker of the Origin

GNSS-based control station

Marked as ▲

3. The coordinates of the stations were calculated under the condition that the coordinate of VLBI station “Tsukuba” is fixed.

Revised coordinates of the origins

(1) Origin of horizontal control network

[1]Longitude

From: 139° 44′ 28.8759″

To: 139° 44′ 28.8869″ (+0.011″)

[2]Latitude

35° 39′ 29.1572″ (±0)

Moved eastward by 27cm

(2) Origin of vertical control network

From: 24.4140m (above the mean sea level in Tokyo Bay)

To: 24.3900m (-0.024m)

Moved downward by 2.4cm

Order for Enforcement of the Survey Act was revised and enforced on 21 October 2011.

It was the first time since Kanto EQ in 1923 to revise the coordinates of origins due to earthquake.

Revision of survey data (GNSS-based control stations)

East Japan

Survey data were closed (Mar. 14)

↓

GPS & VLBI observations & analyses.

↓

Poor precision around the border of revised / non-revised area.

↓

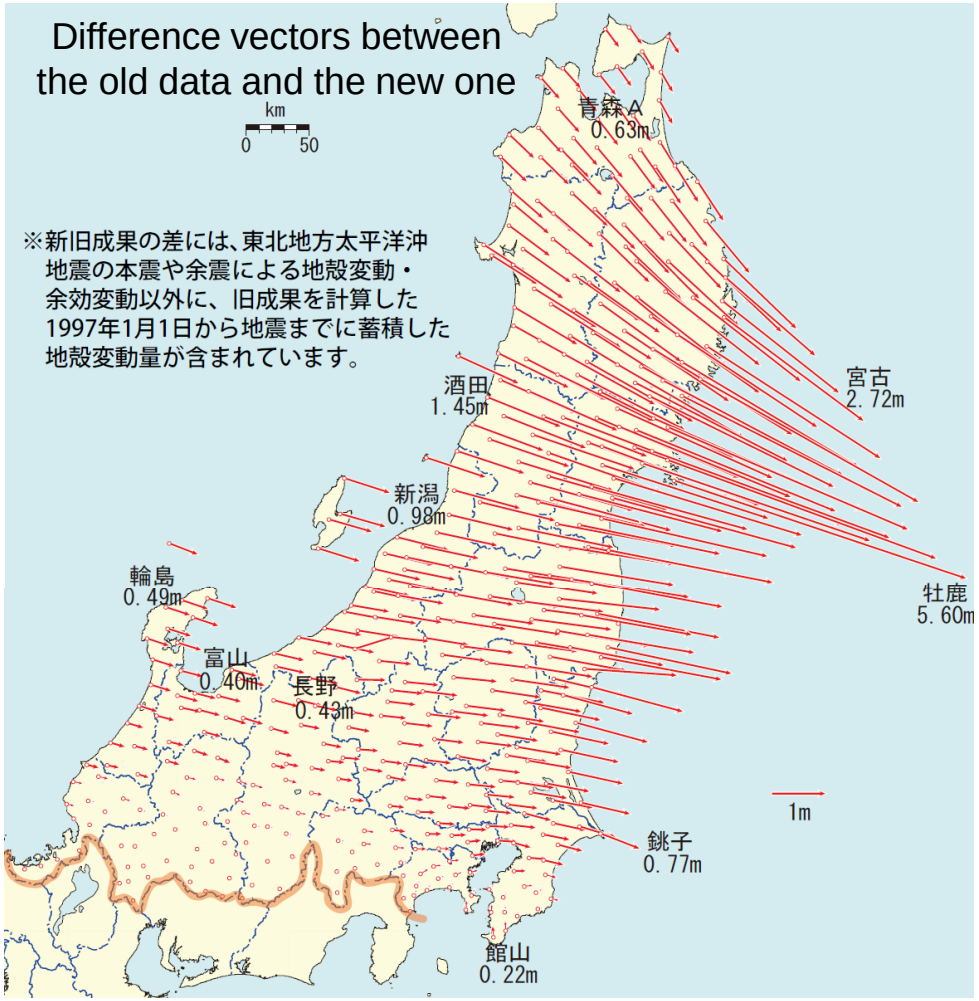
Revising area was extended

↓

New survey data were opened (May. 31)

West Japan & Hokkaido

Not revised



All data set is called "Geodetic Coordinates 2011"

Procedure of revision (Triangulation stations)

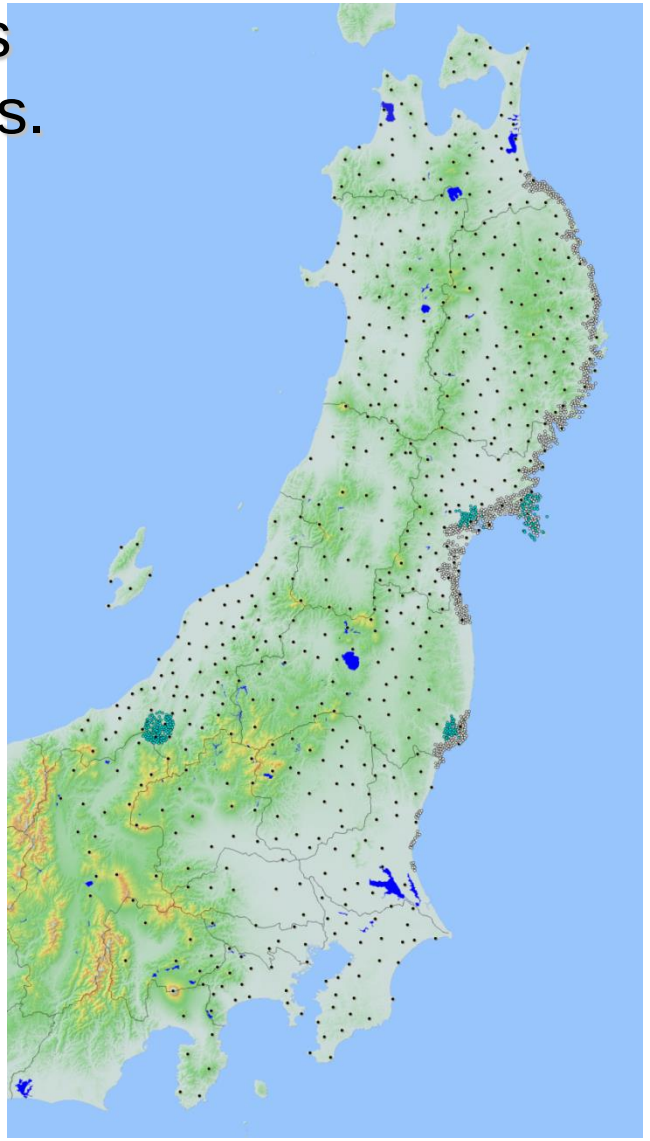
- It was impossible to operate observations at ~44,000 suspended triangulation stations.
  → How to revise all data?

- GNSS observations at about 600 selected stations

- Correction parameters were calculated using the results of observation.

- Adapt the parameters to other non-observed triangulation stations.

- Check the results by supplementary GNSS observation.



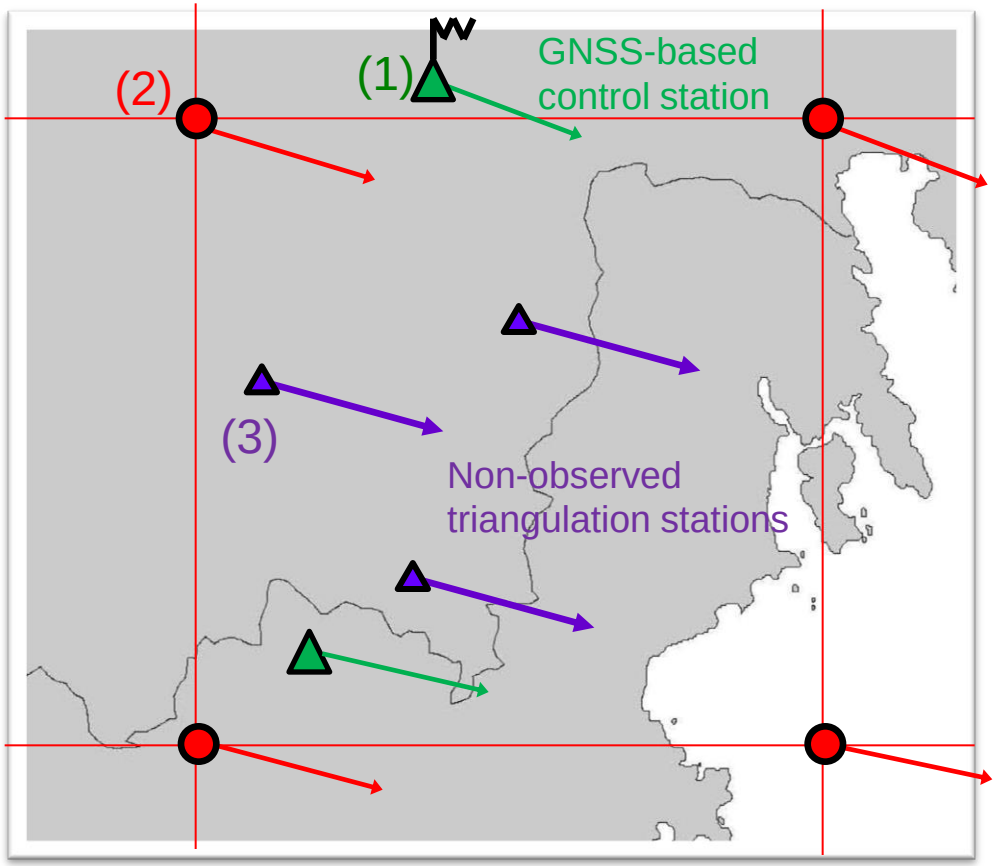
600 “high order control points” in Tohoku – Kanto, Koshin’etsu areas

Generation & Adaptation of correction parameters

(1) GNSS observation at the selected stations

(2) Each corner of 1km grid is given correction parameters

(3) The correction vector of the station is interpolated



● : Grid point having parameters

→ : Known displacement of the station

→ : Correction vector at the grid point

→ : Interpolated correction vector

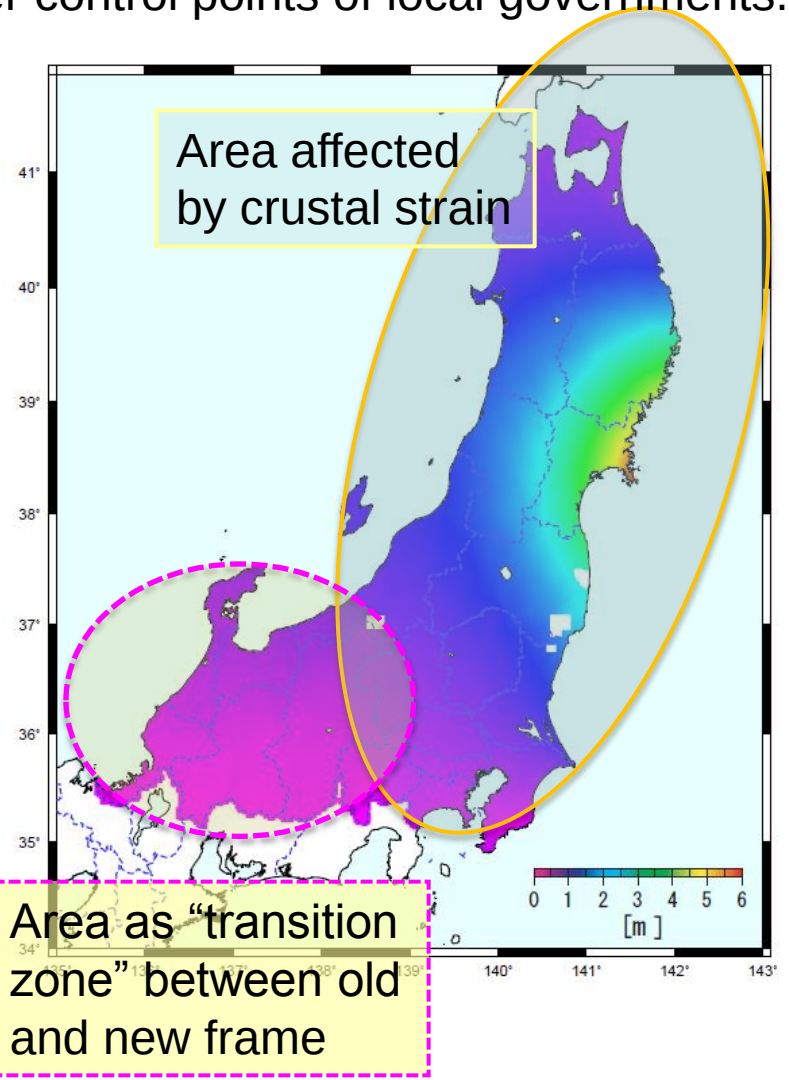
Correction image

Before the EQ		Correction		After the EQ
X=1234. 00m	+	X=−0. 10m	=	X=1233. 90m
Y=7890. 00m		Y=+0. 50m		Y=7890. 50m

Correction parameters for horizontal coordinates

The coordinates for control points of Basis Survey (managed by GSI) are revised by re-survey and re-calculation by interpolation method.
Correction parameters are provided for other control points of local governments.

- Correction parameters are provided for the area of coordinates revision (20 prefectures)
- A web site for surveyors to convert the coordinates is provided by GSI
- *Parameters are not created for the areas affected by large aftershocks (as interpolation method cannot be applied)*
- *Neither for the evacuation area of Fukushima nuclear accident.*



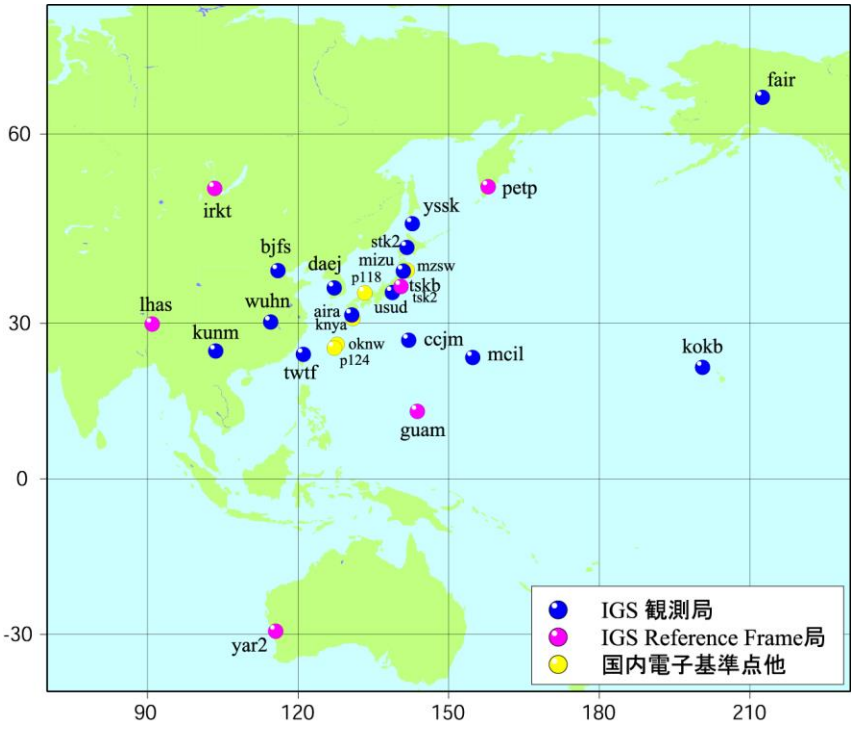
Recent revisions of survey data due to earthquakes

Earthquake	*Horizontal Displacement &* Data suspension	Time Schedule
Sep. 26, 2003 Off-Tokachi	*87cm* No suspension of data provision	Jun. 1, 2004 Survey data of GNSS-based control stations were revised Maximum after slip of the stations became shorter than 1cm/month Re-survey at 196 triangulation stations Correction parameters (PatchJGD) — Re-calculation Apr. 1, 2005 6,700 data are completely revised
Oct. 23, 2004 Niigata-Chuetsu	*20cm* Survey data of 432 control points were closed	Nov. 19, 2004 New survey data of GNSS-based control stations were opened Re-survey at 608 triangulation stations Dec. 28, 2004 90 data were precedently opened Dec. 22, 2005 600 data are completely revised
Jun. 14, 2008 Inland Iwate-Miyagi	*150cm* Survey data of 2,631 control points were closed	Aug. 4, 2008 New survey data of GNSS-based control stations were opened Re-Survey at 285 triangulation stations Correction parameters (PatchJGD)* — Re-calculation *Not applicable for some area Mar. 2, 2009 2,300 data are completely revised
Mar. 11, 2011 Off-Tohoku	*530cm* Survey data of 44,000 control points were closed	May 31, 2011 New survey data of GNSS-based control stations were opened Re-survey at 1,900 triangulation stations Re-survey of bench marks along 3,600km leveling route Oct. – Nov., 2011 All survey data are revised

3.3 Some examples in Asia and Pacific region

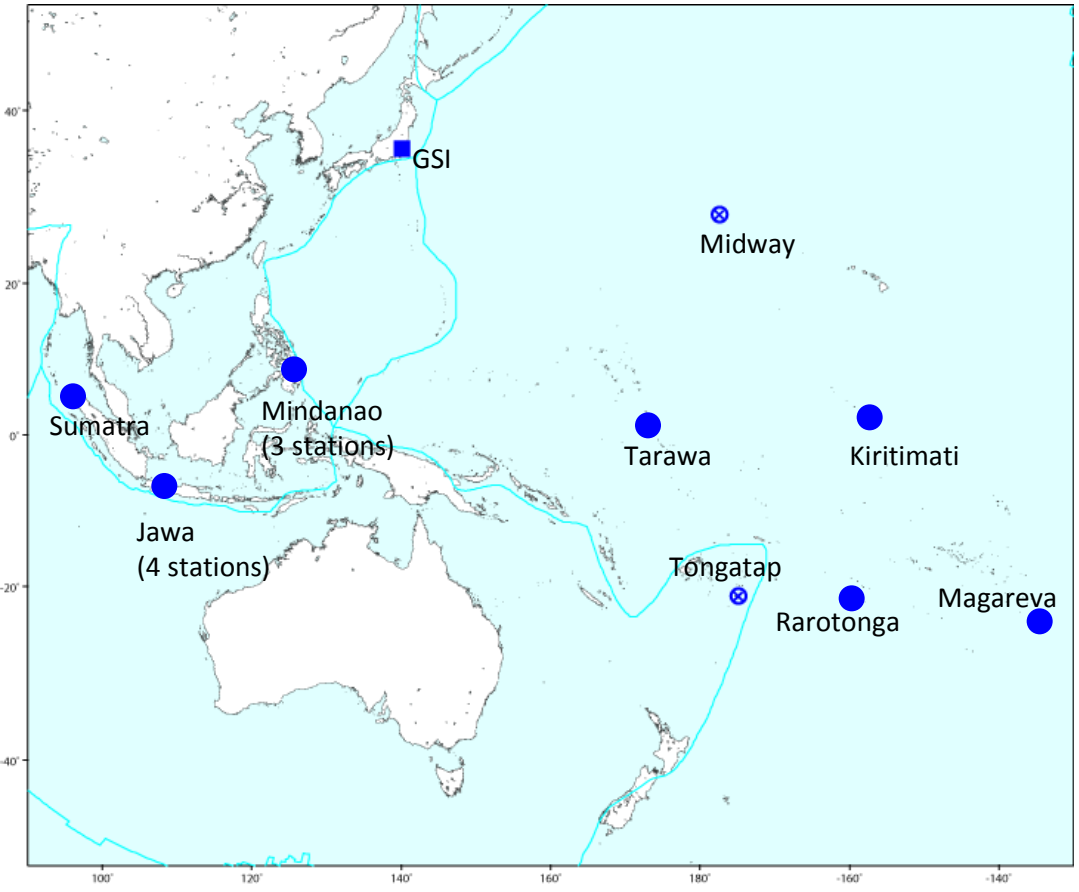
Effects of crustal deformation should be counted, always.

- Secular movements and co-seismic movements can be observed regional GNSS CORS network.
- GSI is contributing IGS regional analysis as sub-center.
- GSI has been also deploying some GNSS observation sites around Asia and Pacific region.



Management of GNSS Stations

GSI GNSS stations The Asia-Pacific region



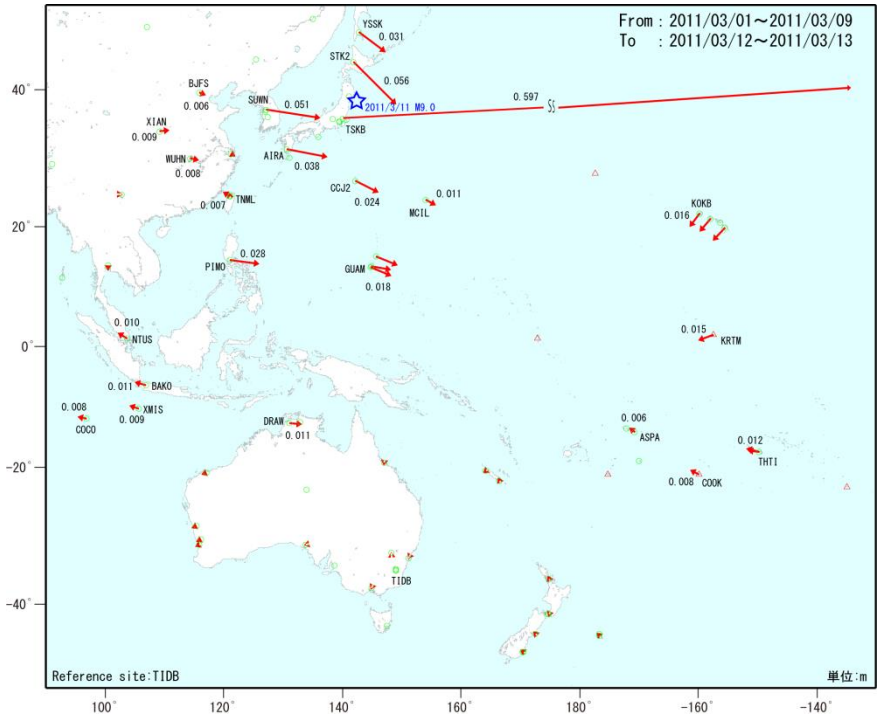
History and Plan of GPS observation and on-line data transfer

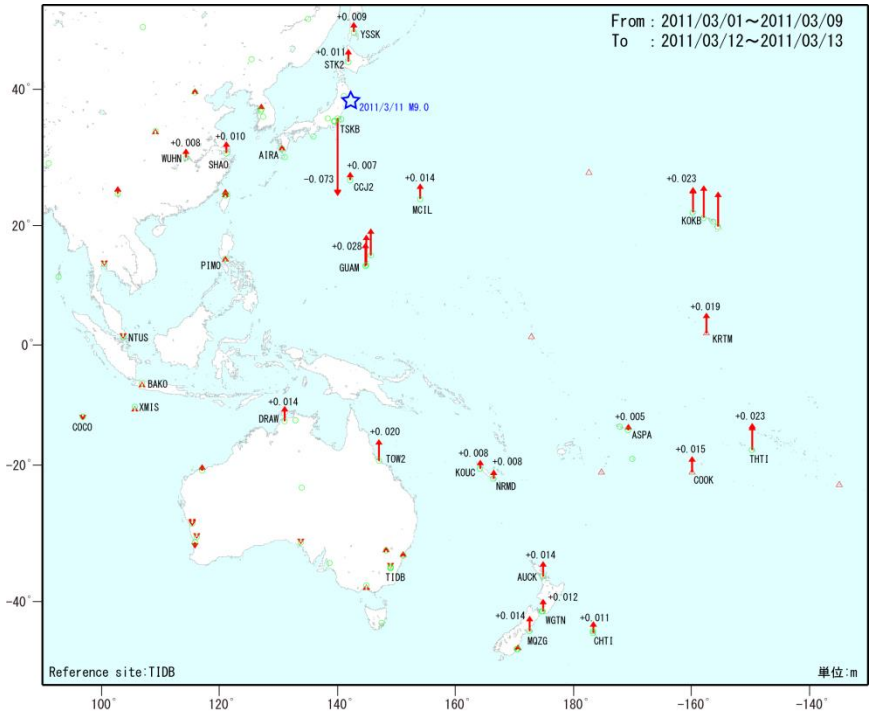
	2009	2010	2011	2012	2013	・・・・
Rarotonga	● →	→	→	→	△ (abolishment)	
Tarawa	→	● →	→	→	△ (abolishment)	
Kiritimati	→	→	○ →	→	→	
Midway	?	?	?	?		
Tongatap	?	?	?	?		
Mangareva	→	→	△ (Transferred to IGN)			
Sumatra/Java	→	→	→	→	→	
Mindanao		● →	→	→	→	

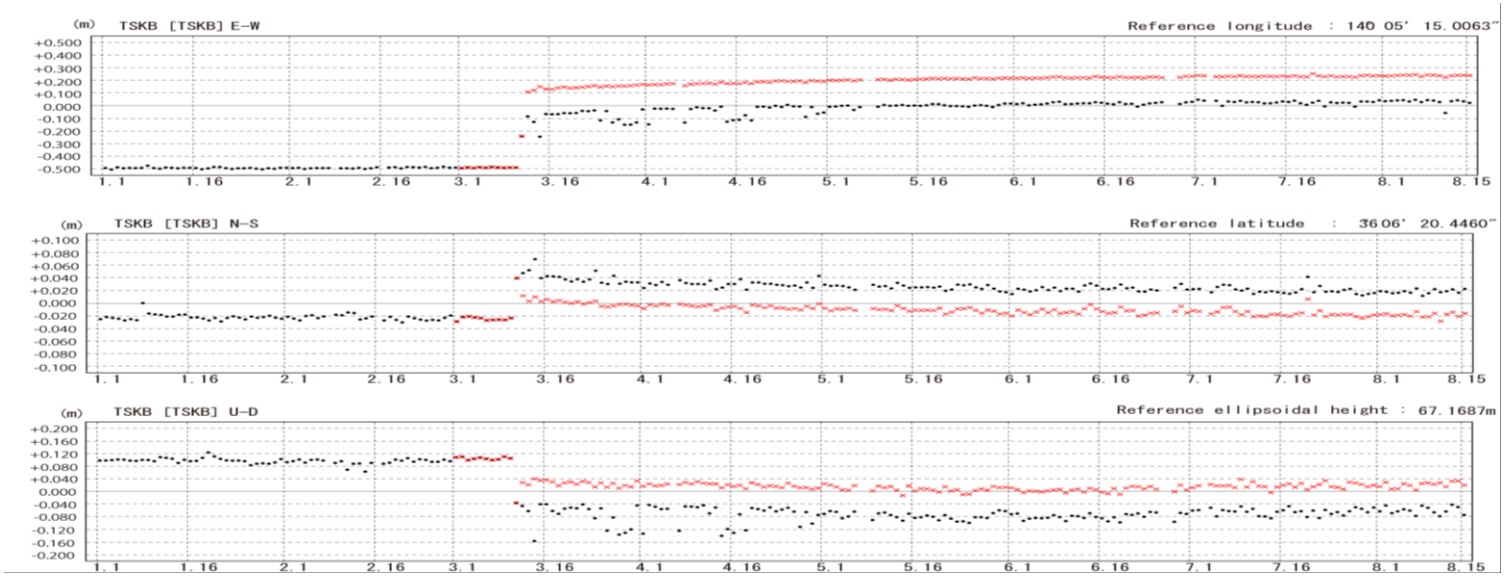
On-line data transfer

Off-line data transfer

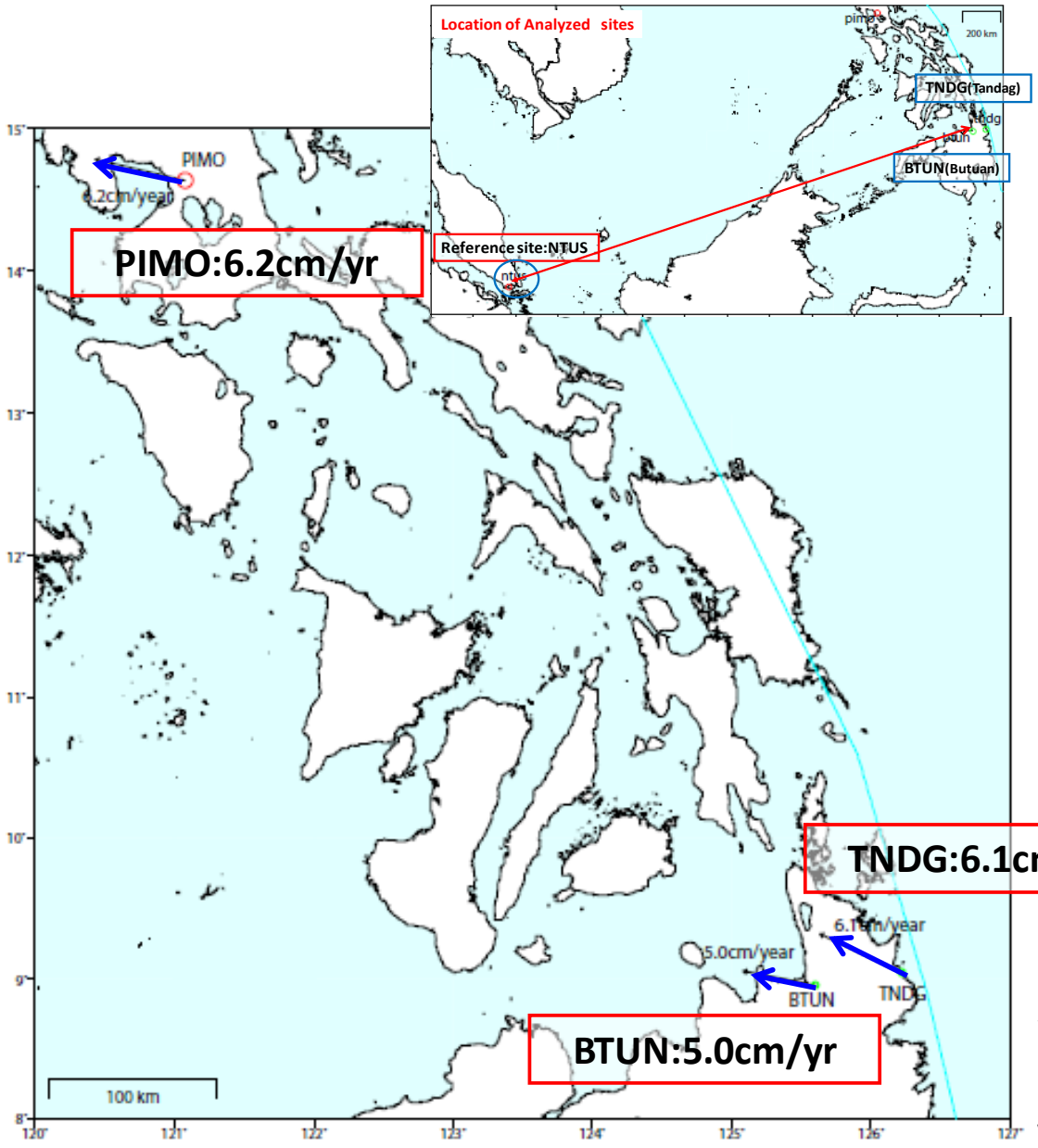
Effect of Tohoku Earthquake in Asia and Pacific Region



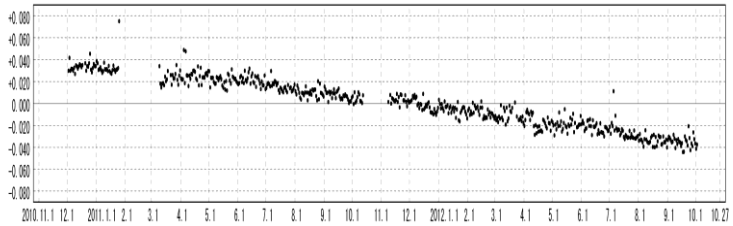




Crustal deformation in Philippines

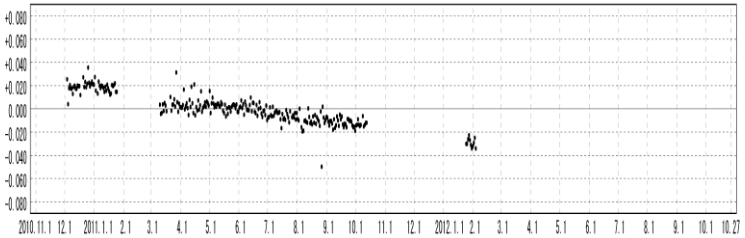


PIMO



BTUN

TNDG



GSI installed two GNSS CORS sites in Mindanao, in the cooperative project supported by JICA.

4. Summary

- GSI has been operating GEONET, GNSS CORS covering all over Japan.
- The purposes of the observation and analysis are, to establish regional reference frame consistent with global frame and to monitor crustal deformation.
- The result of this analysis reveals the crustal deformation caused by the Great East Japan EQ, and contributed the quick revision of the geodetic coordinates after the earthquake.

Reference Frame in Practice

Manila, Philippines 21-22 June 2013

Thank you for your attention !