The new application of GEONET for multi-GNSS observation and height determination with new Japanese geoid model

Basara MIYAHARA, Tomoaki FURUYA, Tokuro KODAMA, Toshihiro YAHAGI, Masaki MURAKAMI and Tetsuro IMAIIRE

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GEONET & its brief history

<Beginning: two CORS networks>
dual-frequency GPS observation stations
5m-tall pillar with 2m-depth ground base
Central control station at Tsukuba h.q.

• April 1, 1994: dots in red
  intensive monitoring of crustal deformation
  110 stations at average spacing of 15 km
  in metropolitan area & anticipated area of
  large earthquake occurrence

• October 1, 1994: dots in blue
  Nationwide network of CORS
  100 stations at average spacing of 120 km
  Geodetic reference & crustal deformation
  monitoring

Two networks of permanent GPS stations

GEONET & its brief history (cont.)

co- seismic crustal deformation
Oct 4, 1994, east off Hokkaido Eq. (M8.1)
Oct 6 preliminary results reported in two days
max: 44 cm east/ 10 cm down at Nemuro

Horizontal coseismic displacement vectors
1994 East Off Hokkaido Earthquake (M8.1)

co- & post-seismic crustal deformation
Dec 28, 1994, far off Sanriku Eq. (M7.5)
post-seismic for 3 days: slow earthquake
for 60+ days: post-seismic deform

Powerful tool for monitoring & detecting
  crustal deformation
Contribution to understanding of crustal
  activities
GEONET now: enhancement

GEONET: GNSS Earth Observation NETwork System

- Nationwide about 1,300 sites
  - at average spacing of 20km
  - multi-GNSS signal reception

- Real-time data at 1Hz sampling
  - Data provision via a distributor for network RTK & positioning service etc.
  - GPS, GLONASS, QZSS

- Data & position results available free of charge
  - Data at 30-second intervals
  - Operational precise coordinates
    (3 modes of analysis)

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Specification of GEONET station

- Pillar: 5m Stainless steel Pillar
- Receiver: Trimble NetR9, TOPCON NET-G3 GPS, GLONASS, QZSS
- Antenna: Trimble Choke Ring (TRM59800.80),
  Topcon Choke Ring (TPS CR-G5) GPS, GLONASS, QZSS
- Data transport: IP-VPN for real-time + Mobile phone for emergency
- Battery: ~72 hour continuation
- Other: UPS, Heater, Fun, Power Monitoring, Lightning arrester, etc.
Roles as a national geodetic infrastructure

(1) Backbone of geodetic control stations
   - CORS for survey: making triangulation points unnecessary
     1. For GNSS survey
        Providing coordinates at the antenna and 30s data without fees
     2. Ground survey such as TS survey and leveling
        Providing coordinates on the attached metal markers
   - Effective updates of reference coordinates

(2) Support for real-time positioning (services) & weather forecast (GPS meteorology)
   - RTK-GNSS positioning of aircrafts in aerial photogrammetry, airborne LiDAR survey, most effectively in emergency response

Roles as a national geodetic infrastructure

(3) Global and regional geodetic reference frame
   - development and maintenance of ITRF for global and APREF for regional geodetic reference frames

(4) Continuous monitoring of crustal deformation,
   - understanding of earthquake occurrence/volcanic activities
   - contributions to emergency response/countermeasures to natural disasters
   - fault slip inversion for supporting tsunami alert

- 11/Mar/2011 05:46:23 UT
- 38.32N, 142.37N, 24km
- Mw=9.0
- Dead/Unknown : 21,176
e.g.1: 2011 Great Tohoku EQ

- 19/Jan/2011 e.g.2: 2011 Mt. Kirishima’s Eruption
- 19/Jan/2011
Support for real-time positioning (service)

- 1 Hz data of GEONET is provided to the end users in real-time by private companies through NPO distributors
- Main purpose of the service is
  - Network RTK for surveying
  - RTK positioning for photogrammetry, ICT construction
  - Location-Based services
- GLONASS and QZSS real-time data are now available (from May 10, 2013) in addition to GPS

Schematic view of network RTK positioning with GEONET real-time data

2011 Off the Pacific coast of Tohoku Earthquake

Co-seismic Movement

[ Horizontal ]

Oshika 5.3m

[ Vertical ]

Oshika -1.2m

Preliminary results reported on the same day
Revised Coordinates of CORS stations: published on May 31, 2011
Those of other control points & benchmarks: published on Oct 31, 2011
1. GNSS positioning  
2. Detection of permanent displacements  
3. Estimation of fault model and Mw  
4. Results

**Methods**
- "RAPiD" (Ohta et al., 2012) for automatic detection of permanent displacements  
- Triggered by Early Earthquake Warnings (JMA)  
- Automatic estimation of single rectangular fault (Nishimura et al., 2010 (in Japanese))  
- Notification message via E-mail  
- Expect contribution to TEW system

*This project was launched in 2011 with the support of Tohoku University

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**How to get GEONET data**

- **30sec epoch data**
- Fill in the application form and send it to gsi-data@gsi.go.jp
- The application form is available from http://datahouse1.gsi.go.jp/terras/terras_english.html

http://datahouse1.gsi.go.jp/terras/terras_english.html
Japanese hybrid geoid model, “GSIGEO2011”

- Japanese new hybrid geoid model, “GSIGEO2011”, has been open on April 1, 2014.
- Main purpose of the model is enabling height determination of third order benchmarks by GNSS surveying.
- The model is established by fitting gravity geoid model, “JGEOID2008”, to geoid heights determined from GPS/Leveling at 850 GEONET stations, 29 tidal stations and 142 benchmarks.
**Evaluation of GSIGEO2011**

- Comparing the model (GSIGEO2011) and inputs (GPS/Leveling) to evaluate the consistency of the model with Japanese vertical datum.

<table>
<thead>
<tr>
<th>GSIGEO2011 – GPS/Leveling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0 cm</td>
</tr>
<tr>
<td>SD</td>
<td>1.9 cm</td>
</tr>
<tr>
<td>Max Difference</td>
<td>8.3 cm (-6.2 cm)</td>
</tr>
</tbody>
</table>

Differences between Model and GPS/Leveling Geoid Heights.

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**Height determination by GSIGEO2011 and GEONET**

- Orthometric height determination by GNSS survey with GSIGEO2011 has been authorized and available as public survey in Japan mainland since April 1, 2014.
- The operation procedure for the survey was also defined and has been available since April 1, 2014.

Orthometric Height \( H \) = Ellipsoidal Height \( h \) - Geoid Height \( N \)
Re-calculation of heights of triangular points

• GSI re-calculated heights of triangular control points with GSIGEO2011, and revised the survey results on April 1, 2014.

• Difference between the original and the re-calculated heights is around 1m in maximum and 15cm in average. The difference contains both model improvement and vertical deformation by crustal movements from 1880’s.

Difference between original and re-calculated heights (a) Difference by model improvement. (b) By cumulative crustal deformation since 1880’s. (c) (a)+(b).

Summary

• GSI has been operating GEONET, GNSS CORS network covering all over Japan for the past two decades.

• The purposes are to establish a regional reference frame consistent with the global frame and to monitor crustal deformation throughout the country.

• It supports a variety of applications and plays a major role as a national geodetic infrastructure.

• Japanese new hybrid geoid model, “GEIGEO2011” has been established on April 1 2014, and combination of the model and GEONET enables height determination for third order benchmarks in Japan by GNSS surveying.

• Orthometric heights of triangular control points were also re-calculated with GSIGEO2011, and became available as revised survey results on April 1, 2014.

Two decades of experience in operation & analysis of GEONET provided GSI with accumulated knowledge & skills in CORS network, sufficient to extend technical assistance to other countries in an advanced and flexible manner. GSI is ready for supporting construction/operation of CORS in your own country. Contact: JICA training course Group International Affairs Div., Planning Dept., GSI gsi-training@gsi.go.jp
**Data transmission flow**

- **Analysis Center**
- **Administration Unit**
- **Communication Unit**
- **Data Analysis Unit**
- **Data Storage Server**
- **Observation Data Provision**
- **Daily coordinates**

**GEONET analysis strategy**

- **Hardware**: HP ProLiant 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 sec. data
- **Higher frequency analyses**: *(not for all sites)*
  - Real-time and post-processing by 1 sec. data
### Routine analysis strategies (Post Processing)

Three types of routine analysis are provided:

<table>
<thead>
<tr>
<th></th>
<th>Q3 (Quick)</th>
<th>R3 (Rapid)</th>
<th>F3 (Final)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>6-hours</td>
<td>24-hours</td>
<td>24-hours</td>
</tr>
<tr>
<td>Orbit</td>
<td>IGS ultra-rapid</td>
<td>IGS rapid</td>
<td>IGS final</td>
</tr>
<tr>
<td>Schedule</td>
<td>Every 3 hours</td>
<td>Everyday</td>
<td>Every Sunday</td>
</tr>
</tbody>
</table>

**Promptness**

- **Quick**
- **Slow**

**Accuracy**

- **Low**
- **High**

And more … >>> Real–time analysis for tsunami mitigation

### Re-surveying of benchmarks in Tohoku

- GSI re-surveyed orthometric heights of almost all leveling routes and 55% of GEONET in Tohoku after 2011 Off the Pacific coast of Tohoku Earthquake.
- Displacements are up to 1.1m, and survey results were revised with the leveling survey.
- The revised orthometric heights are combined to GEIGEO2011, and the model is consistent with orthometric heights after the earthquake.

Yellow line is leveling route with re-surveying and green is without re-surveying.