ICG Working Group D
Reference Frames, Timing and Applications

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

ICG-13, Nov.4-9, 2018 @ Xi’an, China

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Geospatial Information Authority (GSI) of Japan
1. Introduction to GNSS CORS in Japan
   • GEONET

2. Topics
   • Realization of ITRF2014 in Japan
   • Real-time coseismic fault model estimation system “REGARD” based on RTK-GNSS analysis

3. Towards the "Society 5.0"
   • Importance of dense CORS
**GNSS CORS in Japan GEONET**

**GNSS Satellites**
- GPS
- QZSS
- GLONASS
- Galileo

**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**
- Data Collection
- Data Analysis

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

**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
1993

Model 94
1994

Model 95
1995-1997

Model 02
2002-

Mt. Fuji

North American plate

Eurasian plate

Pacific plate

Philippine Sea plate

Okino Tori island

Minami Tori island

5-m high stainless pillar

GNSS antenna

Receiver

IP Router

UPS

Batteries

Tilt meter

Heater

Arrester

1,318 stations with 20 – 25 km spacing

Model 93
1993

Model 94
1994

Model 95
1995-1997

Model 02
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.
• 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

1996
GEONET established

F0 F1 F2 F3 F4
ITRF94/96 ITRF97 ITRF2000 ITRF2005 ITRF2014

Multi-GNSS observation begins

2013
Daily coordinates (F3) at TSKB (Tsukuba)

2009-Jan-01 to 2018-May-05

Tohoku EQ (M9.0), 2011/3/11
Differences between F3 and SINEX(IGS) at TSKB

2009-Jan-01 to 2018-May-05

A few cm deviation from SINEX(IGS) after Tohoku EQ in 2011
## Analysis strategy for “F4”

<table>
<thead>
<tr>
<th></th>
<th>F3</th>
<th>F4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Software</strong></td>
<td>Bernese ver.5.0</td>
<td>Bernese ver.5.2</td>
<td>Newest version</td>
</tr>
<tr>
<td><strong>Satellite type</strong></td>
<td>GPS only</td>
<td>GPS and GLONASS</td>
<td>Multi-GNSS</td>
</tr>
<tr>
<td><strong>Coordinates</strong></td>
<td>ITRF2005</td>
<td>ITRF2014</td>
<td>Newest RF</td>
</tr>
<tr>
<td><strong>Mapping function</strong></td>
<td>NIELL</td>
<td>GMF/VMF1</td>
<td>More localities</td>
</tr>
<tr>
<td><strong>ZTD space</strong></td>
<td>3h</td>
<td>1h (GPS) 2h (GLONASS)</td>
<td>More time resolution for tropospheric delay parameters</td>
</tr>
<tr>
<td><strong>Grd space</strong></td>
<td>24h</td>
<td>3h (GPS) 6h (GLONASS)</td>
<td></td>
</tr>
</tbody>
</table>

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

Time series at "Hateruma" station
Jan. 1\textsuperscript{st} 2014 – Dec. 31\textsuperscript{st} 2016

±5 cm offsets are given
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: \( Y = y_0 + \text{trend} + \text{year} + \text{half-year} \)

The offsets from antenna exchanges are estimated from time series.
Comparison of precision

Mean RMS at 20 Backbone stations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>E</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS solution (F3)</td>
<td>2.04 mm</td>
<td>2.16 mm</td>
<td>6.52 mm</td>
</tr>
<tr>
<td>(F4)</td>
<td>2.01 mm</td>
<td>2.10 mm</td>
<td>6.21 mm</td>
</tr>
<tr>
<td>GLO sol. (F4)</td>
<td>2.51 mm</td>
<td>3.68 mm</td>
<td>8.71 mm</td>
</tr>
<tr>
<td>Comb. sol. (F4)</td>
<td><strong>2.00 mm</strong></td>
<td><strong>2.11 mm</strong></td>
<td><strong>5.76 mm</strong></td>
</tr>
</tbody>
</table>

- 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. Kawamoto¹, S. Abe¹, K. Ohashi¹, Y. Ohta², M. Todoriki³, and T. Nishimura⁴ 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?
Real-time Kinematic GNSS provides:

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

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

<table>
<thead>
<tr>
<th>Year</th>
<th># of sites</th>
<th>Satellites</th>
<th>Inversions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>160</td>
<td>GPS</td>
<td>・Single rectangular fault</td>
</tr>
<tr>
<td>2013</td>
<td>600</td>
<td>GPS</td>
<td>・Slip distribution</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td>GPS+GLO</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td>GPS+GLO</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>1200+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

What is Society 5.0

Society 1.0
Hunting society

Society 2.0
Farming society

Society 3.0
Industrial society

Society 4.0
Information society

Society 5.0
Super smart society

https://www.gov-online.go.jp/cam/s5/eng/
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](http://terras.gsi.go.jp)
  - To access from non-jp domain, see [http://datahouse1.gsi.go.jp/terras/terras_english.html](http://datahouse1.gsi.go.jp/terras/terras_english.html)
  - Old RINEX before April 2010 (marginal cost)
    ⇒ Contact [data@geo.or.jp](mailto: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](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.jenoba.jp/support/contact/)
    [https://www.gpsdata.co.jp/contact_us/](https://www.gpsdata.co.jp/contact_us/)
    [https://www.terasat.co.jp/contact.html](https://www.terasat.co.jp/contact.html)