Realization of semi-dynamic reference frame using multi constellation of GNSS and IGS products in Japan

ICG-12, Dec.2-7, 2017  Kyoto, Japan

H.Tsuji, S.Abe, N.Takamatsu, Y.Miura, B.Miyahara
Geospatial Information Authority (GSI) of Japan
1. Necessity of semi-dynamic correction to relate
   - the current ITRF coordinates obtained from GNSS positioning, and
   - the past ITRF coordinates at the epoch of national datum that existing maps follow

2. Status on the realization of ITRF using GNSS CORS (GEONET) in Japan
   - “F3” (ITRF2005) ⇒ “F4” (ITRF2014)
     • Source of semi-dynamic correction
     • QZSS CLAS also refers
Crustal deformation since 1997

http://www.gsi.go.jp/common/000151438.wmv
GNSS CORS in Japan (GEONET)

GNSS antenna
5-m high stainless pillar

Receiver
IP Router
UPS
Batteries
Tilt meter
Heater
Arrester

Model 93
1993

Model 94
1994

Model 95
1995-1997

Model 02
2002-

Minami Tori island
Okino Tori island

Mt. Fuji

Eurasian plate
North American plate
Pacific plate
Philippine Sea plate

5-9 m high
stainless pillar

Batteries
Tilt meter
Heater
Arrester

IP Router
Receiver
UPS

4
VLBI: from Tsukuba to Ishioka

Tsukuba 32-m VLBI

- Used to be the core station of geodetic reference frame in Japan from 1999 to 2016.

Ishioka 13-m VLBI

- The state-of-the-art telescope conformable to the IVS VGOS specification
- Collocated with GNSS CORS

17 km NE of Tsukuba
What is the Problem?

- GNSS positioning yields coordinates in WGS84, PZ90.11, GTRF, ... = current ITRF coordinates

- Existing maps are made by surveys based on the static datum = past ITRF coordinates at the epoch of static datum definition

There will be a difference between GNSS positioning and maps, as time goes by, and as GNSS precision increases ...
Semi-Dynamic correction

- Cumulative deformation model from GNSS CORS is used to align the current and epoch coordinates
  - Model is updated once a year for surveying
  - Now proposing to apply semi-dynamic correction for precise positioning, with more frequent model updates

Flow of Semi-Dynamic correction for surveying

Due to the 2011 Tohoku EQ, reference epoch is 2011/05/24 in East Japan, and 1997/01/01 for West Japan and Hokkaido
Cumulative crustal deformation is calculated from time series of ITRF coordinates of each CORS (average spacing 20km in Japan).

Deformation is estimated for each 5km grid by interpolating the cumulative deformation at each CORS.

Users can estimate crustal deformation anywhere within the CORS network by interpolating the deformation at nearby grids.

The cumulative crustal deformation model is updated once a year and available on the Internet.
R&D status on the realization of ITRF using GNSS CORS in Japan
GSI calculates daily coordinates of each GEONET station

Results of GEONET analysis (daily coordinates at TSUKUBA-1)

1999-Mar-21 to 2016-Aug-02

We call the way of calculating coordinates of each GEONET station as "analysis strategy".

Start of GEONET

1996

Multi-GNSS observation

2013

Overview of GEONET analysis strategy

F0  F1  F2
1996～ 2001～ 2004～
ITRF94/96 ITRF97 ITRF2000

F3  F4
2009～ 2017？～
ITRF2005 ITRF2014

GPS  GPS+ GLONASS
Step of NEW GEONET analysis strategy

ITRF2014
Bernese software ver.5.2

- Calculate coordinates of one GEONET fixed point with IGS stations. (connected to ITRF)
Geospatial Information Authority of Japan (GSI)

Step of NEW GEONET analysis strategy

- Select some Backbone (BB) stations in the whole of Japan.
- Calculate the coordinates of each BB station with fixed TSUKUBA-1.
- Calculate coordinates of one GEONET fixed point with IGS stations. (connected to ITRF)

ITRF2014
Bernese software ver.5.2

- Calculate coordinates of one GEONET fixed point with IGS stations. (connected to ITRF)
- Select some Backbone (BB) stations in the whole of Japan.
- Calculate the coordinates of each BB station with fixed TSUKUBA-1.
Step of NEW GEONET analysis strategy

ITRF2014
Bernese software ver.5.2

- Calculate coordinates of one GEONET fixed point with IGS stations. (connected to ITRF)
- Select some Backbone (BB) stations in the whole of Japan.
- Calculate the coordinates of each BB station with fixed TSUKUBA-1.
- Select some Basic Cluster (BC) stations in the whole of Japan.
- Calculate the coordinates of each BC station with fixed BB stations.
Step of NEW GEONET analysis strategy

- Calculate other stations which connected to BB and BC stations by radial baselines with fixed BB and BC stations.

ITRF2014
Bernese software ver.5.2

- Calculate coordinates of one GEONET fixed point with IGS stations. (connected to ITRF)
- Select some Backbone (BB) stations in the whole of Japan.
- Calculate the coordinates of each BB station with fixed TSUKUBA-1.
- Select some Basic Cluster (BC) stations in the whole of Japan.
- Calculate the coordinates of each BC station with fixed BB stations.
- Calculate other stations which connected to BB and BC stations by radial baselines with fixed BB and BC stations.
Solve GPS and GLONASS independently
coordinates and tropospheric delay

- Ambiguity resolution (GPS)
- Make normal equation (GPS)
- GPS only

- Make normal equation (GPS)
- Ambiguity resolution (GLO)
- GLONASS only
Initial Result of combination

Time series of Baseline components at farthest station from fixed station for a year

The periodic noise in GLONASS only solution also affects the combined solution
Periodic noise (~8 days) is clear for GPS+GLONASS.

The geometry of GLONASS constellation may contribute to the periodic noise (Ray et al., 2013).
Improved combination of GPS and GLONASS

- Ambiguity resolution (GPS)
  - Make normal equation (GPS)
    - Combine both NEQs
      - Add Helmert 7 parameters
        - Eliminate the tropospheric parameters
          - Ambiguity resolution (GLO)
            - Make normal equation (GLO)
              - GLONASS only
              - Combined
              - GPS only

Geospatial Information Authority of Japan (GSI)
Power spectrum of time-series of baseline
Stuck all GEONET stations.

Periodic noise removed

Combined with deleted tropospheric parameters + helmert transformation parameters
## Evaluation of accuracy

### RMS error of time series of GEONET station

<table>
<thead>
<tr>
<th></th>
<th>NS[mm]</th>
<th>EW[mm]</th>
<th>UD[mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>1.52</td>
<td>1.60</td>
<td>6.24</td>
</tr>
<tr>
<td>GLONASS</td>
<td>1.81</td>
<td>3.03</td>
<td>8.04</td>
</tr>
<tr>
<td>Combined</td>
<td>1.44</td>
<td>1.54</td>
<td>5.65</td>
</tr>
<tr>
<td>Combined (without GLONASS tropospheric parameter)</td>
<td>1.45</td>
<td>1.58</td>
<td>5.71</td>
</tr>
</tbody>
</table>

The **Combined solution** does not contain periodic noise.

But, RMS error is not the best.

For short-term crustal deformation monitoring, we consider that removing periodic noise is better.
Conclusions

• Necessity of semi-dynamic correction to relate precise GNSS positioning and existing maps

• GSI is developing a new analysis strategy of GEONET("F4")
  – ITRF2014, GPS+GLONASS

⇒ Realization of semi-dynamic reference frame using multi constellation of GNSS and IGS products in Japan

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