How GNSS CORS in Japan works for geodetic control and disaster mitigations

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1. Introduction to GNSS CORS in Japan
   - GNSS Earth Observation Network system (GEONET)
2. How GEONET works for
   - Geodetic control
     - Realization of ITRF in tectonically active regions
   - Disaster mitigations
     - Real-time GNSS analysis system for rapid earthquake fault estimations
Introduction to GEONET
Positioning with GNSS

**Car Navigation**

- Point positioning (XYZ) or (Lon, Lat, H)
- Precision ~ 10 m

**Land Surveying**

- Relative positioning between 2 receivers
- Precision ~ 1 cm
What is GEONET?

• One of the Largest Continuously Operating Reference Stations networks
  – 1,300 permanent stations with 20km spacing in Japan
  – Collects GNSS data every seconds, and provides data / products to users
  – Includes 7 IGS stations

• Infrastructure for surveying and precise positioning in Japan since 1994
GEONET Stations
(GNSS-based control points)

- 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-m high stainless pillar

Batteries

Tilt meter

Heater

Arrester

IP Router

Receiver

UPS
GEONET data / outcomes

GNSS Satellites
- GPS
- QZSS
- GLONASS
- Galileo

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

GNSS-based control points
- 20 km spacing
- Operated 24/7
- Transferring real-time 1 Hz observation data

Analysis Center in Tsukuba

Data Collection

Data Analysis

Observed data (every 30 sec)

Crustal deformation Monitor
- Monitoring of Earthquakes and Volcanic activities
- (new) Tsunami early warning

Precise real-time positioning
- ICT construction
- precision farming
- Source of QZSS augmentation

Real-time data

Provided to the Industry

Surveyed data (coordinates)

Applications
- Weather forecast using water vapor info from GNSS
- Ionosphere studies

Analyzed data (coordinates)

Other data
How GEONET works for geodetic control
- Realization of ITRF in tectonically active regions
Earthquakes > M5.0 in 1977-2014

Earthquake Research Institute, University of Tokyo, http://www.eri.u-tokyo.ac.jp
Crustal deformation observed by GEONET since April 1997

- Eurasian plate
- North American plate
- Pacific plate
- Philippine Sea plate

Fixed point

10 cm

1997年4月から 2年後 4年後 6年後 8年後 10年後 12年後 14年後 16年後 18年後 20年後

1998年 3月
Coseismic deformation field observed by GEONET with 1Hz

14:46, March 11, 2011
Main shock  M9.0

15:15, March 11, 2011
Largest after shock  M7.7

Post processed 1 Hz PPP kinematic solutions with GIPSY 6.1 (Nishimura, 2011)
www.gsi.go.jp/cais/chikakuhendo40010.html

Vectors whose error exceeds 0.1m are not plotted.
Site Coordinates of GEONET

Japanese Geodetic Datum (JGD) 2000

- Official coordinates for surveyors in Japan
- Static datum: Realization of ITRF94 with the epoch 1997.0
- Obsolete in east Japan after 2011 Tohoku EQ
- Should be updated using VLBI and GEONET results
- The timing was decided by the predicted post-seismic deformation.

\[ y(t) = c + a \ln \left(1 + \frac{t}{\tau_{\text{log}}} \right) \]

Days after the mainchock
Update of official site coordinates (JGD2011)

- New official coordinates of GEONET form JGD2011 (ITRF2008) with the epoch May 24, 2011 for eastern Japan
- Accelerated infrastructure reconstruction in Tohoku area.
- This quick response was achieved by the continuous observation of GEONET.

Although JGD2011 is a static datum whose epoch is fixed, we also provide daily site coordinates aligned with ITRF and semi-dynamic correction parameters.
How GEONET works for disaster mitigations

- Real-time GNSS analysis system for rapid earthquake fault estimations (REGARD)

The following slides are prepared by Mr. Satoshi Kawamoto, GSI. Development of REGARD is the joint effort with Tohoku University.
Motivation:

Improvement of tsunami warning in Japan

Tsunami Warning after the 2011 Tohoku Earthquake (Mw 9.0)

- Early Earthquake Warning: 30 sec.
- Tsunami Warning: 3 min.

Initial magnitude (EEW) was Saturated at M7.9

Underestimating tsunami heights

How to prevent saturations?

(Ozaki, 2011)
Kinematic GNSS analysis

Provides:

• Displacement wave-form
• Mw free from the saturation problems
• Rupture length and width
• Size of a potential subsequent tsunami

(www.gsi.go.jp/cais/chikakuhendo40010.html)
Geospatial Information Authority of Japan (GSI)

Geonet stations

GEONET real-time analysis system (REGARD)

GEONET real-time analysis system:
- Calculates 1Hz displacement
- Detects earthquake event
- Automated fault model inversion

GOAL: Provides Mw < 3 minutes
Flow diagram of REGARD

1. Real-time Positioning subsystem
   - RTKLIB 2.4.1 (Takasu, 2011)
   - RTCM convert
   - RTCM

2. Event detection subsystem
   - RAPiD (Ohta et al., 2012)
     Station position time-series’ $|LTA-STA| > 0.03m$
   - Early Earthquake Warning EEW $> M7.0$
   - Low-pass filter (20s moving average)

3. Fault model inversion subsystem
   - Automatic estimation of finite fault model

DATA

GEONET stations
- Real-time 1Hz BINEX

IGS
- Ultra-Rapid orbit

JMA
- Early Earthquake Warning (option)
2003 Tokachi-oki Earthquake (Mw 8.0)

• Stable magnitudes were derived within 100 sec by both modeling routines

Mw estimates

- GCMT (Mw 8.3)
- JMA (Mw 8.0)

VR: 13.06%
Mw: 7.04

VR: 75.68%
Mw: 8.00
2011 Tohoku Earthquake (Mw 9.0)

- Stable after 120 seconds
- No saturation occurred for magnitude estimates using GPS real-time positionings
Horizontal Crustal deformation from REGARD

- Observed significant horizontal displacements of up to 1 m
Real-time earthquake fault estimates at Kumamoto EQ

- **T=58s**
  - Mw 6.85

- **T=100s**
  - Mw 6.84

- **T=116s**
  - Mw 6.81

- **T=290s**
  - Mw 6.96
The fault model (final)
Kumamoto EQ

- Earthquake fault with right-lateral slip along the Futagawa fault segment
Conclusions

- GSI has been operating GEONET in Japan for the past two decades
  - to establish a regional reference frame consistent with the ITRF, and
  - to monitor crustal deformations for disaster mitigations.
- GNSS is a great tool for society!
- Geodetic reference frame (i.e. ITRF) is necessary to connect GNSS and society.