Monitoring of Permanent GNSS Networks used for Accessing the Terrestrial Reference Frame

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EPN Central Bureau, http://www.epncb.eu/
Outline

• Motivation
• Metadata Management System
• RTCM data
• RINEX data
• Conclusion
Terrestrial Reference Frame

International Terrestrial Reference Frame, latest release ITRF2014 (Altamimi, 2016)

- Set of reference stations with ITRF2014 coordinates and velocities

GNSS is primary mains to provide access to the terrestrial reference frame:

- Precise Point Positioning (PPP): a priori orbits & clock corrections
- Differential techniques: require direct access to reference station(s)
Reliability of the Reference Stations

Process GNSS reference station data together with GNSS data measured at unknown points

For the reference stations, users needs to know about:

- Data availability
- Correctness of metadata (e.g. antenna height)
- Data quality

The position of reference station computed by the user based on data / metadata on specific date \( \sim \) ITRF2014 position of reference station?

If too large difference \( \Rightarrow \) station is unsuitable as reference station
Network Used

• This presentation
  • Results based on monitoring of the EUREF Permanent GNSS Network (EPN) – access to ETRS89
    • http://www.epncb.eu/ or http://www.epncb.oma.be/
  • Any GNSS CORS network with
    • Site logs
    • RINEX 2 (and RINEX 3 data) (at least daily)
    • Real-time data distributed through Ntrip broadcasters, RTCM 3 format
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Changing GNSS Landscape in Europe

EPOS (European Plate Observing System) operational in 2019

European Scientific Research Infrastructure for **Solid Earth science**

Provide **(open) access** to data and products as well as tools for visualization, processing and analysis through one unique EPOS portal

http://www.epos-ip.org
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European Scientific Research Infrastructure for Solid Earth science
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GNSS-component:

**Data portal**
Provide access to GNSS data and site logs of ~3000 GNSS stations all over Europe

**Product portal**
Provide access derived products

**Metadata portal (M3G)**

http://www.epos-ip.org
Centralized system for submitting and validating GNSS metadata
- Unique site log submission system for all networks (EPN, EPN densification, EPOS)
- After validation, site logs are distributed to the portals of the networks
  - EPN, EPN densification → EPN Central Bureau
  - EPOS → EPOS Data Portal
- Validation process: handles the different requirements of different networks
  - EPN → DOMES number mandatory
  - EPOS → DOMES number NOT mandatory

Manage content of IGS-style site logs, but also additional station metadata: DOI, license, embargo time, nominal data submission, local/national network, ...
M$^3$G Centralized Contact Information

- New European General Data Protection Regulation - May 25, 2018
  - Defines minimum standards for processing personal data from EU citizens
  - Personal data: name of a person, email, telephone number, ..., location, IP address, cookie data,
  - GNSS station metadata include personal data – made available publicly without restrictions
  - GDPR rules: each ‘data subject’ must be
    - Able to edit/remove his/her personal data
    - Agree/disagree to make his/her personal data publicly available
  - In M3G centralizes management of personal data (contacts in multiple site logs need to indicate their preferences just once)
M³G Supports GeodesyML

Modern metadata: Discoverable, interoperable and authoritative, and closely aligned with Geography Markup Language (GML)

GML provides already a rich set of primitive objects like (geometry, coordinate reference system, time etc.)

GML lacks specific application schema that meets the needs of the geodetic community.

New GML application schema: Geodesy Markup Language (GeodesyML)

• Australia and New Zealand, with IGS support
• http://geodesyml.org/
• Includes objects like GNSS antenna, receiver, cable, ...

XML schema of GeodesyML Supported by M³G
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EPN Real-Time Streams

- Available from three regional EPN NTRIP broadcasters, operated by Italian Space agency (ASI), Federal office of Cartography and Geodesy (BKG, Germany), and Royal Observatory of Belgium (ROB)

<table>
<thead>
<tr>
<th>Broadcaster</th>
<th>Streams set up</th>
<th>Running streams</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASI</td>
<td>149</td>
<td>95</td>
</tr>
<tr>
<td>BKG</td>
<td>161</td>
<td>142</td>
</tr>
<tr>
<td>ROB</td>
<td>169</td>
<td>153</td>
</tr>
</tbody>
</table>

- Manual maintenance required by broadcaster operator

- STR;POTS00DEU0;Potsdam;RTCM 3.2; 1006(10),1007(10),1077(1),1087(1),1097(1);2; GPS+GLO+GAL;EUREF;DEU;52.19;13.07;0;0; JAVAD TRE_G3TH DELTA; none;B;N;3000;kg3-dmz.gfz-potsdam.de/POTS0(1)

July, 2018
Monitoring of Real-time Data - Method

For each broadcaster:

Loop over streams in sourcetable, keep streams with valid site log

a. Listens between 30s-900s to the stream

b. Decodes the stream
   • Compile list of message types in stream
   • Retrieve metadata in stream \(\rightarrow\) validate station metadata in stream vs site log + cross check with content in sourcetable

c. Listen again to the stream for 10-60s:
   • Decode the time stamp of the observables
   • Compute mean (computer time - observation time stamp) \(\rightarrow\) data latency

*Can be applied on all NTRIP broadcasters and all streams of stations with public site log*
Errors in Stream Metadata

Issue warning on station web pages at EPN CB web site:

example

Real-time data:

**WTZR00DEU0 available from:**
- BKG (broadcaster, registration) - RTCM 3.2 : GPS+GLO
- ROB (broadcaster, registration) - RTCM 3.2 : GPS+GLO

**WARNING:** ETRS89 reference position deviates significantly (more than 0.5 m) from EUREF values

**KIR000SWE0 available from:**
- BKG (broadcaster, registration) - RTCM 3.0 : GPS+GLO
- ROB (broadcaster, registration) - RTCM 3.0 : GPS+GLO

**WARNING:** missing ANTENNA TYPE
**WARNING:** missing ANTENNA HEIGHT
**WARNING:** missing ETRS89 reference position
Errors in Stream Metadata: Reference Position

59% : less than 5 cm error
21% : more than 50 cm of error (or missing)
Multi-GNSS Observations in Real-Time Streams

~ 160 EPN stations provide their data in real-time (50% of EPN)

<table>
<thead>
<tr>
<th>Constellations tracked</th>
<th>From real-time streams</th>
<th>According to site log</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS-only</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>GPS+GLO</td>
<td>66%</td>
<td>29%</td>
</tr>
<tr>
<td>GPS+GLO+GAL+...</td>
<td>31%</td>
<td>68%</td>
</tr>
</tbody>
</table>

Large amount of potential Galileo observations not available in real-time today.
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Multi-GNSS Tracking Network

Based on observations in RINEX data:

- GPS-only: 21 stations (6%)
- GPS+GLO: 128 stations (40%)
- GPS+GLO+GAL+... (RNX 3): 175 stations (54%)
Multi-GNSS Data Quality Monitoring

Running at the EPN Central Bureau since end 2016, but interpretation remains challenging

Based on G-nut/Anubis (Václavovic P, Dousa J, 2016) and self-developed scripts

• Types of observables
• Completeness of the observations
• Max. # of observations
• Number of cycle slips (x1000/nr. Obs)
• Average RMS of code multipath
Completeness of Daily Observations

**Motivation**

**Metadata**

**RTCM**

**RINEX**

**Conclusions**

**Navigation Message**

**Station Position**

**# Expected Observations**

**% Observed vs Expected All Observations**

**All Constellations**

**GPS**

**GLO**

**GAL**

**BDS**

**QZSS**

**# Observations**

**# 2+Freq Observations**

**% Observed vs Expected 2+Freq. Observations**

**All Constellations**

**GPS**

**GLO**

**GAL**

**BDS**

**QZSS**

**RINEX 2**

**RINEX 3**
## Data Completeness Overview

<table>
<thead>
<tr>
<th>Receiver Type</th>
<th>CAG100ITA</th>
<th>CAK00HRV</th>
<th>CANT0ESP</th>
<th>CARG0ESP</th>
<th>CAS800RL</th>
<th>CASC00FRT</th>
<th>CASE0ESP</th>
<th>CEBR0ESP</th>
<th>CEUT0ESP</th>
<th>CFRV00CZE</th>
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<tbody>
<tr>
<td>Name</td>
<td>TPS NET-G5</td>
<td>TRIMBLE NETR5</td>
<td>LEICA GR10</td>
<td>LEICA GR25</td>
<td>LEICA GRX1200GGPRO</td>
<td>LEICA GRX1200GGPRO</td>
<td>LEICA GR10</td>
<td>SEPT POLARX4</td>
<td>TRIMBLE NETR9</td>
<td>LEICA GRX1200-GNSS</td>
</tr>
<tr>
<td>RINEX 2</td>
<td>TOT 89</td>
<td>GPS 94</td>
<td>GLO 84</td>
<td>TOT 87</td>
<td>GPS 94</td>
<td>GLO 84</td>
<td>GAL 88</td>
<td>BDS</td>
<td>QZSS</td>
<td>TOT 93</td>
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<tr>
<td>RINEX 3</td>
<td>TOT 91</td>
<td>GPS 94</td>
<td>GLO 86</td>
<td>TOT 87</td>
<td>GPS 94</td>
<td>GLO 84</td>
<td>GAL 80</td>
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<td>QZSS</td>
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### Mean values over last 28 days:
- More than 90%
- Between 80% and 90%
- Below 80%
Completeness of Multi-GNSS Data

Ratio observed/expected observations
BBYS00SVK - RINEX 3

Date
182/2017  274/2017  001/2018  091/2018  182/2018

Observed/Expected Obs. (%)
Data Completeness

Motivation

Metadata

RTCM

RINEX

Conclusions
Simultaneous Galileo and BeiDou Tracking

Ratio observed/expected observations

EUSK00DEU - RINEX 3

LEICA GR25 Activation of BDS tracking

LEICA GR25 → GR50

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Larger Number of GPS/GLO obs. in RINEX 3?

Comparison of completeness of dual+ freq. data from RINEX 2 with RINEX 3

Mostly affected receivers

JAVAD TRE_G3TH DELTA (3.6.7)
TRIMBLE NETR9 (5,22)
JAVAD TRE_3 DELTA (3.7.3 Feb,02,2018)
Daily StDev of Completeness of Observations over all Stations
Beidou Tracking

Ratio observed/expected observations
M0SE00ITA - RINEX 3

Ratio observed/expected observations
LEIJ00DEU - RINEX 3

Ratio observed/expected observations
KOS100NLD - RINEX 3

Motivation  Metadata  RTCM  RINEX  Conclusions
Handling of Unhealthy Satellites

G-nut/Anubis

• Stations tracking unhealthy satellites emitting only on one frequency get lower % due to missing dual frequency data on some unhealthy satellites
• Stations tracking only healthy satellites get higher %

• IGS recommendation is to track unhealthy satellites

• Generate an new set of data quality results based on RINEX data files from which unhealthy satellites have been eliminated
Unhealthy satellites included

Unhealthy satellites excluded
Comparison of Station Performance

http://epncb.oma.be/_networkdata/data_quality/comparison.php
Monthly Sky Plots

http://epncb.oma.be/_networkdata/data_quality/skyplots/
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Conclusions

• Using GNSS stations as reference stations → knowledge about performance of the station to verify the suitability of a GNSS station as reference stations

• M3G : new management tool for GNSS metadata also used in EPOS

• EUREF monitors daily RINEX 2/3 and real-time metadata and data

• Correct interpretation of multi-GNSS RINEX quality checks continuously under improvement
Conclusions

• Lessons:
  • Real-time streams not always suitable for accessing the reference frame
  • Use RINEX 3 (above RINEX 2) when available, even if only processing GPS+GLO
  • Keep receiver firmware up to date
  • In case of degraded receiver performance: prioritize satellite systems tracked
    • in EPN: GPS+GLO+GAL
Future Work

Data quality checks available since 1996 on all EPN stations

• Improve our understanding of temporal variations in data quality metrics
• Correlate between e.g. receiver types/firmware versions
• Optimization of data quality metrics
• Intelligent algorithms to detect “abnormal behavior”
Thank you

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