GNSS data analysis for Geodesy and Atmospheric Research at the Institute of Geodesy and Geoinformatics

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Real-time Positioning

GNSS-WARP
Wroclaw Algorithms for Real-time Positioning

- original, self-developed, state-of-the-art PPP software
- purpose: multi-GNSS RT-PPP & PPP-RTK algorithms development
- GNSS: GPS+GLO, GAL & BDS only with MGEX products, RT
- implemented in Matlab (2015a) + Instrument Control Toolbox
- BNC used as RTCM decoder of IGS RTS streams
Real-time PPP – GPS solution

Station WROC, 6h of data, 30 sec. interval, 5° elevation cut-off angle, VMF
### New GNSS systems

<table>
<thead>
<tr>
<th>System</th>
<th>GLONASS</th>
<th>Galileo</th>
<th>BeiDou</th>
<th>QZSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>GLONASS-M</td>
<td>GLONASS-K</td>
<td>IOV</td>
<td>FOC (extended orbit)</td>
</tr>
<tr>
<td>PRN Number</td>
<td>R01-R08, R10-R19, R21-R25</td>
<td>R09, R20</td>
<td>E11, E12, E19, E20</td>
<td>E18, E14</td>
</tr>
<tr>
<td>Retroreflectors</td>
<td>115</td>
<td>132</td>
<td>84</td>
<td>60</td>
</tr>
<tr>
<td>Mass [kg]</td>
<td>1450</td>
<td>750</td>
<td>695-697</td>
<td>661/662</td>
</tr>
<tr>
<td>Semi-major axis [km]</td>
<td>25 500</td>
<td>25 520</td>
<td>29 600</td>
<td>27 978</td>
</tr>
<tr>
<td>Altitude [km]</td>
<td>19 130</td>
<td>19 130</td>
<td>23 225</td>
<td>17 178-26 019</td>
</tr>
<tr>
<td>Orbit</td>
<td>MEO</td>
<td>MEO</td>
<td>MEO</td>
<td>MEO</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001-0.0002</td>
<td>0.1585/0.1584</td>
</tr>
<tr>
<td>Inclination [deg]</td>
<td>64.8</td>
<td>68.8</td>
<td>54.93-55.57</td>
<td>50.10/50.16</td>
</tr>
</tbody>
</table>

**Nominal orbit (E30)**

**Extended orbit (E14)**

Variable velocities: from 1.9 km/s in the apogee up to 3.4 km/s in the perigee (in the Earth-fixed frame, w.r.t. the observer)
Comparison of real-time orbit and clocks w.r.t. MGEX final IGS solutions

![Chart showing comparison of GPS, GLONASS, Galileo, and BeiDou orbits and clocks]
Validation of GNSS clocks

Graphs showing the performance of different GNSS systems:
- GPS: IIR-A, IIR-B, IIR(M), IIF
- GLONASS: plane #1, plane #2, plane #3, GLONASS K
- Galileo: IOV, FOC
- BeiDou: GEO, IGSO, MEO
Laser retroreflectors installed on GNSS satellites

GPS-35/36

GLONASS-M

GLONASS-K1

GLONASS

Galileo 101-104 (84 CCRs)

Galileo 201-204 (60 CCRs)
Validation of real-time orbits using Satellite Laser Ranging (SLR)

GLONASS

Plane #1

Plane #2

Plane #3

Galileo

Plane A

Plane B

Plane C

BeiDou

GEO

IGSO C08

IGSO C10

MEO
Validation of GNSS orbit models using SLR

The classical Empirical CODE Orbit Model (ECOM1) includes the following parameters:

\[
\begin{align*}
D &= D_0 \\
Y &= Y_0 \\
X &= X_0 + X_C \cos u + X_S \sin u
\end{align*}
\]

where \( u \) is the satellite argument of latitude.

ECOM2 includes following parameters:

\[
\begin{align*}
D &= D_0 + D_{C2} \cos 2\Delta u + D_{S2} \sin 2\Delta u \\
&\quad + D_{C4} \cos 4\Delta u + D_{S4} \sin 4\Delta u \\
Y &= Y_0 \\
X &= X_0 + X_C \cos \Delta u + X_S \sin \Delta u
\end{align*}
\]

where \( \Delta u \) is the satellite argument of latitude with respect to the argument of latitude of the Sun.

The smallest offset and RMS of SLR residuals is obtained for C-SPAD stations tracking Galileo in incorrect orbital planes.

The smallest offset cannot be explained by the change of satellite center-of-mass due to the fuel consumption during the maneuvers when correcting the orbit eccentricity.

The difference of the mean offsets between C-SPAD and MCP is about 12 mm for IOV and incorrect.
GNSS orbit determination using SLR - GLONASS

The dependency of the determination accuracy of GLONASS semi-major axis on the number of SLR observations and tracking stations.
Near-Real Time troposphere recovery

E-GVAP

http://egvap.dmi.dk/

Arrival time window of Observations

- No Data or before 05/08 07h
- between 05/10 04h and 05/10 07h
- between 05/10 01h and 05/10 04h
- between 05/10 01h and 05/08 07h
Near-Real Time troposphere recovery

Gradients and lighting strikes over distribution of 2D integrated water vapour (IWV) in troposphere over Poland for June 2016 (selected)
GNSS Tomography

TOMO2

\[ L_{\text{atm}}(\varepsilon, \alpha) = \text{STD} = 10^{-6} \int N ds \]

- resolving vertical structure of severe weather
- 3D NRT model for area of Poland
- a way to derive wet refractivity
- Kalman filter for forward processing

Reference: Rohm, W., and Bosy, J. (2011). The verification of GNSS tropc area. Advances in Space Research, 47(10), 1721-1730, DOI:
Troposphere delay modeling for SLR (horizontal gradients)

\[ d_{atm} = m_{f5} \times (d_h^2 + d_w^2) + \tau(\varepsilon) \times [G_N \cos\alpha + G_E \sin\alpha] \]

\[ \tau(\varepsilon) = \frac{1}{\sin(\varepsilon) \tan(\varepsilon) + c} [G_N \cos(\alpha) + G_E \sin(\alpha)] \]

From left: LAGEOS, LAGEOS-2, LARES

WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES
The Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences would like to cordially invite you to the EUREF 2017 Symposium, that will be held in Wroclaw, Poland, on May 17-19, 2017 (Wednesday to Friday).

The EUREF Symposium is the forum where the EUREF activities are discussed and the resolutions are taken. It has been organized every year since 1990.

EUREF is the IAG Reference Frame Sub-Commission for Europe, integrated in the Sub-Commission 1.3, Regional Reference Frames, under Commission 1 - Reference Frames, following the implementation of the new IAG structure at the IUGG (International Union of Geodesy and Geophysics) General Assembly held in Sapporo, 2003. The Sub-Commission EUREF was founded in 1987 at the IUGG General Assembly held in Vancouver.

The scope of the symposium covers the definition, realization and maintenance of the European Reference Frame - the geodetic infrastructure for multinational projects requiring precise geo-referencing (e.g. three-dimensional and time dependent positioning, geodynamics, precise navigation, geo-information) - in close cooperation with the IAG components (Services, Commissions, and Inter-commission projects) and EuroGeographics, the consortium of the National Mapping Agencies (NMA) in Europe.
Thank you for your Attention
Near-Real Time troposphere - METEO

Ground meteo networks: EPN, METAR, SYNOP i CWOP