Impact of the SRP model on CODE's 5-system orbit and clock solution for the MGEX

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Contents

- Data base and network
- CODE MGEX orbit solution
- CODE MGEX clock solution
- Impact of CODE’s new solar radiation pressure model
- Summary and outlook
MGEX data monitoring

Number of stations providing daily RINEX3 files and included in CODE’s raw data monitoring (data sources: IGS-MGEX and EPN)

![Graph showing the number of stations providing daily RINEX3 files from 2012 to 2015 for different satellite systems: GPS, GLONASS, Galileo, SBAS, BeiDou, QZSS. The graph illustrates the increase in the number of stations over the years.]
## CODE MGEX orbit solution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS considered</td>
<td>GPS + GLONASS + Galileo + BeiDou (MEO+IGSO) + QZSS (≈70 SV)</td>
</tr>
<tr>
<td>Processing mode</td>
<td>Post-processing (≈2 weeks latency)</td>
</tr>
<tr>
<td>Timespan covered</td>
<td>GPS-weeks 1689 - today</td>
</tr>
<tr>
<td>Number of stations</td>
<td>130 (GPS), 110 (GLONASS), 85 (Galileo); 55 (BeiDou); 20 (QZSS)</td>
</tr>
<tr>
<td>Processing scheme</td>
<td><strong>Double-difference</strong> network processing (observable: phase double differences)</td>
</tr>
<tr>
<td>Signal frequencies</td>
<td>L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) Galileo; B1 (L1) + B2 (L7) BeiDou</td>
</tr>
<tr>
<td>Orbit characteristic</td>
<td>3-day long arcs; SRP: ECOM / ECOM2 (since 2015)</td>
</tr>
<tr>
<td>Reference frame</td>
<td>IGS08 (until week 1708); IGb08 (since week 1709)</td>
</tr>
<tr>
<td>IERS conventions</td>
<td>IERS2003 (until 1705); IERS2010 (since 1706)</td>
</tr>
<tr>
<td>Product list</td>
<td>Daily orbits (SP3) and ERPs</td>
</tr>
<tr>
<td>Designator</td>
<td>comwwwwd.???.Z</td>
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</table>
## CODE MGEX clock solution

<table>
<thead>
<tr>
<th><strong>GNSS considered:</strong></th>
<th>GPS + GLONASS + Galileo + BeiDou + QZSS (≈70 SV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Processing mode:</strong></td>
<td>Post-processing (≈2 weeks latency)</td>
</tr>
<tr>
<td><strong>Timespan covered:</strong></td>
<td>GPS-weeks 1710 - today</td>
</tr>
<tr>
<td><strong>Number of stations:</strong></td>
<td>130 (GPS), 35 (GLO), 45 (Galileo); 50 (BeiDou); 20 (QZSS)</td>
</tr>
<tr>
<td><strong>Processing scheme:</strong></td>
<td><strong>Zero-difference</strong> processing (observable: code+phase undifferenced)</td>
</tr>
<tr>
<td><strong>Signal frequencies:</strong></td>
<td>L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) Galileo; B1 (L1) + B2 (L7) BeiDou</td>
</tr>
<tr>
<td><strong>A priori information:</strong></td>
<td>Orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known</td>
</tr>
<tr>
<td><strong>Reference frame:</strong></td>
<td>IGb08</td>
</tr>
<tr>
<td><strong>IERS conventions:</strong></td>
<td>IERS2010</td>
</tr>
<tr>
<td><strong>Product list:</strong></td>
<td>Epoch-wise (300s) satellite and station clock corrections in daily clock RINEX files; daily inter-system biases for mixed stations in Bernese DCB and BIAS-SINEX format</td>
</tr>
</tbody>
</table>
MGEX products availability

Status: 01-Jan-2016
Satellite system IDs according to the content of the precise orbit files at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/
Orbit description and Yaw attitude

Angles and vectors:

**Beta**: Elevation of Sun above orbital plane

**Du**: Argument of latitude

**Z**: Direction satellite -> Earth (antenna direction)

ECOM axes:

**D**: Direction satellite -> Sun

**Y**: Solar panel axis

**B**: Third ECOM axis
Solar radiation pressure

Satellite cross-section as seen from the Sun (Beta ≈ 30°) during one orbital revolution:

=> solar panel area does not change

=> but: cross-section of long satellite bodies w.r.t. the Sun varies
New Empirical CODE radiation pressure Model

- MGEX-reprocessing for 2014 using ECOM (5 RPR par.; Beutler et al., 1994, Springer et al., 1999) vs. ECOM2 (9 RPR par., Arnold et al., 2015)
- Validation with SLR residuals and satellite clock corrections
- The new ECOM takes into account the periodically changing cross section of elongated satellite bodies wrt. the Sun

=> Improvements expected for Galileo, GLONASS, QZSS

ECOM1 (old):

\[ D(u) = D_0 \]
\[ Y(u) = Y_0 \]
\[ B(u) = B_0 + B_C \cos(u) + B_S \sin(u) \]

ECOM2 (new):

\[ D(u) = D_0 + D_{2C} \cos(2Du) + D_{2S} \sin(2Du) \]
\[ + D_{4C} \cos(4Du) + D_{4S} \sin(4Du) \]
\[ Y(u) = Y_0 \]
\[ B(u) = B_0 + B_C \cos(Du) + B_S \sin(Du) \]
Impact of new ECOM on Galileo orbits

⇒ Significant reduction of size and dependency of SLR residuals on the Beta-angle
Impact of new ECOM on Galileo orbits

ECOM1 (all Galileo satellites):

⇒ SLR residuals of 2014 are large at small and medium Beta angles and with argument of latitude around 0° and ±180°
Impact of new ECOM on Galileo orbits

ECOM2 (all Galileo satellites):

⇒ Systematics in the SLR residuals are significantly reduced
⇒ Significant SLR offset remains
Impact of new ECOM on Galileo clock corrections

 ⇒ Significant reduction of Beta angle dependency
 ⇒ Pronounced signal remains during eclipse season or close-by (impact of mis-modelled attitude?)
Impact of new ECOM on Galileo clock corrections

Impact of new ECOM on Galileo clock corrections

Large beta-angle:
=> Clock signal has small amplitude
   (about ±0.15 ns)

Small beta-angle:
=> Periodic signal caused by mis-modelled orbit
   (ECOM1)
=> Significant reduction of signal amplitude
   from ±0.75 ns to ±0.15 ns (ECOM2)
Impact of new ECOM on QZSS orbits

ECOM2 reduces dependency on Beta angle
Significant SLR offset remains
Impact of new ECOM on QZSS orbits

Large orbit errors occur at $|\beta| < 20^\circ$ (marked grey)

Test of new ECOM version suited for orbit normal attitude mode
Impact of new ECOM on QZSS orbits

ECOM1:

$|\beta| < 20^\circ$: SLR residuals of 2014 are dominated by not correctly considered orbit normal attitude mode

$|\beta| > 20^\circ$: correlation with Beta angle and argument of latitude
Impact of new ECOM on QZSS orbits

**ECOM2:**

- $|\beta| < 20^\circ$: SLR residuals remain large
- $|\beta| > 20^\circ$: systematics in the SLR residuals are reduced
- SLR offset remains
Significant reduction of Beta angle dependency at Yaw attitude thanks to ECOM2

Large errors remain at orbit normal attitude
Impact of new ECOM on QZSS clock corrections

⇒ Significant reduction of Beta angle dependency at Yaw attitude thanks to ECOM2
⇒ Experiments with ECOM version suited for normal attitude mode
Impact of new ECOM on BeiDou orbits

⇒ No significant impact of new ECOM on BeiDou orbits
⇒ Large residuals for $|\beta| < 4^\circ$ (marked grey), because orbit normal attitude not yet correctly considered
Impact of new ECOM on GLONASS orbits

Moderate reduction of SLR residuals at low Beta angles for majority of GLONASS satellites
Impact of new ECOM on GLONASS orbits

ECOM1:

→ Moderate correlation of SLR residuals from 2014 with Beta angle and argument of latitude
Impact of new ECOM on GLONASS orbits

ECOM2:

⇒ Systematics in the SLR residuals are reduced for most GLONASS satellites
Impact of new ECOM on GLONASS - exceptions

But: ECOM2 does not work well for all GLONASS satellites (related to attitude issues?)
Summary

- Galileo, QZSS: significant improvement of orbits and clocks with ECOM2, when in yaw-attitude
- GLONASS: moderate orbit improvement with ECOM2 for the majority of satellites; degradation for some satellites
- ECOM2 is possibly more sensitive to attitude modelling (compared to ECOM1)
- Normal attitude steering mode at low beta-angles causes very large orbit errors if not correctly considered
- Stable satellite clocks (GPS IIF, Galileo PHM, QZSS) are well suited for orbit validation
- Reprocessing of data from 2015 planned
Thank you for your interest!