Orbit modelling in CODE's MGEX solution

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Contents

- Data base and network
- CODE MGEX orbit solution
- CODE MGEX clock solution
- Model changes and implementations
- Validation of satellite orbits and clock corrections
- Summary and outlook
MGEX products availability

Satellite system IDs according to the content of the precise orbit files at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/


Status: July 2016

Astronomical Institute University of Bern
MGEX data monitoring

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

![Graph showing number of stations over years for different satellite systems]

**CODE MGEX orbit solution**

<table>
<thead>
<tr>
<th>GNSS considered:</th>
<th>GPS + GLONASS + Galileo + BeiDou (MEO+IGSO) + QZSS (≈70 SV)</th>
</tr>
</thead>
<tbody>
<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>
</tr>
</tbody>
</table>

## CODE MGEX clock solution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS considered</td>
<td>GPS + GLONASS + Galileo + BeiDou + 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 1710 - today</td>
</tr>
<tr>
<td>Number of stations</td>
<td>130 (GPS), 45 (GLO), 45 (Galileo); 50 (BeiDou); 20 (QZSS)</td>
</tr>
<tr>
<td>Processing scheme</td>
<td>Zero-difference processing</td>
</tr>
<tr>
<td></td>
<td>(observable: code+phase undifferenced)</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>A priori information</td>
<td>Orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known</td>
</tr>
<tr>
<td>Reference frame</td>
<td>IGb08</td>
</tr>
<tr>
<td>IERS conventions</td>
<td>IERS2010</td>
</tr>
<tr>
<td>Product list</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>
Angles and vectors:

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

<table>
<thead>
<tr>
<th>ECOM1 (old):</th>
<th>ECOM2 (new):</th>
</tr>
</thead>
<tbody>
<tr>
<td>D(u) = D₀</td>
<td>D(u) = D₀ + D₂C \cos(2Δu) + D₂S \sin(2Δu) + D₄C \cos(4Δu) + D₄S \sin(4Δu)</td>
</tr>
<tr>
<td>Y(u) = Y₀</td>
<td>Y(u) = Y₀</td>
</tr>
<tr>
<td>B(u) = B₀ + B_C \cos(u) + B_S \sin(u)</td>
<td>B(u) = B₀ + B_C \cos(Δu) + B_S \sin(Δu)</td>
</tr>
</tbody>
</table>
Galileo orbit validation

Significant reduction of dependency on beta-angle, when changing to the ECOM2
Significant reduction of dependency on beta angle
Pronounced signal remains during eclipse season or close-by
Galileo clock validation

Clock corrections of Galileo E11, SVN E101

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 when switching to ECOM2
GPS clock validation

GPS G01, SVN G063

ECOM 1

ECOM 2

RMS of linear clock fit [ns]

Moderate dependency on beta angle
No impact of new ECOM
Different possible reasons for signal (e.g., thermal issues)
QZSS orbit validation

- Yaw-steering: ECOM2 reduces dependency on beta angle
- Significant SLR offset remains
QZSS orbit validation

Normal attitude mode (|β| < 20°; marked grey): large orbit errors

Test of new ECOM versions better suited for orbit normal attitude mode
QZSS orbit validation

Test of new ECOM versions better suited for orbit normal attitude mode
QZSS clock validation

- Yaw-steering: significant reduction of dependency on beta angle thanks to ECOM2
- Orbit normal attitude mode (grey): large errors remain
QZSS clock validation

Experiments with ECOM versions better suited for orbit normal attitude mode
Experiments with ECOM versions better suited for orbit normal attitude mode
BeiDou orbit validation

- Yaw-steering: no significant impact of ECOM version
- Orbit normal attitude mode (|β| < 4°; grey boxes; not correctly considered): large residuals

L. Prange et al.: Orbit modelling in CODE's MGEX solution
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BeiDou orbit validation

Test of new ECOM versions better suited for orbit normal attitude mode
BeiDou orbit validation

Test of new ECOM versions better suited for orbit normal attitude mode
Beidou clock validation

- Yaw-steering: no significant difference between ECOM versions
- Orbit normal attitude mode ($|\beta| < 4^\circ$, marked grey; wrong attitude considered): ECOM2 may even degrade solution
BeiDou clock validation

Experiments with ECOM versions better suited for orbit normal attitude mode
Experiments with ECOM versions better suited for orbit normal attitude mode
GLONASS: inhomogeneous (unknown issues with some SCs)

New systems: significant offsets due to modelling deficiencies (e.g., ANTEX, albedo, antenna thrust)
Orbit validation 2015: 3-day long-arc fit
(Median and IQR; satellites in eclipse or normal mode are not considered)

Galileo and BeiDou: almost comparable to GLONASS
QZSS performs worst
BeiDou MEOs better than IGSOs
Clock validation 2015: median RMS of daily linear fit
(Median and IQR; satellites in eclipse or normal mode are not considered)

Galileo PHM, QZS-1, most GPS IIR and IIF: excellent performance
GPS IIA, some IIF, GLONASS, Galileo RAFS: less good (RMS: 0.5 ns or bigger)
BeiDou: mixed performance
COM to-do list

☑ Implementation of Galileo, QZSS, BeiDou (except GEOs)
☑ Use of RINEX3 files from IGS and EPN - now also with long file names; selection of observation types
☑ Improved SRP model for yaw-steering attitude (ECOM2, Arnold et al., 2015)

☐ Normal attitude and related SRP models for QZSS and BeiDou
☐ Attitude laws for GPS, GLONASS, (Galileo?) eclipses
☐ ANTEX (PCO+PCV) for Galileo, QZSS, BeiDou
☐ Proper handling of observation biases; new BIAS-SINEX version

☐ Ambiguity resolution for Galileo, BeiDou, QZSS; improvement for GLONASS
☐ Albedo radiation modelling for Galileo, QZSS, BeiDou
☐ Antenna thrust for (GLONASS), Galileo, QZSS, BeiDou
Summary

- Still a some way to go until the new GNSS can contribute to CODE’s IGS solutions to the same extent as GPS

- Our current focus: orbit normal attitude (challenges are, e.g., SRP modelling, detection and consideration of mode-transitions, …), correct handling of observation biases, PCO+PCV estimation for new systems

- Reprocessing of data from 2015 or 2016 planned after implementation of further improvements
Thank you for your interest!