Precise Orbit Determination for GNSS satellites

E. Schoenemann¹, T. Springer², F. Dilssner³, C. Garcia Serrano⁴, C. Flohrer², F. Reichel⁵, W. Enderle¹, R. Zandbergen¹

(¹) ESA/ESOC, (²) PosiTim@ESOC, (³) CGI@ESOC, (⁴) GMV@ESOC, (⁵) TU Darmstadt@ESOC

28/10/2015
Outline

• Introduction
• Experimental setup
• Exemplary discussion of results
• Conclusions
**Motivation:**
Generation of best GNSS Precise Orbit Determination solution for all GNSS satellites

**Difficulties:**
- Reference frames (aligned to ITRF with limited accuracy)
- Time scales (aligned to UTC with limited accuracy)
- Different signals/frequencies and combinations (different characteristics, biases)
- Satellite properties and characteristics
- Different orbit characteristics (altitude, inclination, revolution, eccentricities)
Trend in satellite area to mass ratio:

- More signals (requiring and emitting more power)
- Larger solar panels
- Increase of area to mass ratio

More difficult to model:

- Antenna thrust
- Albedo
- Solar radiation pressure (orbit normal mode needs to be handled properly)

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Approx. Area/mass(^1)</th>
<th>Est. -DO (Beta 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS IIA</td>
<td>0.011</td>
<td>~93nm/s(^2)</td>
</tr>
<tr>
<td>GPS IIRM</td>
<td>0.012</td>
<td>~99nm/s(^2)</td>
</tr>
<tr>
<td>GPS IIR</td>
<td>0.012</td>
<td>~102nm/s(^2)</td>
</tr>
<tr>
<td>GPS IIF</td>
<td>0.018</td>
<td>~108nm/s(^2)</td>
</tr>
<tr>
<td>Galileo</td>
<td>0.019</td>
<td>~113nm/s(^2)</td>
</tr>
<tr>
<td>QZSS</td>
<td>0.020</td>
<td>~155nm/s(^2)</td>
</tr>
</tbody>
</table>

\(^1\) Properties from public available data
General introduction
Satellite shapes (relationship between box and wing)

Difficult to model SRP, if attitude is not accurately known.

### GNSS attitude modes

<table>
<thead>
<tr>
<th>GNSS</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>Yaw steering</td>
</tr>
<tr>
<td>GLONASS</td>
<td>Yaw steering</td>
</tr>
<tr>
<td>Galileo</td>
<td>Yaw steering</td>
</tr>
<tr>
<td>BeiDou (MEO)</td>
<td>Yaw steering / orbit normal</td>
</tr>
<tr>
<td>BeiDou (IGSO)</td>
<td>Yaw steering / orbit normal</td>
</tr>
<tr>
<td>BeiDou (GEO)</td>
<td>Orbit normal</td>
</tr>
<tr>
<td>QZSS</td>
<td>Yaw steering / orbit normal</td>
</tr>
</tbody>
</table>

Difficulty to use estimated solar radiation pressure parameters (empirical models such as CODE, ECOM2) in orbit normal mode.

ESOC decided to use analytical a-priori models (in this case box-wing).
Reprocessing

**Approach:**
Reprocessing of multi-GNSS observation data to analyse data and resulting products and to develop, optimise and test different satellite models.

**Time period:**

**Observation data:**
- ESOC + JAXA + MGEX tracking network

**GNSS:**
- All available GNSS (GPS, Glonass, Galileo, BeiDou, QZSS)

**Processing setup:**
- Aligned to ESOC IGS processing, but adjusted for multi-GNSS

**Approach:**
- Iterative process, introducing/improving the models step by step
**First run** (as ESOC IGS run (box-wing for GPS+GLONASS)):
+ All GNSS (Galileo, BeiDou, QZSS)

**Second run** (as previous run):
+ Attitude modelling for BeiDou and QZSS

**Third run** (as previous run):
+ Box-wing model for all constellations (+CODE parameter)

**Forth run** (as previous run):
+ Tuned Box-wing models QZSS and BeiDou (+CODE parameter)
+ ESOC ANTEX (IGS GPS only + ESOC corrections Galileo, BeiDou, QZSS)
Phase centre offsets/variations
Impact of incorrect PCO offset on POD (BeiDou)

RMS of orbit overlap differences (3D)
Ionosphere free linear combination (B1-B2 & B1-B3)

- PCO correction as recommended by MGEX in 2014 (in red)
- ESOC estimated PCO/PCV-based solution (in blue)

Dilßner, F. et al.: Estimation of Satellite Antenna Phase Center Corrections for BeiDou. IGS workshop 2014, June 23-27, Pasadena, USA
Impact of analytical SRP models (box-wing)

QZSS-01 radial orbit difference (box-wing + CODE vs. CODE)

Box-wing model generated empirically.
Impact of analytical SRP models (box-wing)

QZSS-01 SLR 2-way range residuals (Empirical SRP mod.)

Note: Figure shows 2-way SLR residuals!
Impact of analytical SRP models (box-wing)

QZSS-01 SLR 2-way range residuals (Box-wing mod.)

Note: Figure shows 2-way SLR residuals!
Impact of analytical SRP models (box-wing)
QZSS-01 est. CODE D0 parameter (without box-wing mod.)
Impact of analytical SRP models (box-wing)

QZSS-01 est. CODE D0 parameter (box-wing mod.)

- D0 reduced by 97%
- Still not zero, but pattern reduced significantly
- Still problems in transition phase and in orbit normal mode
Impact of analytical SRP models (box-wing)
QZSS-01 difference of est. clock to linear fit (daily)

- Orbit error mapped to clock
- Still problems in transition phase and in orbit normal mode

Impact of analytical SRP models (box-wing)
QZSS-01 epoch wise clock estimates (CODE vs. box-wing)

Difference to linear fit:
CODE 0.64ns  
Box-wing 0.30ns  

Difference to linear fit:
CODE 0.71ns  
Box-wing 0.32ns
Conclusions

• The evolutions in the GNSS space segments introduce challenges for modelling of spacecraft dynamics (new satellites with different characteristics, shapes weights, etc.)

• This presentation highlights the importance of GNSS satellite dynamics modelling for GNSS POD on the example of SRP impact on QZSS

• Additional evaluation of the results for GNSS satellite dynamic models can be obtained by the characterisation of the highly accurate on-board clocks

• Independent evaluation of the GNSS satellite dynamic models can be performed via processing of SLR
We gratefully acknowledge the excellent cooperation with Japan Aerospace Exploration Agency
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