Impact of GPS box-wing models on LEO orbit determination

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Motivation

• Copernicus Sentinel POD does for some products rely on IGS products
  • Changes in the IGS products will require reprocessing
  • Can not wait for IGS so do our own reprocessing
  • Our reprocessing results may be a contribution to the IGS reprocessing

• Need for the GPS orbit and clock reprocessing:
  • ITRF2008 => ITRF2014 switch and related IGS Antex change
  • 24h restriction of IGS products

• GPS orbit and clock reprocessing investigations have been started
  • To validate implementation of ITRF2014 and PSD, and usage of IGS14.atx
  • Study use of a solution interval of 36 h (24h + 6h on each end)
  • Orbit modelling of GPS satellites not yet optimized
    • Tune/validate box-wing model for GPS-IIF satellites

• One issue is that the Sentinel PCV maps are based on the ITRF08 and IGS08.atx
  • Significant changes in IGS14.atx compared to IGS08.atx for GPS satellites
**Copernicus POD Overview**

- **Copernicus POD Service**: Operational service to provide **accurate orbit and attitude products** for the Sentinel-missions
- Software core: **NAPEOS** (Navigation Package for Earth Orbiting Satellites)
- GPS-based orbit determination for the satellites

=> Poster: PS07-04 *The Copernicus POD Service* by Fernández et al.
### Sentinel missions – satellites description

<table>
<thead>
<tr>
<th></th>
<th>Sentinel-1</th>
<th>Sentinel-2</th>
<th>Sentinel-3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Altitude</strong></td>
<td>639 km</td>
<td>786 km</td>
<td>814.5 km</td>
</tr>
<tr>
<td><strong>Inclination</strong></td>
<td>98.18 deg.</td>
<td>98.58 deg.</td>
<td>98.65 deg.</td>
</tr>
<tr>
<td><strong>Period</strong></td>
<td>98.6 minutes</td>
<td>100.6 minutes</td>
<td>100.99 minutes</td>
</tr>
<tr>
<td><strong>Cycle</strong></td>
<td>12 days</td>
<td>10 days</td>
<td>27 days</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>2300 kg</td>
<td>1140 kg</td>
<td>1250 kg</td>
</tr>
<tr>
<td><strong>GPS</strong></td>
<td>2 GPS receivers</td>
<td>2 GPS receivers</td>
<td>2 GPS receivers</td>
</tr>
<tr>
<td><strong>LRR</strong></td>
<td>None</td>
<td>None</td>
<td>1 LRR</td>
</tr>
<tr>
<td><strong>DORIS</strong></td>
<td>None</td>
<td>None</td>
<td>1 DORIS</td>
</tr>
<tr>
<td><strong>Attitude</strong></td>
<td>Zero-Doppler + roll steering</td>
<td>Yaw steering</td>
<td>Yaw steering</td>
</tr>
<tr>
<td><strong>Instruments</strong></td>
<td>C-Band SAR</td>
<td>Multi-Spectral Instrument</td>
<td>Radar Altimeter, OLCI, Microwave Radiometer</td>
</tr>
<tr>
<td><strong>Launch date</strong></td>
<td>3rd April, 2014 (S1A)</td>
<td>23rd June, 2015 (S2A)</td>
<td>16th February, 2016 (S3A)</td>
</tr>
<tr>
<td></td>
<td>22nd April, 2016 (S1B)</td>
<td>7th March, 2017 (S2B)</td>
<td>Expected spring 2018 (S3B)</td>
</tr>
</tbody>
</table>
Sentinel Requirements

<table>
<thead>
<tr>
<th>Mission</th>
<th>Category</th>
<th>Orbit Accuracy (RMS)</th>
<th>Latency</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>NRT</td>
<td>10 cm (2D)</td>
<td>180 min</td>
<td>2 orbits</td>
</tr>
<tr>
<td></td>
<td>NTC</td>
<td>5 cm (3D)</td>
<td>20 days</td>
<td>26 h</td>
</tr>
<tr>
<td>S-2</td>
<td>NRT (pred.)</td>
<td>3 m (2D)</td>
<td>90 min before ANX</td>
<td>2 orbits</td>
</tr>
<tr>
<td></td>
<td>NRT</td>
<td>1 m (3D)</td>
<td>30 min</td>
<td>Received PVT span + 2 orbits backwards</td>
</tr>
<tr>
<td>S-3</td>
<td>NRT</td>
<td>10 cm radial (target of 8 cm)</td>
<td>30 min</td>
<td>Received PVT span + 5 OSV before and after</td>
</tr>
<tr>
<td></td>
<td>STC</td>
<td>4 cm radial (target of 3 cm)</td>
<td>1.5 days</td>
<td>26 h</td>
</tr>
<tr>
<td></td>
<td>NTC</td>
<td>3 cm radial (target of 2 cm)</td>
<td>25 days</td>
<td>26 h</td>
</tr>
</tbody>
</table>

- Due to a coverage > 24h, three consecutive days of the IGS Finals have to be concatenated
  - Orbit and clock discontinuities at midnight
  - Switch to ITRF2014 on 29 Jan 2017 => inconsistent time series => Reprocessing necessary

The non time-critical (NTC) orbit products make use of the IGS Final orbit and 30 sec clock products
GPS Reprocessing Investigations

- Generated 4 different solutions using first 130 days of 2017
  - sol1: no a priori model
  - sol5: IGS box-wing model
  - sol4: Tuned box-wing model for the GPS-IIF satellites, IGS values for GPS-IIR
  - sol3: Tuned box-wing model with reradiation
    - Based on GPS orbit overlap statistics sol4 “the best”

- Differences between the solutions only at the 10-20 mm level sigma, largest in radial component
  - Relative differences (sol1 vs sol5, sol5 vs sol4, sol4 vs sol3):

<table>
<thead>
<tr>
<th></th>
<th>IGS BW</th>
<th>Tuned</th>
<th>Rerad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial</td>
<td>19</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Along</td>
<td>10</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Cross</td>
<td>11</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

- But very systematic (see plots on next slides) and significant mean in cross-track
Cross-track Orbit Differences
Radial Orbit Differences (IIR sats only)
Radial Orbit Differences (IIF sats only)
Tuned Radial Orbit Differences (IIF only)
Resulting LEO Orbit Differences

- Differences between the solutions only at the few mm level RMS, largest in cross-track component
  - Solution 1 vs 5 – 5 vs 4 – 4 vs 3
    - Cross-track non-zero mean: -7 – -2
    - Small differences but very systematic (see plots on next slides)
  - Solution 1 vs 5: Effect of box-wing
    - Radial noise only
    - Cross-track clear signal with non-zero mean
    - Along-track and Earth-Fixed Z Interesting patterns as function of longitude and latitude
      - See following plots
Cross-track Orbit Differences

[Graph showing cross-track orbit differences over years from 2017 to 2017.35]
Along-track Orbit Differences
Earth-Fixed Z-direction orbit differences
Resulting Orbit Differences

• Solution 5 vs 4: Effect of tuning IIF satellite box-wing
  • Radial noise only
  • Cross-track clear signal with non-zero mean
  • Along-track interesting patterns as function of longitude and latitude
    • See following plots
Cross-track Orbit Differences
Along-track Orbit Differences
Conclusions

• Sentinel mission depends on IGS final products
  • But in return is able to contribute to IGS reprocessing efforts!

• Significant modeling issues persist in the IGS GPS orbit products
  • These have systematic influences on the LEO solutions
  • This may have an impact on the scientific results obtained with these LEO satellites
  • More and better information regarding the satellites needed!

• Day boundary effect of IGS 24 hour solutions
  • Not really noticeable
  • Nevertheless Sentinel reprocessing considers to deliver 36h solutions
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