Solar Radiation Pressure Model Performance Test Using GNSS Precise Ephemeris

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1. Summary

The solar radiation pressure (SRP) is one of many forces acting on orbiting satellites. It has been the most difficult force to model for satellites at altitude higher than Low Earth Orbit (LEO) and hence the biggest error source in GNSS orbit determination. Most of GNSS satellites are orbiting at Medium Earth Orbit (MEO) with exception of Beidou, which has satellites at Inclined Geosynchronous Orbit (IGSO) and Geostationary Orbit (GEO) as well as MEO.

NGS uses 5 parameter Reduced Empirical CODE Orbit Model (ECOM-Re), to model SRP acting on GPS satellites. However, several researchers have shown its deficiency in modeling SRP acting on other GNSS satellites, especially Galileo and Beidou satellites. To address this deficiency in the traditional ECOM model, a new model, called Extended ECOM (ECOM-Ex), has been proposed in [Arnold, 2015]. The Extended ECOM introduces more parameters to represent SRP acting on GNSS satellite in the satellite-Sun direction.

We have tested the performance of the NGS implementation of the Extended ECOM model on GNSS orbit determination by making use of the approach called orbit fit analysis. In orbit fit analysis, the performance of force models is evaluated by comparing the propagated ephemeris to the high quality precise ephemeris products. In this study, we used GNSS precise ephemeris products from IGS MGEX working group.

Analysis results show that NGS propagated orbits using ECOM-Ex agree to the MGEX precise ephemeris products.

2. Data Used

Precise ephemeris products from IGS MGEX (Multi-GNSS Experiment) working group [Montenbruck, 2017] for days from 2017-09-01 to 2017-09-30 were used for this study. Five analysis centers provided products and their products contain ephemeris for the following GNSS satellites (GZSS not considered in this study):

- COD (CODE): GPS, GLONASS, Galileo, Beidou (except GEO)
- GBM (CODE/GPS/GRACE/GAL/BEIDOU): GPS, GLONASS, Galileo, Beidou
- GRM (CODE/GRACE/GRM): GPS, GLONASS, Galileo
- TUM (TUM): Galileo
- WUM (Wuhan Univ): GPS, GLONASS, Galileo, Beidou

3. Ephemeris Comparison Results

To show the quality of MGEX precise ephemeris products, differences in the ephemeris have been computed and their mean values of daily RMS are presented below in cm. Two Galileo-2 satellites in elliptical orbits are denoted as GAL-2E.

<table>
<thead>
<tr>
<th>Analysis Center</th>
<th>GPS-IIR</th>
<th>GPS-IOF</th>
<th>BDS-2G</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>2.6 cm</td>
<td>3.2 cm</td>
<td>3.0 cm</td>
</tr>
<tr>
<td>GBM</td>
<td>3.2 cm</td>
<td>3.2 cm</td>
<td>3.2 cm</td>
</tr>
<tr>
<td>GRM</td>
<td>2.7 cm</td>
<td>2.7 cm</td>
<td>2.7 cm</td>
</tr>
<tr>
<td>TUM</td>
<td>5.5 cm</td>
<td>5.5 cm</td>
<td>5.5 cm</td>
</tr>
<tr>
<td>WUM</td>
<td>5.5 cm</td>
<td>5.5 cm</td>
<td>5.5 cm</td>
</tr>
</tbody>
</table>

4. Solar Radiation Pressure Model

The ECOM (Empirical CODE Orbit Model) decomposes the perturbing accelerations into three orthogonal vectors, $\mathbf{e}$ unit vector points along the satellites' solar panel axes, $\mathbf{u}$ unit vector vector points along the satellites' solar panel axes, $\mathbf{v}$ unit vector completes the orthogonal system. Now, the perturbing acceleration can be represented using these unit vectors:

$$\mathbf{a} = a_0 + D(u) \cdot \mathbf{e} + Y(u) \cdot \mathbf{v} + B(u) \cdot \mathbf{v}$$

where $u$ is the satellite's argument of latitude and $D(u)$, $Y(u)$, and $B(u)$ are defined as:

$$D(u) = D_0 + D_1 \cdot \cos(u) + D_2 \cdot \sin(u) + D_3 \cdot \cos(2u) + D_4 \cdot \sin(2u) + D_5 \cdot \cos(3u) + D_6 \cdot \sin(3u) + \cdots$$

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$$\mathbf{a} = a_0 + D(u) \cdot \mathbf{e} + Y(u) \cdot \mathbf{v} + B(u) \cdot \mathbf{v}$$

5. Orbit Fit Analysis Results

Orbit fit analysis is a method to assess the quality of satellite dynamic models by comparing the propagated orbits using a set of force models against a high quality precise ephemeris. In this study, two propagated orbits, one using ECOM model and the other using ECOM-Ex model as well as other force models being used within NGS, are compared to MGEX precise ephemeris products described in the Section 2. The plotted values are mean values of daily RMS values between NGS propagated orbits and precise ephemeris products from the denoted analysis centers.

6. References

1. Montenbruck, O., et al., The Multi-GNSS Experiment (MGEX) of the International GNSS Service (IGS) - Achievements, prospects and challenges, Advances in space research 59 (2017) 1697-1697