Troposphere delay modeling in SLR solutions

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Motivation

Satellite Laser Ranging (SLR) is the only space geodetic technique in which troposphere models do not consider horizontal asymmetry of the atmosphere above the station. Due to low number of observations, poor geometry, and weather dependency the estimation of horizontal gradients from laser observation leads to a deterioration of weekly solutions. This work presents comparison of different approaches of troposphere delay modeling which are currently available.

PMF & VMF3o products

Differences between PMFs, VMF3o and FCULa mapping functions projected onto elevation angles 10, 15 and 20 degrees are shown in figure 1. We observe characteristic differences between FCULa and PMFs as well as VMF3o for stations located in the northern and southern hemisphere which reach more than 5 mm for 10 degrees elevation angles. For stations located in the northern hemisphere we also observe that the differences between solutions VMF3o and PMF could reach 1 mm.

Function Commonly Used in Laser ranging (FCULa, Mendes et al., 2004):

\[
m(\varepsilon) = \frac{1}{\sin \varepsilon} + \frac{a_1}{\sin 2\varepsilon} + \frac{a_2}{\sin 3\varepsilon} + \frac{a_3}{\sin 4\varepsilon}
\]

\[
d_{\text{VMF3o}} = d_{\text{FCULa}} - m(\varepsilon)
\]

VMJ Mapping Function 3 optical (VMF3o Boisits et al., 2018):

\[
m(\varepsilon)_{\text{VMF3o}} = \frac{1 - d_4}{\sin \varepsilon} + \frac{b_1}{\sin 2\varepsilon} + \frac{b_2}{\sin 3\varepsilon} + \frac{b_3}{\sin 4\varepsilon} - \frac{b_4}{\sin 5\varepsilon}
\]

\[
d_{\text{VMF3o}} = d_{\text{FCULa}} - m(\varepsilon)_{\text{VMF3o}}
\]

FCULa + simple model of gradients derived from numerical weather models (NWM):

\[
f(\varepsilon) = a_0 + a_1 \sin \left(\frac{\varepsilon}{\varepsilon_0}\right) + a_2 \cos \left(\frac{\varepsilon}{\varepsilon_0}\right)
\]

Observation residuals

In analysed period observations below 27 degrees constitute on average 10% of total amount of observations. For station San Juan this value reaches over 32%. For the majority of the stations, observations provided at low elevation angle constitute above 15% of all observations to LAGEOS-1 and LAGEOS-2.

In this study, we compared three solutions that consider azimuthal asymmetry of the atmosphere above the stations with respect to currently used troposphere delay model. We observe that mapping functions projected at an elevation angle of 10 degrees show a significant difference.

Conclusions

- In this study, we compared three solutions that consider azimuthal asymmetry of the atmosphere above the stations with respect to currently used troposphere delay model. We observe that mapping functions projected at an elevation angle of 10 degrees show a significant difference.

- The differences of median values of observation residuals show an improvement at the level of 30% for low elevation angles for the station Grasse. These observations constitute 12% of the total amount of observations at the site.

- All models improved the consistency between pole coordinates derived from SLR and IERS-14-C04 combined series. Due to this fact, we recommend models that take account horizontal gradients.

Fig. 2. Horizontal gradients derived from PMF (red-colored) and VMF3o (blue-colored). The green-dashed line describes the hydrostatic part of VMF3o.

Fig. 3. Time series of troposphere delay horizontal gradients (PMF–01), with semi annual and annual signal (black line).

Fig. 4. Differences of median values of residuals for observations provided below 27 degree of elevation angle. Analyzed period 2005/07–2010/05.

The negative values correspond to a reduction of mean biases (median residuals) for solutions based on PMF, VMF3o or FCULa + model with respect to the standard aproach. Nevertheless for some stations we observe a significant deterioration of observation residuals (Greenbelt, Monument Peak and Wetzell).

Fig. 5. Differences of median value of residuals for observations provided below 27 degree of elevation angle. Analyzed period 2007/03–2010/05.

Fig. 6. Percentage of observations below 27 degrees of elevation angle. Analyzed period 2005/07–2010/05.

Table 1 Differences between estimated Earth rotation parameters and the IGS-C04-14

<table>
<thead>
<tr>
<th>Parameter</th>
<th>X-POLE [μm]</th>
<th>Y-POLE [μm]</th>
<th>LOO [μm/day]</th>
<th>Number of epochs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>12</td>
<td>7.5</td>
<td>8.7</td>
<td>7.7 ± 7.5</td>
</tr>
<tr>
<td>PMF-G3</td>
<td>7.2</td>
<td>14.7</td>
<td>7.6</td>
<td>7.7 ± 7.5</td>
</tr>
<tr>
<td>VMF3o</td>
<td>7.5</td>
<td>12.7</td>
<td>7.6</td>
<td>7.6 ± 7.5</td>
</tr>
<tr>
<td>FCULa</td>
<td>7.7</td>
<td>13.5</td>
<td>7.6</td>
<td>7.6 ± 7.5</td>
</tr>
</tbody>
</table>

Tab. 1 Differences between estimated Earth rotation parameters and the IGS-C04-14

Fig. 6 show differences between pole coordinates including PMFs, VMF3o models and the standard FCULa approach. The solutions with horizontal gradients are characterized by offsets at the range from 20 μas to 10 μas. We do not observe significant differences for LOO.

The consistency of the pole coordinates between SLR solutions with horizontal gradients and the IERS-14-C04 series is improved (for details see table below).

Earth rotation parameters

Geocenter coordinates