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Extended troposphere delay model dedicated to Satellite Laser Ranging

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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 conditions the estimation of horizontal gradients from laser observation provide to deterioration of weekly solutions. To model this effect in sufficient way we propose to use the ray-traced mapping function coefficients and the horizontal gradients dedicated for laser observations.

PMF products

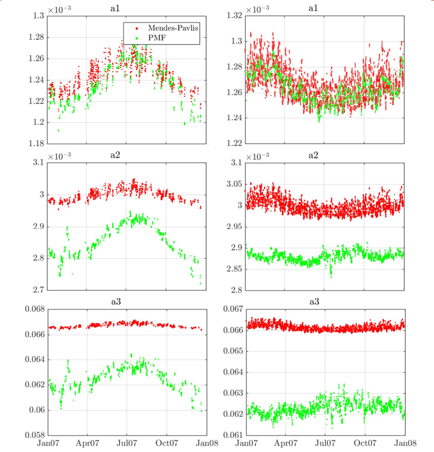

Fig. 1. Comparison of mapping function coefficients, a1, a2, a3 derived from FCULa and from PMF mapping functions. For year 2007. For station GRAZ (left) and Yarragadee (7090).

The time series of mapping function coefficients derived from Mendes - Pavlis model (red) and NWM solution (Green) are shown in figure 1. The a1 coefficient derived from NWM is smoothed in comparison to a1 MP coefficient. Moreover, the coefficients a2 and a3 show characteristic offset at the level of 3% to 6%. The impact of the differences between coefficients from PMF and Mendes-Pavlis models is transformed to differences of the slant total delay estimation at the level of 5 mm for the elevation angle equal to 10 degrees (fig 2).

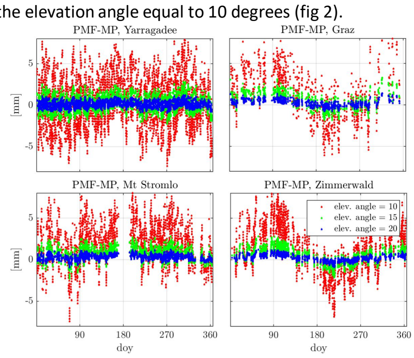

Fig 2.Impact of differences between PMF and Mendes-Pavlis mapping function.

Methodology

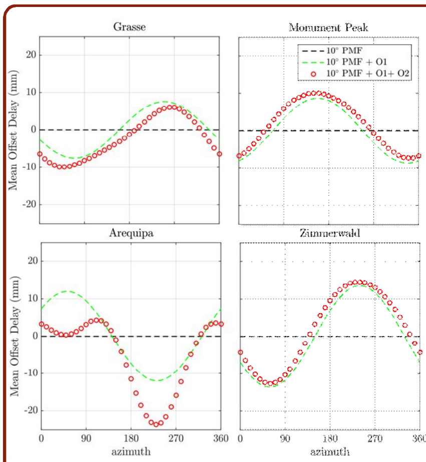

Fig 3. Impact of the first (green dashed line) and second degree (red doted line) of PMF Horizontal gradients for 10⁰ elevation angle, at the 28 January 2007. The second degree of horizontal gradients improves the horizontal asymetricity above SLR station. The differences between linear gradients can reach even 11 mm.

Tab 1. Characteristics of PMF solution.

Parameter	description
Ray-tracing software	GFZ direct numerical simulation (DNS) tool
Ray tracing method	2D
Data source (NWM)	ERA-Interim
NWM horizontal resolution	0.5° x 0.5°
NWM vertical resolution	60 levels
Elevation granularity	3,5,7,10,15,20,30,50,70,90
Horizontal resolution	30 degrees

Horizontal gradients and mapping function coefficients are derived using ray-trace algorithm developed by Zus et al., (2014). The state vector of PMF consists of the mapping function coefficients a_1, a_2, a_3 and the horizontal gradients of the first (G_N, G_E) and the second order (G_{NN}, G_{NE}, and G_{EE}). PMF is estimated for all SLR stations with time resolution equal to 6 hours. For each station, 120 slants factors as well as mapping factors were computed (Table 1). In the second step the zenith delays are applied to obtain the azimuth-dependent and azimuth independent slant delays. Finally, the mapping function coefficients and G_N, G_E, G_{NN}, G_{NE}, and G_{EE} are estimated using the least-square fitting. We present three solutions: PMF – which is based only on the new mapping function coefficients, PMF+O1 – including the new mapping function coefficient and linear horizontal gradients, and PMF + O1 + O2 which considers the PMF mapping function coefficients and linear and non linear horizontal gradients. The solutions mentioned above are compared with the standard Mendes – Pavlis (MP) model using observations to Lageos 1 and Lageos 2.

Residuals statistics

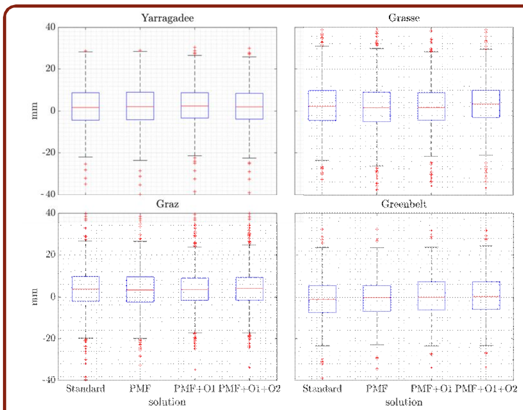

Fig 4. Box plots of residuals for low elevation angle below 15 degrees.

We can observe the improvements of interquartile distance of the SLR observation residuals to Lageos - 1/2 solutions with horizontal gradients at the level of **1.1**, **1.5** and **1.7** for stations Graz, Yarragadee and Grasse.

Differences of coordinates repeatability

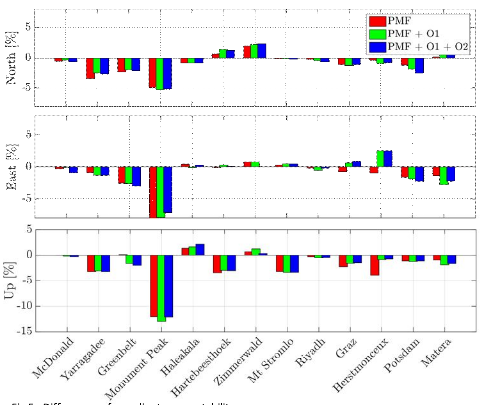

Fig 5. Differences of coordinates repeatability.

The negative values correspond to the improvement for solutions based on PMF mapping functions and horizontal gradients. The largest improvement due to using PMF model is for station Monument Peak.

Earth rotation parameters

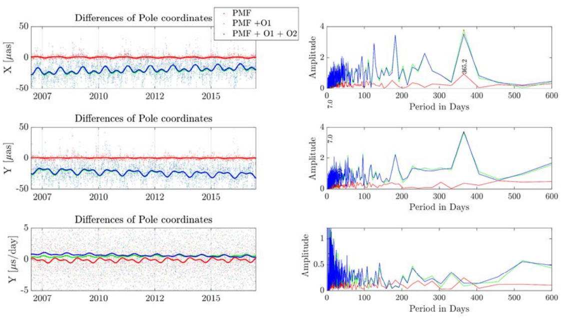

Fig 6. Differences of Earth rotation parameters, between the standard solution and solutions with PMF.

Figure 7 presents the differences between pole coordinates including PMFs models and Mendes-Pavlis approach. The solutions with horizontal gradients characterize offsets at the level of 20 µas. The consistency of the pole coordinates between SLR solutions with horizontal gradients and the IERS-14-C04 series is improved and reduced from **22** µas and **38** µas to **2** µas and **14** µas for X and Y pole coordinates, respectively.

The differences of the geocenter coordinates are shown in figure 8. The mean shift in the solution PMF+O1 and O2 is up to 0.04, -0.13, -0.04 mm for the X, Y, and Z components which suggests that the currently used origin of the ITRF realization may be affected by neglection of horizontal gradients in the SLR solutions.

Geocenter coordinates

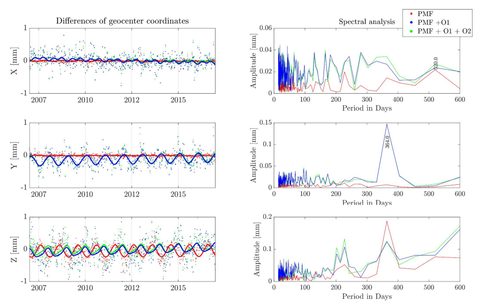

Fig 7. Differences of geocenter coordinates between standard solution and PMF solutions.

Conclusions

We propose to extend the currently used troposphere delay model by linear horizontal gradients derived from NWM. The mapping functions coefficients give the same results as the mapping function coefficient derived from FCULzd proposed by Mendes and Pavlis 2002. The horizontal gradients improve the consistency between SLR and other space geodetic techniques. The nonlinear horizontal gradients bring measurable results in dynamic weather conditions however the SLR stations provide observations only in good cloudless conditions so the second degree of horizontal gradients could be neglected to simplify the troposphere model.

Acknowledgments

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