Impact of atmospheric pressure loading on SLR-derived station coordinates using range measurements to multi-GNSS satellites

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The current requirements imposed by the Global Geodetic Observing System (GGOS) demand an integrated, stable in time, and accurate at the level of 1 mm, reference frame. Satellite Laser Ranging (SLR) contributes to GGOS to a great extent i.e., provides the origin of the International Terrestrial Reference Frame, the global scale, satellite orbits, gravity field parameters, and station coordinates. The Multi-GNSS Experiment was initiated, because of the emerging of new navigation system i.e., Galileo, BeiDou, QZSS, and NavIC and modernized GPS and GLONASS. SLR measurements are performed to new GNSS, because all new active multi-GNSS satellites are equipped with Laser Rendezvous Reflectors Arrays. The omission of atmospheric pressure loading (APL) models during SLR data processing may lead to inconsistency in the multi-GNSS (GNSS) and optical (SLR) solutions. SLR observations can be performed only during cloudless conditions, which coincide with high values of air pressure. High atmospheric pressure deforms the Earth’s crust. The systematic shift of the stations heights is called the Blue-sky effect. The goal of this study is to determine the value of the Blue-sky effect for particular SLR stations using range measurements to multi-GNSS satellites (1 GPS, 31 GLONASS, 18 Galileo, 4 BeiDou, 1 MEO, 3 IGS0, and 1 QZSS) and evaluate the influence of the omission of APL on SLR-derived parameters i.e., range biases, multi-GNSS orbits, station coordinates, geocenter coordinates and Earth Rotation Parameters (ERP). We thus assess how the omission of APL limits the consistency level between SLR and GNSS solutions for the GGOS applications.

**RESULTS**

Atmospheric pressure loading (APL) deforms the Earth’s crust mainly in the vertical direction. The impact of APL is thus visible especially in the height component of SLR stations (Fig. 1). A clear seasonal signal can be visible for all stations. The amplitude of the annual signal reaches up to 6.8 and 5.2 mm for Alay and Changchun, respectively. The semi-annual signal is visible as well, but with much smaller amplitudes i.e., 1.0 and 0.9 mm for Komomolok and Braslavia, respectively (see Fig. 1). For several stations horizontal displacements can be seen as well. Although horizontal signals are not as intensive as the vertical with the amplitude of the level of 0.7 and 0.6 mm in the North direction for Alay and East direction of Changchun, respectively, they are still of a significant value (see Fig. 2).

Station coordinates are estimated in solutions “1” and “2”. We calculate the differences between respective solution with and without APL corrections. Although both annual and semi-annual signal are statistically significant in solution “1”, variations of coordinates in solution “2” are more prominent. Signals from solution “2” are characterized by an amplitude at the level of 0.4, 1.2 and 1.9 mm for X, Y and Z, respectively (see Fig. 3). Significant offsets occur for the Z coordinate and equal 0.4 and 0.2 mm for solution “1” and “2”, respectively.

**EARTH ROTATION PARAMETERS**

Earth rotation parameters i.e., X and Y pole coordinates and Lengths-of-Day (LoD) parameters are estimated in solutions “1” and “2”. The results are more noisy in solution “1”, when GNSS orbits are additionally estimated. However, in the case of ERPs differences in solutions “1” and “2” provide higher variation of ERPs with the amplitude at the level of 8.1 and 21.6 μas for X and Y coordinates, respectively, whereas differences in LoD parameters are not significant in both solutions (see Fig. 4).

**MULTI-GNSS ORBITS**

For both orbit solutions we perform a Helmert transformation as in the case of station coordinates. The largest amplitude of the annual signal characterizes the Z component and equals 2.7 μm. The annual signal for the scale is much smaller than in the case of station coordinates (see Fig. 5).

**SUMMARY**

- APL corrections should be applied at the observation level, and not just in the post-processing (at the solution level) because APL affects also other estimated parameters i.e., orbit parameters, geocenter coordinates and ERPs.
- The Blue-sky effect calculated using range measurements to multi-GNSS constellations provides reliable information about the Earth’s crust deformation. In contrary to LAGEOS whose passes are relatively short, GNSS satellites can be tracked for the whole time, therefore the GNSS measurements are limited only by weather conditions.

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**Methodology**

We calculate Helmert transformation for solutions with and without APL corrections. Both translation and scale indicate a significant annual and semi-annual sub-millimeter effects with an amplitude of annual signal at the level of 0.3 and 0.4 mm for Y and Z, respectively. An amplitude of annual signal for the scale equals 0.5 mm (Fig. 4). A systematic effect can be seen in differences in station coordinates of an amplitude at the level of 3.2, 2.9 and 2.2 mm for 1879, 7237 and 7990, respectively (see Fig. 5). Moreover, an offset can be observed, but not of the same value as a priori, thus APL affects not only station coordinates but also different SLR-derived parameters.

**Station Coordinates**

**Earth Rotation Parameters**

**Multi-GNSS Orbits**

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**Figure Captions**

- Fig. 1: Variations of APL for the Up component of SLR stations. An empirical model was fitted in order to detect seasonal changes.
- Fig. 3: Amplitude (in mm, left) and phase (in degrees, middle) of an annual signal of APL acting on the Up component of SLR stations. Blue-sky effect represented in mm (right). Size of circles denotes the number of SLR observations gathered in the analysis period (2016-2019).
- Fig. 4: Transition parameters and scale provided from Helmert transformation solution with and without APL correction applied solution “2” for the whole SLR network.
- Fig. 5: Differences in correction of Up coordinate for particular SLR stations.
- Fig. 6: Differences in geocenter provided by the solution “2” and without APL correction described into X, Y, Z coordinates. Annual and semi-annual signal fitted into all coordinates.
- Fig. 7: Estimated range biases with (solid) and without (dashed) APL corrections for particular station for the whole multi-GNSS constellation: B - Bistri, G - Galileo, C - Comsol, and F - Galileo. In the first column we put relative single station stations, in second column we put relative station and in the third one absolute multi station stations.