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

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INTRODUCTION

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 Retroreflector Arrays.

The omission of atmospheric pressure loading (APL) models during SLR data processing may lead to inconsistency between microwave (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 IGSO, 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.

ATMOSPHERIC PRESSURE LOADING

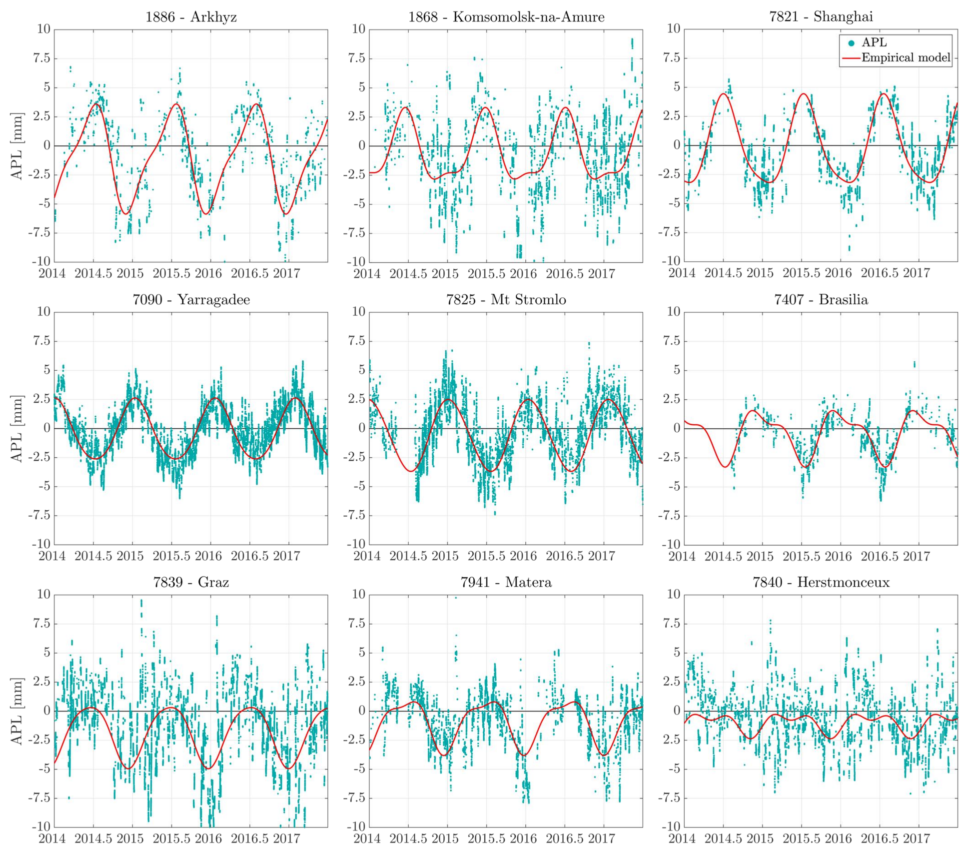


Fig. 1 Variations of APL for the Up component of SLR stations. An empirical model was fitted in order to detect seasonal changes.

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 Altay 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 Komsomolsk and Brasilia, 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 at the level of 0.7 and 0.6 mm in the North direction for Altay and East direction of Changchun, respectively, they are still of a significant value (see fig 2).

Costal stations, such as Herstmonceux and Yarragadee, are less vulnerable for APL variations due to the presence of the ocean which reduces the influence of APL. The farther from ocean, the higher APL influence (see fig 3 – left), with the maximum amplitude of annual signal reaching up to 7.4 mm for Baikonur and 6.8 mm for Altay (see fig 3 – left).

The annual signal of APL for European and central Asian stations is in out-of-phase with respect to all stations located in the southern hemisphere (fig 3 – middle).

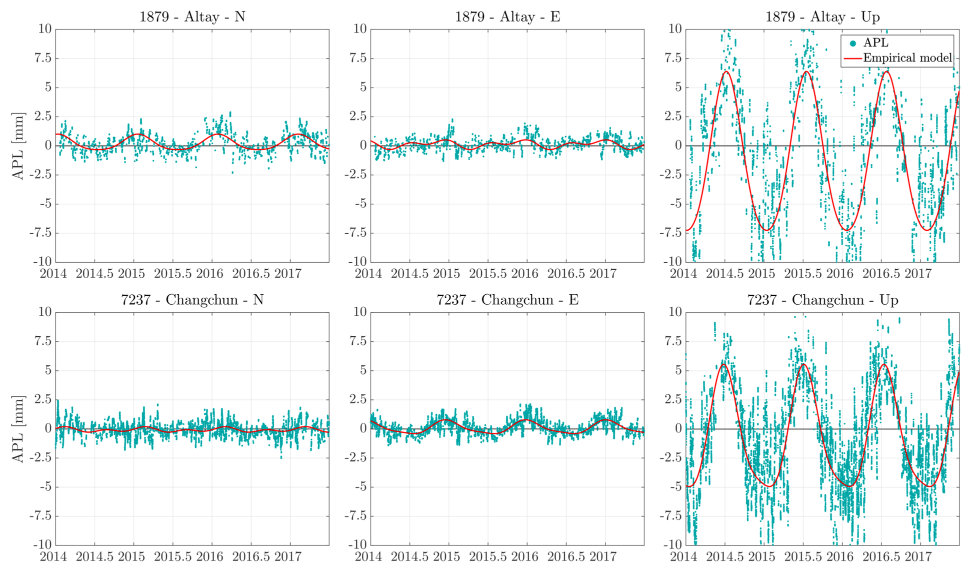


Fig. 2 Impact of atmospheric pressure loading on North, East (horizontal) and Up (vertical) component of SLR stations.

THE BLUE-SKY EFFECT

The largest value of the Blue-sky effect is for the central part of Asia i.e., **2.3 and 2.2 mm for Svetloe and Zelenchukskaya**, respectively and in Europe i.e., **2.5 and 2.1 mm for Wettzell and Potsdam**, respectively. The significance of the Blue-sky effect value depends on the number of SLR observations (fig 3 – right).

Code	Location	No of NPs	Blue-Sky effect	mean APL
1888	Svetloe	2809	2,3	4,7
1889	Zelenchukskya	3268	2,2	3,8
7841	Potsdam	6870	2,1	3,9
1887	Baikonur	5947	2,0	5,5
1879	Altay	16203	1,9	6,2
7839	Graz	46088	1,8	3,6
7308	Koganei	267	1,8	1,0
7237	Changchun	42925	1,7	4,5
1824	Golosiiv	18	1,6	2,6
8834	Wettzell	23755	1,4	3,4
1884	Riga	56	1,4	3,1
1868	Komsomolsk	12559	1,3	3,6
1891	Irkutsk	2727	1,3	4,4
7501	Hartebeesthoek	4991	1,3	1,8
1886	Arkhyz	7695	1,2	3,8
7810	Zimmerwald	41274	1,1	2,4
7249	Beijing	7800	1,1	4,4
7840	Herstmonceux	28271	1,0	2,5
7407	Brasilia	8069	1,0	2,0
1873	Simeiz	1282	1,0	2,9
1890	Badary	1988	0,9	4,5
7821	Shanghai	22439	0,9	2,8
1874	Mendeleevo 2	1550	0,9	4,7
7105	Greenbelt	10808	0,7	2,7
7941	Matera	24111	0,7	2,4
7825	Mt Stromlo	32244	0,5	2,7
7845	Grasse	3334	0,4	2,3
7838	Simosato	895	0,4	1,4
7110	Monument Peak	7329	0,3	1,3
7090	Yarragadee	66922	0,3	2,2
7080	McDonald	1134	0,1	2,2
1893	Katzively	464	0,0	2,5
7124	Tahiti	4919	0,0	0,9
7406	San Juan	2813	-0,5	1,9

Table 1 Blue-sky effect value (in mm) for particular SLR stations and the mean value of APL (in mm) for the Up component of SLR stations ordered by the size of the Blue-sky effect.

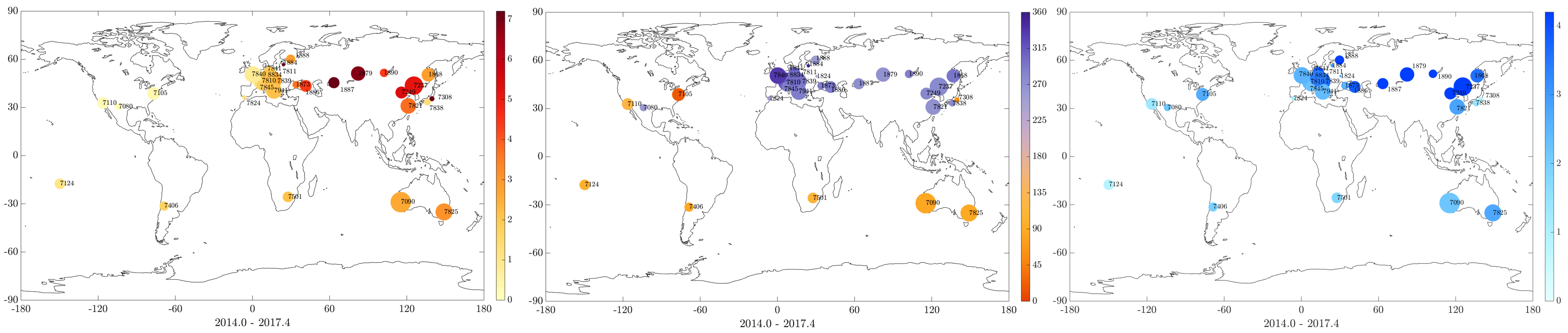
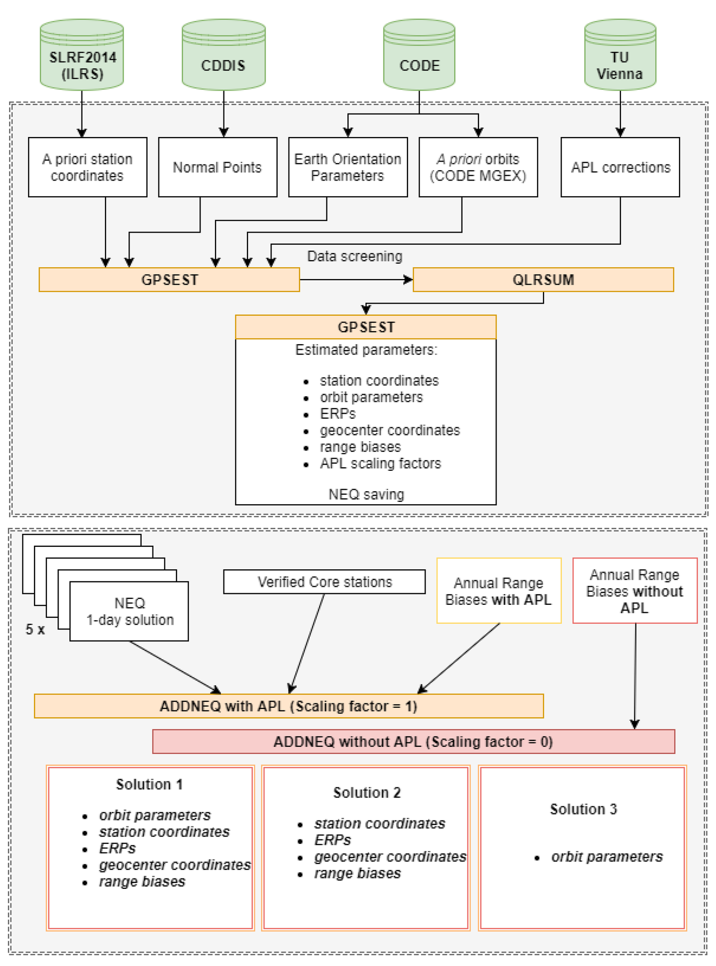


Fig. 3 Amplitude (in mm, left) and phase (in degrees, middle) of an annual signal of APL acting on the Up component of SLR stations. Blue-sky effect represented in mm (right). Size of circles denotes the number of SLR observation gathered in the analysis period (2014.0 – 2017.4)

METHODOLOGY



RESULTS

STATION COORDINATES

We calculate Helmert transformation for solutions with and without APL corrections. Both translation and scale indicate a significant annual and semi-annual sub-milimeter 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** (see fig 4).

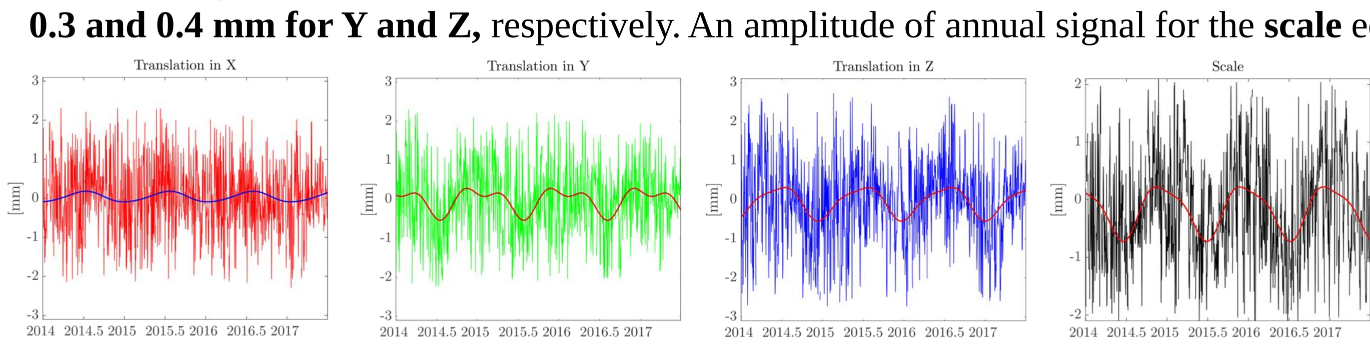


Fig 4 Translation parameters and scale provided from Helmert transformation between solution with and without APL correction applied. Solution „1" – for the whole SLR network.

A systematic effects can be seen in differences in station corrections of an **amplitude** at the level of: **3.2, 2.9 and 2.2 mm for 1879, 7237 and 7090,** 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.

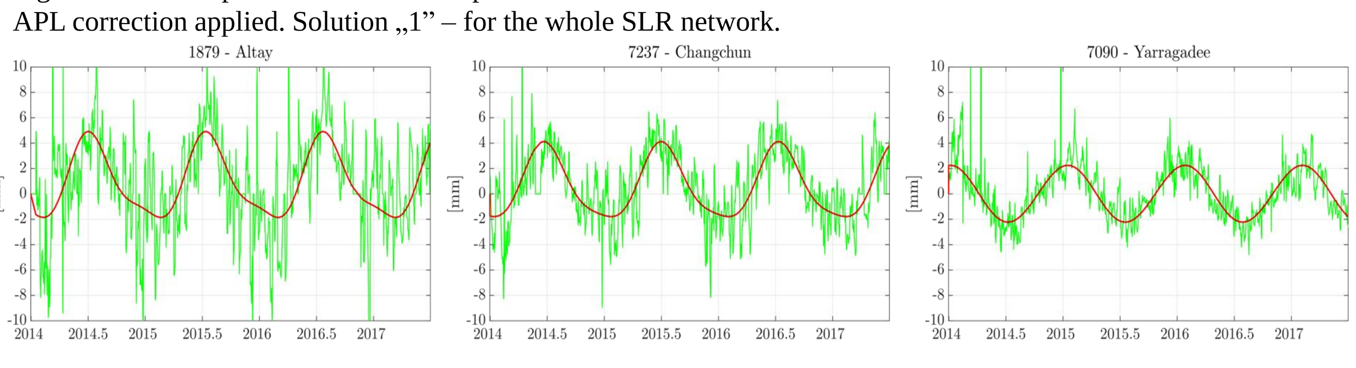


Fig 5 Differences in correction of Up coordinates for particular SLR stations

EARTH ROTATION PARAMETERS

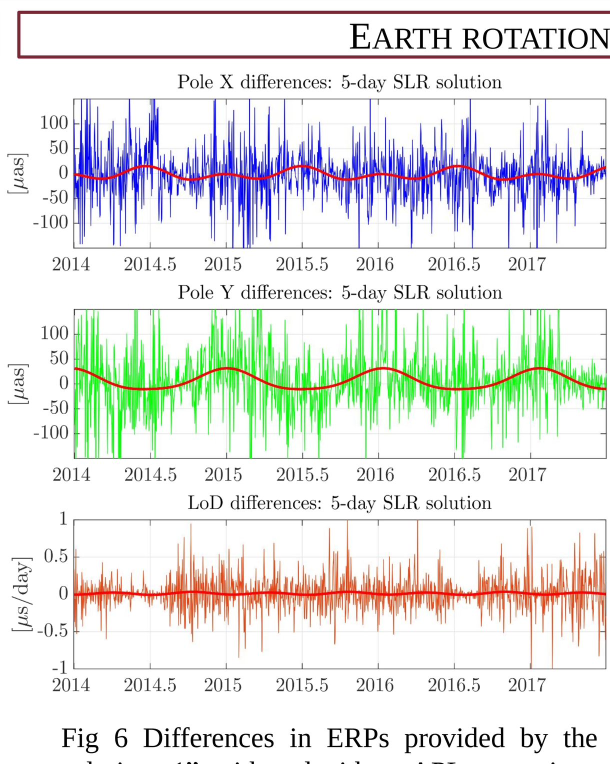
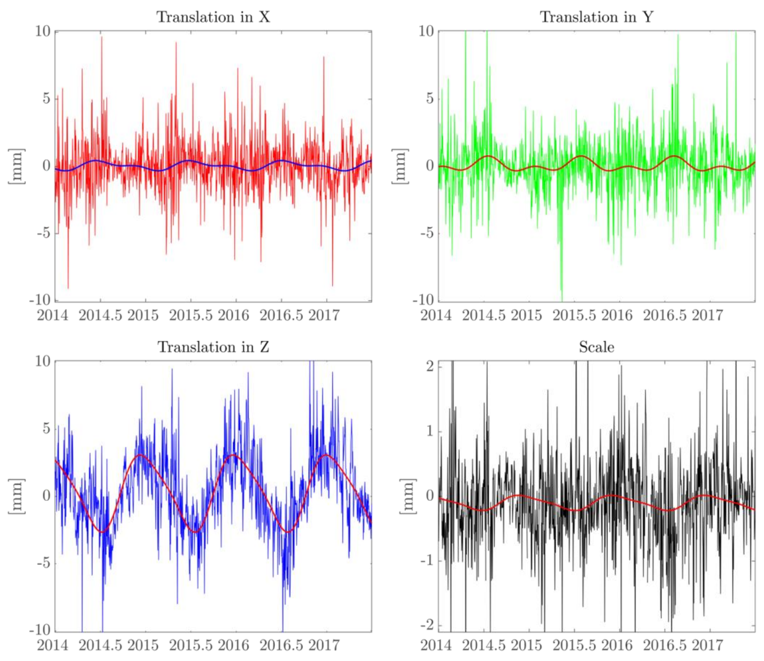


Fig 6 Differences in ERPs provided by the solution „1" with and without APL corrections

Earth rotation parameters i.e., X and Y pole coordinates and Length-of-Day (LoD) parameters are estimated in solutions „1" and „2". The results are more noisy in solution „1" as GNSS orbits are additionally estimated. However, in the case of ERPs differences in solutions „2" provide higher variation of ERPs with the **amplitude** at the level of **8.1 and 21.0 µas for X and Y coordinates,** respectively, whereas differences in LoD parameter are not significant in both solutions (see fig 6).

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 mm**. The annual signal for the scale is much smaller than in the case of station coordinates (see fig 9).

Fig 9 Translation parameters and scale provided from Helmert transformation between orbit solution with and without APL correction applied. Solution „3"

RANGE BIASES

We calculate annual average range biases in order to re-substitute them as an a priori values in the final calculations. When APL correction are not considered estimated range biases partly absorb the influence of APL (see fig 7).

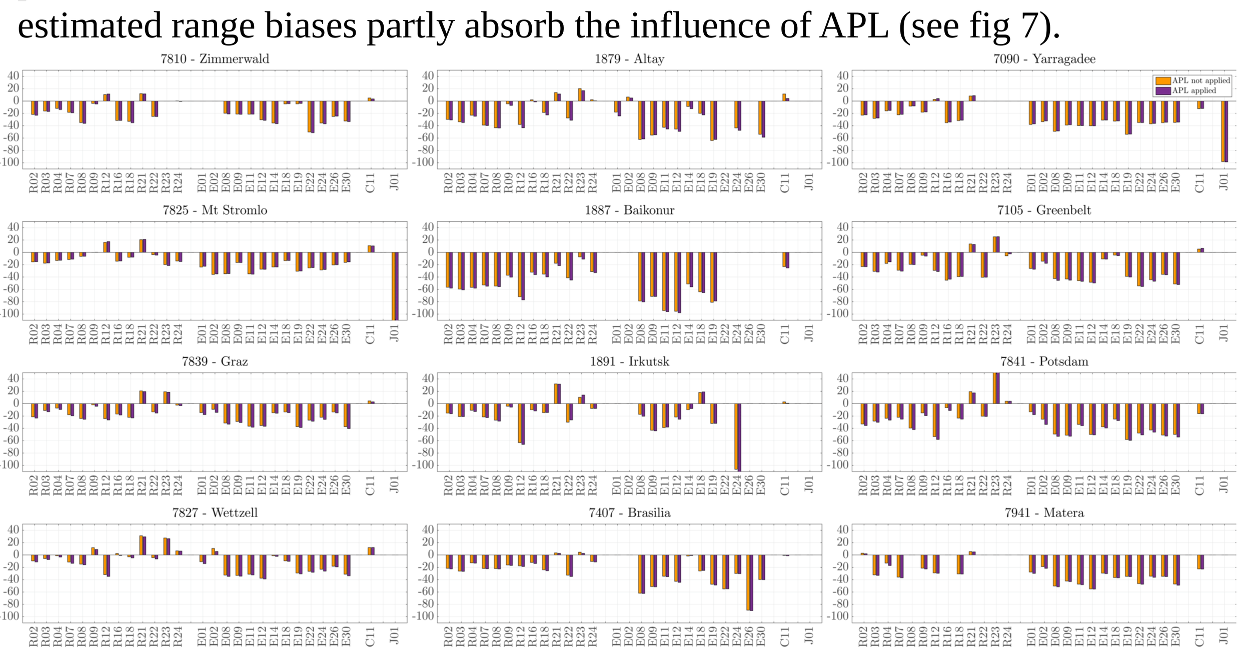


Fig 7 Estimated range biases with (violet) and without (orange) APL corrections for particular station for the whole multi-GNSS constellation. R- denotes GLONASS, E-Galileo, C-BeiDou and J-QZSS. In the first column we put reliable single photon stations, In second column we put inland station and in the third one, a reliable multi-photon stations.

GEOCENTER COORDINATES

Geocenter 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-annul signal are statistically significant in solution „1", variation of geocenter coordinates from 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 8). Significant offsets occur for the Z coordinate and equal 0.4 and 0.2 mm for solution „1" and „2", respectively.

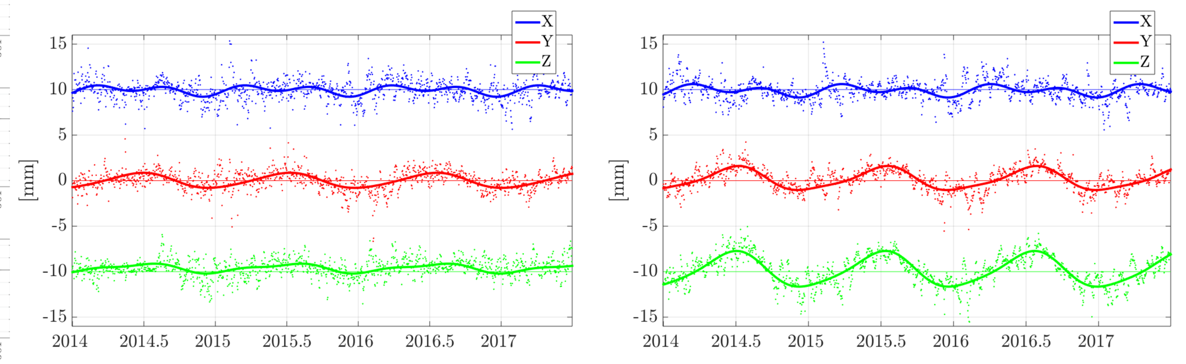


Fig 8 Differences in geocenter provided by the solution „1" (left) and „2" (right) with and without APL corrections decomposed into X, Y, Z coordinates. Annual and semi-annual signals fitted into all coordinates

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 measurement 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.

ACKNOWLEDGMENT

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APL model were kindly provided by Vienna University of Technology: http://ggosatm.hg.tuwien.ac.at/loading.html