Impact of Atmospheric Loading Corrections on SLR Solutions and on the Consistency Between GNSS and SLR Results

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Introduction

Tidal and non-tidal surface loading plays a crucial role in high-precision space geodesy. Some of the corrections are well established and recommended by the IERS Conventions to be applied at the observation level: solid Earth tides, Ocean Tidal Loading (OTL), Atmospheric Tidal Loading (ATL), whereas Atmospheric Non-Tidal Loading (ANTL), oceanic and hydrological corrections are not recommended for inclusion in operational space geodetic solutions. The central aim of improving the surface loading modeling is to improve the quality of the products of space geodetic techniques and consequently to increase the consistency between the geodesy techniques.

Models and Data

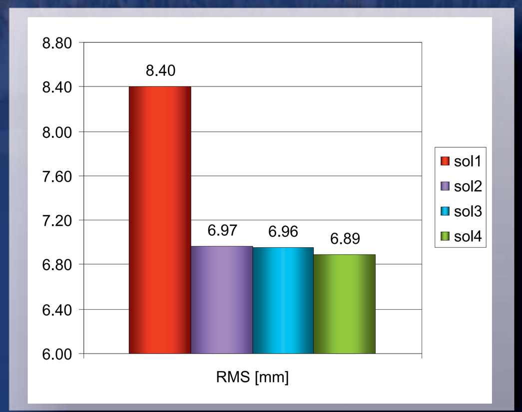


Fig. 1. RMS of observation residuals for Solutions 1-4

	OTL + CMC	ATL + CMC	ANTL
Solution 1	NO	NO	NO
Solution 2	YES	NO	NO
Solution 3	YES	YES	NO
Solution 4	YES	YES	YES

Tab 1. Characteristics of SLR solutions

For the assessment of the impact of loading corrections on SLR solutions we processed SLR observations to the two LAGEOS satellites for the time span 1990.0-2011.0 according to four different solution strategies (see Tab.1). To investigate the order of magnitude of different loading corrections, the impact of Atmospheric Pressure Loading (APL=ATL+ANTL) corrections is compared with the impact of the OTL corrections. In Solution 1 none of the ocean and atmospheric loading corrections are applied. In Solution 2 we only consider OTL EOT11a displacement corrections for the SLR stations with corresponding Center of Mass Corrections (CMC) for the LAGEOS orbits. Solution 3 additionally includes ATL Ray-Ponte corrections with corresponding CMC. Therefore, modeling in Solution 3 is consistent with the IERS2010 conventions. In Solution 4 the ANTL corrections are applied using Vienna Grids with station displacements (see Tab. 1). Fig. 1 shows that the largest improvement in terms of RMS of residuals is due to OTL, but ATL and ANTL corrections have also a non-negligible positive impact on the SLR solution.

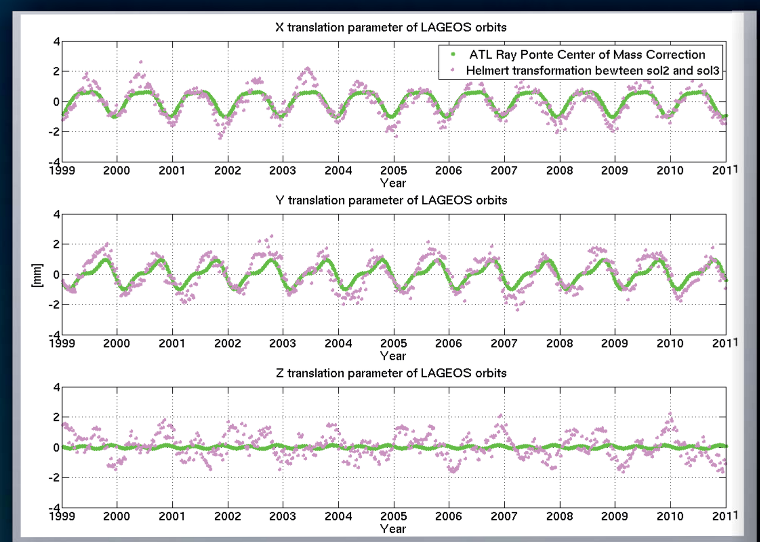


Fig. 3. Translation between orbits from Solution 2 and Solution 3 for LAGEOS-1 and LAGEOS-2

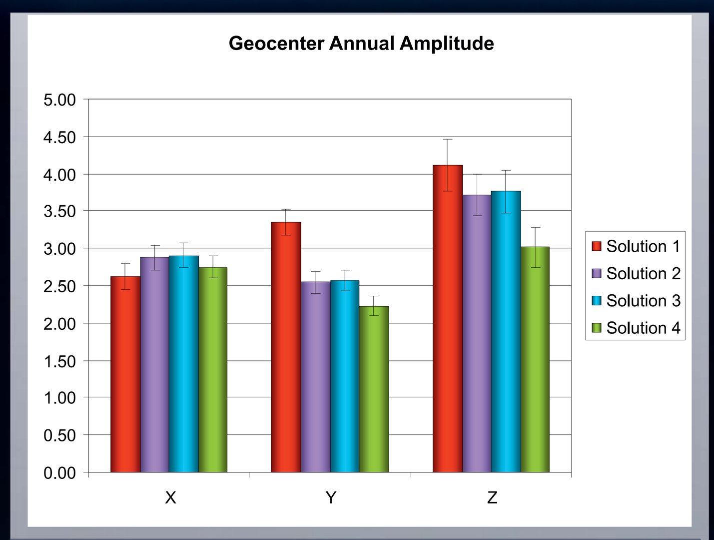


Fig. 4. Amplitudes of annual signals of SLR derived Geocenter coordinates

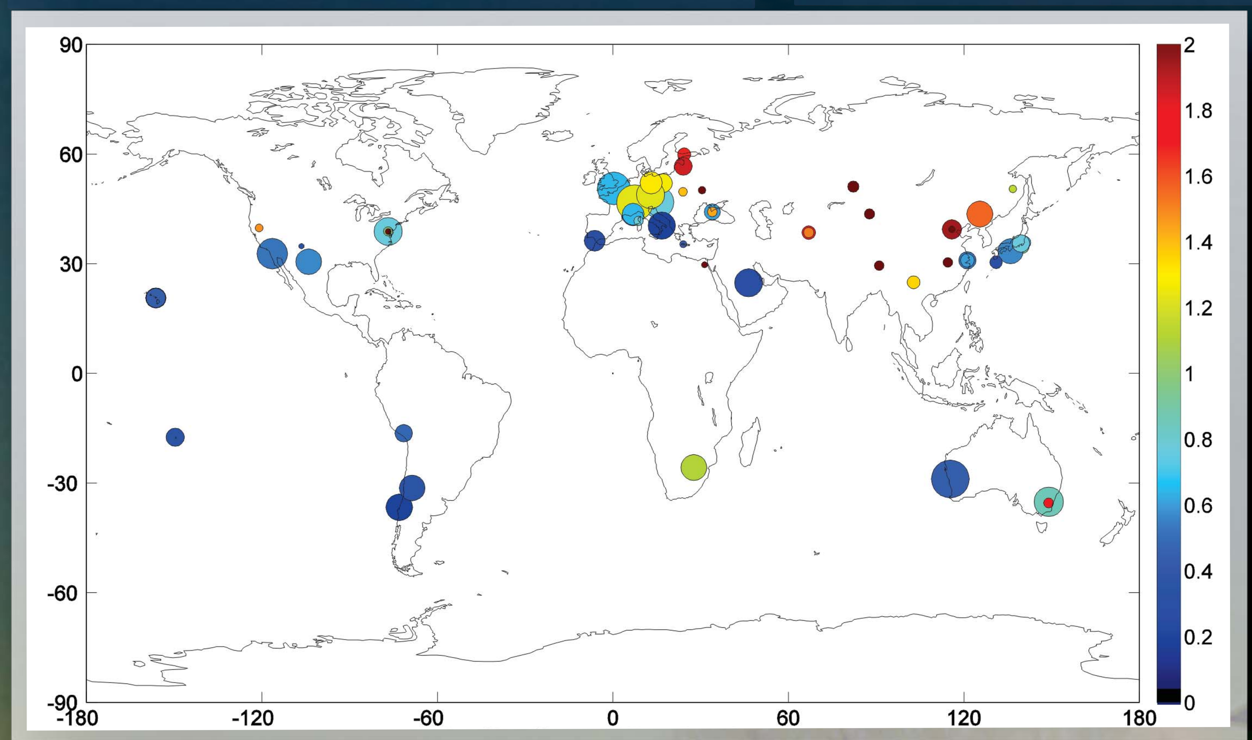


Fig. 7. Assessment of the impact of Blue-Sky effect on SLR stations using mean APL vertical correction applied on SLR stations (the size of circles denotes number of weekly solutions). The Blue-Sky effect (the difference between vertical displacement correction, when SLR station observes and the mean displacement, which supposes to be zero) is more than 2 mm for in-land stations.

Fig. 2. Estimates of annual and semiannual periods of 'up' components of station coordinates in Solution 1, Solution 2, Solution 3 and Solution 4

Orbits, EOPs, Geocenter and Station Coordinates

Fig. 3 shows the translation parameters derived from Helmert transformations between orbits from Solution 2 and Solution 3 (the impact of ATL only). For the X and Y component the translation of the LAGEOS' orbits reflects the applied CMC corrections. For the Z component the estimated translation is much larger than the applied CMC corrections. The basic periods of these variations are 560 and 222 days, what corresponds to the draconitic years of LAGEOS-1 and -2, respectively. It implies a relationship between Z Geocenter coordinate and the elevation of the Sun over the satellites' orbital planes (see Meindl et al., poster no. EGU2012-7913, presented on Thursday). Applying ANTL corrections significantly reduces the amplitudes of annual signal of geocenter coordinates (see Fig. 4). APL corrections are strongly related to annual seasons (see Fig. 5); during the winter the omission of ANTL corrections causes a positive increase (especially due to the impact on stations in the northern hemisphere), whereas during the summer the difference between the solutions without ANTL is negative w.r.t. solutions with ANTL corrections. ATL has a much smaller impact on geocenter coordinates with basic periods related to the draconitic years of LAGEOS-1 and -2. There is also a small positive impact of APL corrections on Earth Orientation Parameters (EOPs) derived from SLR observations (see Tab. 2 and Fig. 6). OTL, ATL and ANTL corrections can improve the repeatability of SLR stations (see Fig. 10) to some extend by the reduction of the annual and semiannual amplitudes of SLR derived coordinate time series (see Fig. 2). The mean improvement of coordinates repeatability due to ATL and ANTL is 3.5 %, even if the impact of APL is rather small for most SLR stations.

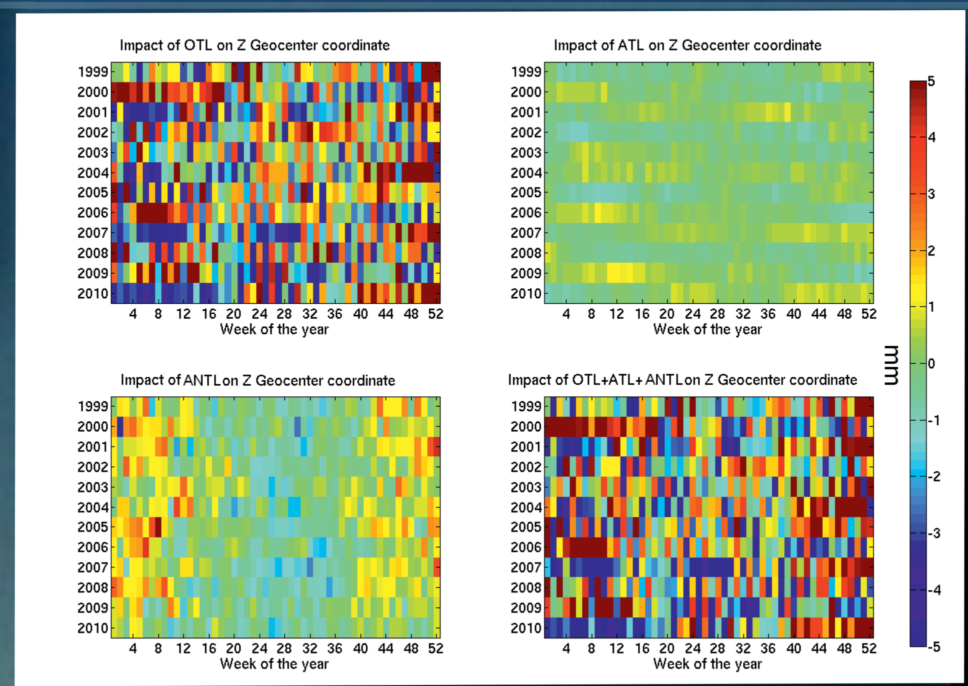


Fig. 5. Differences between Z Geocenter coordinate derived from SLR observations to LAGEOS-1 and -2 (Solution 1 - Solution 2, Solution 2 - Solution 3, Solution 3 - Solution 4, Solution 1 - Solution 4, respectively)

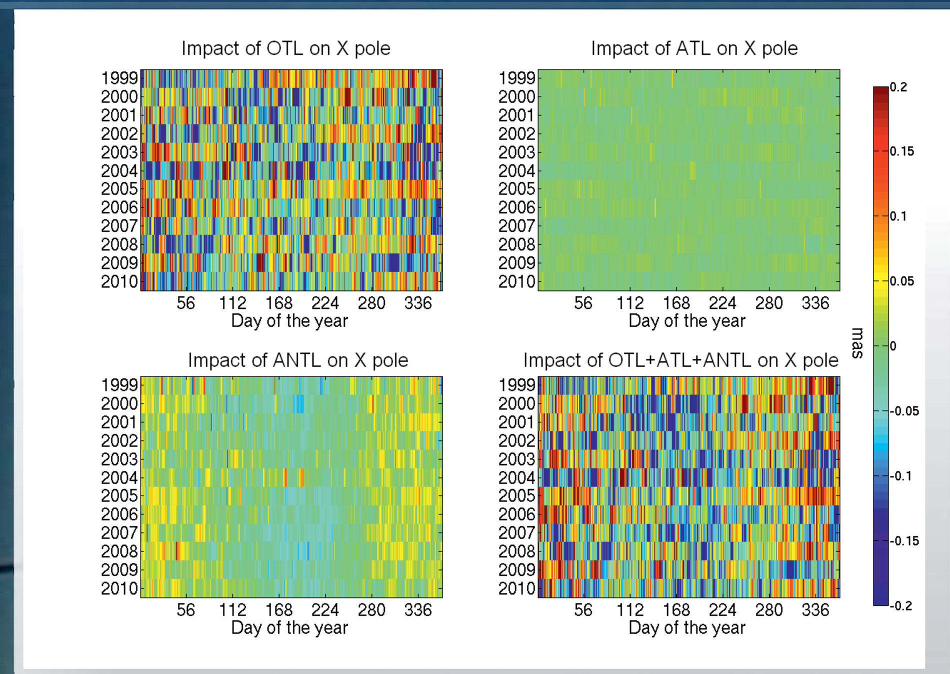


Fig. 6. Differences between X Pole coordinate derived from SLR observations to LAGEOS-1 and -2 (Solution 1 - Solution 2, Solution 2 - Solution 3, Solution 3 - Solution 4, Solution 1 - Solution 4, respectively)

	Mean bias			Weighted RMS		
	X pole [µas]	Y pole [µas]	LoD [µs]	X pole [µas]	Y pole [µas]	LoD [µs]
Solution 1	42	-2	-2.1	205	210	40
Solution 2	38	-2	-1.4	179	180	37
Solution 3	37	-2	-1.3	179	180	37
Solution 4	36	-2	-1.2	180	178	36

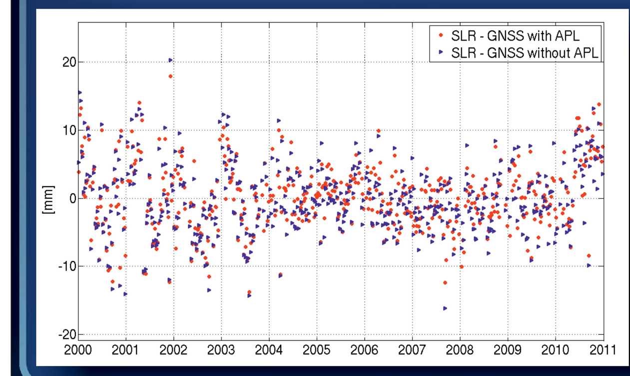
Tab 2. EOPs estimations derived from SLR (comparison w.r.t. C04 series)

Blue-Sky Effect

The omission of the Atmospheric Pressure Loading (APL) may especially lead to inconsistencies between optical (SLR) and microwave (GNSS, VLBI, DORIS) techniques. SLR observations can be carried out only during good weather conditions, whereas microwave observations are weather-independent. Weather dependence of the optical observations causes the so-called Blue-Sky effect (see Fig. 7), i.e., a systematic shift of the station height, up to several mm. Applying APL corrections can partially compensate the Blue-Sky effect (good weather conditions are typically related to the high air pressure at the SLR station).

Impact on GNSS-SLR co-locations

We assess the improvement of consistency between microwave GNSS and SLR solutions when APL corrections are applied. For both techniques (i.e., GNSS and SLR) two multi-year solutions covering 2000.0 - 2011.0 have been computed: one solution with applying APL, and the second solution without APL corrections. The corresponding GNSS and SLR solutions are compared by analyzing the time series of co-located sites. Tab. 3 shows the comparisons of the 'up' component differences of GNSS and SLR collocated stations. The mean RMS of differences of 'up' component improvements between SLR and GNSS is 11.43 mm when APL is applied, and 11.56 mm when APL corrections are omitted. It shows a slight improvement of the GNSS-SLR collocated stations' stability. From the analysis of differences of 'up' components between SLR solutions with APL and without APL corrections, one can notice that the mean difference has a positive value of 0.35 mm. For GNSS it is only 0.13 mm, what emphasizes again the impact of the Blue-Sky effect, even if most of the SLR tracking stations are located in areas with moderate or small APL impact. The variations of GNSS stations with APL and without applying APL are larger than in case of SLR stations (see Blue-Sky Effect). However, all well-performing SLR stations co-located with GNSS are characterized by a small impact of APL, because they are located rather close to oceans.



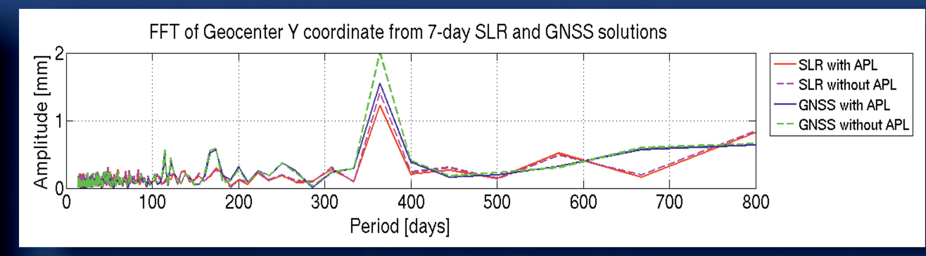


Fig. 8. FFT of Geocenter cordinates

Fig. 9. Time series of differences between improvements of 'up' components in SLR and GNSS solutions for the station Graz (Austria)

Co-location		RMS of differences between SLR and GNSS solutions **with APL** [mm]	RMS of differences between SLR and GNSS solutions **without APL** [mm]	Differences between **SLR** solutions with APL and without APL		Differences between **GNSS** solutions with APL and without APL	
GNSS Station	SLR Station			RMS [mm]	MEAN [mm]	RMS [mm]	MEAN [mm]
GRAZ	7839	5.2	5.4	1.8	0.2	2.8	0.0
MDO1	7080	10.2	10.3	1.4	0.2	2.3	0.2
MONP	7110	8.6	8.6	1.0	0.3	1.6	0.2
ZIMM	7810	8.8	9.1	1.4	0.4	2.4	0.1
YAR2	7090	5.8	5.9	1.5	0.4	2.6	0.2
GODE	7105	6.6	6.9	1.7	0.2	2.0	0.0
MATE	7941	7.4	7.7	1.0	-0.1	2.3	-0.1
HARB	7501	8.4	8.3	1.8	0.4	2.4	0.3
SFER	7824	19.7	19.5	1.0	0.0	1.7	0.0
CONZ	7405	16.3	16.3	0.9	0.3	2.2	0.0
GRAS	7845	12.9	12.7	1.4	0.1	1.9	-0.1
BOR1	7811	15.8	16.0	2.5	0.7	2.9	0.2
STR1	7825	5.2	5.7	1.5	0.6	3.0	0.2
BJFS	7249	19.1	19.2	3.1	0.7	3.4	0.6
THTI	7124	10.9	11.2	1.0	0.1	3.4	0.0
RIGA	1884	19.4	19.4	3.1	1.2	3.0	0.4
AREQ	7403	18.5	18.5	1.0	0.1	1.8	0.0
POTS	7836	7.0	7.3	2.3	0.5	2.5	0.1
MEAN		**11.43**	**11.56**	**1.63**	**0.35**	**2.46**	**0.13**

Tab 3. Impact of APL corrections on co-located GNSS-SLR stations (ordered by the decreasing number of weekly co-locations)

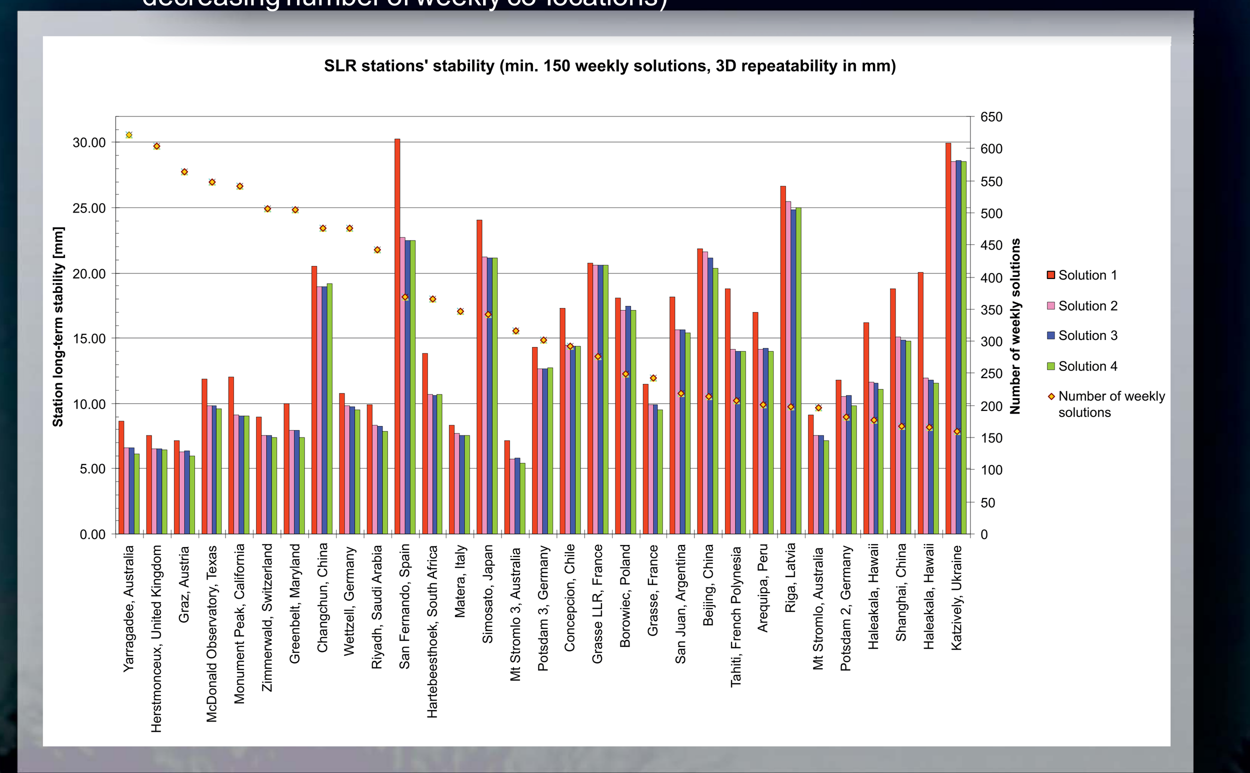


Fig. 10. The 3D stability of SLR stations for Solution 1, Solution 2, Solution 3 and Solution 4. The improvement of SLR stations repeatability due to ANTL (3.5%) is smaller than for GNSS stations (20%), because the GNSS network contains well-performing in-land stations. In the SLR network the station distribution is uneven with no well-performing in-land sites.

Summary on the impact of APL

- APL corrections significantly reduce the annual signal of geocenter coordinates (see Fig. 8)
- There is a minor impact of APL on EOPs estimates
- SLR station coordinate repeatability is improved by 3.5% when applying APL corrections
- The Blue-Sky effect can be reduced and the consistency between SLR and GNSS solutions can be increased by applying APL corrections

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