

ATMOSPHERIC “BLUE SKY” EFFECTS ON SLR STATION COORDINATES

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Abstract

Satellite laser ranging (SLR) station coordinates are found to be dependent on local atmospheric pressure through a precise 5-year orbit analysis of LAGEOS-I and LAGEOS-II satellites. The loading coefficients of the station heights are estimated to be mostly around -0.3 to -0.5 mm/hPa. This result indicates that the site displacement due to the atmospheric pressure loading effect is detected for the first time by the SLR technique. Furthermore, due to its weather restriction, a -0.4 to -1.3 mm offset is theoretically predicted in the height of SLR stations when it is compared to all-weather microwave-based geodetic techniques like GPS and VLBI.

Introduction

Earth's crust is deformed by the load of atmospheric mass, as well as other factors, such as solid earth tides, ocean loading, and snow loading. The displacement due to the atmospheric pressure loading is typically 10 to 20 mm peak-to-peak, mainly in the vertical component, at hardly predictable frequencies from a day or so (distribution variation of atmospheric pressure) to a year (seasonal distribution variation).

Rabbel and Zschau [1985] applied the Green's function convolution to the idealized atmospheric load distribution, and derived a simplified form to approximate the vertical variation of the station coordinates Δu (in mm):

$$\Delta u = -0.35\Delta p - 0.55\Delta\tilde{p} \quad (1)$$

where Δp is the pressure variation at the surface point in hPa, and $\Delta\tilde{p}$ is the long-wavelength (circular 2000-km region) averaging pressure variation in hPa ignoring the variation of the

ocean area. Note that the first term contributes more than the second term as Δp changes more than $\Delta \tilde{p}$.

The effect was already seen in Global Positioning System (GPS) and Very Long Baseline Interferometry (VLBI) data [*van Dam and Herring, 1994; MacMillan and Gipson, 1994; van Dam et al., 1994*]. Compared to these microwave-based geodetic techniques, satellite laser ranging (SLR) observation has an advantage in accurate model of propagation delay, which must result in accurate determination of a vertical component of station coordinates. Variation of a vertical component due to atmospheric loading effect has been researched for a couple of decades, and the amount of deformation is typically 1 cm peak-to-peak or less. On the other hand, unlike GPS and VLBI, SLR observation data volume is, in general, not sufficient to derive the station coordinates at a high time resolution like a daily interval. Analysis Working Group of International Laser Ranging Service (ILRS) has recently started generating weekly solutions, but most of the atmospheric pressure change is averaged out for a week's time span. Therefore, we cannot use such 'preformed' station coordinates to detect the signal of the atmospheric pressure loading from SLR observation data.

Signal of atmospheric pressure loading in SLR data

Our attempt to detect the atmospheric pressure loading in SLR data is basically described as:

$$\Delta u = \alpha \Delta p = \alpha (p - p_0) \quad (2)$$

where α is the station-dependent loading coefficient to be adjusted, and p is the local atmospheric pressure at the observation epoch and p_0 is the average atmospheric pressure at the site.

Instead of using daily 'preformed' station coordinates, the estimation procedure of the α coefficient is implemented in the orbit analysis software 'concerto' that has been developed in NICT, and the coefficient is solved for simultaneously with other parameters such as satellite orbits, station coordinates, etc.

We used the five-year (Jan 1999 to Dec 2003) SLR data to LAGEOS-1 and LAGEOS-2 satellites. The atmospheric pressure p is taken from the SLR normal point data, and the average pressure p_0 was just a simple five-year average of observed atmospheric pressure. We estimated the orbits (six elements, constant along-track acceleration and once-per-rev along-track acceleration) every 5 days, and station coordinates, range biases every year. The α coefficients were, at the same time, solved for every year for the 12 stations which has been produced consistent quantity and quality. This procedure was performed for LAGEOS-1 and independently for LAGEOS-2. After all, we therefore obtained ten α solutions per site.

Figure 1 shows the five-year estimates of the α coefficients for Graz (Austria; 7839) and Herstmonceux (UK; 7840). They are constantly negative throughout the period, which means the station heights get lower when the atmospheric pressure is high. The averages were -0.43 mm/hPa for Graz and -0.29 mm/hPa, which are close to the values -0.47 mm/hPa and -0.33 mm/hPa respectively referred in IERS Conventions [IERS, 2003]. This analysis also reveals the station height of Herstmonceux is less sensitive to atmospheric pressure change than Graz. This is probably because the station is more surrounded by oceans which partly absorb the variation of atmospheric pressure. The peak-to-peak ranges of atmospheric pressure are about 40 hPa at these two sites, so the peak-to-peak height changes due to atmospheric pressure loading amount to 12 mm (Herstmonceux) to 19 mm (Graz).

Such stable results, however, cannot be seen for some stations. Figure 2 shows the estimates for McDonald (USA; 7080) and Monument Peak (USA; 7110). They scatter much more than Figure 1, and the average values -0.82 mm/hPa and -0.01 mm/hPa are more deviated from the IERS values -0.47 mm/hPa and -0.40 mm/hPa respectively, despite of the data quality being as good as the previous two stations. We found that the variation range of atmospheric pressure is narrow at these sites — only 3 hPa rms. Therefore the height change itself is smaller, which is considered to have resulted in the poor estimates of the loading coefficients α .

A numerical summary of the 12 stations are listed in Table 1. Except for three stations, McDonald, Monument Peak and Hartebeesthoek, where the atmospheric pressure changes less, the loading coefficients are estimated around -0.3 to -0.5 mm/hPa.

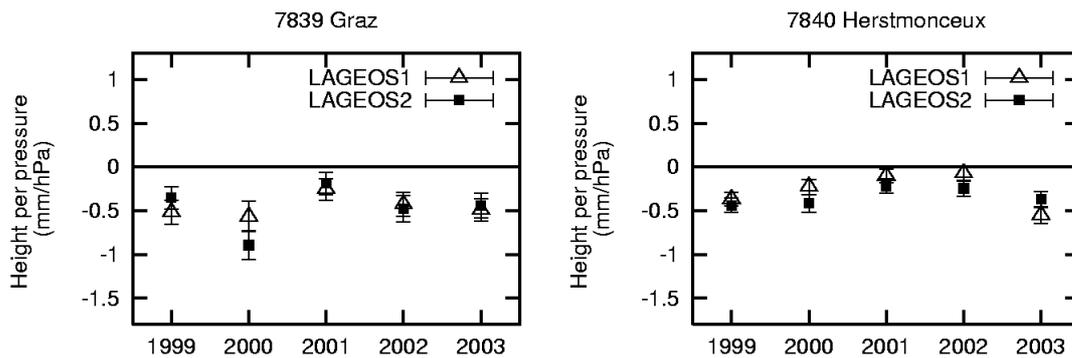


Figure 1. Estimated loading coefficients α (well estimated case). The average values are -0.43 mm/hPa for Graz and -0.29 mm/hPa for Herstmonceux.

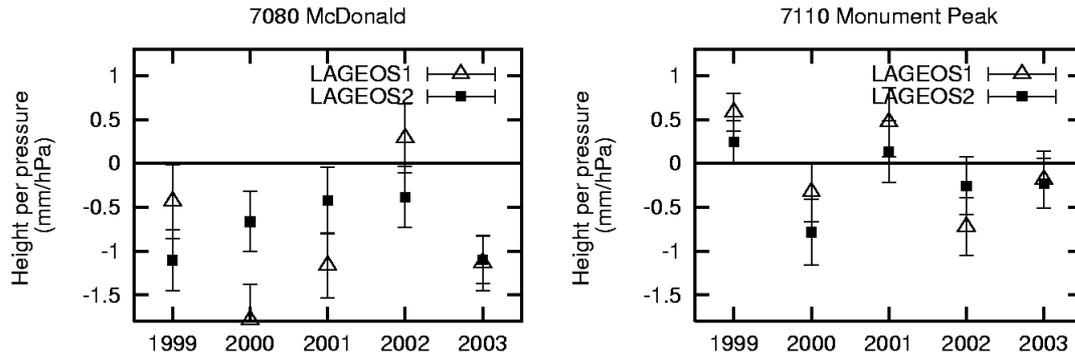


Figure 2. Estimated loading coefficients α (poor estimated case). The average values are -0.82 mm/hPa for McDonald and -0.01 mm/hPa for Monument Peak.

Table 1. Estimated loading coefficients α for 12 SLR stations.

Station (ID)	estimated (mm/hPa)	Pres. rms (hPa)	IERS (mm/hPa)
McDonald (7080), USA	-0.82 ± 0.16	3.4	-0.47
Yarragadee (7090), Australia	-0.36 ± 0.10	5.3	-0.42
Greenbelt (7105), USA	-0.37 ± 0.07	6.5	-0.36
Monument Peak (7110), USA	-0.01 ± 0.14	2.9	-0.40
Changchun (7237), China	-0.73 ± 0.22	8.0	
Hartebeesthoek (7501), S. Africa	-0.10 ± 0.42	3.2	-0.57
Zimmerwald (7810), Switzerland	-0.48 ± 0.11	5.0	-0.41
Grasse (7835), France	-0.38 ± 0.09	5.6	-0.34
Graz (7839), Austria	-0.43 ± 0.05	6.3	-0.47
Herstmonceux (7840), UK	-0.29 ± 0.04	8.9	-0.33
Mt. Stromlo (7849), Australia	-0.33 ± 0.07	6.1	-0.37
Wetzell (8834), Germany	-0.49 ± 0.15	5.7	-0.44

All from 1999-2003 data, except Hartebeesthoek (2000-2003) and Mt. Stromlo (1999-2002).

Blue Sky Offset

Multiple space geodetic techniques can currently define the scale of a terrestrial reference frame. In the analysis of the most recent International Terrestrial Reference Frame (=ITRF2000 [Altamimi, 2002]), the agreement between analysis centres was more or less within ± 1 ppb, equivalent to ± 6 mm for the radius of the Earth.

The SLR data can be obtained only when a sky is clear, whereas other microwave-based

techniques such as VLBI and GPS can be operational under any sky conditions. Considering the fact that the atmospheric pressure is generally high under a blue or starry sky, the ‘mean’ station coordinate for SLR is expected to be biased—lower than the all-weather techniques.

In order to assess the blue-sky height offset, the difference between the blue-sky mean and all-time mean of atmospheric pressure is required. This is possible for just six SLR stations where the collocated GPS facility has constantly recorded the meteorological data. We here define that the all-time mean is just a plain average of IGS meteorological time series and the blue-sky mean is an average of ones at the SLR (LAGEOS-1 and LAGEOS-2) time stamp. Processing the 3 to 5 years’ data, the differences were:

McDonald	+0.8 hPa
Greenbelt	+1.0 hPa
Zimmerwald	+1.9 hPa
Graz	+1.6 hPa
Herstmonceux	+3.3 hPa
Wettzell	+2.6 hPa

The blue-sky pressure means are found to be indeed higher than the all-time pressure means. Multiplying these by the α coefficients in Table 1, we obtain the blue-sky height offset:

McDonald	-0.7 mm
Greenbelt	-0.4 mm
Zimmerwald	-0.9 mm
Graz	-0.7 mm
Herstmonceux	-1.0 mm
Wettzell	-1.3 mm

Such small height offsets are not sensitive by the current level of multi-technique comparison/combination, but they should be seen in the future with a further enhancement of observation/analysis accuracy in SLR and other techniques.

Conclusions

Our orbit analysis of recent five-year SLR data detected the site displacement due to atmospheric pressure loading, and it amounts up to 2 cm peak-to-peak. When one compares/combines the terrestrial reference solutions from multiple geodetic techniques at 1 mm accuracy, particular care should be taken for the site-dependent blue sky height offset. The other way is that all analysts should use a theoretically calculated displacement table (e.g. Petrov’s website [*Petrov, 2003*]).

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