CENTRE-OF-MASS CORRECTION ISSUES: TOWARD MM-RANGING ACCURACY

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Abstract

Target signature effect is currently one of the major error sources in satellite laser ranging (SLR) observations. We need to handle station-dependent centre-of-mass corrections, and, more importantly, eliminate the intensity dependence of range measurements which have been detected for most multi-photon C-SPAD systems. Otherwise, the station height solutions may be significantly biased, which results in a degradation of SLR-based terrestrial reference frame.

Introduction

Along with the system noise and potential errors in the current tropospheric delay models, the spread of retroreflection due to multiple reflectors on the satellites is now recognized as a key error factor and is called "satellite signature effect" [*Appleby*, 1992]. As reported in past workshops ([*Neubert*, 1994; *Otsubo and Appleby*, 2002]; also published in [*Otsubo and Appleby*, 2003]), the centre-of-mass correction for spherical satellites cannot be treated as a constant.

It depends on the optical detectors and also on the observation policy. For single photon systems like the Herstmonceux station, the correction is likely to be smaller than the widely used standard values; for instance 242 mm instead of 251 mm for LAGEOS. Also, for multi-photon systems, the correction depends upon the optical strength of each return pulse. We calculated the effect for LAGEOS, AJISAI and ETALON based on the actual characteristics and location of each reflector, and found that the centre-of-mass correction varies by about 1 cm for LAGEOS and by between 4 and 5 cm for AJISAI and ETALON. The variation range is illustrated in Figure 1. Note that, except for the Herstmonceux values (marked as "Hx"), these correction values are based not on the actual systems but on the simplified, simulated system responses.

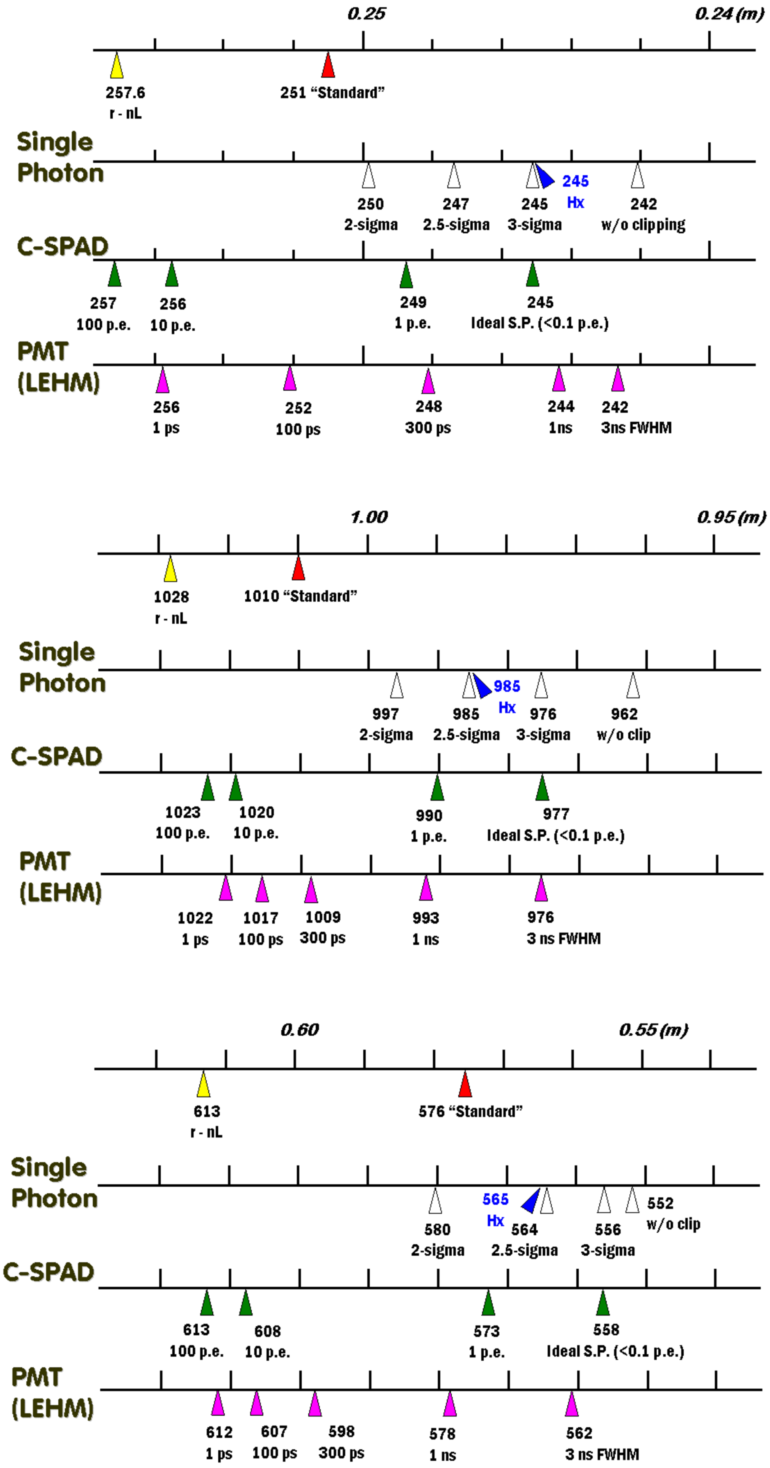

Figure 1. Centre-of-mass correction for geodetic satellites (top: LAGEOS, centre: AJISAI, bottom: ETALON). See *Otsubo and Appleby* [2003].

The centre-of-mass correction is not only station-dependent but can be intensity-dependent as seen in "C-SPAD" measures in Figure 1. The station dependency can be removed by solving for a range bias in the orbit determination process, as long as it is a constant offset.

However, the intensity dependency is more troublesome.

Existence of intensity-dependent bias

A special data analysis reveals the existence of such intensity-dependent range bias. We looked into the dependence of post-fit SLR residual data on the average intensity of return in each normal point. Following the previous studies [*Otsubo*, 2000; *Otsubo and Genba*, 2002], we used the number of single-shot returns per normal point bin width (i.e. column 44-47 of data record) as a measure of return intensity.

We analysed LAGEOS (two satellites) and AJISAI data observed from July 2003 to May 2004 (300 days). One set of station coordinates and range bias was adjusted per site and per satellite. The orbits were solved for every 4 days for LAGEOS and every day for AJISAI. The

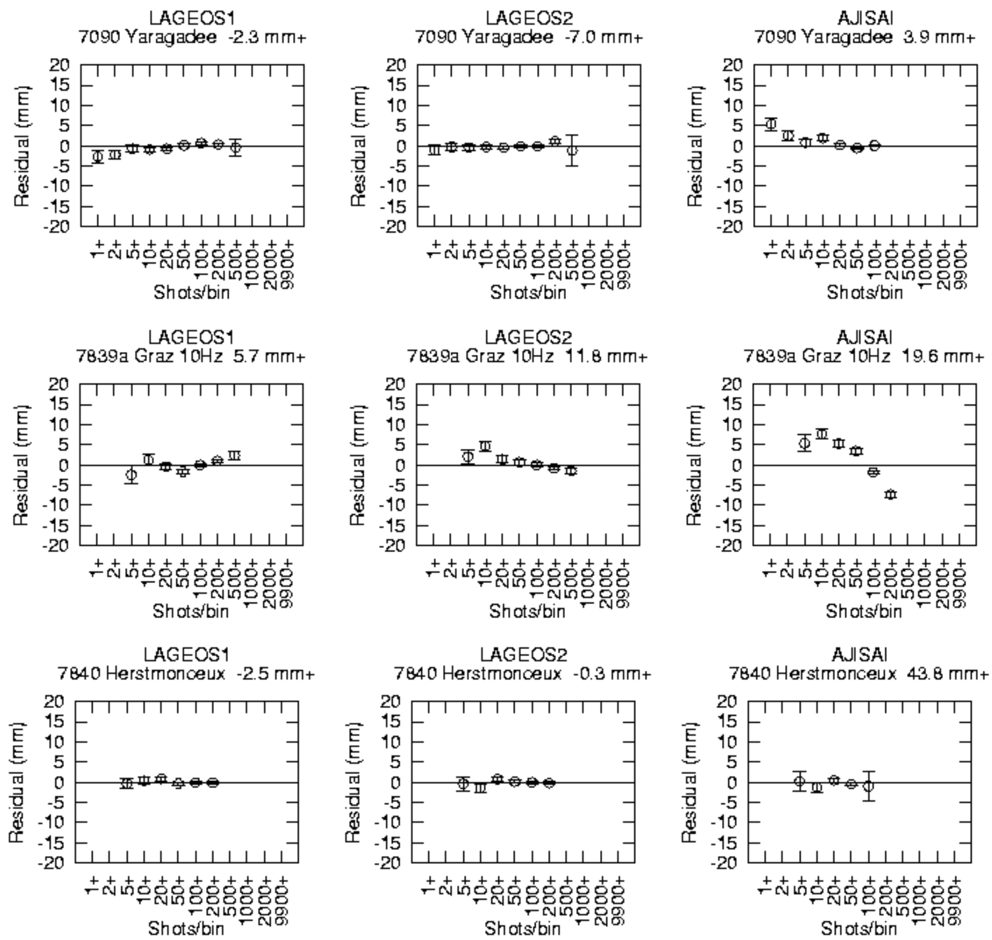

Figure 2. Range residuals sorted by number of returns per bin for an MCP-CFD system Yarragadee (top), a multi-photon C-SPAD system Graz (centre) and a single-photon system Herstmonceux (bottom).

post-fit RMS was about 1.3 cm for LAGEOS and 2.5 cm for AJISAI.

The residual profile with respect to the number of single-shot returns per bin was generated for each of the ILRS laser ranging stations. Figure 2 shows three typical results, for an MCP systems, a C-SPAD system and a single photon system. The graphs for all 24 systems analysed are available at:

http://www.nict.go.jp/ka/control/pod/bias-intensity2.pdf

This result indicates that the C-SPAD range has a significant intensity dependence of up to 5-cm peak-to-peak for AJISAI and sub-cm for LAGEOS. Smaller trends are also seen in some MCP stations. On the other hand, the single photon systems (Herstmonceux and Zimmerwald) are the most robust with a nicely flat trend.

This analysis method used post-fit residuals, but, during the parameter estimation process, such a systematic error will be partly absorbed, and therefore any intensity dependence will tend to be underestimated. It should be further noted that this analysis is special — the SLR data analysts do not apply this kind of approach on a regular basis, which means these biases have been routinely contaminating the geodetic products.

Intensity-dependent bias corrupting the geodetic results

Due to varying station-satellite distance and atmospheric attenuation, the intensity variation is related to the elevation angle. That is, a strong signal is expected from a high elevation and a weak signal from a low elevation. Such a systematic effect might be expected to corrupt the geometry in the observation equation.

To assess the extent of this effect, we artificially added a systematic bias to a set of actual SLR data. For a 50-day LAGEOS-1 and LAGEOS-2 data set (April to June 2003), we added ±5 mm systematic bias to the normal points of three most productive stations in the 50-day span (Yarragadee, Hartebeesthoek and Graz (10 Hz)) based on the following rule:

- Using the number of single shot returns per bin, categorise all normal point data as [a] dense points (highest 25%), [b] medium points (middle 50%) and [c] sparse points (lowest 25%).

  (The [a]-[b] boundary was 223 shots/NP bin for Yarragadee, 322 for Hartebeesthoek, and 234 for Graz. The [b]-[c] boundary was 48, 109 and 65, respectively.)

- Add -5 mm range bias to the group [a] and +5 mm range bias to the group [c], which makes laser range shorter for strong returns and longer for weak returns.

We then solved for station coordinates and range bias before and after adding this artificial bias, and determined the effect by comparing the results:

	Height change	Range bias change
Yarragadee	+ 7.4 mm	+ 4.2 mm
Hartebeesthoek	+ 8.4 mm	+ 4.8 mm
Graz	+ 6.0 mm	+ 4.9 mm

The horizontal components did not change by more than 1 mm. This result shows that the applied intensity-dependent bias quite directly degrades the solutions for station height that are used to define the scale of a terrestrial reference frame. It also suggests that such bias is possibly routinely being absorbed in the parameter estimation solutions.

Conclusions

The intensity-dependent range bias induced by the satellite signature effect is actually seen in a number of stations. It amounts to 4 to 5 cm in AJISAI. For LAGEOS, it is theoretically expected to be about 20% of AJISAI (= 1 cm) although it is not quite seen at that level in our analysis. Through a test analysis where we added an artificial, but realistic, intensity-dependent range bias, derived station heights are found to be sensitive to such biases.

Stations should strive to keep such biases constant by avoiding variable intensity in their laser returns, which inevitably leads to a variable bias that is almost impossible to remove. Otherwise, SLR-advantageous geodetic products such as a terrestrial reference frame [*Altamimi*, 2002] are sure to be contaminated.

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