Attempts to separate apparent observational range bias from true geodetic signals

Graham Appleby[1], Matthew Wilkinson[1], Vincenza Luceri[2], Philip Gibbs[1] , Victoria Smith[1]

[1]Space Geodesy Facility, Herstmonceux, UK
[2]e-GEOS, ASI/CGS, Matera, Italy

Abstract

Orbital solutions that include laser range bias naturally produce results that are highly correlated with station height variations. In this paper we investigate features of a long time-series of Herstmonceux LAGEOS and LAGEOS-II range bias solutions derived by the ILRS Primary Combination Centre at ASI. We discuss time-of-flight counter effects apparent in the results as well as attempting to separate bias and height signals using other on-site geodetic techniques including GNSS and absolute gravity.

Introduction

We currently use satellite laser range, GPS and absolute gravity data in a programme for long-term monitoring of the Herstmonceux site. This programme includes analyses of the global laser range observations of LAGEOS and ETALON by the in-house analysis package SATAN, and use of and analysis of GPS data from the global IGS and UK networks that include HERS and HERT, using the GAMIT package (REFERENCE). The UK, non-Herstmonceux GPS data was obtained from the British Isles GNSS Facility (BIGF, http://www.bigf.ac.uk/) located at the IESSG, Nottingham, UK. In addition to the space-geodetic observations, we are operating and analysing data from the FG5 absolute gravimeter that is permanently located in the basement at SGF, with a particular interest in looking into local geology and hydrological loading effects.

Of course, long time-spans of accurate observations are key to the definition of the ITRF. Within the ILRS Analysis Working Group, a programme of re-analysis of LAGEOS data from 1983-date is ongoing, and includes the generation of time series of station range-bias at weekly intervals which has the potential to reveal possible engineering problems. However, because of the high correlation that exists between station height and range bias, the degree of which depends upon the minimum ranging elevation, there is a potential danger of attributing real station-height changes to ranging-system problems. The ideal is to have good on-site QC and not allow system changes to affect range accuracy and also to use orbit-based QC (see, for example, the new daily LAGEOS and ETALON analysis at http://sgf.rgo.ac.uk) that might rapidly detect an unexpected system change. However, recent email exchanges between some ILRS Analysis Centres suggest that some Herstmonceux range accuracy issues have been apparent since early 2007. Here we investigate those issues in the context of the AWG re-analysis work, in particular using the time-series of range bias values.

Range bias solutions (ASI/CGS) for SGF Herstmonceux

Shown in Figure 1 are fortnightly solutions for range bias at Herstmonceux for the period 1983-2008 (Fig. 1a, LAGEOS) and 1992-2008 (Fig. 1b, LAGEOS-II). These have been estimated recently in a consistent way with a multi-year global geodetic solution at the ASI Space Geodesy Center. For the time-period between 1983 and 1992, a 'Maryland' event timer was used in the SGF ranging system, leading to a single-shot precision of some 45mm. During that period, large systematic range bias of up to 40mm was present and mostly un-removable (Appleby *et al*, 1989). From 1992 to 2007, Stanford counters replaced the Maryland event timer and the 'bias' time series is dominated by a clear seasonal signal, almost certainly representing real height changes at the 10 to 15mm level. However, for this time period, engineering tests at Herstmonceux revealed that up to 8mm range bias is also present in the data, dependent upon satellite range (Gibbs and Appleby, 2006).

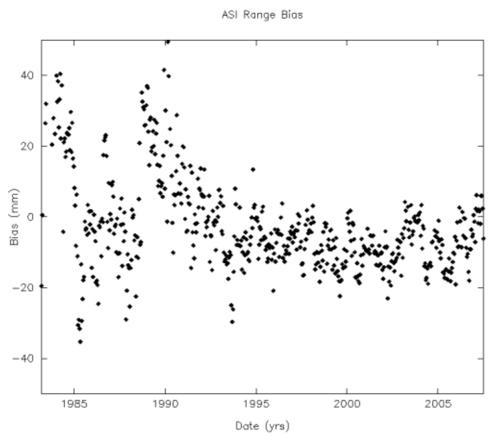

Figure 1a. LAGEOS range-bias

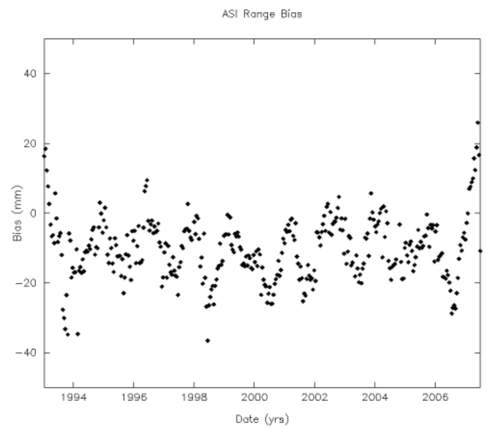

Figure 1b. LAGEOS-II range-bias

In close up, the range-bias series for LAGEOS is shown in Figure 2, where the epochs of removal of the Maryland Event Timer and the Stanford Counters are 1992 and 2007.

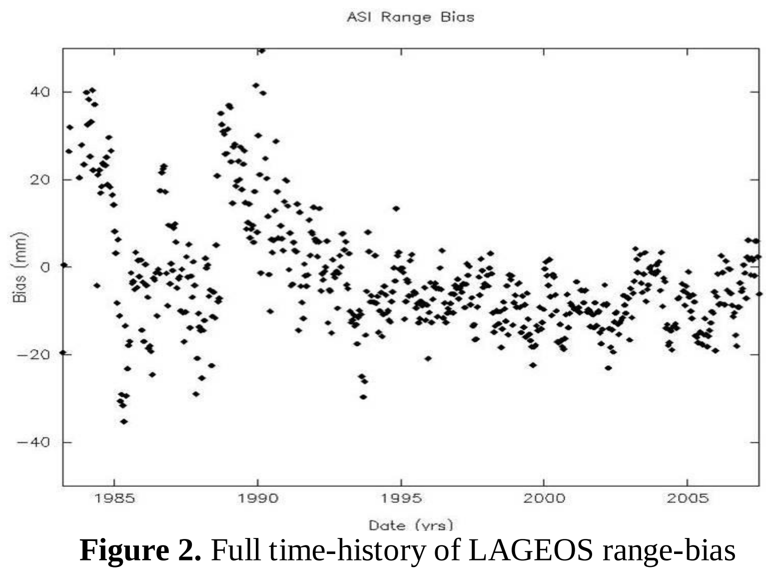

Figure 2. Full time-history of LAGEOS range-bias

Stanford Counters

Work to compare the Stanfords' behaviour at close, target board, and long, satellite, ranges as reported in Gibbs and Appleby (2006), has been extended to include several, mainly European, stations that use or have used the counters. This work was reported at the EGU in

2007 (Appleby, Otsubo and Gibbs, 2007) and discussed within the ILRS Analysis Working Group and the GGOS Unified Analysis Workshop of 2007. Corrections of up to 12mm were recommended for some stations, but with the understanding that the uncertainties of the corrections themselves may reach 5 or even 10mm. These uncertainties are mainly driven by the inherent high-frequency (90MHz) error-curve of amplitude some 50ps in the counters, meaning that estimating the range error especially during target-board ranging is very problematic. The value of such 'calibration' work for the historical data sets from the 'Stanford' stations is currently under review by the AWG.

High-quality event timer

As previously reported (*e.g.* in Gibbs, *et al*, 2006), a high precision event timer based on Thales units was installed in the ranging system on 2007 February 11, with the expectation that from that date the range data should be bias-free at the single mm level. However, the weekly, unconstrained reference-frame solutions carried out using global LAGEOS and ETALON data by the ILRS Analysis Centres, including SGF, suggested that the height of Herstmonceux underwent an abrupt negative change of some 10mm at about the same time, in early 2007, as shown in Figure 3.

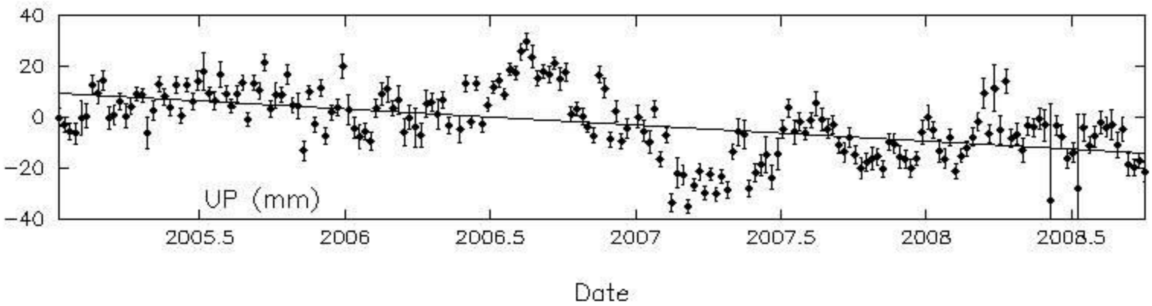

Figure 3. Weekly time-series of height variations at Herstmonceux determined by the SGF AC

Initially, this jump was not recognised as such, especially given the context of the quasi-seasonal height variations apparently related to water-table loading that are the subject of multi-sensor site-stability work currently underway at the Facility. In that work, taking results from 1996 to date, there is a clear relationship between water-table height and station height as shown in Figure 4, but we note here that atmospheric pressure loading, also of course seasonally correlated, has not been removed from the height series and which may be exaggerating the height variations.

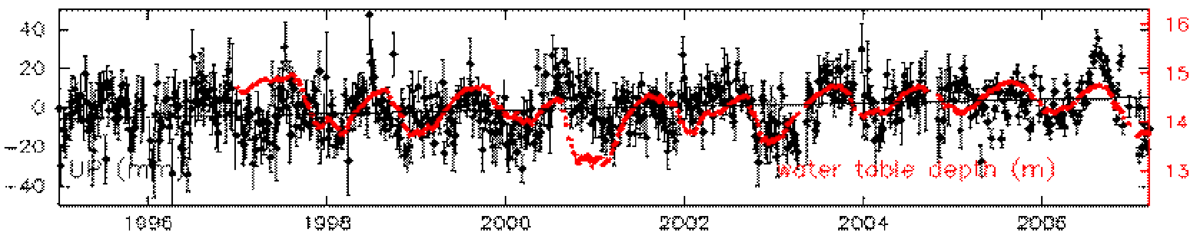

Figure 4. Weekly time-series of height variations and water-table levels at Herstmonceux

Comparison with GPS and absolute gravity

As a further check and interesting comparison of results from closely-situated techniques, we compare the SLR height time series first with that from the long-standing HERS Z12 receiver, using GAMIT to determine weekly coordinate solutions. The two series, with the laser solutions in green and the HERT series in black, are shown in Figure 5, where the mean values of each height series have been removed from the weekly values; seasonal signals are evident in both solutions, and a drop in height relative to the GPS results is suggested by the laser results from early 2007 onwards.

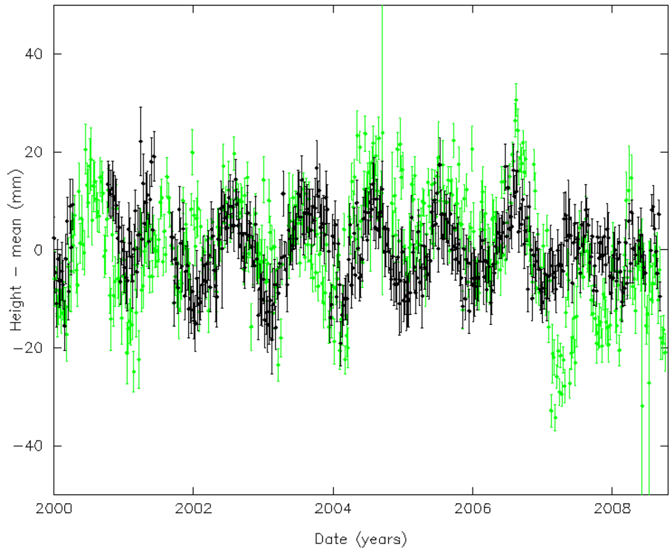

Figure 5. Weekly GPS (HERS, black) and SLR-derived (green) height series

The FG5 absolute gravimeter has been operational in the basement of the Facility since late 2006 to derive weekly values of the local gravitational acceleration from 24-hour sessions centred on mid-GPS week. For this comparison, the resulting series of average gravity variations have been converted to equivalent height changes using an estimated 1μGal = -4.5mm, following Zerbini *et al* (2007).

In Figure 6 we show the results from the beginning of 2006 from all three techniques, with the gravity values in red. During the period of interest from late 2006 through to the end of the comparison, the heights inferred from the gravity results show much less variation that that from the satellite techniques, although the exact nature of the atmospheric correction implicit in the G7 software is yet to be clarified. However and importantly, the gravity data do not see the height change suggested by the laser data.

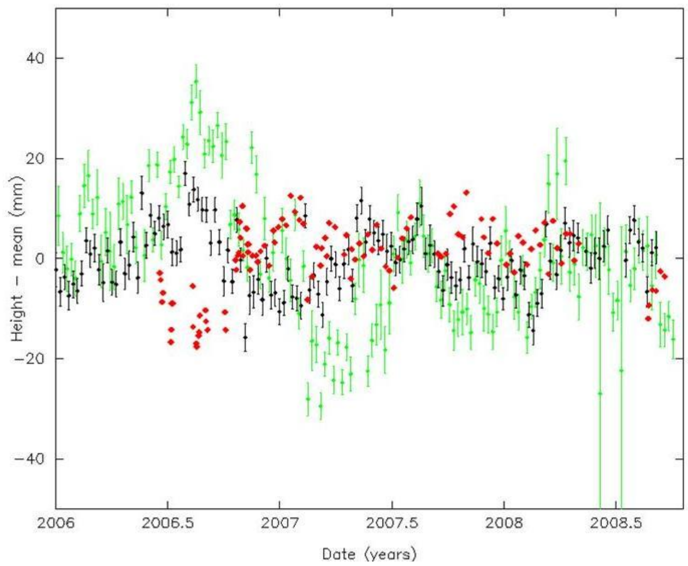

Figure 6. Weekly GPS (HERS, black), SLR (green) and gravity-derived (red) height series

Conclusion

An apparent discontinuity in the laser range data from Herstmonceux, as revealed from range-bias solutions, has been identified and coincides with the introduction of a high-accuracy event timer in 2007 February. Supporting evidence for the existence of the discontinuity in the laser data itself, rather than from a real change in station height, has been obtained from a comparison between the height time series derived from SLR, from on-site GPS and from on-site absolute gravity data. Further work suggests that the laser data ***prior*** to 2007 February is biased by about 12mm, with the modern data essentially bias-free. Correction tables for the Herstmonceux laser data will be issued in due course.

References

Appleby G M**,** Otsubo T and Gibbs P., **"**Further Improvements in Understanding Subtle Systematic Effects in Laser Ranging Observations" (Solicited presentation), *Geophysical Research Abstracts, Vol 9, EGU, 2007*

Appleby, G.M. and Matthews, W.E., "An analysis of range calibration values from the UK SLR system, 1985-1989", Proc. of the 7th International Workshop on Laser Ranging Instrumentation, Matera, Italy, October 2-8, published by OCA/CERGA, Grasse, France, p. 303, 1989.

Gibbs, P., Appleby, G.M., Potter, C.B. "A reassessment of laser ranging accuracy at SGF Herstmonceux", Proc. *15th Int. Laser Ranging Workshop, Canberra*, 2007

King, R., and Bock, Y. "Documentation for the GAMIT GPS analysis software, release 9.9", Mass. Inst. of Technol., Cambridge, 2004.

Zerbini, S., B. Richter, F. Rocca, T. Van Dam, F. Matonti "A Combination of Space and Terrestrial Geodetic Techniques to Monitor Land Subsidence: Case Study, the Southeastern Po Plane, Italy". *Journal of Geophysical Research*, 112, B05401, doi:10.1029/2006JB004338, 2007.