A reassessment of laser ranging accuracy at SGF Herstmonceux, UK

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Introduction

Gibbs *et al* (2007, these proceedings) reports on a major upgrade and expansion of capability at the Space Geodesy Facility, Herstmonceux, UK. A prerequisite of the laser ranging upgrade to kHz repetition rate is the in-house build of a ps-level precision event timer, based on Thales clock units and dubbed HxET. Extensive use has been made of HxET since it was completed during the summer of 2006 to calibrate the existing cluster of Stanford counters prior to making routine use of HxET. In particular, we are very interested in back-calibrating all the Herstmonceux data for the period 1994-present, during which time the Stanford counters had been exclusively used. In this paper we detail the results of this re-calibration, and also consider the affect the correction to our LAGEOS data will have on the published site coordinates in the ITRF.

Previous calibrations

Extensive tests on the linearity of the Stanford counters at satellite ranges, from a few to approximately 150ms were carried out by Gibbs (1999, 2001) using the Portable Pico Event Timer (PPET, Prochazka 1999). The method used is to record start signals and subsequent noise events simultaneously by the PPET and by the Stanford counter(s) that are under test. A hardware delay is used to move the average interval between start events and detected noise events from a few ms up to 150ms, the range encountered during real satellite ranging. For each event, comparison of the time interval as measured by each Stanford relative to that determined by the highly-linear PPET, gives an estimate of the error in time interval determined by each Stanford. From this work, a correction table as a function of range was compiled and issued in SLRMail 0891 in 2002 January. The effective dates of application of the results are 1994 October to 2002 January and the magnitude of the corrections reaches 8mm. From 2002 February the corrections are applied at the station as part of pre-processing.

With the availability of HxET, these linearity tests were repeated during 2006 October; the results were found not to be significantly different from those determined in 1999 and 2001, confirming the ongoing validity of the correction table given in SLRMail 0891. The comparison between HxET and the three Stanfords in use at Herstmonceux (coded SRa, SRb and SRd) is shown graphically in Figure 1. The horizontal axis gives the time delay after which each set of measurement comparisons are made of ‘flight time’ as recorded by the Stanford counters and by HxET. The vertical axis records the mean difference of each Stanford-recorded flight time from that recorded by HxET. It is noted that SRd, the counter currently in use at the station, exhibits close-to linear behaviour over the entire time-range. Excursions from linearity of up to 100ps (15mm in range) are seen for the other two counters.

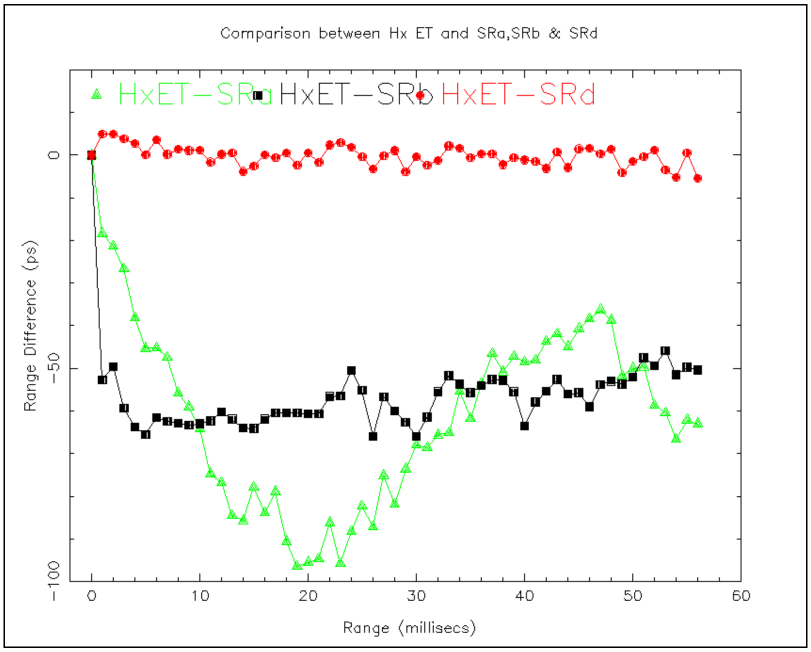

Figure 1 SGF long-range linearity determination of three Herstmonceux Stanford counters relative to the event timer HxET.

New Calibrations

The availability of HxET has meant that more detailed measurements of non linearity effects can be made on the Stanford counters. In particular, we are interested in the behaviour at close ranges, within the first few micro-seconds. Time constraints on our previous experiments with the PPET precluded such a detailed study, and errors in this time-region will directly affect calibration ranging results and thus all satellite ranges from the station. We expect some significant effects in this region since the Stanford

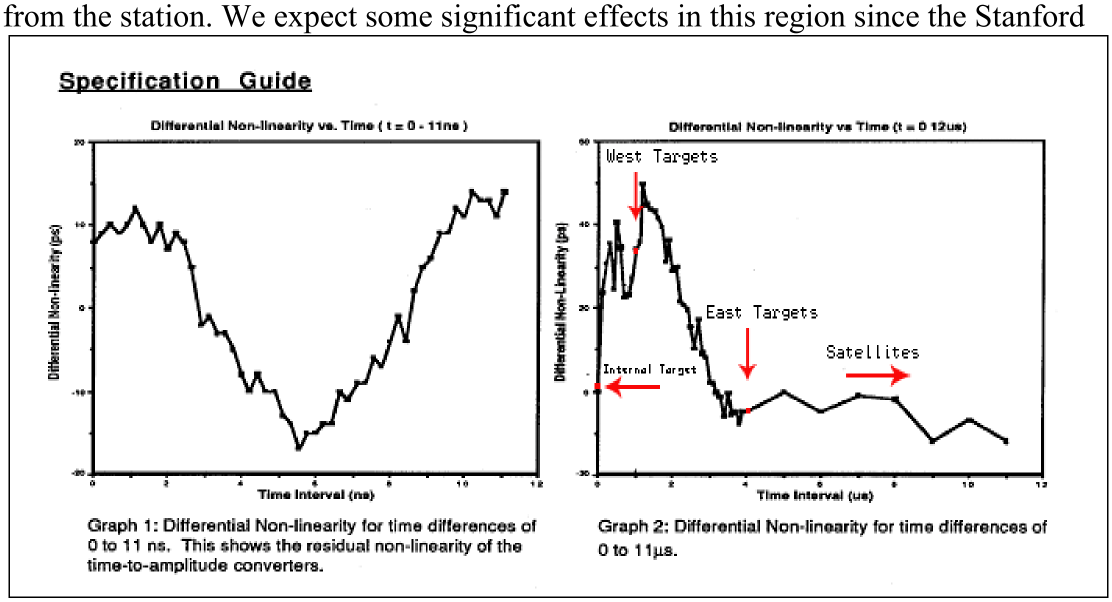

Figure 2 Short-range non-linearity of Stanford counters as given in specification

manual (???, 199?) shows both high-frequency periodic signatures and more random departures from linearity in the critical range of about 1micro-second, the distance of the prime SGF calibration target. A figure from the Stanford manual is reproduced here as Figure 2, with the time-range locations of the calibration targets marked. We carried out our tests on the behaviour of Sra, SrB and SRd against HxET in this critical range of from zero to 5µs; the results are shown in Figure 3 below and are to be compared with the Stanford manual results in the right-hand plot of Figure 2.

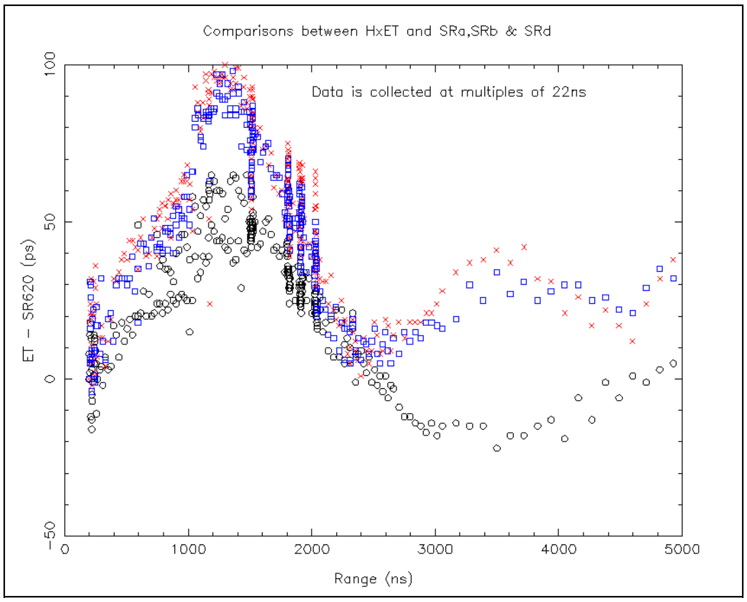

Figure 3 SGF close-range linearity determinations of three Herstmonceux Stanford counters relative to the event timer HxET.

In the range of from zero to 2µs the measured behaviour of our three Stanford counters is close to that expected from the specifications, with maximum departure from linearity of from 50 to 100ps, at a range of 1µs. Beyond a range of 2µs, the behaviour of the counters diverges. A probable explanation for the inter-counter scatter evident in these results is the high-frequency periodic structure shown in the specification (Figure 2, left-hand plot) and in our high-resolution results shown in Figure 4 where we find 22ns periodic effects (cf 11ns expected from specifications) of amplitudes up to 20ps (~3mm). This final result places a limit to the accuracy with which we will be able to determine corrections to range measurements made with the Stanford counters.

In summary, at the effective range of the SGF primary calibration target (890-930ps, dependent on electronic set-up), the non-linearity of the counters imparts an average of ~50ps error into the observed range; this value is dependent on the range itself and the uncertainty of the value is ~20ps due to the observed 22ns periodicity in the non-linearity function.

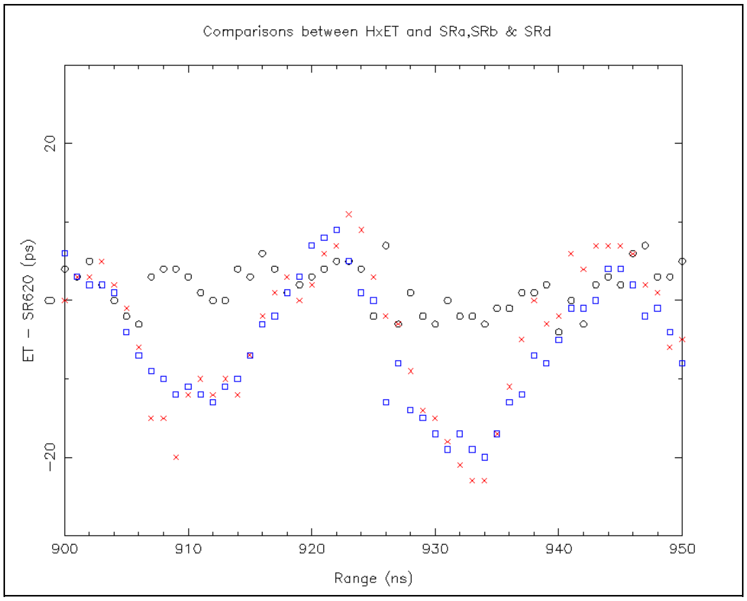

Figure 4 Observed periodic behaviour in Stanford counters' error functions.

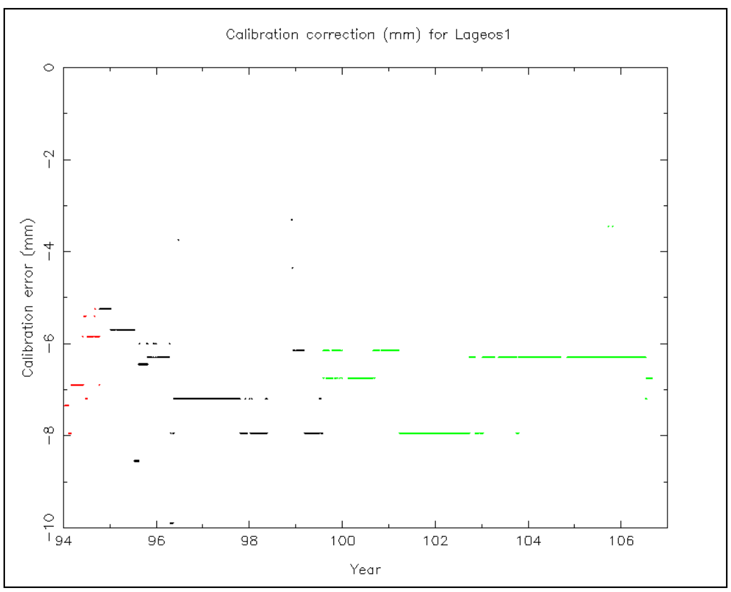

Figure 5 Correction to calibration values used for LAGEOS during 1994-2006

Effect on LAGEOS data 1994-2006

We have taken the results for the appropriate counter from Figure 3 along with the actual calibration range given in the ILRS normal point header of SGF LAGEOS data for the period 1994-2006 to estimate corrections in mm to calibrations taken over that period. The results are displayed in Figure 5, where it is apparent that errors of between 5 and 8mm have been made to the calibration values. However, given our estimate of the uncertainty of these average values, we finally derive an average calibration error of 7±2 mm, and in the sense that the calibration correction is too large by that amount. During this re-assessment we also discovered that no account had been taken for the effect on total delay of a glass neutral density filter that is placed in the optical path during calibration but not during satellite ranging. This correction amounts to 1.5mm, again in the sense that the calibration correction derived from target-board ranging is too long. Therefore our calibration corrections in the period 1994-date are too long by 8.5±2 mm and thus calibrated satellite ranges short by the same amount. This correction, which affects all satellite data equally, is of course in addition to the range-dependent correction discussed under 'previous calibrations' above and announced for the period 1994 October to 2002 January in SLRMail 0891 in 2002 January.

Assuming that the corrections presented in SLRMail 0891 have been made to the Herstmonceux ranges, it is interesting to look at the implications for and evidence in geodetic solutions of this newly-discovered correction of 8.5±2 mm. The centre-of-mass (CoM) correction for LAGEOS for 7840 Herstmonceux single photon data is 245 ± 1mm (Otsubo and Appleby, 2003). However, in computing ITRF2000, the Analysis Centres used the 'standard' 251mm CoM for all stations, thus effectively *increasing* Herstmonceux ranges by 6mm and nearly cancelling the bias of -8.5mm present since 1994. Thus the coordinates (height) of Herstmonceux in ITRF2000 should have only a small bias from the true value, given that a range bias (RB) affects primarily the solution for height. Indeed, the mean of Herstmonceux LAGEOS 1/2 residuals in our daily QC based on fixed ITRF2000 coordinates is currently -11 ± 2mm, close to the expected bias of -8.5mm. Thus it appears that the coordinates have not absorbed the range error and the full range bias is apparent. Further evidence comes from an analysis of LAGEOS 1/2 data between 1992 and 2006, J Ries (personal communication, April 2006) finds a range bias of minus 10 to12mm and a height change of ~7mm; from an analysis of LAGEOS 1/2 data 2001-2005, Otsubo, Appleby, Gotoh and Kubooka (EGU 2006) find a range bias of -9mm, and a similar value for Etalon data.

For the ILRS combined product included in ITRF2005, the individual Analysis Centres used the correct value of 245mm for Herstmonceux's LAGEOS CoM, and did not solve for a bias for this station (AWG resolution at ILRS Fall Meeting, Eastbourne 2005). Thus it is likely that station (height) will be in error in the ITRF2005. To test this, we apply the +8.5 mm range correction to LAGEOS 1/2 data for 2004, and solve simultaneously for station coordinates and range bias. On average, we find RB = +1 ± 2 mm and $\Delta H = -5 \pm 1$ mm, implying that station height in ITRF2005 has absorbed half the RB and is in error by +5mm.

Conclusion

All range data from 7840 Herstmonceux will from early 2007 be determined using HxET and will then be free of systematic error greater than 1 or 2mm. An SLRMail will announce the date and confirm that 8.5 mm should be *added* to all Herstmonceux satellite ranges from 1994 to that date, and re-iterate that the range dependent corrections given in SLRMail 0891 should also be applied for the period 1994 October to 2002 January. As a consequence of this work the station height in ITRF2005 is approximately 5mm too large. We regret this long-term error and encourage other users of Stanford counters to investigate possible similar effects in their data.