Systematics at the SGF, Herstmonceux

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Abstract

Systematic errors are likely to be present to varying degrees in the laser range measurements from every SLR station in the ILRS network. Detecting such errors can be difficult and the possible sources are numerous. The GGOS goal for a reference frame of 1mm accuracy and 0.1mm/year stability is demanding and so stations must continue to work to seek out and eliminate all potential systematic errors. The SGF, Herstmonceux has made many efforts over the years to discover, minimise, eliminate and correct systematic errors to make its range measurements as accurate and consistent as can be. This report will discuss some of the past and ongoing work of the SGF, Herstmonceux to tackle potential systematics in its laser ranges. It will then consider what is required to further address systematics in the ILRS network, both from analysis feedback and international operational cooperation.

Introduction

A satellite laser ranging station in the ILRS network can improve its performance by increasing the number of satellites observed per day and by decreasing the uncertainty in normal points by making many range measurements, as the current generation of kHz stations are able to do. Crucially to further improve, a SLR station must monitor for and identify potential sources of systematic error. It must then operate in a way to minimise the impact of systematics on laser range data. The Space Geodesy Facility in Herstmonceux aims to operate with minimal systematic bias and this report discusses some of the past and ongoing work to ensure this is achieved.

The ILRS has an important role in addressing station systematics. It is needed firstly to coordinate feedback to stations from analysis groups as the operators may not have the tools to detect range errors. Furthermore, the ILRS can promote best practices and can bring stations together to identify common potential systematics and recommend mitigation techniques.

Single photon SLR @ SGF, Herstmonceux

The SGF, Herstmonceux has long kept to a 'single-photon' mode of operation for satellite laser ranging. The rate of successful returns at the detector is kept at a low level to avoid range measurement error due to making inconsistent observations across retro-reflector targets. In addition, keeping to single-photon levels avoids signal intensity dependent detector time walk.

Keeping to single-photon signal levels is achieved in two steps. Firstly, a graded neutral density filter wheel is adjusted in real-time in reaction to the calculated instantaneous return rate. The second step is in post-processing the data by filtering for high return rate data. A new method of post-processing Poisson filtering is under consideration at the SGF (Rodriguez, 2016).

Timers @ SGF, Herstmonceux

In 2006, the SGF upgraded from using multiple Stanford SR620 interval timers to using the HxET event timer, built in-house from 2 Thales Systems timing modules and a clock module. This provided the opportunity to compare and calibrate the linearity of the SR620 timers (Gibbs et al, 2006). The Stanford timers were found not to be linear when compared to the HxET and in addition the timers diverged considerably from each other.

A calibration dependent error was also investigated, caused by the SR620 timer non-linearity for short intervals. A correction table was published in 2006 to all SGF SR620 measurements for this error. This correction was later re-determined by solving for a bias in weekly laser solutions (V. Luceri, 2011).

An A033-ET Riga event timer was installed in 2014 to simultaneously collect laser ranges. A comparison of the two event timers showed good agreement and linear behaviour. However, the A033-ET timer gave reduced RMS values for terrestrial calibrations and SLR normal points. The jitter was also greater than should be expected, at approximately 10ps. By feeding the 2 channels of each timer the same start pulse, it was possible to attribute this additional jitter to the HxET timer (Wilkinson, 2015).

Calibrations @ SGF, Herstmonceux

Regular calibrations are made to a terrestrial target approximately 120 metres away. In order to monitor the system delay the observer visually inspects a time-series plot after each calibration. Over the years 2010 to 2012, calibration ‘jumps’, 8mm in magnitude, were spotted in the time series plot, see figure 1. SLR continued in this period with repeat calibrations taken or data discarded when necessary.

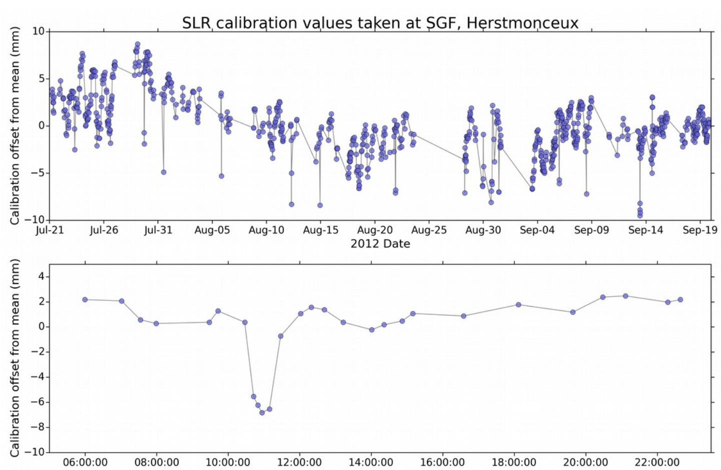

Figure 1. Time series of SLR system delay from terrestrial calibrations. 8mm jumps are present in the upper plot with a close up on a single jump in the lower plot.

Finally, the cause of the jumps was found to be a faulty Ortec rack power supply used for discriminators and signal distribution. When this was replaced no more jumps were seen in the time series. The magnitude of this systematic is at a level that would be difficult for current analysis feedback to detect. Yet it was detectable given the right tool at the station. The larger problem, however, was finding the source of the systematic.

There is possible bias in SLR measurements from Herstmonceux due to the build of the current primary calibration target. The target was surveyed in 2008, with difficulty in determining the target reference point. A new and improved target was designed and built at the SGF and is now installed alongside the primary calibration target (Shoobridge, 2016). Once this new target has been surveyed it will become the primary SLR calibration target.

Levelling @ SGF, Herstmonceux

The SGF is a multi-technique facility and in order to monitor the local site for instability a campaign of digital levelling was started in 2010 (G Appleby, 2014). Using a Leica DNA03, instrumental accuracy of 0.3mm, and a number of barcode reference staffs, step height change is measured over a total of 22 monuments across the site.

In figure 2, the time series between the SLR pillar and an absolute gravimetry marker show little variation over time. The time- series between the SLR pillar and the base of the HERS GNSS monument contains an annual variation of magnitude ±0.5mm.

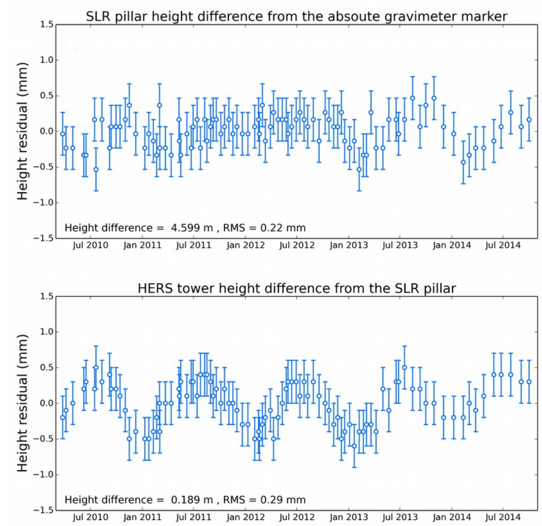

Figure 2. Relative height change between the SLR pillar and the absolute gravimetry marker (upper plot) and the height time series between the SLR pillar and HERS GNSS monument tower (lower plot).

Systematics seen in POD analysis

Hitotsubashi University has provided considerable feedback to all SLR stations in the form of range residual plots for the Lageos, Ajisai and Starlette satellites showing variations with, for example, the number of normal point returns, normal point RMS, range rate, time of day and system delay (Otsubo, 2014). For the SGF, Herstmonceux, the most revealing plot was the slope in range residual when plotted against normal point RMS, as presented in figure 3.

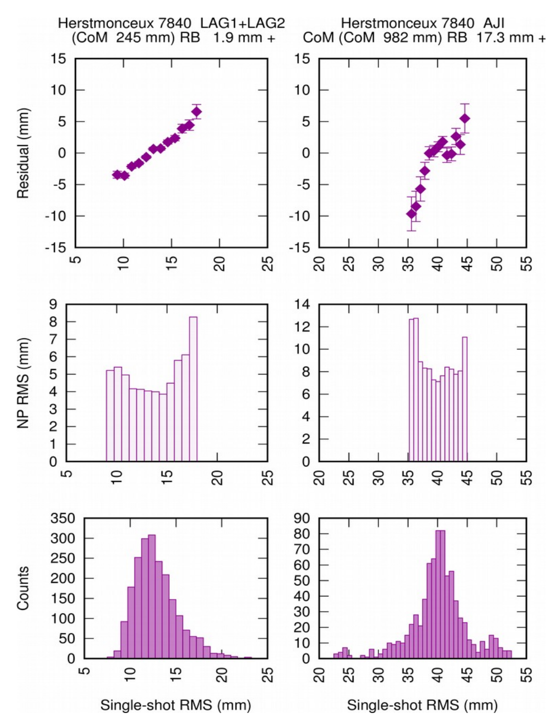

Figure 3. Range residual plots verses normal point RMS taken from Otsubo, 2014.

The pass-by-pass variation in the distribution of range residuals was investigated as a possible source of this trend. Before forming normal points from SGF SLR data, the flattened residuals are clipped at 3*sigma above the Gaussian fit centre, resulting in some variation in the actual clipping point. A greater variation was observed for the Lageos 2 satellite than for the Lageos 1 satellite. The peak of the distribution was determined by fitting a tangent and

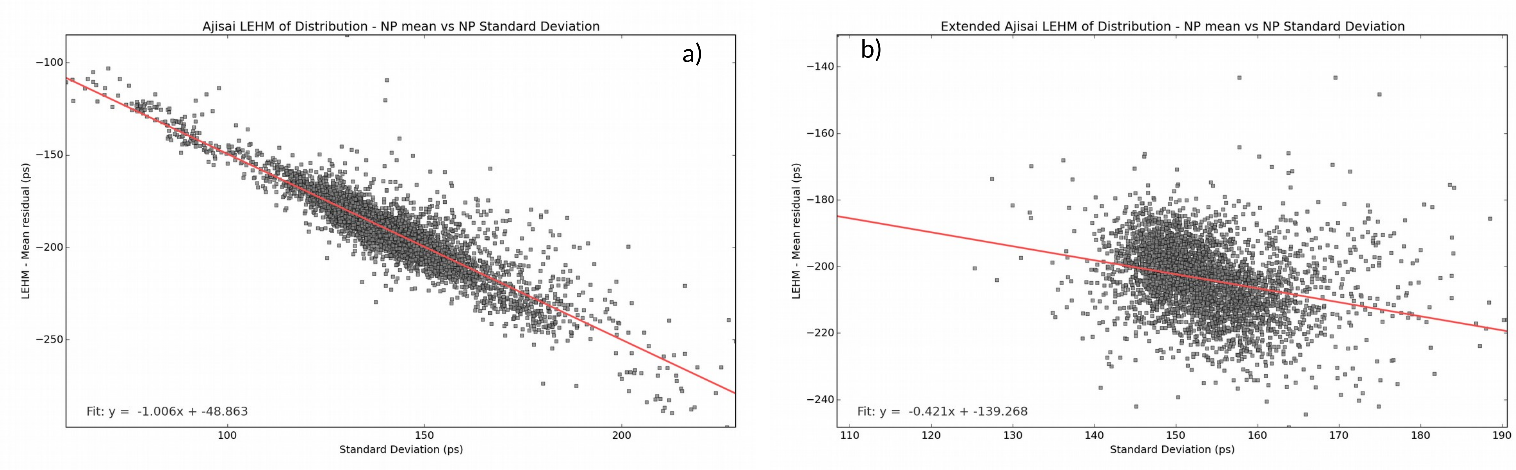

Figure 4. Range difference from the leading edge half maximum (LEHM) of the residual distribution to the normal point mean verses normal point RMS for Ajisai passes 2012-2015. Figure 4a) shows the variation from the original fullrate data, as submitted to the ILRS. Figure 4b) shows the reduced variation for the newly generated data with a fixed clipping point of 600ps behind the LEHM.

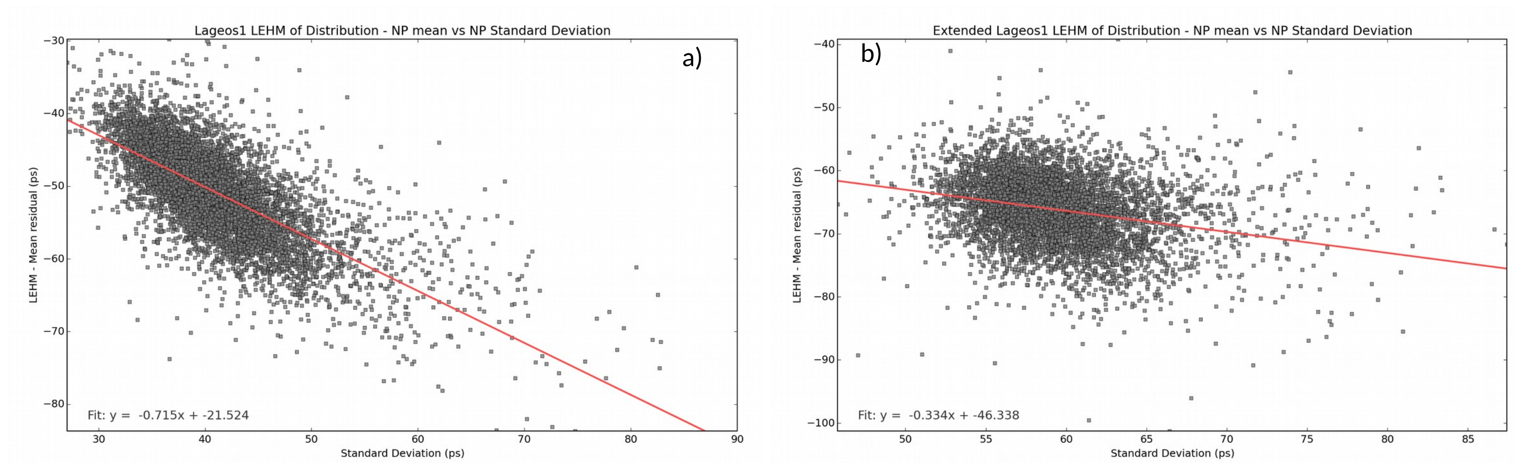

Figure 5 LEHM-NP mean verses NP RMS for Lageos 1 passes 2014-2016. Figure 5a) contains the original fullrate data. Figure 5b) shows the variation for the newly generated data with a fixed clipping point of 250ps.

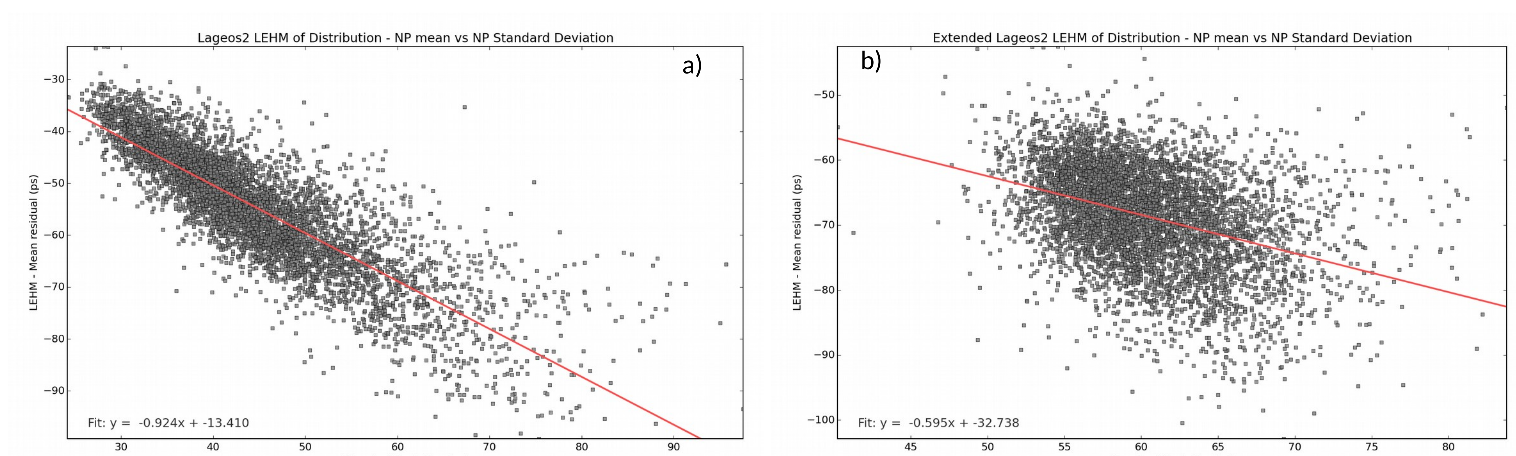

Figure 6. LEHM-NP mean verses NP RMS for Lageos 2 passes 2014-2016. Figure 6a) contains the original fullrate data. Figure 6b) shows the variation for the newly generated data with a fixed clipping point of 250ps.

from this the leading edge half maximum (LEHM) point was defined. Figure 4a) shows the range differences from the LEHMs to the normal point means verses the normal point standard deviations for Ajisai passes from 2012 to 2015. The equivalent plots for Lageos 1 and Lageos 2 are shown in figures 5a) and 6a). Slopes are present in each of these plots with Ajisai showing the largest slope at -1.006, followed by Lageos 2 at -0.924. Lageos 1 has a lesser slope at -0.715.

To generate new distributions with a fixed clipping point, it was necessary to go back to the raw data file. Using the satellite track identified in the full rate data file, it was possible reselect the track data. A clipping point for the flattened residuals was experimentally set at a fixed point of 600ps for Ajisai and 250ps for Lageos from the LEHM. New normal points were formed and the corresponding LEHM-mean vs RMS plots are shown in figures 4b), 5b) and 6b). The previous slopes have reduced in magnitude in each plot.

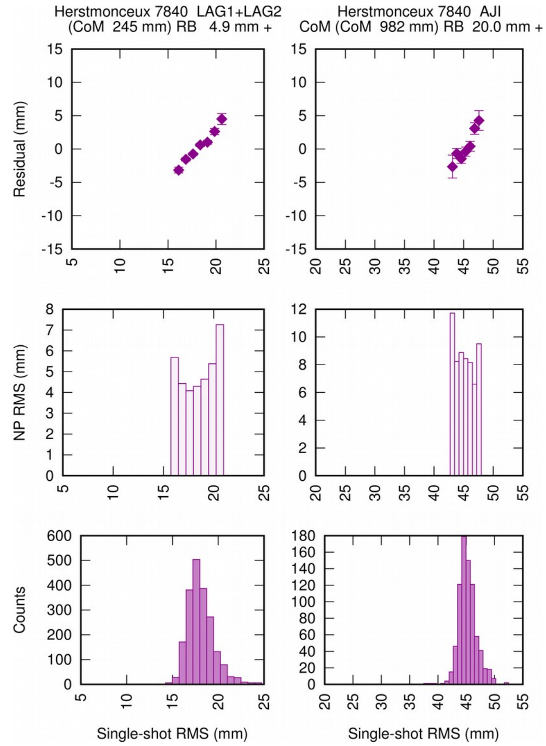

Figure 7. Range residual plots verses normal point RMS from the regenerated normal point data using fixed clipping points.

The new normal points generated from the flattened residuals with fixed clipping were used for reanalysis and the results are plotted in figure 7. The revised plots show a reduction in the spread of RMS values, but a trend is still present in each plot.

ILRS activities to address station systematics

There are many informative feedback services from different analysis groups available for stations to assess, monitor and use to improve data quality. These include the bias reports from Hitotsubashi University (Otsubo et al, 2016), the bias analysis from DGFI-TUM (Müller and Bloßfeld, 2016) and the JCET performance assessment tools (Pavlis et al, 2016). The SGF website contains a normal point residual plot service http://sgf.rgo.ac.uk/analysis/nporbit.html. Using longer timescales, it is possible to estimate station systematics with greater precision. A recent paper by Appleby, Rodríguez and Altamimi (2016) estimated systematic biases for all stations.

ILRS Quality Control Board

The newly formed ILRS ‘Quality Control Board’ (QCB) is addressing the need for a coordinated ILRS response to station systematics. The QCB was set up following the 19th International Workshop on Laser Ranging in 2014 to address systematic bias in the range data and the impact on data products. It meets by regular teleconference and available analysis feedback is discussed along with the requirements from stations to have the right diagnostics. It is has a new page on the ILRS website http://ilrs.gsfc.nasa.gov/science/qcb/index.html

ILRS Networks and Engineering Standing Committee (NESC) Forum

At this workshop the NESC launched an online forum with the expressed aims to:

- Strengthen the connection, communication and collaboration between international colleagues.
- Exploit the wealth of experience and knowledge in the ILRS network to address problems that are common to multiple stations.

The NESC forum (http://sgf.rgo.ac.uk/forumNESC) is open to the ILRS community and registered members can post topics and replies, get notifications by email and see attachments.

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