Systematic range bias 2005-06

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Introduction

Most of modern laser ranging systems potentially have 1-millimetre-precision measurement ability in a normal-point basis. However, when it comes to 1-millimetre 'accuracy', it has not been fully achieved yet and it is still a challenge for the International Laser Ranging Service (ILRS) network.

At National Institute of Information and Communications Technology (NICT), Kashima, Japan, we check the quality of laser ranging data from the whole ILRS network, in two folds. One is routine automated quality check analysis which gives quick alarms for large and obvious anomalies, and the other is precise residual analysis for sub-centimetre systematic range biases.

Routine quality check analysis

We started the 3-satellite (two LAGEOS and AJISAI) routine bias report in 1997 (Otsubo and Endo, 1998) and enhanced it to the 7-satellite (plus STARLETTE, STELLA and two ETALON) analysis in 1999 (Otsubo, 2000). It was again significantly upgraded in May 2005 as follows.

Firstly, we further added satellites: ERS-2, JASON-1, ENVISAT, GPS-35, GPS-36, GLONASS-87, GLONASS-89 and GLONASS-95. Note that some of these satellites might be omitted from the analysis report in the case of failing a certain criteria in terms of data quality and quantity. Nevertheless, the analysis reports constantly include well more than 10 satellites. The increase of number of satellites and the variety of satellite altitudes will certainly help the ILRS stations easily point the problem and the cause.

We have switched the orbit analysis software from 'concerto v3' to 'concerto v4'. The new version is almost compatible to the physical models recommended in IERS Conventions (2003). The station coordinates basically unchanged to ITRF2000, but those of new or significantly improved stations after the year 2000 were readjusted. Therefore the quality of our analysis reports should be more accurate.

We now publish the report every day, which used to be a week interval before May 2005. The report timing was also improved from 48-hour delay to 24-hour delay. Every morning in Japanese Standard Time (around 0 to 1 hr UT), a report covering up to two days before is being released. Such a quick reporting scheme became possible thanks to the rapid submission (typically within a few hours after the observation) and the rapid archive service (at CDDIS and EDC) of normal point data. The daily reports are available at our website and also via email. See figure 1 for previous website page. New website is: http://www.science.hit-u.ac.jp/otsubo/slr/bias/ [ed].

The reports are distributed through the SLReport mailing list every Wednesday, and they are being sent to registered users even on a daily basis.
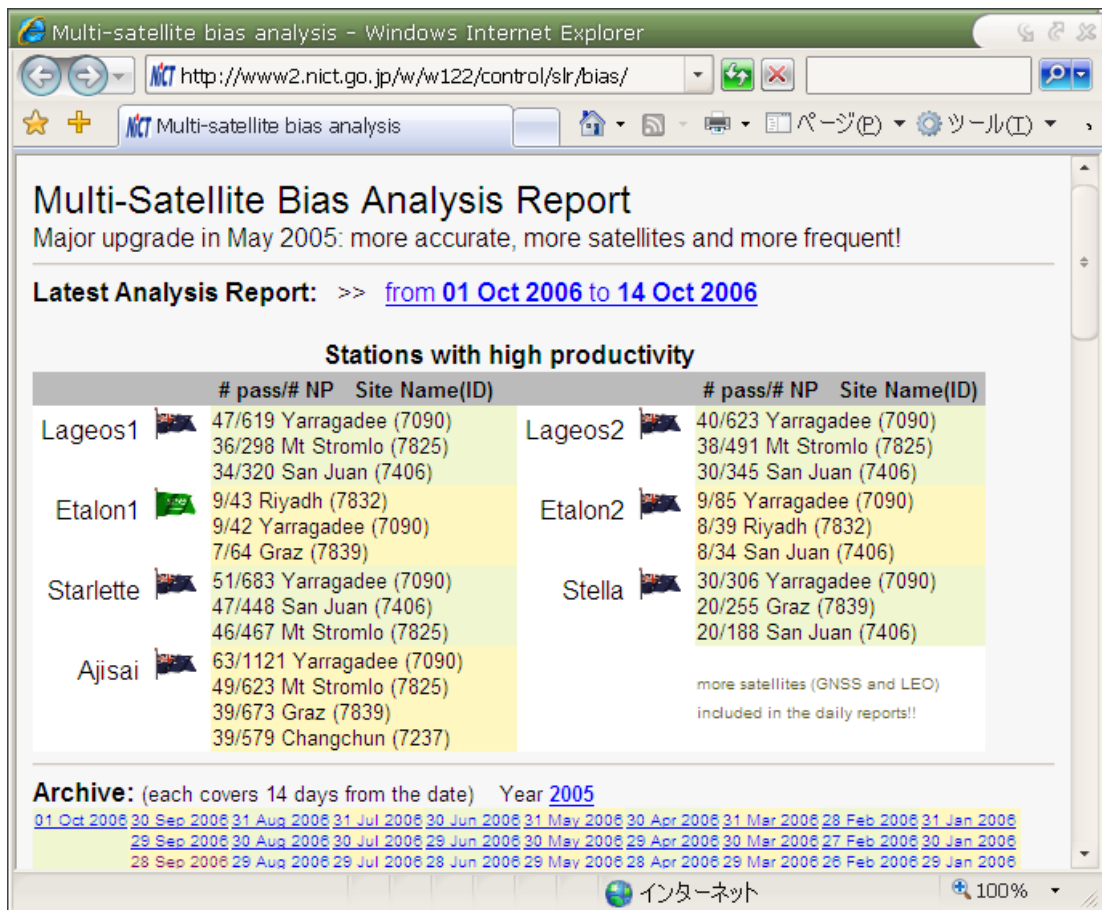
Figure 1. Multi-satellite bias analysis webpage at NICT.

Range bias vs intensity

We have proposed a quality assessment method for the intensity-dependent biases (Otsubo, 2000). The post-fit residual data were sorted by the number of single-shot returns per normal point bin which should be strongly related with the signal intensity into a detector. If the detection signal intensity varies, and if the detection timing is dependent on it, there will be intensity dependent bias. Our previous studies also pointed out it is also related to the so-called target signature effect, which is now the major error source of laser ranging technique due to the reflection from multiple retroreflectors on board. The range measurement can differ, at maximum, by 4 to 5 cm for AJISAI and ETALON, and 1 cm for LAGEOS (Otsubo and Appleby, 2003).

We applied the same procedure to the 2005-2006 data set. Three sets of satellite types were chosen: LAGEOS-1 + LAGEOS-2, AJISAI, and STARLETTE + STELLA. For each satellite, the worldwide laser ranging data for 360 days from September 2005 to August 2006 were used for orbit determination. Orbits were solved for every 5 days for LAGEOS satellites and 2 days for others. The station coordinates and range bias were adjusted for all stations. The post-fit residual weighted rms of normal points was 1.0 to 1.2 cm for LAGEOS satellites and 1.5 to 2.5 cm for others.

The intensity dependent tests were carried out for most productive 24 stations during the period. The whole results are available at:

http://www.nict.go.jp/w/w122/control/pod/bias-intensity-0506.pdf

Fig. 2 (a) to (c) shows the three typical samples of them. The first case of Herstmonceux is the station where the return signal energy is almost strictly controlled to single photoelectron. This observation policy successfully results in the flat trend, that is, no intensity dependence seen for this station, in Fig. 2 (a). The Yarragadee station in Fig. 2 (b) represents good MCP stations. There is no intensity dependence larger than a few millimeters either. The typical result of (C-) SPAD stations is shown by Mt Stromlo in Fig. 2 (c). As the target signature studies suggested the strong signal makes the range measurement shorter. The AJISAI case is the largest in most cases, but a number of stations show significant trend (mostly negative) even for LAGEOS and STARLETTE + STELLA.
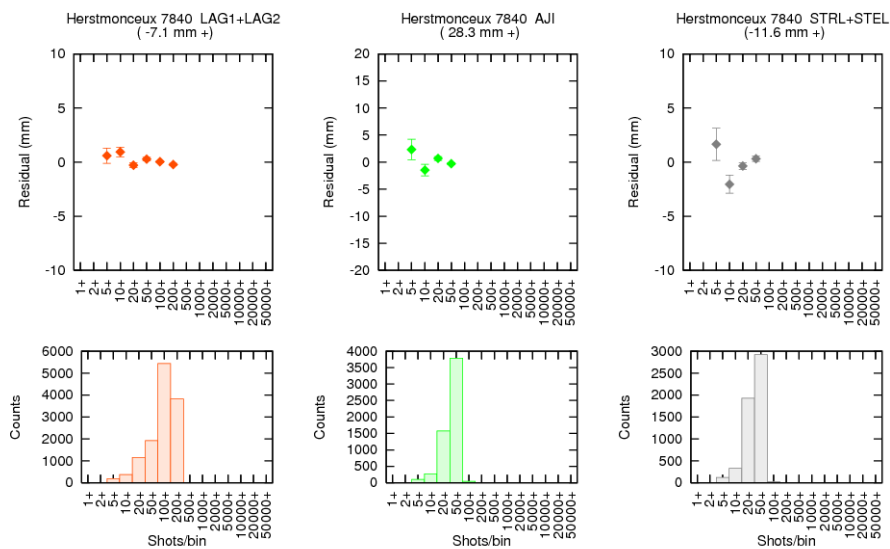

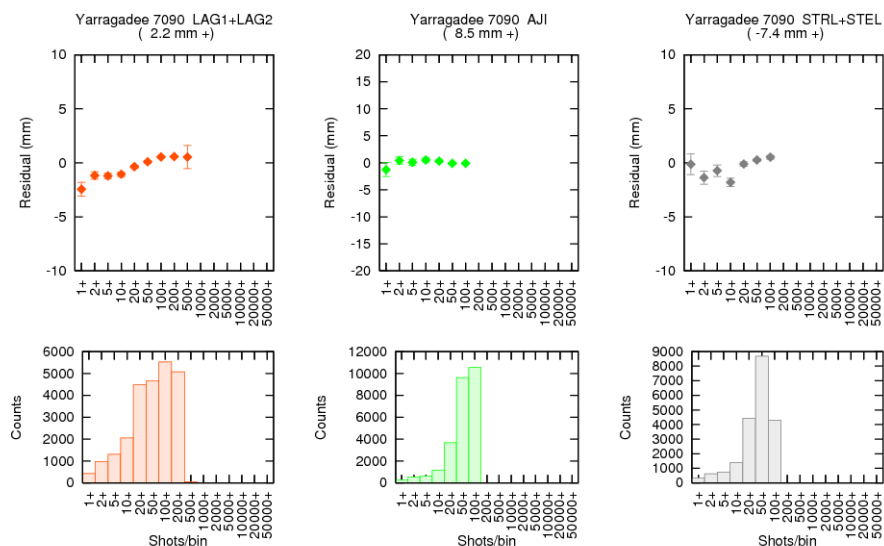**Figure 2 (a).** *Intensity dependence test. Single photon Herstmonceux station.*

Figure 2 (b). *Intensity dependence test. MCP Yarragadee station.*

It is strongly recommended for every ILRS station to look into the result, and consider how the intensity dependent bias can be removed if it exists. As proven in previous
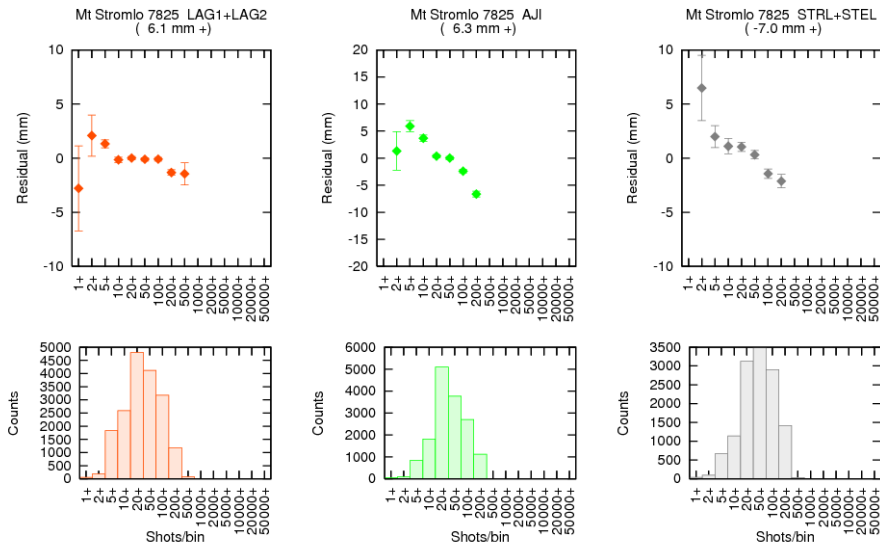
Figure 2 (c). Intensity dependence test. C-SPAD Mt Stromlo station.

studies (Otsubo and Appleby, 2004), the signal intensity is closely related to the elevation angle, and as a result the height component of station coordinates can be affected. This study probably underestimates the true intensity dependence. Note that the results from this study are just a guideline - it is the best to check the intensity dependence at each station, for example by inserting and removing the neutral density filter in front of the detector.

Range bias vs applied system delay

The alternative approach is the use of the applied system delay (given in the ILRS normal point format) as a sorting parameter.

The applied system delay is the value to be subtracted from the raw range observations, and it is not constant. Therefore it is to be regularly observed by ranging to terrestrial targets, what we call 'calibration'. There should not be any correlations between the range residuals and the applied system delay, in the ideal case. If there were, the station would have a systematic error in its ranging procedure to a terrestrial target or in its data processing stage.

We used the same set of the residual data as the previous section. At a number of stations, there have been jumps in the applied system delay itself probably due to some changes in optical or electronic path. Some stations seem to have multiple configurations (dual detectors, etc.) each of which gives different applied system delay. Such discontinuities themselves are not a problem at all as long as the reason is exactly known.

The bin size was set to the two-way range of 66 ps (1 cm in one-way distance). We applied the sorting procedure to the same 24 station as the previous section. The sorting procedure was chopped into a few portions for stations with large jumps. The graphs are also available at our website:

http://www.nict.go.jp/w/w122/control/pod/bias-delay-0506.pdf
(graphs for calibration dependent bias)

http://www.nict.go.jp/w/w122/control/pod/delay-0506.pdf
(auxiliary graphs for variation of applied system delay for the 1-year period)
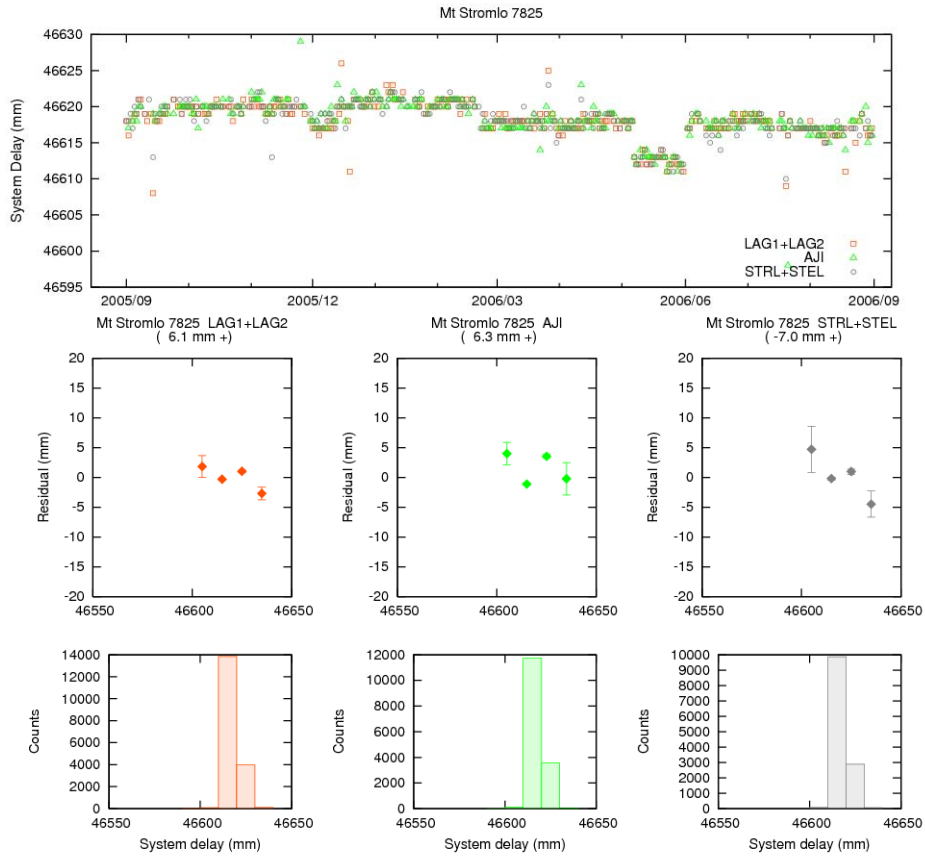
Figure 3 (a). *Calibration dependence test. Mt Stromlo station.*
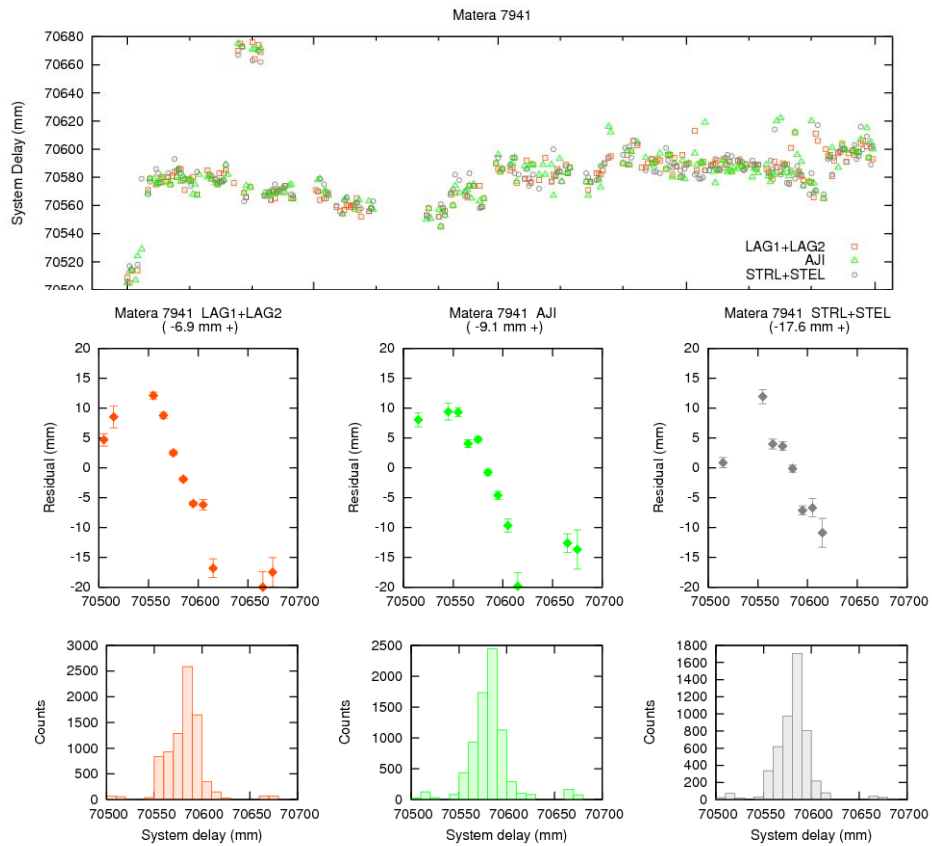

Figure 3 (b). *Calibration dependence test. Matera station.*

Two results are shown in Fig. 3 (a) and (b) among the 24 cases. The first case (Fig. 3 (a)) is probably the best one of all: Mt Stromlo. Its applied system delay has been very stable throughout the year, almost within ± 1 cm (top). There has been no significant calibration dependent bias (bottom). Such long-term stability of calibration ranging helps the long-term stability of satellite ranging. The next graph of Fig. 3 (b) shows those for Matera station. The stability of applied system delay is also good (± 3 cm) for this station. However, there is a steep negative trend for all three types of satellites. A possible reason is that a part of the variation in calibration ranging might not be true and therefore the raw observation would be 'wrongly calibrated' by the calibration procedure.

The long-term variation of terrestrial target ranging is hardly separable from the seasonal or secular variation of station height. Therefore, the result from this approach has a risk of sending a wrong alarm if the station coordinates experience unmodelled effects like loading displacement. It is strongly recommended for each station to understand why the calibration measurement varies and strive to reduce the variation.

Conclusions

In addition to the multi-satellite daily bias reporting system, we demonstrated the more precise ways for quality assessment of laser ranging data. We use the single shot returns per normal point bin, and the applied system delay, as a sorting parameter. Some correlations were found between the range data and these sorting parameters.

It is important to note that most of the information that is potentially useful to assess the quality is lost in the process of normal point generation. It is essential that each station performs extensive tests on site in order to eliminate any systematic bias and to keep the data quality stably high.

References

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