New Approach to Quality Check: Multiple Satellite and Intensity Dependence

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1. Introduction

The precision of laser ranging normal-point data is nearing the millimetres level. We have found it useful to feed a quick-look analysis back to laser stations since there are sometimes systematic errors in the ranging data. Several analysis centres are regularly assessing the data quality at centimetres accuracy through the range residual after the orbit determination process. They are providing analysis reports in a style of pass-by-pass range bias and time bias [1-5] or in a style of post-fit residuals themselves [5], and the feedback loop is operational on a weekly or even daily basis. The LAGEOS satellites are widely used for this; however, some centres analyse data for other satellites.

Communications Research Laboratory (CRL) has provided web-based bias reports for the LAGEOS-1, 2 and AJISAI satellites three times per week using our automated system [4] since 1997. This paper describes a testing status of a new approach for assesssing the behaviour of laser ranging data.

2. Multi-satellite bias report

At CRL, a new version of our CONCERTO software package has been developed in Java language (JDK 1.1 or higher) with up-to-date models mostly compatible with IERS Conventions 1996. Like the LAGEOS satellites, AJISAI data was found to be useful for assessing the quality of laser systems [4]. We have just increased the number of satellites for bias reports from three to seven by adding the STARLETTE, STELLA and two ETALON satellites. The range of altitudes and satellite shapes should make it possible for us to examine the behaviour of each ranging system and

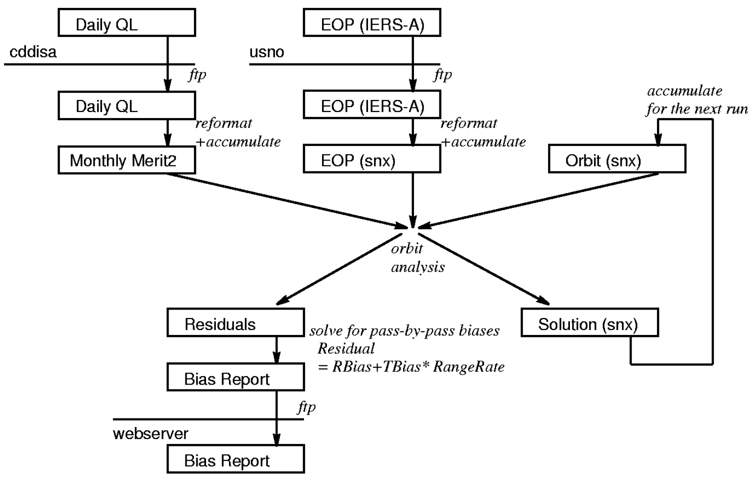

Fig. 1: Data flow of CRL bias reporting system.

to find problems resulting from the combination of a system and a satellite.

Every week a bias report covering the past two weeks is being generated. In the first stage in which the residuals are generated, the six orbital elements and some empirical force parameters are solved for every 7 days (LAGEOS), 14 days (ETALON) or 2 days (other low orbiters). Most of the station coordinates are from ITRF97 while some are added or revised by us. We use IERS Bulletin-A prediction for the earth orientation parameters. The "standard" centre-of-mass corrections are applied: 251 mm for LAGEOS, 558 mm for ETALON, 1010 mm for AJISAI, and 75 mm for STARLETTE and STELLA. The post-fit weighted-rms after estimating the best-fit orbits is typically 1.5-2.0 cm for LAGEOS, 1.5-4.0 cm for ETALON, 3-4 cm for AJISAI, 4-8 cm for STARLETTE, and 6-12 cm for STELLA. Using these post-fit residuals, a range bias and a time bias are estimated for every pass, and the biases are listed with 1-sigma formal errors.

The seven satellites cover 800 to 20,000 km in altitude, 5 to 150 ms in a two-way range. Received intensity differs by a magnitude of 10^4 between targets mainly because the link budget of laser ranging is proportional to $(\text{range})^4$. If a system has an intensity-dependent bias, multi-satellite analysis should detect it. The multi-satellite approach is also sensitive to the frequency bias, which is propotional to the range.

The seven satellites are spherical, but their sizes are quite different, ranging from 12 cm to 1.05 m in radius. Therefore, the retro-reflection spreads differently in time although strictly speaking the size is not a perfect parameter. For instance, the spread of the LAGEOS and AJISAI satellites is smaller due to uncoated backface of their corner cube reflectors. This satellite-dependent effect, the so-called satellite signature, is one of the major error sources in laser ranging. We expected the effect would be found in the multi-satellite analysis.

Another important point is that multi-satellite analysis can be used to assess a large number of passes. Even if a biased LAGEOS pass is obtained, one cannot always tell whether or not the pass was really biased. However, in many cases, biased data continue for multiple passes due to problems from calibration, meterological sensor, or operation error and so on. Listing many passes in a time series makes such problematic data more obvious. The analysis for STARLETTE, STELLA, and AJISAI are useful in evaluating the performance of those laser ranging systems that are concentrated on low-orbit satellites and obtaining insufficient LAGEOS observations.

We started testing the new analysis procedure in October 1999. The report covering two weeks is regularly updated at

http://www.crl.go.jp/hk/slr/bias/

We plan to automate the whole procedure in the future.

3. Intensity dependence

We need to overcome system biases due to differences in received intensity in order to attain millimetre accuracy. Single-shot precision is usually better when a return pulse is strong, but the variation of the received intensity can cause an offset error.

Although there is no straightforward information about intensity in ILRS normal-point data, we found the number of single-shot returns should be related to it. The number of single-shot returns in a normal-point bin should be

(return rate) × *(shot rate (per sec))* × *(bin size (sec))*.

The return rate somehow depends on the received intensity when it is sufficiently below 100 %, whereas the other two are usually constant numbers. In those stations whose ranging targets are switched more frequently than the bin size, the number of single-shot returns may not be a good parameter.

It is impossible to diagnose this effect at a pass-by-pass frequency. We need a large amount of data to extract millimetre phenomena from the post-fit residuals whose scatter is a few cm. The residual data generated from the regular weekly analysis were accumulated from October 1999 to June 2000. The averaged residuals for 24 stations sorted by the number of single-shot returns are shown in Figs. 2 A-D. The results for LAGEOS (two satellites combined), AJISAI, and STARLETTE are plotted. The results for other satellites were too noisy to detect any signatures. Intuitively, the range is likely to be measured shorter at a high energy due to a time-walk problem or a target signature effect, and some stations actually showed such a trend, especially for AJISAI, the largest target of the three.

4. Conclusions and future studies

Our quality assessment using seven satellites is providing laser stations with information useful for investigating their systematic problems. We are going to supply an analysis result once per week or even more frequently via the SLReport mailing list and our website. We also plan to improve our set of station coordinates in the near future although it will cause a discontinuity of estimated biases.

Using the number of single-shot returns per bin, the return intensity dependence of the range was detected for a number of stations. This is a tottally new approach to evaluating the quality of laser ranging data. Our results indicated that some stations have systematic trends that cannot be explained by a satellite signature effect alone.

This approach depends heavily on the quality of the station coordinates, so its result is less valid if they are not precisely determined in advance. Because of the nature of the least square method, some systematic biases are likely to be absorbed in the orbital parameters, especially since they are probably systematically related to the elevation angle. As a result, the estimated bias in the current analysis procedure may be underestimated, especially for heavily weighted "good" stations. In particular, as we usually use LAGEOS data to estimate station coordinates, systematic bias in LAGEOS data might remain hidden. The target signature study suggests the effect should be roughly 20% that of AJISAI, but we did not find that in this study.

More investigation is strongly recommended at local stations because this approach has several limitations. Direct measurement is possible, for instance, by examining the shot-by-shot range difference of different return energy returns or by measuring the behaviour of a timer [6].

References

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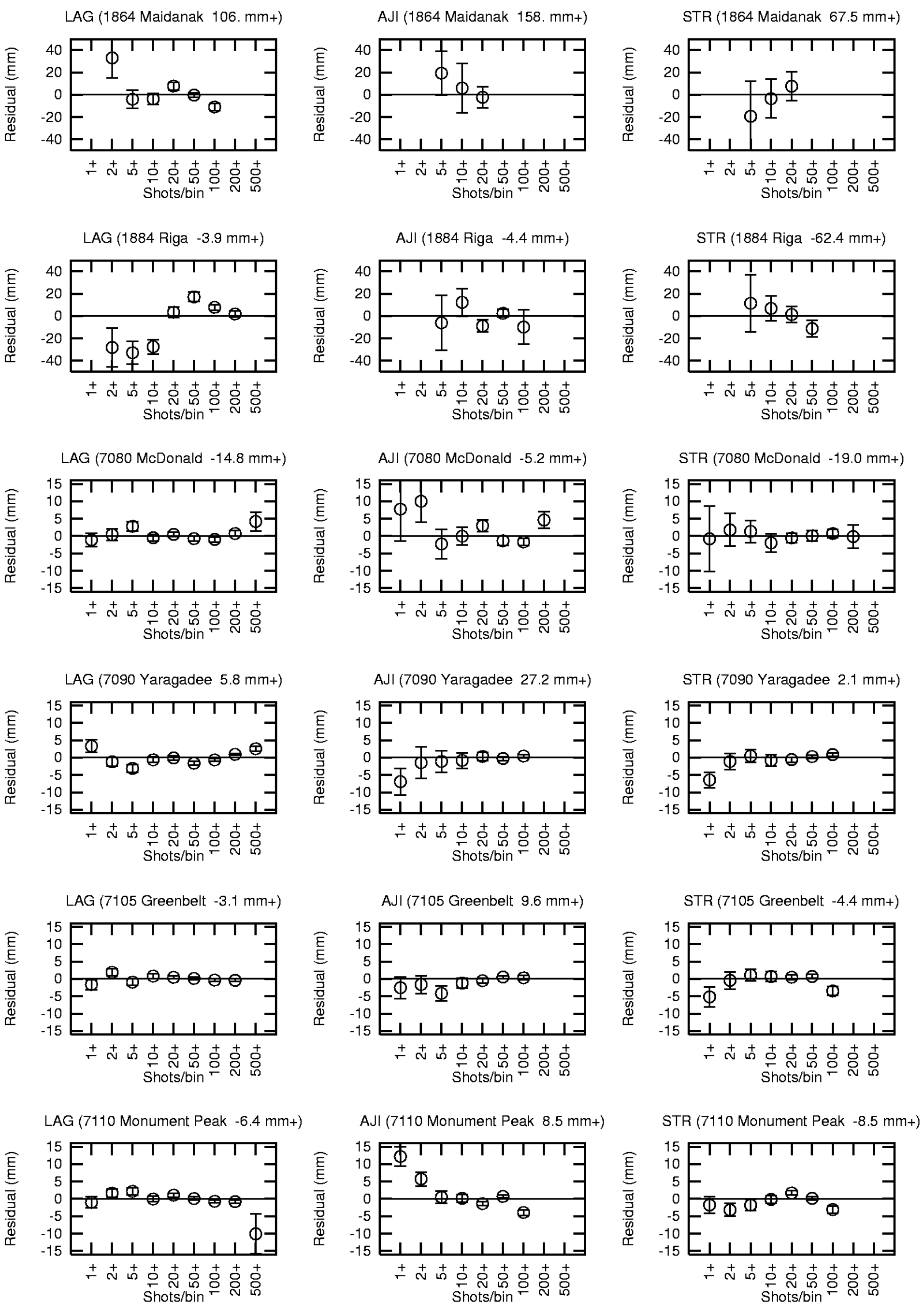

Fig. 2A: Range residuals sorted by number of single-shot returns / bin.

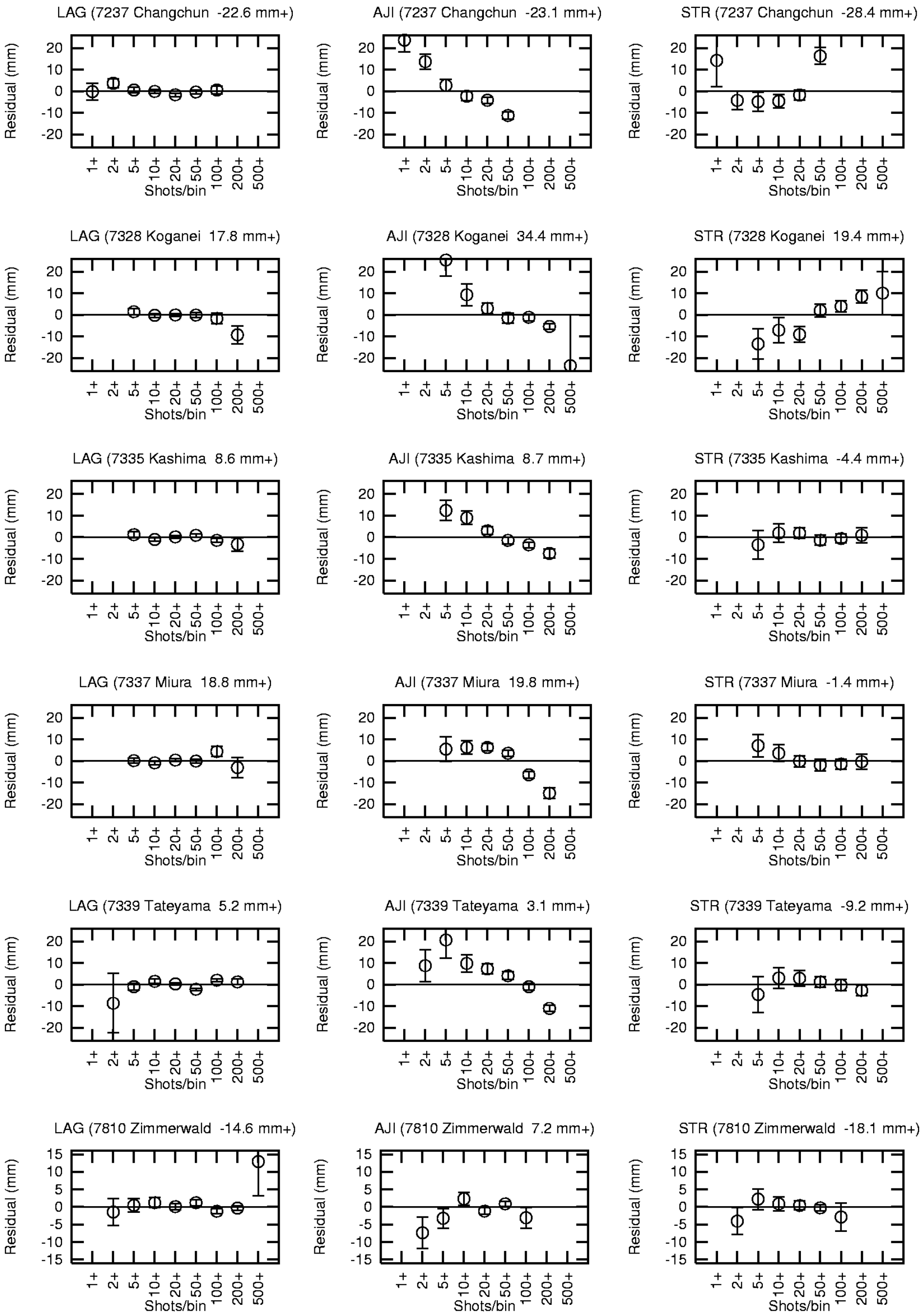

Fig. 2B: Range residuals sorted by number of single-shot returns / bin.

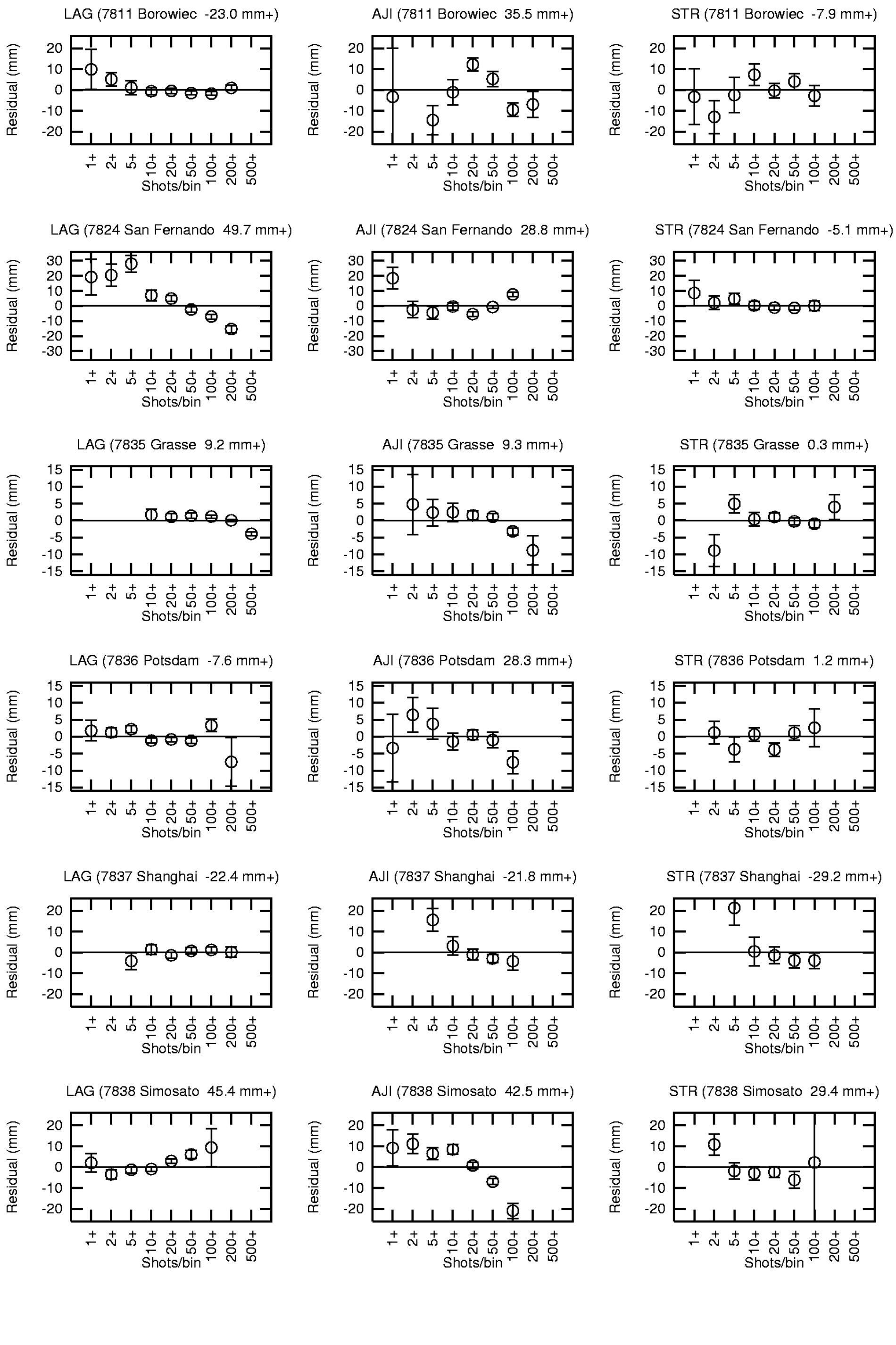

Fig. 2C: Range residuals sorted by number of single-shot returns / bin.

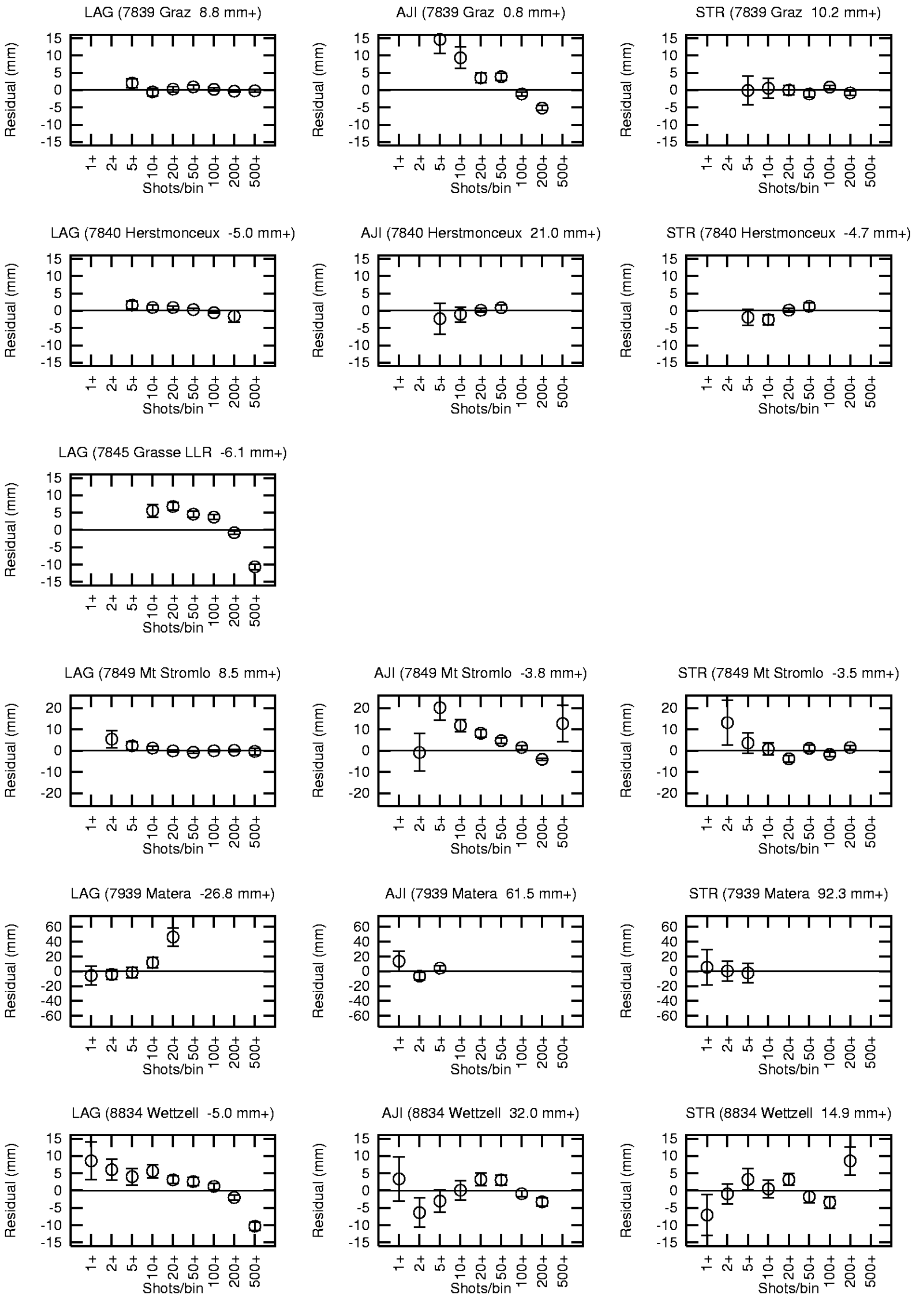

Fig. 2D: Range residuals sorted by number of single-shot returns / bin.