A New Approach to Quality Check (2) - Range Bias vs Applied System Delay

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1. Introduction

The laser ranging technology has attained the millimetre precision; 3 to 8 mm in a single-shot basis and 1 mm or better in a normal point basis. To quickly assess the quality of high-precision laser ranging data, several analysis centers regularly analyse recent data and distribute the results via email and/or ftp/www. The two LAGEOS satellites are most intensively analysed [1-3], but other satellites are also being used to check the data quality more comprehensively [4,5].

Communications Research Laboratory (CRL) started the 3-satellite (two LAGEOS and AJISAI) bias report in 1997 [4] and enhanced it to the 7-satellite (plus STARLETTE, STELLA and two ETALON) analysis in 1999 [5]. It is available at

http://www.crl.go.jp/hk/slr/bias/ and ftp://ftp.crl.go.jp/pub/mt/cybernetics/slrqc/

and also via the SLReport mailing list.

We also proposed a new concept for quality evaluation of laser ranging data; it is possible to see the energy-dependence of range measurement by sorting the post-fit residuals by the number of single-shot returns per normal point bin [5]. This paper deals the update of the results from this method and a new method to detect systematic error sources in a calibration stage.

2. Range bias vs intensity (update)

To see the change from the results obtained two years ago [5] we made a similar analysis using the recent data. We took a 300-day span from Jul 2001 to May 2002. We used the analysis software "concerto" v 3.41 developed at CRL. The aim of this analysis was to generate a set of residuals after precisely fitting the orbit. The station coordinates were fixed to ITRF2000 for most of the stations but some are added or readjusted. The range biases were adjusted every 50 days. The orbit was solved for every 4 days for LAGEOS and every day for AJISAI and STARLETTE. The post-fit residual rms (root mean square) was 1.2 to 1.5 cm for LAGEOS-1 and LAGEOS-1, 2.0 to 2.5 cm for AJISAI and STARLETTE.

The residual profile with respect to the number of single-shot returns per bin was generated for each of laser ranging station. As the number of single-shot returns per bin is strongly related to the average intensity during the bin, the profile is expected to show the systematic range bias dependent on the return energy. The profiles for the top-25 high-productive stations are shown in Fig. 1A to 1E. Major differences from our previous studies [5] are the period of data (from 1999-2000 to 2001-2002) and the terrestrial reference frame (from ITRF97 to ITRF2000).

Let us roughly categorise the stations to some groups:

Cleanly flat (mostly within ±5mm):

      7080, 7090, 7105, 7110, 7210, 7403, 7501, 7806, 7810, 7840 and 7848

Negative trend for LAGEOS and AJISAI (and sometimes STARLETTE):

      1884, 7237, 7820, 7824, 7832, 7835 and 7845

Flat for LAGEOS but negative trend for AJISAI (and sometimes STARLETTE):

      7838, 7839 and 7849

where some stations are too noisy to tell. In the light of satellite signature studies, the spread of retroreflection can cause intensity-dependent systematic biases to C-SPAD systems. It amounts to about 1 cm for LAGEOS and 4 cm for AJISAI. This effect was clearly seen in this categorization: most of the stations fallen into the last two groups adopt C-SPAD detectors and operate mostly at multiphoton level.

It is likely the return energy gets weaker when the satellite flies at a low elevation. If a station has an intensity-dependent bias, the estimated parameters such as the station height and the range bias are contaminated. This analysis method requires the post-fit residuals, so the parameter estimation can partly absorb such a systematic error, and therefore it will underestimate the intensity dependence. In reverse, if the station coordinates are erroneous, the obtained profile can send a false alarm.

The best solution is that each station pays more attention to its data – the shot-by-shot intensity-dependent variation can actually be tested on site [6].

3. Range bias vs applied system delay

The new approach is the use of the applied system delay (given in the ILRS normal point format in a 1-ps resolution) as a sorting parameter. The two-way range in the ILRS format is calculated on site:

      (two-way range) = (raw obs) – (applied system delay)

where

      (applied system delay) = (two-way range to target) – (two-way telescope-target distance).

Ideally there should not be any correlations between the range residuals and the applied system delay. If there were, the station is considered to have a systematic error in ranging to a terrestrial target or in subtracting the system delay from the raw observation.

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 two configurations (dual detectors, etc.) each of which gives different applied system delay. The sorting procedure should be chopped into a few portions for such stations.

The bin size was set to the two-way range of 20 ps (~3 mm in one-way distance). We applied the sorting procedure for the 25-station data set. Some typical results are shown in Fig. 2A to 2C. The best result was found in the Graz (7839) station; the applied system delay itself scatters within merely 200 ps in each of the portions (there were two portions due to a 600-ps jump in Nov 2001). The average residuals per bin were fairly flat around zero which means no correlation between the applied system delay and the satellite range measurement. The second case (McDonald (7080) in Fig. 2B) and the third case (Changchun (7237) in Fig. 2C) showed the pattern that the range get smaller when applying a large system delay. Especially in the top of the Changchun case, the slope was almost 1:1, which can be explained by an error in terrestrial target ranging despite a proper observation to a satellite.

Here is rough categorization, although the graphs are not included in this paper:

Cleanly flat: 7839, 7840, 7845 and 7849

Slope or systematic pattern: 7237 (almost 1:1)

Jump in different portions: 1884 and 7249

where the profiles of some stations were too noisy to tell.

Note that this residual analysis can be affected by a long-term (annual/seasonal) change of the station position such as atmospheric loading. If the seasonal variation pattern of system delay is somewhat similar to that of the station position, there is a possibility to send a false alarm. As mentioned in the previous section, each station should test any potential error sources for the accurate calibration.

4. Conclusions

In addition to the multisatellite weekly bias-reporting system, we demonstrated the enhanced method for quality assessment of laser ranging data. The new approach is the use of the applied system delay as a sorting parameter. We detected correlations between the range data and the applied system delay, which probably comes from erroneous calibration.

Full reports for the 25 stations are available at our website:

http://www.crl.go.jp/ka/control/pod/bias-intensity.pdf (bias vs intensity)

http://www.crl.go.jp/ka/control/pod/bias-delay.pdf (bias vs applied system delay)

Once the range data are released from a station, most of the information that is potentially useful to assess the quality is lost. 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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[6] G. M. Appleby and P. Gibbs, "Monitoring potential range biases in single-photon SLR systems," Proc. 9th International Workshop on Laser Ranging Instrumentation, Annapolis, 1, 92-102, 1994.
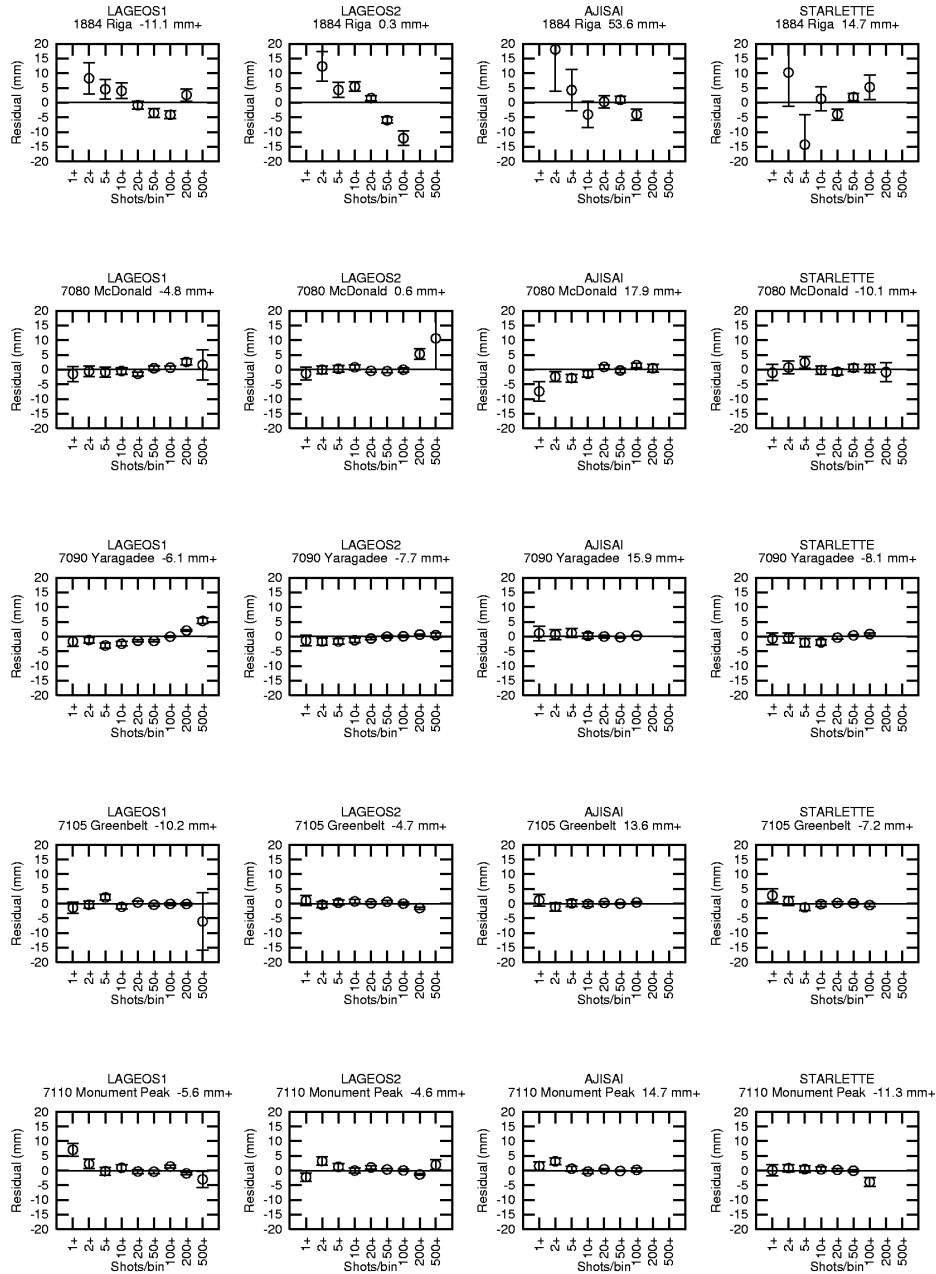
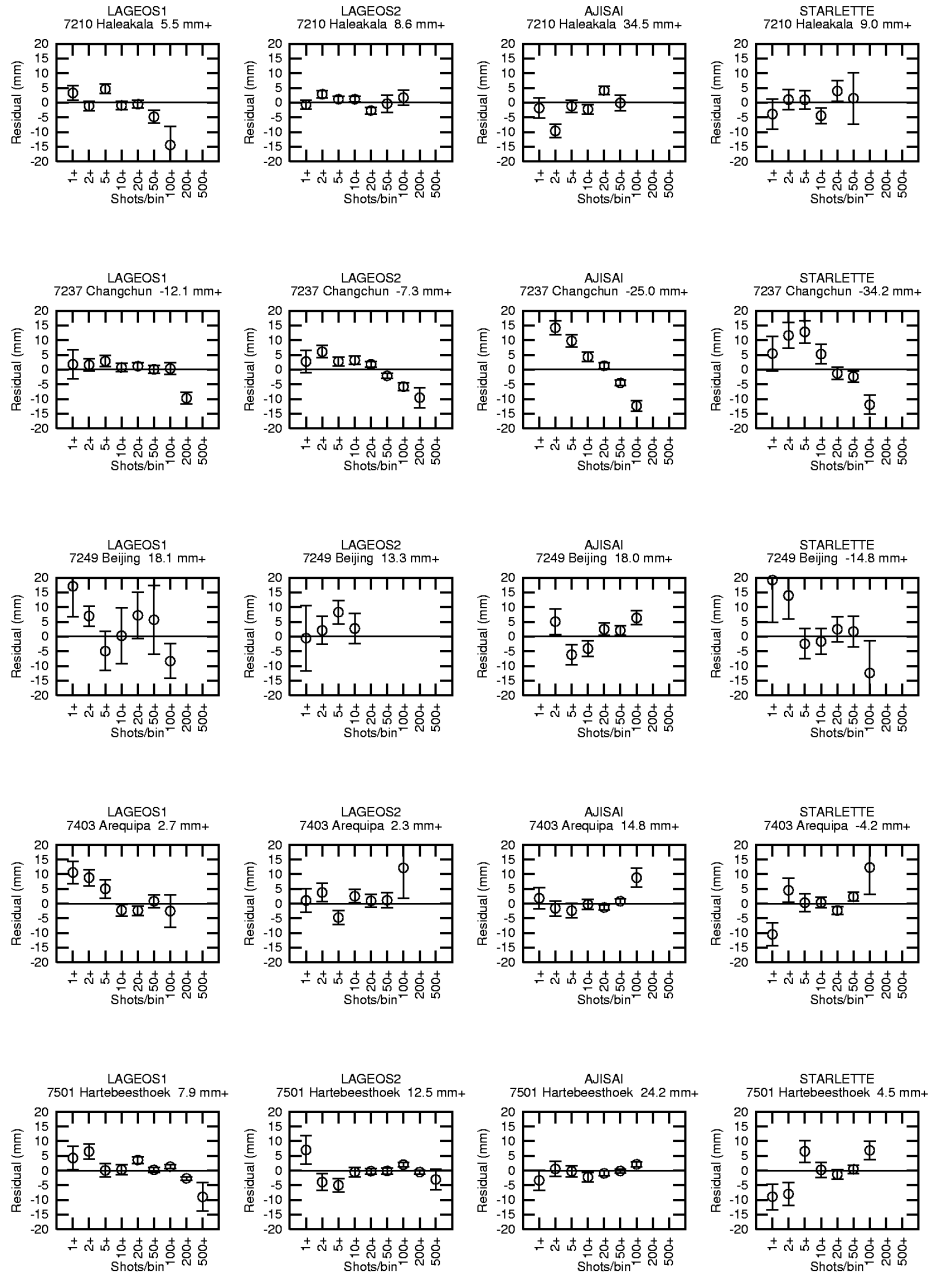Fig. 1A: Range residuals sorted by number of returns per bin.

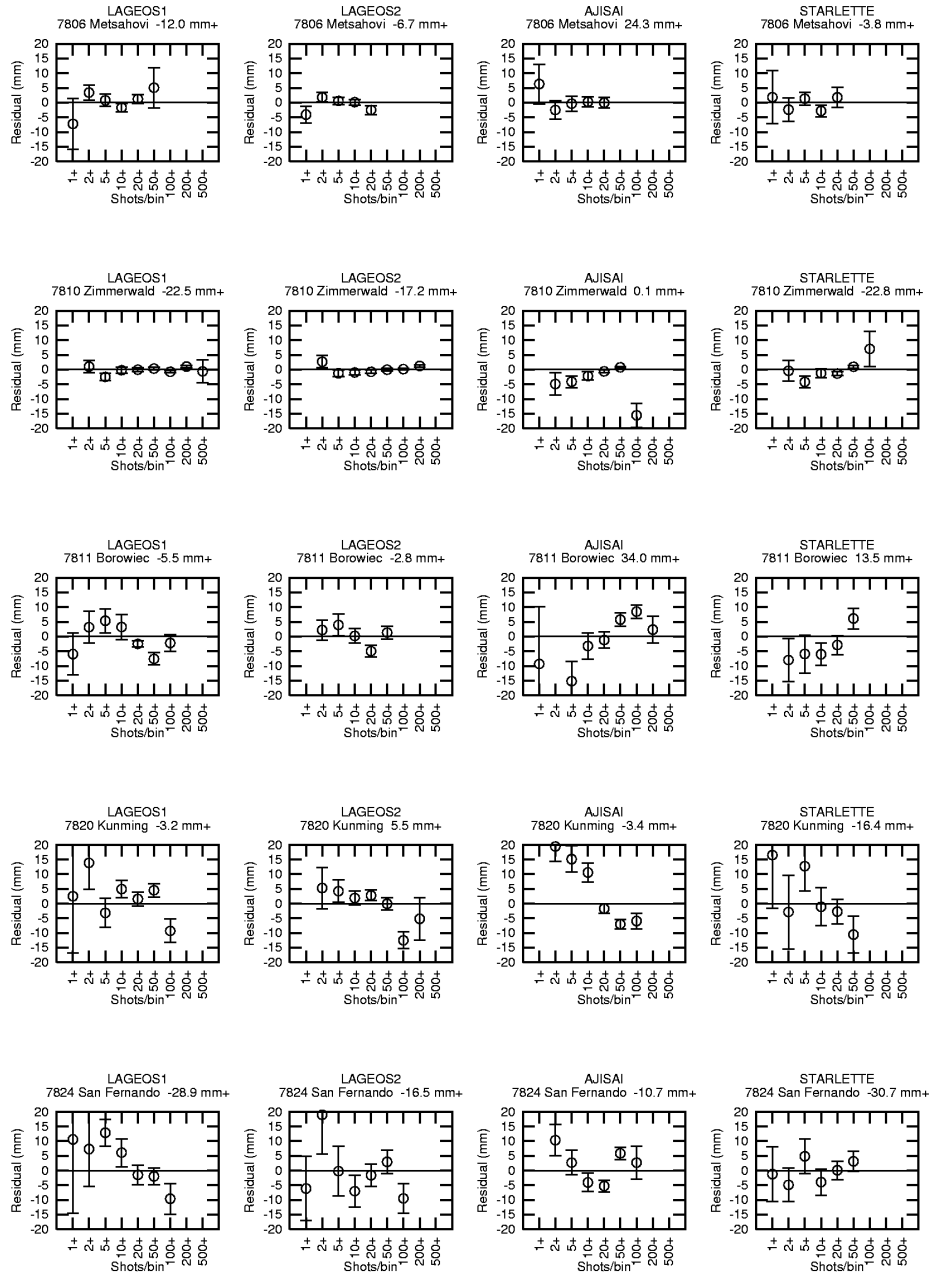Fig. 1B: Range residuals sorted by number of returns per bin.

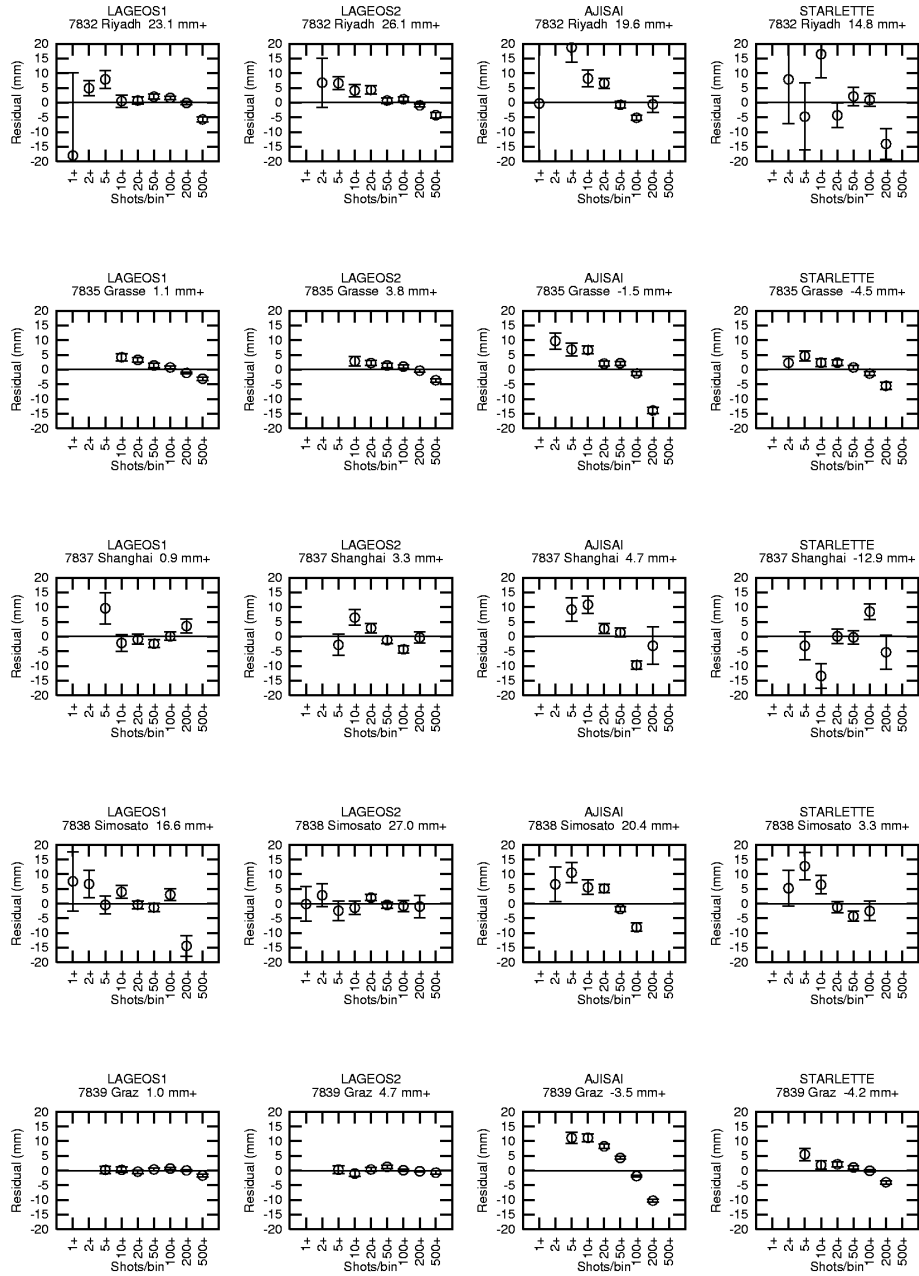Fig. 1C: Range residuals sorted by number of returns per bin.

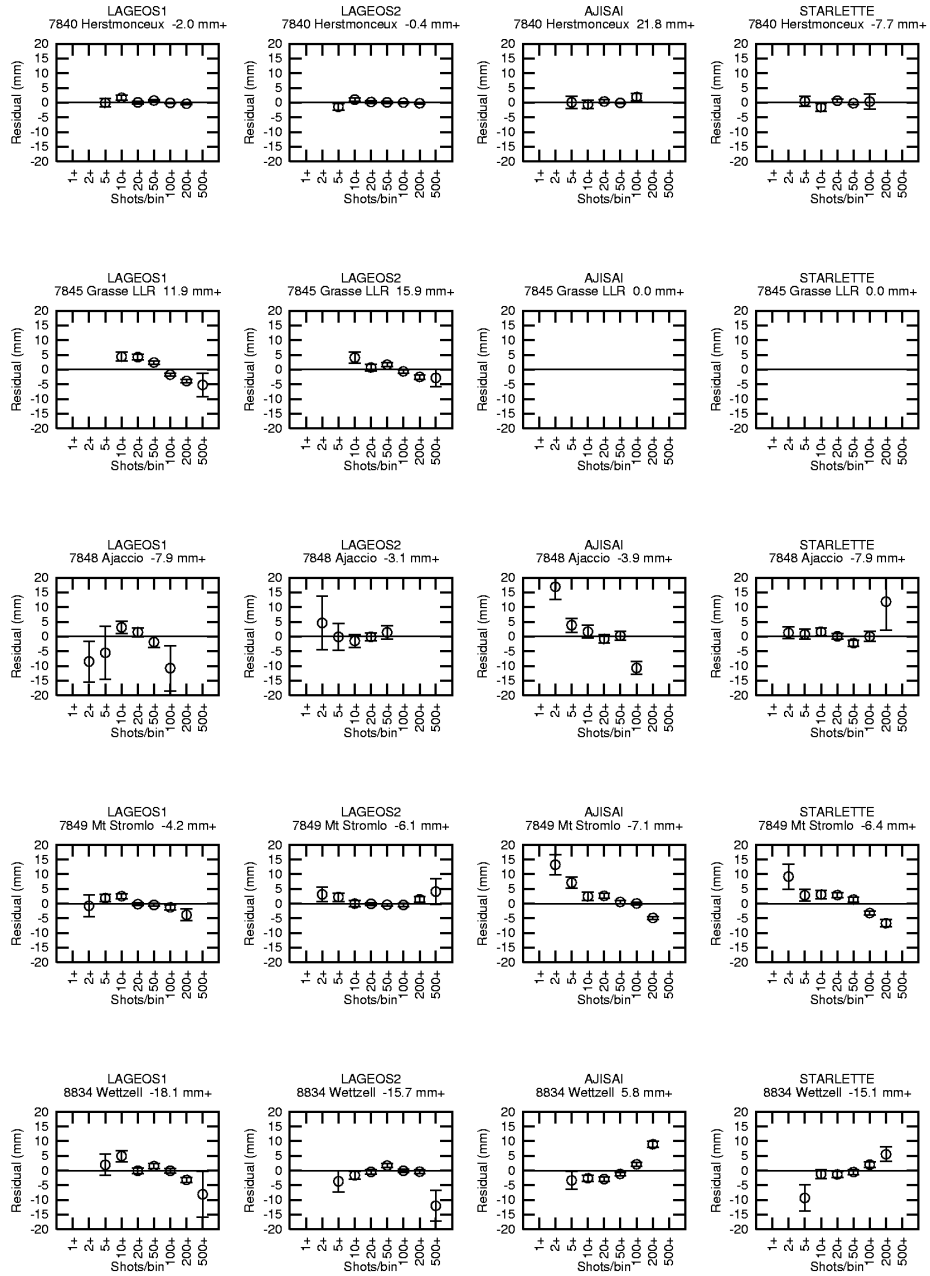Fig. 1D: Range residuals sorted by number of returns per bin.

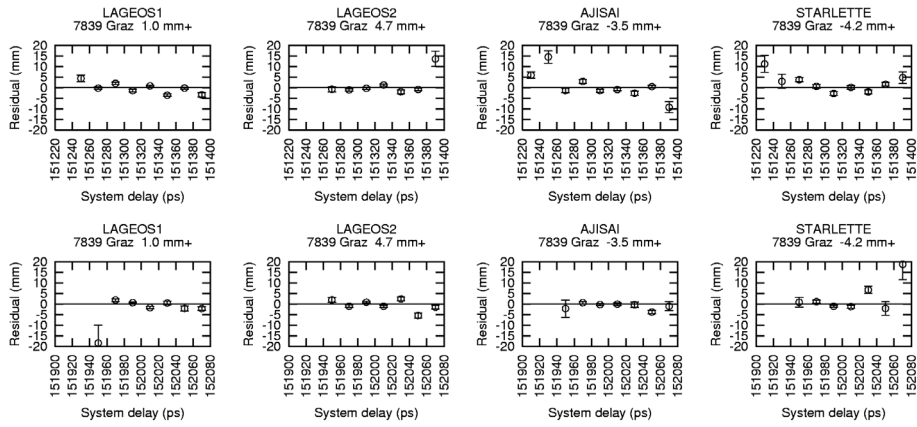Fig. 1E: Range residuals sorted by number of returns per bin.

Fig. 2A: Range residuals sorted by applied system delay. Graz (7839).
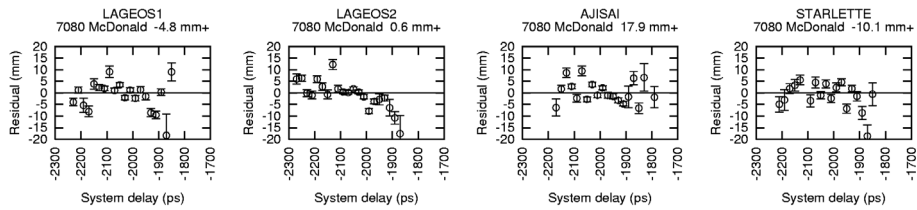
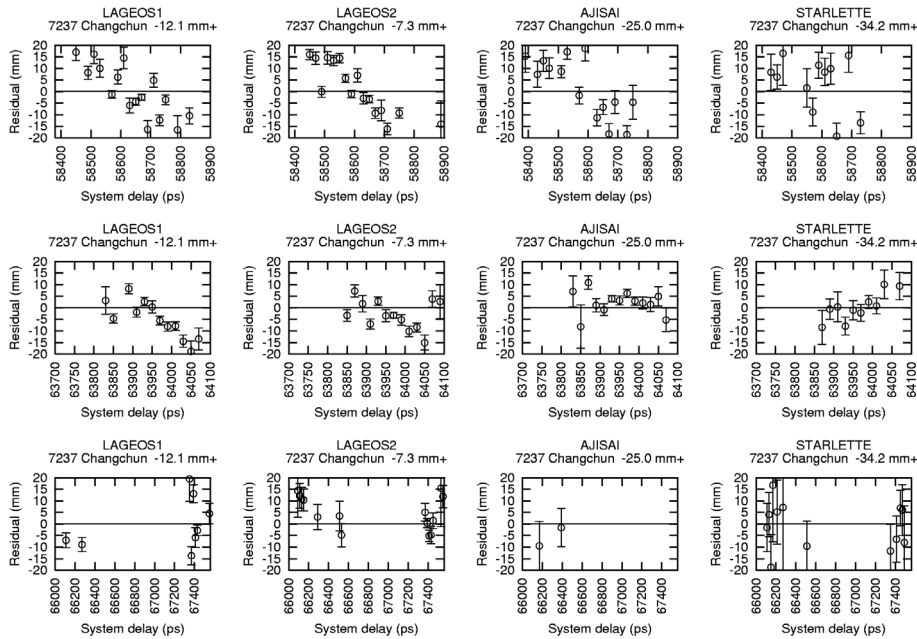Fig. 2B: Range residuals sorted by applied system delay. McDonald (7080).

Fig. 2C: Range residuals sorted by applied system delay. Changchun (7237).