Systematic Range Error 2013-2014

Toshimichi Otsubo (t.otsubo@r.hit-u.ac.jp)
Hitotsubashi University, Kunitachi, Japan

Introduction

As the second half of our "two-fold" quality check [1], this paper deals with the in-depth problem detection procedure and results which requires a long-term data set. In our previous study [2], the post-fit residuals of precise orbit analysis are useful to detect systematic behavior of laser-ranging observations. The intensity (returns per normal point bin) and the system delay were used in the study [2], and we not only repeat these tests but also apply a similar procedure newly for four parameters.

Analysis scheme and POD configurations

The whole procedure is illustrated in Fig. 1. It is important to accumulate a long-term data set so as to average out random noise and curb one-off and short-term issues.

In the first stage ("1-year batch POD" in Fig. 1) we took 5 satellites, i.e., LAGEOS 1+2, AJISAI, STRLETTE & LARES, spanning one year from July 2013 to June 2014. One-year data span is expected to reduce the mapping of any annual (unmodelled or imperfectly modelled) signals into the final results. We used our "c5++" software for the orbit determination.

The overall configuration of the orbit determination is as follows:

- Orbit: 5-day arc for LAGEOS-1 and -2. 3-day arc for LEOs (Low Earth Orbiters).
- Station-dependent center-of-mass correction applied for LAGEOS-1, -2 & AJISAI. Constant standard values applied for STARLETTE and LARES.
- Acceleration parameters: Gravity field 4x4 solved for as 1-year common parameters, and 5 empirical parameters also solved for each satellites twice per arc.
- Station coordinates: all solved for with loose constraints. Velocity fixed to SLRF2008.
- Range bias: solved for per station per satellite types ("LAGEOS-1&-2", "AJISAI", "STARLETTE", "LARES").

and we get the post-fit weighted RMS is 7-8 mm for LAGEOS 1 and 2, and 13-22 mm for

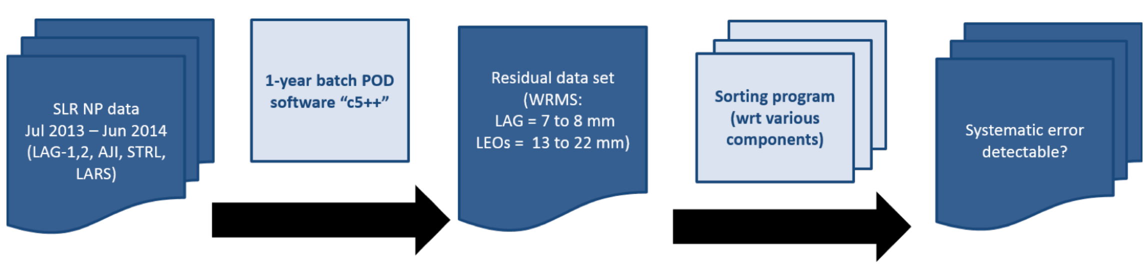

Fig. 1: Analysis procedure of the long-term in-depth quality check.

other LEOs.

In the second stage ("Sorting program" in Fig. 1) we develop short script (Perl) programs that stratify the residuals by six parameters. Most productive 25 stations are looked into. The following sections are dedicated to the six tests.

Graphs for the Greenbelt (7105) station are presented in this paper, but all the plots for the 25 stations are available at:

http://geo.science.hit-u.ac.jp/research-en/memo-en/systematic-range-bias-2013-2014?set_language=en

Test 1: Single-shot returns per normal point bin

The number of single-shot returns is recorded for each normal point. It should be highly correlated with the intensity of a return signal, with the exception at the both ends of a pass and the satellite switching (interleaving).

Fig. 2 is a sample set of plots for the Greenbelt (7105) station. The mean of residuals (top), the residual RMS (middle) and the frequency (bottom) are shown. If there are a

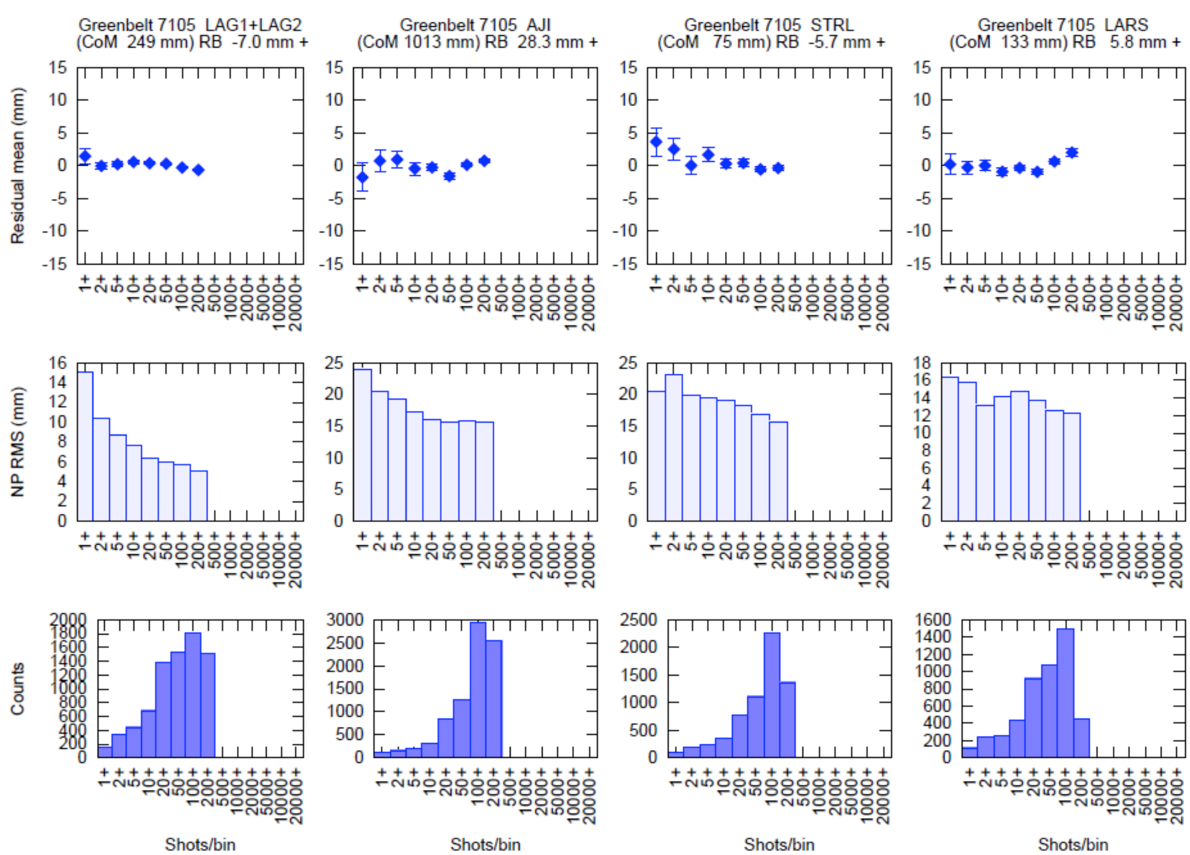

Fig. 2: Example of Test-1 plots (Greenbelt).

positive or negative trend in the residual mean (top), it is likely that an intensity-dependent error exists in the station.

It also depends on the target signature. As Ajisai is the largest among them, it clearly indicates the intensity dependence. The measurement is stable either at single (or zero) photon or at a stably high energy [3]. It is highly recommended that a station performs an on-site measurement test of changing energy level (such as [4] and [5]) especially if a negative or positive trend is seen.

The ILRS recommends a minimum single-shot returns per normal point: 6 for daytime and 3 for nighttime ranging. However, there are a number of cases that 1-2 shot/bin data are included.

Test 2: Single-shot RMS of a normal point bin

The single-shot RMS is recorded for each normal point. This is considered to be related to the intensity (likely case: weak signal → large scatter) and also to the noise rejection procedure (tight rejection → small scatter). It is also possibly related to the atmospheric delay.

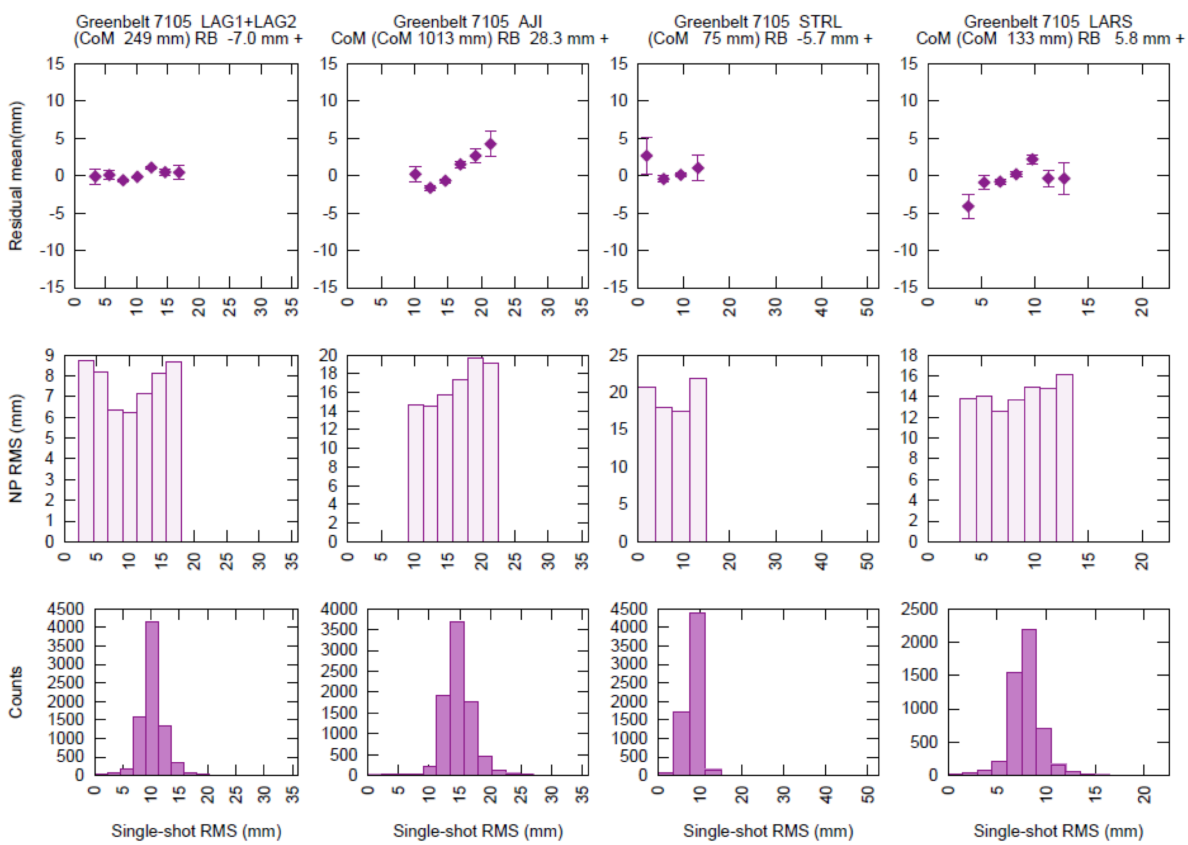

Fig. 3: Example of Test-2 plots (Greenbelt).

Fig. 3 shows the behavior of Greenbelt data. Looking through the 25 stations, there are cases that a positive/negative trend is likely to be linked with the Test 1, but there are also some cases that a positive/negative trend is only seen in Test 2.

Although it does not point a problem clearly, stations should strive to understand why the residual RMS changes in time or pass by pass. We point out that unrealistically small RMS (< calibration RMS) are sometimes given.

Test 3: Applied system delay

Laser-ranging data are always calibrated so that the variation of the internal system delay is cancelled. It is not easy to calibrate at picosecond accuracy. The majority of current ranging stations perform a set of terrestrial target ranging before and after a pass and sometimes more often. Some stations can measure the system delay using an internal calibration target in real time.

In the stratifying stage, first of all, we observe a huge station-by-station difference in the range (variation) of the applied system delay itself: from only a few tens of picoseconds throughout the year in the smallest case, to over 1 ns in the largest case, excluding the cases of system change or upgrade. Although this variation does not directly affect the observation precision, it is important for a station to monitor it and understand the reason.

The residual mean and counts for Greenbelt is given in Fig. 4. There are some stations that negative, sometimes close to 1:1, trends are detected. A negative 1:1 trend means that the variation in terrestrial target ranging does not match satellite ranging at all. Unlike the first two tests, the system delay is likely to have temperature dependence, and

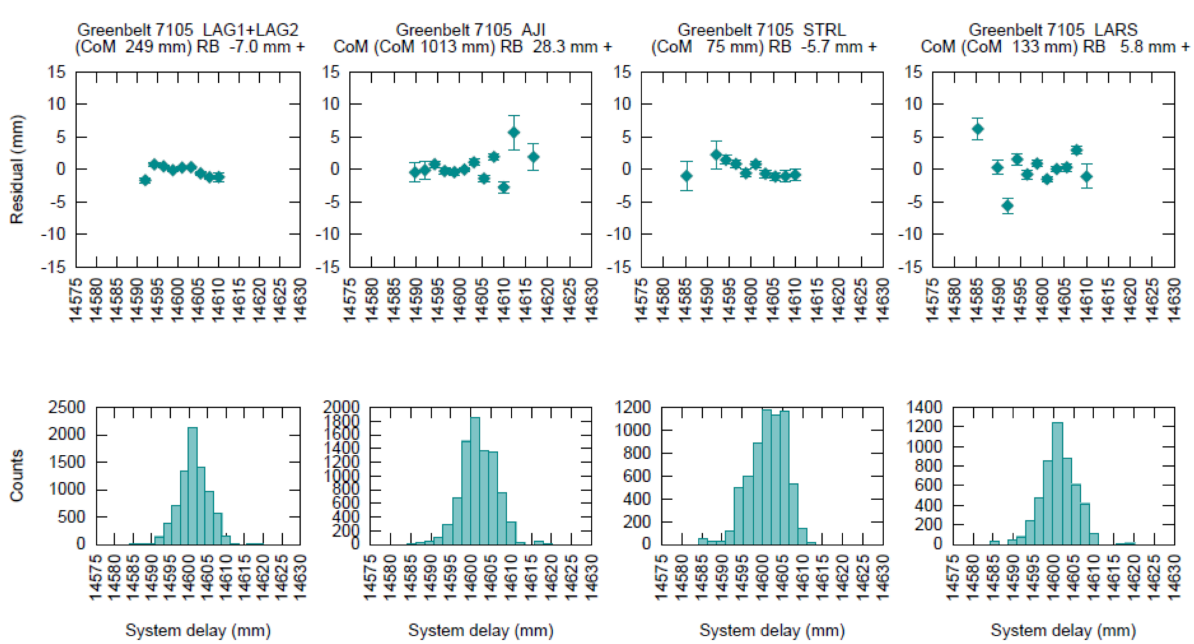

Fig. 4: Example of Test-3 plots (Greenbelt).

consequently annual variation. Therefore there is a risk of extracting a different annual signal.

Test 4: Time to the nearest calibration

As the system delay varies in time, the distance to a terrestrial target should be monitored frequently enough to compensate the variation. The required frequency of such calibration should be dependent on the stability of the system delay, and there have been no quantitative discussion about the optimal frequency although it has been generally told to do it every hour.

It should be noted that many stations provide only one calibration record per pass, even if they seem to do twice or more. There is seemingly no calibration after the observation in the example of Greenbelt (Fig. 5), but they actually do it before and after a pass. Similar issues are found in a number of stations. The current observation data format (CRD) can flexibly accommodate multiple sets of calibration records, and the author recommends every station to leave their calibration data as it is.

There are also some stations who do not track their calibration target often enough. The

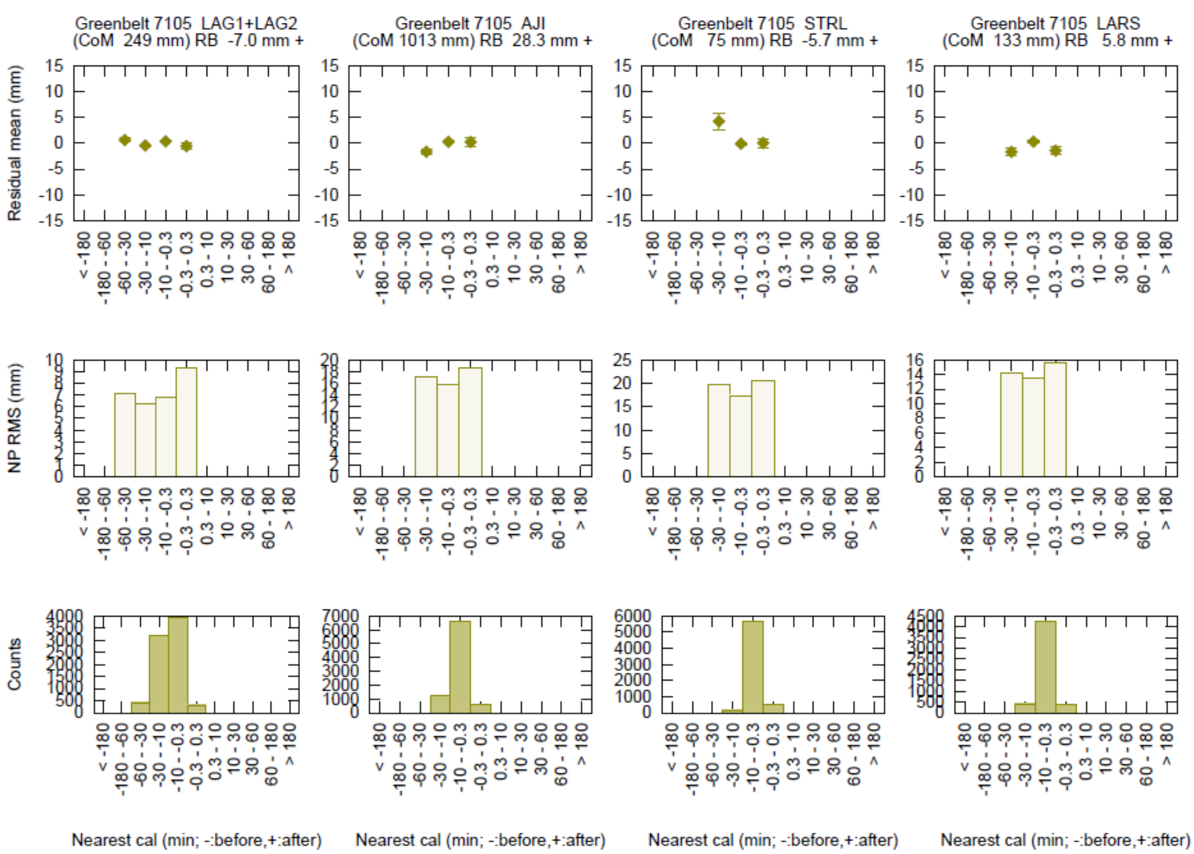

Fig. 5: Example of Test-4 plots (Greenbelt).

time interval sometimes exceeds 3 hours, and the data quality (the normal-point residual RMS) is found to be poor in such a case. These stations should improve the calibration sequence.

Test 5: Range rate

Range rate indicates the coverage of a pass, that is, from the horizon (negative) via the closest point (0) to the horizon (positive).

The stratified plots are shown for Greenbelt in Fig. 6. Like this case, data should be distributed almost symmetric in negative and positive range rate. However, there are less ideal cases that ranging observation seems to be stopped far before the end of a pass when the data distribution has a peak at the negative side.

The "U" shape trend clearly seen in Ajisai is likely to be related with the intensity-dependent measurement (Test 1) because intensity is also correlated with the elevation angle. This test partly suggests an imperfect orbit determination as similar patterns remain in the stations located nearby. Nevertheless, if there is a consistent positive or negative trends, it is highly suspected that there should be a clock error, i.e. the time tag

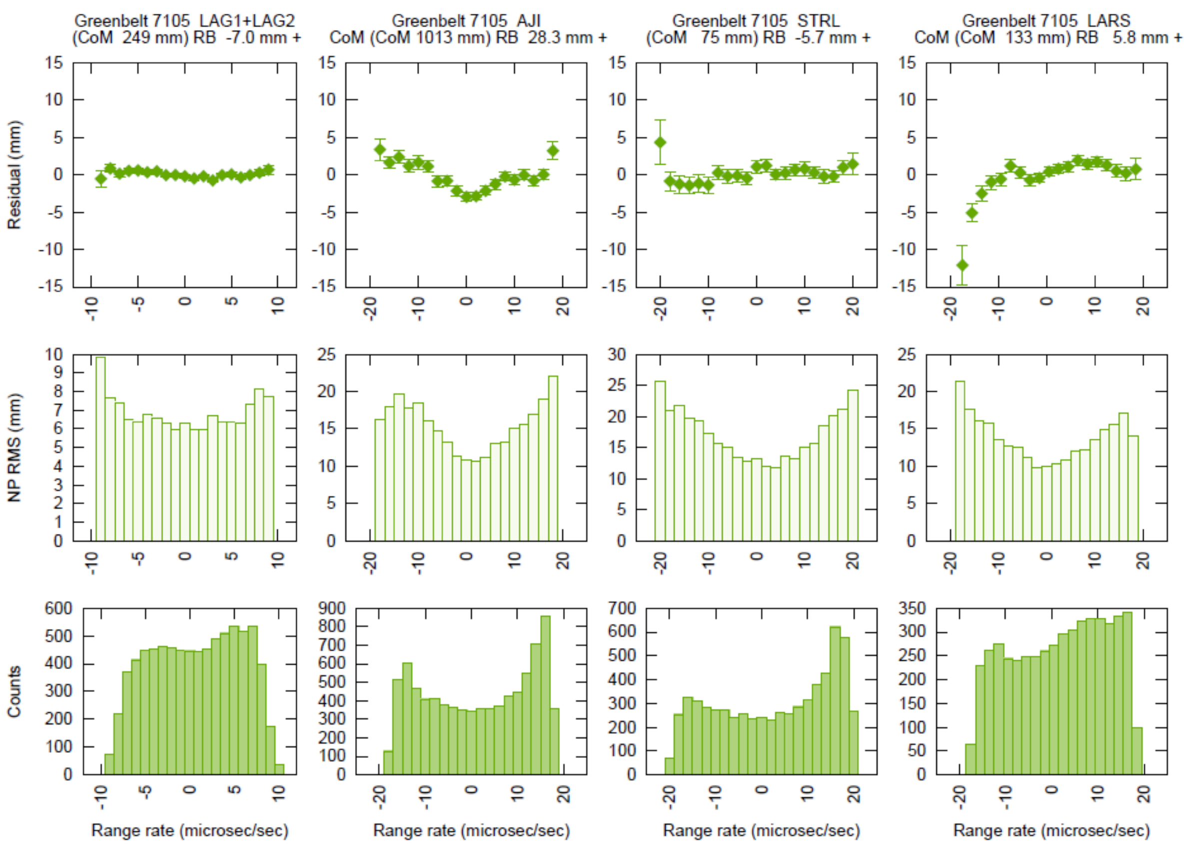

Fig. 6: Example of Test-5 plots (Greenbelt).

being significantly deviated from UTC.

Test 6: Time of day

Daytime ranging is sometimes disturbed by sunlight, and the temperature changes at a daily cycle. Laser ranging stations often have different configurations, such as wavelength filters, in daytime and nighttime. Still, it is crucial that the range measurement consistent throughout 24 hours.

Time of day, approximated just by subtracting the longitude from the tagged UTC time, is used as a sorting parameter like Fig. 7. Greenbelt is one of 24-hour-operational stations, but there are stations being operational only in a limited time of day. Different day/night patterns are seen in LAGEOS and LEOs.

Although it requires a large number of good observations to obtain a reliable result especially in LEO cases and an imperfect orbit model makes the signal noisy, there are some stations where a day/night difference is clearly seen. They should strive to find the cause and remove the difference.

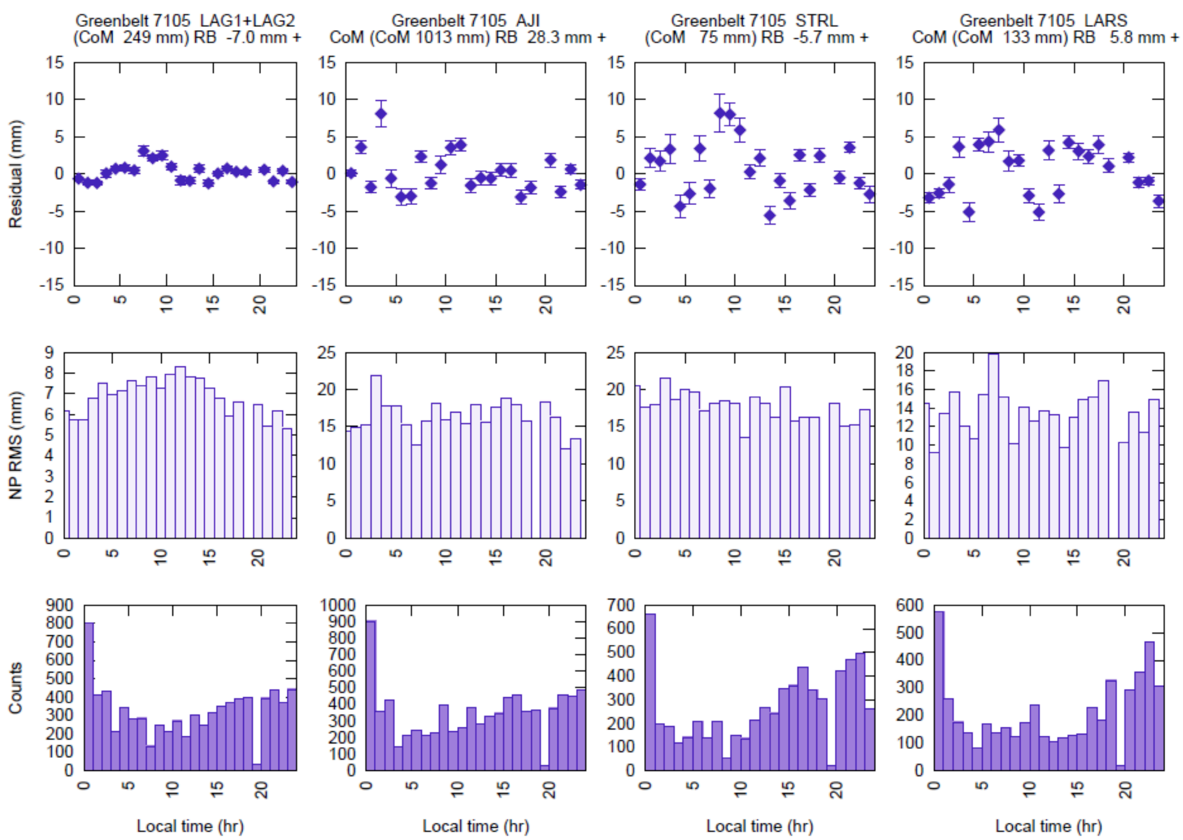

Fig. 7: Example of Test-6 plots (Greenbelt).

Conclusions

Residual analysis is found to be very powerful to extract mm-order systematic behavior. Six parameters are chosen to evaluate the in-depth quality of each stations. Station managers are expected to see the graphs, and, if they find a systematic trend, they should look into their systems. High and stable productivity is required to obtain reliable information about the quality.

It should be noted that such systematic biases have contaminated geodetic solutions, not just its coordinates but also global parameters.

References

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