Systematic SLR Errors Detected in Precise Orbit Determination

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Harmless random noise

The satellite laser ranging (SLR) data basically consists of the time tag and the two-way range measurement. Neither of them is perfectly measured due to a large number of error sources. The measurement errors are in general categorized into random errors and systematic errors. SLR systems are often evaluated by its single-shot RMS (root mean squares) given in the CRD (Consolidated Laser Ranging Data Format) data, which is just a part of the random errors. Systematic errors are hardly seen in the CRD data directly, and we apply an orbit determination process to detect them as shown in the next section.

Here let us have a very rough discussion and calculation about how large single-shot RMS will be accepted to achieve the 1-mm goal of GGOS (Global Geodetic Observing System). Let us assume an ideal and unrealistic case where there are zero systematic errors. Note that random error is reduced in proportion to the square root of the number of observations. The geodetic community is being requested to provide a 1 mm accurate TRF (terrestrial reference frame) which primarily consists of set of worldwide station coordinates. Assuming the 1 mm accuracy is defined in a monthly basis, a 100 set of 1 cm accurate station coordinates will roughly suffice, which can be achieved by 4-5 sets (about a weekly solution) of 20-25 stations' network. Then, assuming that a station yields 100 normal-point observations per week, a normal-point observation can be 10 cm accurate. Lastly, assuming a typical normal point is made of 10,000 single-shot observations in a state-of-the-art kHz SLR system, the accuracy requirement for a single-shot observation can be surprisingly low: just 10 metre!

This numerical discussion indicates that an SLR station with a meter-level single-shot RMS can even contribute to constructing a high-accuracy TRF. In reality, however, we have not reached a 1 mm accurate TRF due to systematic error sources in observations (the scope of the following section), and also systematic error sources in orbit determination process (to be investigated in the future).

Systematic trends in 2017-2018 SLR data

Post-fit residuals after precise orbit determination still contain some information about the quality of SLR observations. Although we can detect just a part of possible systematic errors, the residual analysis is useful to make a diagnosis of each station. In this study, we look at the global SLR data from July 2017 to June 2018. The software "c5++" is used for orbit determination stage and the analysis procedure is almost common with Otsubo (2014) and Otsubo et al (2016). Post-fit residuals of LAGEOS-1+2 (combined), LARES, Ajisai, and Starlette+Stella (combined) data are plotted with respect to various parameters for 29 stations.

The quality-check sheets are shown at the Clinic Session (Room #3) and given to each station. The online version is now stored at Hitotsubashi University and linked from the ILRS NESC Forum:

http://sgf.rgo.ac.uk/forumNESC/index.php?topic=53.0

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where the one-year average of residual trend is plotted with respect to:

- Range rate
- Local time
- Single-shot RMS
- Skew
- Kurtosis
- System delay

followed by long-term time series plots of the applied system delay.

Stations are strongly encouraged to look at the charts carefully, to investigate the cause of systematic trends, and to remove the cause. It should be noted that those systematic errors are almost all being taken in geodetic analyses and it is likely that they have affected geodetic products. Very large errors (> decimeters) can be detected and eliminated (Otsubo et al, 2018) but small-size errors cannot. A problem at one station can alter not just its own coordinates but also global geodetic parameters.

Conclusions

The SLR community has made efforts to reduce the single-shot RMS for many decades, but it is a time to pay more attention to the short- to long-term stability and to reduce/remove systematic trends. What analysts can see from the CRD file is limited, and therefore on-site experiments, for instance changing the return energy level, changing the room temperature, using a different ground target…, are highly recommended.

High-repetition laser transmission and reception will ease the requirement on the single-shot precision. Use of nanosecond pulse-width laser systems (e.g. Kirchner et al, 2015; Hampf et al, 2018) can make the whole system significantly smaller and cheaper, and they will be able to contribute to the future millimetre geodesy.

References

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