Calibrating GNSS orbits with SLR tracking data

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Abstract

SLR tracking data allow for a completely independent validation of GNSS orbits that are derived from microwave data. SLR validation results show mean range residuals of several centimeters for both, GPS and GLONASS satellites, as well as significant seasonal variations for the two GPS satellites that are equipped with retroreflector arrays. It was, however, not clear whether these systematic effects could be assigned to orbit modeling deficiencies or to SLR tracking biases. We present new SLR validation results, which point to serious GPS orbit modeling problems. Moreover, we address the question, whether it would make sense to perform a combined analysis of microwave and SLR data for GNSS orbit determination. With the available low number of SLR observations no significant improvement of the orbit accuracy is found. An a priori variance-covariance analysis shows an improvement of the situation, if continuous SLR tracking data of already a very small number of globally distributed SLR sites were available.

1. Introduction

The International Laser Ranging Service (ILRS) provides Satellite Laser Ranging (SLR) tracking data of Global Navigation Satellite Systems (GNSS, at present consisting of GPS and GLONASS). Two GPS satellites that are equipped with laser retrorereflector arrays (LRAs), and a subset of three GLONASS satellites (all GLONASS satellites carry LRAs) are tracked by SLR.

SLR data allow for an independent validation of GNSS orbits that are derived from microwave data. In Section 2 we present recent SLR validation results, covering about four years of SLR data.

SLR observations may contribute to the GNSS orbit determination in a combined analysis of microwave and SLR observations. The possible improvement of the orbit accuracy is demonstrated on the basis of an a priori variance-covariance analysis in Section 3.

The main results of this work were already presented at the COSPAR 36th Scientific Assembly in Beijing. As this analysis is of a particular interest for the ILRS community, we will briefly introduce and sum up the most important results. We refer to (Urschl et al., 2007) for a detailed discussion.

2. GNSS orbit validation using SLR

For orbit validation we compare the SLR range measurements with the ranges derived from GNSS orbits. We used SLR normal points provided by the ILRS (Pearlman et al., 2002), and final orbits of CODE (Center for Orbit Determination in Europe). CODE is one of the analysis centers of the International GNSS Service (IGS) generating daily orbit solutions for all active GNSS satellites. The orbit determination is based on GNSS microwave observation provided by the IGS (Dow et al., 2005).

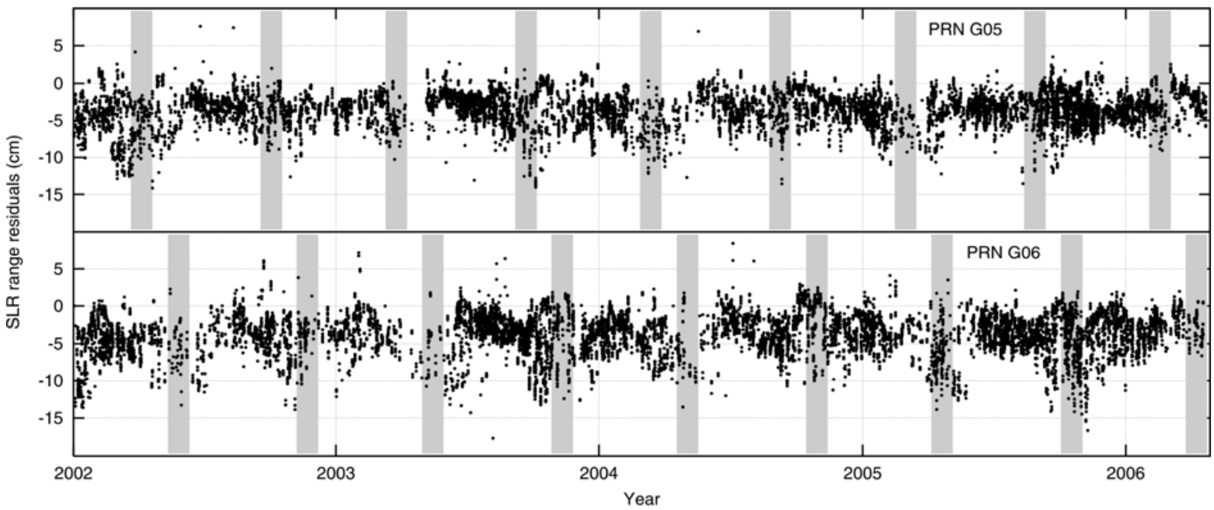

Figure 1. *SLR range residuals in cm for GPS satellites PRN G05 and G06, derived from CODE final orbits. The shaded areas indicate eclipse seasons*

The resulting range residuals indicate the GNSS orbit accuracy, but mainly in radial direction due to the observation geometry. SLR data of about four years starting 2002 were used for the range residual analysis.

Figure 1 shows the range residuals for the two GPS satellites. A standard deviation of the range residuals of 2 cm and 5 cm was estimated for the GPS and GLONASS satellites, respectively. The GPS orbits have a better accuracy compared to the GLONASS orbits due to the much denser GPS microwave tracking network. The GPS range residuals show a mean bias of about –3 to –4 cm. This bias is already known from previous studies, but its origin still remains unexplained. A wrong value for the retroreflector offset, giving the distance from the LRA's center to the satellite's center of mass, could be a possible explanation. It is interesting to note that there is no significant mean bias for the GLONASS satellites.

As part of the analysis, systematic variations were found in the SLR residuals of the GPS satellites, correlated to eclipsing seasons and with amplitudes of up to 10 cm. The largest residuals occur when the satellite is observed within the Earth's shadow during eclipsing seasons (indicated with shaded areas in Figure 1).

We could attribute the periodic signature to orbit modeling problems by displaying the range residuals in the (β,u)-coordinate system. β is the Elevation of the Sun above the orbital plane, and u is the argument of latitude of the satellite with respect to the argument of latitude of the Sun.

Figure 2 shows the range residuals in the (β,u)-system. The residuals are color-coded according to their values. The dependency of the range residuals on the satellite's position within the orbital plane is visible, and rules out SLR tracking biases. The pattern is rather caused by the microwave analysis, indicating attitude or orbit modelling problems.

3. Combined analysis of microwave and SLR data for GNSS orbit determination

Beside the validation purpose, SLR data can be used for GNSS orbit determination in a combined analysis together with microwave observations. But does this make sense in terms of orbit improvement? To answer this question an a priori variance-covariance analysis is performed.

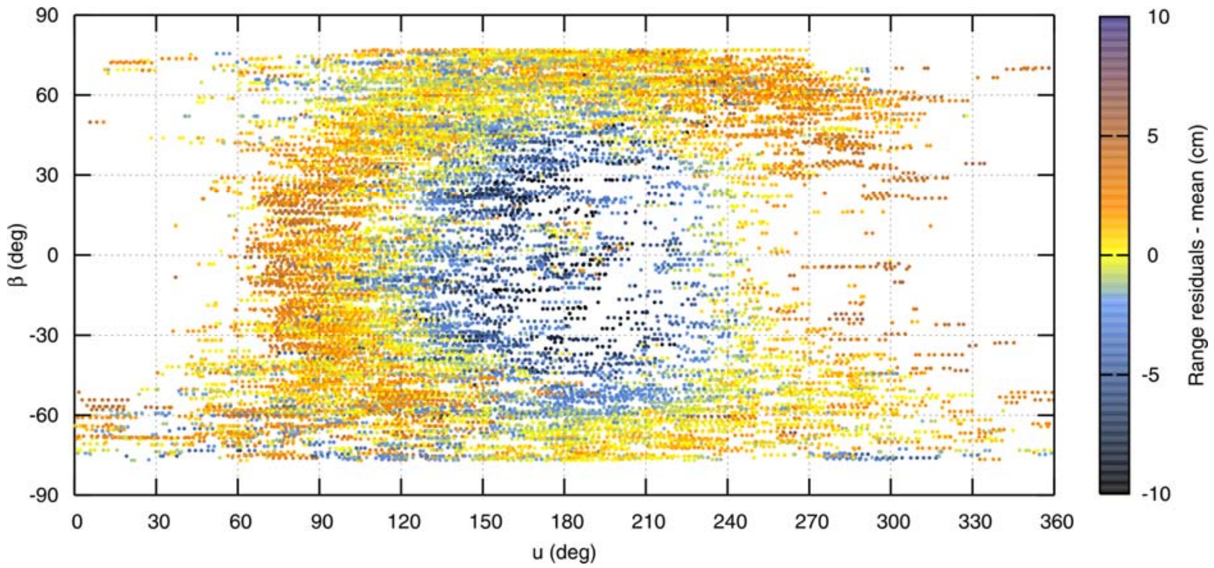

Figure 2. *Color-coded SLR range residuals in cm minus mean value for the GPS satellites PRN05 and PRN06, derived from CODE final orbits*

We used microwave phase observations of about 150 IGS sites and SLR data of 13 ILRS sites. For the variance-covariance analyses only the number, the temporal distribution, and an error model of the observations are needed. The a priori formal errors of the orbit components can be derived from the covariance matrices.

Several experiments were performed using different SLR observation weights. In the first experiment the SLR observation weight is set to zero by setting the a priori sigma of the SLR observations σ_{SLR} to infinity. Thus, the first experiment corresponds to a pure microwave solution. In the second experiment σ_{SLR} is set to 1 cm, similar to that of the microwave observations. In the third experiment the weight of SLR is increased by setting σ_{SLR} to 1 mm.

We compare the a priori formal errors of the orbital parameters of the different experiments. The a priori formal errors only decrease with very strong SLR observation weights (σ_{SLR} = 1 mm) and only around epochs, where SLR observations are available. When using real SLR observations, no significant improvement of the orbit accuracy was found, as SLR tracking data of GNSS satellites are very sparse and not well distributed.

But the situation changes, if SLR data would cover the entire satellite arc. Evenly distributed SLR observations have been simulated with an accuracy of 5 mm, equally spaced at 15 min interval, for altogether four globally distributed SLR tracking sites. SLR data of four sites can cover as much as 90% of a GNSS satellite arc. The a priori formal errors of the orbit parameters decrease significantly for SLR observations with 1 cm accuracy, and even more for SLR observations with increased weighting.

Two additional experiments have been performed using SLR data of only two or three SLR sites. With the data of two sites about 50% of a GNSS satellite arc can be covered, with three sites about 75%. The a priori formal errors in radial orbit component decrease by about 20% including additional SLR data of two sites into orbit determination. The formal error decreases even more if data of three sites are used. Data of the fourth site leads to no further improvement.

For the GLONASS satellites the a priori formal errors of the radial orbit component decrease by about 50%. The impact of additional SLR data on GLONASS orbit determination is larger than for GPS satellites as the number of GLONASS microwave observations is much smaller.

4. Conclusion

The quality of GNSS orbits can be validated using SLR observations of GNSS satellites. An orbit accuracy of about 2 cm and 5 cm was estimated for the GPS and GLONASS orbits, respectively, from a 4-year time series of range residuals covering 2002-2006. A mean bias of –3 to –4 cm for the GPS satellite orbits remains still unexplained. Periodic variations of the GPS range residuals were found, which are highly correlated with eclipsing seasons. We could demonstrate that these variations are not caused by SLR tracking data, but due to deficiencies in the GNSS orbit modeling. An improved solar radiation pressure model might solve the problem. Radiation pressure caused by Earth albedo was not considered in the GNSS orbit determination, but it may have a non-negligible effect on the orbit. Attitude modeling problems might also cause similar periodic variations in the range residuals. Further studies will follow to understand the source of the systematic residual pattern.

The combined analysis of microwave and SLR observations could improve GNSS orbit determination, assuming that the SLR observations are evenly distributed over the entire arc. Already a small network of three globally distributed SLR sites tracking the GNSS satellites continuously may contribute significantly to GNSS orbit improvement.References

References

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