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The First SLR Double-Difference Baseline

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We introduce the SLR double-difference approach of space geodesy. With real and simulated SLR measurements it is shown how common SLR biases are removed by forming SLR double-differences, i.e. station range biases, common retro-reflector effects and orbit errors (GNSS) for baselines up to e.g. 5000 km. In this way we obtain SLR observables of utmost precision and accuracy. We show how remaining noise in the SLR measurements nicely averages out, leading to orbit-free and bias-free estimation of station coordinates, local ties between different space geodesy techniques and precise comparison of optical/microwave tropospheric effects. It shall be noted that SLR scale is preserved by double-differencing. When ETALON and LAGEOS satellites are observed by SLR, any orbit error propagates directly into estimated station coordinates. However, by forming differences between two satellites and two ground stations this orbit error can be eliminated. Both satellites need to be observed quasi-simultaneously in the same tracking sessions in order that station range bias and common retro-reflector effects are removed by differencing.

When SLR measurements from GRZL and HERL SLR stations are taken to GLONASS and LAGEOS satellites and processed in double-difference mode, clear common orbit errors are visible in the SLR residuals from both stations. The same stands for small range biases that are visible between the consecutive observing sessions and are removed by forming SLR baselines. Longer SLR passes reveal other interesting systematic effects common to both stations at mm-level.

An error in the order of 4-6 cm RMS was introduced to GNSS orbits, however the effect on station coordinates in negligible over such a short SLR baseline. We show how with just one-two SLR double-difference passes one can estimate station coordinates at mm-level. When in parallel, both GNSS satellites are observed with microwave measurements, one can estimate very accurate local ties by comparing (or subtracting) GNSS and SLR double-difference measurements. Thus, such a set up could be used for very precise comparisons of troposphere models and mapping functions between optical and microwave domains.

There are different ways to form SLR double-differences based on satellites in different orbits, such as Lunar orbit, Moon, MEO and LEO. In this case, one could combine orbits of GNSS satellites with ETALON and LAGEOS satellites used for realization of terrestrial reference frame, as well as Lunar Laser Ranging. One could also form double-differences between two retro-reflectors on the Moon. It is expected that in the future GNSS satellites will be observed by ground VLBI antennae, therefore this is a proper set up for double-difference space geodesy approach to consistently combine (bias-free) all three space geodesy techniques (GNSS, SLR and VLBI) on double-difference level. An alternative is to observe quasars at approximate locations of GNSS satellites and to process VLBI data in double-difference mode in order to remove clock related parameters (freq. offset).

In sequel, we focus on the SLR double-difference approach in the light of altimetry and gravity field missions such as Sentinel-3 and GOCE mission. With the SLR bias-free approach, double-differences allow proper orbit calibration and combination of SLR and onboard LEO GNSS measurements. This especially stands for the proper combination of SLR and GNSS based terrestrial reference frame, considering the “SLR network effect” that directly propagates into results of altimetry and gravity field missions.