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Progress Report on the WLRS: Getting ready for GGOS, LLR and Time Transfer

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Abstract. *The goals set forward by the GGOS have stringent implications for the SLR stations. Most prominently this requires a good control over systematic effects reducing the accuracy on the range measurements. At the same time the observation load on the system increases as more satellites are endorsed for tracking by the ILRS. We have taken up the challenges and remodeled the WLRS. A new laser with shorter pulse duration and higher reliability and stability is currently being integrated as well as a new ground target providing higher accuracy. We also concentrated on the support for high altitude satellites in order to get back to LLR observations. Last but not least, we have improved our control system to support satellite interleaving. A lot of effort went into the construction of a calibrated timing link between the WLRS and the master clock of the Geodetic Observatory Wettzell in order to support optical time transfer between T2L2 on Jason 2 and eventually ELT on the ISS.*

Introduction

Satellite Laser Ranging (SLR) is one of the essential techniques that significantly contributes to the International Terrestrial Reference Frame. The International Association of Geodesy has launched a project several years ago, that seeks to establish a Global Geodetic Observing System (GGOS) by developing the geodetic observation techniques to a point where an Earth fixed reference frame with a relative inaccuracy of less than 1 part in a billion or a relative error of 10^{-9} is achieved (Plag and Pearlman, 2009). On top of this comes the demand to provide a high spatial and temporal resolution for this reference frame. When set on such a basis, GGOS will be an important contributor to general Earth System Research, that seeks to model physical, chemical and biological processes on Earth. The main contributions of GGOS are by quantifying mass transport, surface deformations and the dynamics of these processes. Breaking these goals down to an observatory level, this means that the geodetic measurement techniques have to provide 1 mm of accuracy for measured positions and 0.1 mm/year for the corresponding velocities. In particular we have to aim for a much better control of systematic biases and measurement errors within the measurement techniques of space geodesy as well as a better control of the biases in the linkage between the different techniques with respect to each other. Well established local ties and an exquisite control over the instantaneous system delays are key elements in this effort. What do we experience at the level of an SLR station? Over the last 5 years the observation load has been significantly increased, while at the same time many stations find, that the available resources are becoming progressively sparser. This requires a higher level of automation, not only for the instrumentation, but also for the quality control of the measurements themselves. Support for precise orbit determination for altimetry missions and gravity missions also calls for a reduction in data latency, which is another requirement that the stations have to accommodate.

Operations at the WLRS

With the background outlined above in mind, we have improved the operations of the WLRS of the Geodetic Observatory Wettzell in several ways over the past 5 years. In order to increase the tracking accuracy we have refurbished our telescope control system and realigned the optical path in the telescope. A new rotating disc assembly to switch between the transmit and receive path of the mono-static telescope now allows a pulse repetition rate of 20 Hz and reduces the blind region of the system from about 400 km to 200 km. This allowed the routine observation of satellites like GOCE with the WLRS. A new control system for the ranging functions added more autonomous functions, an improved timer and strongly enhanced the satellite interleaving functionality of the control system. A new detector concept with reliable receive signal level detection has also been implemented (see contribution of J. Eckl et al. elsewhere in these proceedings). Finally we have obtained a new Nd:YAG laser system, that utilizes a reduced pulse width of now 12 ps FWHM as opposed to about 120 ps (80 ps nominal) FWHM of the 16 years old legacy laser of the WLRS. The changes listed here essentially affected each sub-system of the WLRS and were carried out one at a time over the years. At the same time the continuity of the observations was kept with a high priority. Whenever the changes had potential impact on the system accuracy, the observation data was quarantined and checked for consistency by the European Data Center at the Deutsches Geodaetisches Forschungsinstitut (DGFI) and the wider SLR community. As a result of these improvements the productivity of the WLRS has increased as fig. 1 illustrates for the observation of the high altitude satellites.

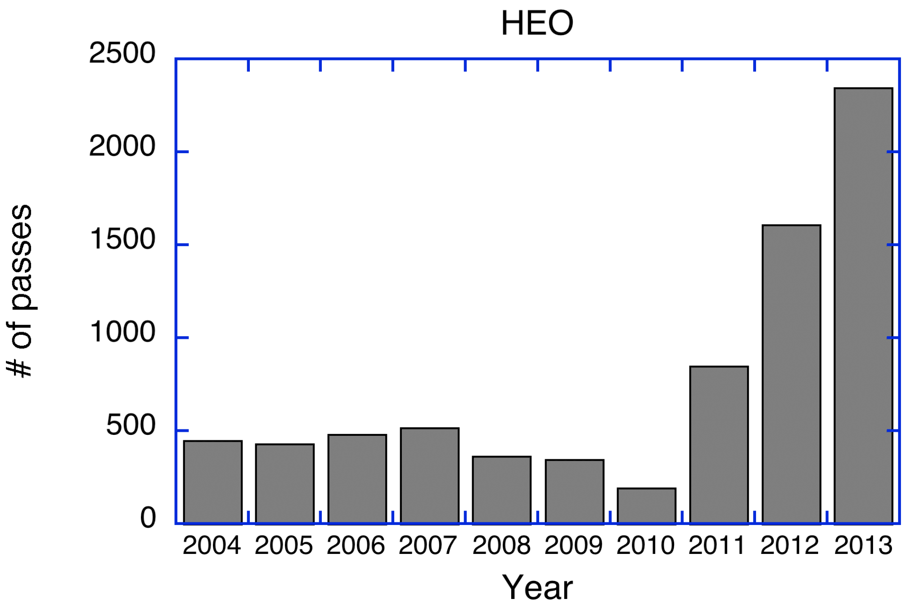

Figure 1. Number of observed “High Earth Orbiters” as a function of time. The dip in 2010 was caused by the telescope refurbishment period. The subsequent increase reflects better pointing, an improved control system, a new detector concept and an increase in available targets.

The obvious dip in the number of observed passes in 2010 marks the refurbishment of the telescope, when the system was out of operation over several month. The subsequent progressive increase of observations has several reasons. Better pointing and higher system transmission are only one cause. The new control system with much more effective satellite interleaving functionality is another contributor, while the significantly increased number of supported GLONASS satellites as of 2013 also plays an important role.

WLRS Bias Stability

Systematic system biases are a continuous concern for all techniques in space geodesy. Typically these errors are caused by unaccounted for system delays and they are not constant in time. For monostatic SLR systems like the WLRS the system calibration is difficult to establish along the actual signal path through the SLR system, because of the blind region as a consequence of the rotating mirror disc, acting as a transmit-/receive- switch. Usually monostatic systems have some sort of asymmetry between the signal path used for ranging and the signal path used for the calibration. In addition one has to ensure that the receive signal power levels are always comparable for both signal paths at all times. Over the last year we have installed an additional ground target, a peak voltage detection unit along with a new photo-detector concept. Furthermore, we have started to investigate the system delays in particular with respect to their variability over time. Figure 2 shows an arbitrarily chosen example.

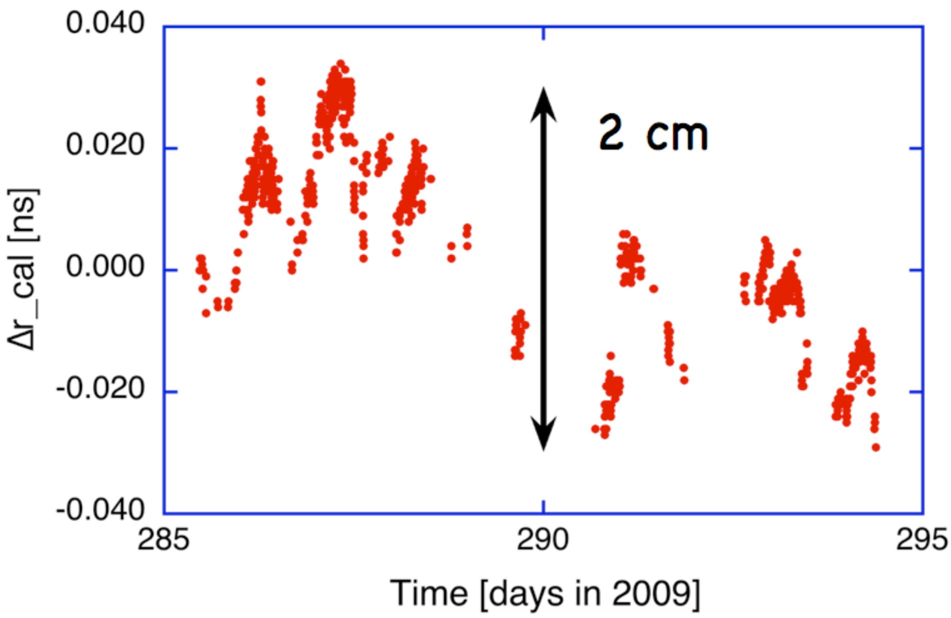

Figure 2. Variability of the WLRS system calibration over a 10 day period. Mostly because of temperature variations in the electronic components of the signal transfer chain one finds a peak to peak change of 2 cm in this case. Since ranging and calibration are affected similarly, these instabilities do not propagate into the reported normal points.

The variability of the calibration delay of the WLRS is established on a pass by pass basis. Over the here shown period of 10 days, one can see a peak to peak variability of 2 cm along with a periodic approximately diurnal signature. Most of this signature can be associated with temperature variations affecting the experienced delays within the electronic components of the SLR system and as such these delays are not generally of concern. The system calibrations usually correct for this effect, because this delay is identical for the calibration and SLR measurement, provided that the electric portion of the signal is passing through identically the same electronic components and within a time interval where temperature changes do not become visible. This however is not completely true for SLR systems that utilize pre- and post- pass calibration and also the realtime calibration systems such as the WLRS may encounter a subtle difference. How to avoid such potential bias issues? First of all it is important to ensure a high measurement bandwidth of the signal channel. This reduces timing delay variation from fluctuating detection thresholds, due to floating ground references. Furthermore it is important to reduce any sort of asymmetry in the measurement process. Delays can be introduced by:

- receive signal strength depending satellite responses (target signature)
- non-identical electronic signal path within the SLR system
- the system delay stability between the ranging and calibration function

All these effects are rather small, potentially causing combined variabilities of up to 100 ps in time. However GGOS requires this to drop down to a total of about 3 ps, which is a demanding task. In order to identify and measure at least the system specific error sources we have adopted a two-way timing concept (Kodet et al., 2012) that provides the required stability to do these measurements. Figure 3 shows the concept in a block diagram applied to the comparison of two widely spaced apart clocks on the observatory.

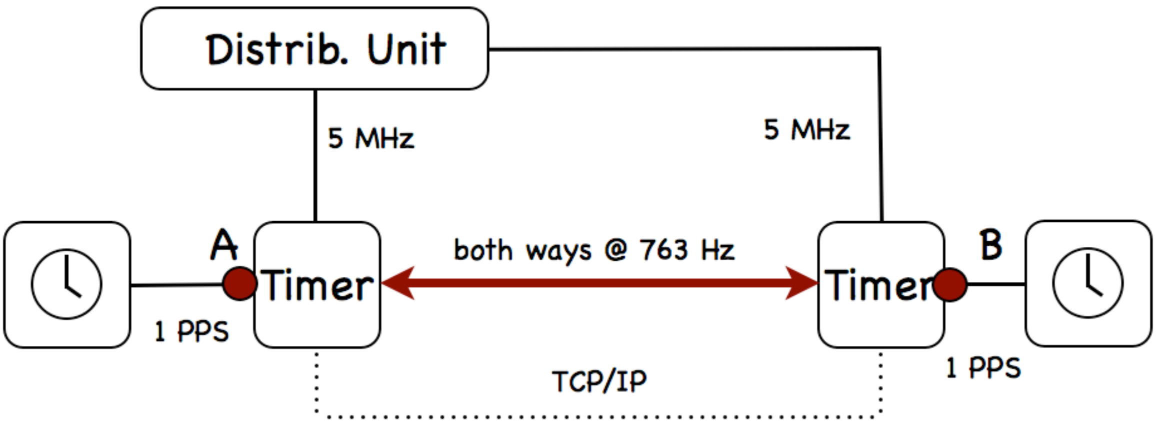

Figure 3. Block diagram of a two-timer clock comparison setup. Each timer measures timing pulses from each respective local clock. The timers exchange timing pulses alternatingly to establish the offset between the timers and the corresponding cable delay.

For two clocks in different buildings driven by different reference frequency sources, we have compared the rising edge of the 1 pulse per second timing pips against each other by using a local event timing unit at each clock. The two timers are connected by a single coaxial cable and each of the timers generates local timing pulses, which are time tagged at both timers, passing through the coaxial cable in both directions. An additional TCP/IP line coordinates this process and records the measurements. From the measurements the offset between the two clocks as a function of time and the variability of the effective cable delay can be established with a resolution of about 2 ps (Kodet et al., 2012). Figure 4 shows such a result for the comparison of the cesium master clock of the geodetic observatory Wettzell and the H-maser referenced clock used at the WLRS for SLR operations. The observed drift over the two month of continuous comparison can mostly be attributed to the H maser and is in accordance with the specifications. The same two-timer delay comparison can also be applied to investigate the delay stability of the complete timing chain in the SLR facility. This is currently work in progress.

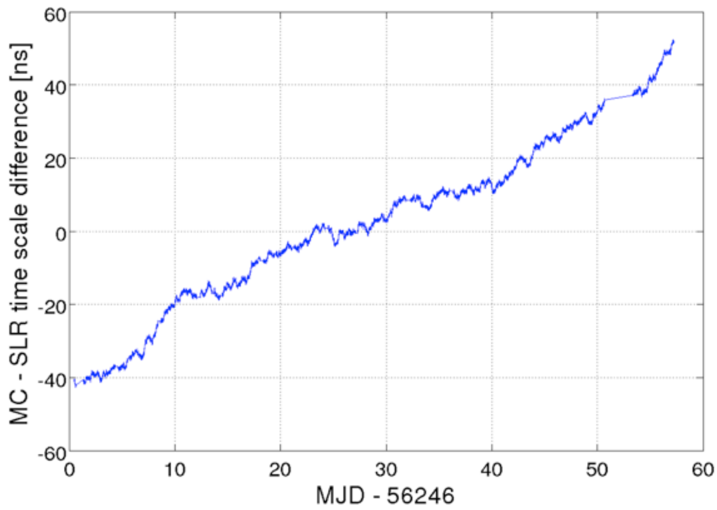

Figure 4. Comparison of the cesium master clock of the Geodetic Observatory Wettzell against the H-maser referenced SLR timing system. Over the two month of time comparison, the expected maser drift behavior can be recovered.

Discussion

In order to improve the contributions of the WLRS to the ILRS, we have modernized nearly all aspects of the SLR operations. The telescope control system was refurbished and newly aligned. The blind region was dropped below the GOCE orbit and the new control system now allows faster satellite interleaving. The new detector system provides a reliable estimate of the receive signal intensities on a shot by shot basis, which is a prerequisite for timewalk compensation (more details in Eckl et al. also in these proceedings). Finally a new laser with much shorter pulse-width of 12 ps FWHM has been introduced at the end of 2013. In order to approach the goals of GGOS by significantly increasing the stability of the instrumentation in space geodesy, we have started to investigate the stability of the entire timing chain in the WLRS with a two-way timer concept. This process is also required for high accuracy time comparisons by laser link, such as T2L2 and the upcoming ELT project. A resolution of 2 ps has been obtained for this concept and the stability appears to be comparable.

References

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