SLR in the framework of the EGISEM project

Introduction
This contribution describes the role of Satellite Laser Ranging (SLR) within the European Gravity
Service for Improved Emergency Management (EGISiem). One of the purposes of this Horizon 2020
project is to combine monthly gravity field solutions from the Gravity Recovery and Climate Experi-
ment (GRACE) mission that are derived by different institutions. The combined gravity field product
will provide complementary information to traditional products for flood and drought monitoring
and forecasting. SLR data (Pearman et al., 2002) to geodetic satellites are used

• to validate the microwave-based GNSS orbits,
• to estimate low-degree terrestrial gravity field coefficients, and
• to establish a reference frame from both GNSS and SLR data.

The poster gives a status report on the current work of the first two out of the three bullets above.

Validation of GNSS orbits using SLR
A reprocessing campaign (Repro15, Süssnik et al. 2016) was initiated at the Astronomical Institute of
the University of Bern (AIUB) covering more than 250 globally distributed tracking stations of
the International GNSS Service (IGS, Dow et al. 2009). The purpose of this reprocessing is to establish
a homogenous and state-of-the-art basis for the GNSS-based orbit determination of GRACE. As
an example, the extended Empirical CODE Orbit Model (ECOM, Arnold et al. 2015) was used for
this reprocessing campaign. The reprocessing products include GNSS orbits (GPS since 1994,
GLONASS starts in 2002) and ultra-high-rate satellite clock corrections with a sampling of up to
5 seconds (GPS since 2003; GLONASS 30 seconds between 2008 and 2011, later 5 seconds).

The principle of validating GNSS orbits using SLR is as follows: the SLR observations (‘observed’)
are directly compared against the geometry based on the coordinates of the SLR stations in the
SLR 2008 reference frame and the microwave-based orbit (‘computed’) without estimating any
parameter. The residuals (‘observed minus computed’) indicate how well the orbits agree with the
SLR observations. Fig. 1 demonstrates the benefit of the extended ECOM over the classical one. Thanks to the
twice-revolution empirical parameters in the satellite burn direction, which are estimated in case of the
extended ECOM, the elongation-dependent systematic pattern has been significantly reduced.

The principle of validating GNSS orbits using SLR is as follows: the SLR observations ('observed') are,
directly compared against the geometry based on the coordinates of the SLR stations in the SLR 2008 reference frame and the microwave-based orbit ('computed') without estimating any parameter. The residuals ('observed minus computed') indicate how well the orbits agree with the SLR observations. Fig. 1 demonstrates the benefit of the extended ECOM over the classical one. Thanks to the twice-revolution empirical parameters in the satellite burn direction, which are estimated in case of the extended ECOM, the elongation-dependent systematic pattern has been significantly reduced.

The residuals to the orbits of certain GLONASS satellites (SVN 723, 725, 736, and 737, for instance) increase with the life time of the satellite as shown in Fig. 2. The four mentioned satellites belong to the same orbital plane. The effect of the increasing residuals, however, is not a modeling issue since other satellites in the same orbital plane (e.g., SVN 716, 729) do not show this effect.

The validation of the reprocessed GNSS orbits using the extended ECOM showed that the
bias between the two SLR series is under investigation.

Summary
The validation of the reprocessed GNSS orbits using the extended ECOM showed that the
elongation-dependency of the SLR residuals could be significantly diminished. Apart from a small
bias, the monthly C20 coefficients derived from SLR data agree well with the solution from CSR. The
bias between the two SLR series is under investigation.

References

Contact address
Andrea Maier
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
andrea.maier@aiub.unibe.ch

Fig. 1 (left) depicts our estimated C20 coefficients. It is interesting to notice that the long-term trend of our solution fits the trend of the GRACE solution significantly better than the SLR solution from CSR. The dots offset between our solution and the external SLR-based solution is under investigation.

Fig. 2 (left) shows the SLR residuals w.r.t. 1-day GLONASS orbits between January 2008 and December 2014 using the extended ECOM. Observations during solar eclipses (red) and non-occulting solar eclipses (blue) are shown. The residuals of SVN 723 are generally larger compared to other satellites. The residuals of all four satellites seem to increase the longer the satellites are in orbit.

Using the classical ECOM the daytime residuals are slightly shifted towards negative values. They are, however, more evenly distributed when the extended ECOM is used (cf. Fig. 3).

Fig. 3 (left) depicts the SLR residuals w.r.t. 1-day GLONASS-M orbits between January 2008 and December 2015 using the classical ECOM (top) and the extended ECOM (bottom). The residuals are subdivided into daytime (07:00 to 19:00 local time) and nighttime (19:00 to 07:00 the following day) for the classical and the extended ECOM, respectively. Residuals to SVN 723, 725, 736, and 737 as well as residuals during eclipse have been excluded.

Fig. 4 (right) shows the SLR residuals w.r.t. 1-day GLONASS-M orbits between January 2008 and December 2015 using the classical ECOM (top) and the extended ECOM (bottom). The residuals are subdivided into daytime (07:00 to 19:00 local time) and nighttime (19:00 to 07:00 the following day) for the classical and the extended ECOM, respectively. Residuals to SVN 723, 725, 736, and 737 as well as residuals during eclipse have been excluded.

Fig. 5 (left) depicts our estimated C20 coefficients. It is interesting to notice that the long-term trend of our solution fits the trend of the GRACE solution significantly better than the SLR solution from CSR. The dots offset between our solution and the external SLR-based solution is under investigation.

The above mentioned 161-frequency is easy to detect in the amplitude spectrum of the GRACE series (Fig. 5, right). Annual and semiannual signal are well distinguishable in the two SLR series.

Using the classical ECOM the daytime residuals are slightly shifted towards negative values. They are, however, more evenly distributed when the extended ECOM is used (cf. Fig. 3).

Low-degree gravity field estimation using SLR
Satellite laser ranging to geodetic satellites is the best technique to derive the Earth’s dynamical
oblateness (i.e., the C20 gravity field coefficient). Typically, GRACE-based estimates of C20 do not
reflect the seasonal signals as well as SLR-based ones due to aliasing on the 161-day frequency.
This is why the monthly gravity field normal equations (NEQs) resulting from GRACE data analysis
will be combined with SLR normal equations. Up to this date, monthly gravity field coefficients up to
degree and order (d/o) 20 have been estimated between January 2003 and December 2015. Observations to LAGEOS-1 and -2, Alaisa, Stella, and Starlette were analyzed. Fig. 4 depicts the number of normal points (NPs) to all geodetic satellites and Beacon-C. To strengthen our solution, we intend to include data to Larets, Larets and Beacon-C. For the time being, however, each 30-day gravity field set is composed by 30 1-day LAGEOS NEQs and 30 1-day NEQs to the lower orbiting satellites Alaisa, Stella, and Starlette (see Table 1 and Süssnik et al. 2015 for more information about orbit modeling and estimated parameters).

Table 1: Estimated arc-specific and common parameters from SLR data.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LAGEOS-1/2</th>
<th>Stella, Alaise, Ajalis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc-specific parameters:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osciulations</td>
<td>1 set per 10 days</td>
<td>1 set per 10 days</td>
</tr>
<tr>
<td>Dynamical parameters</td>
<td>constant and 1/rev in along track</td>
<td>constant and 1/rev in along track</td>
</tr>
<tr>
<td>Pseudo-stochastic pulses</td>
<td>none</td>
<td>1/rev in cross track</td>
</tr>
<tr>
<td>Common parameters:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth rotation parameters</td>
<td>X0, Y0, UT1-UTC (piecewise linear, 1 set per day)</td>
<td>X0, Y0, UT1-UTC (piecewise linear, 1 set per day)</td>
</tr>
<tr>
<td>Geocenter coordinates</td>
<td>1 set per 30 days</td>
<td>up to 3 (1 set per 30 days)</td>
</tr>
<tr>
<td>Gravity field coefficients</td>
<td>1 set per 30 days</td>
<td>for all stations</td>
</tr>
<tr>
<td>Station coordinates</td>
<td>1 set per 30 days</td>
<td>for all stations</td>
</tr>
<tr>
<td>Ranges biases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for selected stations</td>
<td>1 set per 30 days</td>
<td>for all stations</td>
</tr>
<tr>
<td>for all stations</td>
<td>1 set per 30 days</td>
<td>for all stations</td>
</tr>
</tbody>
</table>