SLR–derived terrestrial reference frame using observations to LAGEOS–1/2, Starlette, Stella, and AJISAI

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Motivation

Current ILRS products:

- LAGEOS-1/2 & Etalon-1/2 solutions only,
- On average ~3000 normal points to LAGEOS-1/2 and ~300 normal points to Etalon-1/2 per week,
- The impact of Etalon-1/2 on the solution is virtually negligible

See poster session for LARES solutions
Motivation

**Number of SLR observations of geodetic satellites per week**

<table>
<thead>
<tr>
<th>Years</th>
<th>LAGEOS-1</th>
<th>LAGEOS-2</th>
<th>AJISAI</th>
<th>Starlette</th>
<th>Stella</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of normal points per week</td>
<td>1500</td>
<td>1500</td>
<td>3000</td>
<td>1600</td>
<td>800</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No of SLR stations observing satellites per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAGEOS-1/2</td>
</tr>
<tr>
<td>No of stations per week</td>
</tr>
</tbody>
</table>
## SLR solutions in the Bernese GNSS Software

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LAGEOS</th>
<th>LEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station Coordinates</td>
<td>Weekly</td>
<td>Weekly</td>
</tr>
<tr>
<td>Earth Rotation Parameters</td>
<td>PWL daily</td>
<td>PWL daily</td>
</tr>
<tr>
<td>Geocenter Coordinates</td>
<td>Weekly</td>
<td>Weekly</td>
</tr>
<tr>
<td>Gravity field</td>
<td>Up to d/o 4</td>
<td>Up to d/o 4</td>
</tr>
<tr>
<td>Range Biases</td>
<td>Selected stations</td>
<td>All stations</td>
</tr>
<tr>
<td>Osculating Elements</td>
<td>Weekly</td>
<td>Weekly</td>
</tr>
<tr>
<td>Constant along-track S0</td>
<td>Weekly</td>
<td>-</td>
</tr>
<tr>
<td>Air Drag Scaling Factor</td>
<td>-</td>
<td>Daily</td>
</tr>
<tr>
<td>Once-per-rev SS, SC</td>
<td>Weekly</td>
<td>Daily</td>
</tr>
<tr>
<td>Once-per-rev WS, WC</td>
<td>Weekly</td>
<td>Daily</td>
</tr>
<tr>
<td>Pseudo-Stochastic Pulses</td>
<td>-</td>
<td>Once-per-rev in along-track</td>
</tr>
</tbody>
</table>

**Bernese GNSS Software, v.5.3**

**10 years of processed data (2002-2012)**

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**Astronomical Institute University of Bern**
Scale

TRF scale estimated from the Helmert 7-parameter transformation of weekly SLR solutions.

Orbit modeling deficiencies related to non-gravitational forces appear as the periods of the draconitic year.

Draconitic year is a time interval between two consecutive passes of the Sun through the orbital plane of a satellite (in the same direction).

Draconitic years of geodetic satellites:
- 222 days: LAGEOS-2,
- 560 days: LAGEOS-1,
- 89 days: AJISAI,
- 73 days: Starlette,
- 182 days: Stella.

Annual signal is preserved
The origin of the reference frame (geocenter coordinates) are best defined by the SLR technique. The X and Y components can be also defined by other techniques, e.g., DORIS, GNSS, but the Z component is strongly affected by the deficiencies in the solar radiation pressure modeling, and thus, can only be established by the SLR solutions*.

The LAGEOS-1/2 solutions or the Star+Ste+Aji solutions show very small orbit modeling deficiencies (draconitic year of LAGEOS–2 and Ajisai). All amplitudes related to draconitic years are substantially reduced in the combined solutions.

Weekly repeatabilities of station coordinates

Station coordinate repeatability in LAGEOS–1/2 and the combined solutions

The station repeatability is improved in the combined solutions for East and North components of non-core SLR station

Stations ordered by increasing number of weekly solutions

Better repeatability in combined solution

Weekly repeatabilities of station coordinates

Better repeatability in combined solution

The station repeatability is improved in the combined solutions for East and North components of non-core SLR station
Correlations

Correlation coefficients between selected parameters.

Estimated parameters (ERPs, geopotential, station coordinates) can be substantially decorrelated when using many SLR satellites, due to:

- better observation geometry,
- larger number of SLR observations,
- different orbital characteristics (altitudes, inclination angles, eccentricities).
Simultaneous estimation of all parameters (gravity field + station coord + ERPs + orbits) is beneficial for SLR solutions (in particular for combined L1/L2/Sta/Ste/Aji solutions).
Gravity field parameters

\( C_{20} \) can be well-established from LAGEOS-1/2 solutions, but the amplitude of annual signal is by 20% larger than in the multi-SLR solutions. 

\( C_{30} \) from LAGEOS-1/2 shows a clear alias period with draconitic year of LA-2.
Gravity field parameters (besides C20) can be much better established from the multi-SLR solutions (in particular for degree higher than 2). LAGEOS-1/2 solution reveals variations related to the draconitic years or their harmonics.
Summary

Advantages of the multi-SLR solutions:

- The estimated parameters can be substantially decorrelated.
- The observation geometry is improved.
- Orbit modeling deficiencies of non-gravitational forces (solar radiation pressure, albedo, Earth’s infrared radiation, the Yarkovsky effect, the Yarkovsky–Schach effect, light aberration, etc.) can be reduced.
- As a result, the terrestrial reference frame parameters (scale, geocenter coordinates, ERPs) can be better established.
- The repeatability of some SLR station coordinates can be improved.

Disadvantages of the multi-SLR solutions:

- The repeatability of some of best-performing SLR station coordinates is slightly worse w.r.t. the LAGEOS–1/2 solutions,
- High-quality solutions of low orbiting satellites require more user’s attention (screening process and the orbit modeling optimization).
Thank you for your attention
Single-satellite solutions

Stella leads to worse Coordinates, but LoD is improved

<table>
<thead>
<tr>
<th></th>
<th>Aposteriori sigma of unit weight [mm]</th>
<th>Mean number of observation per week</th>
<th>X pole bias [μas]</th>
<th>X pole WRMS [μas]</th>
<th>Y pole bias [μas]</th>
<th>Y pole WRMS [μas]</th>
<th>LoD bias [μs]</th>
<th>LoD WRMS [μs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AJISAI</td>
<td>6.31</td>
<td>3011</td>
<td>36.4</td>
<td>266.3</td>
<td>3.6</td>
<td>233.9</td>
<td>-17.3</td>
<td>108.5</td>
</tr>
<tr>
<td>Starlette</td>
<td>6.45</td>
<td>1697</td>
<td>21.8</td>
<td>339.5</td>
<td>-6.5</td>
<td>290.5</td>
<td>-18.0</td>
<td>133.0</td>
</tr>
<tr>
<td>Stella</td>
<td>6.03</td>
<td>813</td>
<td>120.0</td>
<td>901.6</td>
<td>-11.8</td>
<td>829.0</td>
<td>9.6</td>
<td>110.7</td>
</tr>
<tr>
<td>AJISAI+Starlette</td>
<td>6.85</td>
<td>4708</td>
<td>207.3</td>
<td>184.4</td>
<td>-3.0</td>
<td>256.6</td>
<td>-35.2</td>
<td>136.9</td>
</tr>
<tr>
<td>AJISAI+Stella</td>
<td>7.24</td>
<td>3824</td>
<td>171.8</td>
<td>304.4</td>
<td>-3.8</td>
<td>256.6</td>
<td>-1.0</td>
<td>93.1</td>
</tr>
<tr>
<td>Starlette+Stella</td>
<td>7.62</td>
<td>2510</td>
<td>75.2</td>
<td>291.5</td>
<td>-3.7</td>
<td>291.5</td>
<td>-3.7</td>
<td>99.4</td>
</tr>
<tr>
<td>All satellites</td>
<td>7.78</td>
<td>5521</td>
<td>57.7</td>
<td>269.8</td>
<td>-8.7</td>
<td>218.1</td>
<td>-3.6</td>
<td>106.5</td>
</tr>
</tbody>
</table>
The Y geocenter component from the multi-SLR solution shows large annual variations and a secular drift, whose origin remains unclear. Nevertheless, the combined solutions are slightly less noisy than the LAGEOS–1/2 solutions.
References

References:

- Sośnica K, Thaller D, Dach R, Jäggi A, Beutler G (2013c) Time variable Earth's gravity field from SLR and the comparison with polar motion, CHAMP, and GRACE results. To be submitted to J Geod