Consistent estimation of Earth rotation, geometry and gravity with DGFI’s multi-satellite SLR solution

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GGOS aims

**Geometry**
- measuring the geometric shape of the Earth’s surface and its kinematics & variations

**Earth rotation**
- monitoring the variations of the Earth’s rotation as indicator of angular momentum and torques

**Gravity field**
- determining and monitoring the Earth’s gravity field
  - Highly-accurate and consistent **reference frames** are required to integrate the three pillars.

[acc. to Plag & Pearlman, 2009]
• **GGOS goal**: Consistent estimation of the Earth’s geometry, the Earth’s orientation and the Earth’s gravity field and its temporal variations

• **problem**: High interaction between different parameter groups in a common adjustment (also complementary parameters!)

• **inter-technique solution**: Combination of observation techniques with different advantages (e.g. GNSS, SLR, VLBI, DORIS, GRACE, GOCE, …)

• **intra-technique solution**: Combination of SLR observations to satellites with different orbit characteristics
Correlations I

- **sat 1**: high correlations between Earth gravity field, nodal precession, empirical cross-track accelerations and Earth rotation
Correlations II

- **sat 1**: high correlations between Earth gravity field, nodal precession, empirical cross-track accelerations and Earth rotation
- **sat 1 + sat 2**: mixed inclinations are important to decorrelate Earth gravity field, satellite orbit and Earth rotation
- optimal mix would be the **butterfly configuration** ($I_1 - 90^\circ = 90^\circ - I_2$) → precession of nodes in opposite direction with the same velocity
Correlations III

- **sat 1**: high correlations between Earth gravity field, nodal precession, empirical cross-track accelerations and Earth rotation
- **sat 1 + sat 2**: mixed inclinations are important to decorrelate Earth gravity field, satellite orbit and Earth rotation
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Data I

satellite altitude [km]

19135
19105
5850
5625
1485
1450
927
832
815
815
691

time

not included yet

Computation period 2000.0 until 2013.5

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09.04.2013: Collision with space debris

BLITS

© ILRS

© ILRS

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Data II

- Observations are combined on the NEQ-level
- Weighting of NEQs is done via VCE
- LARETS, BLITS, BEACONC and STELLA get lower weights

<table>
<thead>
<tr>
<th>satellite</th>
<th>mass [kg]</th>
<th>diameter [m]</th>
<th>rev.-period [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAGEOS1</td>
<td>406.97</td>
<td>0.60</td>
<td>3.76</td>
</tr>
<tr>
<td>LAGEOS2</td>
<td>405.38</td>
<td>0.60</td>
<td>3.76</td>
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<td>ETALON1</td>
<td>1415.0</td>
<td>1.294</td>
<td>11.26</td>
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<tr>
<td>ETALON2</td>
<td>1415.0</td>
<td>1.294</td>
<td>11.26</td>
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<tr>
<td>STELLA</td>
<td>47.3</td>
<td>0.24</td>
<td>1.74</td>
</tr>
<tr>
<td>STARLETTE</td>
<td>47.0</td>
<td>0.24</td>
<td>1.69</td>
</tr>
<tr>
<td>AJISAI</td>
<td>685.0</td>
<td>2.15</td>
<td>1.93</td>
</tr>
<tr>
<td>LARETS</td>
<td>23.28</td>
<td>0.21</td>
<td>1.64</td>
</tr>
<tr>
<td>LARES</td>
<td>386.8</td>
<td>0.364</td>
<td>1.91</td>
</tr>
<tr>
<td>BLITS</td>
<td>7.53</td>
<td>0.17</td>
<td>1.68</td>
</tr>
<tr>
<td>BEACONC</td>
<td>52.6</td>
<td>non-sph.</td>
<td>1.80</td>
</tr>
</tbody>
</table>
Earth gravity field I

**LAGEOS1**

- low sensitivity on GFCs of degree $> 3$
- high correlations of low-degree GFCs with satellite orbit
Earth gravity field II

**LAGEOS1/2**

- stable estimation of GFCs of degree $\leq 4$
- decorrelation of low-degree GFCs with satellite orbits due to mixed inclinations
Earth gravity field III

**LAGEOS1/2 + STARLETTE**

- stable estimation of GFCs of degree $\leq 6$
- decrease of STD of tesseral GFCs
- STARLETTE has slightly lower $\lambda$ than LAGEOS1/2 $\Rightarrow$ high impact on GFC estimation
Earth gravity field IV

**LAGEOS1/2 + ETALON1/2 + LARETS + STARLETTE + STELLA + AJISAI**

- small STD of sectoral/tesseral GFCs up to degree ≤ 20
- zonal GFCs have higher STDs
- resonances of LEOs allow to estimate GFCs of high degree
Earth gravity field V

- weekly $\sigma^2(c_2)$ of DGFI (11 sat.) is smaller than monthly $\sigma^2(c_2)$ of CSR!
weekly / monthly global observation coverage

weekly solution
- poor observation distribution
- sometimes bad observation geometry due to station outage
- high weekly variability

monthly solution
- dense observation distribution
- good network geometry
- low monthly variability
Earth Orientation Parameter I

weekly solution between Feb. 2012 and May 2013 (LARES period)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Δ x-pole [μas]</td>
<td>39.2</td>
</tr>
<tr>
<td>RMS Δ y-pole [μas]</td>
<td>50.0</td>
</tr>
</tbody>
</table>
Earth Orientation Parameter II

weekly solution between Feb. 2012 and May 2013 (LARES period)

(UT1–UTC) w.r.t. IERS 08 C04

[year]

STD((UT1–UTC) w.r.t. IERS 08 C04)

[year]

<table>
<thead>
<tr>
<th>RMS Δ x-pole [μas]</th>
<th>39.2</th>
<th>15.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Δ y-pole [μas]</td>
<td>50.0</td>
<td>16.1</td>
</tr>
</tbody>
</table>
Earth Orientation Parameter III

weekly solution between Feb. 2012 and May 2013 (LARES period)

\[
\begin{align*}
\text{RMS } & \Delta x\text{-pole [}\mu\text{as}] & 39.2 & 15.1 & 15.3 \\
\text{RMS } & \Delta y\text{-pole [}\mu\text{as}] & 50.0 & 16.1 & 15.8 
\end{align*}
\]
Earth Orientation Parameter IV

weekly solution between Feb. 2012 and May 2013 (LARES period)

<table>
<thead>
<tr>
<th>Solution</th>
<th>RMS $\Delta x$-pole [\mu as]</th>
<th>RMS $\Delta y$-pole [\mu as]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA1</td>
<td>39.2</td>
<td>50.0</td>
</tr>
<tr>
<td>LA12</td>
<td>15.1</td>
<td>16.1</td>
</tr>
<tr>
<td>LA12 + LRS</td>
<td>15.3</td>
<td>15.8</td>
</tr>
<tr>
<td>All (11 sat)</td>
<td>14.6</td>
<td>14.7</td>
</tr>
</tbody>
</table>
Terrestrial Reference Frame

RMS of translation / scale parameter w.r.t. SLRF2008

- **Tx**: -14 % (ILRS+LRS)
  - 7 % (11 sat)
- **Ty**: -6 % (ILRS+LRS)
- **Tz**: -7 % (ILRS+LRS)
  - 6 % (11 sat)
- **Sc**: +4 % (ILRS+LRS)
  +3 % (11 sat)

Global mean coordinate WRMS

- **north**: -14 % (ILRS+LRS)
  -40 % (11 sat)
- **east**: -5 % (ILRS+LRS)
  -17 % (11 sat)
- **height**: -10 % (ILRS+LRS)
  -18 % (11 sat)
Summary

• **Earth gravity field:**
  - mix of different satellite heights and resonances allows to estimate stable GFCs together with orbit parameters, TRF and EOPs
  - the longer the arc length is, the smaller are the STDs of the estimated GFCs (well-determined GFCs up to d/o 20 with monthly (4 weeks stacked) solutions!)

• **EOP:**
  - mix of different satellite inclinations allows to reduce the (UT1-UTC) systematics (decorrelation of gravity, orbit and ΔLOD)
  - The more satellites are combined, the smaller is the scatter of the pole coordinates

• **TRF:**
  - LARES helps to reduce the scatter of the transformation parameters & the global WRMS of the coordinates
  - with 11 satellites, the global WRMS is reduced by about 20-40 % w.r.t. the ILRS (LA1/2, ET1/2) solution
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Bloßfeld M., Müller H., Gerstl M., Stefka V., Bouman J. (2013)
*Improved monthly Earth’s gravity field solutions using multi-satellite SLR, J Geophys Res,* submitted soon
Relative weighting of satellites

- relative weighting using a variance component estimation (VCE) based on normal equations

\[ N_c = \lambda_1 N_1 + \lambda_2 N_2 + \cdots + \lambda_{10} N_{10} \quad \text{with} \quad \lambda_i = \frac{1}{\sigma_i^2} \]

<table>
<thead>
<tr>
<th>satellite</th>
<th>( \sigma_0^2 ) (TRF+EOP+GFC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA1</td>
<td>3.8</td>
</tr>
<tr>
<td>LA2</td>
<td>2.2</td>
</tr>
<tr>
<td>ET1</td>
<td>8.6</td>
</tr>
<tr>
<td>ET2</td>
<td>7.0</td>
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<tr>
<td>STE</td>
<td>34.6</td>
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<tr>
<td>STA</td>
<td>13.3</td>
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<tr>
<td>AJI</td>
<td>12.9</td>
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<tr>
<td>LTS</td>
<td>46.2</td>
</tr>
<tr>
<td>LRS</td>
<td>12.9</td>
</tr>
<tr>
<td>BTS</td>
<td>52.2</td>
</tr>
<tr>
<td>BEC</td>
<td>163.0</td>
</tr>
</tbody>
</table>

- Estimation of TRF+EOP+GFC in one combined adjustment
- STE: sun-synchronus orbit
- LTS: very poor AMR
- BTS: new reflector type, low weight
- BEC: non-spherical shape appr. With spherical model