Benefit of tracking GNSS satellites with SLR

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Overview

1. **Statistics**

2. Two major applications:
   1. GNSS orbit validation using SLR
   2. **Combined GNSS+SLR solution**

3. **Expectation** from a combination GNSS and SLR@GNSS

4. **Results** from one year of combining GNSS and SLR@GNSS

5. Conclusions and outlook
Network in 2008

SLR sites that tracked GNSS satellites in 2008

Altogether:
- 8 sites with > 1000 NP
- 5 sites with > 500 NP
- 6 sites with > 100 NP
- 6 sites with < 100 NP
- 25 SLR sites
- 32165 normal points (NP)
Number of observations in 2008

Number of SLR observations

- G05
- G06
- R15
- R24
- R07
- R11

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SLR residuals

SLR residuals for satellite G05, Orbit G3

Residual [mm]

Month in 2008
SLR residuals: Mean Bias

Satellite- / site-specific bias

Bias [mm]

-100 -80 -60 -40 -20 0 20 40 60 80 100

Satellite / site-specific bias

- G05
- G06
- R15
- R24
- R07
- R11

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SLR residuals: RMS

Satellite-/site-specific RMS of SLR residuals

RMS [mm]

G05  G06  R15  R24  R07  R11
Expectation from combined analysis

Strength of *SLR to geodetic satellites* (Lageos,...): Reference frame scale and geocenter
⇒ Applicable as well for SLR @ GNSS?

**GNSS deficiencies**: modeling of radiation pressure and satellite antenna phase center
- Radiation pressure (RPR) correlated with geocenter
- Antenna phase center correlated with scale
⇒ GNSS scale and geocenter not “true”

**SLR@GNSS**:
- RPR parameters have to be estimated from SLR as well
  ⇒ Geocenter is affected as well
- SLR observations independent from GNSS antenna phase center
  ⇒ Scale can be gained from SLR
## Expectation from combined analysis

<table>
<thead>
<tr>
<th></th>
<th>GNSS @GNSS</th>
<th>SLR @GNSS</th>
<th>SLR @Lageos</th>
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<tbody>
<tr>
<td><strong>Radiation pressure ↔ Geocenter</strong></td>
<td>Problems in RPR modelling</td>
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<td><strong>GNSS satellite antenna phase center ↔ Scale</strong></td>
<td>Problems in phase center modelling</td>
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<td>-</td>
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<td><strong>Range biases ↔ Scale</strong></td>
<td>-</td>
<td>To be defined</td>
<td>For a few sites only</td>
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</tbody>
</table>

Other topics to be considered:
- “Local ties” and “space ties”
GNSS+SLR combination

- Studies using one year of data: 2008
- Analysis and combination with the Bernese GPS Software

→ **GNSS-only NEQs (daily):**
  - Combined GPS+Glonass analysis performed at CODE

→ **SLR-only NEQs (daily):**
  - SLR data to GPS and Glonass satellites
  - Parameterization identical to GNSS analysis (orbits, ERP, geocenter)
  - In addition: Range biases

→ **Combination on normal equation level:**
  - Daily combination
  - Accumulation to annual solution
  - Use of “space ties” only, no “local ties”!
GNSS+SLR combination

Validation of estimated coordinates and of datum definition:
- Comparison of coordinate differences at co-located GNSS–SLR sites using **local tie values**
- Helmert transformation of combined solution to GNSS-only and SLR-only solutions: **Scale**

Parameters to be checked:
- SLR range biases
- GNSS satellite antenna offsets
- Geocenter
- Orbits
- …
Comparison with local ties

Level of agreement when using one year of data only
→ Coordinate differences from GNSS-only and SLR-only solutions (1 year)
→ Datum definition for both solutions using NNR+NNT (core sites)
→ Velocities from ITRF2005

3D vector difference: AIUB (zero difference), ITRF2008

Red: ITRF2008 (prelim.)

Blue: From annual single-technique solutions

Plot provided by M. Seitz, DGFI
Comparison with local ties

Changes when combining GNSS and SLR@GNSS using „space ties“ only
→ Combined yearly GNSS+SLR solution
→ Datum definition: NNR+NNT (GNSS core sites), **no Local ties**
→ **GNSS antenna phase center (SAO) fixed** = Scale defined by GNSS and SLR

3D vector difference [mm]

Red:
From annual single-technique solutions

Blue:
Combined solution, GNSS SAO fixed

Plot provided by M. Seitz, DGFI
Comparison with local ties

Changes when combining GNSS and SLR@GNSS using „space ties“ only
→ Combined yearly GNSS+SLR solution
→ Datum definition: NNR+NNT (GNSS core sites), no Local ties
→ GNSS antenna phase center (SAO) estimated = Scale defined by SLR only!

Plot provided by M. Seitz, DGFI
Comparison with local ties

Impact of GNSS antenna phase center (SAO) estimation:
→ No big differences ⇒ Estimation of SAO is possible
→ Slightly better agreement with local ties if scale is NOT defined by GNSS (has to be verified using longer time span of data!)

Blue:
Combined solution,
GNSS SAO fixed

Green:
Combined solution,
GNSS SAO estimated

Plot provided by M. Seitz, DGFI
SLR range biases

Question 1:
What is reasonable from technical point of view?

- Satellite-dependent? → Separate for every satellite
- System-dependent? → Average over GPS, over Glonass, ...
- Station-dependent? → Average over all GNSS satellites

Question 2:
Are the SLR range bias estimates influenced by estimating GNSS satellite antenna offsets?
System-specific range biases seem to be sufficient for most sites
Station-specific range biases seem to be sufficient

SLR range biases
Simultaneous estimation of GNSS antenna phase center offsets and SLR range biases is possible.
### Scale between solutions (GNSS core sites)

**Scale between solutions (GNSS core sites)**

$L = $ Satellite-specific SLR range biases  

$K = $ System-specific SLR range biases  

$J = $ Station-specific SLR range biases  

<table>
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<th>K1A</th>
<th>J1A</th>
<th>L1B</th>
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<td>0.3 ±1.0</td>
<td>-0.6 ±0.6</td>
<td>-0.3 ±0.7</td>
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</tbody>
</table>

**Notes:**

- **A**: GNSS Sat.ant. fixed  
  = Scale fixed
- **B**: GNSS Sat.ant. estimated  
  = Scale free $\Rightarrow$ from SLR

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Conclusions and outlook

- Combination on observation level using SLR@GNSS works fine

- Connection via „space ties“ is possible (without local ties)

  **BUT:**
  
  Accurate ties (in space and on sites) required for combination

- Scale from SLR can be transferred to GNSS (estimation of GNSS SAO)

- Open question: Best handling of SLR range biases to GNSS satellites?

- Studies have to be extended to longer time span

- Thanks to Manuela Seitz from DGFI for providing comparisons with local tie values!
SLR orbit validation for R23

- Switch to new z-offset for GNSS antenna of Glonass satellite R23 within IGS
- ILRS agreed to track R23 during the transition phase (10 weeks)

⇒ Many thanks to all SLR sites for supporting this tracking request!

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SLR residuals to satellite R23
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```
Day of the year 2009
```

```
SLR residuals [mm]
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```
190 200 210 220 230 240 250 260
−300 −200 −100 0 100 200 300
```

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SLR residuals

SLR residuals for satellite G06, Orbit G3

Month in 2008

Residual [mm]
SLR residuals

SLR residuals for satellite R24, Orbit G3

Residual [mm]

Month in 2008
SLR residuals

SLR residuals for satellite R15, Orbit G3

Month in 2008

Residual [mm]