Determination of a TRF from simulated VLBI and SLR data in the frame of GGOS

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Outline

1. Introduction
   - Motivation
   - Project GGOS-SIM
Outline

1 Introduction
   - Motivation
   - Project GGOS-SIM

2 VLBI
   - Input data
   - Strategy
   - Results
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4 Summary
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4. Summary
Reference frame as the realization of a reference system

Figure: Terrestrial reference frames connect the three pillars of geodesy, according to IAG (2015)
Combination of different space-geodetic techniques

- GPS
- DORIS
- SLR
- VLBI
ITRF2008 (Altamimi et al., 2011)

Requirements to a TRF for GGOS

- Accuracy of 1 mm
- Stability of 0.1 mm/yr
Project overview

Simulation of the Global Geodetic Observing System

- Funded by the German research foundation (DFG)
- Cooperation of TU Berlin (H. Schuh, S. Glaser) with GFZ Oberpfaffenhofen (R. Koenig, D. Ampatzidis)
- Simulation of GNSS, SLR, DORIS and VLBI observations to realize a TRS
- In the framework of the PLATO-WG
### Objectives of the project

Questions to be answered:
- What is necessary in order to achieve the requirements to a TRF in the framework of GGOS?
  - technique-specific (e.g., improvements of the space techniques, network geometry, ...)
  - combination related issues (e.g., local ties, level of combination, ...)
- What is the effect of co-location in space on the TRF?
Objectives of the project

Questions to be answered

What is necessary in order to achieve the requirements to a TRF in the framework of GGOS?

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- What is the effect of co-location in space on the TRF?
Outline

1. Introduction
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Input data

- Rapid turnaround R1, R4 sessions (24h)
- Time span: 2008-2014 (695 sessions)
- 28 globally distributed stations
- Reduction models according to IERS Conventions 2010
- No discontinuities
Simulation strategy

Prominent random error sources

- Troposphere
- Clock

Monte Carlo Simulator (Pany et al., 2011) with the software VieVS@GFZ

\[ \text{\texttt{o}} \cdot \text{\texttt{c}} = (\text{\texttt{zwd}}_1 \cdot \text{\texttt{wmf}}_1 (\text{\texttt{e}}) + \text{\texttt{clk}}_1) + (\text{\texttt{zwd}}_2 \cdot \text{\texttt{wmf}}_2 (\text{\texttt{e}})) - (\text{\texttt{zwd}}_1 \cdot \text{\texttt{wmf}}_1 (\text{\texttt{e}}) + \text{\texttt{clk}}_2) + \text{\texttt{wn}}_{\text{\texttt{bsl}}} \]

- \text{\texttt{zwd}}_1, \text{\texttt{zwd}}_2: zenith wet delay at station 1 and 2 of the baseline
- \text{\texttt{wmf}}_1, \text{\texttt{wmf}}_2: wet mapping function of elevation \text{\texttt{e}} at station 1 and 2 of the baseline
- \text{\texttt{clk}}_1, \text{\texttt{clk}}_2: clock correction at station 1 and 2
- \text{\texttt{wn}}_{\text{\texttt{bsl}}}: white noise of baseline

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Simulation strategy

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## Simulation strategy

### Prominent random error sources
- Troposphere
- Clock

### Monte Carlo Simulator (Pany et al., 2011) with the software VieVS@GFZ

$$o - c = (zwd_2 \cdot wmf_2(e) + clk_2) - (zwd_1 \cdot wmf_1(e) + clk_1) + wn_{bsl}$$

- $zwd_{1,2}$: zenith wet delay at station 1 and 2 of the baseline
- $wmf_{1,2}(e)$: wet mapping function of elevation $e$ at station 1 and 2 of the baseline
- $clk_{1,2}$: clock correction at station 1 and 2
- $wn_{bsl}$: white noise of baseline $bsl$
Simulation strategy

Monte Carlo Simulator (Pany et al., 2011) with the software VieVS@GFZ

\[ o - c = (zwd_2 \cdot wmf_2(e) + clk_2) - (zwd_1 \cdot wmf_1(e) + clk_1) + wn_{bsl} \]
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\[ o - c = (zwd_2 \cdot wmf_2(e) + clk_2) - (zwd_1 \cdot wmf_1(e) + clk_1) + wn_{bsl} \]

- **Troposphere**: turbulence model (Nilsson and Haas, 2010), same for all stations
- **Clock**: random walk plus integrated random walk process (Herring et al., 1990), \( ASD = 1e-14 @ 50 \text{ min} \)
- **White noise**: mean formal error of the observed group delay from reality, \( wn = 15 \text{ ps} \)
### Combination strategy

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**Parameterization**
- Estimated: $X, \dot{X}, x_p, y_p, dUT_1$
- Reduced: clock, troposphere, celestial pole offsets
- Fixed: $\alpha, \delta$

**Datum realization**
- Origin: NNT w. r. t. ITRF2008 using 10 core stations
- Orientation: NNR w. r. t. ITRF2008 using 10 core stations
- Scale: from VLBI observations

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GGOS-SIM

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Combination strategy

Combination of datum-free normal equation systems
Combination strategy

Combination of datum-free normal equation systems

Parameterization

- Estimated: $\mathbf{X}$, $\dot{\mathbf{X}}$, $x_p$, $y_p$, $dUT1$
- Reduced: clock, troposphere, celestial pole offsets
- Fixed: $\alpha$, $\delta$
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Combination of datum-free normal equation systems

Parameterization

- *Estimated*: $X, \dot{X}, x_p, y_p, dUT1$
- *Reduced*: clock, troposphere, celestial pole offsets
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Datum realization

- *Origin*: NNT w. r. t. ITRF2008 using 10 core stations
- *Orientation*: NNR w. r. t. ITRF2008 using 10 core stations
- *Scale*: from VLBI observations
Results - Positions and velocities

**VLBI-TRF from simulated (top) and real (bottom) observations**

<table>
<thead>
<tr>
<th></th>
<th>$T_x$ [mm]</th>
<th>$T_y$ [mm]</th>
<th>$T_z$ [mm]</th>
<th>$R_x$ [µas]</th>
<th>$R_y$ [µas]</th>
<th>$R_z$ [µas]</th>
<th>$D$ [ppb]</th>
<th>$s_0$ [mm]</th>
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</thead>
<tbody>
<tr>
<td>pos</td>
<td>0.4±0.6</td>
<td>-0.4±0.6</td>
<td>-0.0±0.6</td>
<td>22±25</td>
<td>3±21</td>
<td>11±23</td>
<td>-0.17±0.09</td>
<td>2.3</td>
</tr>
<tr>
<td>vel</td>
<td>-0.1±0.1</td>
<td>0.0±0.1</td>
<td>0.0±0.1</td>
<td>-6±4</td>
<td>5±4</td>
<td>-0.01±0.02</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>

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<th>$D$ [ppb]</th>
<th>$s_0$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>pos</td>
<td>-1.9±2.2</td>
<td>0.7±2.2</td>
<td>-0.6±2.1</td>
<td>-16±87</td>
<td>-1±80</td>
<td>51±86</td>
<td>-0.03±0.33</td>
<td>7.3</td>
</tr>
<tr>
<td>vel</td>
<td>0.3±0.5</td>
<td>-0.3±1.2</td>
<td>0.4±1.2</td>
<td>3±19</td>
<td>-1±17</td>
<td>-22±19</td>
<td>0.06±0.07</td>
<td>1.6</td>
</tr>
</tbody>
</table>

In general: agreement on the sub-mm level

Largest differences for "real" VLBI-TRF in $T_x$ and $R_z$ (mm level)

Standard deviations of transformation parameters 3-5 times smaller in case of sim-VLBI-TRF

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Results - Positions and velocities

VLBI-TRF from simulated (top) and real (bottom) observations

14-parameter-Helmert transformation at epoch 2005.0 w. r. t. ITRF2008

<table>
<thead>
<tr>
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<td>11±23</td>
<td>-0.17±0.09</td>
<td>2.3</td>
</tr>
<tr>
<td>vel [yr]</td>
<td>-0.1±0.1</td>
<td>0.0±0.1</td>
<td>0.0±0.1</td>
<td>-6±4</td>
<td>5±4</td>
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- In general: agreement on the sub-mm level
- Largest differences for “real” VLBI-TRF in $T_x$ and $R_z$ (mm level)
- Standard deviations of transformation parameters 3-5 times smaller in case of sim-VLBI-TRF
Results - ERP

ERP w. r. t. IERS 08 C04 (Bizouard and Gambis, 2011)

mean, standard deviation in brackets

\[\Delta dUT1, \Delta y, \Delta x\]
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Input data

Data

Observations to LAGEOS-1 and LAGEOS-2
Time span: 2008-2014
49 globally distributed stations
Reduction models according to IERS Conventions 2010 and ILRS Analysis-WG rules
No discontinuities
→ Consistent with VLBI input data

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Input data

- Observations to LAGEOS-1 and LAGEOS-2
- Time span: 2008-2014
- 49 globally distributed stations
- Reduction models according to IERS Conventions 2010 and ILRS Analysis-WG rules
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Input data

- Observations to LAGEOS-1 and LAGEOS-2
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- No discontinuities
  → Consistent with VLBI input data
Data

Station network
Simulation strategy
Simulation strategy

Simulation of the observations

- Number of observations according to those accepted in Precise Orbit Determination
- Accuracy of observations: station-dependent white noise according to RMS from reality
Results - Station performance: Number of observations

- Simulation similar to reality
- However, homogeneous number of observations for all stations within the simulation
Results - Station performance: Accuracy

- Station-dependent accuracy according to reality
- No variation over the time span within the simulation
Outline

1. Introduction
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Conclusions

VLBI-TRF from simulated observations is in good agreement with "real" VLBI-TRF. Simulated VLBI-TRF is in good agreement with ITRF2008 (station positions, velocities) and IERS C04 series (ERP).

SLR

Simulated station performance (# obs, accuracy) according to reality.

Next steps:
- Refinement of simulated station performance (time- and station-dependent)
- Determination of a simulated SLR-TRF

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Conclusions

**VLBI**

- VLBI-TRF from simulated observations is in good agreement with "real" VLBI-TRF
- Simulated VLBI-TRF in good agreement with ITRF2008 (station positions, velocities) and IERS C04 series (ERP)
Conclusions

**VLBI**

- VLBI-TRF from simulated observations is in good agreement with “real” VLBI-TRF
- Simulated VLBI-TRF in good agreement with ITRF2008 (station positions, velocities) and IERS C04 series (ERP)

**SLR**

- Simulated station performance (# obs, accuracy) according to reality
- Next steps:
  - Refinement of simulated station performance (time- and station-dependent)
  - Determination of a simulated SLR-TRF
Further investigations

- Combination of NEQs from simulated observations
Further investigations

- Combination of NEQs from simulated observations
- Applying different combination strategies
  - Local ties (real and simulated)
  - Space ties (e.g. SLR to GNSS satellites, GRASP, CubeSats)
  - Global ties (ERP)
Further investigations

- Combination of NEQs from simulated observations
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  - Local ties (real and simulated)
  - Space ties (e.g. SLR to GNSS satellites, GRASP, CubeSats)
  - Global ties (ERP)
- Testing different network geometries
- Applying new technical system upgrades
Thank you very much for your attention.

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Appendix

VLBI

Station performance VLBI: Number of observations

- Number of observations according to reality
Simulation strategy

Monte Carlo Simulator (Pany et al., 2011) with the software VieVS@GFZ

- Troposphere: turbulence model (Nilsson and Haas, 2010)
  - Input parameter (same for all stations):
    - refractive index structure constant $C_n = 2.5 \times 10^{-7} m^{-1/3}$
    - effective height of wet troposp. $H = 2000$ [m]
    - north component of wind vector $v_n = 0$ [m/s]
    - east component of wind vector $v_e = 8$ [m/s]
    - a priori zenith delay $wzd_0 = 150$ [mm]
    - correlation interval $dhseg = 2$ [h]

- Clock: random walk plus integrated random walk process (Herring et al., 1990)
  - $ASD = 1e-14$ @ 50 min

- White noise: mean formal error of the observed group delay from reality, $wn = 15$ ps
Homogeneous white noise for all stations
Results - Velocities

Horizontal station velocity field
Results - Station performance

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Reality</th>
<th>Simulation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RMS (cm)</td>
<td>RMS (cm)</td>
</tr>
<tr>
<td></td>
<td># obs</td>
<td># obs</td>
</tr>
<tr>
<td>LAGEOS-1</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>528,688</td>
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<tr>
<td>LAGEOS-2</td>
<td>0.91</td>
<td>0.92</td>
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<tr>
<td></td>
<td>468,834</td>
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<tr>
<td>All</td>
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<tr>
<td></td>
<td>997,522</td>
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