Orbit Determination of Low Earth Satellites at AIUB

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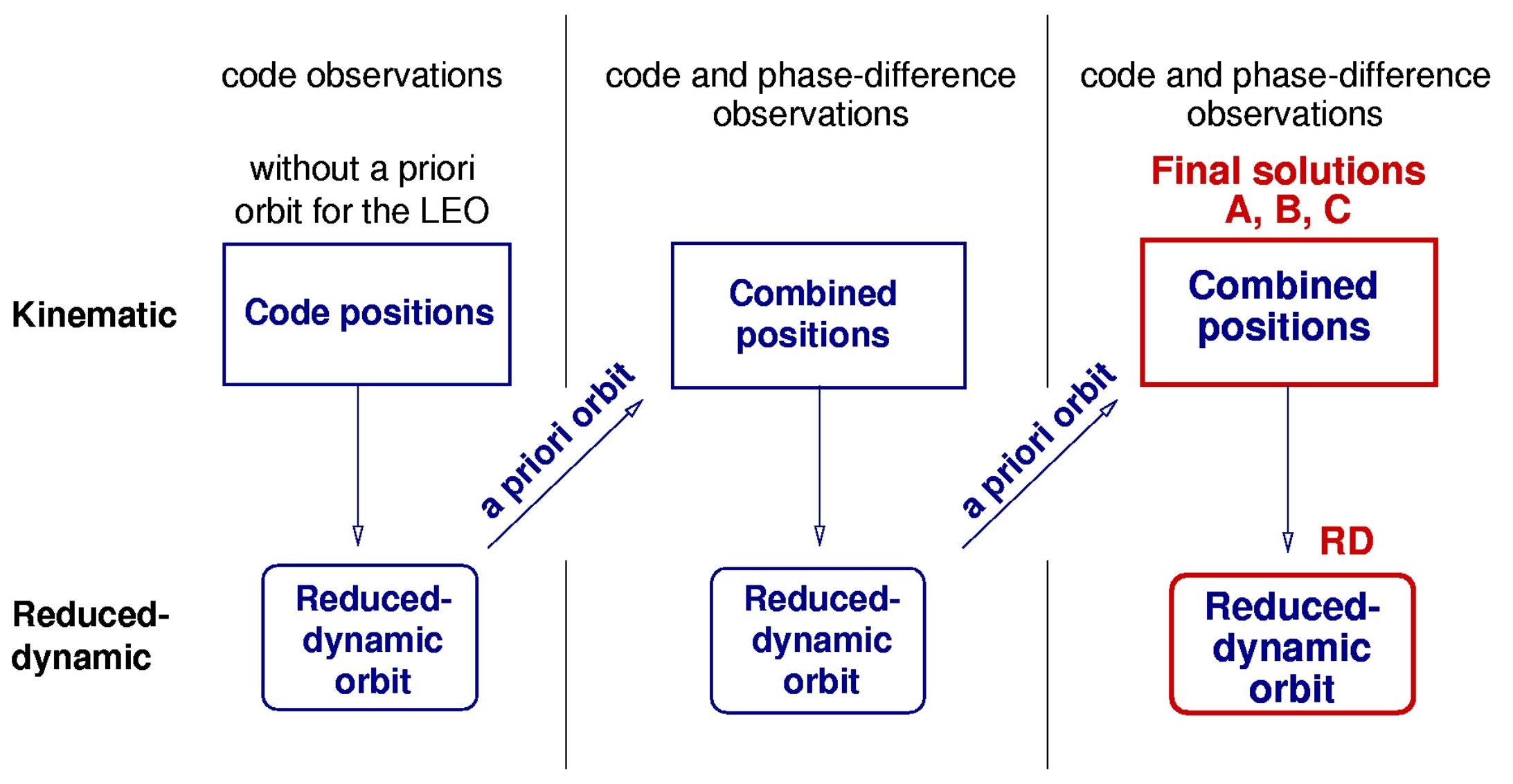
Introduction

The poster presents activities at the Astronomical Institute of the University of Berne (AIUB) in the field of precise orbit determination (POD) for Low Earth Orbiters (LEO) using the GPS. They range from efficient and robust LEO precise orbit determination, orbit modeling using stochastic accelerations, to combined processing of GPS and LEO orbits using double difference observations in a global network.

Efficient LEO POD



code observations

without a priori orbit for the LEO

code and phase-difference observations

code and phase-difference observations

Final solutions A, B, C

Kinematic

Code positions

Combined positions

Combined positions

a priori orbit

a priori orbit

RD

Reduced-dynamic

Reduced-dynamic orbit

Reduced-dynamic orbit

Reduced-dynamic orbit

Figure 1: Flow diagram of iterative procedure for efficient and robust precise orbit determination of LEOs.

Methods

Kinematic procedure:

- Epoch-wise code positions and epoch-differenced phase position-differences are combined into precise positions.
- Data screening procedure is embedded.
- dm-accuracy can be achieved.

Reduced-dynamic procedure:

- Kinematic positions are used as pseudo-observations.

Both procedures are used in a sequence in an iterative procedure composed of three steps [Bock, 2003a].
=> efficient and robust method.

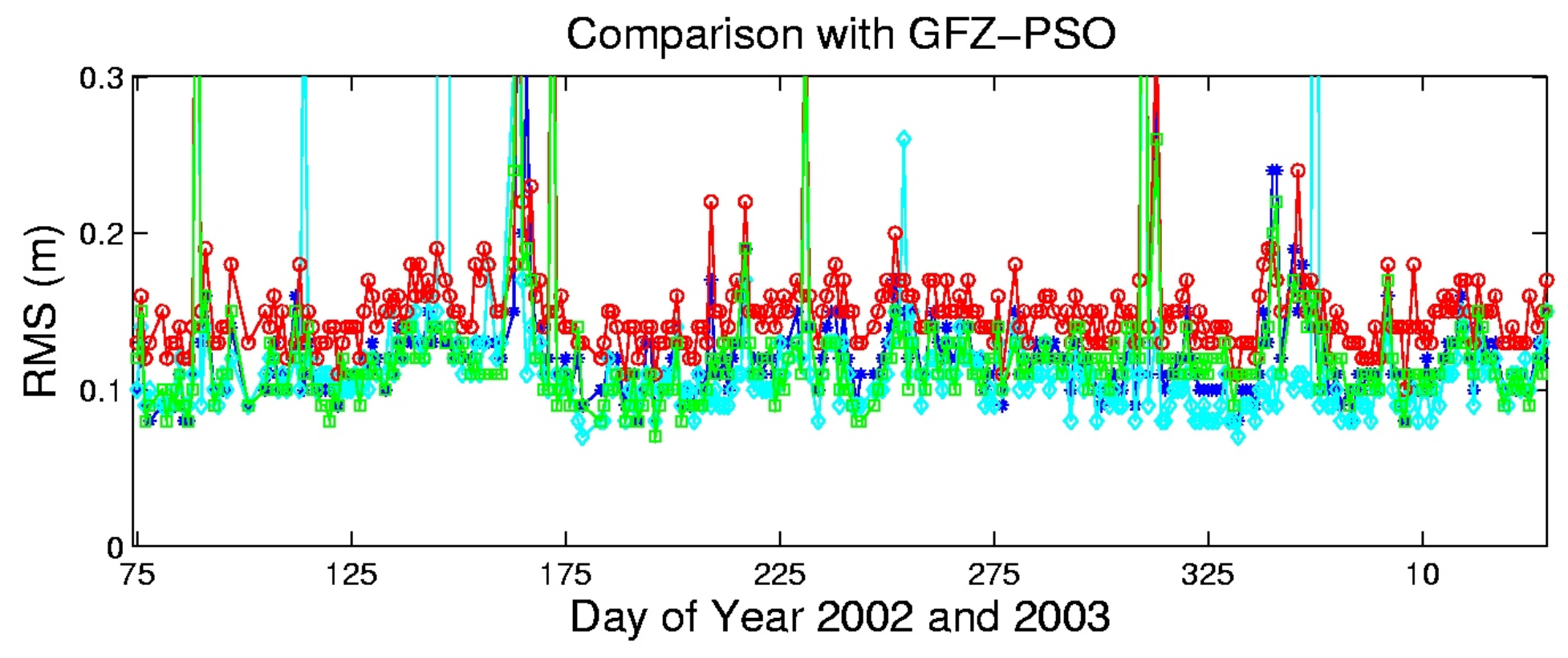


Figure 2: RMS errors (m) per coordinate per day of orbit differences between the orbit solutions and the precise science orbit (PSO) of GFZ (http://isdc.gfz-potsdam.de), **cyan:** solution RD and GFZ-PSO, **blue:** solution A and GFZ-PSO, **green:** solution B and GFZ-PSO, **red:** solution C and GFZ-PSO.

The comparison in Figure 2 shows for both the kinematic and the reduced-dynamic solution dm-accuracy w.r.t. the GFZ orbit. The comparison with SLR measurements (Figure 3) shows dm-level as well.

Orbit Solutions

CHAMP, day 075/2002 to 039/2003 [Bock, 2003b]:

Kinematic solutions:

- **Solution A (blue):**
  - 30-second GPS clock corrections,
  - elevation-dependent weighting of the observations with $\cos^2 z$.
- **Solution B (green):**
  - 30-second GPS clock corrections,
  - no elevation-dependent weighting.
- **Solution C (red):**
  - 5-minute GPS clock corrections,
  - elevation-dependent weighting with $\cos^2 z$.

Reduced-dynamic solution:

- **Solution RD (cyan):**
  - Code positions and phase position-differences of **solution A** used as pseudo-observations,
  - pseudo-stochastic pulses every ten minutes.

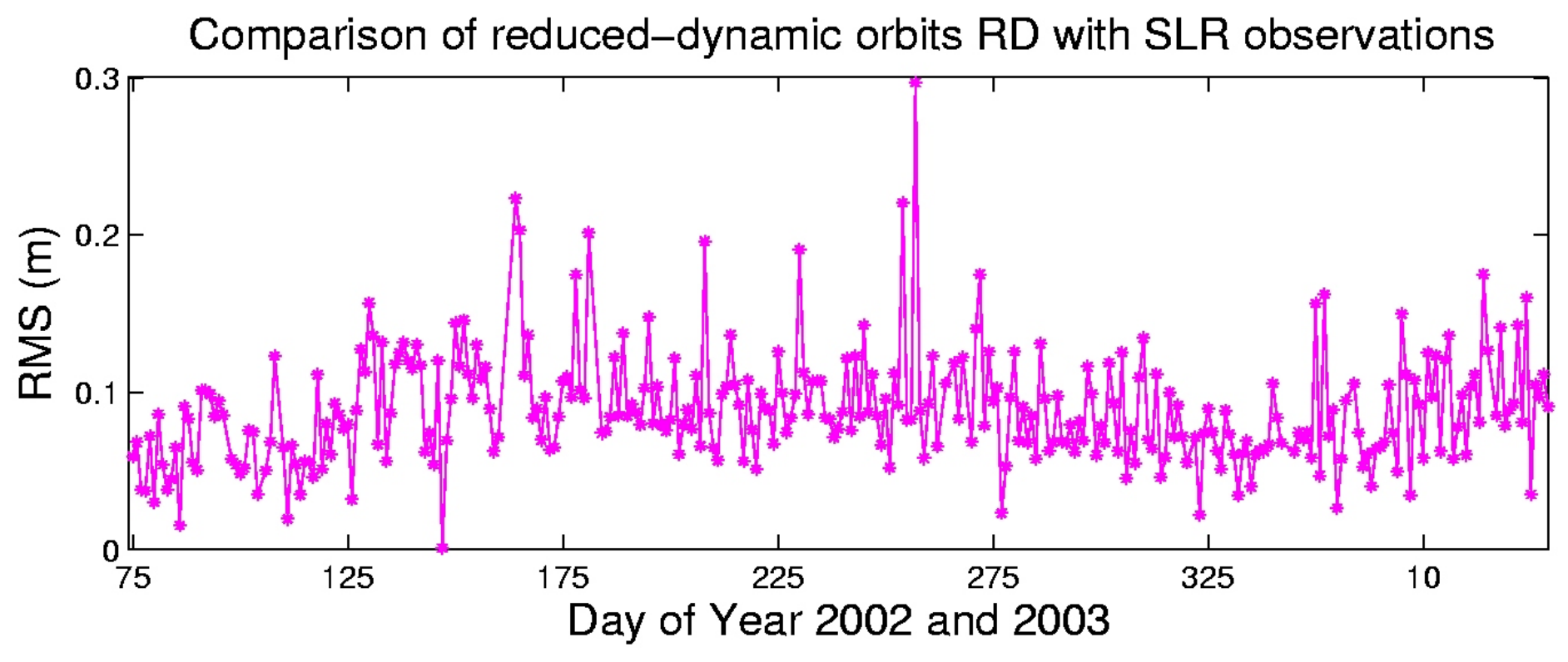


Figure 3: RMS errors (m) per coordinate per day of differences between the reduced-dynamic orbit solution RD and SLR measurements of CHAMP for day 075/2002 to 039/2003.

CHAMP Orbit Modeling using Stochastic Accelerations

Method

Measurement type:

- Zero-difference GPS carrier phase observations.

GPS orbits and clocks:

- Final orbits from CODE,
- High-rate clocks from CODE.

Gravity field model:

- EIGEN-2 [Reigber, 2003].

LEO reduced-dynamic orbit parametrization:

- Six initial conditions (Keplerian elements),
- Piecewise constant accelerations in R, A, O.

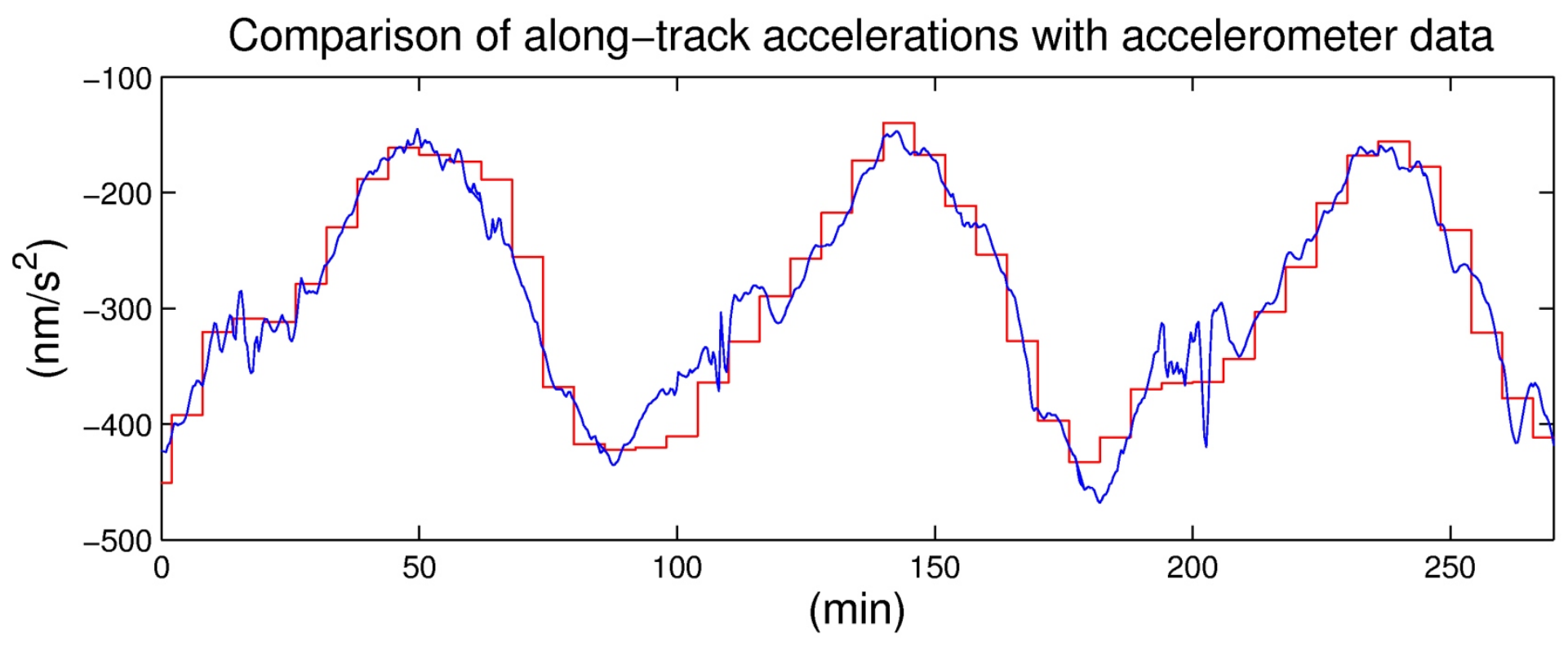


Figure 4: Piecewise constant accelerations for day 198/2002 in along-track direction compared with STAR accelerometer measurements (bias and scale applied) using the gravity field model EIGEN-2.

Along-track accelerations can be well tracked by piecewise constant accelerations (Figure 4) as confirmed by the high correlation (about 95%) with independent STAR accelerometer measurements. In principle bias and scale parameters of the accelerometer could be derived by such comparisons.

Orbit Solutions

CHAMP, day 160/2002 to 260/2002:

Constant accelerations over 6 minutes:

- **Solution (a) (dark blue):**
  Constraints of $5 \cdot 10^{-8}$ m/s^2 (loose) in R, A, O.
- **Solution (b) (blue):**
  Constraints of $1 \cdot 10^{-8}$ m/s^2 in R, A, O.
- **Solution (c) (cyan):**
  Constraints of $5 \cdot 10^{-9}$ m/s^2 (tight) in R, A, O.

Constant accelerations over 15 minutes:

Solutions (a’), (b’), and (c’) (analogue constraining).

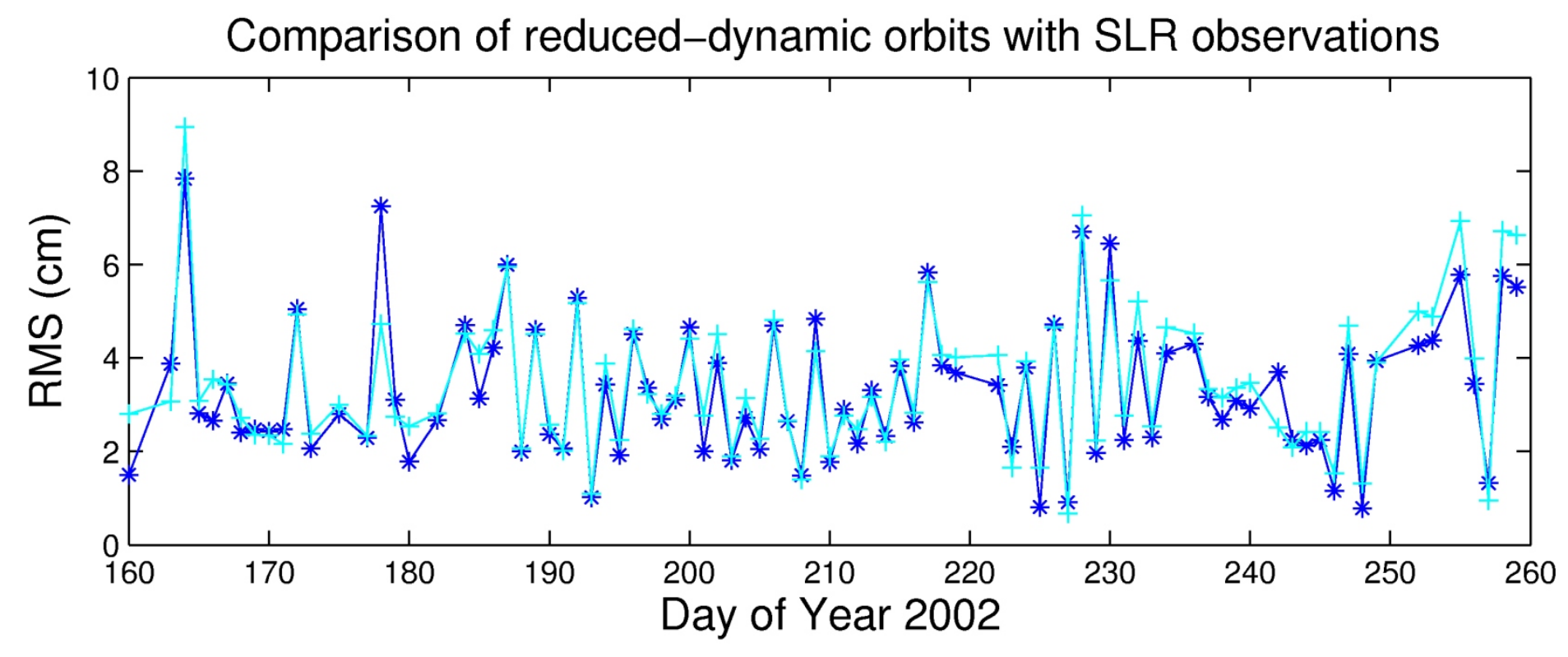


Figure 5: RMS errors (cm) per coordinate per day of differences between reduced-dynamic orbits and SLR measurements of CHAMP for days 160/2002 to 260/2002, **blue:** solution (b), **cyan:** solution (c).

The validation of the CHAMP orbit solutions with independent SLR measurements (Figure 5) shows an accuracy of about 3.5 cm slightly favouring solution (b). The differences between both orbits are very small (Figure 7). Almost identical solutions based on pulses may be generated as well [Jäggi, 2003].

Orbit Comparisons

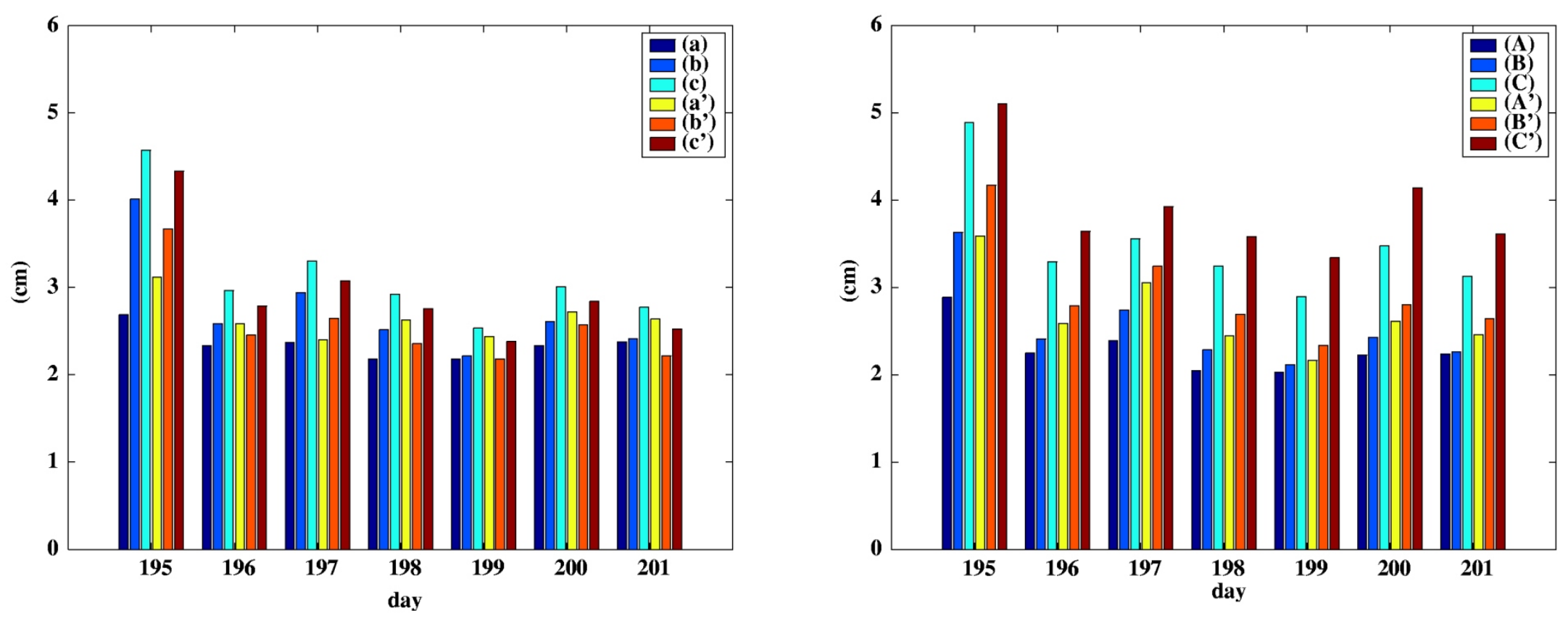


Figure 6 (left): RMS errors (cm) per coordinate per day of plain orbit differences between different orbit solutions and reduced-dynamic orbits from the Technical University of Munich (TUM) [Svehla, 2003] for days 195/2002 to 201/2002.
Figure 6 (right): Analogue comparison with orbits based on pulses (capital letters). Note that such orbits tend to deviate more rapidly from the TUM solutions (based on pulses as well) with varying constraints and number of parameters.

The comparison in Figure 6 shows for all solutions an agreement of a few cm w.r.t. the TUM orbits. Note the impact of attitude information intentionally not taken into account on day 195/2002 for our solutions.

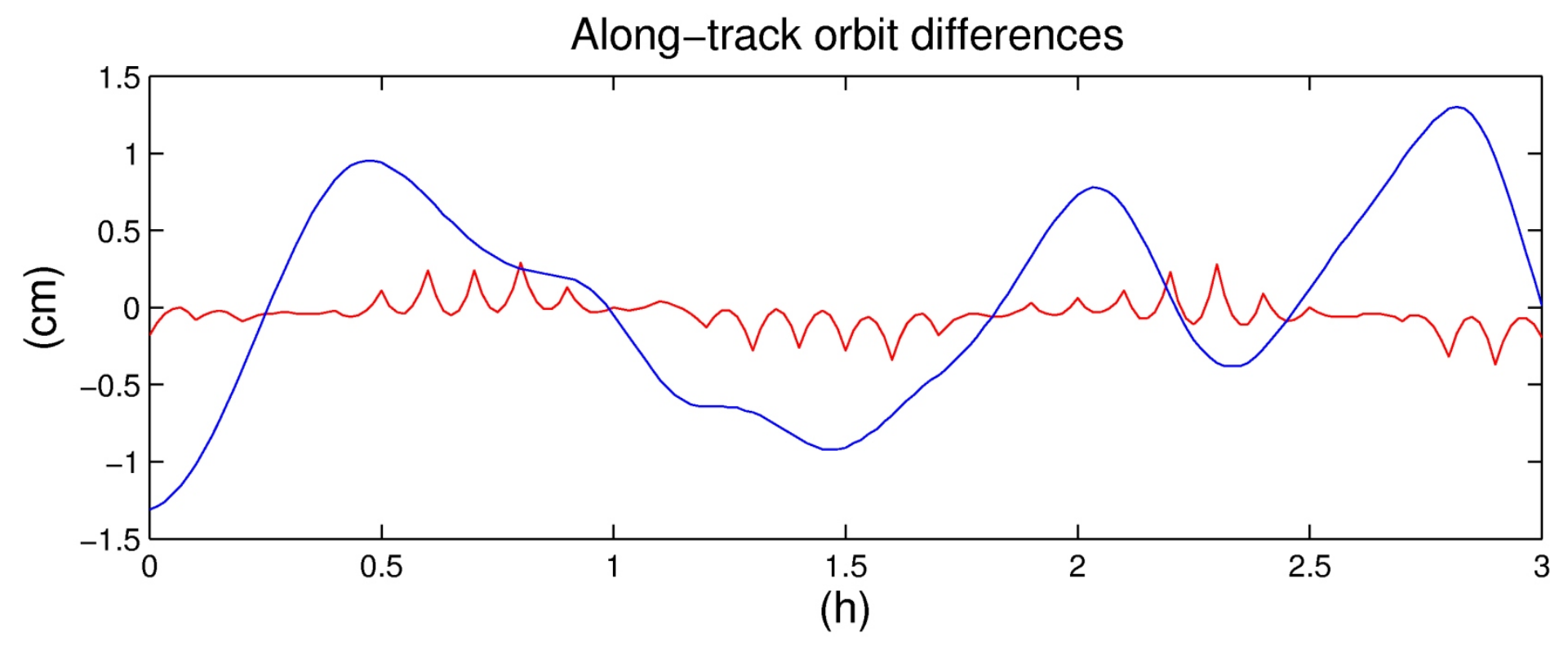


Figure 7: Along-track orbit differences (cm) between different orbit solutions for day 198/2002, **blue:** solution (c) and (b), **red:** pulse solution (B) and (b). Note the effect caused by the instantaneous velocity changes every six minutes.

Combined Processing of GPS and LEO Orbits

Combination Strategy

- JASON GPS data day 154-159/2002.
- CODE single-difference files, screened and ambiguity fixed (120 IGS ground stations).
- Selection of ground stations for baselines space-ground in the following way:
  - Candidate stations track the same satellites as JASON (maximum one missing satellite allowed).
  - Selection of the corresponding stations and time intervals such that one baseline is active at a time and the number of baselines is minimal.
- Baselines are active between 4 and 40 minutes (on average 4-5 baselines per satellite revolution) => 70 stations selected.
- Processing together with CODE ground network in four regional clusters and combination on normal equation level.

JASON Orbit

- Reduced-dynamic orbit with stochastic pulses (15 min).
- Validation of orbit using orbit overlaps, SLR residuals, and comparison with CNES SLR-DORIS orbit.
- Orbit accuracy 3-5 cm.

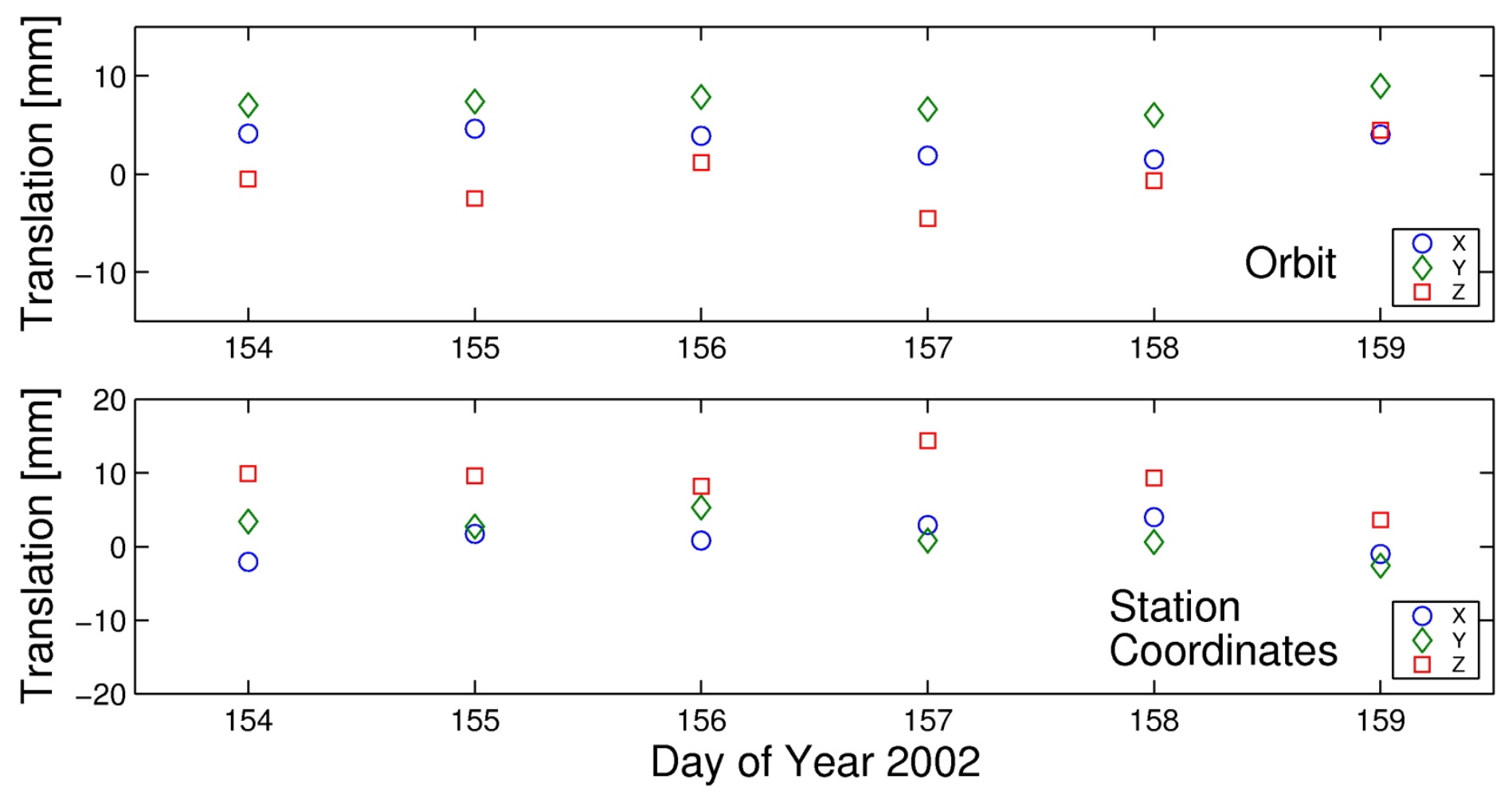


Figure 8: Helmert translation parameter (mm) for GPS orbits (top) and station coordinates (bottom) between solutions GPS and GPS + LEO.

Effect on GPS Solution

- Figure 8 (top) shows the translation of the GPS orbits computed with GPS and GPS + LEO. No significant change in scale or orientation.

=> GPS orbits are affected at the cm-level.

- RMS difference between GPS orbit solutions at the cm-level.

=> LEO orbit modeling problems affect GPS orbits.

- Figure 8 (bottom) shows the translation of the station coordinate solutions, i.e., the effect on the geocenter coordinates of adding JASON to the global solution. Station coordinates agree at the sub-mm-level.

=> Geocenter coordinates are affected at the cm-level.

- Changing the JASON antenna phase center position intentionally affects in particular the translation in z-direction of GPS orbits and ground station network.
- Earth orientation parameters show differences up to 0.2 mas/day for pole rates and up to 10 us/day for LOD.

=> Impact of introducing a LEO into the global processing has a larger effect than expected from adding one station to a ground network of 120 receivers.

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