Precise orbit determination for the maneuvering Sentinel-3 satellites

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Outline

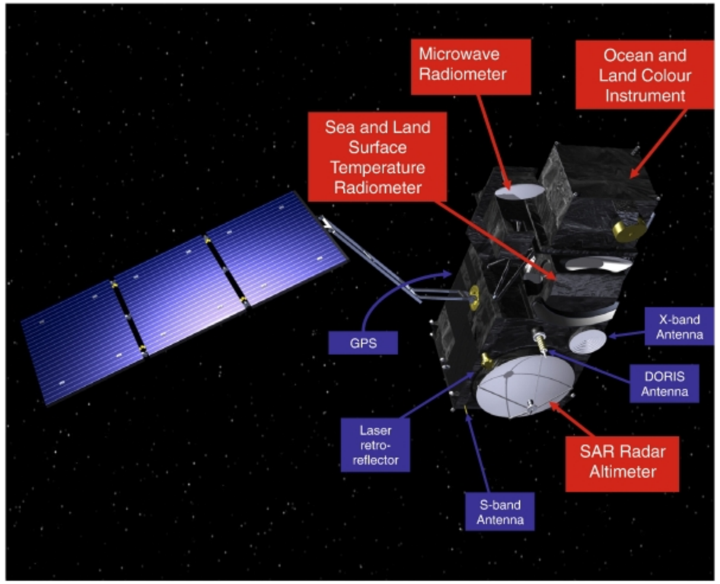
- Motivation
- Bernese POD strategy
- Internal consistency check
- External orbit validations
- Conclusions

Motivation

- Low Earth Orbit (LEO) satellite perform maneuvers to,
  - overcome highly-perturbed in-flight conditions
  - maintain pre-defined trajectory
  - keep formation/constellation flying
  - avoid threatening collisions…
- However,
  - (reduced-) dynamic Precise Orbit Determination (POD) is downgraded
  - follow-on scientific research might be influenced by imperfect orbit…

Motivation

- Sentinel-3A/3B satellites
  - Part of the fleet of European Space Agency’s Copernicus Earth observation satellites
  - Altimetry satellites --> very high demands for (radial) orbit accuracy
  - High-precision GPS receiver and laser retro-reflector for POD and validation
  - Astronomical Institute, University of Bern (AIUB) is a member of the Copernicus POD Quality Working Group
  - Before: no AIUB POD service for maneuver days



Sentinel-3 satellite and payloads (Credit: ESA)

Motivation

- Sentinel-3A/3B maneuvers are challenging
  - Maneuver records from radio telemetry are available
    - might be imperfect
  - Acceleration magnitude: **1e-3 m/s^2**, mostly in cross-track direction
    - As reference, GRACE and GRACE-FO’s magnitudes are **1e-4 m/s^2**
  - Time span: from **a few seconds to 15+ mins**

Aim:

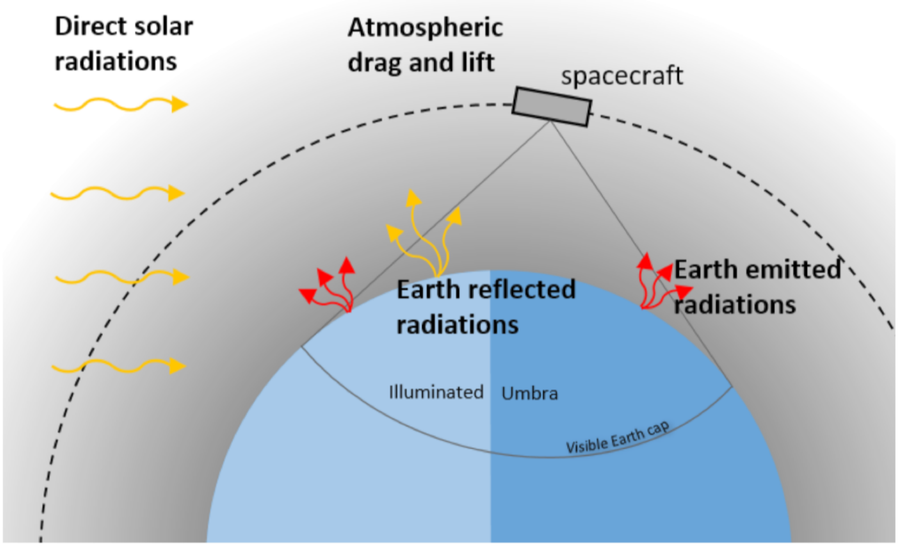
high-quality AIUB POD solution for the maneuvering Sentinel-3 satellites!

Bernese POD strategy

- Software: Bernese GNSS Software v5.3
- Final POD solutions: reduced-dynamic
- Satellite geometry: macro-model
- Gravitational forces
- Non-gravitational forces
- Dynamic parameters:
  - orbit elements
  - constant empirical acc.
  - Constant maneuver acc. in satellite body-fixed frame
- Pseudo-stochastic parameters:
  - piece-wise constant acc.
  - velocity pulses depending on maneuver time span
- Single receiver integer ambiguity resolution
  - Only fix ambiguities that are not crossing maneuver periods!

No a-priori maneuver accelerations are used!

Meanwhile, kinematic POD is free of forces, maneuvers and dynamic/pseudo-stochastic parameters, can be used as reference!



Graphical representation of the four relevant non-gravitational forces acting upon LEOs

Bernese POD strategy

- Data sets
  - All Sentinel-3A/3B maneuver days from year 2020
  - A reference day (YYDOY: 20245) of Sentinel-3A without maneuver

Sentinel-3A

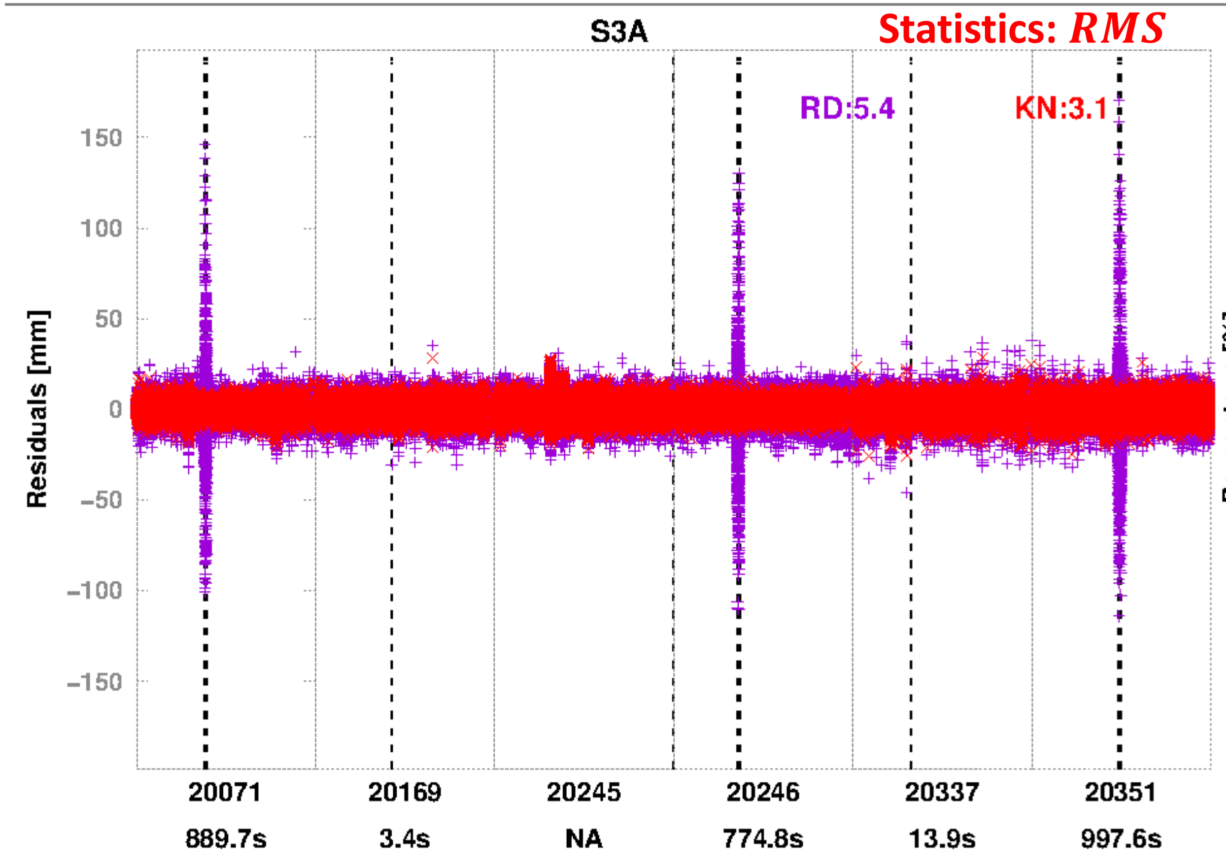
DOY	Maneuver [s]
20071	889.7
20169	3.4
20245	N/A
20246	774.8
20337	13.9
20351	997.6

Sentinel-3B

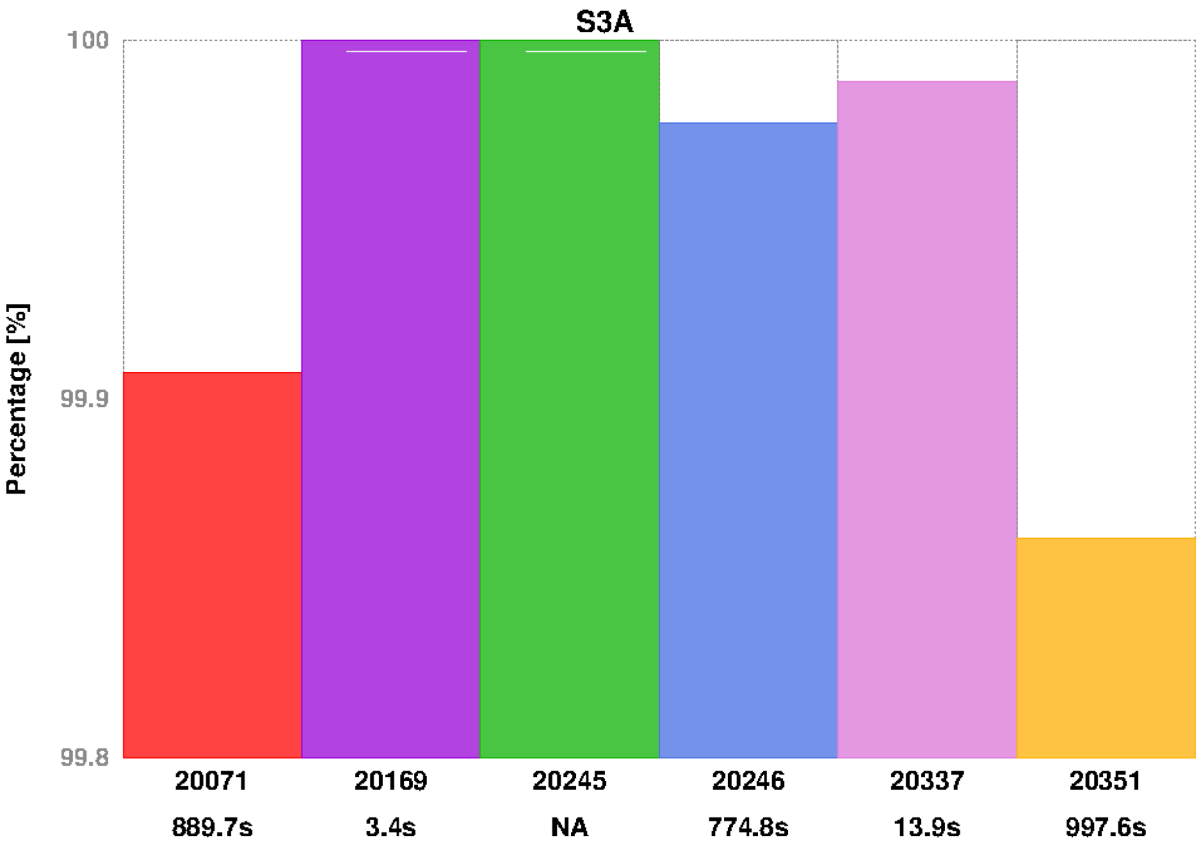
DOY	Maneuver [s]
20036	718.6
20099	673.8
20148	2.9
20211	1.9
20281	885.6
20351	13.8

Internal orbit consistency

The days (YYDOY) and maneuver durations ([s]) will be indicated at the x-axis in all figures.



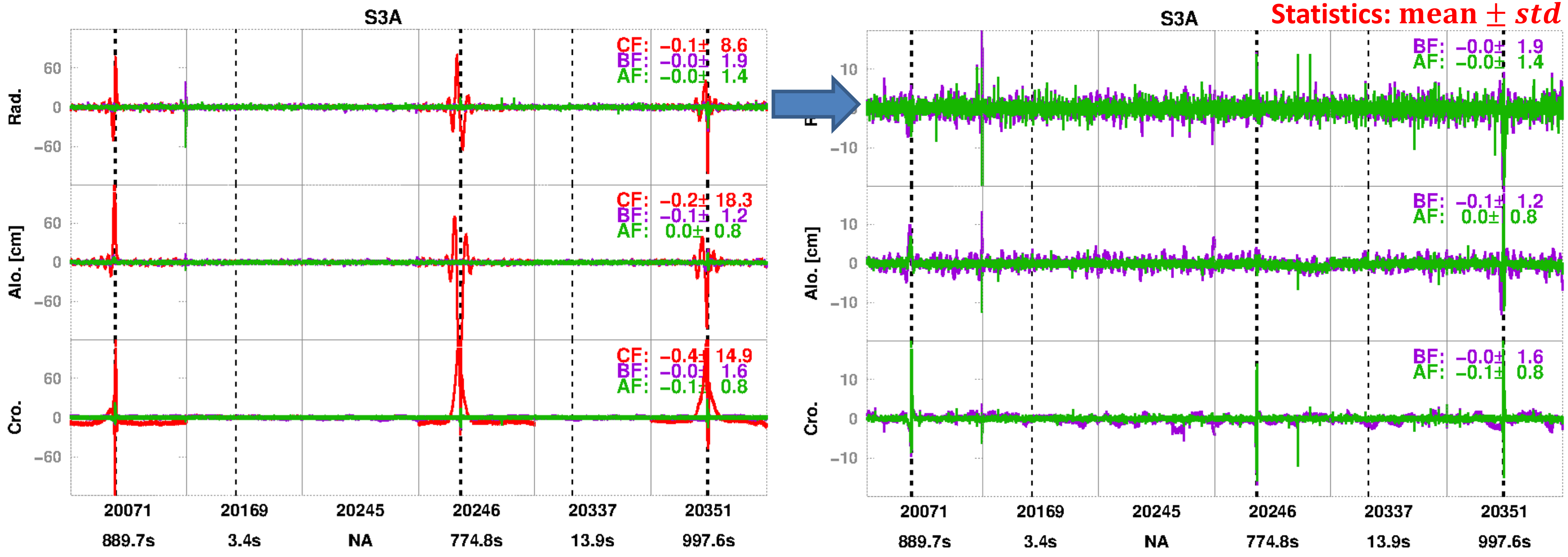
Ionosphere-free carrier-phase residuals and RMS statistics for the ambiguity-fixed POD solution of Sentinel-3A maneuver and reference days.



kinematic orbit availability in 24-hrs for Sentinel-3A.

- Kinematic POD has high availability and is hardly influenced by maneuvers, can be used as reference orbit.
- Reduced-dynamic POD for small-maneuver days works fine, only visible impact from strong maneuvers.

Internal orbit consistency



Kinematic/reduced-dynamic orbit consistency for the different Sentinel-3A orbit solutions. **CF: only estimate accelerations; BF: CF + velocity pulses depending on the maneuver duration, $\sigma = 1\mathrm{m}/s$; AF: BF + integer ambiguity fixing, final POD result for the next analyses**

- Additional velocity pulses estimation is crucial for strong-maneuver days.
- Integer ambiguity resolution further constrains parameter estimation and enhances POD for maneuver days.

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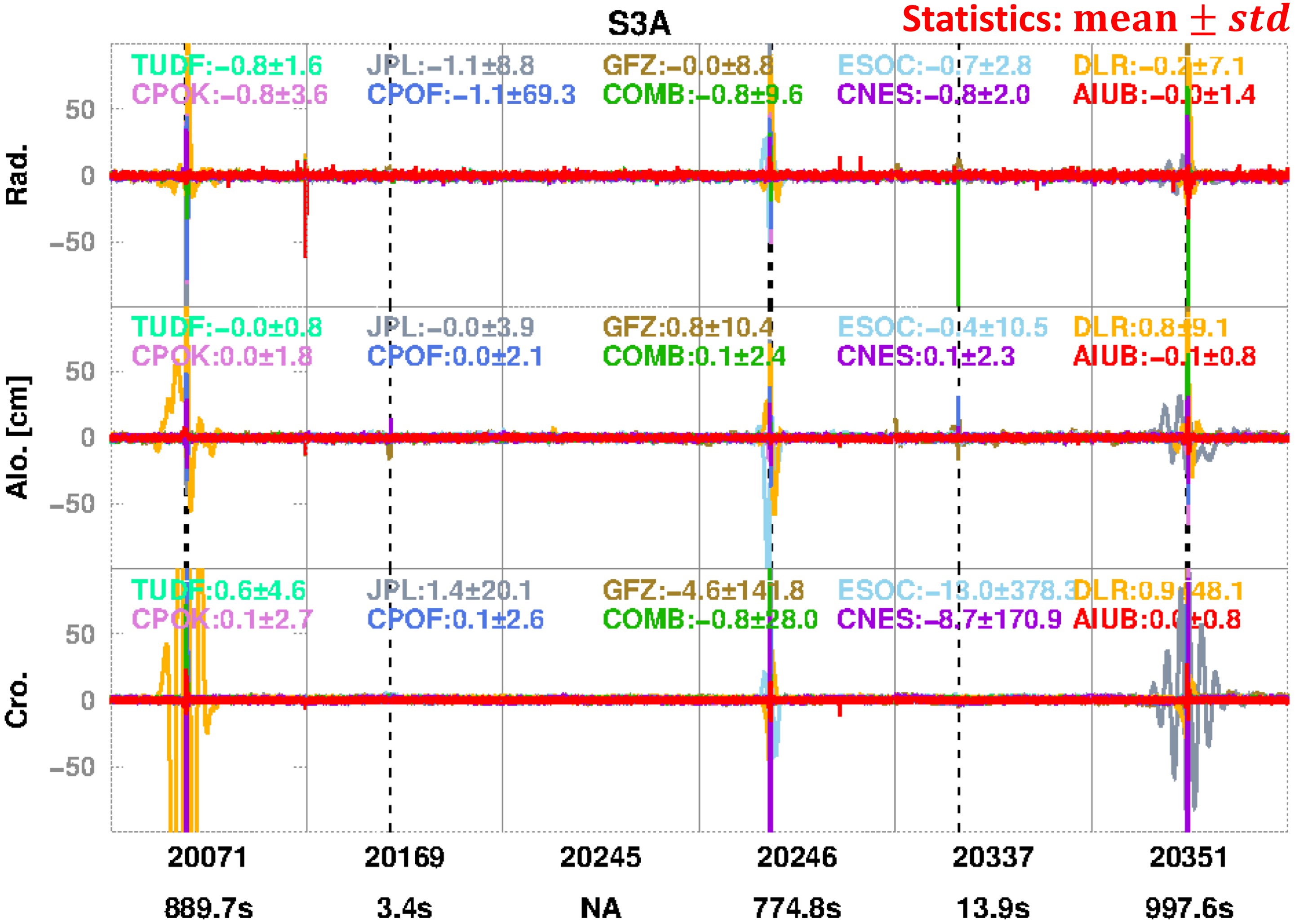
External orbit validation



Consistency between the AIUB ambiguity-fixed kinematic orbit and orbits delivered by different members of the POD Quality Working Group for the Sentinel-3A satellite. No outlier screening.

List of institutes with POD service for maneuver days (alphabet in descending order):

TUDF: Delft University of Technology
JPL: Jet Propulsion Laboratory
GFZ: German Research Centre for Geosciences
ESOC: European Space Operations Centre
DLR: German Aerospace Centre
CPOK: Official CPOD Orbit, kinematic
CPOF: Official CPOD orbit, reduced-dynamic
COMB: Combined solution of different orbits
CNES: French Space Agency
AIUB: Astronomical Institute, University of Bern

AIUB orbit is among the best in terms of agreement with the same reference kinematic orbit.

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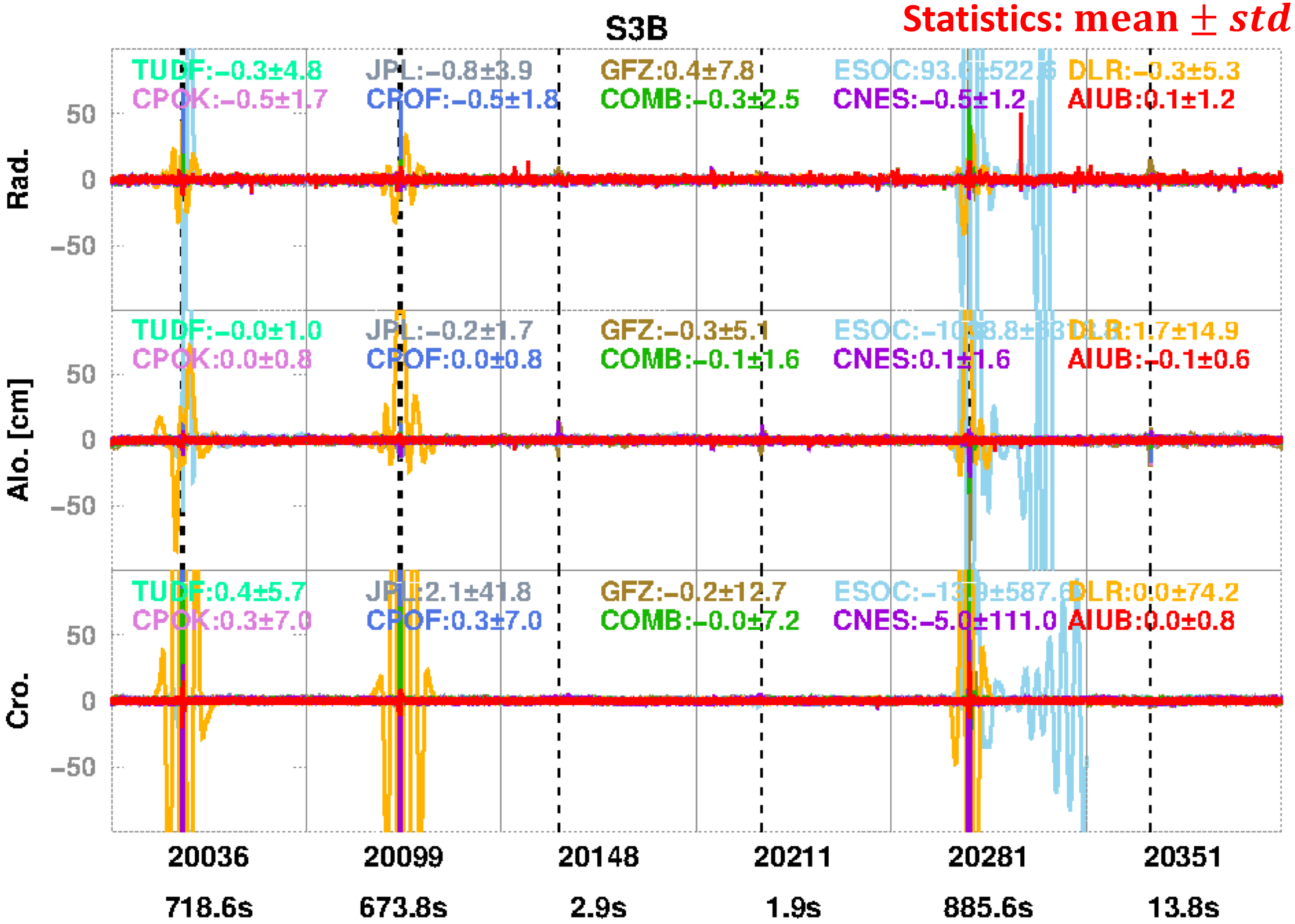
External orbit validation

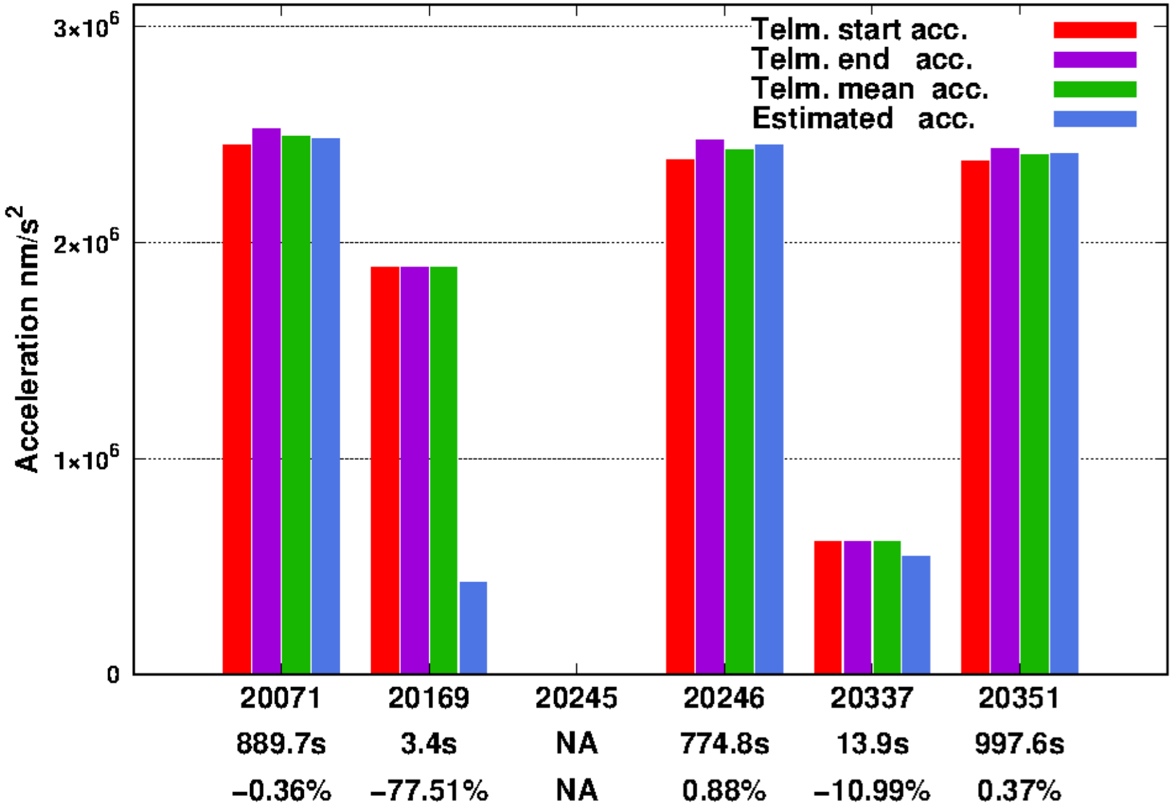
Statistics: mean $\pm$ std

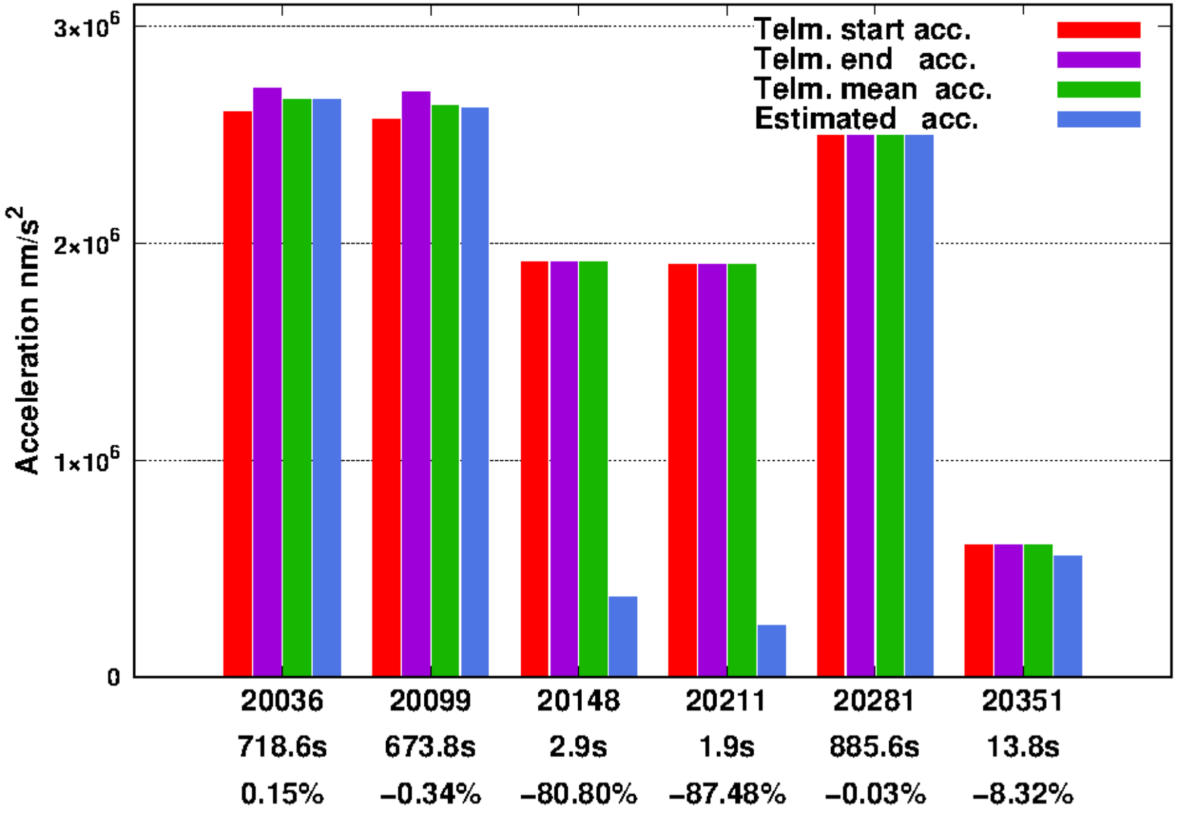


AIUB orbit is among the best in terms of agreement with the same reference kinematic orbit.

Consistency between the AIUB ambiguity-fixed kinematic orbit and orbits delivered by different members of the POD Quality Working Group for the Sentinel-3B satellite. No outlier screening.

External orbit validation

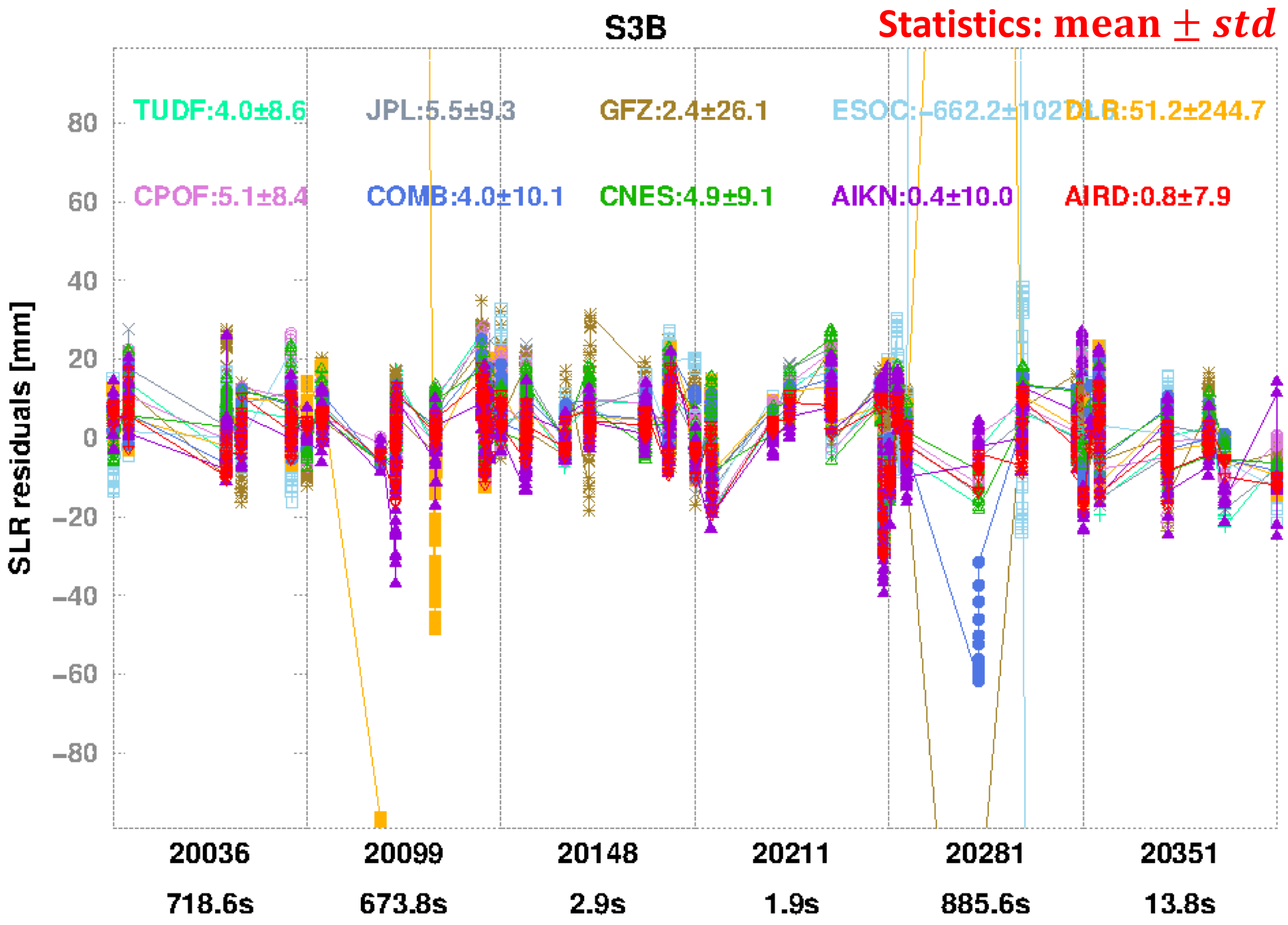




Comparison between the start/end/mean maneuver accelerations from the telemetry data and the AIUB-estimated accelerations for the Sentinel-3A (left) and Sentinel-3B (right) satellite. **The differences between the AIUB-estimated and telemetry mean accelerations are in the bottom line (unit in [%]).**

- For days with strong and long maneuver, the estimated accelerations agree well with the telemetry data.
- For days with small and short maneuver, the estimated accelerations clearly differ from the telemetry data.

External orbit validation



SLR validations to the different CPOD institute orbits for the Sentinel-3B satellite.
10 selected stations, no data screening.

Luckily, the Satellite Laser Ranging (SLR) validations are available for all the maneuvering days of Sentinel-3B.

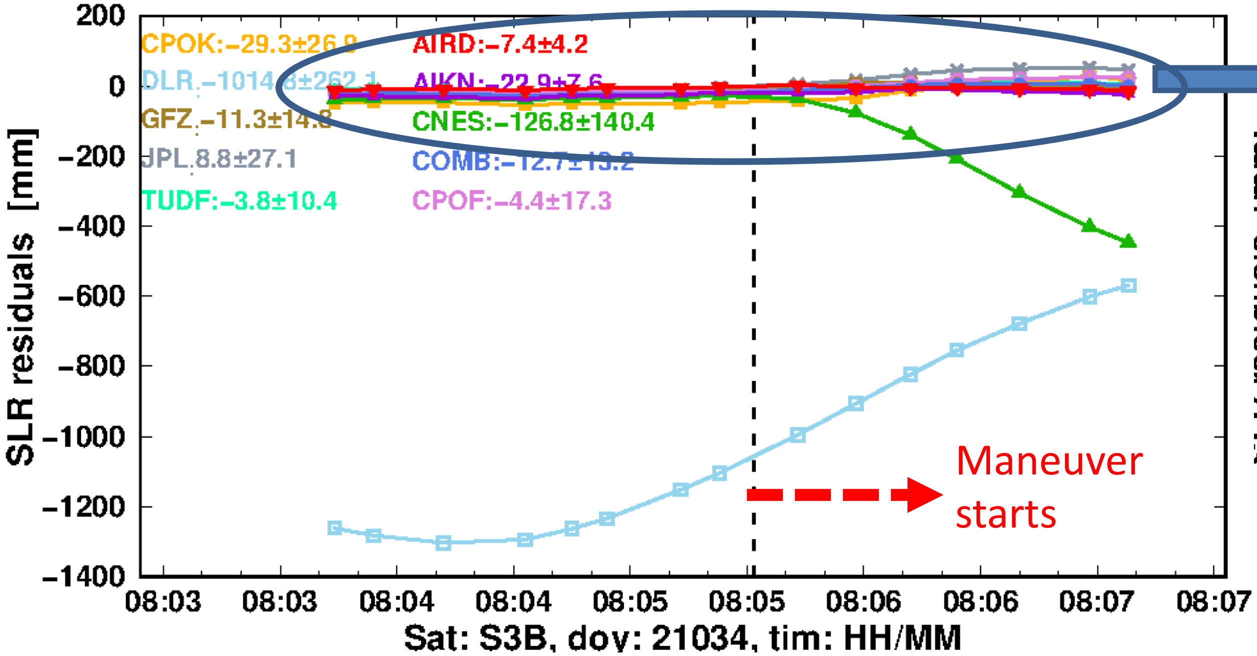
However, no direct tracking during the maneuver time spans.

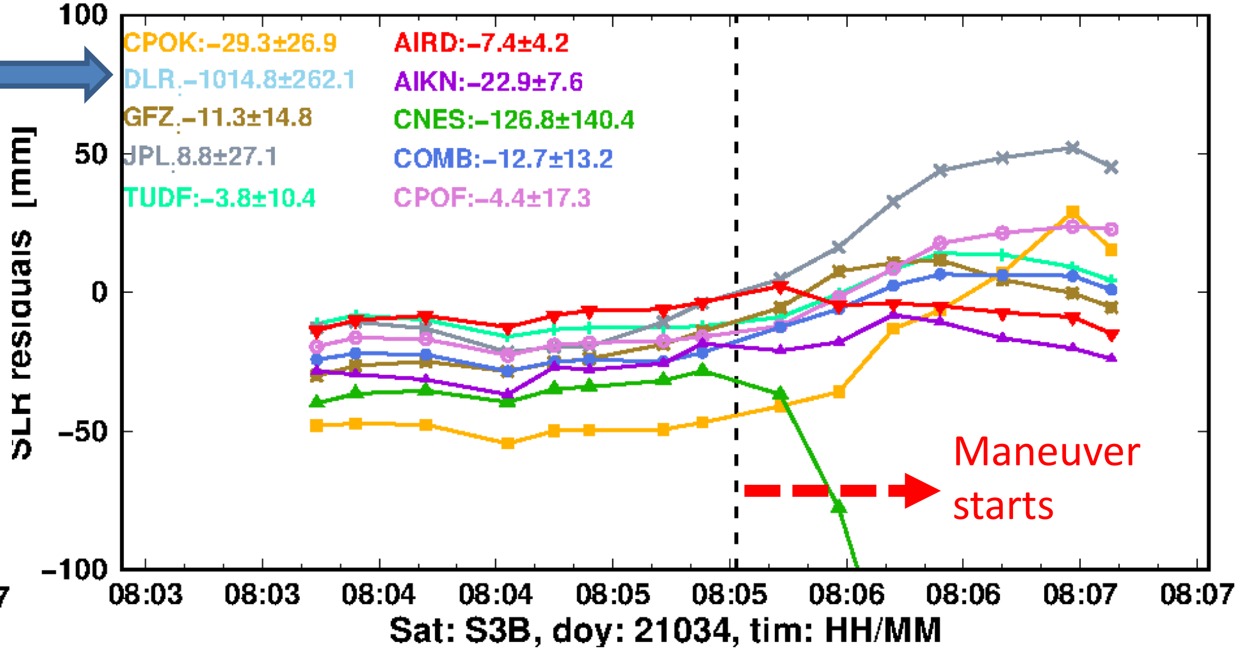
SLR validations show that some orbits can be significantly downgraded due to maneuver processing that influences periods outside maneuvers.

External orbit validation

Luckily, a single SLR tracking pass crossing the maneuver period is available for the Sentinel-3B satellite from the Tahiti SLR station on day 21034, with a strong maneuver lasting for 774.3s.

Statistics: **mean** $\pm$ ***std***





- AIUB orbit is among the best in terms of agreement with SLR measurements crossing maneuvers.

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Conclusions

- Kinematic orbit, which is hardly influenced by satellite dynamics, can be used as a good reference orbit.
- Additional velocity pulses estimation is crucial for days with strong and long maneuvers.
- Integer ambiguity resolution further constrains parameter estimation and enhances POD for maneuver days.
- The estimated accelerations agree well with telemetry data for days with long and strong maneuvers, but show large discrepancy for days with short and small maneuvers.
- SLR validations might be used to check the POD performances during maneuvers, but really need luck (so far only one good example for Sentinel-3).

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For more information, click here!

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