

Precise orbit determination for the maneuvering Sentinel-3 satellites

Xinyuan Mao, Daniel Arnold, Adrian Jäggi

26 May, 2022

Astronomical Institute, University of Bern
Bern, Switzerland



EGU22-7335

<https://doi.org/10.5194/egusphere-egu22-7335>

Outline

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

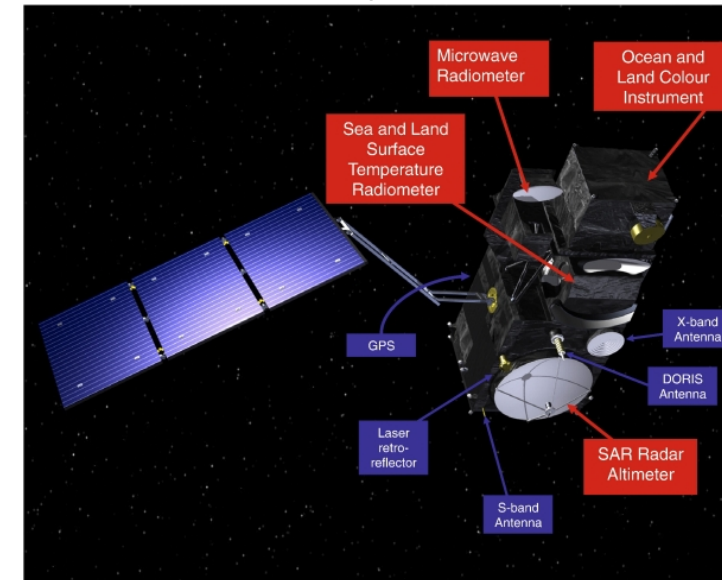
Motivation

- 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/s²**, mostly in cross-track direction
 - As reference, GRACE and GRACE-FO's magnitudes are **1e-4 m/s²**
 - Time span: from **a few seconds to 15+ mins**

Aim:

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

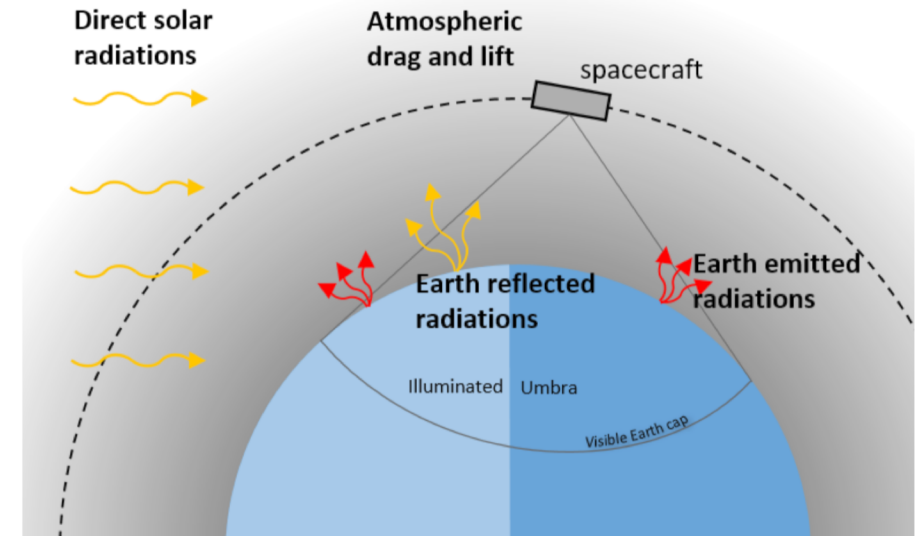
Bernese POD strategy

- 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

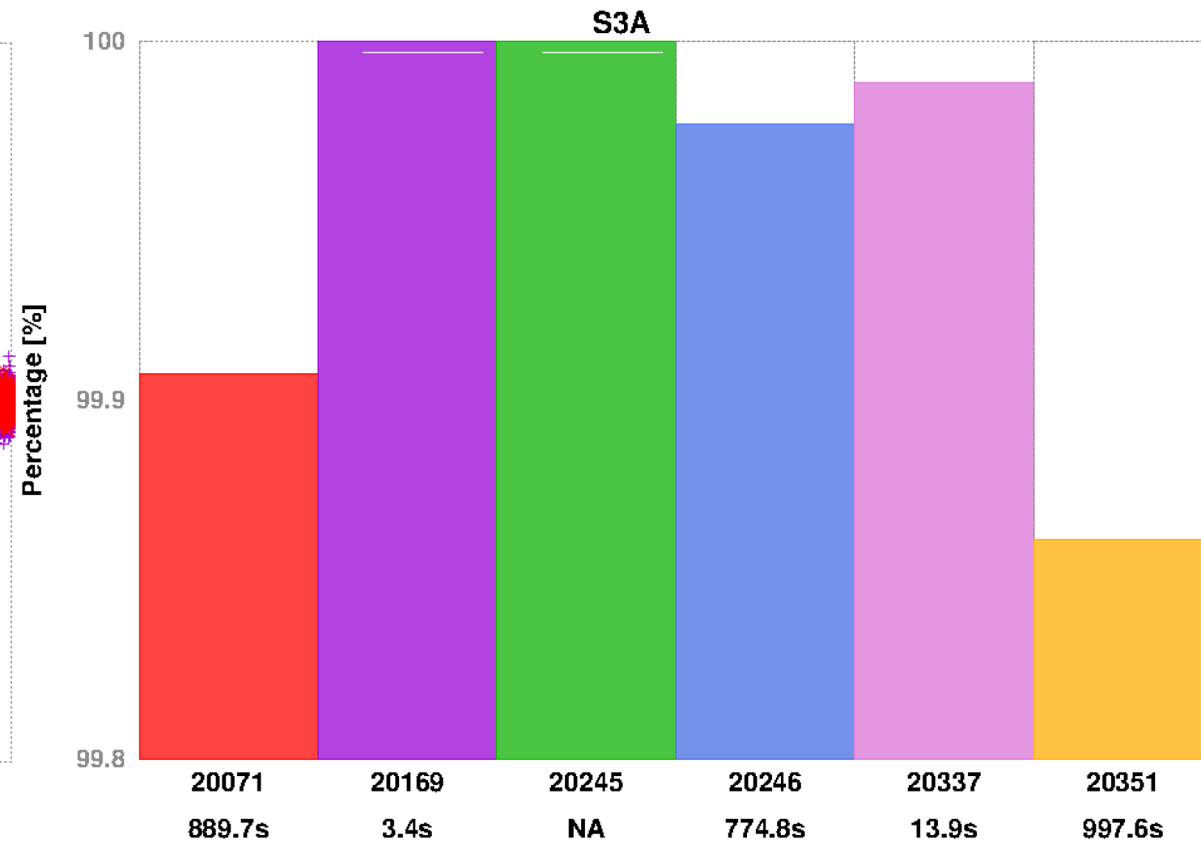
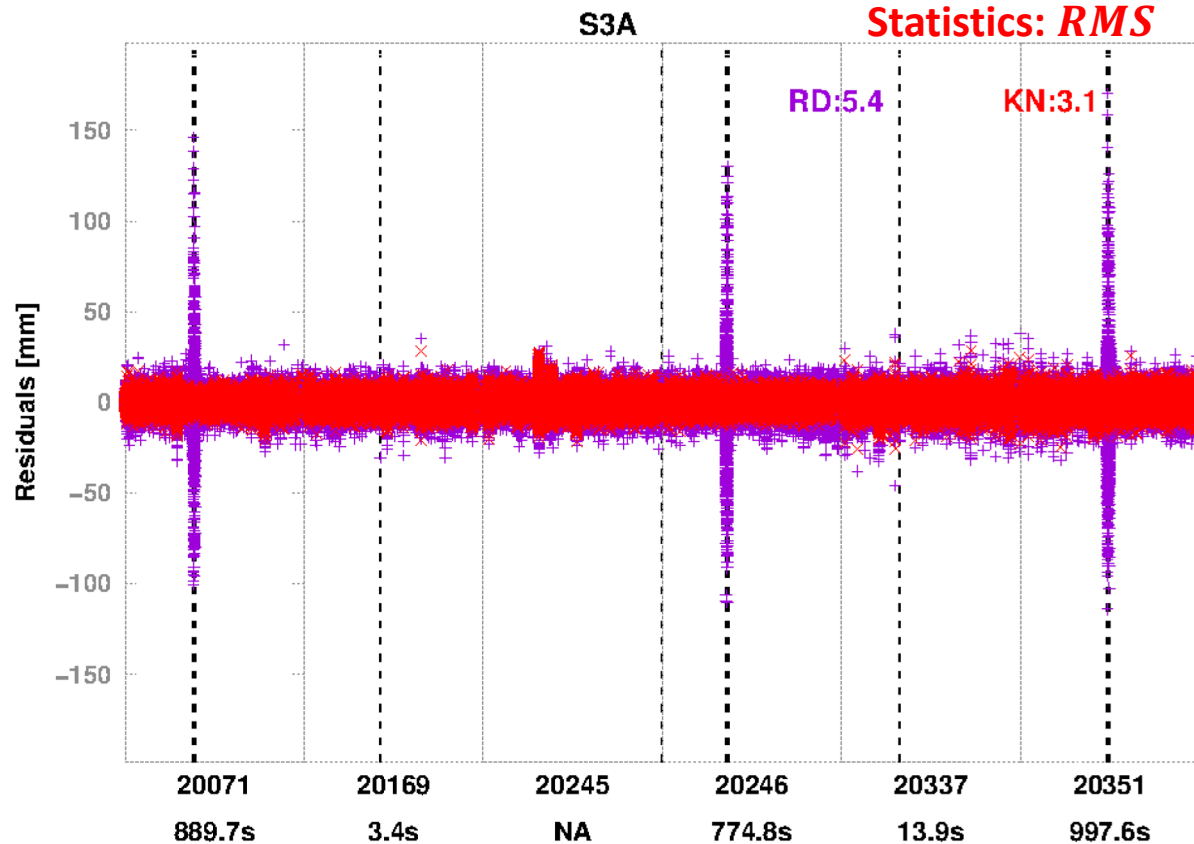
DOY	Maneuver [s]
20071	889.7
20169	3.4
20245	N/A
20246	774.8
20337	13.9
20351	997.6

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.

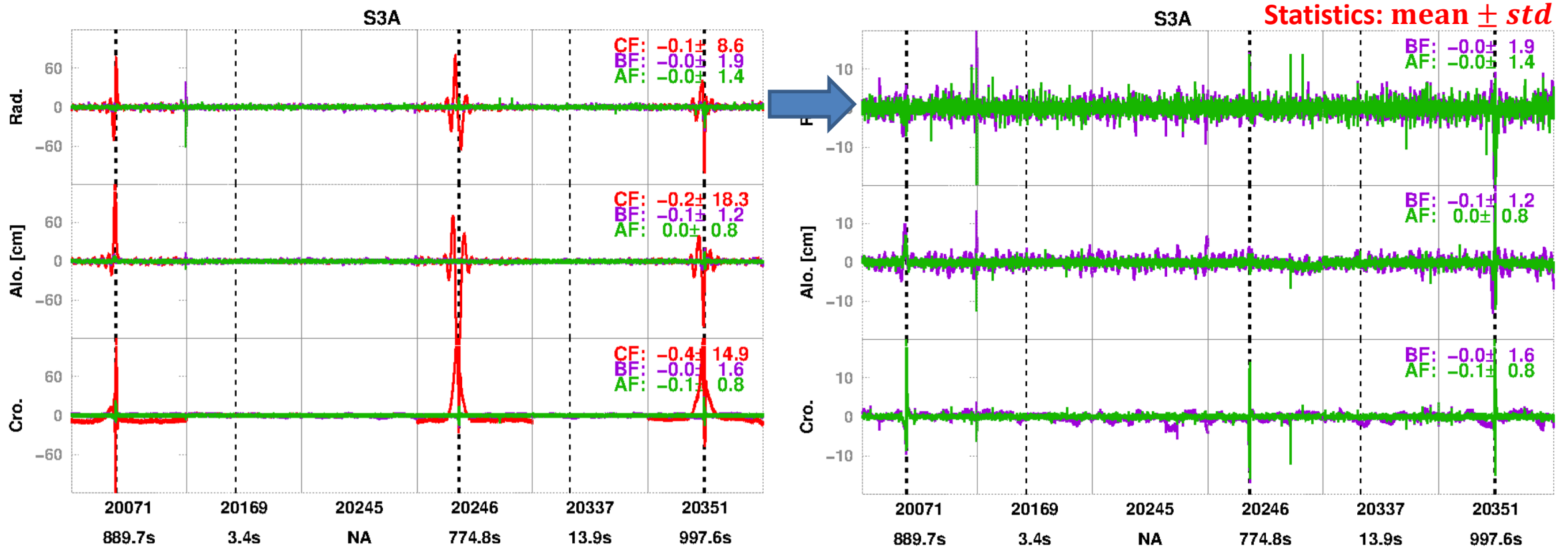


Ionosphere-free carrier-phase residuals and RMS statistics for the ambiguity-fixed POD solution of Sentinel-3A maneuver and reference days.

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.

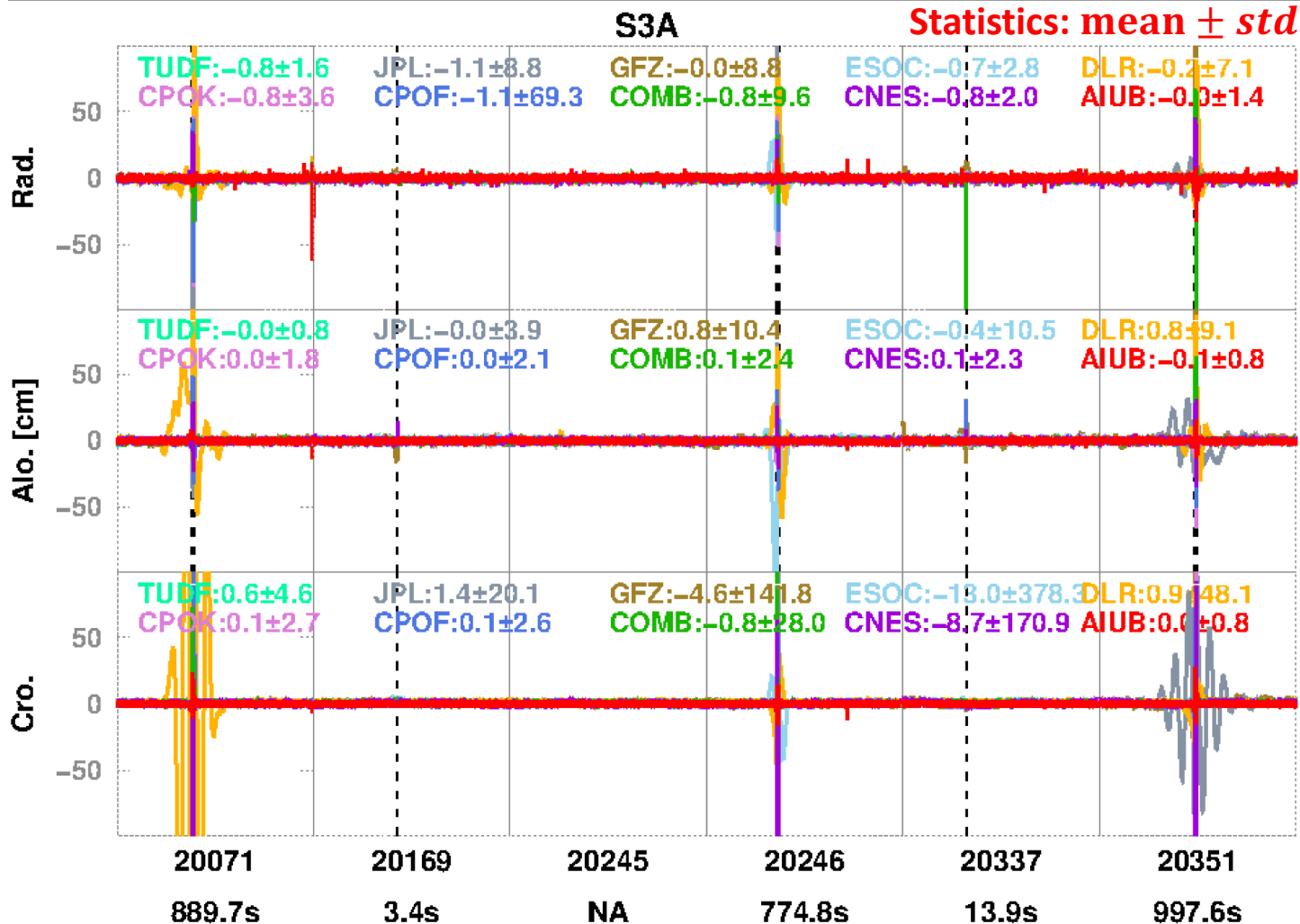
Internal orbit consistency



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, $\sigma = 1\text{m/s}$; 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.

External orbit validation



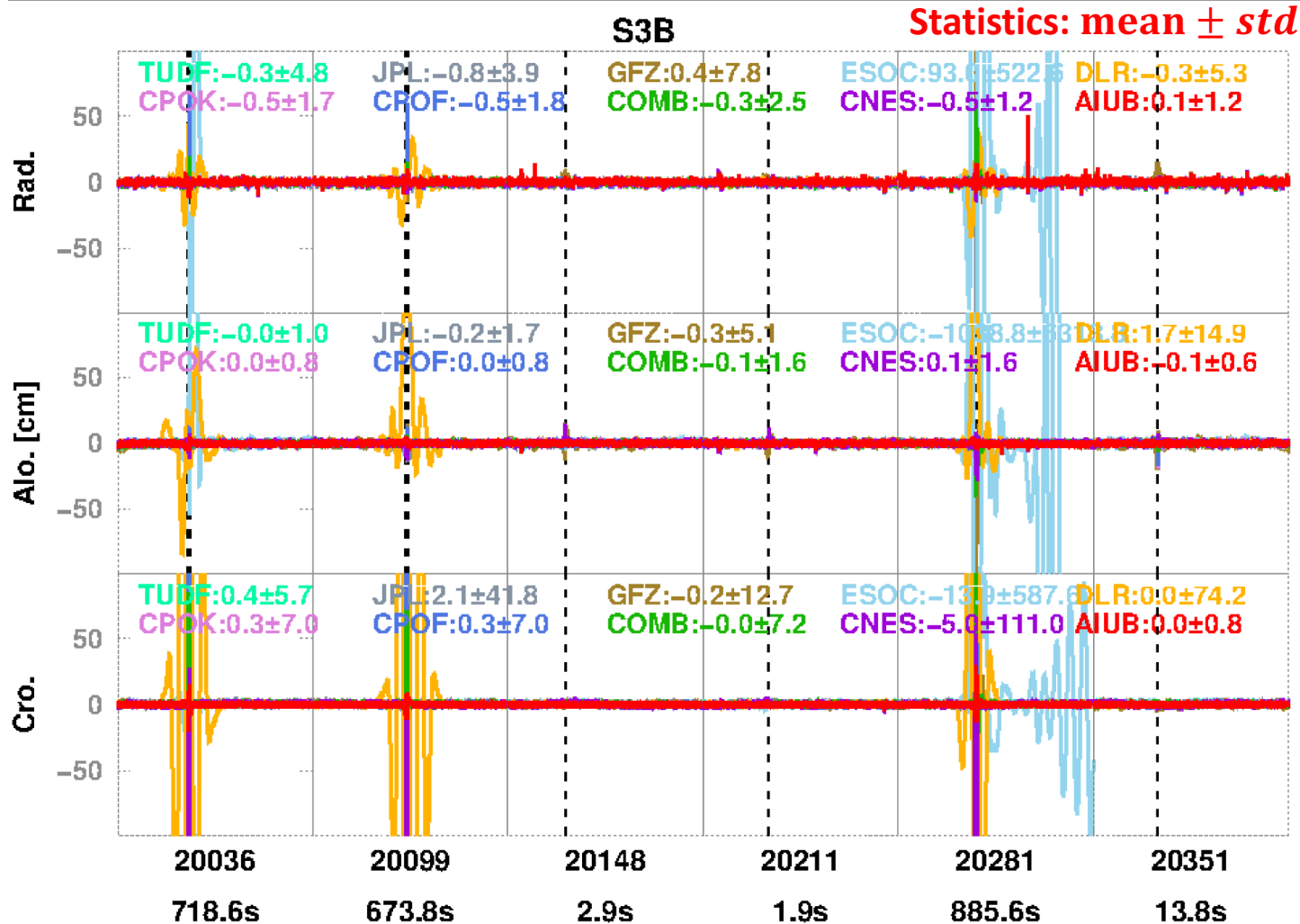
List of institutes with POD service for maneuver days (alphabet in descending order):

- 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.

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.

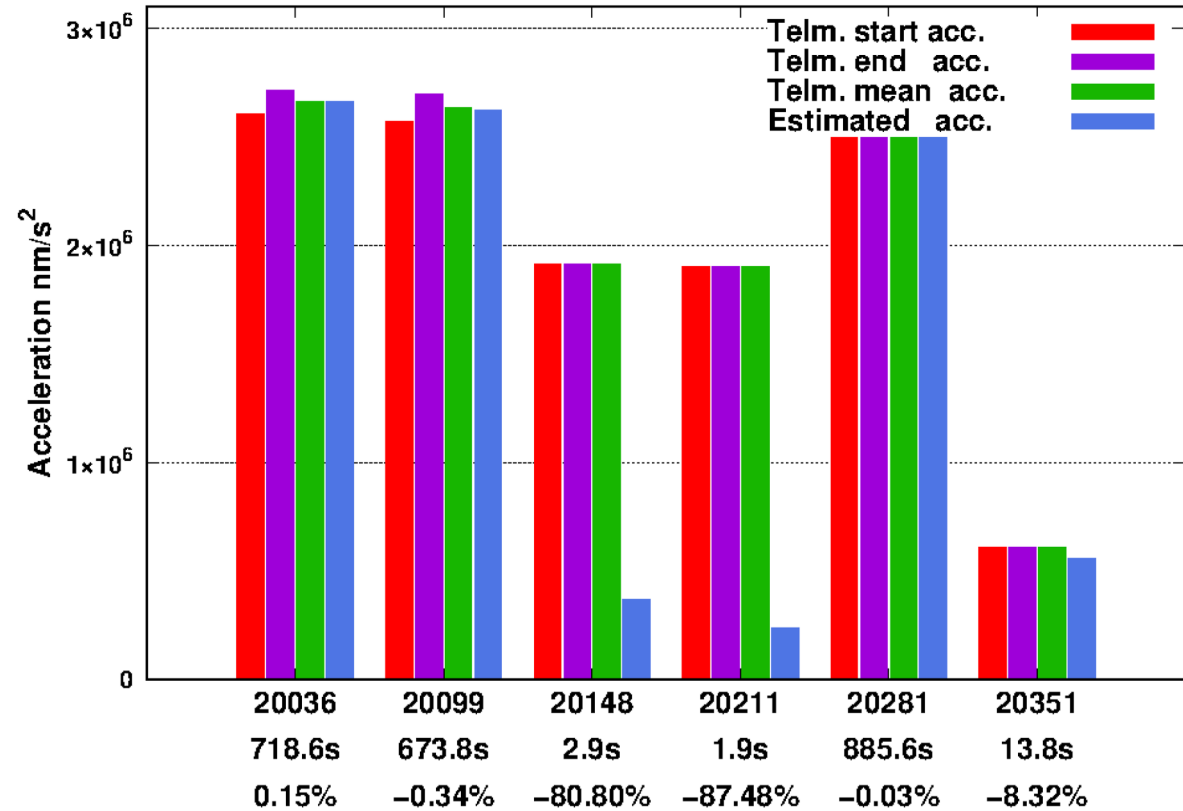
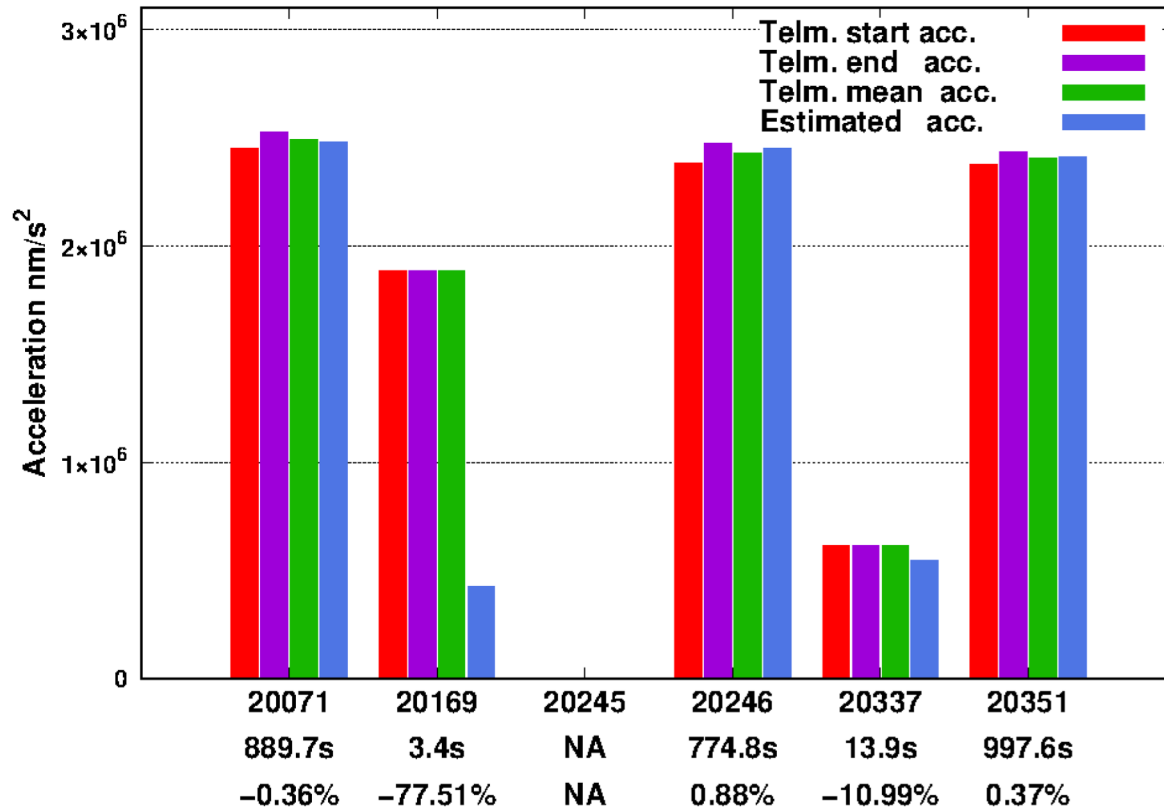
External orbit validation



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.

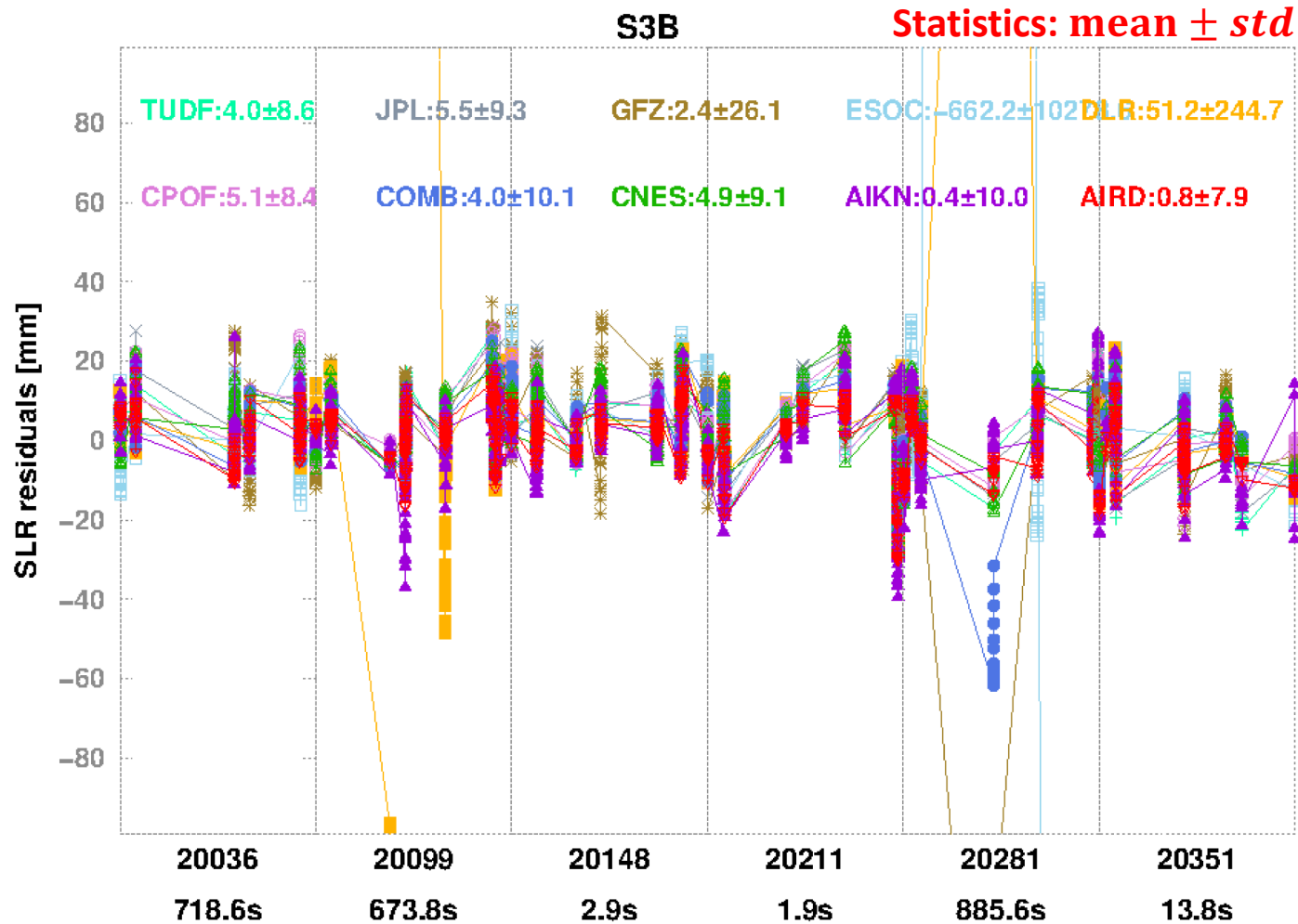
External orbit validation



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



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

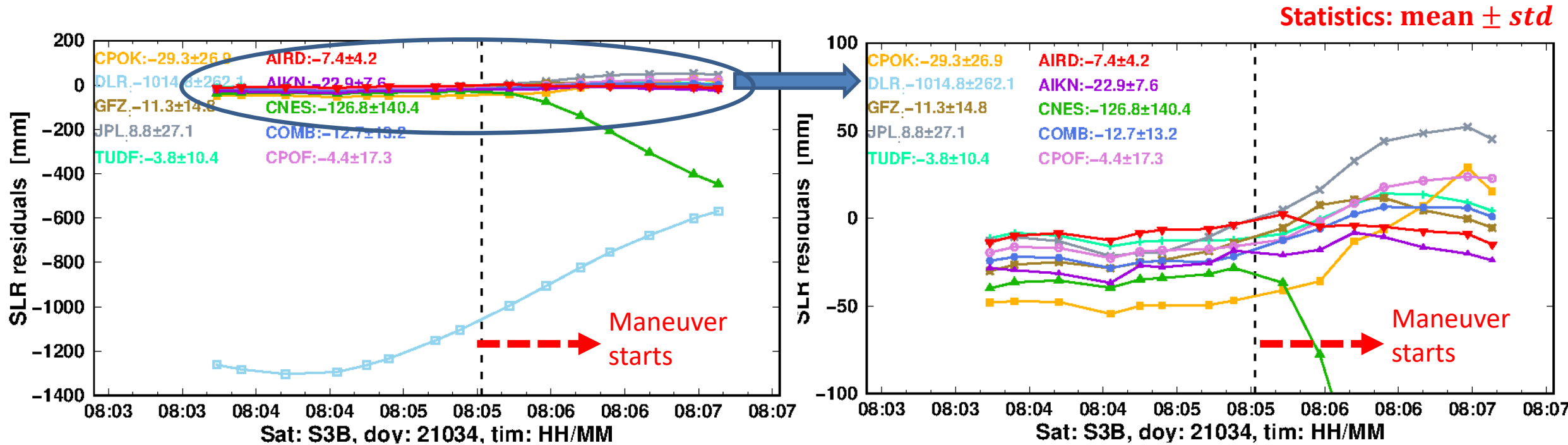
However, no direct tracking during the maneuver time spans.

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

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

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.



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

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).

Precise orbit determination for the maneuvering Sentinel-3 satellites

Xinyuan Mao, Daniel Arnold, Adrian Jäggi

26 May, 2022

Astronomical Institute, University of Bern
Bern, Switzerland

**For more
information,
click here!**



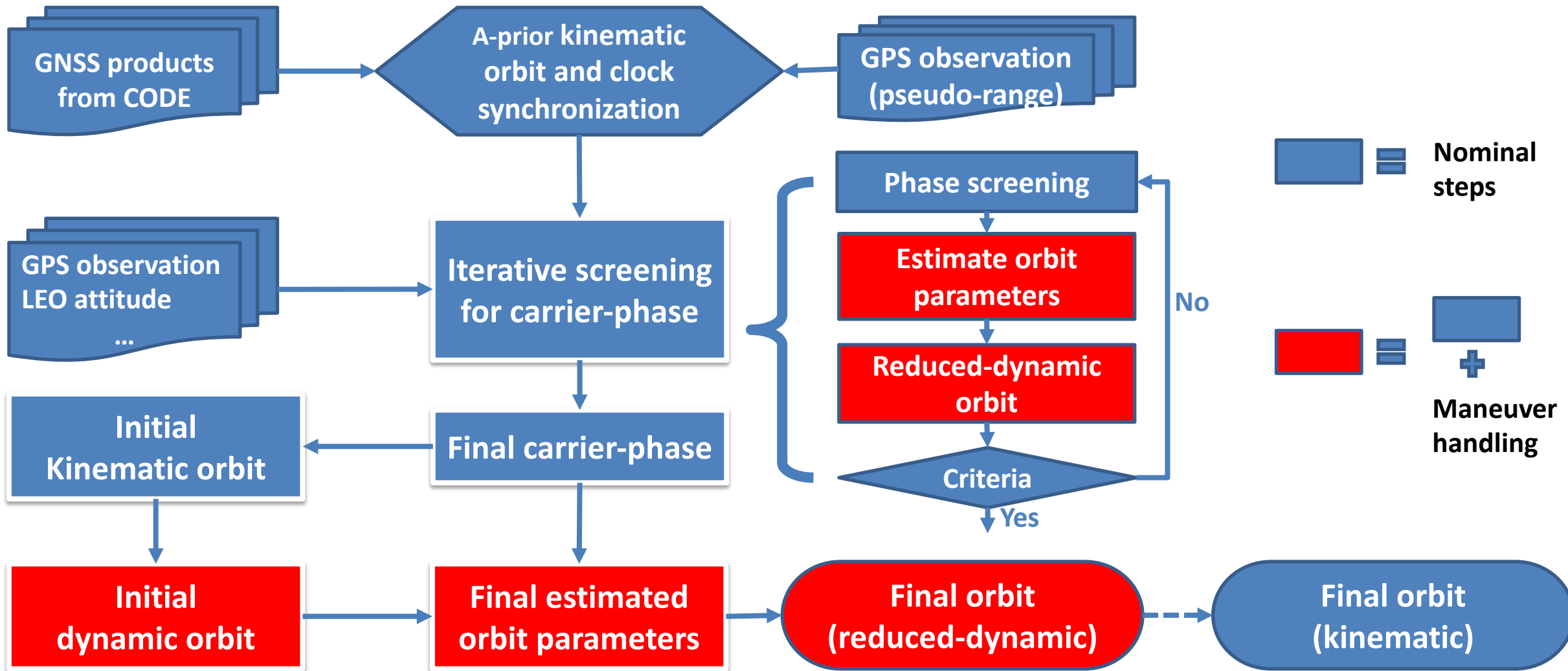
EGU22-7335

<https://doi.org/10.5194/egusphere-egu22-7335>



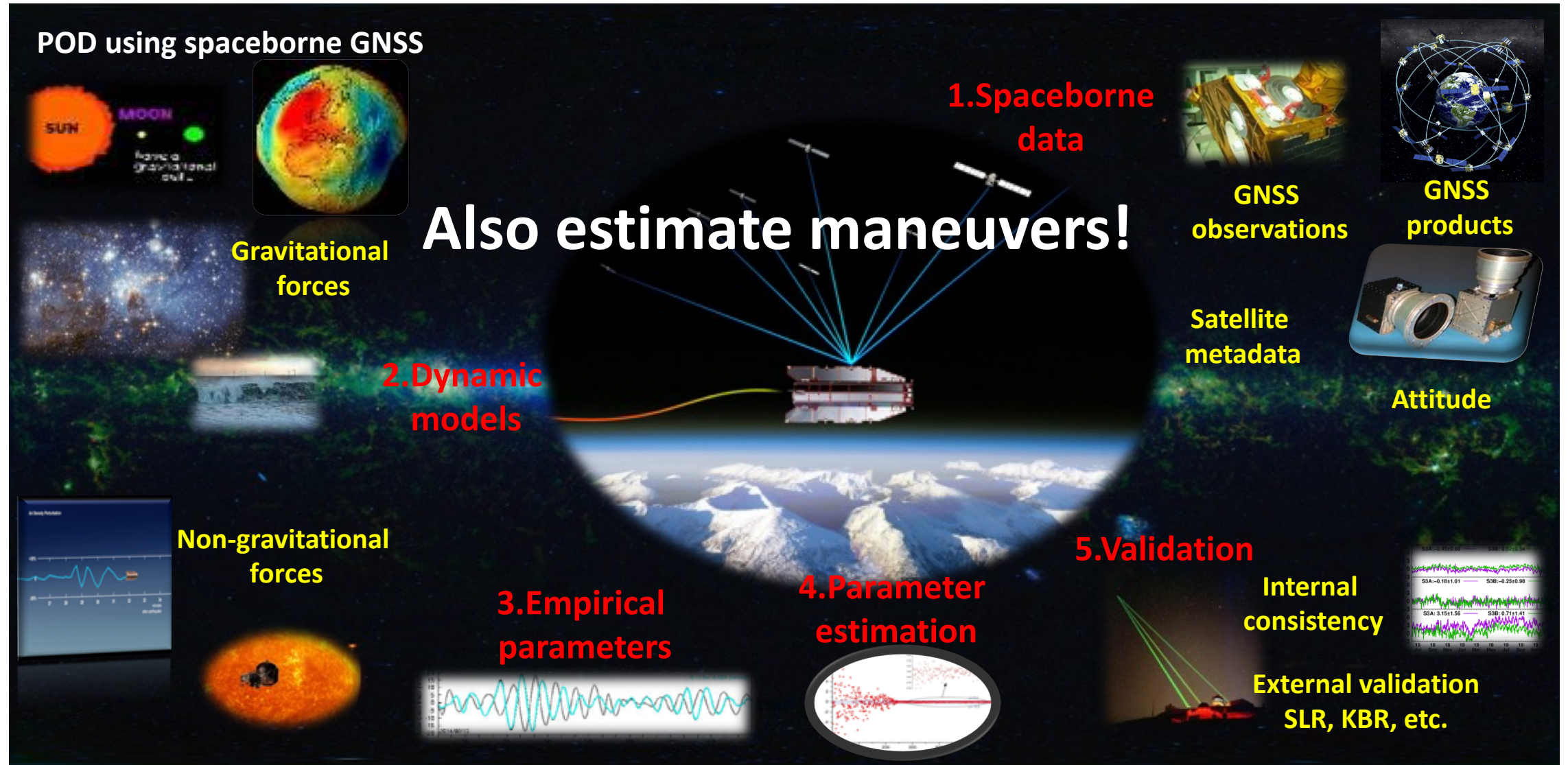
Backup slides

Bernese POD strategy



Xinyuan Mao, et al., Precise orbit determination for the maneuvering Sentinel-3 satellites
EGU General Assembly, 23-27 May 2022, Vienna, Austria & Online

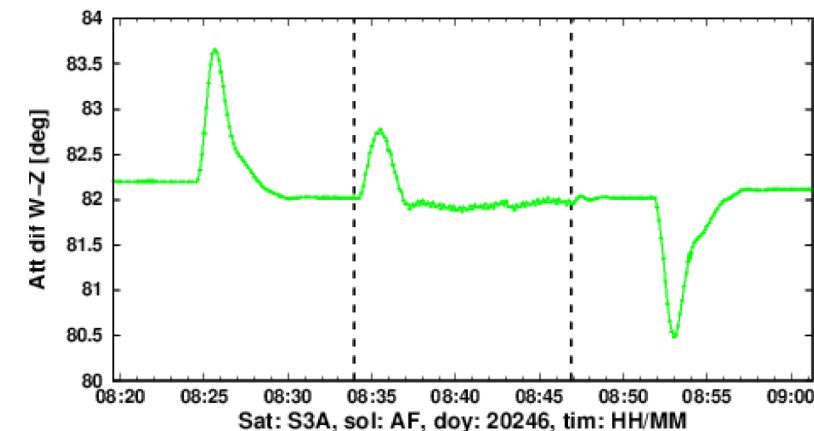
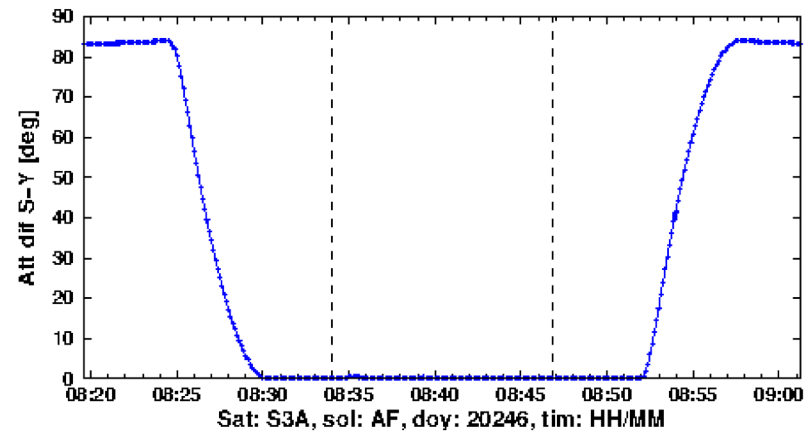
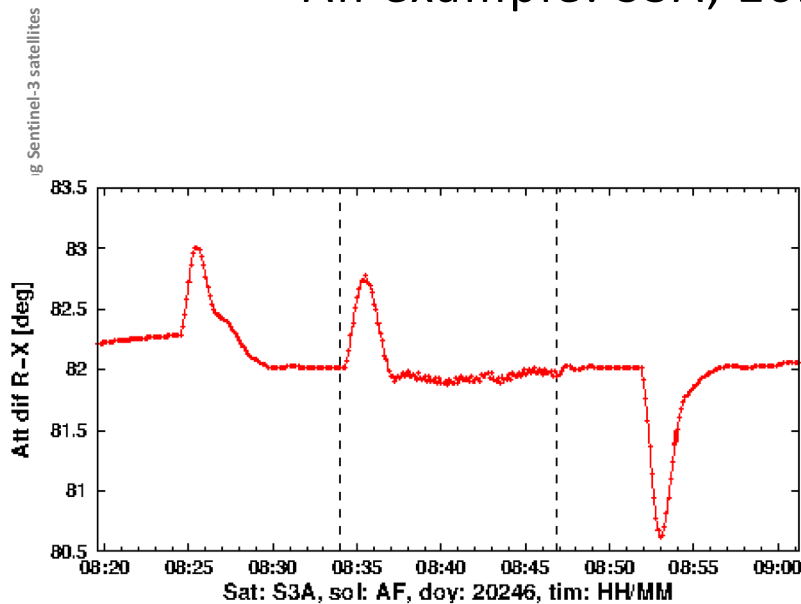
Bernese POD strategy



Xinyuan Mao, et al., Precise orbit determination for the maneuvering Sentinel-3 satellites
EGU General Assembly, 23-27 May 2022, Vienna, Austria & Online

Bernese POD strategy

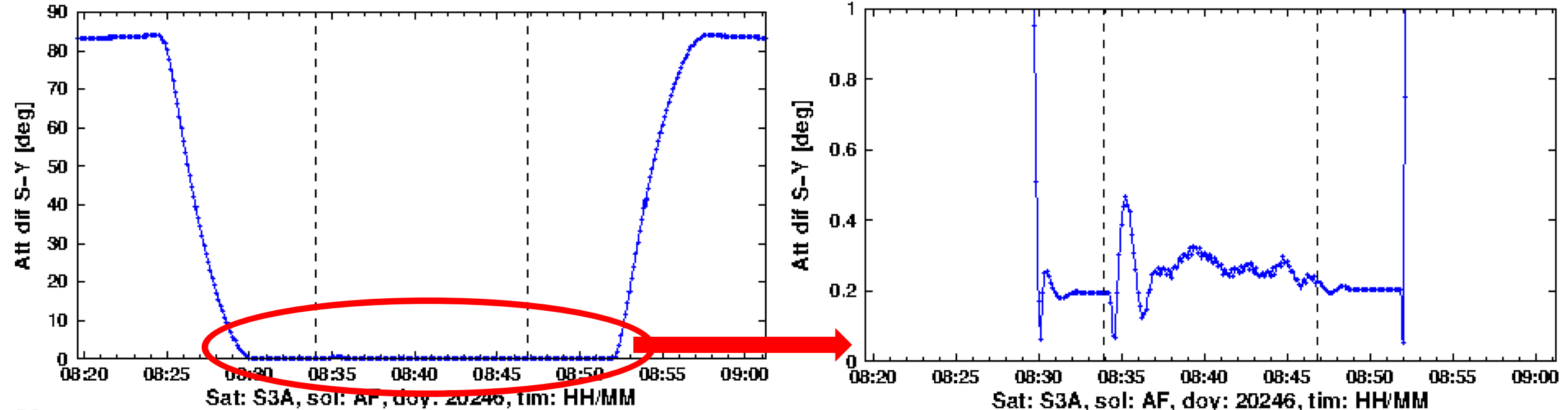
- Estimate maneuvers in Satellite Body Fixed (SRB) reference frame
 - Maneuvers will first perform attitude changes, particularly for the out-of-plane/cross-track maneuvers
 - Otherwise the data screening and maneuver estimate will be heavily influenced
 - An example: S3A, 20246, cross-track maneuver for 775 seconds



Attitude angle difference between local orbit and XYZ (SBF) for Sentinel-3A on DOY 20246

Bernese POD strategy

- Should only estimate maneuvers in satellite body fixed frame
 - rather big attitude change before and after the main maneuvers
 - Even during maneuvers the attitude is not stable w.r.t. local orbit reference frame, might cause problems to estimate maneuvers



Attitude angle difference between S and Y (SBF)

Bernese POD strategy

- Orbit integration interval adjustment
 - Case 1: maneuver in middle of an interval
 - Case 2: maneuver short but cross two intervals
 - Case 3: maneuver longer than a few intervals

