Impact of satellite dynamics parameterization on precise orbit determination of Sentinel-3

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Outline

- Motivation
- New Bernese reduced-dynamic POD: **1-cm precision**
- Orbit validations
  - Internal consistency check
  - External validations: SLR and **altimetry crossover-analysis**
- New Bernese dynamic POD: **estimate the least parameters**
- Conclusions and discussions

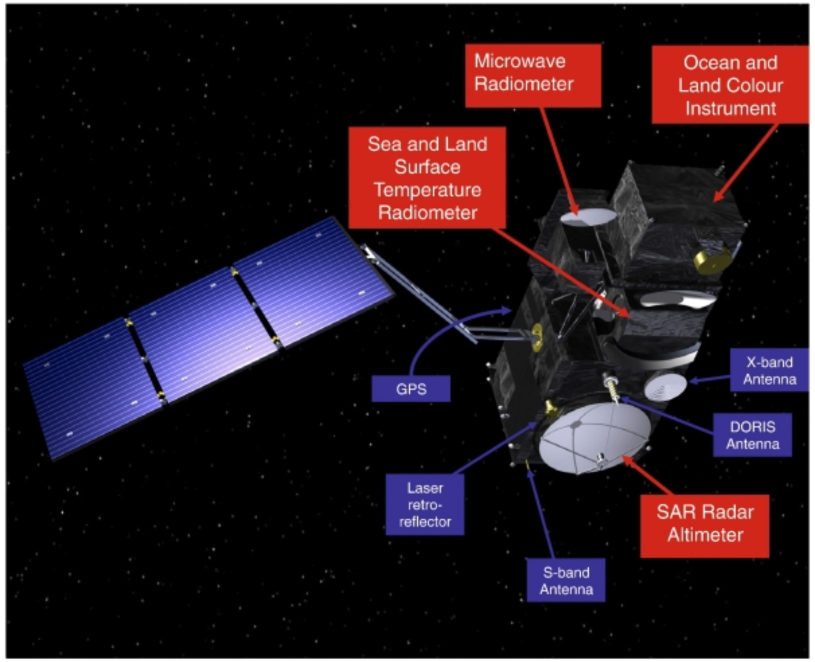
Motivation

- Copernicus Precise Orbit Determination (CPOD) Quality Working Group

- Orbit for satellite altimetry research
- Improve the Bernese GNSS software

Satellites: **Sentinel-3A and -3B**

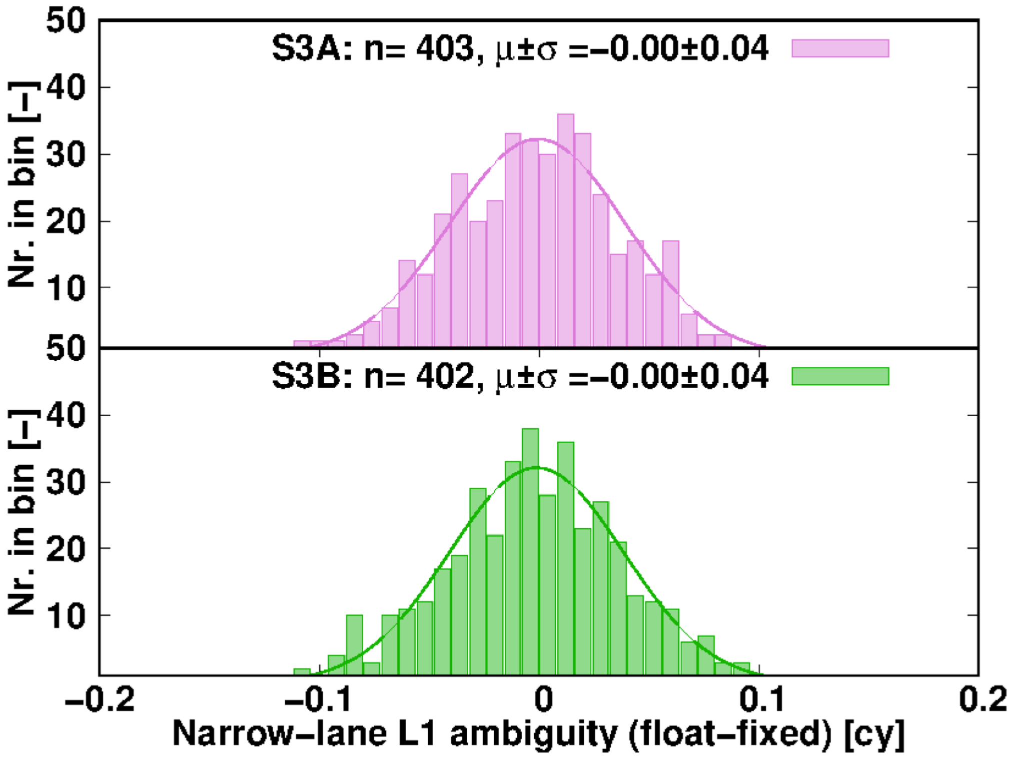
Time span: 7 **June, 2018 to 31 December, 2019**



Sentinel-3 satellite and payloads (Credit: ESA)

Bernese reduced-dynamic POD

- Single-receiver (zero-difference) integer ambiguity resolution
  – Use the GNSS Observation-Specific Bias (OSB) and clock products provided by the Center for Orbit Determination in Europe (CODE)
  – Wide-Lane (WL) and Narrow-Lane (NL) ambiguity resolution
  – Success rate of NL ambiguity resolution w.r.t. all ambiguities (around 410 per day)
    S3A: 99.0%, S3B: 99.2%



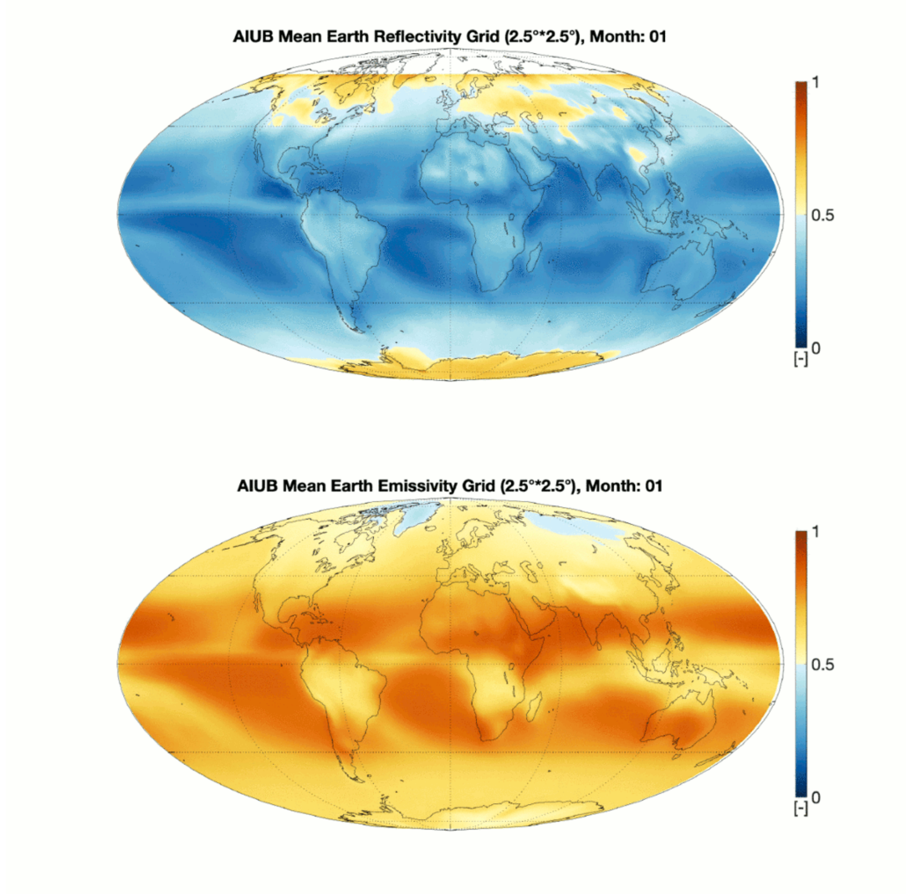
Distribution of relative narrow-lane N_1 ambiguity fractional cycles on 7 June, 2018 (DOY: 158).
Curves: gaussian distribution with the corresponding std.

Schaer, S., Villiger, A., Arnold, D., et al, 2020. The CODE ambiguity-fixed clock and phase bias analysis products: generation, properties and performance. J. Geod. Submitted.

Bernese reduced-dynamic POD

- Non-gravitational force modeling

Aerodynamic Force	Plate-wise lift and drag DTM-2013 atmospheric density model HWM-14 horizontal wind model Goodman accommodation coefficients Scale factor
Solar Radiation Pressure	Plate-wise direct pressure Spontaneous thermal re-emission for non-solar panels Conical Earth and Moon shadow Coefficients for optical radiation Scale factor
Earth Radiation Pressure	Plate-wise reflectivity and emissivity radiation pressure Spontaneous thermal re-emission for non-solar panels Coefficients for optical and infrared radiation Monthly grids based on CERES-S4 radiosity products Interpolation between neighboring monthly grids



Earth reflectivity and emissivity grids used for the Earth radiation pressure modeling

Mao, X., Arnold, D., Girardin, V., et al., 2020: Dynamic GPS-based LEO orbit determination with 1 cm precision using the Bernese GNSS Software. Adv. Space Res., in press, proof online.

Bernese reduced-dynamic POD

Satellite dynamics parameterization and orbit solutions

Orbit Solutions	Grav. Forces	Non-grav. Forces	Scale Factors	Constant Acc.	Piece-wise Constant Acc. (PCA)	Periodic Acc.	Estimated Par. Nr.
IAKN	No	No	No	No	No	No	Most
IANM	Yes	No	No	Yes	Yes (loose constraint)	No	Medium
IANG	Yes	Yes	Yes	No	Yes (tight constraint)	No	Medium

- The IAKN solution is fully independent from dynamic models and serves as benchmark.
- The **IANG** solution uses more tightly constrained PCAs due to the refined force modeling.

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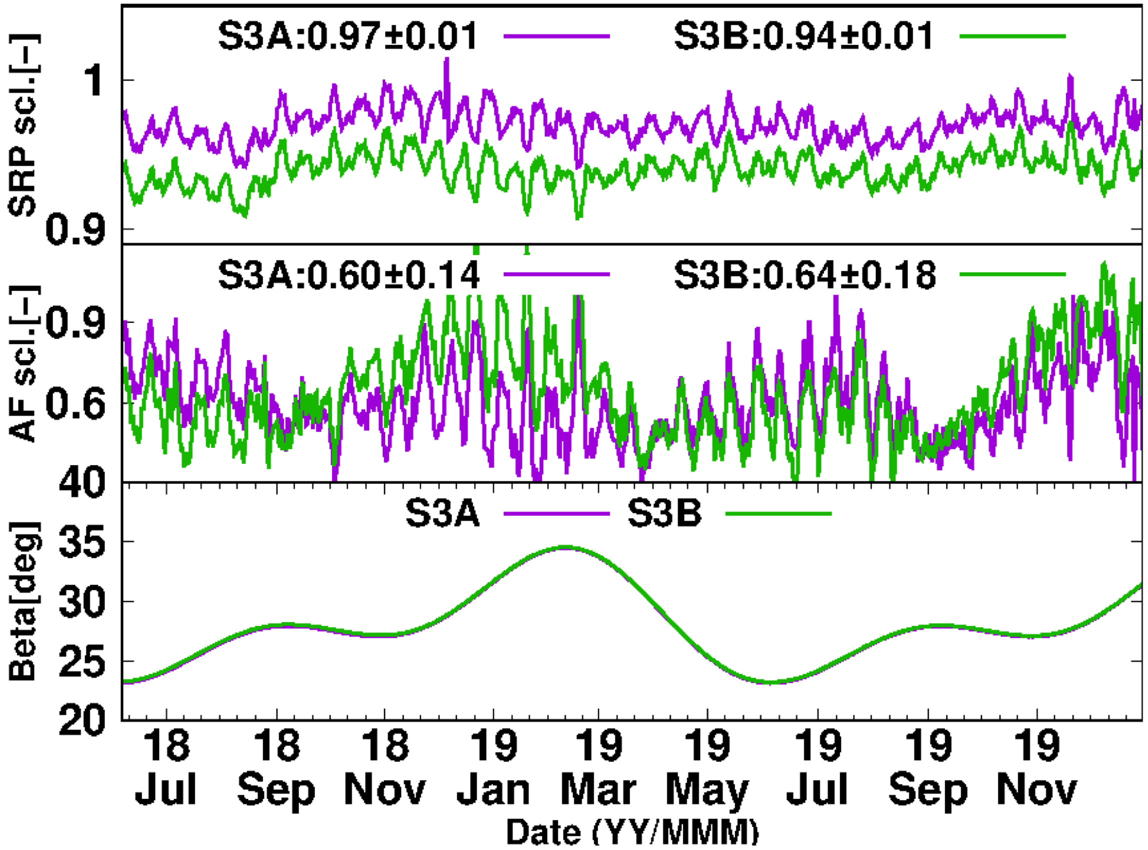
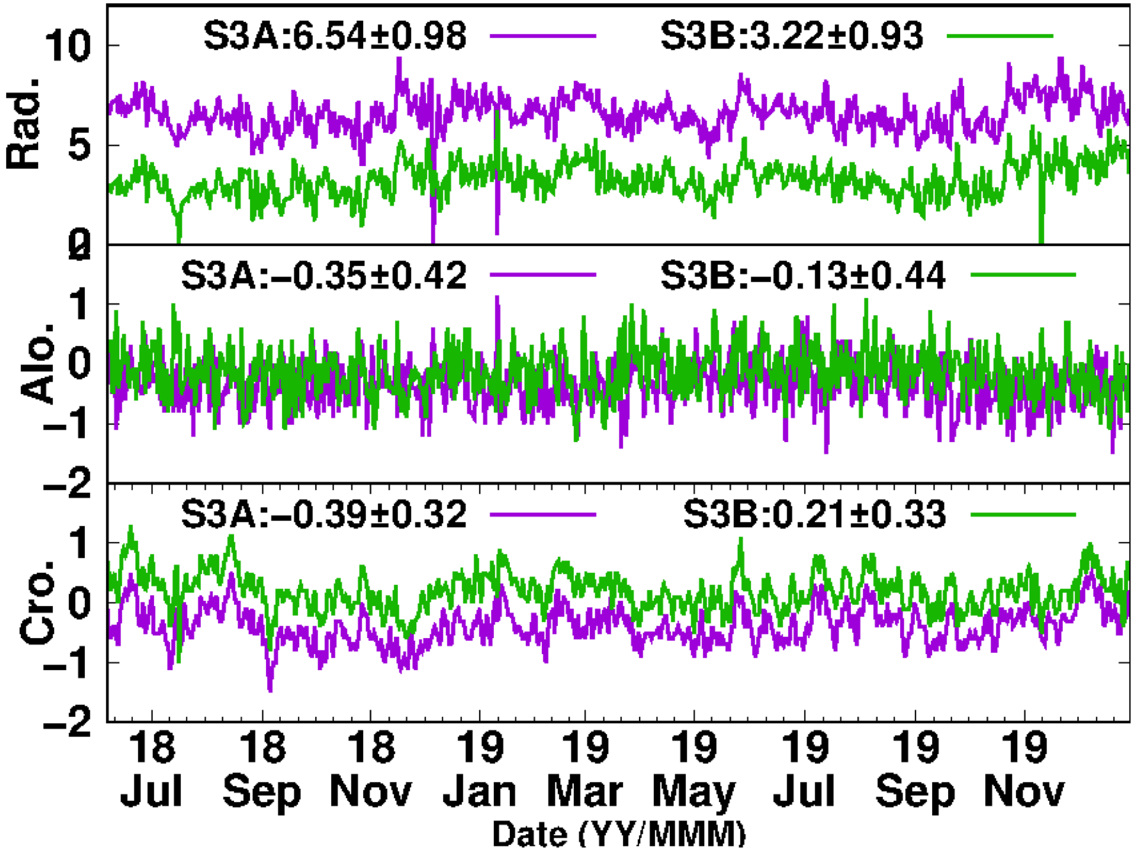
Bernese reduced-dynamic POD



Non-gravitational force SRP and AF scale factor estimates for the two satellites

- Scale factors are important to compensate non-gravitational force modeling deficiency, e.g., the over-performed atmospheric density modeling at high altitude (~800 km).

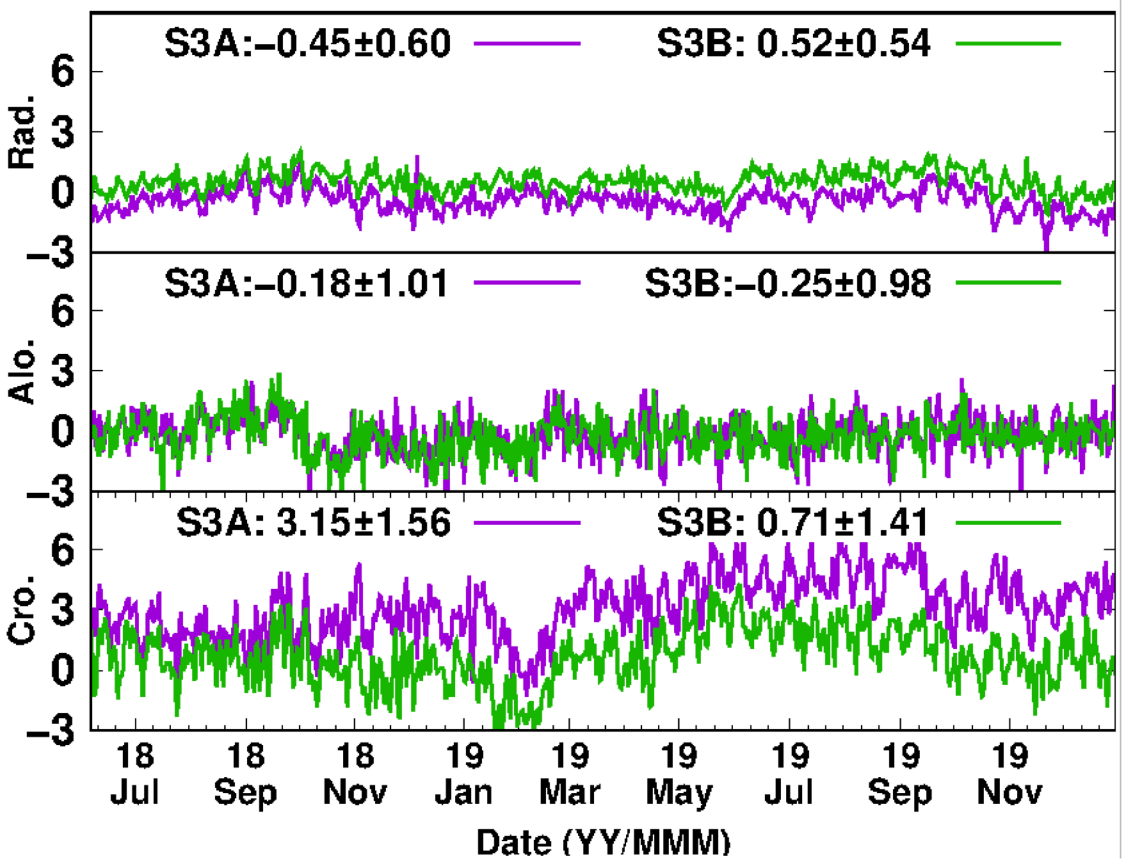
Bernese reduced-dynamic POD



Daily mean of orbit comparisons between the IANG and the IAKN solutions. Unit: [mm]

- Comparison between the IANG and IAKN solutions reveals potential errors in the antenna phase center offset (PCO) or the reference point (ARP) that are computed w.r.t. Center of Mass (CoM).

Bernese reduced-dynamic POD



Daily mean of orbit comparisons between the IANG and the official CPOD solutions. Unit: [mm]

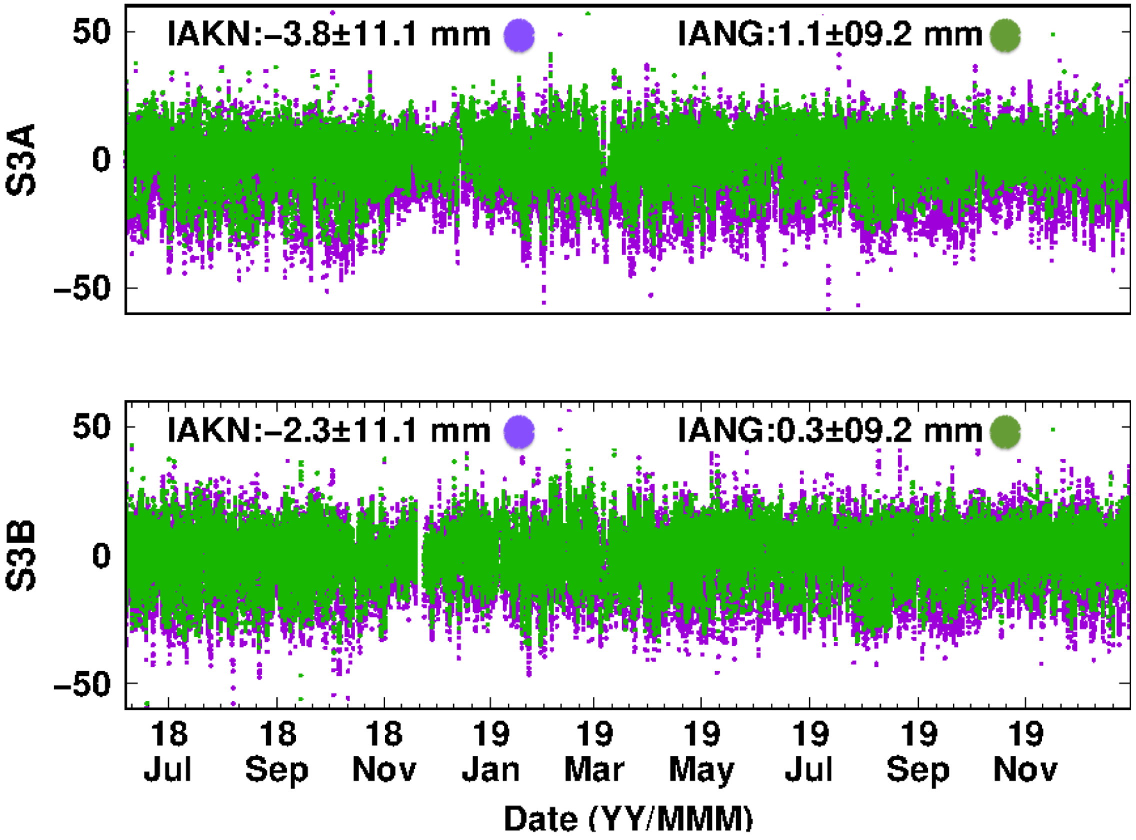
- In general, quite good agreement between the two independent products.
- Might exist geometric (e.g. CoM) discrepancy of ~3 mm in cross-track direction for Sentinel-3A.

Satellite laser ranging validation

SLR validations for the different orbit solutions
(10 selected stations, elevation cut-off angle: 10 deg,
outlier screening: 200 mm unit: [mm]).

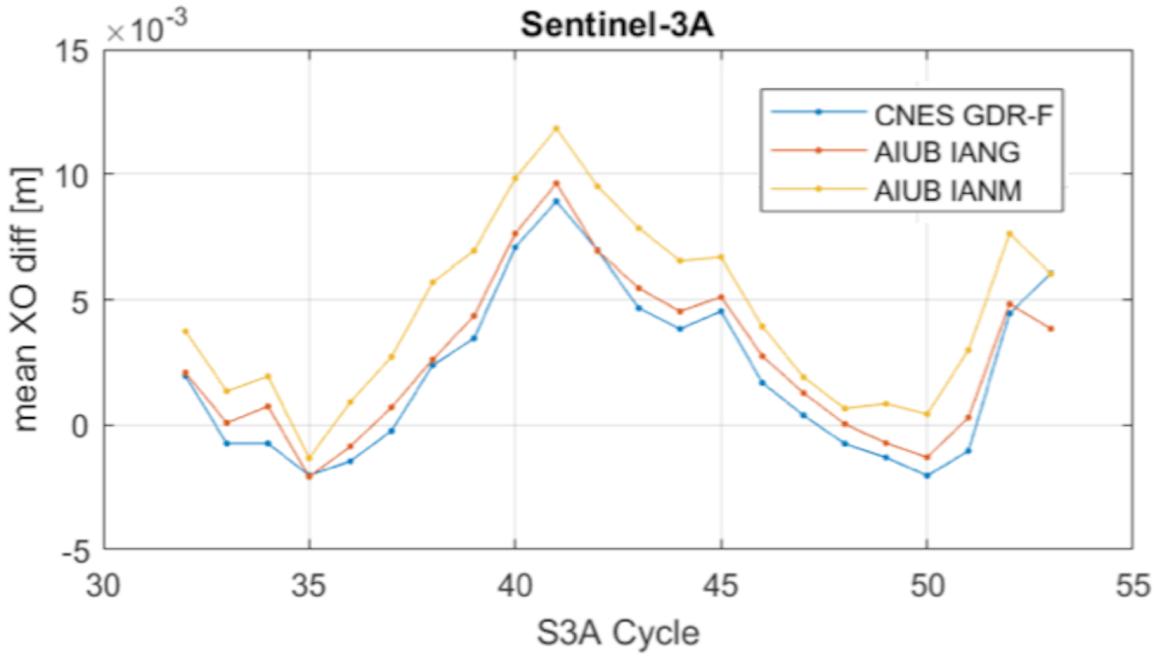
Sat.	Solution	Mean	STD	Rad.	Alo.	Cro.
S3A	IAKN	-3.8	11.1	-6.0	0.2	2.2
	IANM	-3.7	9.7	-5.8	0.2	1.5
	IANG	1.1	9.2	1.6	-0.2	1.1
	CPOD*	1.4	12.7	1.9	1.7	4.8
S3B	IAKN	-2.3	11.1	-3.8	2.9	3.6
	IANM	-2.3	9.6	-3.8	2.9	3.0
	IANG	0.3	9.2	0.3	2.7	3.0
	CPOD*	0.6	12.6	0.5	4.7	3.0

- Solutions of the Copernicus POD (CPOD) service did not perform single-receiver ambiguity resolution for the selected period!

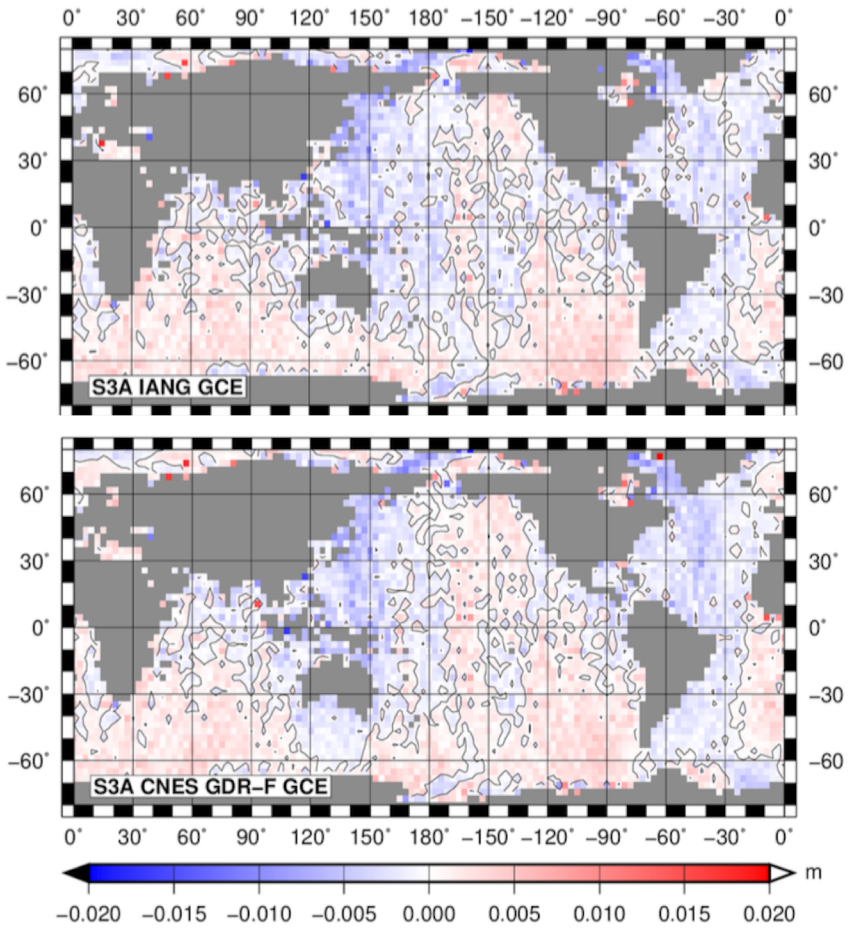


- Single-receiver ambiguity resolution and non-gravitational force modeling are beneficial for generating superior orbit precisions of 1-cm.

Single-satellite altimetry crossover-analysis



Differences of the crossover (XO) differences in mean for the S3A satellite (dtmax = 27days), mean std SXO = 6.68cm (CNES), 6.66 cm (IANG), 6.65cm (IANM)



Geographically correlated mean sea surface height errors [m]

- The **IANM** solution shows small discrepancy in mean w.r.t. the other orbits.
- The **IANG** solution performs reasonably good for satellite altimetry research.

Bernese dynamic POD

Satellite dynamics parameterization and orbit solutions

Orbit Solutions	Grav. Forces	Non-grav. Forces	Scale Factors	Constant Acc.	Piece-wise Constant Acc. (PCA)	Periodic Acc.	Estimated Par. Nr.
IAKN	No	No	No	No	No	No	Most
IANM	Yes	No	No	Yes	Yes (loose constraint)	No	Medium
IANG	Yes	Yes	Yes	No	Yes (tight constraint)	No	Medium
IADN	Yes (refined)	Yes	Yes (10 for AF)	No	No (from 720 to 0!)*	Yes (2 sets alo./cro.)	Least

*A typical Bernese reduced-dynamic POD estimates 3 PCAs (radial/along-track/cross-track) in every 6 mins.

- The **IADN** solution estimates the least number of parameters due to the improved force modeling and completely mitigates the use of empirical parameters (PCAs).
- This is basically computing the CPOD solution in the Bernese GNSS software.

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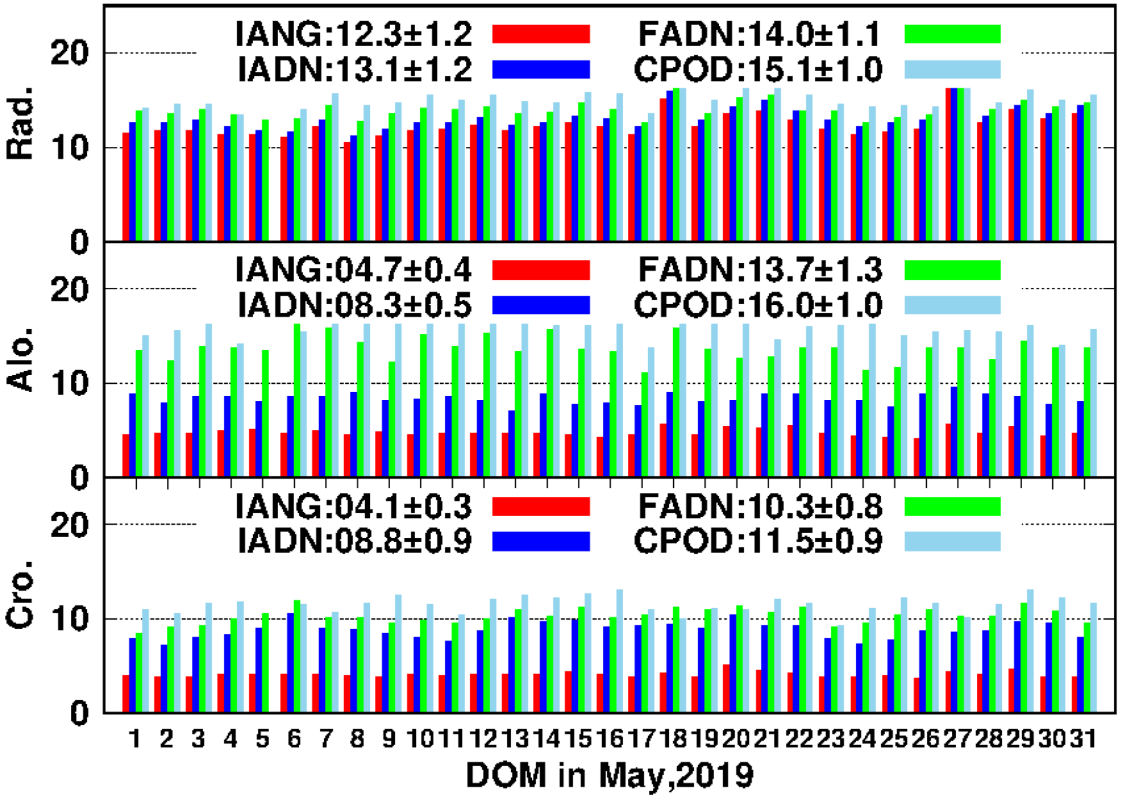
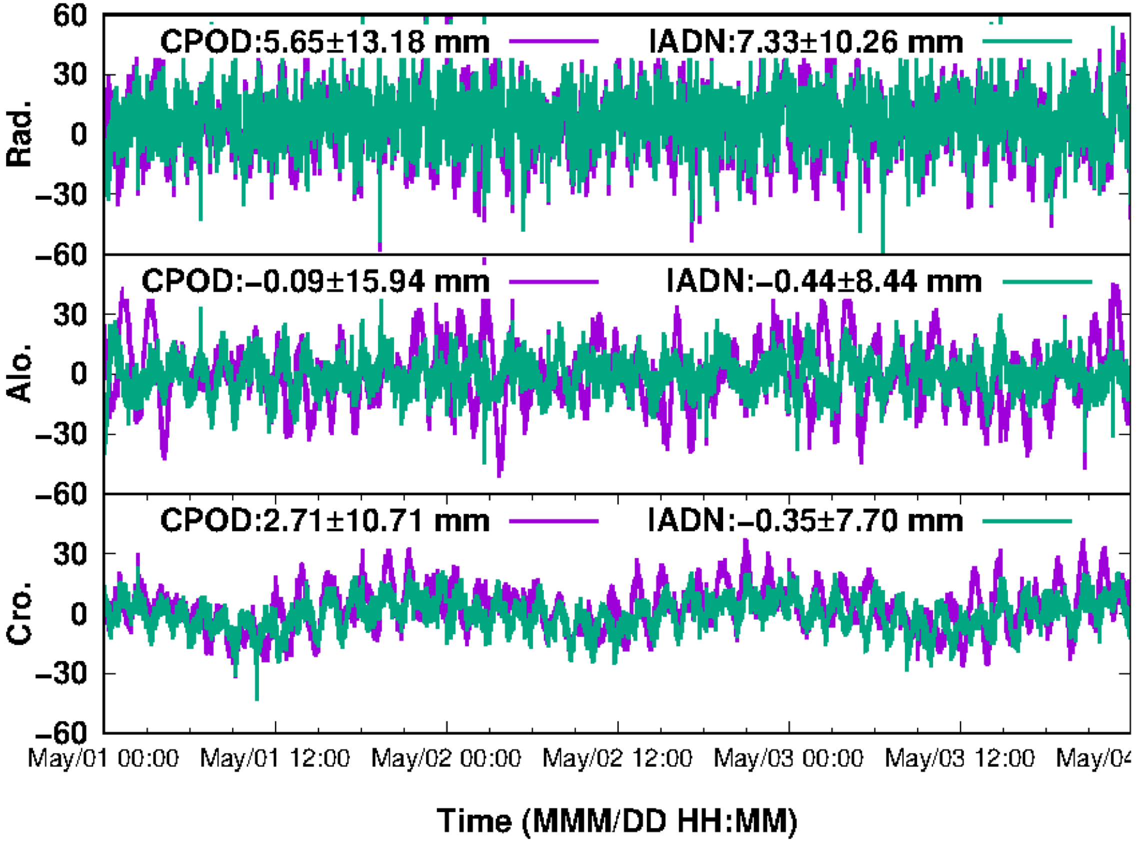
Bernese dynamic POD



Daily RMS of orbit comparison between the different solutions and the IAKN solutions. Time span: May, 2019, Unit: [mm].



Orbit comparisons between the CPOD, the IADN and the IAKN solutions. Example time span: May 1 to May 3, 2019, Unit: [mm].

- The **IADN** and the **FADN (float ambiguity)** solutions all show typical orbit dynamic features (periodic variations), agreeing better with the IAKN solution than the CPOD solution.

Bernese dynamic POD

S3A SLR validations for the different orbit solutions in May, 2019 (10 selected stations, elevation cut-off angle: 10 deg, outlier screening: 200 mm unit: [mm]).

Sat.	Solution	Mean	STD	Rad.	Alo.	Cro.
S3A	IAKN	-3.7	10.2	-5.7	-1.1	1.8
	IANM	-3.2	8.8	-4.9	-0.6	1.2
	IANG	1.8	8.2	3.0	-1.4	1.2
	IADN	2.4	9.3	4.1	-4.2	2.3
	FADN	2.3	11.0	4.2	-4.7	8.2
	CPOD*	3.3	13.9	5.1	1.3	11.2

*A day gap is ignored in the validation. On average 100 normal points per day.

- The **IADN** and **FADN (float ambiguity)** orbit precisions are also reaching 1-cm levels.
- Integer ambiguity resolution especially improves cross-track direction.
- It is expected that they do not outperform the reduced-dynamic solutions which use huge more empirical parameters (PCAs) to absorb force modeling deficiencies.

Conclusions and discussions

- Non-gravitational force modeling and scaling significantly improve the orbit precisions to levels of sub-cm. More refined gravitational and non-gravitational force modeling will further improve the dynamic POD solutions.
- Single-receiver integer ambiguity resolution is crucial for all types of PODs.
- The current reduced-dynamic orbits perform reliably for the single-satellite altimetry crossover-analysis. The values of kinematic (IAKN) and dynamic (IADN) orbits to this field need to be checked.
- Dynamic POD (IADN) uses less empirical parameters, the orbit solutions are more sensitive to the different supporting models, e.g., gravity field. It might be used as an independent validation tool for these models.