Impact of different attitude modes on Jason-3 precise orbit determination and antenna phase center modeling

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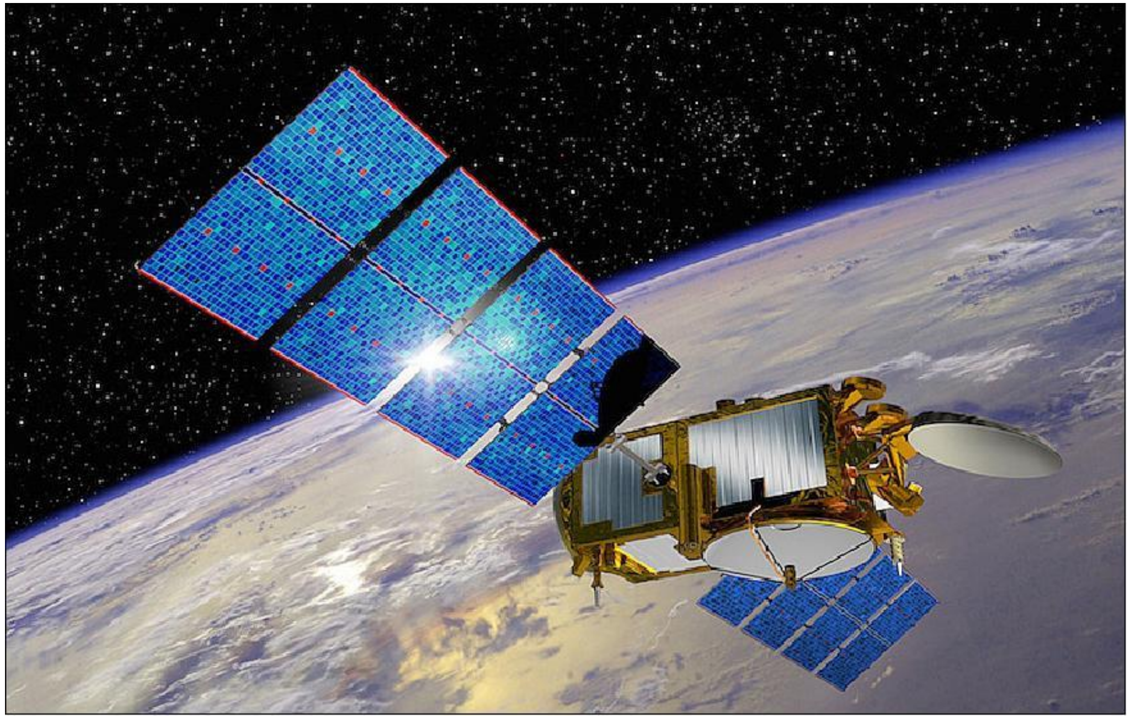
Introduction

- Jason-3
  - Altimetry satellite
    - Altitude: 1331 km
    - Inclination: 66°
    - Period: 112 minutes
- CNES, NASA's JPL and GSFC provide orbit solutions
- Perform POD using Bernese GNSS Software
- Pre-Launch PCV is available
- PCV map to be computed using residual stacking
- Jason-3 operates in different attitude modes
  - Fixed-yaw
  - Yaw-steering
- Attitude mode changes if $\beta = \pm 15°$ (Yaw-steering to Fixed-yaw and vice versa
- Yaw-flip takes place if $\beta = 0°$



https://eoportal.org/web/eoportal/satellite-missions/j/jason-3 (image credit: CNES)

PCV map determination

Make use of GPS measurements and POD results to estimate the PCV map

Using the Bernese GNSS Software this is done using a residual stacking approach.

For the different attitude modes separate PCV maps are derived

Two different orbit parametrizations were used

- Reduced-dynamic (RD): 3 constant accelerations per arc (one per spatial component) + 240 piecewise constant empirical accelerations per arc (every 6 minutes in Radial, Along- and Cross-track direction) constrained to $5\ nm/s^2$
- Dynamic (NG): 160 piecewise constant empirical accelerations per arc (every 6 minutes in Along- and Cross-track direction) constrained to $0.5\ nm/s^2$ + one scaling parameter for radiation pressure per arc

This results in 8 different PCV maps.
(Yaw-Steering+fixed-Yaw)*(forwards+backwards)*(2*orbit parametrization) = 8

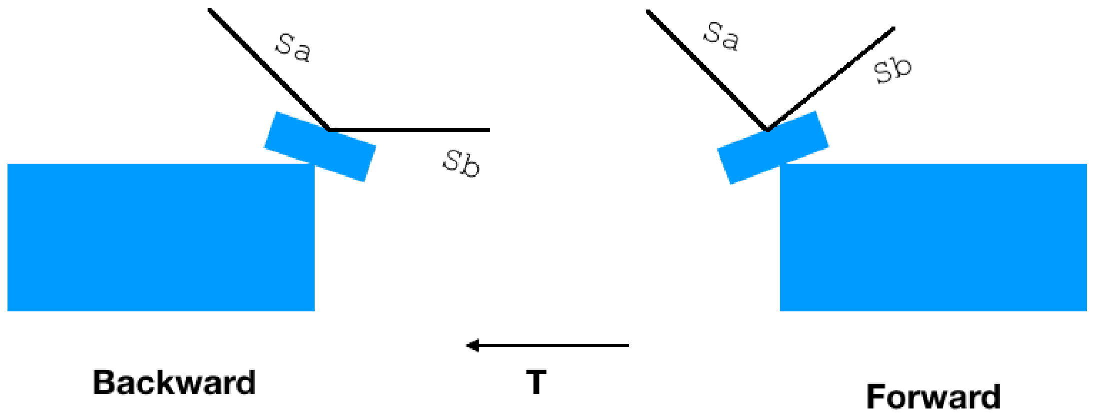
Coverage of GPS measurements in antenna frame

Depending on the attitude mode there is an incomplete coverage in the antenna frame.

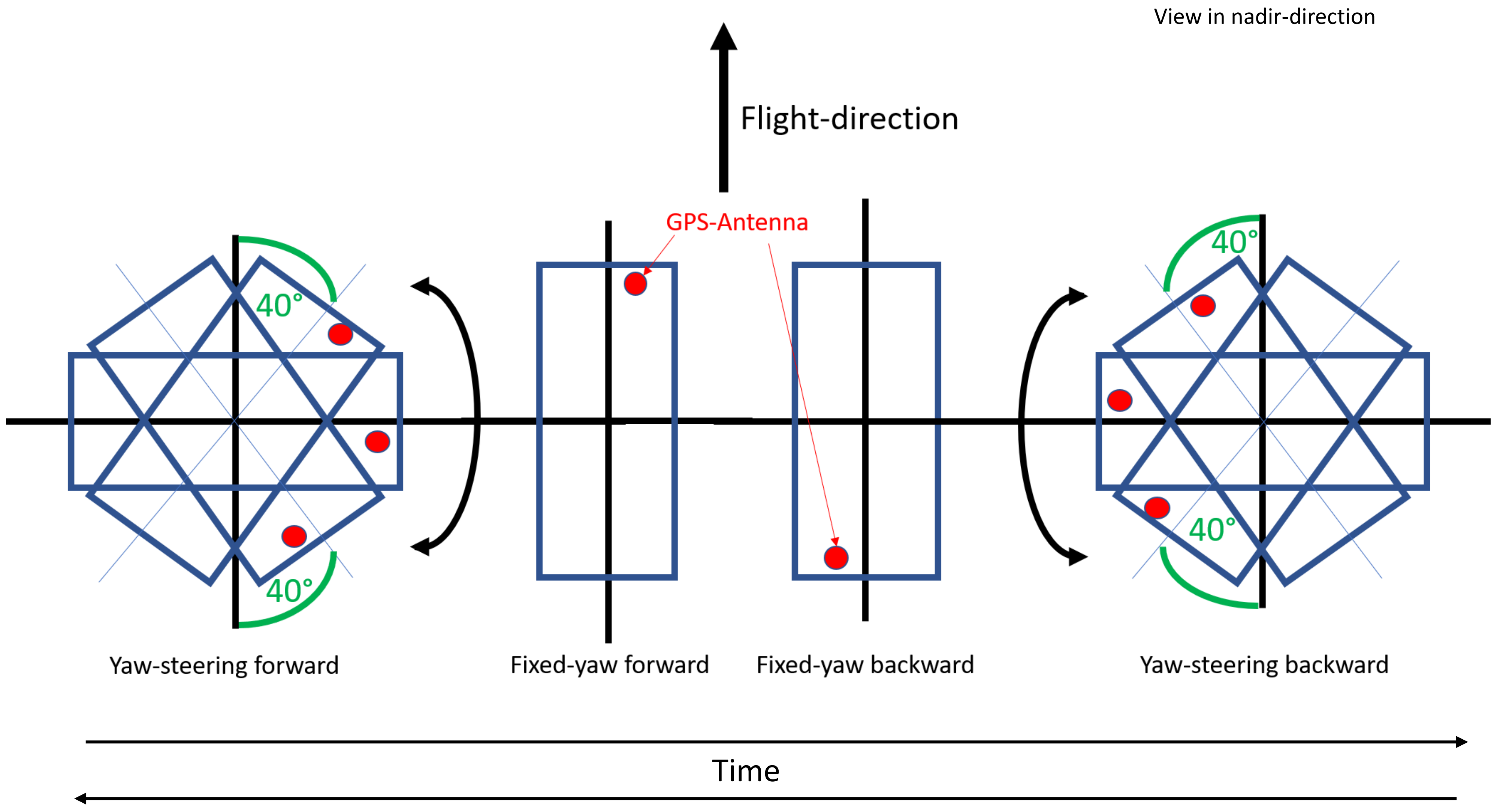
This is mainly visible when comparing forward and backward orientation. This results from the differences in the acquisition or loss of the signal at the beginning or end of a pass of a GPS satellite.

The reason for this is the 15° tilted GPS antenna of Jason-3.

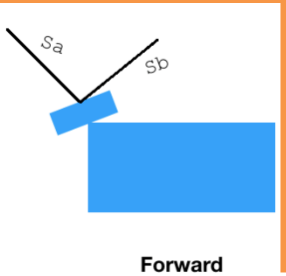
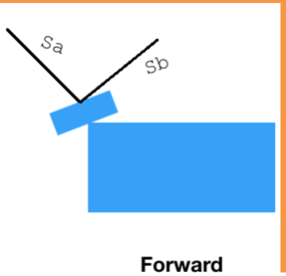
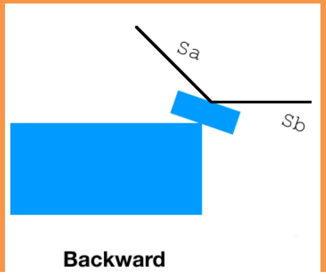
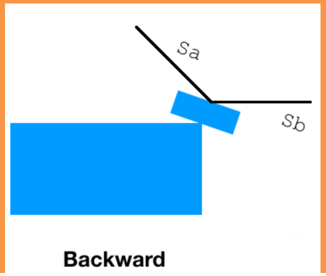
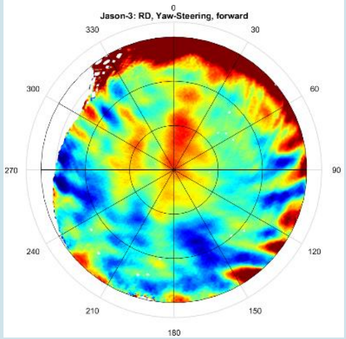
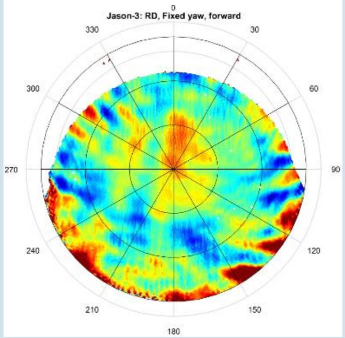
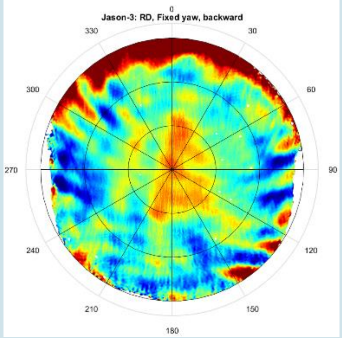
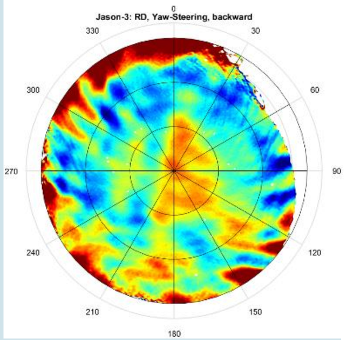
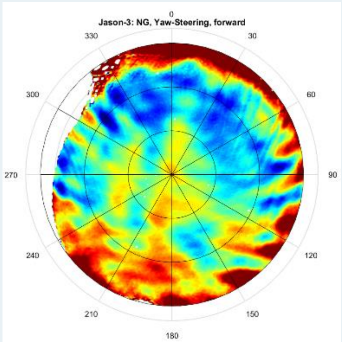
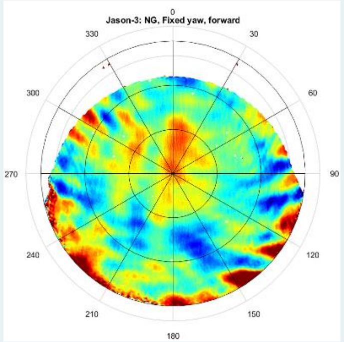
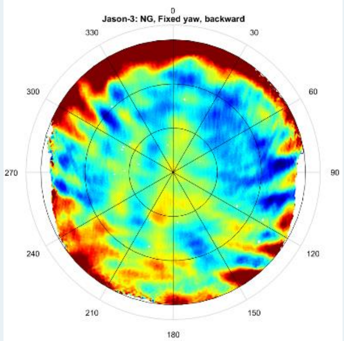
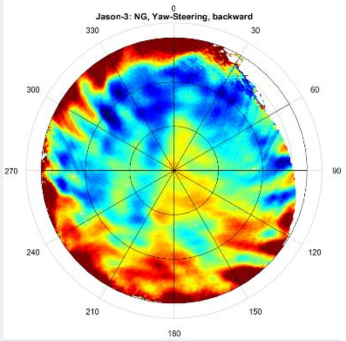
Two S/N thresholds : one value (Sa) for acquisition and another value (Sb) for loss, and Sa>Sb. In the satellite reference frame, the acquisitions are in a visibility cone smaller than the losses. Additionally, some added delays in the acquisition, as the receiver needs a certain time to lock correctly, eliminate the 0.5 phase ambiguity, etc... (Flavien Mercier, personal communication)

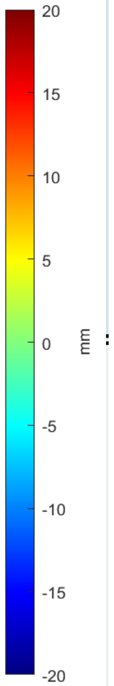


Jason-3 attitude modes



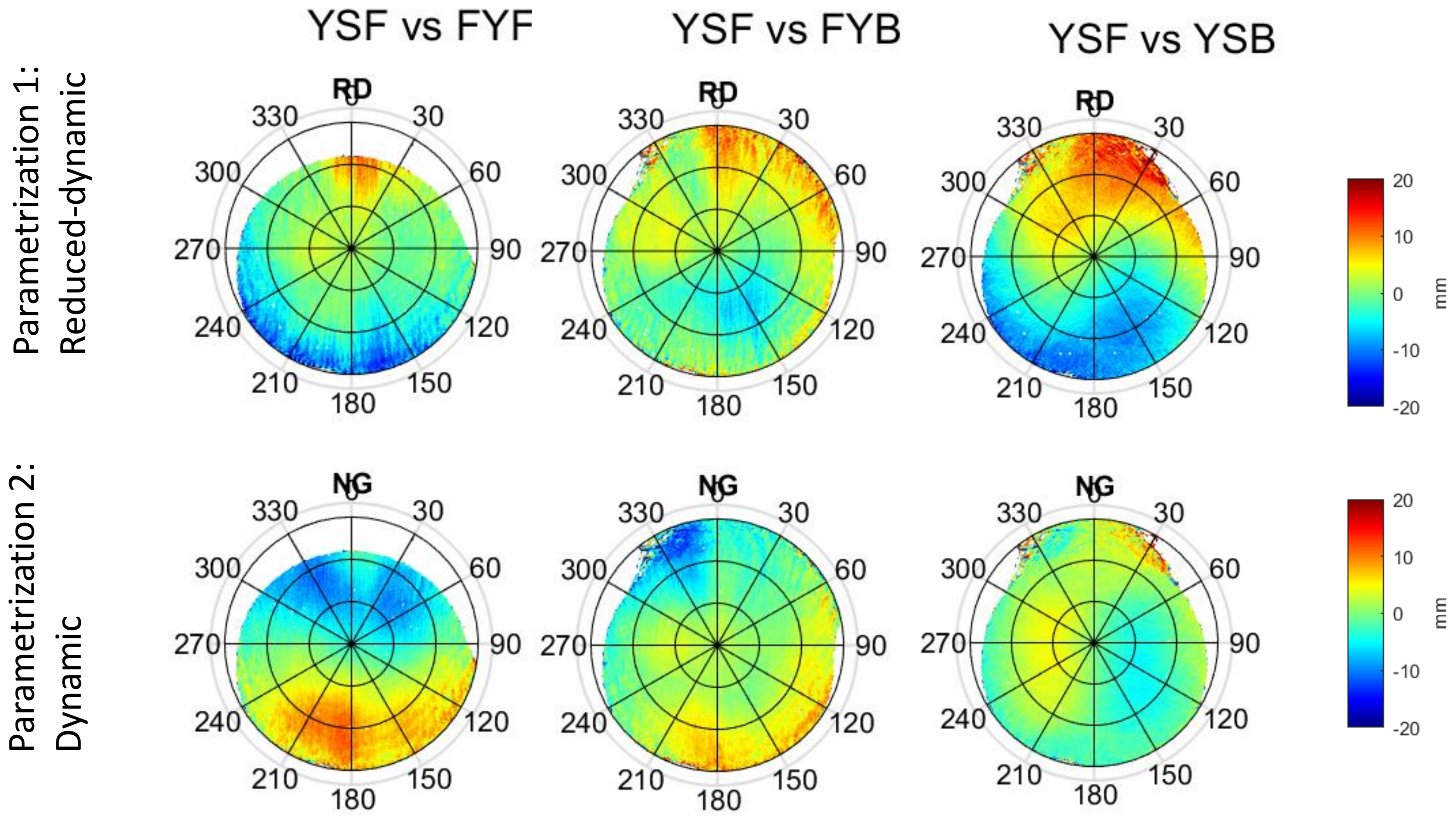
Different PCV maps

Attitude mode / Parametrization	Yaw-steering forward (YSF)	Fixed-yaw forward (FYF)	Fixed-yaw backward (FYB)	Yaw-steering backward (YSB)
				
Reduced-dynamic: No explicit non-gravitational force modelling, 240 piecewise constant empirical accelerations per arc, 3 contant accelerations per arc				
Dynamic: Non-gravitational force modelling, 160 piecewise constant empirical accelerations per arc, 1 scaling parameter for radiation pressure per arc				



PCV maps comparisons

The PCV maps are compared with relation to the map resulting from the yaw-steering forward attitude mode.



Pronounced differences are visible when comparing YSF to YSB.

The resulting PCV maps of the dynamic POD do not show such large variations. The comparison YSF to FYF shows the most significant pattern.

PCV offset removal

It is possible to remove phase center offsets (PCO) from the PCV maps using least squares adjustement.

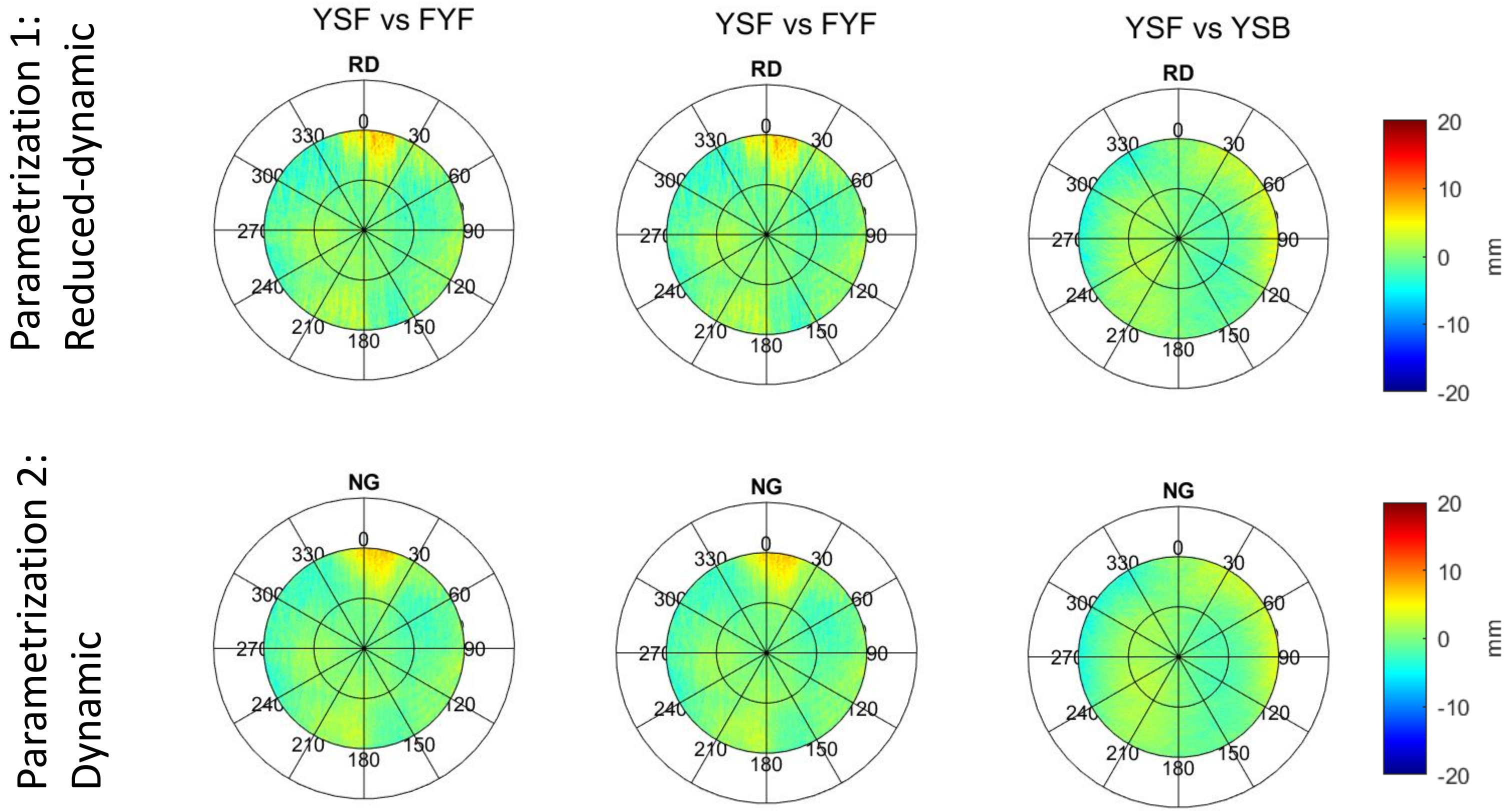
$$\phi'(\alpha, z) = -\sin(\alpha) * \sin(z) * E - \cos(\alpha) * \sin(z) * N - \cos(z) * U$$

Where $\phi'(\alpha, z)$ is the PCV map, α and z are azimuth and zenith angle respectively, E, N and U are the components of the offset vector.
To account for the different, incomplete coverages of the antenna for different attitude modes, an elevation cut-off of 30 degrees was used for the removal of possible induced offsets.
The offsets which are determined for all the PCV maps result to:

(E/N/U)[mm]	Yaw-steering forward	Fixed-yaw forward	Fixed-Yaw backward	Yaw-sterring backward
Parametrization 1 Reduced-dynamic	-0.042 ± 0.010 6.684 ± 0.009 4.324 ± 0.002	0.680 ± 0.010 2.964 ± 0.009 2.903 ± 0.002	1.913 ± 0.010 0.613 ± 0.010 4.068 ± 0.002	2.722 ± 0.011 -3.571 ± 0.010 3.298 ± 0.002
Parametrization 2 Dynamic	-2.403 ± 0.008 -7.229 ± 0.007 0.487 ± 0.002	-0.772 ± 0.009 4.004 ± 0.008 3.245 ± 0.002	-2.203 ± 0.007 -3.970 ± 0.006 -0.937 ± 0.001	3.550 ± 0.008 -8.971 ± 0.008 0.065 ± 0.002

PCV offset removal

The PCV maps are compared to the map resulting from the yaw-steering forward attitude mode. Before the comparison takes place, possible offsets were removed, as described on the previous slide.

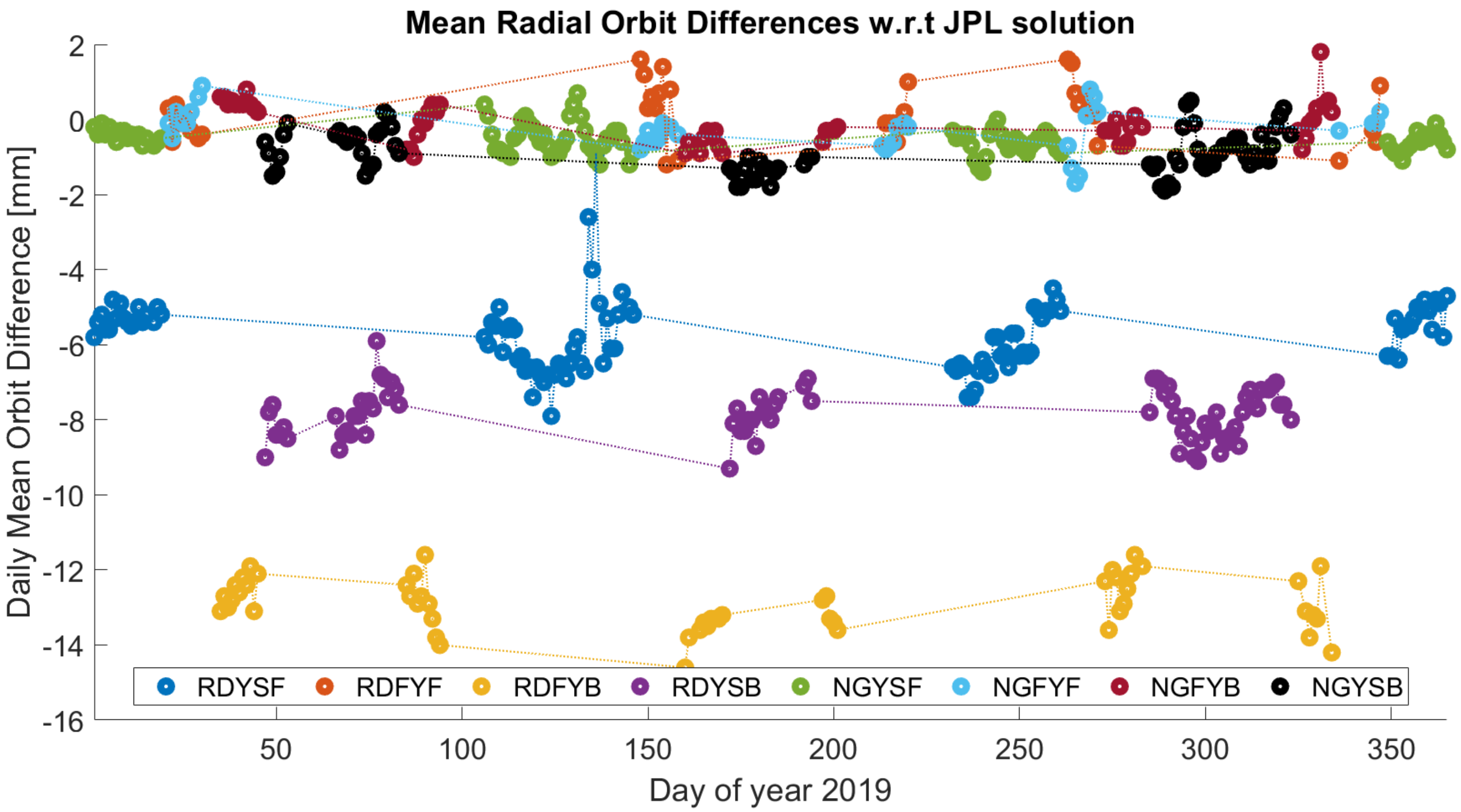


It is visible, that the PCO removal leads to differences in the PCV maps of very low amplitude.

This result is visible in all the PCV map comparisons when a PCO is removed before.

The inference of this result is that apart from different induced offsets, the phase center variation pattern for all the estimated maps is very similar.

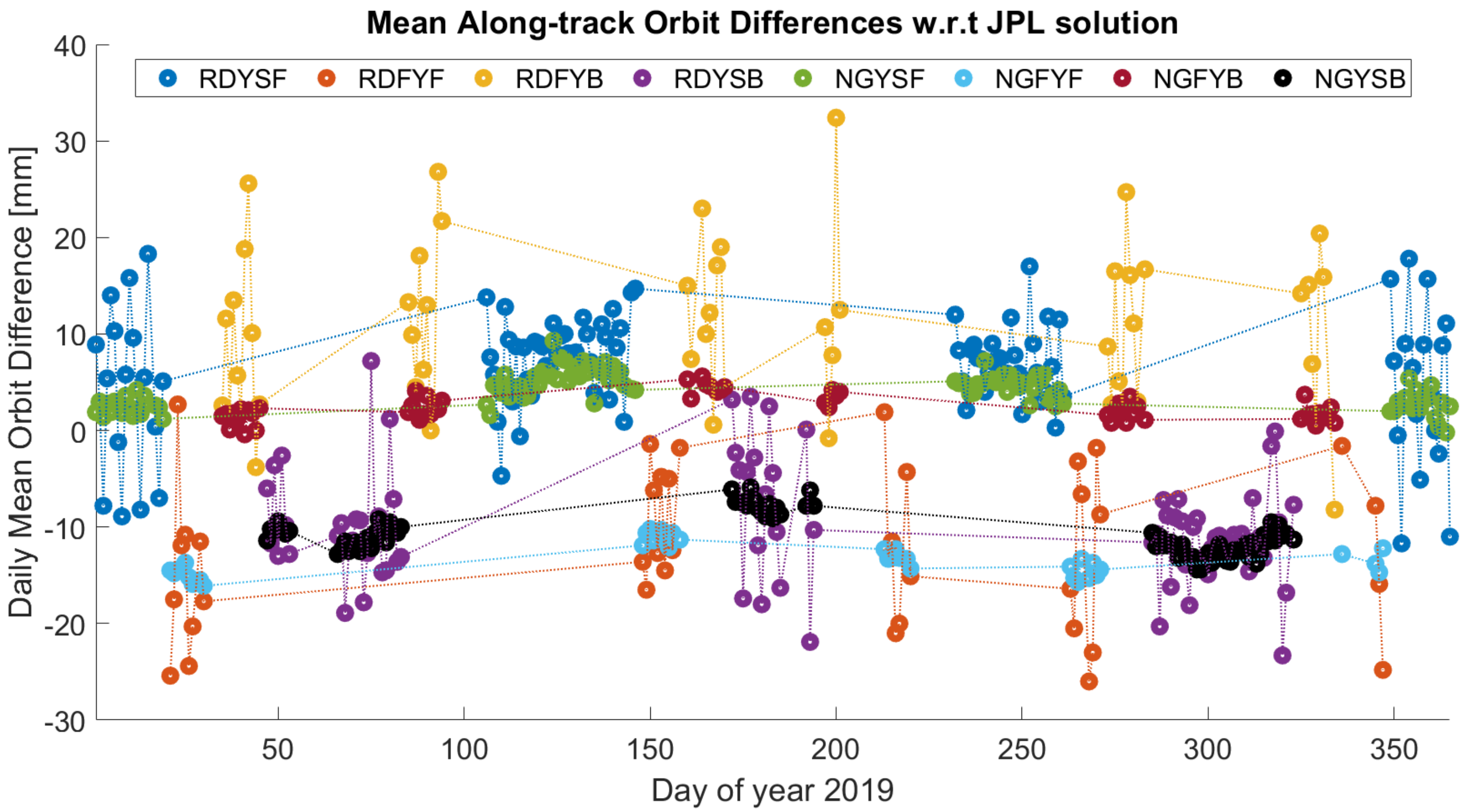
Orbit comparisons of different attitude modes



	Mean ± STD [mm]
RD YSF	-5.8 ± 6.9
RD FYF	0.2 ± 6.8
RD FYB	-12.9 ± 7.3
RD YSB	-7.9 ± 5.8
NG YSF	-0.5 ± 4.2
NG FYF	-0.3 ± 4.2
NG FYB	-0.1 ± 4.3
NG YSB	-0.9 ± 4.1

Systematic differences are visible in the orbit comparisons. For (RD) YSF, FYB and YSB an offset to the JPL solution in radial direction is present. It is evident that the NG solutions have a better agreement with the JPL solutions than the RD solutions.

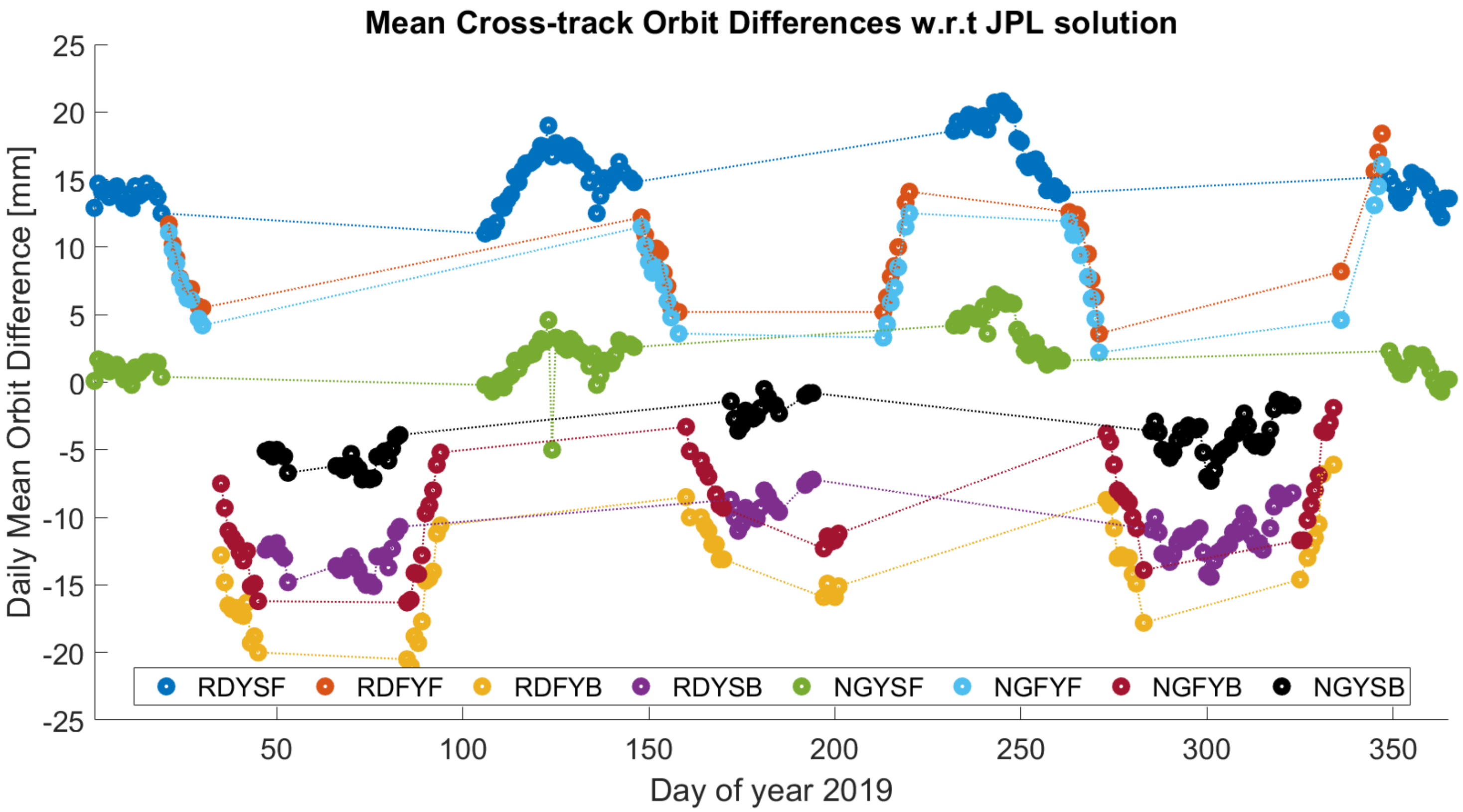
Orbit comparisons of different attitude modes



	Mean ± STD [mm]
RD YSF	6.3 ± 10.5
RD FYF	-12.2 ± 10.0
RD FYB	10.6 ± 10.8
RD YSB	-10.1 ± 7.7
NG YSF	4.2 ± 5.6
NG FYF	-13.3 ± 5.5
NG FYB	2.4 ± 5.6
NG YSB	-10.9 ± 5.2

It is visible, that NG YSF and NG FYB show a higher agreement to the JPL solution than the others. Additionally, the consistency of the offsets to the JPL solutions for the RD and the NG solutions is evident. The standard deviations for the RD solutions is larger than for the NG solutions for all the attitude modes.

Orbit comparisons of different attitude modes



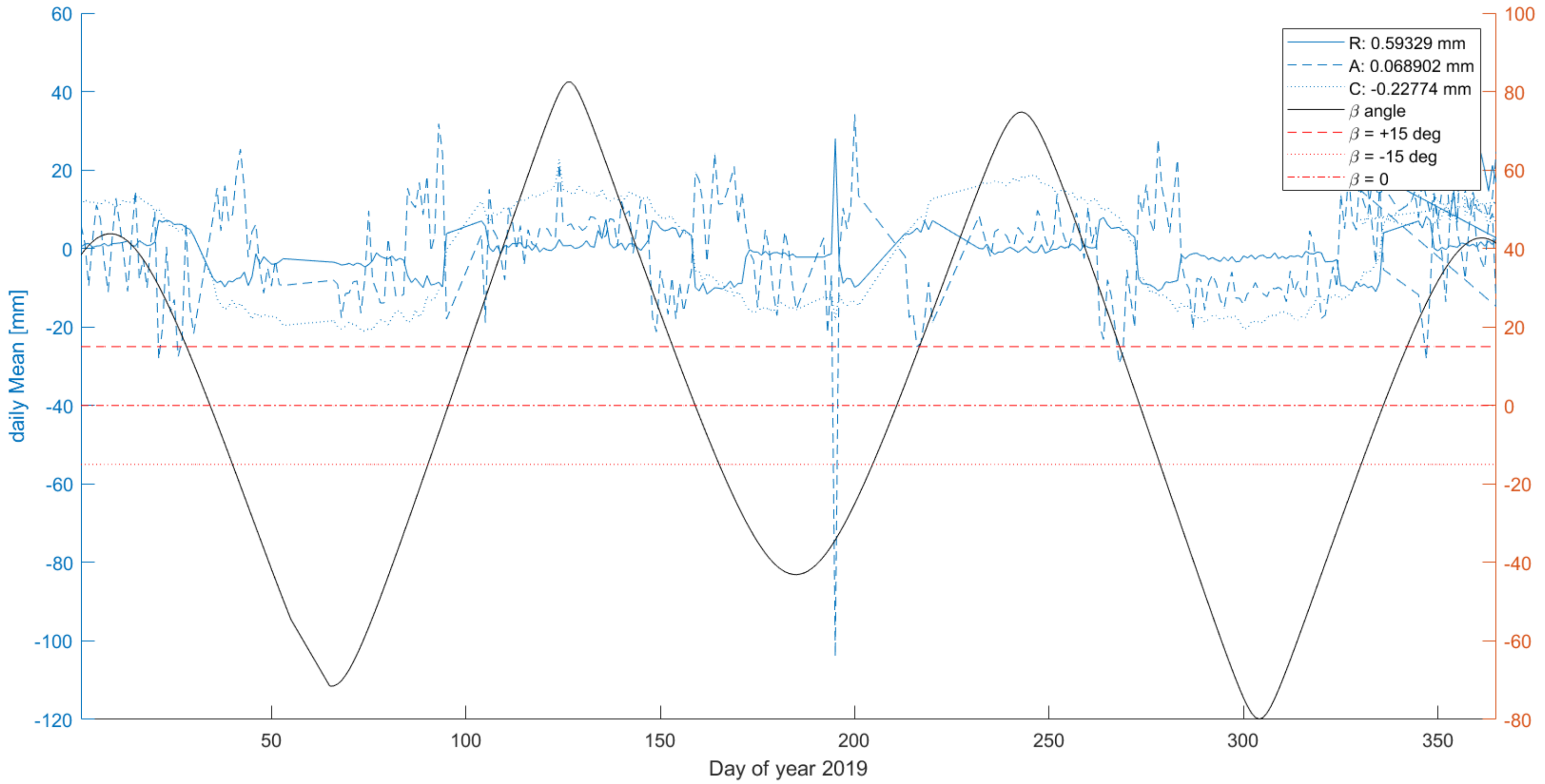
	Mean ± STD [mm]
RD YSF	15.6 ± 7.2
RD FYF	9.4 ± 6.0
RD FYB	-14.0 ± 6.0
RD YSB	-11.0 ± 7.3
NG YSF	2.0 ± 5.8
NG FYF	8.1 ± 5.4
NG FYB	-9.5 ± 5.2
NG YSB	-4.1 ± 6.6

Visible are the systematic differences in the orbit comparison in the Cross-track direction. The NG YSF solution shows the best agreement to the JPL solution. The use of non-gravitational force modelling (NG solutions) leads to smaller mean values in the orbit comparisons. The systematics for the different attitude modes is similar for the two parametrizations (RD and NG).

Orbit quality of different attitude modes

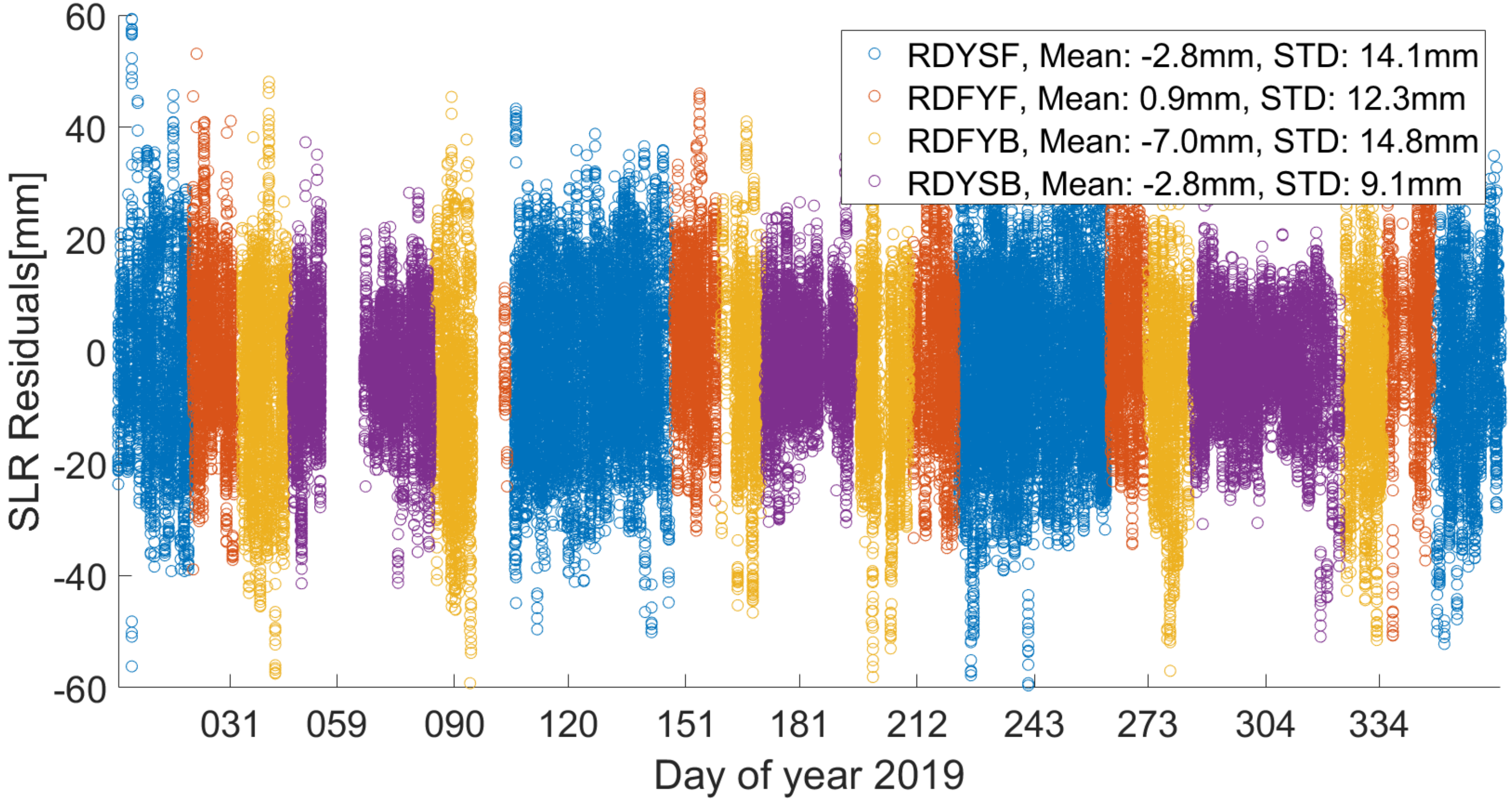
A POD is performed where the Pre-Launch PCV is used for all the attitude modes. This solution is also compared to an external solution (CNES). This serves the investigation whether the systematics in orbit differences from the previous slides is only visible when individual PCV maps are used for the POD. Additionally, this serves as a reference for the comparisons, since the comparison is to another solution than on the previous slides.

It is evident that, depending on the beta angle (which reflects the different attitude modes according to slide 2), systematics are present in the orbit comparisons. Therefore, one can conclude, that making use of individual maps for the POD for different attitude modes is not the (main) reason for the systematic orbit differences.



Orbit quality of different attitude modes

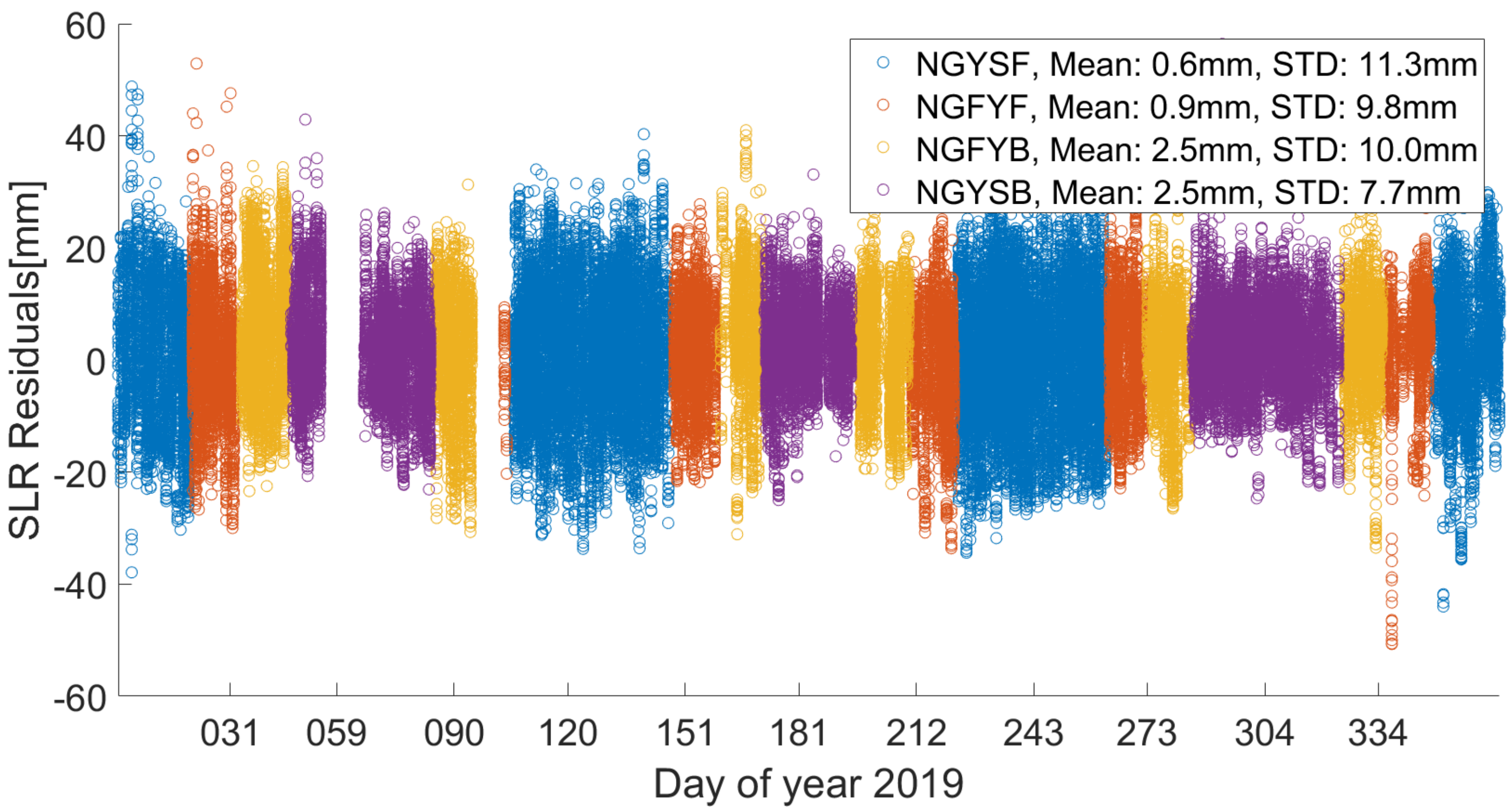
SLR validation of the reduced-dynamic solutions based on individual PCV maps for the different attitude modes.



The SLR validation shows different mean values for the attitude modes.
(RD)FYF has the smallest mean value.
(RD)YSB is the best solution according the the standard deviation.
One can see that the variation of the quality of the solutions for the different attitude modes is significant.

Orbit quality of different attitude modes

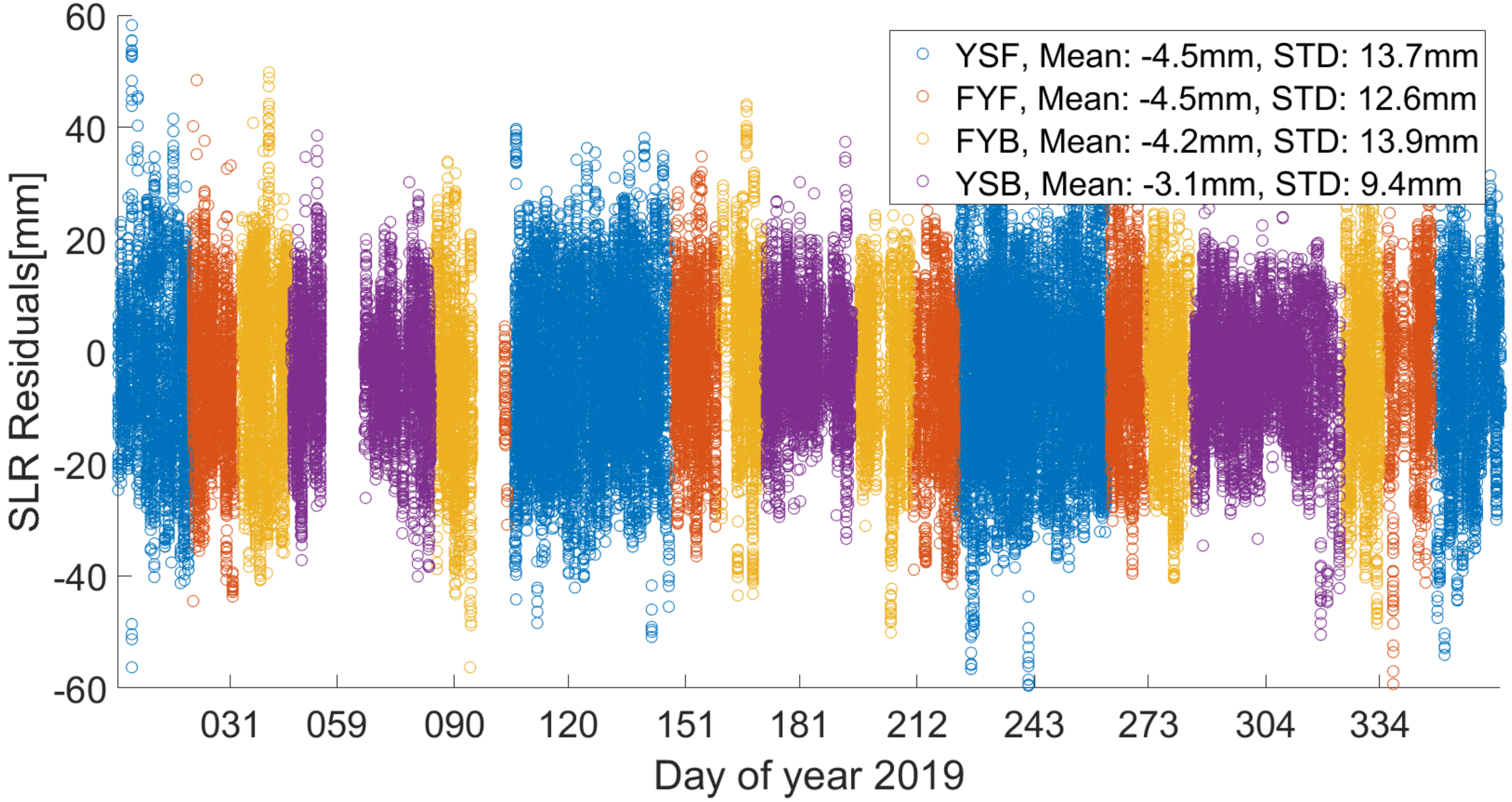
SLR validation of the dynamic solutions based on individual PCV maps for the different attitude modes.



A notable results of the SLR validation of the NG solutions is that the mean values for YSF and FYF are similar, as well as the ones for YSB and FYB. Therefore, a systematic difference between forward and backward orientation of the satellite is visible. When comparing the individual standard deviations of the attitude modes of the NG solutions to the results for the RD case (previous slide), it is evident that the NG solutions are of better quality.

Orbit quality of different attitude modes

The solution where the same PCV was used for the POD for all the attitude modes is SLR validated. The PCV computation is based on data from all the attitude modes from the year 2019.



The mean values are more similar than the ones for RD and NG on the previous slides. Important is, that no systematics is present in the comparison of the different orientations or attitude modes. The solutions for the YSB show the smallest mean value and standard deviation.

Comparing to the results from the previous slides, one can conclude, that, in terms of the SLR validation, making use of an individual PCV map for every attitude mode does improve the orbit quality for of the attitude modes, namely YSF (smaller mean),FYF (smaller mean and STD) and YSB (smaller mean and STD).

Summary and Conclusion

- Different PCV maps result when data from different attitude modes are used, whereas a common pattern can be recognized in all the PCV maps. A PCO removal from the different PCV maps shows that the real physical PCV induced by the satellite environment can be captured well using the residual stacking approch. However, the PCV maps are affected by different induced PCOs, which leads to sytematic differences.

- Orbit differences to an external solution show that the systematics between the PCVs are also visible on orbit level, resulting in different mean offsets for the different spatial components and attitude modes.

- These orbit differences show that using non-gravitational force modelling leads to more consistency with regard to the external solution. This may be due to the reason that the external solution is also based on dynamic orbit modeling approaches.

- An SLR validation allows to conclude that the dynamical parametrization leads to orbit solution of superior quality. This coincides with the results of better orbit agreement to external reference solutions and less variety in the PCV maps.

- The result indicates that it is of importance to take into account the different attitude modes for the PCV map computation.