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NWP Ocean Calibration for the CFOSAT wind scatterometer and wind retrieval evaluation

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Outline

- CSCAT L2A data characteristics
- NWP Ocean calibration (NOC):
    - NOC as a function of incidence angle
    - NOC as a function of incidence angle and antenna azimuth angle
- Wind retrieval performance evaluation
- Summary

CSCAT data characteristics

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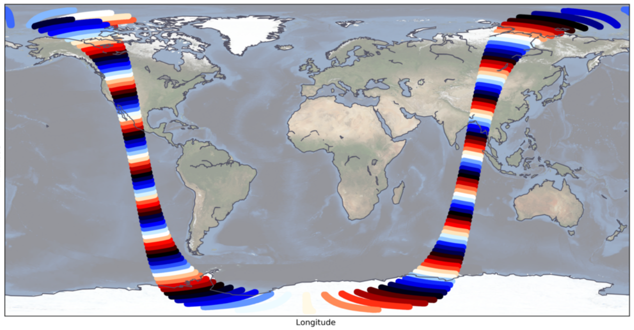
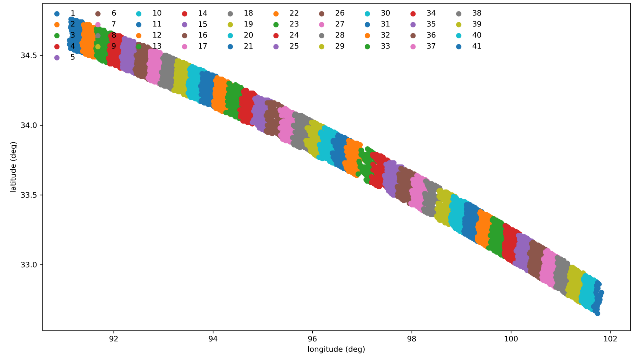
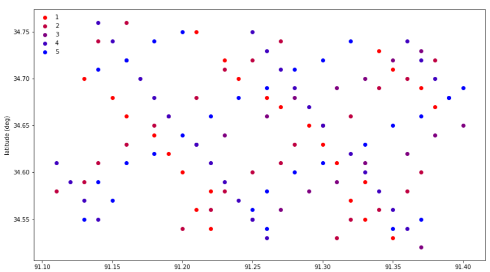


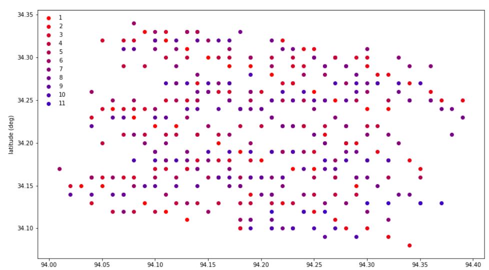
Illustration of the slices organized by rows (10 rows interval)



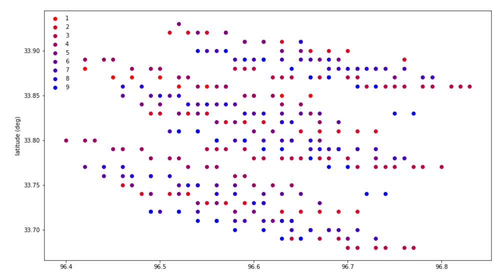
WVC distribution of the row number 300 (different colour indicates different WVCs)



(a)



(b)

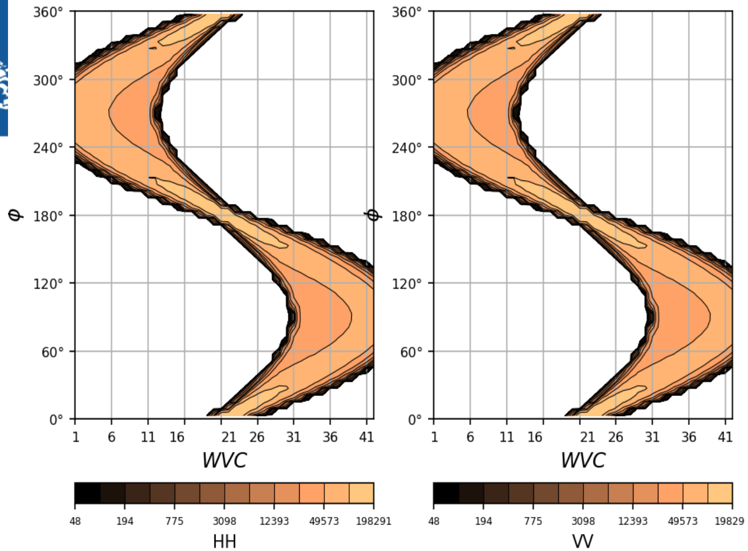


(c)

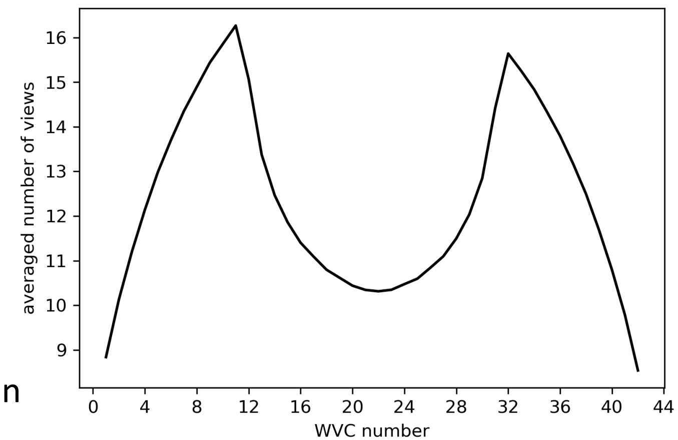
Slice positions in (a) outer WVC number 2, (b) sweet WVC number 11, (c) nadir WVC number 22, different colour indicates different view.

The distribution of the slices in each WVC is varying depending on the across track location. The sweet WVCs contain the largest number of slices compared to the nadir and outer WVCs and the slice position pattern at the sweet WVCs is rather mixed because these WVCs have the most diverse azimuth distribution. At nadir azimuth views are limited to a repeatable pattern depending on WVC . The slices in the outer WVCs are more diverse, because the number of slices and the number of views are both the smallest and somewhat depending on latitude due to earth and orbit characteristics.

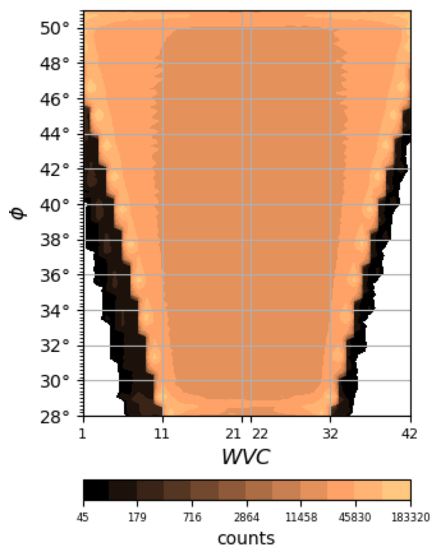
CSCAT data characteristics



Azimuth angle (antenna direction relative to the satellite movement direction) distribution as a function of WVC number across the track.



Average number of views at the WVCs across the swath

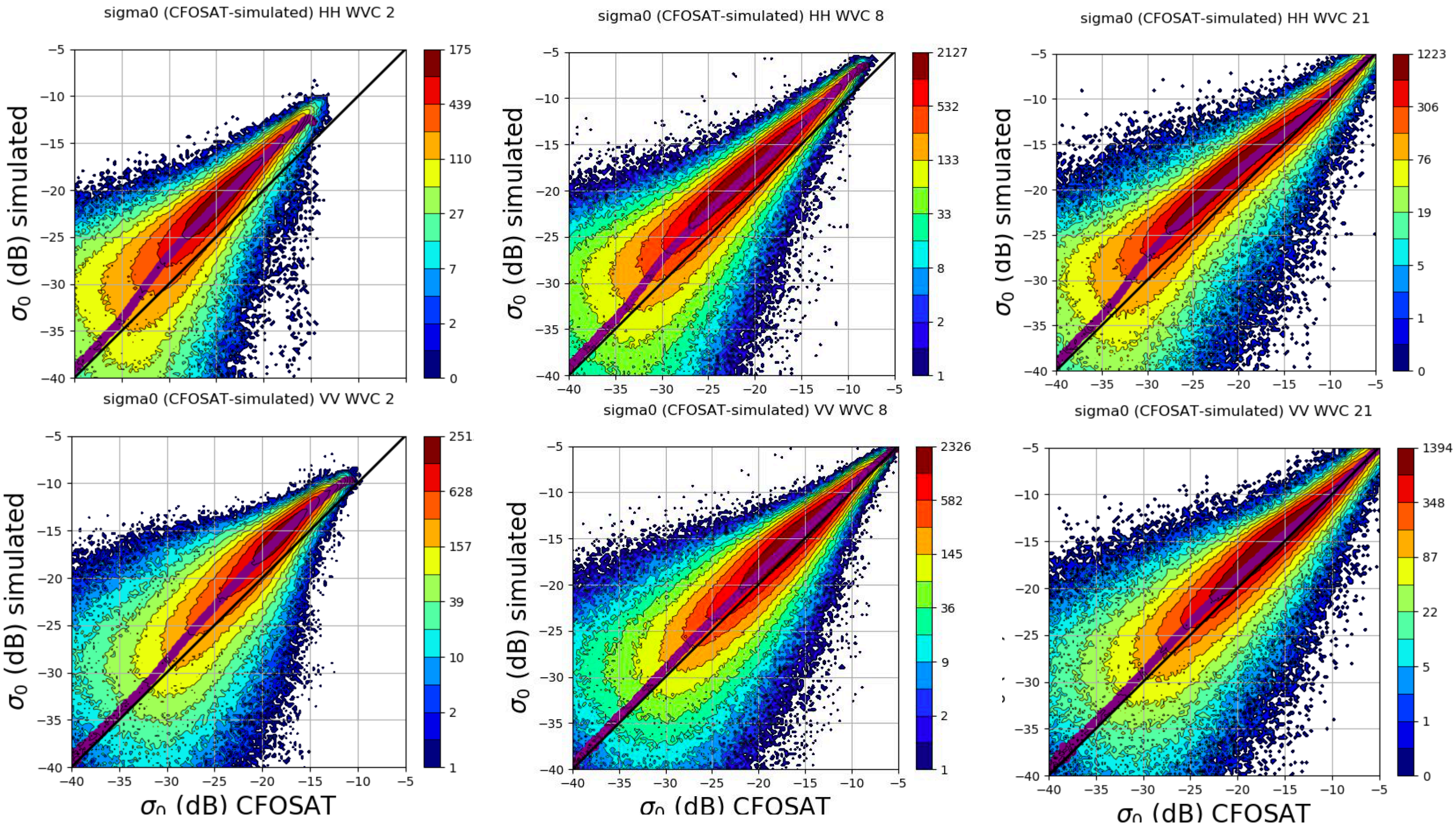


Incidence angle distribution as a function of WVC number across the track

The azimuth (antenna direction relative to the sub-track direction) distribution as a function of WVC, which shows that the azimuth is around 0°/360° or 180° at the nadir WVCs, around 90° and 270° at the outer WVCs and quite diverse at the sweet WVCs. Even though the azimuth diversity is limited at the nadir swath, it contains the large range of incidence angles, while only high incidence angles fall in the outer WVCs. The number of views as a function of WVC has a saddle shape with the largest number of views in the sweet swath.

CSCAT data characteristics

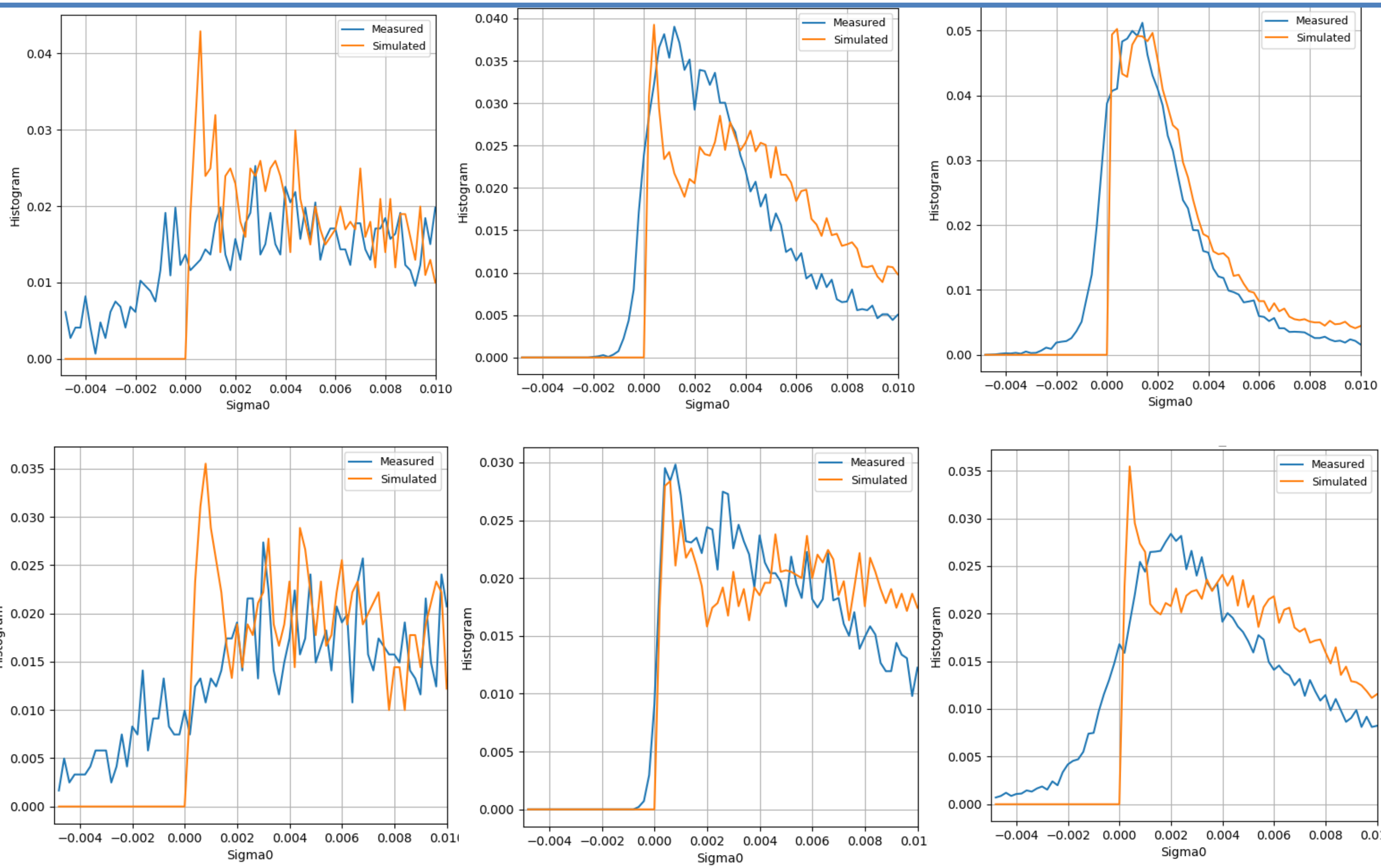
A deviation from the diagonal occurs in the HH $\sigma°$ histogram, while the deviation in the VV $\sigma°$ histogram is rather small. The outer WVCs contribute most to the deviation



Contoured histograms of the joint distribution of measured $\boldsymbol{\sigma}°$ and simulated $\boldsymbol{\sigma}°$ at (a) the outer WVC (number 2), upper plot is HH, lower plot is VV; (b) sweet WVC (number 8), upper plot is HH, lower plot is VV; (c) nadir WVC (number 21), upper plot is HH, lower plot is VV. The purple line denotes the mean difference as a function of average simulated and measured $\boldsymbol{\sigma}°$.

CSCAT data characteristics

measured and simulated $\sigma°$ Probability Density Functions (PDF) per incidence angle. The negative $\sigma°$s indicate the existence of very low winds in the presence of noise, where $\sigma°$s with low incidence angle contain the greatest number of negative $\sigma°$s, while the $\sigma°$s with medium incidence angle contain the smallest number of negative $\sigma°$s. VV polarized $\sigma°$s have more negative values than HH polarized $\sigma°$s. Even though $\sigma°$ theoretically cannot be negative, because wind speed is always positive, negative $\sigma°$s still are valid due to measurement noise



(a) (b) (c)

PDFs of measured $\boldsymbol{\sigma}°$ and simulated $\boldsymbol{\sigma}°$ for polarization HH (upper row) or VV (lower row). Column (a) $\boldsymbol{\sigma}°$ PDF with incidence angle 30°; (b) $\boldsymbol{\sigma}°$ PDF with incidence angle 42°; (c) $\boldsymbol{\sigma}°$ PDF with incidence angle 50°.

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NWP Ocean Calibration (NOC)

The NWP Ocean Calibration (NOC) (Stofflen 1999, Verspeek et al. 2012) is used to assess the difference between the scatterometer backscatter data and the simulated backscatter data from collocated NWP winds using the GMF. This is needed since there is no accurate absolute radar calibration and the scatterometer standard wind processing needs a calibration standard.

input $\sigma°$

$\sigma°_k(i,j)$

azimuth bin (j)
j = 1, 2, …, J

$$\sigma°(i) = \frac{1}{J}\sum_{j=1}^{J}\frac{1}{K(i,j)}\sum_{k=1}^{K(i,j)}\sigma°_k(i,j)$$

$$KJ(i) = \sum_{J=1}^{J} K(i,j)$$

number of $\sigma°_k$ over all azi bins within one wind speed bin

$$KJI = \sum_{I=1}^{I}\sum_{J=1}^{J} K(i,j)$$

number of $\sigma°_k$ over all azi bins and all wind speed bins

wind speed bin (i)
i = 1, 2, …, I

$$\langle\boldsymbol{\sigma}°\rangle = \frac{1}{KJI}\sum_{i=1}^{I} KJ(i)\sigma°(i)$$

Calculation scheme of the mean $\langle\boldsymbol{\sigma}°\rangle$, (i – wind speed bin; I – total number of bins of wind speed; j – azimuth angle bin; J – total number of bins of azimuth angle; k – index of individual measurement at the bin of (wind speed bin, azimuth bin) $\sigma°_k(i,j)$; K – total number of measurement at the bin of (wind speed bin, azimuth bin) K(i, j).

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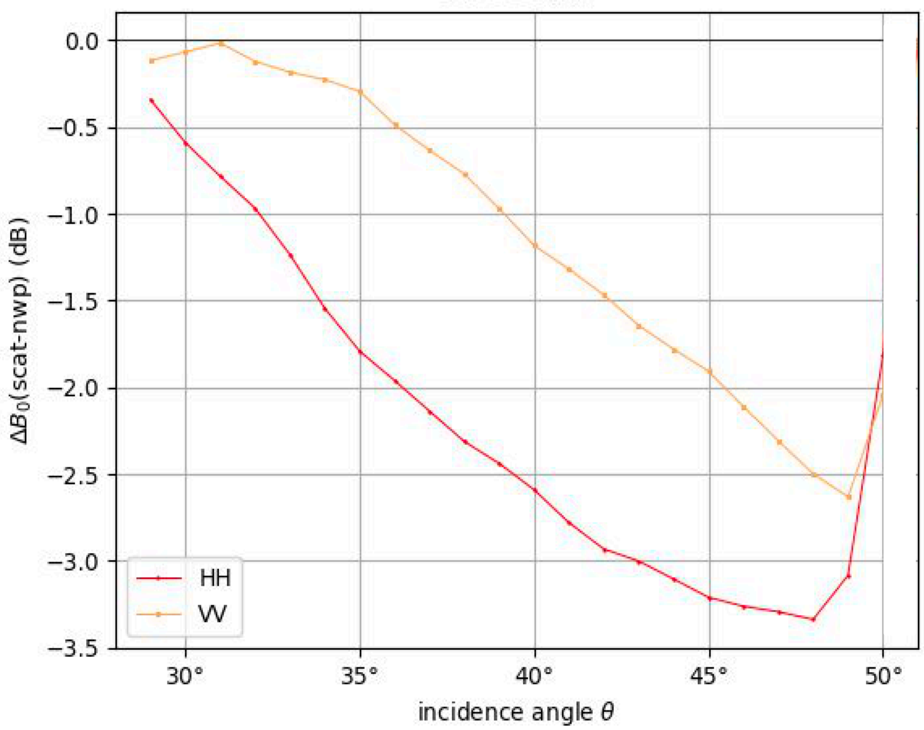
NOC as a function of incidence angle (**NOCinc**)



The value of the HH correction decreases as a function of incidence angle, except that it increases at the high incidence angle bins with quite a large jump at 50°. The value of the VV correction increases a bit at the low incidence angle and then shows a similar pattern to the HH correction with also a large jump at 50°.

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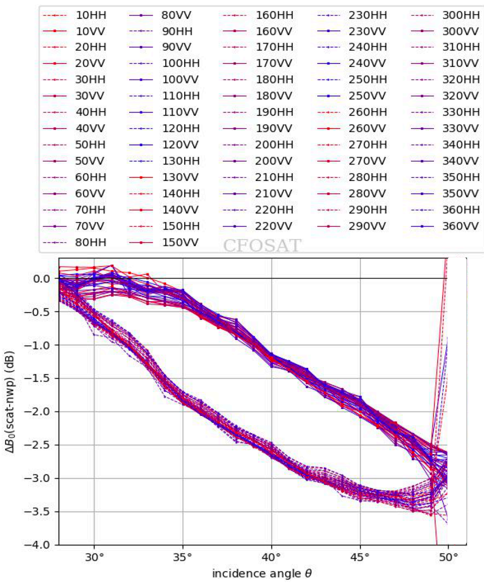
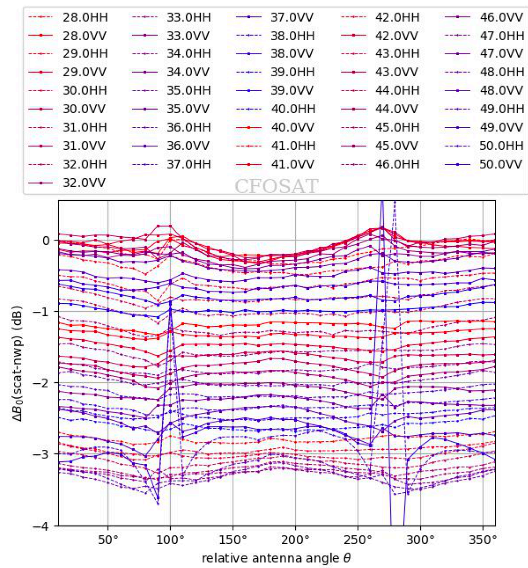
NOC as a function of incidence angle and antenna azimuth angle (**NOCant**)



NOCant for the 25-km product as a function of incidence angle per antenna azimuth angle bin



NOCant as a function of antenna azimuth angle per incidence angle bin. Dashed lines are HH polarization, solid lines are VV polarization

Ideally the NOCant of the same incidence angle at different antenna azimuth angles should have the same value, but there are significant oscillations around the antenna azimuth angle at 90°, 100°, 270°, and 280°, especially at the high incidence angle of 50°.

This might be caused by the changing sign of the frequency modulation for forward and backward looks and a low number of samples in the level 0 data processing, which is inevitable. There are less than five samples per incidence angle and per polarization at those antenna azimuth angles.

NWP Ocean Calibration (NOC)

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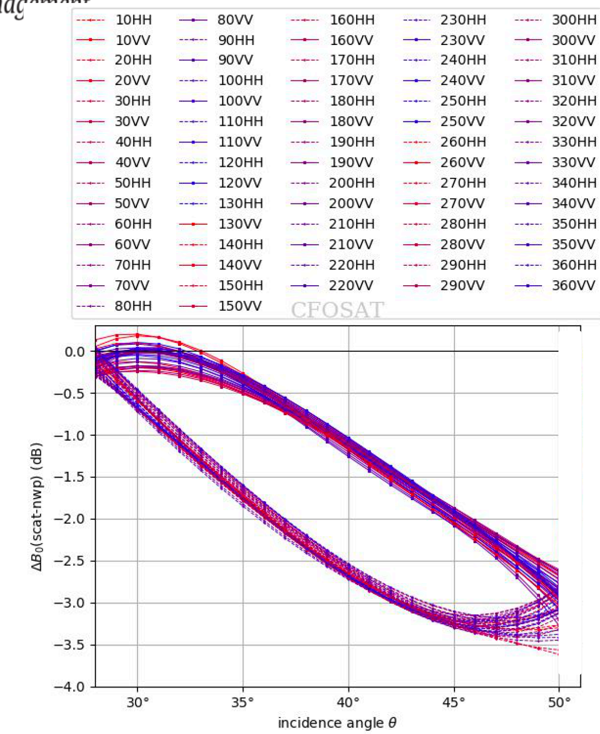

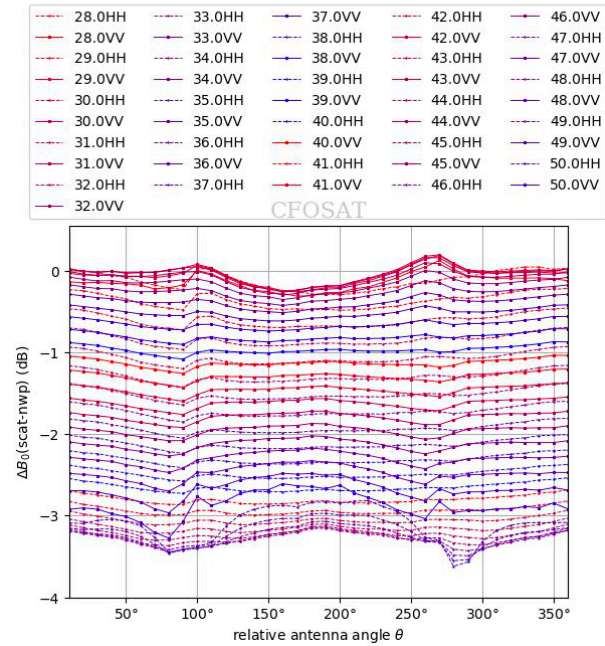

In order to avoid the large oscillation, NOCant is extrapolated at the incidence angle 50° , where the antenna azimuth angles are 90°, 100°, 270°, and 280°. Moreover, the NOCant is not as smooth as the NOCinc due to the binning and the limitation of the number of samples in each antenna azimuth angle bin and incidence bin. A 3rd order polynomial fit function is applied on the extrapolated NOCant in order to have smoother lines.

Wind retrieval performance between NOCinc and NOCant

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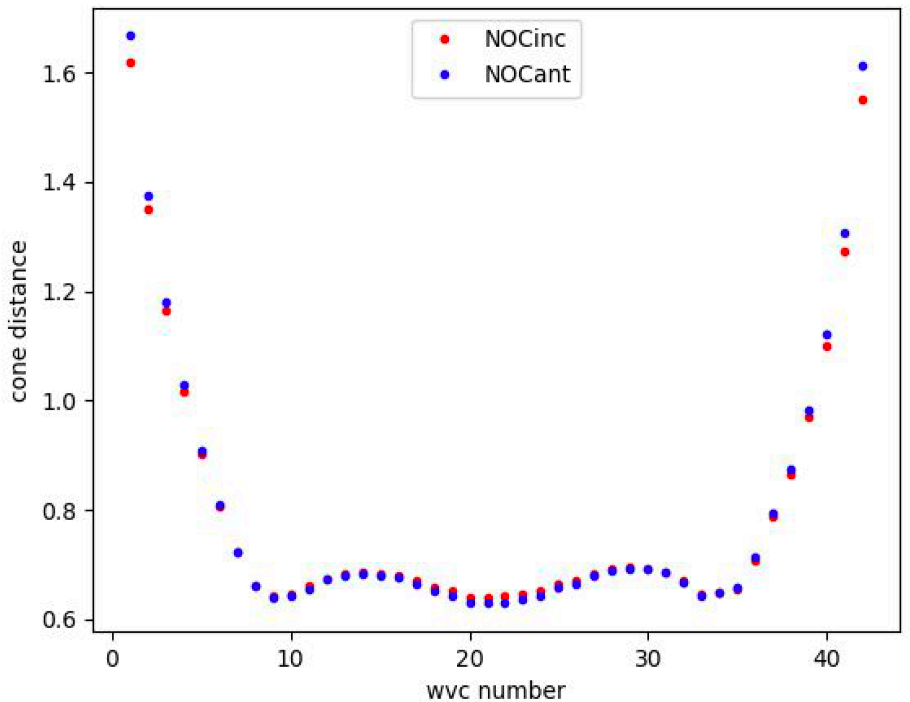

Collocated cone distance as a function of WVC number with the same MLE normalization and quality control threshold

In the NOCinc corrected case, only the MLE values located at outer-swath WVCs are lower than NOCant. This might be because at outer WVCs only high incidence angles are used and NOCint uses all azimuth angles to estimate the backscatter bias, while the NOCant bias estimates using only the antenna azimuth angles around 90° and 270° may be less accurate, which might cause over or under correction. However, the MLE values of NOCant at the other WVCs are lower than NOCinc especially at the nadir WVCs, which implies that NOCant corrections generally result in backscatter values that better fit the GMF than those using NOCinc corrections.

Wind retrieval performance between NOCinc and NOCant

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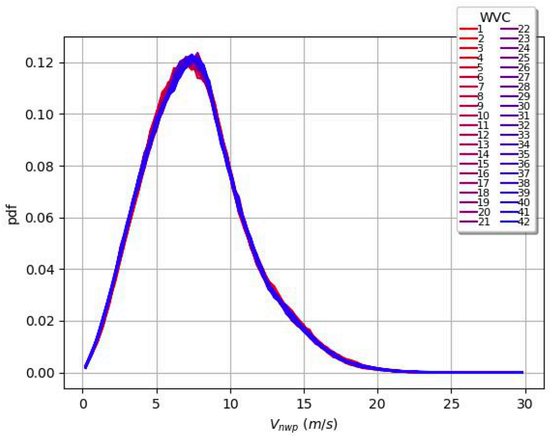
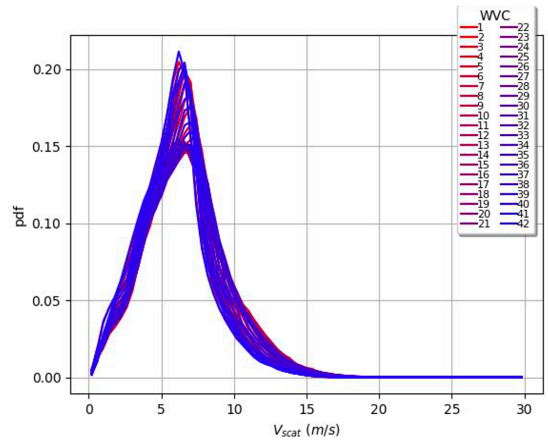
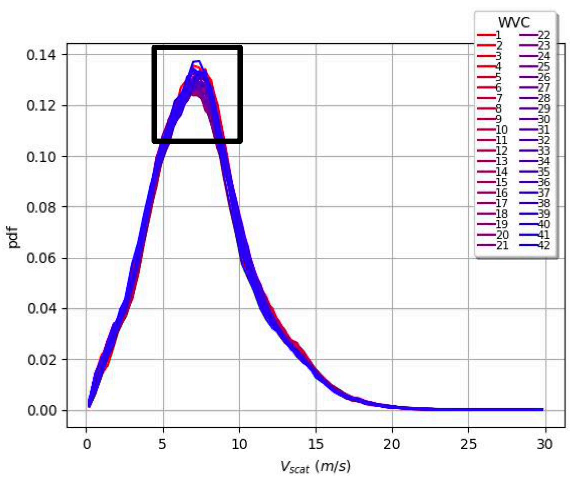
Wind speed PDF per WVC



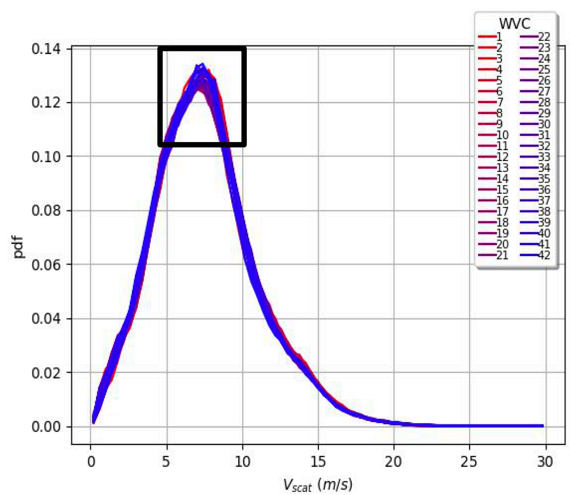
ECMWF



CSCAT without NOC correction



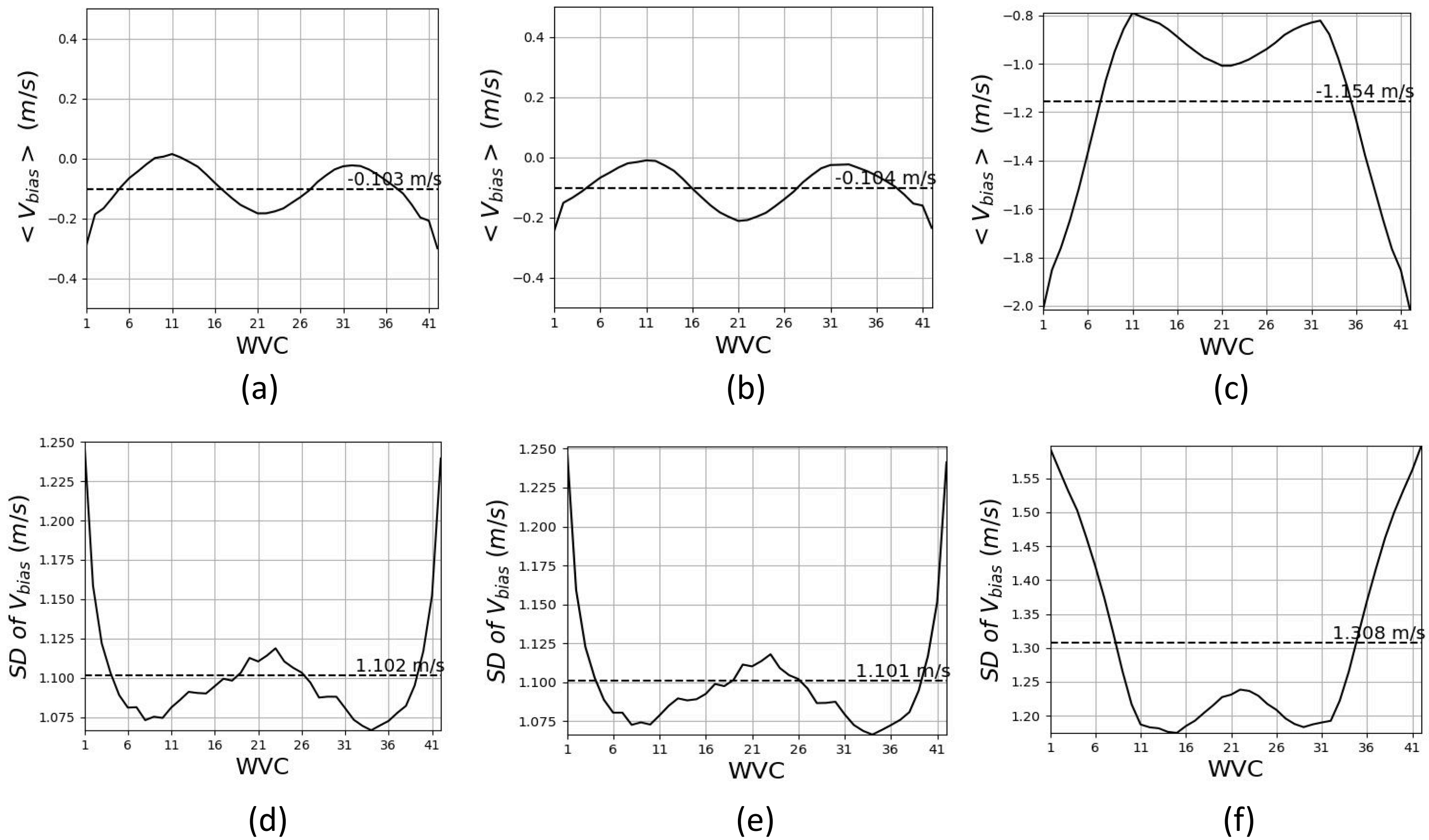
CSCAT with NOCinc correction



CSCAT with NOCant correction

The wind speed PDF improves significantly with both NOCinc and NOCant corrections and the impact can be seen in the rectangular box. The peaks of the wind speed PDFs per WVC come closer together with NOCant than with NOCinc for wind speeds between 5m/s and 8m/s.

Wind retrieval performance between NOCinc and NOCant



(a) wind speed bias as a function of WVC with NOCinc correction; (b) with NOCant correction; (c) without NOC correction. (d) standard deviation of the wind speed bias as a function of WVC with NOCinc correction; (e) with NOCant correction; (f) without NOC correction.

The wind speed bias and SD show very similar patterns for both correction methods. They show a symmetrical pattern where the outer and nadir WVCs have higher bias and SD, whereas the sweet swath WVCs have the lowest bias and SD.

Wind retrieval performance between NOCinc and NOCant

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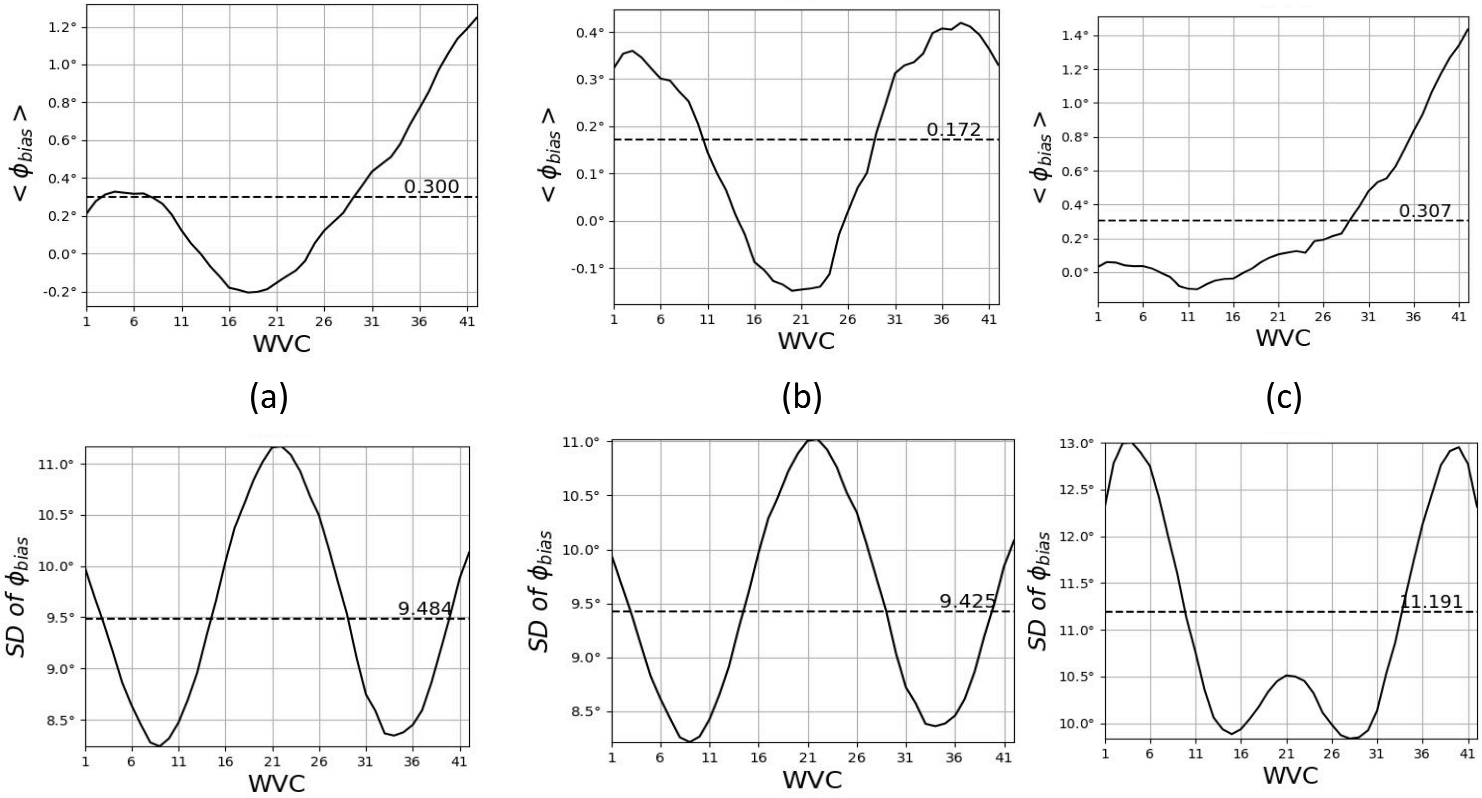
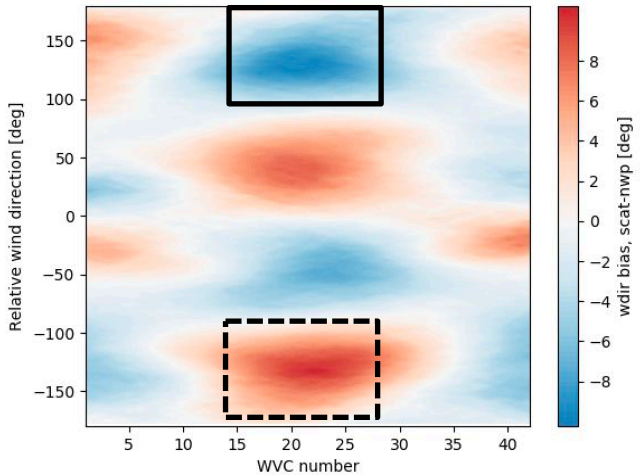


(a) (b) (c)

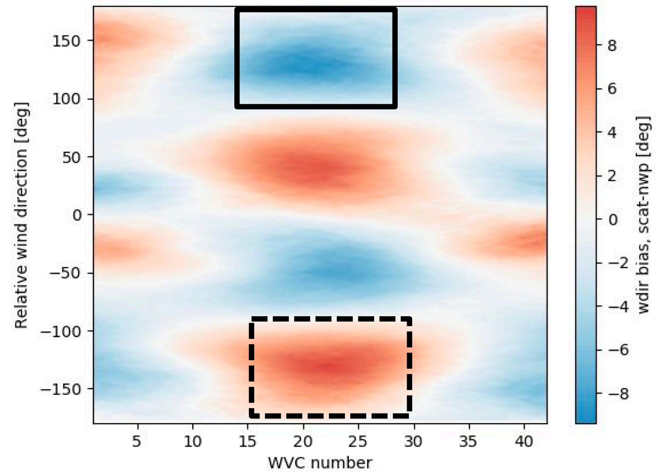
(d) (e) (f)

(a) wind direction bias as a function of WVC with NOCinc correction; (b) with NOCant correction; (c) without NOC correction. (d) standard deviation of the wind direction bias as a function of WVC with NOCinc correction; (e with NOCant correction; (f) without NOC correction.

The average wind direction bias is reduced about 43% with NOCant correction as compared to NOCinc correction. Even though both NOCinc and NOCant are able to improve the wind direction bias, the shape of the wind direction bias keeps symmetry for NOCant correction, and it shows unbalanced bias at the outer WVCs for NOCinc correction.

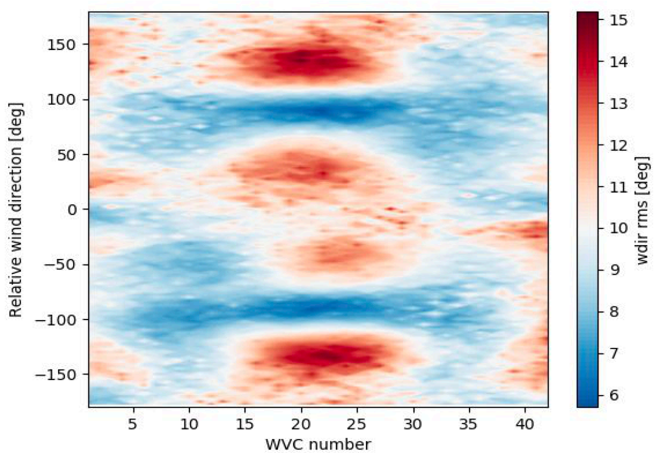


(a)

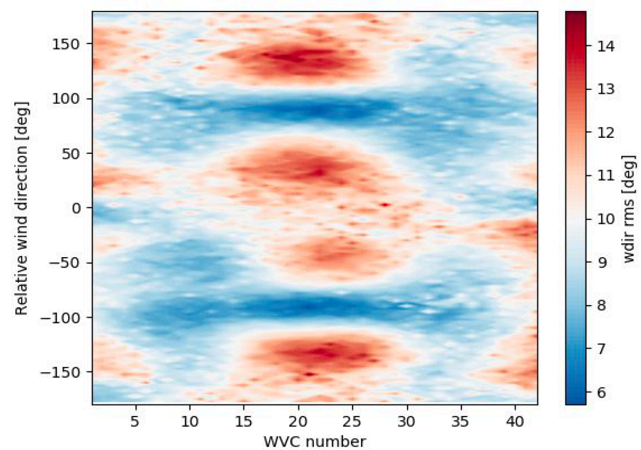


(b)

Relative wind direction bias (relative to the satellite motion direction) per WVC.
(a) with NOCinc correction.
(b) with NOCant correction.



(c)



(d)

Standard deviation of relative wind direction (relative to the satellite motion direction) bias per WVC.

(c) with NOCinc correction.

(d) with NOCant correction.

We are able to see the relative wind direction bias with respect to the satellite track direction at all the WVCs. The nadir swath gives stronger bias as compared to the other parts of the swath. The NOCant correction is better able to reduce the bias in the nadir WVCs than NOCinc correction. the bias distribution pattern is quite similar for NOCinc and NOCant, but the NOCant correction yields smaller biases in the nadir WVCs, especially in the rectangular boxes, as compared to the NOCinc correction. The bias is 6.10° for NOCinc and 5.53° for NOCant (black dashed box), whereas it is -6.16° for NOCinc and -5.62° for NOCant (black solid box). For the entire swath, the bias is -0.27° for NOCinc and -0.17° for NOCant. The same phenomenon can be observed in the standard deviation of the relative wind direction bias.

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Summary

- The characteristics of the CFOSAT SCAT level-2A data are analyzed and the wind retrieval performance strongly depends on the location across the swath.
- NOCant is developed to adapt to the rotation angle of the fan-beam of the SCAT. NOCant and NOCinc corrections are compared, where NOCant corrections makes the $\sigma°$s generally fit better to the GMF than NOCinc, except for the outer WVCs.
- NOCant also largely improves the ECMWF wind direction bias, as compared to NOCinc, especially at nadir WVCs.
- For the future study, it might be possible to combine NOCant and NOCinc in a way to eliminate the over correction of the NOCant at the outer WVCs and possibly keep the advantages of NOCant at the other WVCs.