Higher-Order Calibration on WindRAD scatterometer winds

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Abstract

WindRAD (Wind Radar) is a dual-frequency rotating fan-beam scatterometer instrument on the FY-3E (Fengyun-3E) satellite. Scatterometers are generally calibrated using the linear NOC (NWP Ocean Calibration) method, to control the main gain factor of the radar. While WindRad is stable, the complex geometry, the design of the instrument, and the rotating antenna make the backscatter (σ◦) distributions persistently non-linear, hence NOC is insufficient. Therefore, a higher-order calibration method is proposed, called HOC. The CDF (Cumulative Distribution Function) matching technique is employed to match the CDF of measured σ◦s to simulated σ ◦ s. HOC removes the non-linearities for each incidence angle. However, it is not constructed to remove the anomalous harmonic azimuth dependencies caused by the antenna rotation. These azimuth dependencies are reduced by NOCant (NOC as a function of incidence angle and relative antenna azimuth angle). Therefore, the combination of HOC&NOCant is implemented to correct both anomalous σ◦ amplitude and azimuth variations. The wind 10 retrieval performance is evaluated with NOCant, HOC, and HOC&NOCant combined. The wind statistics and the cone distance metric both show that HOC&NOCant achieves the optimal winds for C-band and Ku-band. The calibrations have been tested on two operational input data versions; HOC works well on both data versions and HOC&NOCant can achieve the optimal wind performance for both data versions. This confirms the usefulness of HOC calibration in the case of non-linear instrument gain anomalies.

Method

HOC uses the CDF (Cumulative Distribution Function) matching technique to calculate σ ◦ dependent calibrations. As illustrated in Fig. 1, The black curve is the reference CDF, whereas the grey curve is the CDF of the data to be calibrated with respect to the reference. To each uncalibrated data point x a calibrated x̃ can be found, and the original CDF value at x equals to the reference CDF value at x̃. x here represents the measured σ◦, whereas x̃ represents the calibrated σ◦.

HOC calculates σ◦ dependent calibration in intervals of 0.1 dB or about 2 percent. The σ◦ distribution has a dependency on incidence angles, thus HOC is derived and implemented on σ◦s as a function of incidence angle for C-band and Ku-band (HH and VV polarization), respectively.

HOC calibrated σ◦ result

Fig. 2 shows the C-band HH contoured histogram of measured σ◦ versus simulated σ◦ for the incidence angle at 38°, C-band VV has a very similar pattern as C-band HH, hence it is not shown. The simulated σ◦s are calculated with collocated ECMWF winds through CMOD_HH for HH polarization. The σ◦ distribution shows non-linearity, especially at the low σ◦ values, where asymmetries from the diagonals occur. NOC calibration has been implemented (Li et al. 2023a) and shows that **NOCant**, which is NOC as a function of incidence angle and azimuth angle, takes the azimuth variations into account, yielding a better calibration result as compared to **NOCinc**, which is NOC only as a function of incidence angle. However, the non-linearities in the σ◦ distribution persist with NOC calibration, therefore, HOC is applied and the result (Fig. 2 right) shows the non-linear effect is successfully removed empirically. The same HOC calibration is also applied on Ku-band (not shown here).

HOC and NOC assessment

The most widely used wind inversion algorithm is the so-called MLE (Maximum Likelihood Estimation) method, and it is applied here for the wind retrieval. We take C-band as example here to compare the wind retrieval result with HOC, NOCinc and NOCant, Ku-band result is analyzed in (Li et al. 2023b).

HOC .vs. NOCinc

Fig. 3 left shows the NOCinc calculated with the original σ◦s, whereas Fig. 3 right shows the NOCinc calculated with the HOC calibrated σ◦s. After HOC, NOCinc becomes flat, which means HOC can not only correct the non-linear gain, but also the incidence angle dependencies, hence HOC can replace NOCinc.

HOC .vs. NOCant

Similar as Fig. 3, Fig. 4 shows the NOCant without and with HOC calibrated σ◦s and the azimuth dependent wave pattern still exists after HOC calibration, which indicates that HOC cannot correct azimuth angle dependencies, therefore, the combination of HOC&NOCant is implemented.

The MLE (cone distance) is a metric to measure the quality of the retrieval. It reveals how well the measurements fit the GMF (Geophysical Model Function), the lower the better. The combination of HOC&NOCant gives the best fit to the GMF.

Conclusion

HOC is able to correct the non-linearity in the σ◦ distribution and the incidence angle dependency, while NOCant can remove the azimuth angle dependency. The combination of these two calibration methods yields the optimal wind retrieval. The detailed analysis is in Li et al. 2023b.

*Li, Z., Verhoef, A., Stoffelen, A., Shang, J., and Dou, F.: First Results from the WindRAD Scatterometer on Board FY-3E: Data Analysis, Calibration and Wind Retrieval Evaluation, Remote Sens, 15, 2087, https://doi.org/10.3390/15082087, 2023a.

*Li, Z.; Stoffelen, A.; Verhoef, A.; Wang, Z.; Shang, J.; Yin, H.. Higher-Order Calibration on WindRAD scatterometer winds. AMT, 2023b, accepted.

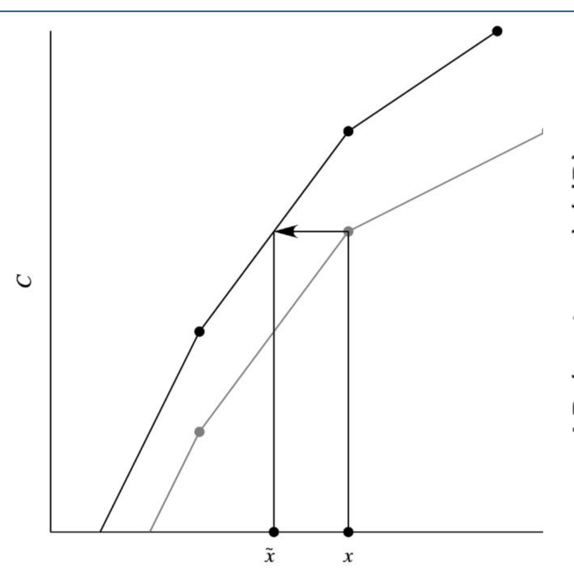

Figure 1. CDF matching technique illustration

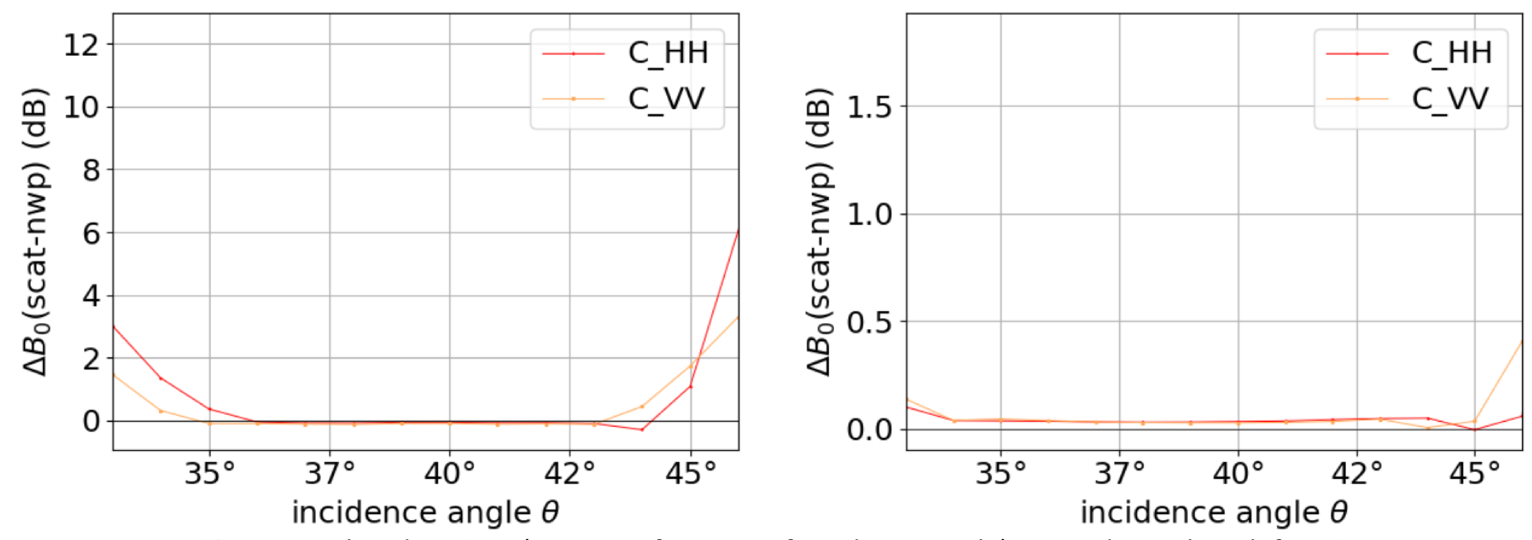

Figure 3. C-band NOCinc (NOC as a function of incidence angle), ascending orbits: left, NOCinc without HOC; right, NOCinc after HOC.

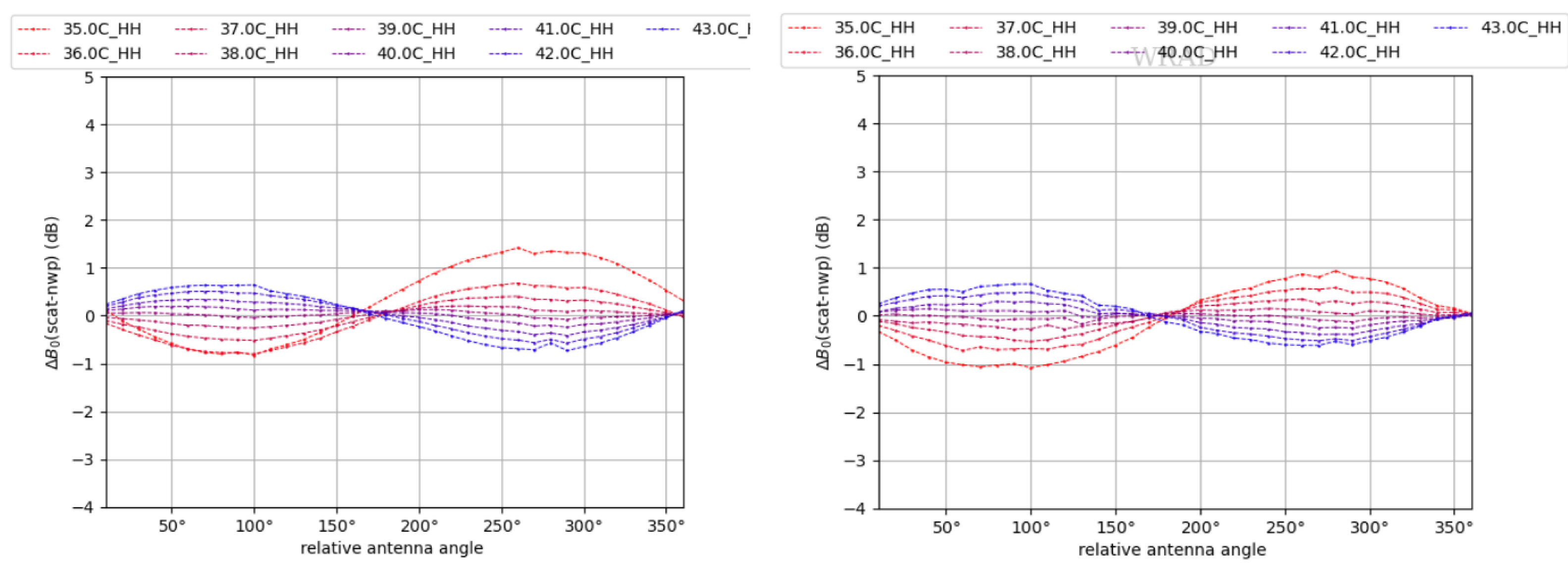

Figure 4. C-band NOCant (NOC as a function of incidence angle and relative azimuth angle), ascending orbits: left, NOCant without HOC; right, NOCant after HOC.

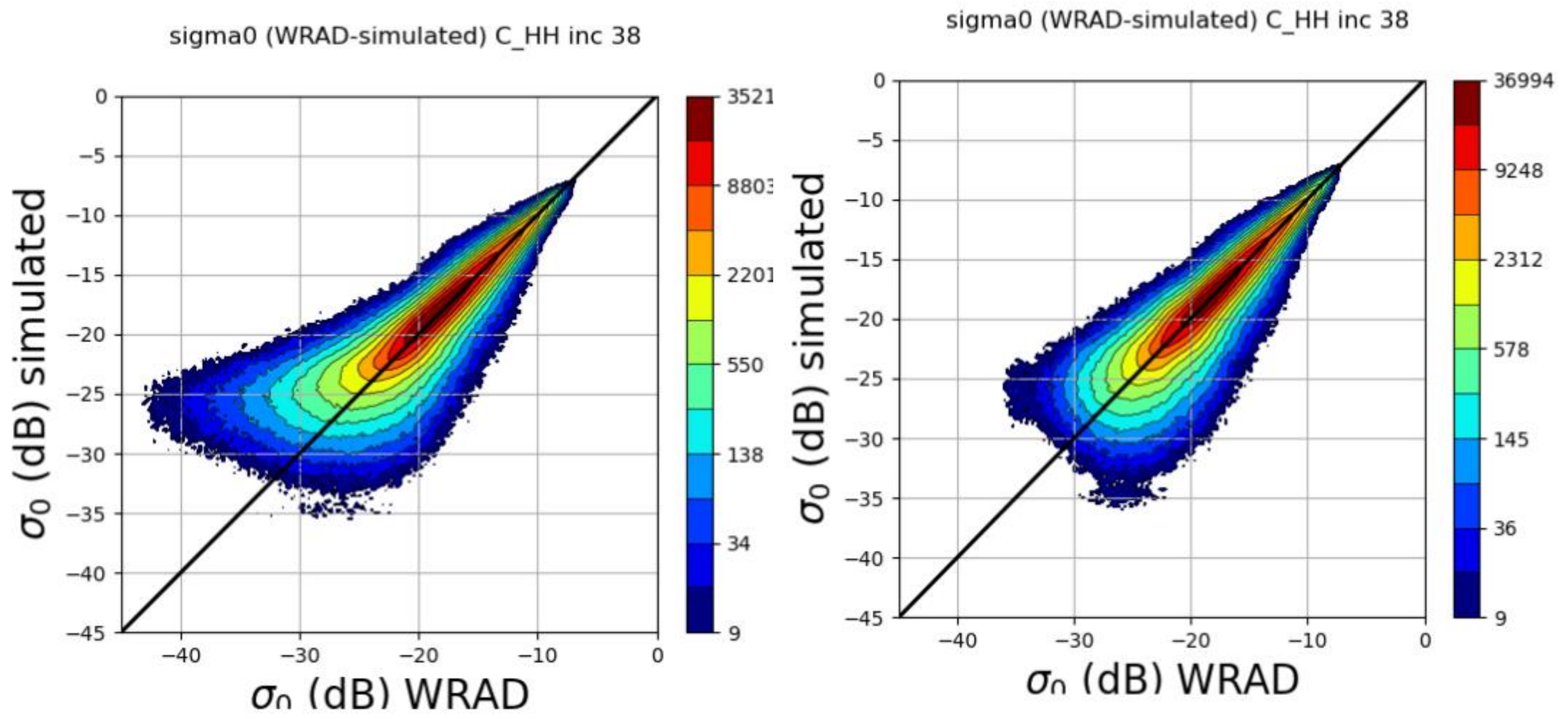

Figure 2. C-band HH polarization measured σ ◦ and simulated σ ◦ joined distribution per incidence angle ascending orbits: left is original incidence of 38◦ , right is HOC calibrated incidence of 38◦

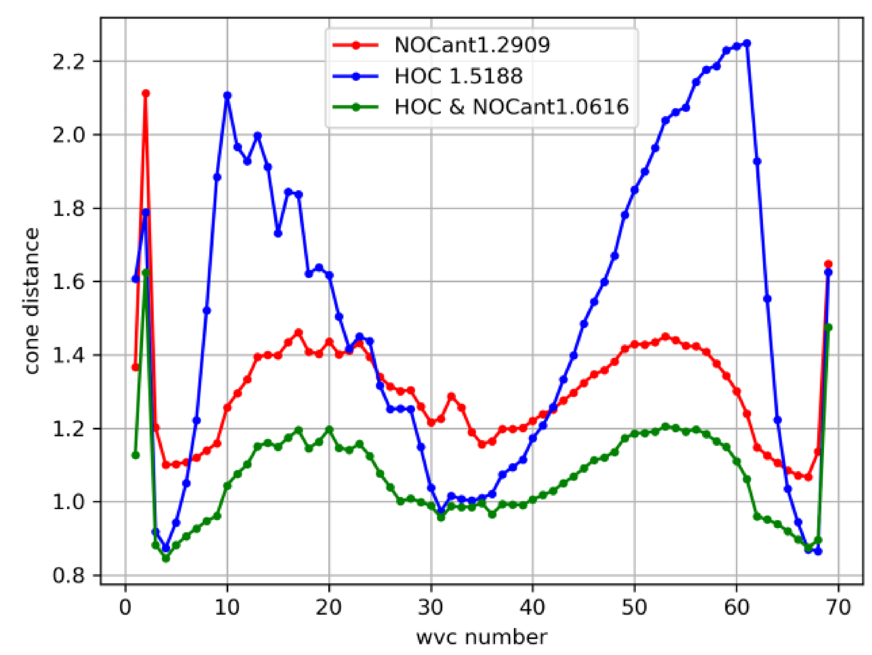

Figure 5. Average MLE (cone distance) as a function of WVC for C-band ascending orbits, NOCant is red, HOC is blue, HOC&NOCant is green.