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 (σ₀) 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 σ₀ to simulated σ₀. 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 σ₀ amplitude and azimuth variations. The wind 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 σ₀ 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. Here represents the measured σ₀, whereas x̃ represents the calibrated σ₀.

HOC calibrated σ₀ result

Fig. 2 shows the C-band HH contoured histogram of measured σ₀ versus simulated σ₀ 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 σ₀ are calculated with collocated ECMWF winds through CMOD_HH for HH polarization. The σ₀ distribution shows non-linearity, especially at the low σ₀ 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 σ₀ 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 σ₀, whereas Fig. 3 right shows the NOCinc calculated with the HOC calibrated σ₀. 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 σ₀ 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 σ₀ distribution and the incidence angle dependency, whereas 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.


References


Figures

Figure 1. CDF matching technique illustration as a function of WVC incidence angle.

Figure 2. C-band HH polarization measured σ₀ and simulated σ₀ joined distribution per incidence angle ascending orbits: left is original incidence of 38°, right is HOC calibrated incidence of 38°.

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