

# ASCAT B OCEAN CALIBRATION AND WIND PRODUCT RESULTS

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## Abstract

The EUMETSAT Metop-B satellite with onboard the Advanced Scatterometer (ASCAT) has been successfully launched on September 17, 2012. ASCAT-B onboard Metop-B is identical to the already operational scatterometer ASCAT-A onboard Metop-A which was launched in 2006. KNMI has further developed an ocean calibration method for ASCAT-A, based on Numerical Weather Prediction (NWP) wind inputs, the so-called NWP Ocean Calibration (NOC). When the corrections based on NOC are applied to MetOp-B backscatter data, also the MetOp-B wind retrieval quality improves to a level very similar to the ASCAT-A wind quality.

## INTRODUCTION

The ASCAT instrument is a real-aperture C-band vertically polarized radar, with three fan beam antennas pointing to the left-hand side of the sub-satellite track and three fan-beam antennas pointing to the right-hand side (Figa-Saldaña et al, 2002). The Numerical Weather Prediction Ocean Calibration (NOC) method is developed within the framework of the EUMETSAT Ocean & Sea Ice (OSI) Satellite Application Facility (SAF). The method for NOC resides in the direct comparison of measured  $\sigma_0$  data with simulated values from Numerical Weather Prediction (NWP) model winds using a forward model or Geophysical Model Function (GMF) (see Stoffelen, 1999; Verspeek et al, 2012). For ASCAT, the CMOD5.n GMF is used (Hersbach, 2009), which is compliant with the GMF of its predecessor, the European Remote-sensing Satellite (ERS) scatterometer. The NOC method has the advantage over other calibration methods (e.g., transponders, rain forest, ice) that it can be applied over a large global area (all the oceans) and thus provides a substantial amount of data and therefore relatively accurate results over a rather short period of time. It is therefore also very suitable for monitoring purposes. NOC corrections are derived from and subsequently applied to ASCAT-B data as a first step within the ASCAT Wind Data Processor (AWDP). AWDP (e.g., Verhoef, Vogelzang, Verspeek and Stoffelen, 2013) is developed within the EUMETSAT NWP SAF. For every valid measurement triplet, AWDP delivers an ASCAT wind vector, quality information (e.g. Portabella M. et al, 2012) and a wind retrieval residual, called Maximum Likelihood Estimator or MLE (Portabella et al., 2012). In this manuscript we present wind, MLE and QC statistics to evaluate the application of NOC corrections for ASCAT-B. A triple collocation with ASCAT-B winds, NWP winds and buoy measurements is presented. Also, analyses using collocated ASCAT-A and ASCAT-B measurements are shown.

## NWP OCEAN CALIBRATION

The NOC method is based on the analysis of a large measurement data set to estimate Fourier coefficients that can be directly compared to those in the CMOD5.n GMF, which may be written as:

$$\sigma_0(v, \theta, \phi) = B_0(v, \theta) [1 + B_1(v, \theta) \cos \phi + B_2(v, \theta) \cos(2\phi)]^{1.6} \quad (\text{Equation 1})$$

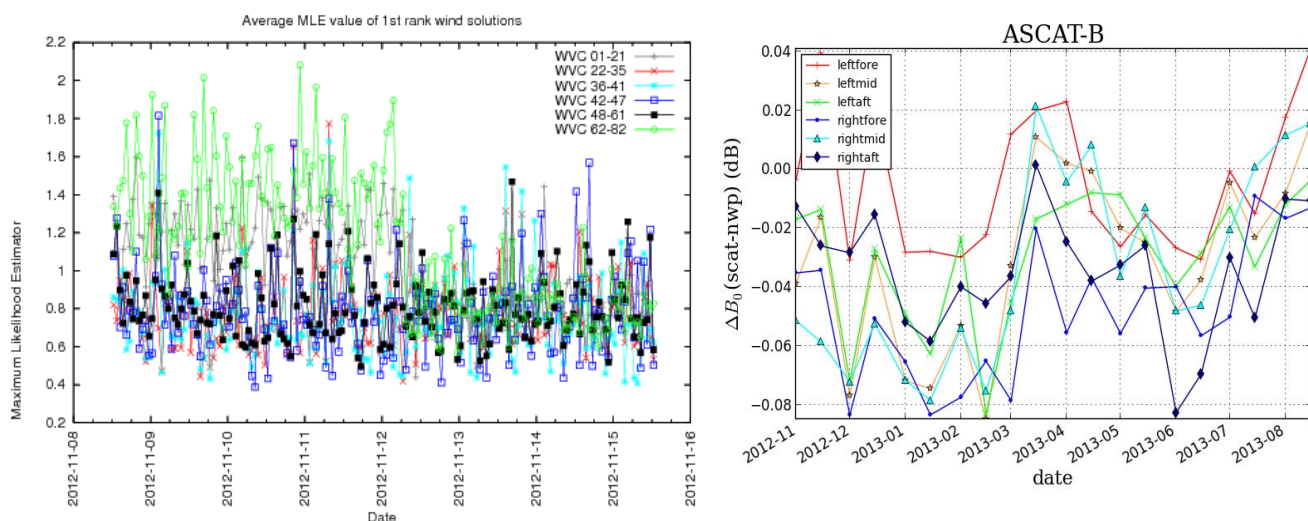
where  $v$  is the wind speed,  $\phi$  the wind azimuth direction relative to the radar beam look angle, and  $\theta$  the radar incidence angle. The  $B$  coefficients are closely related to Fourier coefficients in  $z$  space, where  $z = \sigma_0^{0.625}$ , such that Eq. 1 can be re-written as:

$$z(v, \theta, \phi) = a_0(v, \theta) + a_1(v, \theta) \cos \phi + a_2(v, \theta) \cos(2\phi) \quad (\text{Equation 2})$$

When the true wind direction distribution is uniformly sampled for all wind speeds, then the mean  $\langle a_0 \rangle$  should be identical to the mean  $\langle z \rangle$ . This means that uncertainties in wind direction and in  $a_1$  and  $a_2$  do not contribute to the error in the estimated mean  $\langle z \rangle$ .

In this paper, the ASCAT high resolution mode (coastal product), which has a 12.5 km wind vector cell (WVC) spacing compared to the 25 km WVC spacing for the nominal resolution, is used. To approximate a uniform true wind direction distribution, the collocated European Centre for Medium-range Weather Forecasts (ECMWF) wind data is split into wind speed bins of size  $1.0 \text{ ms}^{-1}$  and azimuth angle bins of size  $12^\circ$ . The OSI SAF operational wind product uses ECMWF winds (3-hourly 3-18 hour forecast winds) at spectral truncation T319 corresponding to a grid with 160 points between pole and equator, interpolated to the ASCAT wind locations and time. These collocated ECMWF forecast winds are used for the NOC as well. Data from the global oceans between latitudes  $-55^\circ$  and  $+65^\circ$  are used. These latitudes are chosen such that regions which possibly contain sea ice are conservatively excluded. The collocated ECMWF equivalent-neutral 10-meter winds are converted to simulated  $z$  values using the CMOD5.n GMF (Eq. 2). The differences between measured and simulated  $\langle z \rangle$  are averaged over all wind azimuth bins weighted in accordance with a uniform wind azimuth (direction) distribution. Next they are averaged over all wind speed bins weighted in accordance with the wind speed distribution. Thus, the NOC method only needs a few days of collocated ASCAT data and ECMWF winds to produce a reasonable estimate of difference in backscatter residuals, i.e., the difference between the two values of  $\langle z \rangle$  as a function of incidence angle for each antenna. Time-averaged residuals are used as correction factors for errors in the instrument, for monitoring the instrument health and for GMF development. For a detailed description of the derivation of the NOC corrections see (Verspeek, Verhoef and Stoffelen, 2013).

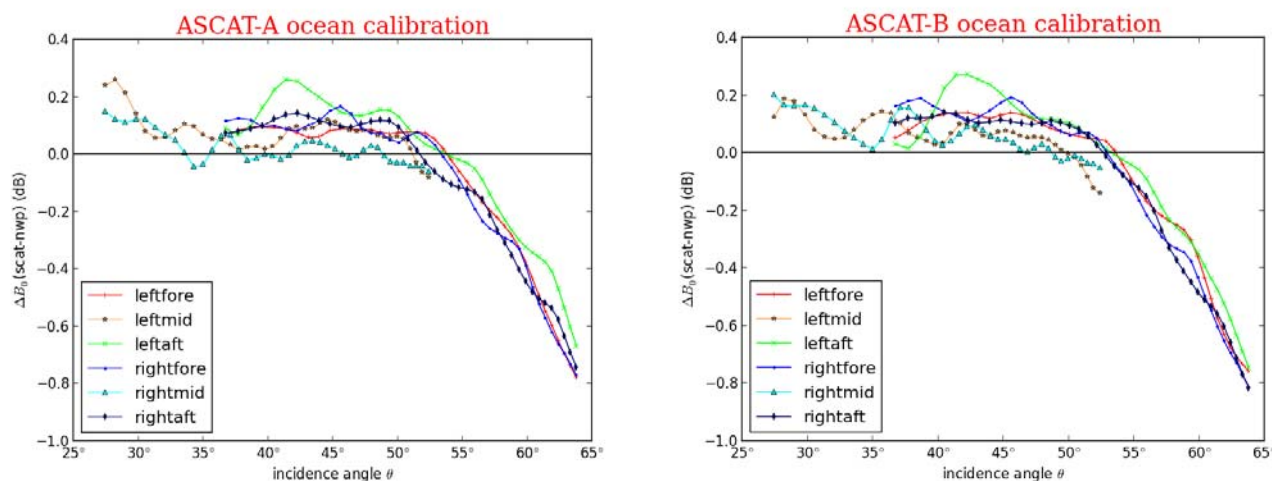
A time series of the ocean calibration is performed over the period of almost one year, from the start of data dissemination in October 2012 to the present (September 2013) for the ASCAT-B scatterometer. The first month is used to correct ASCAT-B for the months thereafter. Fig. 1 shows the MLE residual reduction due to the NOC correction and the NOC residuals after the preliminary correction. Successive periods of day 1-14 and day 15-last day of the month are taken as input for an ocean calibration run. The ASCAT backscatter data (level 1B product) are provided by EUMETSAT. Since the beginning of ASCAT-A operations, the calibration of level 1B data has been adjusted as additional transponder data were collected and calibration algorithms were refined. In order to have a consistent time series, corrections that account for differences in level 1B versions are computed from parallel processed data sets and applied to the backscatter data. These corrections have been able to transform the ASCAT-A backscatter measurements from each level 1B calibration cycle to the next cycle within a few hundredths of a dB (Verspeek et al, 2013). Thus the results are made independent of the level 1B backscatter processing software version that is used. In the right panel of Fig. 1, a seasonal variation is present for all antenna looks, which has been observed for ASCAT-A as well.



**Figure 1:** ASCAT-B monitoring after application on 12 November 2012 of a preliminary NOC correction computed over October 2012. Left: Average MLE for different WVC groups. Right: Average NOC residuals for each antenna per month .

Fig. 2 shows, as a typical example, the ocean calibration residuals from each antenna as a function of incidence angle. The pattern within one line as a function of incidence angle shows distinct peaks and troughs. These incidence-angle-dependent patterns appear to be very persistent over time. They cannot be explained from the NWP comparison procedure since the GMF terms are rather smooth as a function of incidence angle and the global wind

input PDFs are rather similar for each WVC. The small wiggles are presumably ASCAT instrument calibration artifacts and are further investigated.



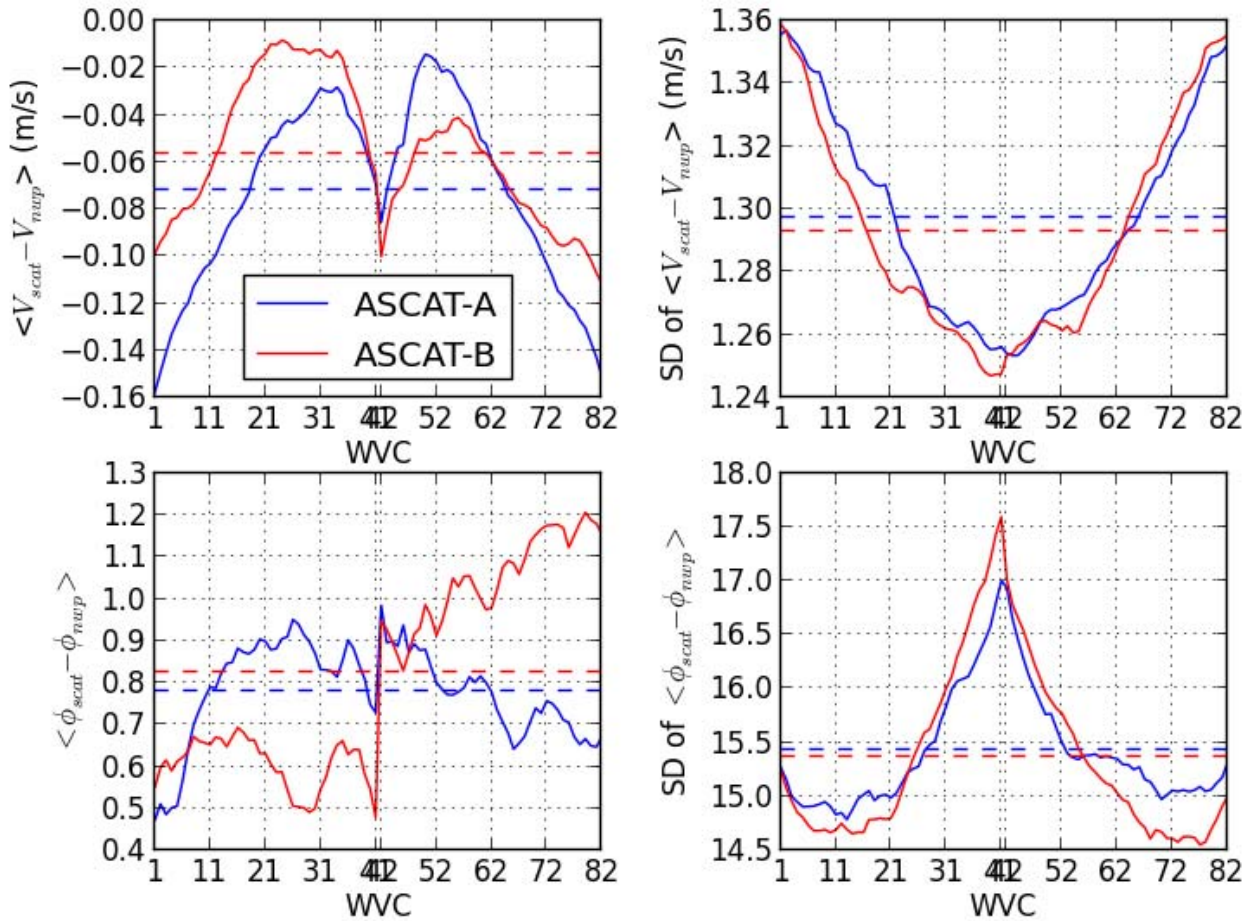
**Figure 2:** NWP ocean calibration residual in dB as a function of incidence angle and antenna for the 12.5-km product for ASCAT-A (left) and ASCAT-B (right) for October 2012.

From a physical point of view, the backscatter is a smooth and slowly varying function of incidence angle and no wiggles with a period of  $\sim 5^\circ$ , as appear in Fig. 2, are to be expected. Similar wiggles also appear in the averaged measured backscatter data (before subtraction of the simulated backscatter from the collocated ECMWF winds) over the rain forest (Anderson et al., 2012). The small wiggles could be caused by level 1B calibration inaccuracies, but could also be introduced in the calculation of the level 1B  $\sigma_0$  value out of the level 0 radar data product, e.g. by inaccuracies in the antenna pointing or footprint area calculation.

## STATISTICS OF THE WIND PRODUCT AND RELATED QUANTITIES

The wind speed statistics of the scatterometer wind (based on applied NOC corrections) and the NWP wind (corrected to equivalent-neutral wind) as a function of WVC have been calculated. The wind direction skill is generally very low for low wind speeds. Therefore, only NWP wind speeds above 4 m/s are considered for wind direction statistics.

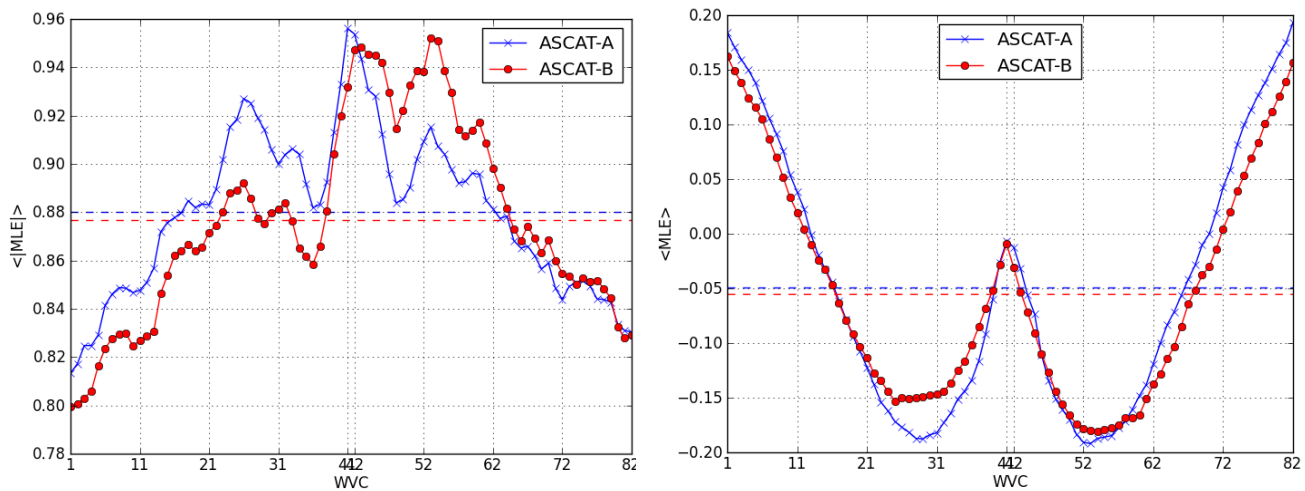
In Fig. 3 the averaged wind speed and wind direction difference between ASCAT-B (blue lines) and ECMWF are shown on the left. Also their respective standard deviations (SD) are shown on the right. The patterns are symmetric for the left and right swath and very similar to those of ASCAT-A (red lines).



**Figure 3:** Averaged differences of (ASCAT-ECMWF) wind speed and wind direction and their standard deviation as a function of WVC from 2012-11-15 to 2012-11-30 for both ASCAT-A and ASCAT-B. NOC corrections are applied. The dashed lines show the value averaged over all WVCs.

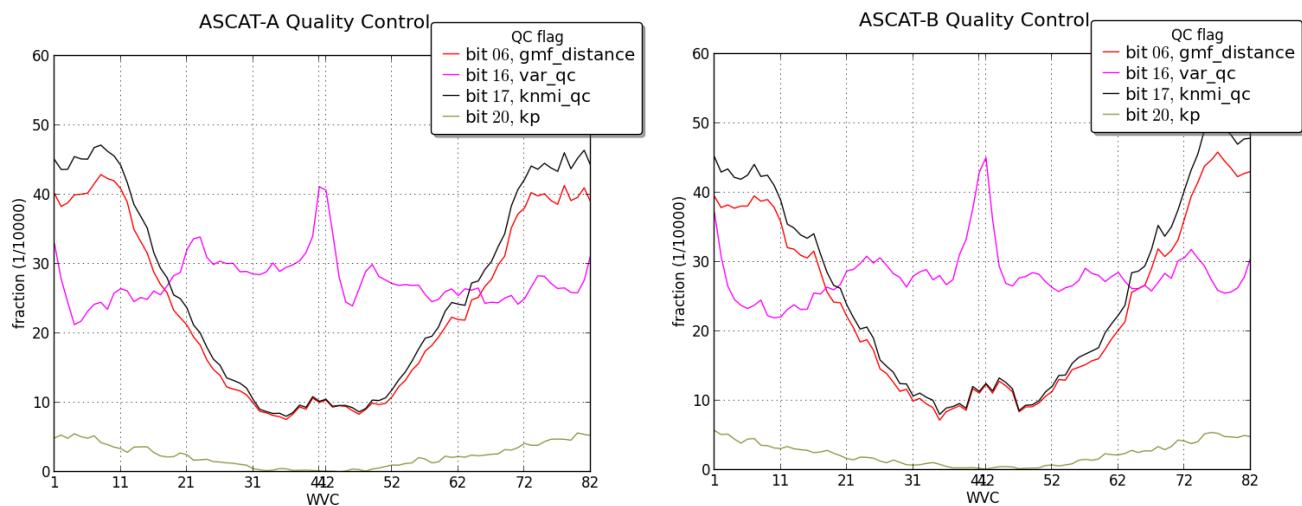
The Maximum Likelihood Estimator (MLE) is the normalised distance in measurement space from a measurement point to the point on the GMF that corresponds to the retrieved wind. It is a measure of how well the measurement and GMF fit to each other. The MLE is normalised using a table in order to get an expectation value of  $\langle |MLE| \rangle = 1$  for each WVC (here  $\langle |MLE| \rangle$  denotes the average of the absolute value of the MLE).

Fig. 4 shows the average  $\langle |MLE| \rangle$  and  $\langle MLE \rangle$  value of the selected wind solution per WVC for NOC corrected data. The figures for ASCAT-A and ASCAT-B are similar. Only a small dependency of the MLE expectation value on WVC number remains.



**Figure 4:** Average value of  $|MLE|$  (left) and  $MLE$  (right) per WVC for ASCAT-A and ASCAT-B. Coastal data from 2012-11-15 to 2012-11-30 is used and the respective NOC corrections are applied. The values averaged over all WVCs are shown as dashed lines.

The occurrence ratio of some important level 2 quality flags and their WVC dependency is shown in Fig. 5 for ASCAT-A and ASCAT-B. The MLE or GMF distance flag (Verhoef and Stoffelen, 2013) is set when the measured triplet has an anomalously large distance to the GMF cone, while the `var_qc` flag is set during 2DVAR ambiguity removal when a wind vector is spatially inconsistent with its neighbours. All rejection fractions are low and comparable for ASCAT-A and ASCAT-B.



**Figure 5:** Some level 2 quality flag occurrence ratios as a function of WVC for ASCAT-A (left) and ASCAT-B (right).

A triple collocation study was performed to assess the errors of the ASCAT, ECMWF and buoy winds independently. Given a set of triple collocated measurements and assuming linear calibration, it is possible to simultaneously calculate the random errors in the measurements and the relative calibration coefficients. The triple collocation method was introduced by Stoffelen, (1998) and extensively discussed in Vogelzang et al. (2011).

Collocated data sets of ASCAT-A 25-km, ASCAT-B 25-km, ASCAT-A coastal and ASCAT-B coastal with ECMWF and buoy winds spanning three months were used in the triple collocation. The precision of the scatterometer error standard deviations is approximately 0.03 m/s, assuming that the errors are independent and Gaussian and that the representation error is known. For buoys, the precision estimate is 0.05 m/s and for ECMWF, this is 0.04 m/s.

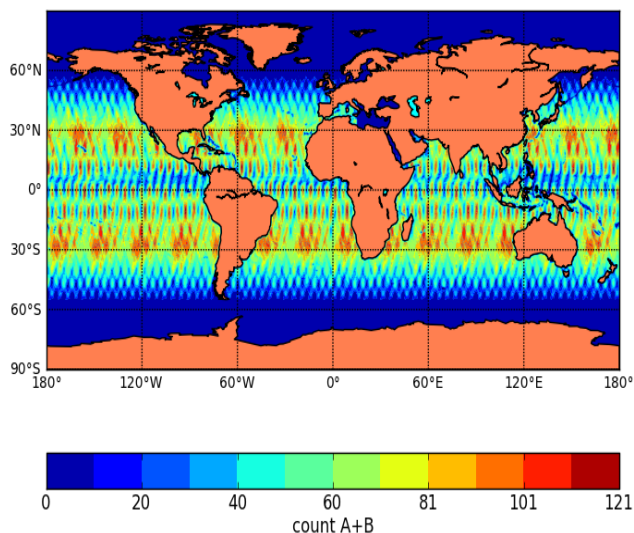
Table 1 lists the error variances of the buoy, ASCAT and ECMWF winds. Table 1 shows that the ASCAT-A and ASCAT-B 25 km products yield the same errors in scatterometer, buoys, and ECMWF background within the precision given above. The same applies to the ASCAT-A and ASCAT-B coastal products. As such, it is concluded

from the triple collocation study that there are no significant differences between the ASCAT-A and ASCAT-B wind retrieval performance.

	Scatterometer		Buoys		ECMWF	
m/s	$\sigma_u$	$\sigma_v$	$\sigma_u$	$\sigma_v$	$\sigma_u$	$\sigma_v$
<b>ASCAT-A 25-km</b>	0.63	0.71	1.21	1.35	1.39	1.44
<b>ASCAT-B 25-km</b>	0.63	0.66	1.26	1.39	1.38	1.42
<b>ASCAT-A coastal</b>	0.76	0.84	1.18	1.34	1.54	1.57
<b>ASCAT-B coastal</b>	0.81	0.79	1.24	1.35	1.53	1.57

**Table 1:** Standard deviations of the meridional and zonal wind components from a triple collocation over the period November 2012 to January 2013 for the ASCAT-A and ASCAT-B 25-km and coastal products.

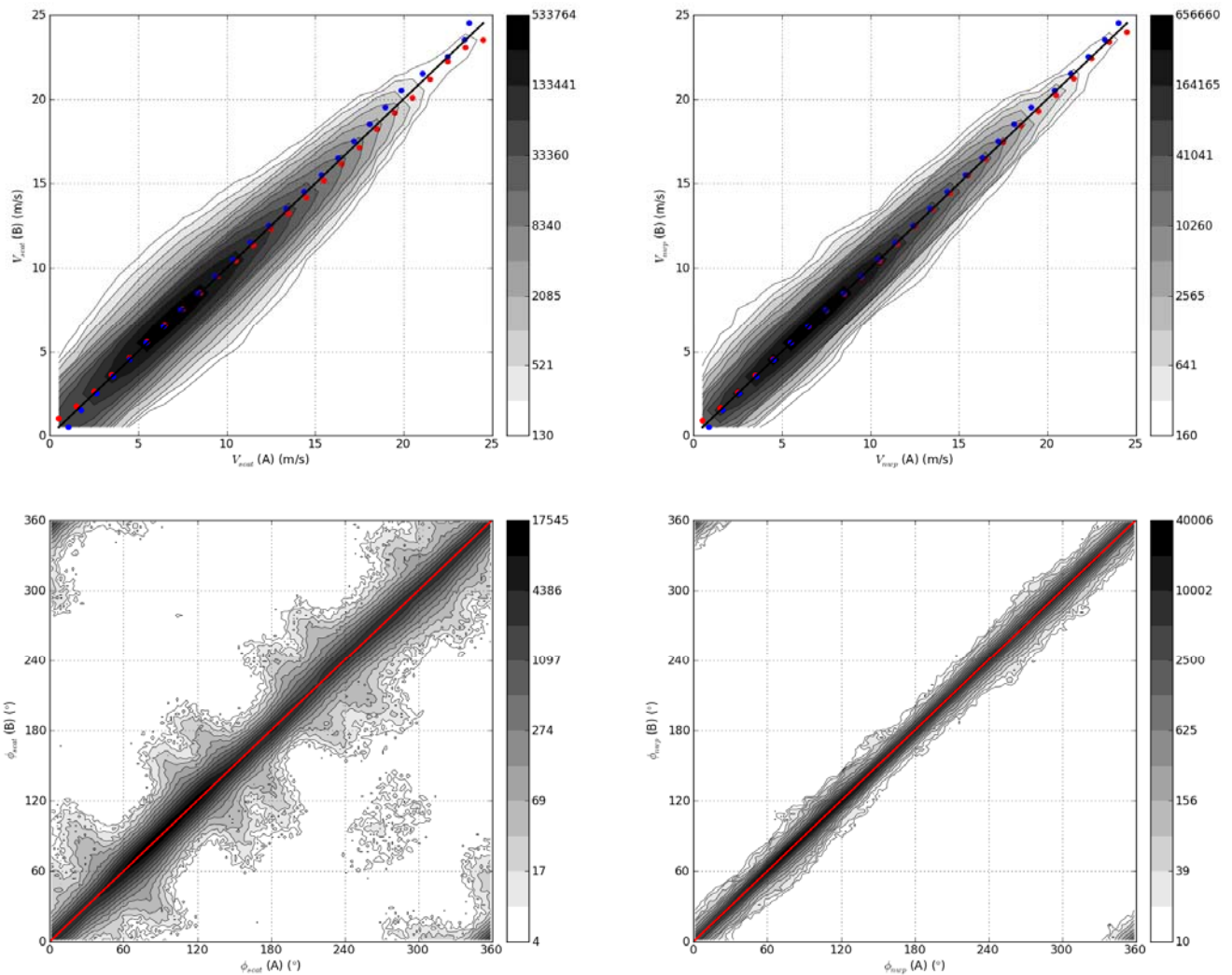
Fig. 6 shows the collocations for ASCAT-A and ASCAT-B for the period that goes from 2012-11-01 to 2012-11-14. The maximum distance between collocated WVCs is 10 km. As a time filter a 6 minute window around the delay time of 48.93 minute is taken (ASCAT-A ahead of ASCAT-B).



**Figure 6:-** Collocations for ASCAT-A and ASCAT-B. Maximum distance between WVCs is 10 km. B-A time difference is +48.93 minutes centered in a 6 minute time window. ASCAT data is used from 2012-11-01 to 2012-11-14.

Fig. 7 shows the wind speed and wind direction histograms of ASCAT-A versus ASCAT-B collocations from fig. 6. The scatterometer wind histograms are on the left and their collocated NWP wind histograms are on the right. All graphs are highly symmetric and show a high correlation. Asymmetry could indicate deficiencies in one of the instruments. The NWP plots have a higher correlation than the scatterometer plots. This is not caused by the fact that the NWP model would have a smaller error in the wind vector than the scatterometer. As shown in table 1 it follows from triple collocation studies that the scatterometer error is smaller than the NWP model error. The apparently smaller error is caused by the fact that the collocated NWP wind vectors from ASCAT-A and ASCAT-B are highly dependent. If we had exact collocations in time and space, the NWP winds would be identical with correlation coefficient  $R=1$  (both satellites would have the same collocated NWP wind). The correlation coefficient for scatterometer winds would be less than unity ( $R<1$ ) because the measurement of the same wind by both satellites is completely independent. Moreover, NWP models see less fine-scale structures in the wind patterns than scatterometers which gives a higher correlation between the NWP wind fields.

The scatterometer wind direction contour plot (bottom left panel) shows some side lobes which are caused by imperfections in the wind retrieval and ambiguity removal.



**Figure 7:** Wind speed and wind direction PDF for the collocated ASCAT-A and ASCAT-B data. Left hand side: scatterometer winds; right hand side: ECMWF forecast winds. Data is taken from the collocations as shown in Fig. 6.

## CONCLUSIONS

The NOC procedure is standard in scatterometer calibration for wind processing. The NOC method can correct errors from various sources (instrument, calibration, GMF) and thus leads to high-quality winds. The two-weekly NOC residuals for data processed with CMOD5n are varying within a small range of  $\sim 0.1$  dB from period to period over the full observed time frame of one year. This shows the consistency in the approach for applying NOC corrections.

The small beam-dependent part in the NOC corrections can be ascribed to instrument or level1B calibration deficiencies. NOC compensates for any remaining beam-dependent error. Most notably it removes the WVC-dependency of wind bias and MLE statistics.

Triple collocation of ASCAT-B, NWP and buoy winds gives an absolute reference of the ASCAT-B wind error. It turns out to be very close to the ASCAT-A wind error. In general, ASCAT-B gives very similar results to ASCAT-A for wind statistics, MLE and quality control rejection rate. Thus, the quality of ASCAT-B (winds) is comparable to the high quality of ASCAT-A right from the start.

Finally, the monitoring of the NOC residuals over a long period proves to be an effective method to detect instrument anomalies or gradual degradation. The actual time series of the ASCAT-B residuals has now only a length of one year. It shows that the instrument is very stable. The NOC only shows a seasonal variation very similar to that of ASCAT-A.

ASCAT-A and ASCAT-B collocations show small differences between the two scatterometers, which are due to wind downbursts near convection and of great physical interest, since they are not resolved by global NWP models. Some small imperfections in the wind direction histogram are observed which are caused by errors in the inversion and ambiguity removal.

## ACKNOWLEDGMENT

The authors wish to thank their colleagues from EUMETSAT and KNMI for their interest in this work, stimulating discussions, provision of data and helpful advice. This work is done in the framework of the EUMETSAT OSI SAF and its associated visiting scientist scheme (Reference OSI-AVS-12-04). The ASCAT winds produced at KNMI can be obtained free of charge from the OSI SAF web site. AWDP has been funded by EUMETSAT in the context of the NWP SAF and can be obtained free of charge from the NWP SAF web site. For more information, please contact the KNMI scatterometer helpdesk: [scat@knmi.nl](mailto:scat@knmi.nl).

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