

# ASCAT SCATTEROMETER CAL/VAL AND WINDS

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## Abstract

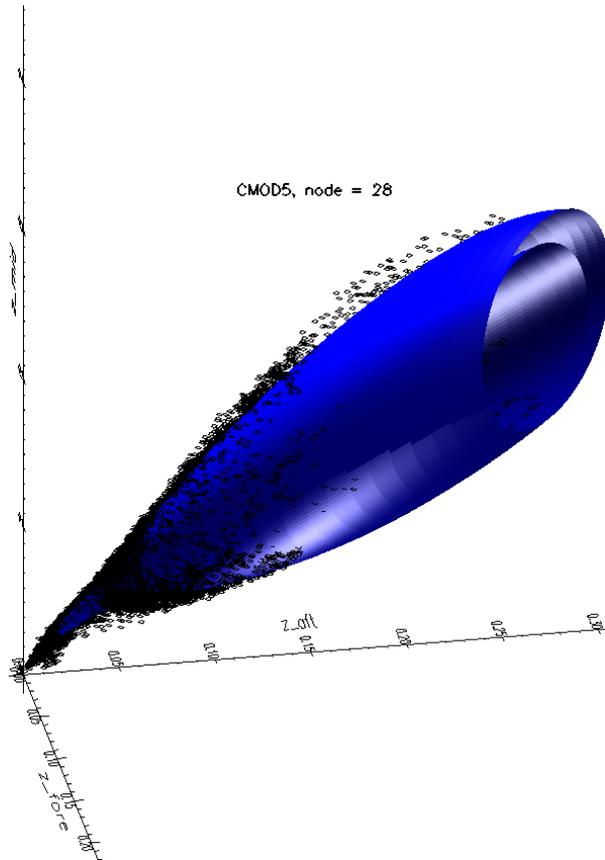
The first MetOp-A L2 product was released on 28 March 2007 by the Ocean & Sea Ice Satellite Application Facility (OSI SAF) at the Royal Netherlands Meteorological Institute (KNMI). Here we present the calibration procedure that lead to these 25-km ASCAT winds. The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) is responsible for the absolute calibration of the new Advanced Scatterometer (ASCAT), onboard MetOp-A, which relies on the use of transponders. A complementary geophysical calibration method uses scatterometer measurements over the ocean. The method is based on the knowledge of the backscatter signal modulation by the ocean surface, which is derived from previous C-band scatterometer missions, and on the use of ancillary wind information as calibration reference. The method proves to be very useful in providing guidance to EUMETSAT calibration efforts and inherently provides continuity of the C-band scatterometers. Also, this so-called "cone" calibration results in very good quality winds visible at <http://www.knmi.nl/scatterometer>. The winds are declared pre-operational since 10 October 2007.

## I - INTRODUCTION

A new scatterometer, the so-called Advanced Scatterometer (ASCAT), onboard MetOp-A satellite was successfully launched on October 19 2006. During the commissioning phase period (for ASCAT extended until the end of 2007), one of the main goals is to accurately calibrate the instrument. Since both the ERS scatterometer and ASCAT are C-band vertically-polarized fan antennae beam systems, an ERS GMF, such as CMOD5.5 [Hersbach et al, 2007], can be used for ASCAT calibration. Moreover, this inherently constrains consistency between the ERS and ASCAT C-band mission, which is useful for climate applications.

An important tool for ASCAT inter-beam calibration is the visualization of triplets of radar backscatter. Every Wind Vector Cell (WVC) is illuminated by three antenna beams at different azimuth angles, which measurements may be visualized in a 3-dimensional measurement space [Stoffelen and Anderson 1998]. For a given WVC number, i.e., position across the swath, it is shown that the ERS measured triplets are distributed around a well-defined "conical" surface and hence that the signal largely depends on just two geophysical parameters, i.e., wind speed and direction. Such cone (see Figure 1) is the visualization of, for example, CMOD5.5 GMF in the measurement space, and can in turn be used for ASCAT calibration. That is, for coincident ERS/ASCAT incidence angle ranges, the ASCAT triplets are also expected to be distributed around the cone in the same way as for the ERS scatterometer. Inconsistencies between the cloud of triplets and the cone in any direction of the 3D space are mainly due to absolute beam biases, which should be adequately removed (calibration).

As such, the visualization tool provides guidance on how to correct for beam biases and by using a wind speed reference an absolute calibration across all incidence angles may be obtained, putting the triple measurement points in close correspondence with the conical surface. These ASCAT calibration steps, called "cone" calibration, are summarized in this paper. More detailed information can be found in [Verspeek et al 2007].



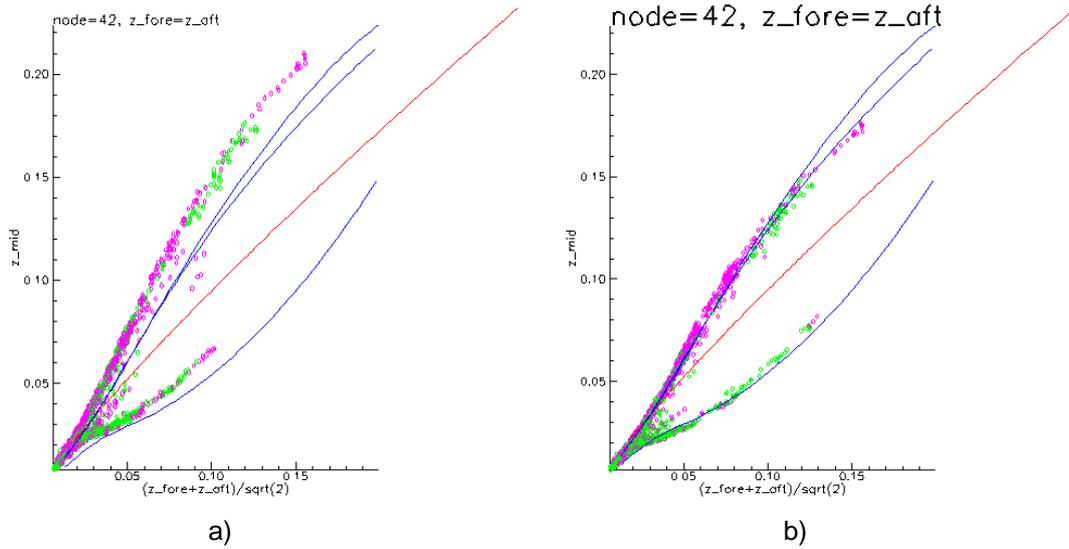
**Figure 1:** Visualization of the CMOD5.5 GMF (blue surface) and the ASCAT triplets (black dots) in 3D measurement space, for WVC number 28.

## II - VISUAL CORRECTION

As mentioned above, visualization in the 3D measurement space can be very helpful for ASCAT inter-beam calibration. In particular, systematic displacements between the ASCAT measurements (triplets) and the CMOD5.5 cone can be easily detected and corrected through this visualization. CMOD5.5 is currently used in the operational level 2 wind processing and is basically identical to CMOD5 with a 0.5 m/s shift in the input wind speed. This wind speed bias came out of a triple collocation study with ECMWF winds and buoy winds [Portabella and Stoffelen, 2007]. A first correction is therefore done in order to match the cloud of ASCAT backscatter ( $\sigma^\circ$ ) triplets (corresponding to the fore, mid, and aft beams) to the CMOD5.5 GMF in the 3-D measurement space.

Figure 1 shows an example of such visualization, where the axes are in z-space, i.e., ( $z_{fore}$ ,  $z_{aft}$ ,  $z_{mid}$ ) where  $z=(\sigma^\circ)^{0.625}$  [Stoffelen and Anderson 1998]. The double folded cone surface of CMOD5.5 is depicted in blue. The measured data are shown as a cloud of black points around the cone surface.

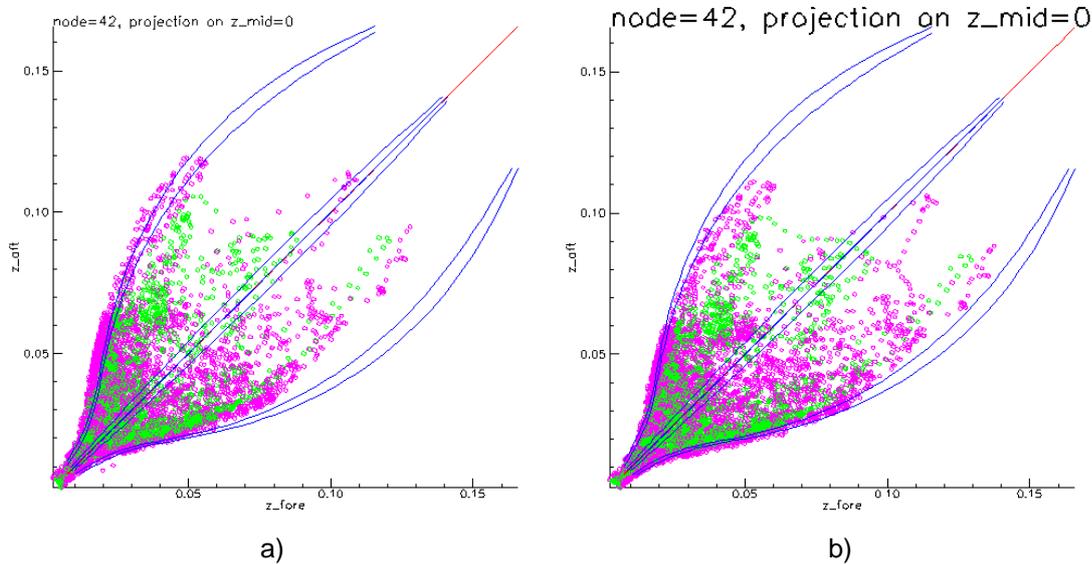
Figure 2a shows a cut of the wind cone at  $z_{fore} = z_{aft}$  and the projection of the triplets in the vicinity of such plane, for WVC 42, i.e., the outermost WVC of the right swath. The measurement triplets correspond to the EUMETSAT first release of the ASCAT level 1b data. Green and purple points belong to the inner (downwind) and outer (upwind) sheets of the cone surface, respectively (see Figure 1). A correction (scaling) factor for the mid beam (vertical axis) is determined such that the triplets fit the CMOD5.5 cone for each WVC. Figure 2b shows the distribution of triplets after correction.



**Figure 2:** Cut of the CMOD5.5 cone (blue curves) at the vertical plane  $z_{fore} = z_{aft}$  for WVC number 42, and projection of the triplets (coloured dots) in the vicinity of such plane before (a) and after (b) visual correction.

Figure 3a shows the projection of the wind cone and the triplets on the plane  $z_{mid} = 0$ . Correction factors for the fore and aft beams can be determined, such that the measurement points are distributed symmetrically with respect to the diagonal. The scaling correction factors ( $s^{cone}$ ) are coupled in the following way:

$$s_{fore}^{cone} = 1 / s_{aft}^{cone} \quad (1)$$

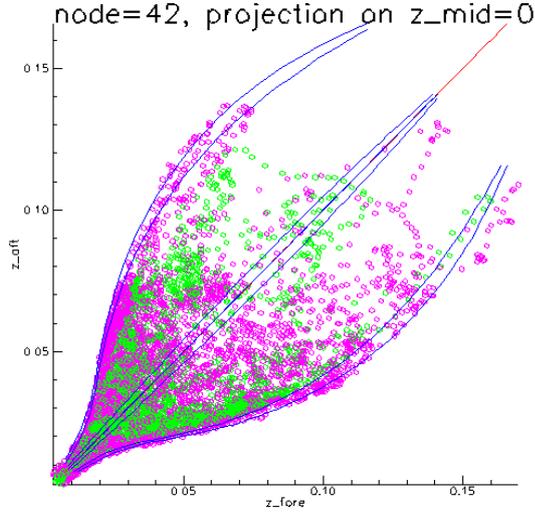


**Figure 3:** Projection of the CMOD5.5 cone (blue curves) and the triplets (coloured dots) on the plane  $z_{mid} = 0$  for WVC number 42 before (a) and after (b) visual correction.

### III - WIND SPEED BIAS CORRECTION

After balancing the fore and aft beam for cone symmetry and bringing the mid beam measurements in line with the CMOD5.5 values on the cone, most systematic deviations perpendicular to the cone disappeared. One degree of freedom remains in the normalisation of the cone and lies in the translation of the cone along its major axis, which mainly depends on wind speed. Its first order effect

is a wind speed bias after CMOD5.5 inversion. Therefore, a second correction is applied on top of the visual correction to achieve a uniform wind speed bias.



**Figure 4:** Same as Figure 3b but for visual + wind speed bias corrected triplets.

To perform the wind speed bias correction, we take the European Centre for Medium-Range Weather Forecast (ECMWF) model 10-m wind as reference to compute the scatterometer retrieved wind speed bias (at each WVC). ECMWF speeds are recently close to unbiased against in situ observations [Hersbach, personal communication]. Given the fact that CMOD5.5 depends quasi-linearly on wind speed [Hersbach 2007] and that 8 m/s is the mean global speed, the CMOD5.5 wind speed sensitivity at 8 m/s is taken to represent the full wind domain sensitivity. As such, the corrections to the backscatter measurements in z-space are formulated as follows:

$$s^{wind} = \Delta v \cdot \frac{1}{z} \cdot \frac{dz}{dv}; \quad (2)$$

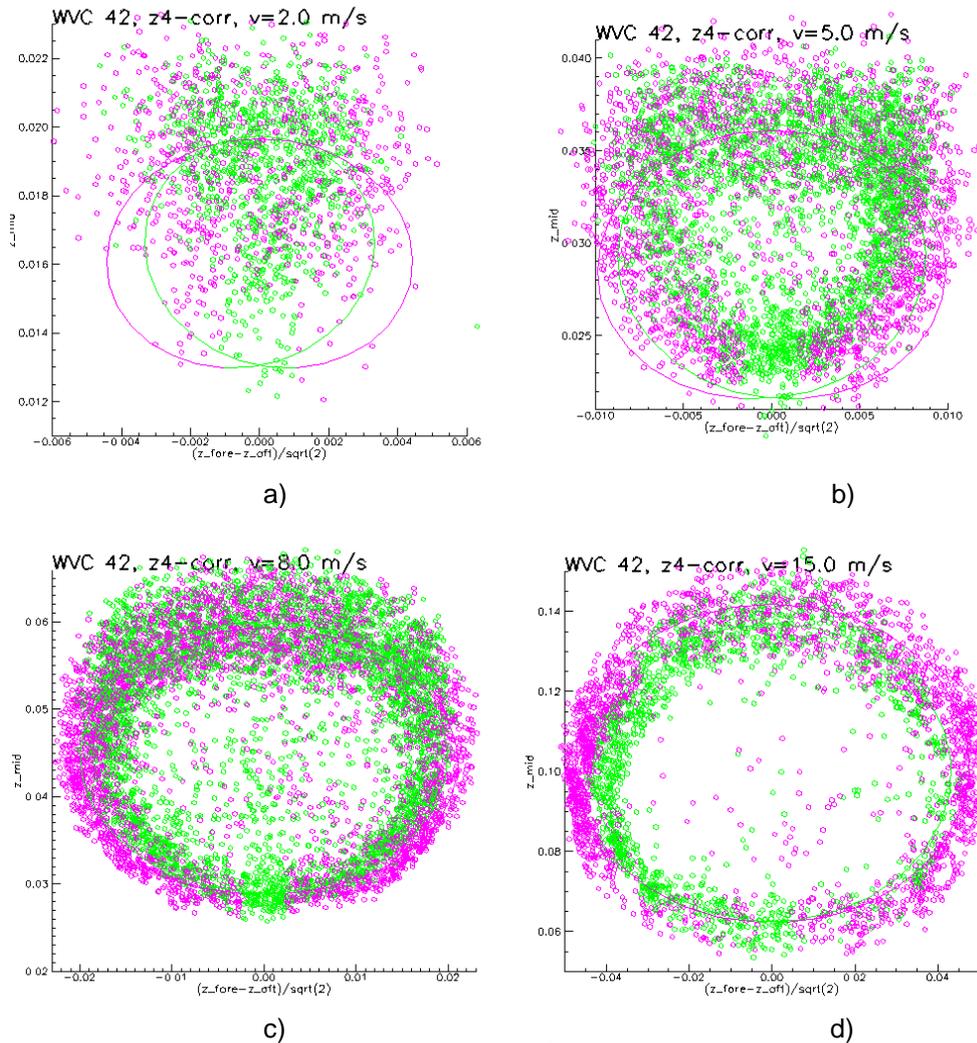
where  $s^{wind}$  is the backscatter correction factor (scaling);  $\Delta v$  is the speed bias;  $\bar{z}$  and  $\frac{dz}{dv}$  are the mean backscatter value and the mean CMOD5.5 sensitivity, respectively, at 8 m/s.

The visualisation tool can now be used to check for consistency of the wind speed bias corrected triplets with the CMOD5.5 cone. Figure 4 shows the same as Figure 3b but with the wind speed bias correction added. Note that the triplets in Figure 4 are stretched away from the origin towards higher CMOD5.5 wind speed values, as compared to Figure 3b, but remain consistent with the CMOD5.5 cone. The same conclusions are derived by looking at the vertical plane ( $z_{fore} = z_{aft}$ ) plot and other WVCs (not shown).

#### IV - CONE CORRECTION

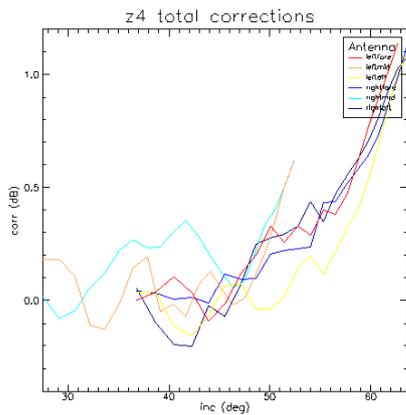
After applying the total “cone” correction, which is the product of the visual correction and the wind speed bias correction, the cloud of measurements still has to be consistent with the GMF. This is checked by examining the visualisation space.

Figure 5 shows the intersection of the cone for the outermost WVC of the right swath with the plane  $z_{fore} + z_{aft} = 2z_{ref}$ . A specific value of  $z_{ref}$  corresponds to an approximately constant wind speed value. Also here the match between measurements and GMF is in general good, although for low wind speeds there is a small displacement. For other WVCs similar plots have been examined (not shown).



**Figure 5: Visualisation for WVC 42 of the corrected  $\sigma^0$  triplets (black dots) and CMOD5.5 (coloured ellipses), for several intersections of the cone with the plane  $z_{fore} + z_{aft} = 2z_{ref}$ , corresponding to the following wind speeds: a)  $V = 2$  m/s b)  $V = 5$  m/s c)  $V = 8$  m/s d)  $V = 15$  m/s**

Figure 6 shows the total cone correction factors per incidence angle and antenna. The pattern looks very consistent for all antennae. This is an indication that the inter-beam biases are small and that only an overall correction, which is basically incidence angle dependent, is needed. For high incidence angles the correction is still large, i.e., around 1 dB. This may be caused by either a level 1b calibration issue or a CMOD5.5 issue, since CMOD5.5 has not yet been validated for such high incidence angles. We suggest ancillary sea ice, rain forest and soil geophysical comparisons to gain confidence.

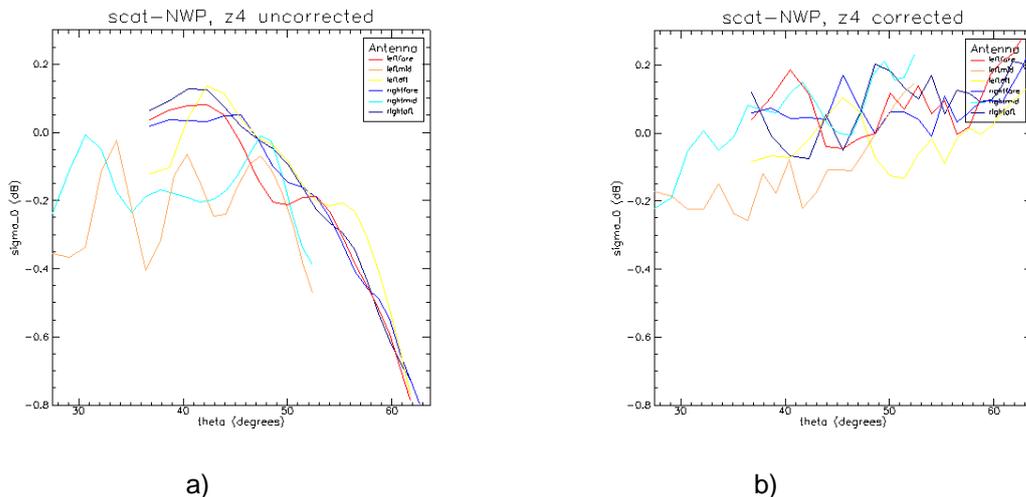


**Figure 6:** Total correction factors per antenna and incidence angle

## V - CONE CALIBRATION ASSESSMENT

To assess the absolute calibration values, we evaluate the statistical distributions of measured and simulated backscatter measurements [Stoffelen 1998]. We compare the average measured backscatter from an antenna with the average simulated backscatter from collocated Numerical Weather Prediction (NWP) winds. As in section III, ECMWF winds are used as reference, but made uniform in wind direction for each speed class. More details on the implementation can be found in [Verspeek et al 2006].

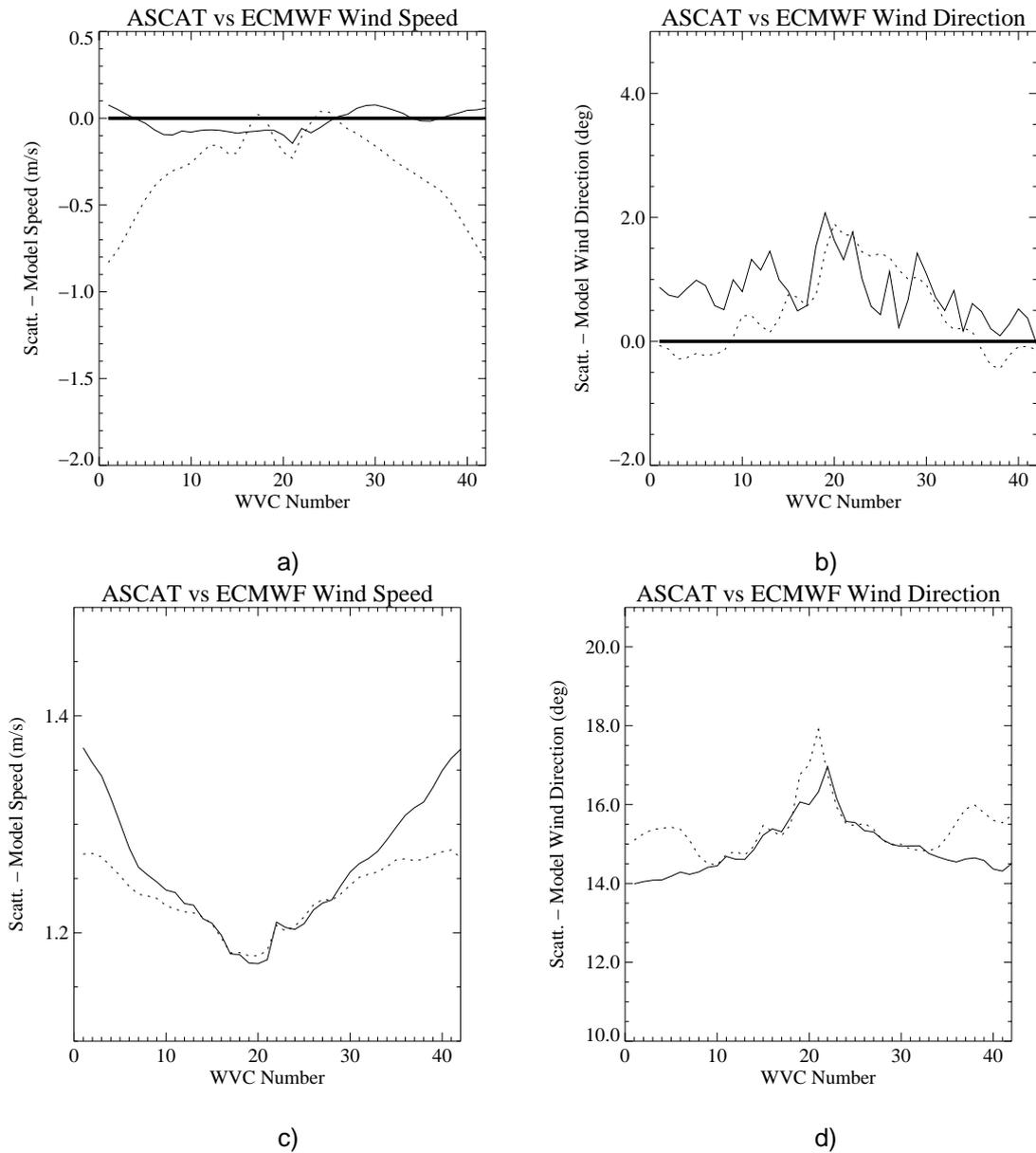
Figure 7 shows the difference between the real and the ECMWF simulated (using CMOD5.5 GMF) measurements as a function of incidence angle, for the six ASCAT antenna beams. The calibration values for the corrected level 1b data (figure 7a) and the KNMI calibrated (i.e., visual + wind speed bias corrected) data (figure 7b) are shown. It is clear that the latter shows smaller values than the former, which is an indication of improved calibration. There is little systematic behaviour in the  $\sigma^0$  bias. Only a slight increase with the incidence angle remains. Moreover, the range of differences in Figure 7b is similar to the one obtained for the calibrated ERS data [Verspeek 2006].



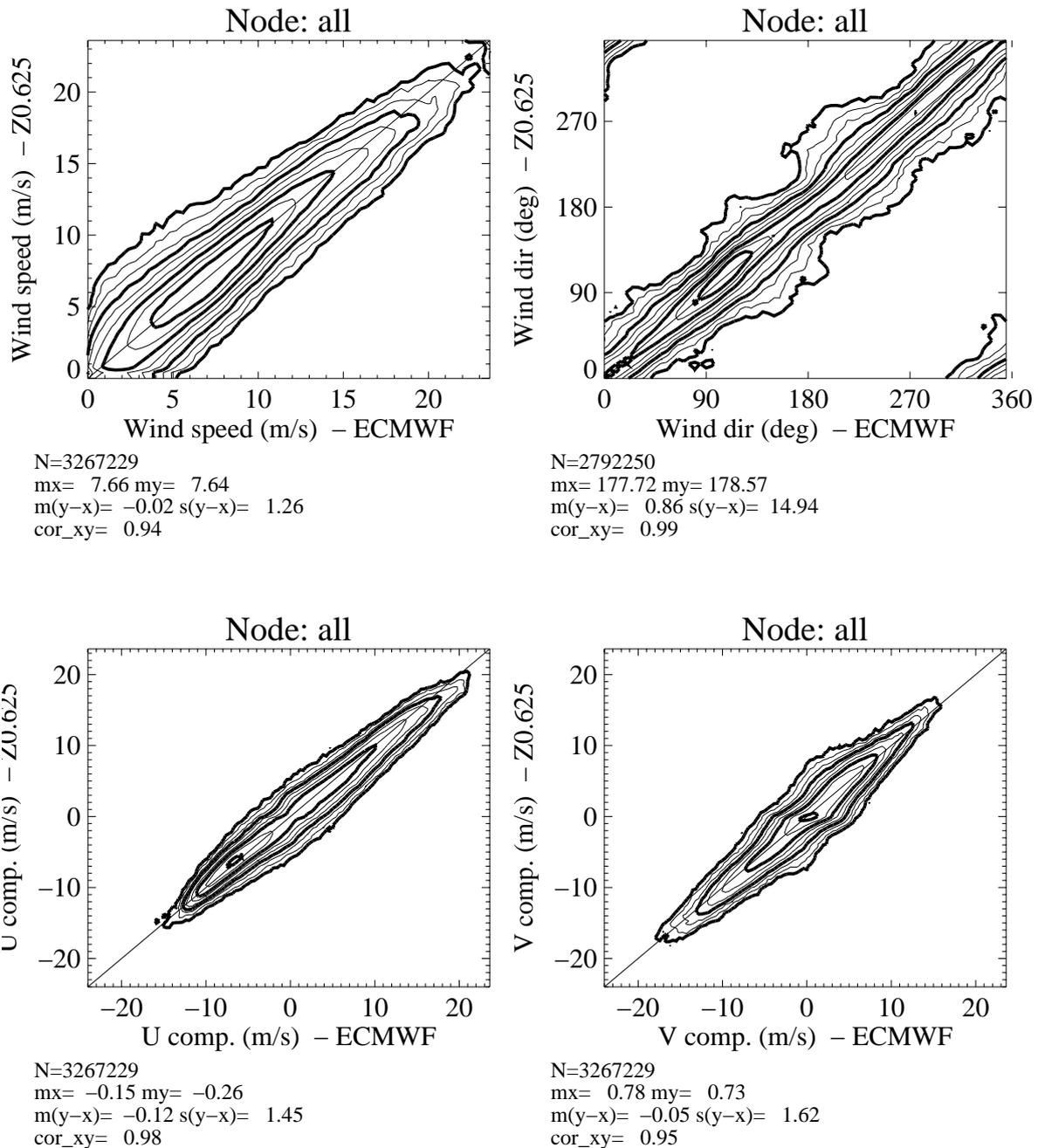
**Figure 7:** Difference between the real (ASCAT) measurements and the ECMWF simulated measurements (using CMOD5.5 GMF) as a function of incidence angle, for the six ASCAT antenna beams, before (a) and after (b) visual + wind speed bias corrections.

## VI - WIND VALIDATION

To further validate the KNMI calibration (visual + wind speed bias corrections), the quality of the retrieved winds is checked against ECMWF winds.



**Figure 8:** Wind speed bias (a), wind direction bias (b), wind speed SD (c), and wind direction SD (d) of ASCAT versus ECMWF (2007-08-23/2007-08-31) as a function of WVC. The solid line corresponds to the corrected, the dotted to uncorrected data. In the bias plots, the thick solid line represents a zero bias. Wind direction statistics are for the closest to the background wind for ECMWF winds larger than 4 m/s.



**Figure 9:** Two-dimensional histogram of the 2D-VAR KNMI-retrieved wind solution versus ECMWF wind for all WVCs (data from 2007-08-23 to 2007-08-31). The one transponder calibrated data after correction is used. The upper left plot correspond to wind speed (bins of 0.4 m/s) and the upper right plot to wind direction (bins of 2.5°). The latter is computed for ECMWF winds larger than 4 m/s. N is the number of data; mx and my are the mean values along the x and y axis, respectively; m(y-x) and s(y-x) are the bias and the standard deviation with respect to the diagonal, respectively; and cor\_xy is the correlation value between the x- and y-axis distributions. The contour lines are in logarithmic scale: each step is a factor of 2 and the lowest level (outer-most contour line) is at N/8000 data points.

In figure 8 wind speed biases are small after correction, but show a trend compatible with the remaining backscatter biases in the uncorrected dataset. The residual bias shown in figure 8a can be removed by applying a second wind speed bias correction on top of the already applied correction, but the 2<sup>nd</sup> order statistics show no significant differences after this additional correction.

Significant bias appears already in WVCs in the projected ERS swath. The underscaled winds from the uncorrected set result in smaller wind speed SD, but a larger wind direction SD than for the

corrected set, as expected. The wind statistics against the background were also computed for the 2D-VAR solutions, resulting in much of the same trends at a slightly higher wind direction SD value (not shown).

Figure 9 shows the 2D-histograms of the difference in wind speed, wind direction (for winds above 4 m/s), and wind speed West-East and South-North components  $u$  and  $v$ . The KNMI calibrated backscatter measurements produce unbiased winds (as expected from the wind speed bias correction in section III) and low root mean squared (RMS) values: 1.26 m/s in wind speed and 14.9° in wind direction. These numbers exceed similar ERS numbers in quality. Also, with the one-transponder calibrated release of EUMETSAT level 1b data, the quality of WVC 22 (innermost WVC of right swath) has largely improved (not shown).

The ASCAT wind product accuracy requirements are 2 m/s in wind speed and 20° in wind direction. Although the RMS scores do not provide a measure of the ASCAT wind accuracy alone, but rather the combined error of ASCAT and ECMWF winds, it is clear that the product quality is high.

## VII - CONCLUSIONS

The KNMI cone calibration proves to be a very effective procedure. Only with a few days of ASCAT data, the corrected backscatter measurements produce good calibration results and winds of high quality. After an operational readiness review, KNMI, the centre responsible for the ASCAT level 2 (wind) processing, was authorized to disseminate ASCAT-derived winds in "demonstration" mode from 28 March 2007 on. With the availability of the EUMETSAT one-transponder calibrated backscatter data, the status of the product has become "pre-operational" on 10 October 2007. With the three-transponder calibration campaign expected to start in November 2007, the product is expected to become "operational" a few months later.

The available KNMI cone corrections appear also useful in other ASCAT applications. Since the commissioning phase started, KNMI has provided feedback to EUMETSAT on the backscatter calibration. EUMETSAT has released several level 1b versions. The latest release is based on a one-transponder calibration, and is the closest to the KNMI cone calibration, some differences still remain, especially at the outermost WVCs of the swath. Such WVCs are outside the incidence angle range for which CMOD5.5 was validated. Since the cone calibration relies on CMOD5.5 cone, independent geophysical calibration results will be useful at the mentioned WVCs. Using sea ice data and the ERS-derived ice model [de Haan and Stoffelen 2001], an ice calibration is being carried out and, together with the ocean and rain forest calibration, it will be used to complement the level 1b transponder calibration. After that EUMETSAT will have established the L1b calibration, the correction tables currently used in the production of the stable L2 wind product will be integrated gracefully in the ASCAT Wind Data Processor (AWDP) at KNMI and an operational ASCAT wind product will be established.

The one-transponder calibration data, although largely improved from the first level 1b data, still needs to be corrected in order to obtain a high quality wind product. Applying the visual and wind speed bias correction, the average difference between measured and simulated backscatter values decreases from a range of +0.2 to -0.8 dB to a range of -0.2 to +0.3 dB. After applying the correction factors, wind statistics of the scatterometer versus ECMWF NWP winds show a standard deviation of 1.26 m/s for the wind speed, and less than 15° for the wind direction. This is a clear improvement on the ERS performance.

The cone calibration tool used in this paper can handle both real and simulated data. Simulations are useful to assess the accuracy of the method. A simulation run with realistic "true" wind distribution and realistic measurement and NWP wind-component error values is performed. The results show that the impact of the NWP wind component errors on the calibration is large compared to the impact of the measurement errors (not shown). Some absolute ocean calibration differences between real and simulated data still need to be further investigated, but relative beam calibration can be done with confidence.

## ACKNOWLEDGEMENT

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