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Calibration and Validation of ASCAT Winds

Jeroen Verspeek, Marcos Portabella, Ad Stoffelen, Anton Verhoef

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Version 1.0	2007-06-15	Major	Adapted description and figures Adapted correction tables and monitoring tables
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Version 2.1	2007-10-22	Minor	Title changed, minor adaptations

Summary

In this report we evaluate normalisation corrections to the demonstration L1b ASCAT backscatter data as provided by EUMETSAT and called “one transponder” data set. Based on the OSI SAF cone visualisation tools at KNMI and the CMOD5 wind sensitivity, calibration of the ASCAT scatterometer is checked. Improved consistency in the KNMI corrections is found, suggesting improved L1b calibration. In the outer swath consistent large departures remain, which need checking against other ancillary geophysical data sources to gain confidence in their validity. Indeed, still the experimental ASCAT wind product shows similar characteristics to the demonstration ASCAT scatterometer wind product and meets the wind product requirements.

Deviations between scatterometer and Numerical Weather Prediction wind derived backscatter show a significant improvement. Without correction the difference ranges from +0.3 dB to -0.8 dB going from the inner side to the outer side of the swaths. After that the scaling correction is applied the difference ranges from -0.2 dB to +0.3 dB and the experimental L1b data show smaller interbeam differences.

The demonstration ASCAT level 2 wind product stream run at KNMI using the pre-validated ASCAT level 1b stream at 25 km sampling as input may be maintained without any significant effects on product quality. The new L1b σ^0 stream will be corrected using the new linear scaling factors in the transformed z domain, which correspond to addition factors in the logarithmic domain (dB). These changes correspond to slightly resetting the ASCAT instrument gain per beam and per Wind Vector Cell (WVC) in order to maintain the backscatter data consistency and wind product quality.

In concert with EUMETSAT more detailed aspects of the ASCAT scatterometer L1b product and L2 product are currently being tested as more ASCAT products become available.

Contents

1 Introduction

A demonstration ASCAT level 2 wind product stream is run at KNMI using the commissioning ASCAT L1b stream at 25 km sampling as input. The L1b σ^0 stream is corrected using linear scaling factors in the transformed z domain [STOFFELEN and ANDERSON 1997], corresponding to addition factors in the logarithmic domain (dB). These changes correspond to resetting the ASCAT instrument gain per beam and per Wind Vector Cell (WVC). The objective is set to reproduce wind distributions similar to those from the ERS scatterometer, which provides a transfer standard from the ERS to the ASCAT era.

The Advanced Scatterometer (ASCAT) [FIGA et al 2002] is part of the payload of the METOP satellite series satellites of which the first one. MetOp-A, is successfully launched on 19 October 2006.ASCAT is a fan beam scatterometer with six fan beam antennae providing a swath of WVCs both to the left and right of the satellite subsatellite track. Each swath is thus illuminated by three beams and is divided into 21 WVCs of 25 km size, numbered from 1-42 from left to right across both swaths (when looking into the satellite propagation direction. [STOFFELEN and ANDERSON 1997] describe the so-called measurement space. In this space the three backscatter measurements are plotted along three axis, spanning the fore, mid and aft beam backscatter measurements. As the satellite propagates and the wind conditions on the ocean surface vary in each numbered WVC, the 3D measurement space will be filled. CMOD5 [HERSBACH et al 2007] describes the geophysical dependency of the backscatter measurements on the WVC-mean wind vector as derived from ERS scatterometer data. Since, this dependency involved two geophysical parameters, namely two orthogonal wind components (or wind speed and direction), the 3D measurement space is filled with measurements closely following a 2D surface [STOFFELEN and ANDERSON 1997]. This folded surface is conical and consists of two sheets, one sheet for when the wind vector blows against the mid beam pointing direction (upwind section) and one for an along mid beam pointing direction wind vector (downwind section). The knowledge on the position of this surface through the Geophysical Model Function, GMF, CMOD5 provides a powerful diagnostic capability for the calibration and validation of the ASCAT scatterometer, since the same geophysical dependency should apply for both the ERS and MetOp scatterometers.

Besides ocean calibration EUMETSAT relies on the rain forest response, the backscatter over ice and transponder measurements for ASCAT calibration [FIGA et al 2004]. In this report we explore ocean calibration. In this report we assume that the main challenge lies in setting the antenna pattern or gain settings of the six beams and explore normalisation corrections to the experimental L1b backscatter data as provided by EUMETSAT during the commissioning phase of MetOp.

EUMETSAT has provided several preliminary datasets during the MetOp commissioning:

1) from 19 October 2006 until 29 January 2007, denoted “ss” data;
2) from 30 January 2007 until 12 February 2007, denoted as “zz” data;
3) 13 February 2007 onwards. (latest configuration of the pre-validated L1b data stream denoted as “zzz” data)
4) one-transponder calibrated data in a data set parallel with the zzz data, denoted “z4” data

z4 corresponds to the so-called “one transponder” L1b data provided by EUMETSAT, using version 5.2.1 of their L1b processor software. Three batches have been provided covering one week of parallel streams in total.

Batch 1: orbit 4372 to 4422, date 2007-08-23 to 2007-08-26
Batch 2: orbit 4423 to 4454, date 2007-08-27 to 2007-08-29
Batch 3: orbit 4455 to 4483, date 2007-08-29 to 2007-08-31

In sections 2, 3, 4 and 5 the correction based on a visual inspection of the measurement space, the wind bias correction, the normalisation correction, and the total correction factor are described respectively. In sections 6, 7 and 8, the NWP σ^0 comparison results, the wind statistics, and the wind processing statistics are discussed, respectively. The conclusions and outlook are presented in section 9. Note that all correction tables are listed in appendix A1 to A4.

2 Visual correction

A first correction is done in order to match the cloud of ASCAT backscatter (σ°) triplets (corresponding to the fore, mid, and aft beams) to the CMOD5 geophysical model function (GMF) in the 3-D measurement space [HERSBACH et al, 2006]. We use the OSI SAF visualisation package [VERSPEEK 2006-2] to produce the plots in z-space, i.e., (z_{fore}, $z_{aft,}$ z_{mid}) where $z=(\sigma°)^{0.625}$ [STOFFELEN, 1998]. Figure 1 is an example of such a visualisation from ERS. The double cone surface of CMOD5 is depicted in blue. The measured data is shown as a cloud of black points around the cone surface

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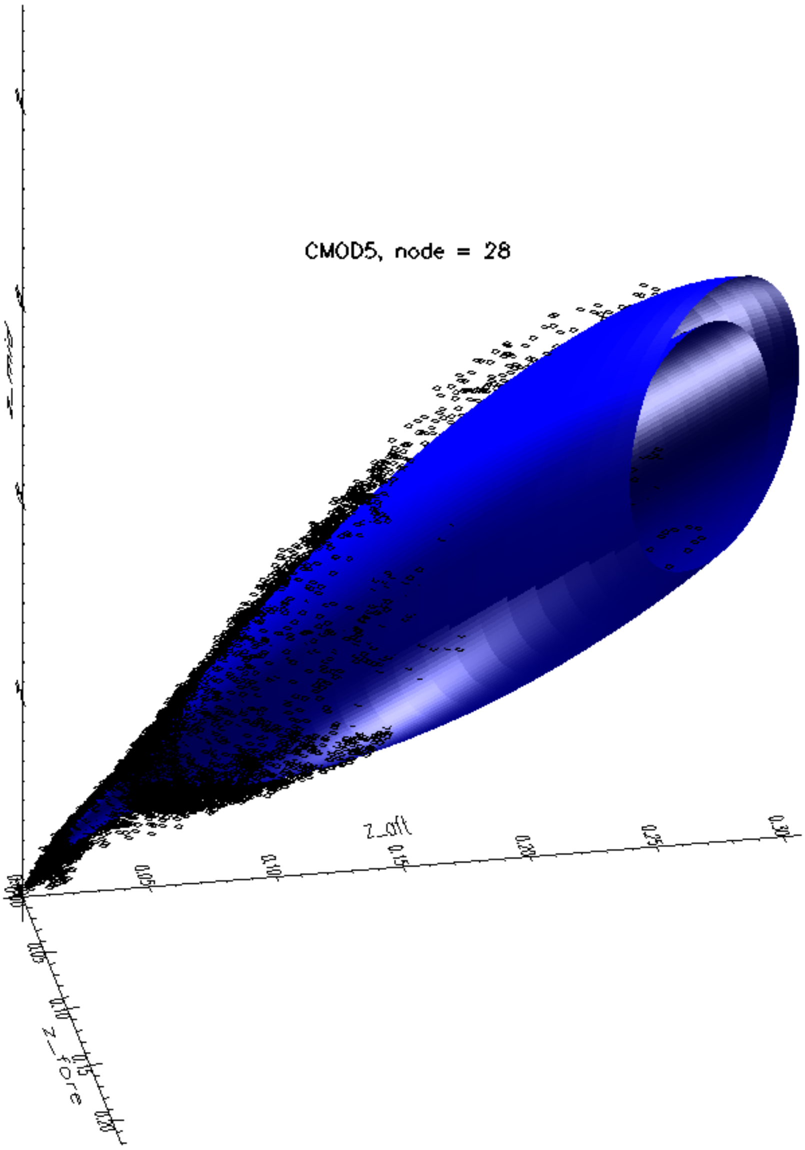


Figure 1 – CMOD5 wind cone with measured data points for WVC 28.

By looking at the projection of the wind cone on and data points in the proximity of the plane z_{fore} = z_{aft}, a normalisation factor for the mid beam is determined such that the CMOD5 cone by approximation fits the measurement points for each WVC. In the same way, by looking at a plot of the z_{fore} versus z_{aft} measurement points and the projection of the CMOD5 cone on the plane $z_{mid} = 0$, correction factors for the fore and aft beam are determined, such that the measurement points are distributed symmetrically. As such, the normalisation factors for the fore and aft beam are coupled in the following way:

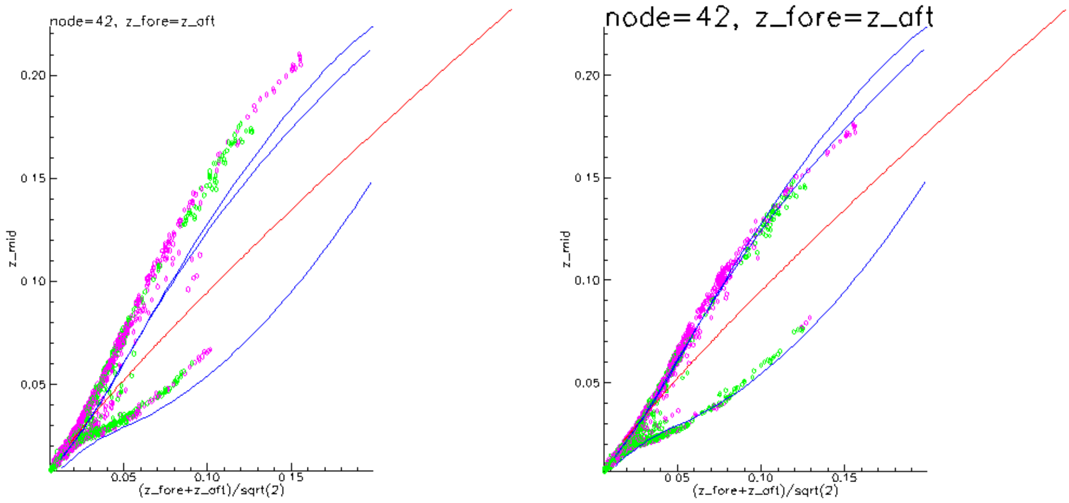
$$z^{corr}_{fore} = 1/z^{corr}_{aft}$$

Equation 1

This deformation has the effect that the cloud of data points becomes symmetric, but does not correct correlated fore and aft beam biases.

The normalisation factors are determined per wind vector cell (WVC). See appendix A1 for the table of visual correction factors on the original EUMETSAT L1B data (ss).

Figure 2 shows the visualisation plots (z_{fore}=z_{aft}) for WVC 42 , i.e., the outer WVC of the right swath. Green points belong to the downwind sheet of the GMF cone surface, while purple points belong to the upwind sheet of the GMF surface. The retrieved wind is the wind solution that has a wind direction that is closest to the collocated NWP wind obtained from ECMWF. Figure 2a) shows uncorrected data from the original normalisation table (ss) and Figure 2b) shows the visual corrected data. Figure 2a) shows a clear discrepancy between data points and GMF, which is much improved in Figure 2b).



a) b)

Figure 2 – CMOD5 wind cone (blue) and ice line (red) on the plane z_{fore}=z_{aft}, data points with 1 dB tolerance on either side of the plane.
a) ss normalisation table, uncorrected data
b) ss normalisation table, visual corrected data
Note the shift of the data points towards the blue lines in b).

Figure 3 shows the visualisation plots (projection on plane z_{mid}=0) for WVC 42. In Figure 3a) (uncorrected) the cloud of data points shows an asymmetry between z_{fore} and z_{aft}. The cloud seems to be rotated around the z_{mid} axis. Figure 3b) (visual corrected data) shows a more symmetrical distribution of data points with respect to the GMF.

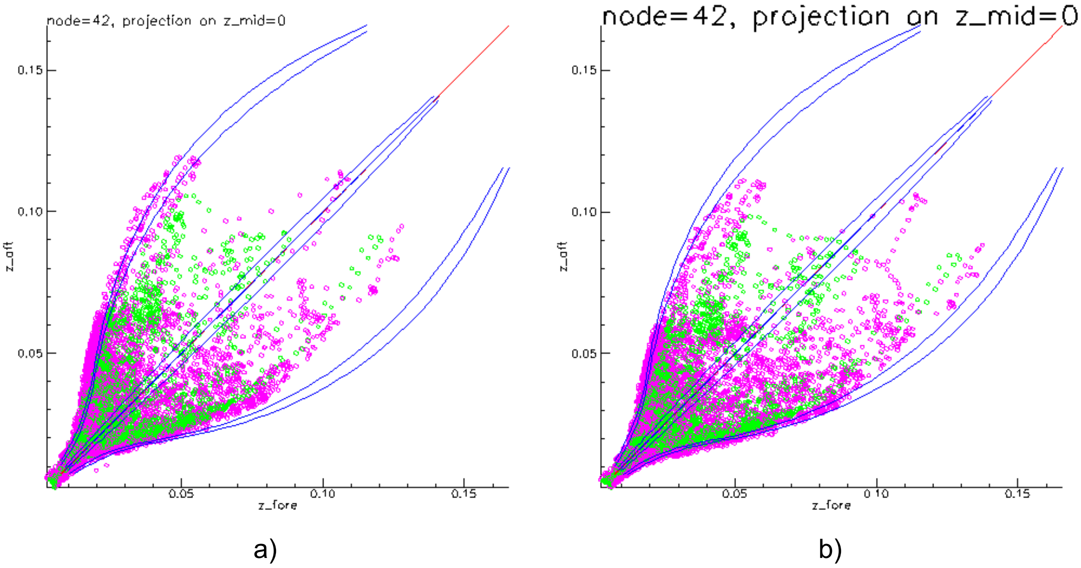


Figure 3 – Projection of the CMOD5 wind cone (blue), ice line (red) and data points on the plane z_{mid}=0.
a) ss normalisation table, uncorrected data
b) ss normalisation table, visual corrected data
Note the more symmetrical data distribution w.r.t. the diagonal in b).

Note that the distribution of measurement points in figures 1-3 depends on:
- Kp noise;
- Beam collocation noise due to wind variability [PORTABELLA and STOFFELEN, 2006];
- The true underlying wind vector distribution that, for example, is far from uniform in wind direction.

It should be mentioned that all corrections are applied to the level 1b data before the level 2 processing. Thus the corrections will have influence on the quality control and inversion of each measured triplet and thus on the resulting level 2 wind field.

3 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 values on the cone, one degree of freedom remains in the normalisation of the cone. This degree of freedom lies in the translation of the cone along its major axis. Its first order effect is a wind speed bias after CMOD5 inversion, while effects on the misfit of the measurement triplets with respect to the cone surface are mainly second order. Therefore, a second normalisation is applied to correct for the remaining wind speed bias on top of the visual normalisation.

First the relative wind sensitivity is determined. It is defined as $(1/z)*(dz/dV)$ and is taken at V_0 = 8 m/s because this gives a good approximation of the modal value, both for the wind speed and for the CMOD5 dz/dV derivative.

The z value is determined as an average over the CMOD5 upwind (Φ = 0°), downwind (Φ = 180°) and the two crosswind values (Φ = 90° and Φ = 270°). Since CMOD5 is a second order harmonic in z space this provides the B_0 value. The derivative of z with respect to V, dz/dV is calculated using the central derivative approximation:

$$z_{ave}(\theta,V)=\frac{1}{4}\sum_{n=0}^{3} z(\theta,V,\phi_n),\phi_n=90^0\cdot n$$

Equation 2

$$(dz/dV)_{V=V_0}=\frac{z_{ave}(\theta,V_0+h)+z_{ave}(\theta,V_0-h)}{2h}$$

Equation 3

with h = 0.1 m/s. The wind speed bias is the difference between the retrieved wind and the first guess ECMWF NWP wind. This bias is multiplied with the relative wind sensitivity to get the wind bias normalisation factors. The correction factors are determined per WVC and per beam. See appendix A2 for tables related to the wind speed bias correction factors.

First guess ECMWF NWP winds are used as reference at this point, since the more precise triple collocation cal/val procedures require a year's worth of data, while only a limited set of ASCAT data has been available. ECMWF [HERSBACH, personal communication] reports that their routine operational comparison with buoys indicates that earlier low biases in the ECMWF winds have disappeared over recent time with the implementation of new ECMWF IFS model cycles.

CMOD5 winds were also found to be biased low [HERSBACH et al, 2007, PORTABELLA and STOFFELEN, 2007]. As such, all CMOD5 winds were corrected here to become 0.5 m/s stronger.

Figure 4 and Figure 5 show the same as Figure 2b and Figure 3b, respectively, but with the windspeed bias correction added to the visual correction. Note that the wind speed bias corrected data points (Figure 4 and Figure 5) are stretched away from the origin towards higher CMOD5 wind speed values as compared to the only visually corrected data points (Figure 2b and Figure 3b).

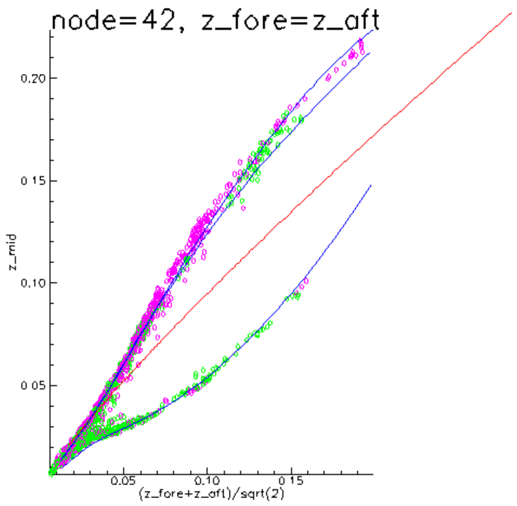


Figure 4 - Same as Figure 2b, but with the wind speed bias correction also applied. Note the improved fit for high backscatter values w.r.t. Figure 2b.

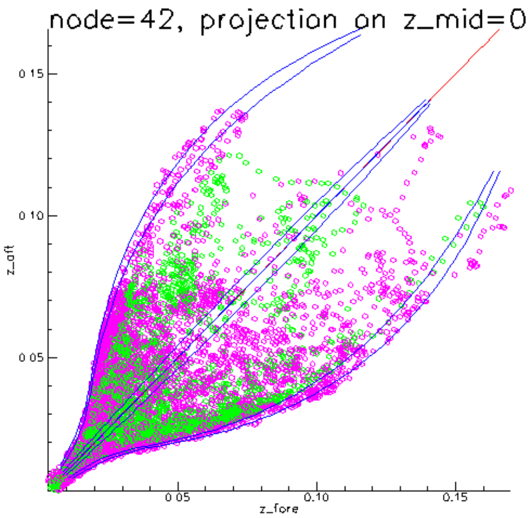


Figure 5 -Same as Figure 3b, but with the windspeed bias correction also applied. Note the improved fit for high backscatter values w.r.t. Figure 3b.

4 Normalisation correction

A correction is applied to adapt the backscatter values in the one-transponder calibrated L1b stream. They are performed on the original data (denoted with ss). Later on, EUMETSAT twice improved their normalisation tables in the L1b processing (tables denoted as zz and zzz). The normalisation factors are assumed to be multiplication factors in linear space, like the visual correction that we apply. Because all correction factors are linear, the corrections can be applied on top of each other. Normalisation correction tables are determined for the conversion of zzz to zz, and for zz to ss, by averaging the σ^0 differences in dB value over one or more collocated orbits. The differences appear rather constant and show insignificant spread, confirming that the main effect in these conversions is a gain factor. Figure 6a) shows the average value per antenna and WVC of the difference in σ^0 value between the one-transponder calibrated L1b stream, hereafter referred as z4, and the zzz L1b stream. Figure 6b) shows the standard deviation (SD) for the correction as shown in Figure 6a). Only data from the second batch are used because they show a more consistent SD than the data from the first batch. Also in the first batch some of the BUFR files, containing orbits 4413 to 4419, showed a shift in the acquisition time of z4 wind vector cells (WVCs) versus zzz WVCs of about 2 s, which corresponds to a lat/lon shift of about 10 km. For a comparison on a Wind Vector Cell (WVC) basis, such as the one performed here, this subset of data cannot be used and is therefore filtered out from the first batch. In the second batch no geographical dislocation was found and all data are used. The differences show a smooth course and a mirror symmetry for the left and right swath. This pattern is persistent. When data from the first batch are taken an almost identical pattern is found (not shown here). Remarkable is the increased SD for WVC 22, the innermost WVC of the right swath, for all three beams. The other WVCs show a rather constant standard deviation, which is approximately a factor of 10 higher than in previous L1b calibration steps (like from zz to zzz L1b calibrated data), but still modest as compared to the corrections.

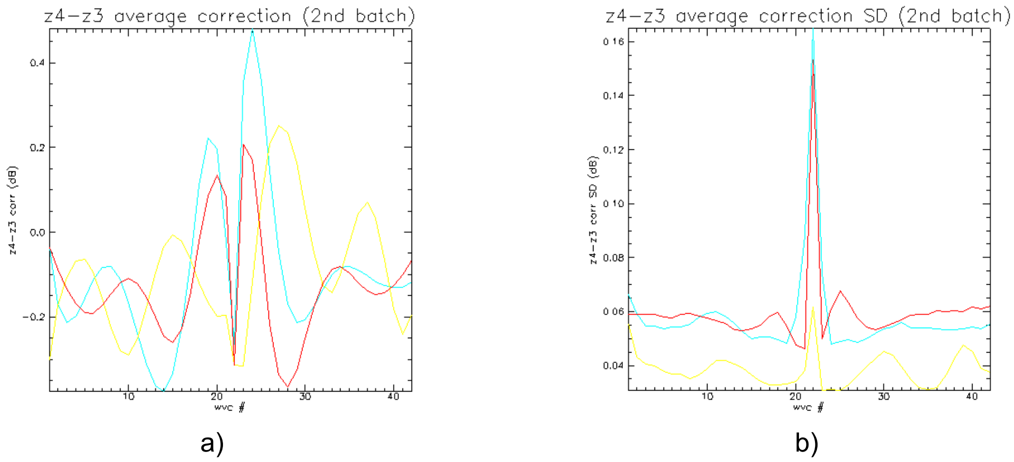


Figure 6 – Average difference and standard deviation of the one transponder calibrated (z4) and zzz calibrated data from batch 2 (2007-08-27 – 2007-08-29)

a) z4-zzz σ^0 difference in dB for the fore (red), mid (yellow) and aft (blue) antenna per WVC.

b) standard deviation of the difference

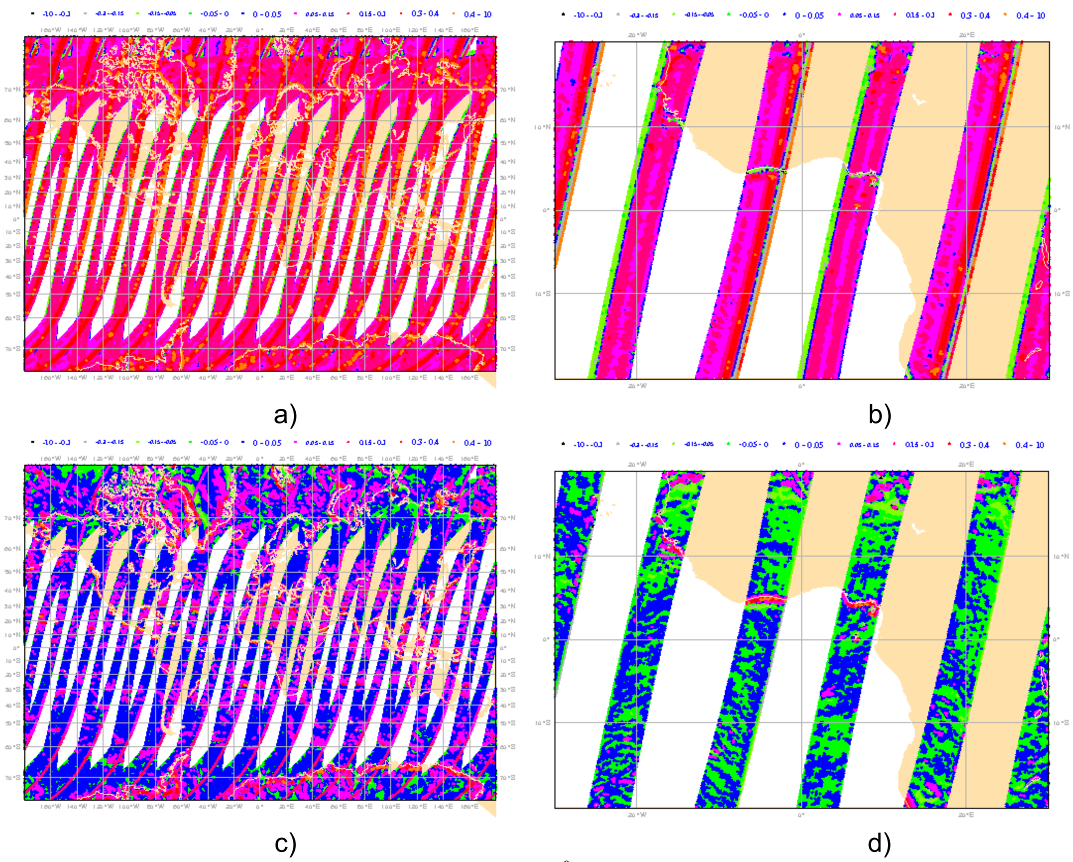


Figure 7 – Spatial plot of the average difference in σ^0 of the one transponder calibrated (z4) and zzz calibrated data for the fore antenna . Data from the first 14 orbits of batch 2 is used (2007-08-27)

a) Global plot

b) Detail plot (West-Africa)

c) Global plot, corrected data

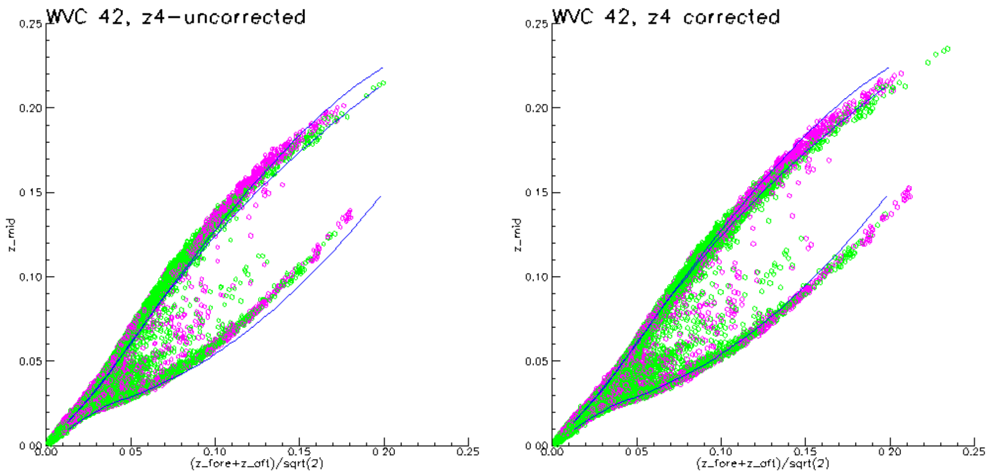
d) Detail plot, corrected data (West-Africa)

Figure 7a) shows the difference for the fore antenna from the first 14 orbits of the second batch on a world map. Figure 7b) shows a detail of the map in Figure 7a). Figure 7c) and Figure 7d) show the same data corrected for the z4-zzz σ^0 difference as shown in Figure 6a). These orbits all have been checked for geographical dislocation between the two streams. No significant dislocation was found. Any dependency of the difference in backscatter on geographical location should be visible

in these figures. The dependency appears to be mainly on WVC number or incidence angle. The orbits have a systematic pattern across the swath, showing the WVC dependency of the correction. Along the swath several structures can be seen, e.g. near the coastline. For other structures it is not clear beforehand where they originate from. Figure 7d) shows some dependency of the difference for the outer WVCs of the right swath for high latitudes. Overall, the corrections show no big systematic trends along the swath direction, and are thus largely independent of geographical location. However, local variations indeed appear in the order of the SD of the z4-zzz corrections.

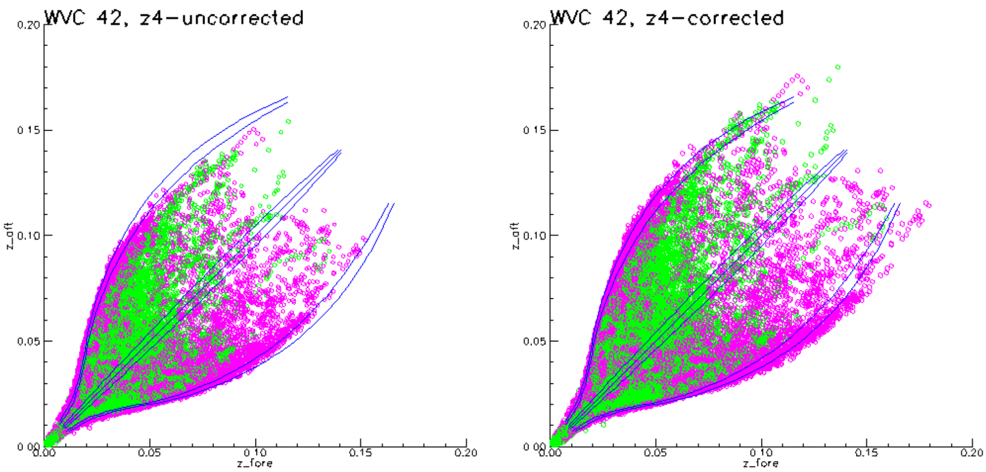
5 Total correction factors

A total correction is applied to adapt the backscatter values in the level 1b stream, which consists of the visualisation correction, the wind speed bias correction, and the normalization correction as discussed in sections 2, 3 and 4. Figure 8a) shows CMOD5 and the data from the uncorrected z4-normalisation for the place $z_{fore} = z_{aft}$. Figure 8b) shows the same data after the total correction has been applied. The z4-data is transformed back to ss-data using the normalisation correction, and then the visualisation and windspeed bias corrections are applied. Figure 9 shows the same as Figure 8 but now for the projection of the wind cone and data points on the plane $z_{mid} = 0$. Figure 10 shows the intersection of the cone with the plane $z_{fore} + z_{aft} = 2z_{ref}$, for several values of z_{ref}, which correspond to (approximately) constant wind speed values. Also here the match between measurements and GMF is good. For other WVCs similar plots have been examined (not shown). For all examined WVCs the correspondence between data and model remains good.



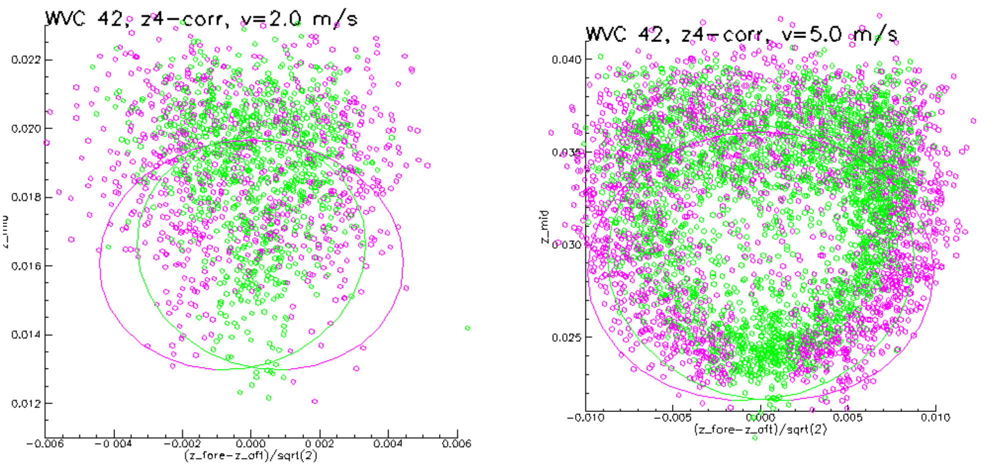
a) b)

Figure 8 - Projection of the CMOD5 wind cone (blue) and data points (green and purple) on the plane $z_{fore} = z_{aft}$. Data from all three batches
a) z4 uncorrected data
b) z4 with KNMI total correction applied
Note the generally improved fit on the right.

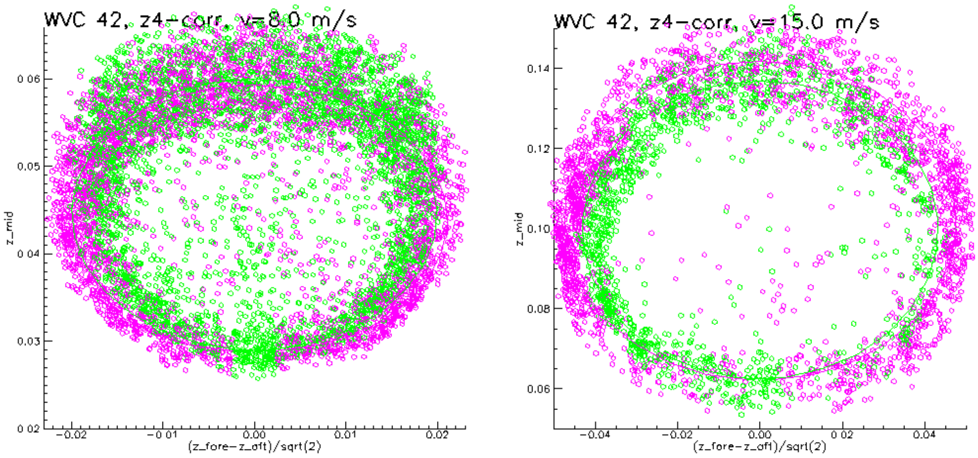


a) b)

Figure 9- Projection of the CMOD5 wind cone (blue) and data points (green and purple) on the plane $z_{mid} = 0$. Data from all three batches
a) z4 uncorrected data
b) z4 with KNMI total correction applied
Note the generally improved fit on the right.



a) b)

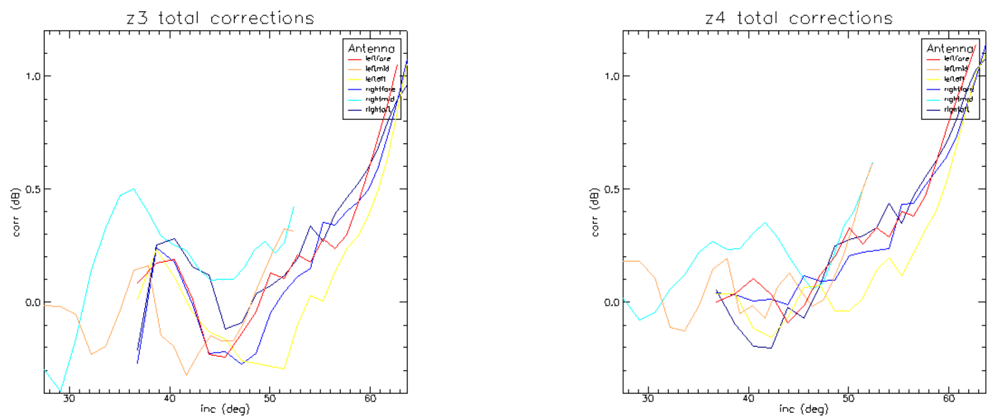


c) d)

Figure 10 – Visualisation for WVC 42 of the corrected σ^0 triplets (black dots) and CMOD5 (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

The correction factors are again determined per wind vector cell (WVC) and beam. See appendix A3 for normalisation correction factor tables.

Figure 11a) and b) show the total correction factor for the zzz and z4 data respectively. The correction from Figure 6a) has been added to the total correction factor for the zzz data [VERSPEEK 2007] in order to generate the total correction factors for the z4 data. In Figure 11b) 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 low incidence angles the corrections for z4 are smaller than for zzz, thus showing a calibration improvement. For high incidence angles the correction is still large, i.e., above 1 dB. This may be caused by either a L1b calibration issue or a CMOD5 issue, since CMOD5 has not yet been validated for such high incidence angles. We suggest ancillary sea ice, rain forest and soil geophysical comparisons to gain confidence.



a) b)

Figure 11 – Total correction factors per antenna and incidence angle
a) zzz data
b) one transponder calibrated data (z4)

The tables with total correction factors can be found in appendix A4.

6 NWP σ^0 comparison

A preliminary comparison of NWP σ^0 to measured backscatter data [VERSPEEK 2006] is performed with the zzz and z4 level 2 data, both for the corrected and uncorrected case, in order to see whether discrepancies are reduced. The method of [STOFFELEN, 1999] is used, which attempts uniform wind direction sampling. The data streams for zzz and z4 are providing the same inputs in terms of geographical location. Both L1b products are processed for all three batches with the ASCAT Wind Data Processor (AWDP) to provide a level 2 product with scatterometer retrieved winds and collocated NWP winds from the ECWMF model. The data is aggressively filtered to exclude land and ice. GMF version CMOD5.5 is used in AWDP and the comparison of NWP σ^0 to measured backscatter data. CMOD5.5 is currently used in the operational level 2 AWDP processing and is basically identical to CMOD5 with a 0.5 m/s shift in the input wind speed. This wind speed bias resulted from a triple collocation study with ECMWF winds and buoy winds [Portabella and Stoffelen 2007]. CMOD5.5 retrieved winds are 0.5 m/s higher than CMOD5 winds.

Figure 12 shows the results. Figure 12a) and Figure 12b) show the zzz and z4 uncorrected case where the difference between the measured averaged σ^0 values and the averaged σ^0 values simulated from the NWP winds is depicted. The difference ranges from +0.3 dB for to inner side to -0.8 dB for the outer side of the swath. Furthermore the difference shows a systematic trend which tends to large negative values for all antennae. The interbeam bias is improved for the z4 case with respect to the zzz case, showing less difference between the antennae. There are still some wiggles left in the mid beam responses.

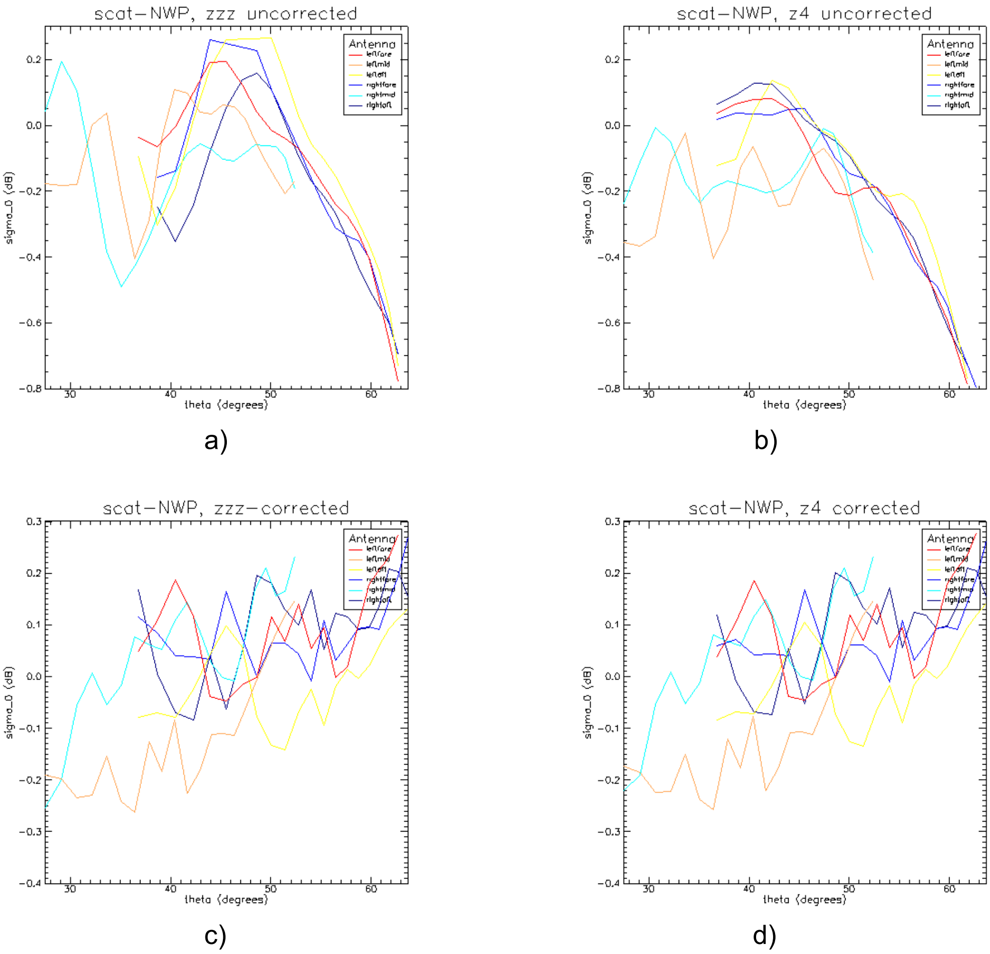


Figure 12 – NWP σ^0 comparison results for the zzz level 1b data from 2007-02-08.. to 2007-02-09 a) zzz operational data (zzz uncorrected), b) one-transponder calibrated data (z4 uncorrected), c) zzz operational data (zzz corrected), d) one-transponder calibrated data (z4 corrected)

For Figure 12c) and Figure 12d) the correction factors were applied to the L1b backscatter values. The difference ranges from -0.2 dB to +0.3 dB. This is a clear improvement with respect to the uncorrected cases. The wind speed bias and the σ^0 bias are both around zero. There is little systematic behaviour in the σ^0 bias. Only a slight increase with the incidence angle remains.

7 Wind statistics

In this section some statistical plots comparing ASCAT wind and ECMWF wind are given.

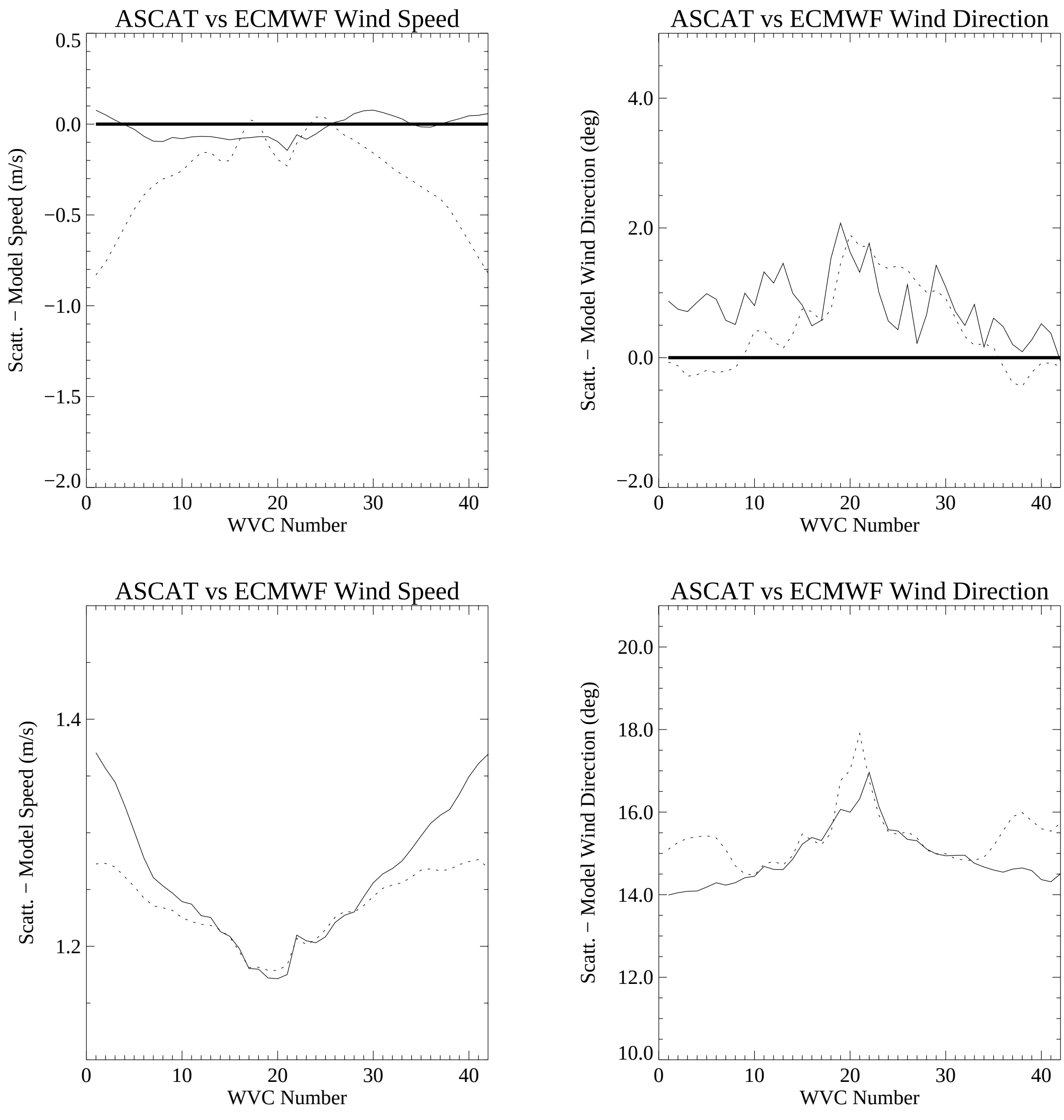
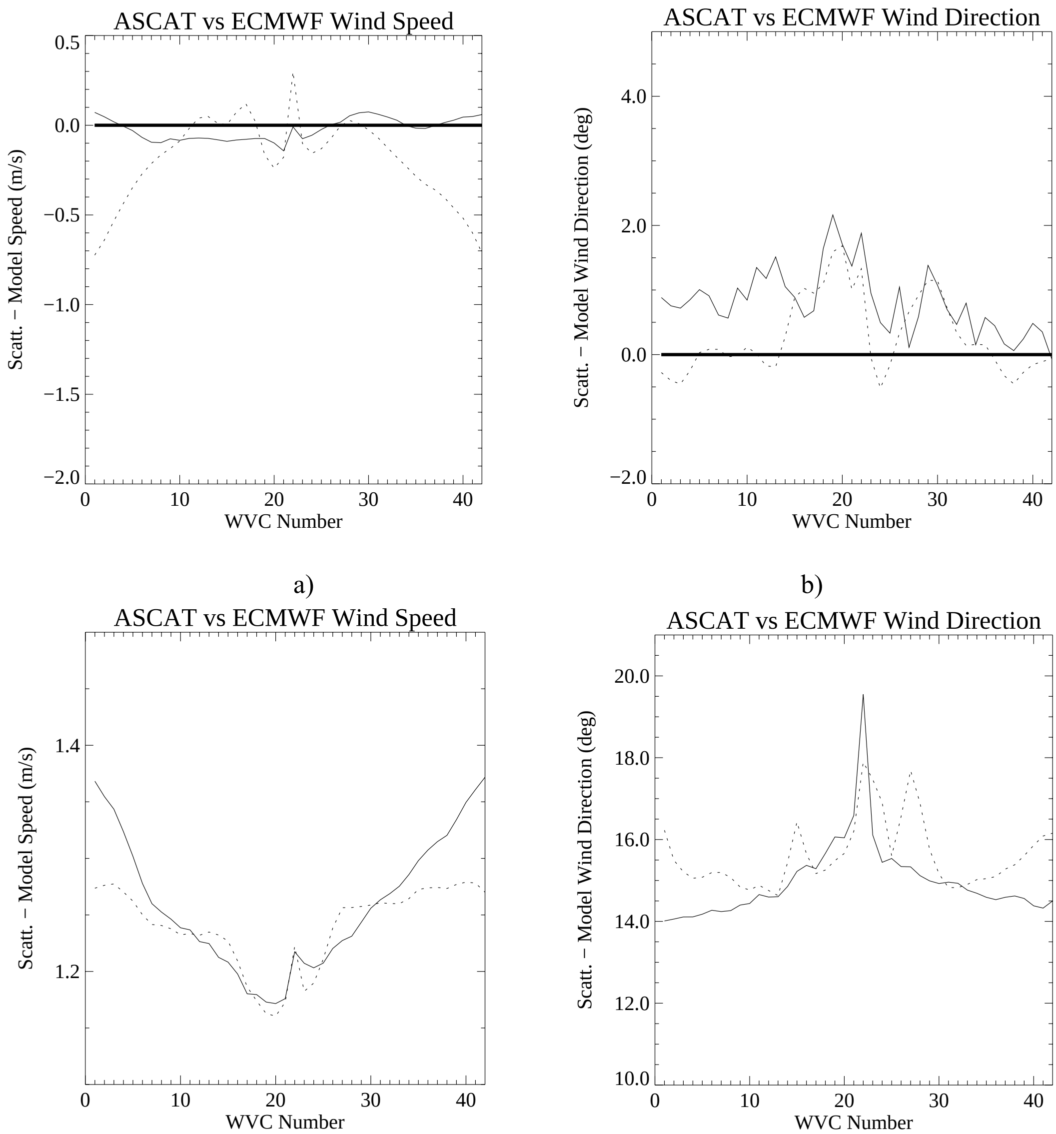


Figure 13 – Wind comparison per WVC between ASCAT and ECMWF for all batches (2007-08-23 / 2007-08-31). The solid line corresponds to z4 corrected, the dotted to z4 uncorrected. In the bias plots, the thick solid line represents a zero bias. Wind direction statistics are for the closest to the background wind for ECMWF winds larger than 4 m/s.
a) wind speed bias, b) wind direction bias, c) wind speed SD and d) wind direction SD.

In Figure 13 wind speed biases are small after correction, but show a trend compatible with the remaining backscatter biases in the uncorrected z4 data set. The residual bias shown in Figure 13a) and Figure 14a) can be removed by applying a second windspeed bias correction on top of the already applied correction, but that the remaining statistics show no significant differences with 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).



a) b) c) d)

Figure 14 – Wind comparison per WVC between ASCAT and ECMWF for all batches (2007-08-23 / 2007-08-31). The solid line corresponds to zzz corrected, the dotted to zzz uncorrected. 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.
a) wind speed bias, b) wind direction bias, c) wind speed SD and d) wind direction SD.

Figure 14 shows the plots of Figure 13, but for the zzz data set. The z4 data set clearly improved WVC 22, both before and after correction. This means that more than a linear scaling in the backscatter data has been achieved. We checked WVC 22 in visualization space, and the scaling numbers still appear appropriate. Besides for WVC 22, these general statistics do not reveal changes in the corrected data set, but do reveal changes in the uncorrected set. Here, the behaviour has generally become smoother, but the wind bias trend appears somewhat more pronounced over the projected ERS swath for the z4 data set.

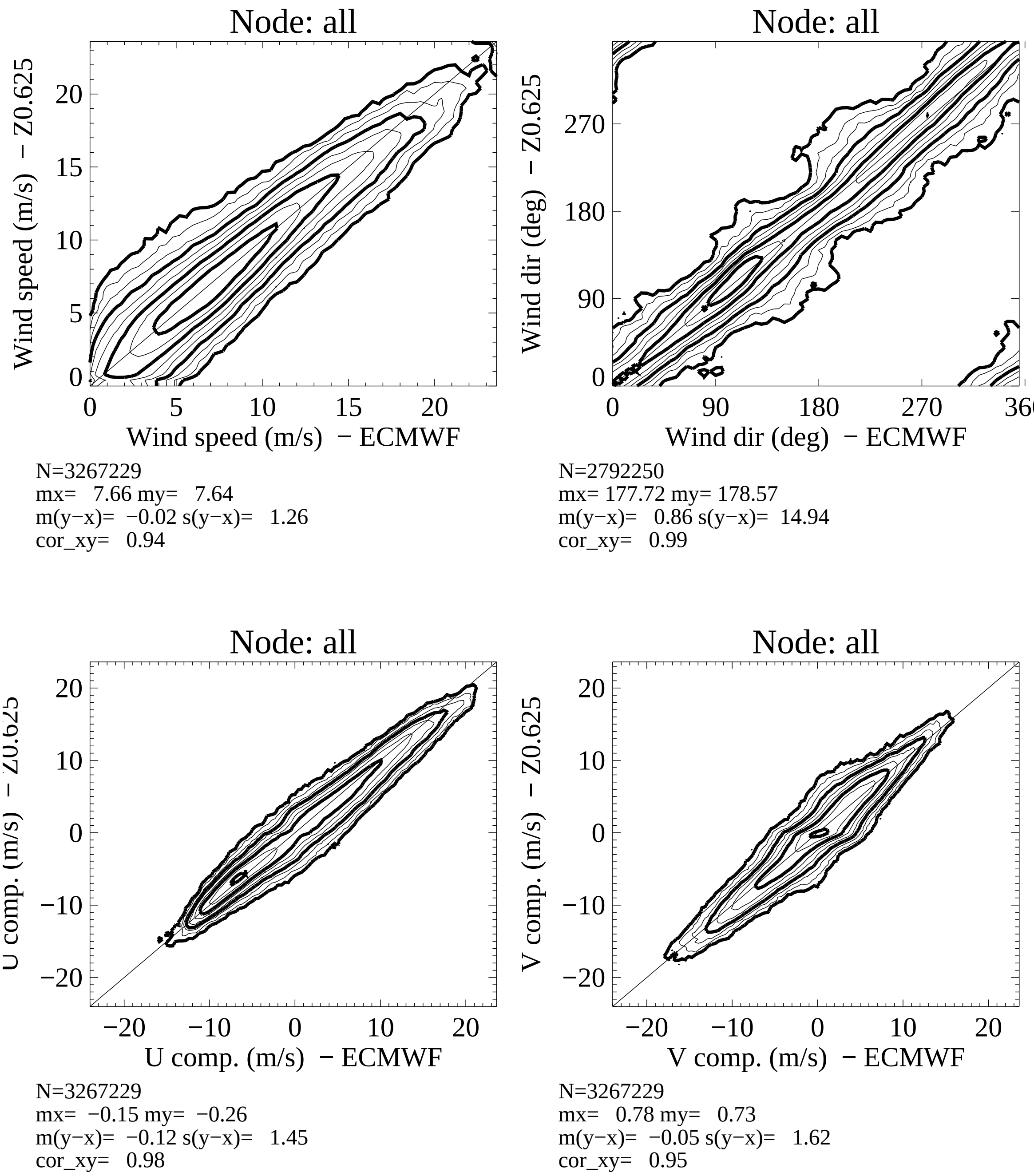


Figure 15 – Two-dimensional histogram of the 2D-VAR KNMI-retrieved wind solution versus ECMWF wind for all WVCs. The one transponder calibrated data from all batches after OSI SAF z4 correction is used. The upper left plot correspond to wind speed (bins of 0.4 m/s) and the upper right plot to wind direction (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.

Figure 15 and Figure 16 show the wind scatter plots for all batches for corrected z4 and zzz data respectively. Only insignificant differences appear in the number of proccessed points and the wind direction standard deviation for ECMWF winds above 4 m/s. The corrected zzz and z4 data sets are statistically very similar in terms of wind performance.

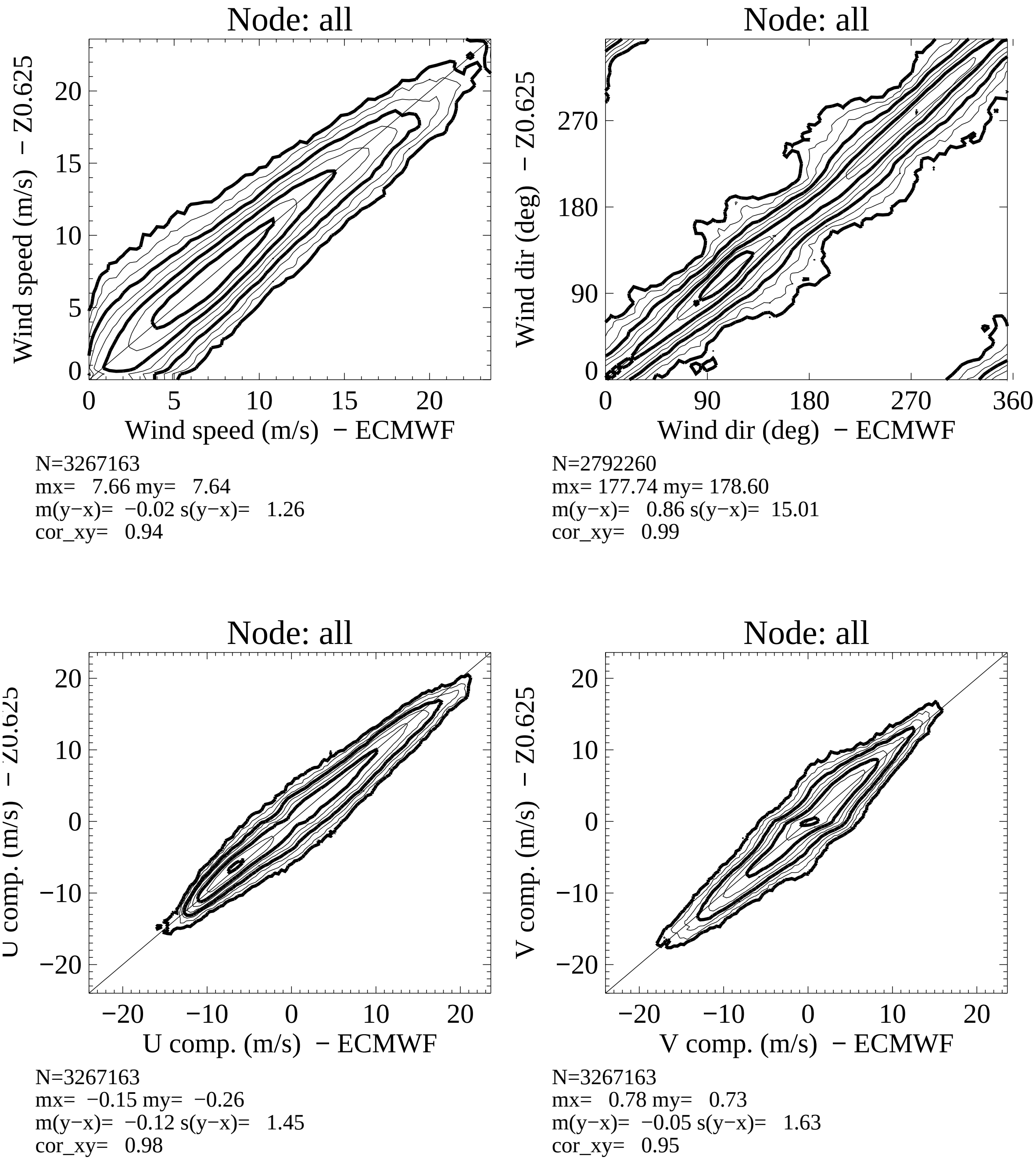
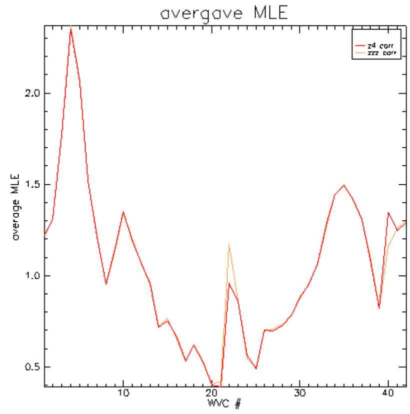


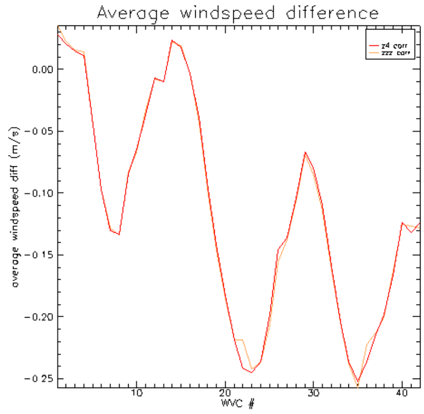
Figure 16 – Same as Figure 15 but now for the zzz operational data (zzz corrected).

8 Level 2 monitoring statistics

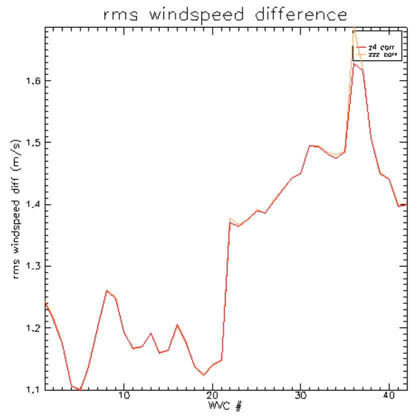
The z4 corrected and zzz corrected L1b products are both processed to get a level 2 wind product. Statistics for several parameters are monitored per WVC to get an idea of the validity and quality of the results. In Figure 17 some monitoring statistical parameters from orbit 4422 are shown per WVC for both the z4 corrected and zzz corrected case. Note the MLE and wind direction statistical improvements in WVC 22 that are also clearly noticeable on orbit level. The two products only show slight differences so the quality of the products is comparable, with noticeable improvement for WVC 22.



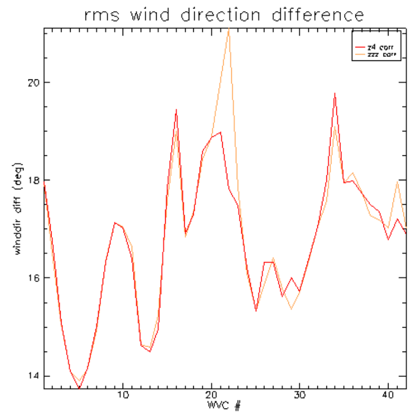
a)



b)



c)



d)

Figure 17 – Level 2 monitoring parameters for orbit 4422 per WVC for the z4 corrected and zzz corrected products
a) average MLE
b) average wind speed difference (scatterometer wind – NWP wind)
c) rms value of the wind speed difference (scatterometer wind – NWP wind)
d) rms value of the wind direction difference (scatterometer wind – NWP wind)

Figure 18 shows the normalised distance to cone [PORTABELLA and STOFFELEN 2006] as a function of WVC (right swath) for the z4 corrected and uncorrected cases. Here the statistics are also accumulated over all three batches. It is clear that the corrected case shows larger accumulations at the origin, i.e., triplets are closer to the CMOD5 cone, as compared to the uncorrected. Furthermore the uncorrected case shows a clear systematic error. For the outermost WVCs the distance to cone shows more negative values, for the innermost WVCs it shows more positive values. This trend is identical for the left swath (not shown). In the corrected case Figure 18b) these systematic errors are not present anymore, except for WVC 22 and WVC 23.

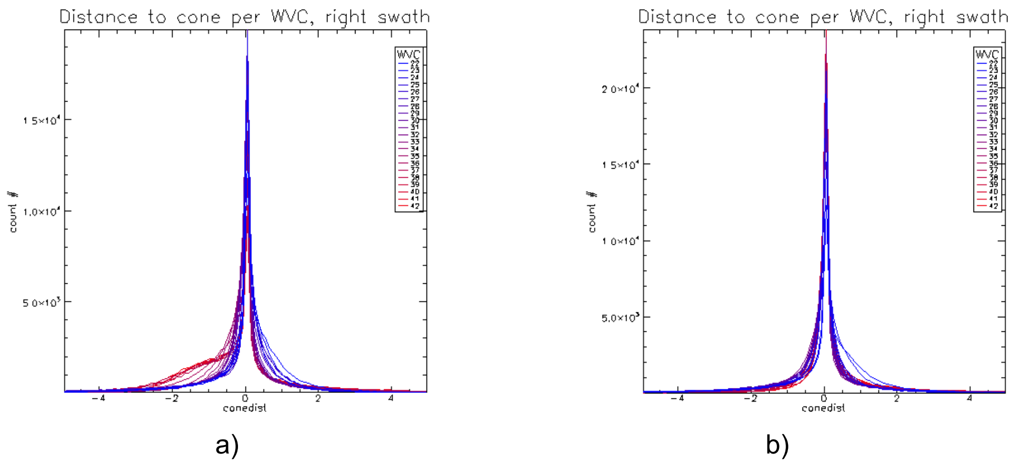


Figure 18 – Cone distance distribution per WVC for the right swath (all batches)
a) Processed z4 measurement triplets
b) KNMI corrected z4

Routine monitoring statistics are provided on the KNMI web site on
www.knmi.nl/scatterometer/ascat_prod/ .

9 Conclusions

Based on the OSI SAF cone visualisation tools at KNMI and the CMOD5 wind sensitivity improved calibration of the ASCAT scatterometer is attempted. CMOD5 was carefully derived for the ERS scatterometer and thus our calibration should result in the compatibility of the ERS and ASCAT scatterometer products. Indeed, the scatterometer wind product of ASCAT is shown to have similar characteristics to the ERS scatterometer wind product and meets the wind product requirements.

ECMWF short range forecast winds are used here as reference. With the implementation of new ECMWF model cycles the ECMWF winds may become more or less biased. ECMWF verification statistics indicate that the low bias of ECMWF winds at the beginning of this century (e.g. [HERSBACH et al 2007]) have compensated by more recent ECMWF model cycles [HERSBACH, personal communication). Moreover, the random wind component errors in ECMWF and ERS scatterometer winds and their respective spatial representation are generally different. These differences may result in absolute overall biases of a few 10^{th} of a m/s; which results in a few 10^{th} of dB uncertainties in backscatter as well, however, rather uniformly spread over the WVCs [STOFFELEN 1999].

The experimental L1b ASCAT backscatter data, the one-transponder calibrated data set, is compared to the currently used demonstration backscatter LB1 data, denoted zzz. Consistency between the two sets is found, and the new “one transponder” set shows smaller interbeam differences suggesting improved L1b calibration. In the outer swath consistent large departures remain, which need checking against other ancillary geophysical data sources to gain confidence in their validity. Indeed, still the experimental ASCAT wind product shows similar characteristics to the demonstration ASCAT scatterometer wind product and meets the wind product requirements.

The level 2 monitoring statistics, per WVC like average MLE, average wind speed bias with respect to the NWP wind speed, RMS values of the wind speed and wind direction show comparable pictures for the demonstration and one-transponder calibrated data. Also the NWP σ^0 comparison shows comparable results. After that the scaling correction is applied the difference ranges from -0.2 dB to +0.3 dB and the experimental L1b data show smaller interbeam differences.

Appendix A1 – Visualisation correction factors

```
# WVC, visualisation correction in dB (fore, mid, aft)
    1       -0.2836604714       -1.5505601168        0.2836608589
    2       -0.2836604714       -1.5505601168        0.2836608589
    3       -0.2836604714       -1.5505601168        0.2836608589
    4       -0.2836604714       -1.5505601168        0.2836608589
    5       -0.2836604714       -1.5505601168        0.2836608589
    6       -0.2836604714       -1.5505601168        0.2836608589
    7       -0.2836604714       -1.5505601168        0.2836608589
    8       -0.2116521597       -1.4642394781        0.2116516829
    9       -0.0698368698       -1.3789786100        0.0698365122
   10       -0.0698368698       -1.3789786100        0.0698365122
   11        0.0691420585       -1.3789786100       -0.0691419244
   12        0.1715815663       -1.0480247736       -0.1715817750
   13        0.2725332081       -0.8882772326       -0.2725330591
   14        0.2053952366       -0.4299544096       -0.2053952366
   15        0.0691420585       -0.4299544096       -0.0691419244
   16       -0.0698368698       -0.5793946981        0.0698365122
   17       -0.1403827816       -0.7321199775        0.1403826773
   18       -0.1403827816       -0.8882772326        0.1403826773
   19       -0.2116521597       -0.8882772326        0.2116516829
   20       -0.3564223349       -1.0480247736        0.3564227819
   21       -0.3564223349       -1.2115315199        0.3564227819
   22        0.6622830629       -1.0480247736       -0.6622830629
   23        0.7874883413       -1.1292968988       -0.7874885201
   24        0.8492552042       -0.8097600341       -0.8492550254
   25        0.8492552042       -0.3564223349       -0.8492550254
   26        0.7251678705        0.0000000000       -0.7251676917
   27        0.7874883413        0.3390282989       -0.7874885201
   28        0.6622830629        0.4701407552       -0.6622830629
   29        0.5347805023        0.3390282989       -0.5347801447
   30        0.5347805023        0.1376028508       -0.5347801447
   31        0.5025356412        0.0000000000       -0.5025355816
   32        0.4701407552       -0.1403827816       -0.4701409936
   33        0.4048937261       -0.3564223349       -0.4048934579
   34        0.5347805023       -0.5042726398       -0.5347801447
   35        0.4701407552       -0.5793946981       -0.4701409936
   36        0.4701407552       -0.6553375125       -0.4701409936
   37        0.4701407552       -0.6553375125       -0.4701409936
   38        0.4701407552       -0.6553375125       -0.4701409936
   39        0.4701407552       -0.7321199775       -0.4701409936
   40        0.4701407552       -0.9676917791       -0.4701409936
   41        0.4701407552       -1.1292968988       -0.4701409936
   42        0.5025356412       -1.2115315199       -0.5025355816
```

Appendix A2 – Windspeed bias correction tables - relative windspeed sensitivity

CMOD5 (1/z)*(dz/dV) at V= 8 m/s

# one-sided WVC	fore	mid	aft
1	0.119159	0.0857779	0.119159
2	0.124659	0.0922501	0.124659
3	0.129497	0.0983018	0.129497
4	0.133716	0.103873	0.133716
5	0.137362	0.109056	0.137362
6	0.140481	0.113831	0.140481
7	0.143130	0.118247	0.143130
8	0.145348	0.122287	0.145348
9	0.147170	0.125973	0.147170
10	0.148632	0.129320	0.148633
11	0.149775	0.132372	0.149775
12	0.150622	0.135122	0.150622
13	0.151213	0.137606	0.151213
14	0.151568	0.139838	0.151568
15	0.151708	0.141815	0.151709
16	0.151658	0.143569	0.151658
17	0.151436	0.145113	0.151436
18	0.151060	0.146460	0.151060
19	0.150548	0.147634	0.150548
20	0.149904	0.148623	0.149904
21	0.149153	0.149459	0.149153

– windspeed bias for ss

WVC, scatWindspeed-NWPwindspeed (m/s)

1	-1.041865
2	-0.850461
3	-0.667734
4	-0.493457
5	-0.311385
6	-0.175995
7	-0.098697
8	-0.011629
9	0.043326
10	0.128109
11	0.197760
12	0.262708
13	0.268704
14	0.187248
15	0.114800
16	0.109325
17	0.061379
18	-0.151700
19	-0.453545
20	-0.646640
21	-0.734591
22	-1.029458
23	-0.865391
24	-0.659519
25	-0.390793
26	-0.100729
27	0.180286
28	0.391641
29	0.491469
30	0.519065
31	0.501218
32	0.413018
33	0.293345
34	0.150037
35	0.007671
36	-0.154353
37	-0.308192
38	-0.463271
39	-0.604827
40	-0.725712
41	-0.847465
42	-0.982344

- windspeed bias correction factors for ss

```
# Windspeed bias correction factors in dB
#    WVC          fore          mid          aft
      1      1.569614     1.573227     1.569614
      2      1.357468     1.344669     1.357468
      3      1.149168     1.125022     1.149168
      4      0.975064     0.943260     0.975064
      5      0.820573     0.784301     0.820573
      6      0.676105     0.638334     0.676105
      7      0.568740     0.530199     0.568744
      8      0.468421     0.431020     0.468421
      9      0.400052     0.363094     0.400052
     10      0.334474     0.299301     0.334474
     11      0.266030     0.234591     0.266030
     12      0.114930     0.099889     0.114931
     13      0.078903     0.067483     0.078903
     14      0.004670     0.003929     0.004670
     15      0.068210     0.056304     0.068210
     16      0.122410     0.099022     0.122410
     17      0.228750     0.180992     0.228750
     18      0.508881     0.392033     0.508881
     19      0.827278     0.618801     0.827278
     20      1.088548     0.788738     1.088548
     21      1.241614     0.870847     1.241614
     22      1.411981     0.986662     1.411981
     23      1.325342     0.955733     1.325342
     24      0.995430     0.742277     0.995430
     25      0.550349     0.423687     0.550349
     26      0.120715     0.095667     0.120715
     27     -0.281540    -0.229000    -0.281540
     28     -0.531137    -0.441667    -0.531137
     29     -0.599706    -0.507944    -0.599706
     30     -0.558416    -0.480701    -0.558416
     31     -0.491500    -0.429570    -0.491503
     32     -0.368874    -0.327004    -0.368874
     33     -0.194323    -0.174575    -0.194323
     34     -0.017210    -0.015663    -0.017210
     35      0.161933     0.149265     0.161933
     36      0.350777     0.327355     0.350779
     37      0.516439     0.487903     0.516439
     38      0.685344     0.655335     0.685344
     39      0.874740     0.846411     0.874740
     40      1.093792     1.070901     1.093792
     41      1.284003     1.271961     1.284003
     42      1.465337     1.468684     1.465337
```

Appendix A3 – Normalisation correction tables - z4 to zzz

The z4 to zzz calibration correction factors (dB) as a function of WVC and beam:

# wvc	diff_sigma0(dB) fore	mid	aft
1.	-0.0370333903	-0.3018574119	-0.0372132584
2.	-0.0867435783	-0.1729753613	-0.1677785069
3.	-0.1342121810	-0.1076786891	-0.2142298371
4.	-0.1691072881	-0.0690770745	-0.1988888681
5.	-0.1898018420	-0.0630657524	-0.1567329168
6.	-0.1912569404	-0.0945294574	-0.1124063209
7.	-0.1736918539	-0.1553879231	-0.0836619660
8.	-0.1454696804	-0.2254291773	-0.0820216015
9.	-0.1190418303	-0.2790581286	-0.1102506518
10.	-0.1086801440	-0.2909408510	-0.1660518944
11.	-0.1206367612	-0.2525698245	-0.2392058820
12.	-0.1530949324	-0.1781437248	-0.3116568923
13.	-0.2002111375	-0.0964003950	-0.3622547388
14.	-0.2460798621	-0.0334451608	-0.3746898174
15.	-0.2614217997	-0.0057791495	-0.3328388631
16.	-0.2275087386	-0.0205562748	-0.2252153009
17.	-0.1407288760	-0.0658641607	-0.0625925735
18.	-0.0202942006	-0.1198330373	0.1103230864
19.	0.0854148120	-0.1659138501	0.2220056653
20.	0.1338241398	-0.1978767663	0.1964467764
21.	0.0835229233	-0.1959892809	-0.0231189765
22.	-0.3135213554	-0.3128969967	-0.2646456063
23.	0.2065495700	-0.3155142665	0.3543663025
24.	0.1713631749	-0.1163798422	0.4794062078
25.	-0.0218976960	0.0815279260	0.3568073809
26.	-0.2170903534	0.2072746009	0.1454687417
27.	-0.3365450203	0.2527061999	-0.0458683409
28.	-0.3659032583	0.2346272320	-0.1675790399
29.	-0.3257602751	0.1640122384	-0.2125920802
30.	-0.2513826191	0.0572210178	-0.2063862085
31.	-0.1767978370	-0.0498710796	-0.1741460264
32.	-0.1186584085	-0.1249945834	-0.1336213797
33.	-0.0867970437	-0.1425857395	-0.0997030586
34.	-0.0815665275	-0.1009307429	-0.0823161006
35.	-0.0961823165	-0.0251438916	-0.0811731592
36.	-0.1188202873	0.0448322110	-0.0902518630
37.	-0.1386291981	0.0712327287	-0.1033248827
38.	-0.1469563544	0.0320821814	-0.1164994761
39.	-0.1426671296	-0.0670931265	-0.1258317828
40.	-0.1259345114	-0.1822225451	-0.1312264353
41.	-0.1009131819	-0.2413870096	-0.1304559410
42.	-0.0660245270	-0.1951905638	-0.1168597117

- zzz to zz

```
# zzz-zz per WVC, sigfore, sigmid, sigaft
       1   0.0243748464  -0.0033332903  0.1477082968
       2  -0.0402082391  -0.1643749028  0.1902081817
       3  -0.0887499526  -0.2291665971  0.2172916830
       4  -0.1185418442  -0.2352083474  0.2310415506
       5  -0.1374998987  -0.2135416120  0.2337499112
       6  -0.1433332115  -0.1804165393  0.2235416323
       7  -0.1402084529  -0.1508332789  0.2016668022
       8  -0.1289583147  -0.1270834804  0.1724999845
       9  -0.1079166755  -0.1127082855  0.1356248707
      10  -0.0822916552  -0.1024999693  0.0949999616
      11  -0.0535415784  -0.0891666934  0.0564582758
      12  -0.0189582910  -0.0683333278  0.0239582863
      13   0.0154165421  -0.0320832506  0.0039584036
      14   0.0522916876   0.0279165544  0.0006249944
      15   0.0902083889   0.1087499857  0.0222915802
      16   0.1289582253   0.2054166347  0.0749999955
      17   0.1752082556   0.2979166508  0.1656250060
      18   0.2312500030   0.3718750477  0.3072914481
      19   0.3133332431   0.4056249559  0.5120832920
      20   0.4452083111   0.3706250489  0.8112499714
      21   0.6649999619   0.2675000727  1.2452085018
      22   1.9952083826   0.7999998927  1.7406249046
      23   1.4435416460   0.8027083278  0.9791665673
      24   1.2383333445   0.7074999213  0.5647916198
      25   1.0525003672   0.5577083230  0.3314582705
      26   0.8247916102   0.3952084482  0.1895833313
      27   0.5785415769   0.2458332926  0.1010416746
      28   0.3364583254   0.1218750477  0.0462499894
      29   0.1310416609   0.0327083319  0.0139582967
      30  -0.0177082997  -0.0147917457 -0.0004166563
      31  -0.1143750101  -0.0245835353 -0.0047916374
      32  -0.1595833451  -0.0035416684 -0.0018750230
      33  -0.1652082950   0.0420833454  0.0054166522
      34  -0.1429166645   0.1033333763  0.0156249395
      35  -0.1049999371   0.1729166806  0.0239583664
      36  -0.0591667369   0.2424999774  0.0322916731
      37  -0.0183332767   0.3016666174  0.0385416821
      38   0.0139582744   0.3406250477  0.0429167263
      39   0.0252083912   0.3531248868  0.0468750447
      40   0.0191666521   0.3289583325  0.0481250547
      41  -0.0077083716   0.2599999309  0.0497915782
      42  -0.0564584509   0.1420833021  0.0500000231
```

- zz to ss

```
# zz-ss per WVC, sigfore, sigmid, sigaft
       1   0.0482655130 -0.2895376086  0.6462509036
       2   0.0593577623 -0.3686678112  0.6049097776
       3   0.0677057356 -0.4443484843  0.5659368038
       4   0.0773898736 -0.5172165036  0.5282182693
       5   0.0914745107 -0.5858699083  0.4860347509
       6   0.1076411679 -0.6473990083  0.4468710423
       7   0.1287017763 -0.6976425648  0.4115951359
       8   0.1487030834 -0.7344702482  0.3729788661
       9   0.1571636498 -0.7553432584  0.3270730674
      10   0.1674532294 -0.7559102774  0.2782683074
      11   0.1804929376 -0.7317994237  0.2388679087
      12   0.1986887008 -0.6877077818  0.2135602683
      13   0.2060010880 -0.6416571140  0.2025974393
      14   0.2004764080 -0.6149933934  0.2099165469
      15   0.1861767918 -0.6240960360  0.2348827422
      16   0.1660306156 -0.6510289311  0.2781338990
      17   0.1424836814 -0.6563382745  0.3322808146
      18   0.1220258325 -0.6377570033  0.3863241076
      19   0.1111740917 -0.6209232211  0.4184640646
      20   0.1136913672 -0.6130168438  0.4009121656
      21   0.1348361969 -0.5943609476  0.3381395638
      22   0.3508432508 -0.5647418499 -0.7795034647
      23   0.4270028770 -0.5816165209 -0.6958812475
      24   0.4274401963 -0.6120569110 -0.7022020221
      25   0.3565745652 -0.6305339932 -0.7866245508
      26   0.2482697964 -0.6284136176 -0.9179996252
      27   0.1452310830 -0.6099900007 -1.0538300276
      28   0.0669959411 -0.5963429213 -1.1511170864
      29   0.0313193686 -0.6015726924 -1.1864163876
      30   0.0382982418 -0.6231390834 -1.1651347876
      31   0.0803977028 -0.6583665013 -1.1091285944
      32   0.1479337364 -0.6935549974 -1.0325934887
      33   0.2239565998 -0.7170857191 -0.9415782094
      34   0.3068754971 -0.7211312652 -0.8362450004
      35   0.3941792548 -0.7053554058 -0.7209556699
      36   0.4790285528 -0.6716300845 -0.6141123176
      37   0.5615235567 -0.6244813204 -0.5137995481
      38   0.6431853771 -0.5696477294 -0.4197139740
      39   0.7232847810 -0.5091590285 -0.3285492957
      40   0.7982527614 -0.4447305799 -0.2317700535
      41   0.8733042479 -0.3786087334 -0.1357937753
      42   0.9467259049 -0.3112885952 -0.0479744412
```

Appendix A4 – Total correction tables – total for z4

The total calibration correction factors (dB) as a function of WVC and beam:

total correction factors in dB for z4

# WVC	fore	mid	aft
1	1.2503467	0.6173953	1.0965289
2	1.1414015	0.50012696	1.0137894
3	1.0207639	0.3556557	0.8638302
4	0.9016627	0.21420181	0.6983539
5	0.77273965	0.096218154	0.5411821
6	0.6193935	0.01011885	0.40175956
7	0.47027808	-0.016497448	0.32280484
8	0.38249376	0.05376345	0.21661538
9	0.40001002	0.13122502	0.11744121
10	0.28815567	0.06967351	0.19709414
11	0.32885745	-0.07085171	0.14076778
12	0.2598761	-0.013950959	0.017487556
13	0.3302297	-0.050653443	-0.037931174
14	0.203377	0.19449659	-0.036576986
15	0.12238866	0.1474748	0.0747326
16	-0.014906973	-0.014204141	0.06432791
17	-0.08859584	-0.12684219	-0.06618055
18	0.03551657	-0.1105292	-0.15467502
19	0.10570371	0.11173591	-0.11362332
20	0.03940183	0.18098183	0.036361814
21	0.001832597	0.18216565	0.037807677
22	0.04173377	0.016276151	0.05322209
23	0.035736308	-0.07914144	-0.09979808
24	0.007548481	-0.046546176	-0.19582084
25	0.012426965	0.05856242	-0.20054713
26	-0.010088161	0.12159757	-0.021505147
27	0.118720666	0.22147879	-0.07037181
28	0.09359506	0.26831436	0.07902609
29	0.09847376	0.23593642	0.25056392
30	0.20715716	0.23761165	0.27874148
31	0.22181079	0.30325115	0.29402766
32	0.23157474	0.35470447	0.32907492
33	0.23861948	0.2865908	0.4366482
34	0.43517822	0.198793	0.350946
35	0.43907678	0.12745288	0.46996248
36	0.5198762	0.05631538	0.55271053
37	0.58201873	0.08414746	0.6248808
38	0.6452974	0.196938	0.7084997
39	0.7390548	0.3374183	0.812105
40	0.8724477	0.40120405	0.9385224
41	0.98946106	0.5026599	1.0303202
42	1.1436298	0.6215483	1.0776356

– total for zzz

The total calibration correction factors as a function of WVC and beam:

total correction factors in dB for zzz:

# WVC	fore	mid	aft
1	1.2133132219	0.3155378401	1.0593156815
2	1.0546579361	0.3271515965	0.8460109234
3	0.8865517378	0.2479770184	0.6496003866
4	0.7325554490	0.1451247334	0.4994649887
5	0.5829378366	0.0331524014	0.3844491839
6	0.4281365871	-0.0844106078	0.2893532515
7	0.2965862155	-0.1718853712	0.2391428649
8	0.2370240837	-0.1716657281	0.1345937848
9	0.2809681892	-0.1478331089	0.0071905553
10	0.1794755459	-0.2212673426	0.0310422480
11	0.2082206905	-0.3234215379	-0.0984380990
12	0.1067811698	-0.1920946836	-0.2941693366
13	0.1300185770	-0.1470538378	-0.4001859128
14	-0.0427028686	0.1610514224	-0.4112668037
15	-0.1390331388	0.1416956484	-0.2581062615
16	-0.2424157113	-0.0347604156	-0.1608873904
17	-0.2293247133	-0.1927063465	-0.1287731230
18	0.0152223706	-0.2303622365	-0.0443519354
19	0.1911185235	-0.0541779399	0.1083823442
20	0.1732259691	-0.0168949366	0.2328085899
21	0.0853555202	-0.0138236284	0.0146887004
22	-0.2717875838	-0.2966208458	-0.2114235163
23	0.2422858775	-0.3946557045	0.2545682192
24	0.1789116561	-0.1629260182	0.2835853696
25	-0.0094707310	0.1400903463	0.1562602520
26	-0.2271785140	0.3288721740	0.1239635944
27	-0.2178243548	0.4741849899	-0.1162401438
28	-0.2723082006	0.5029416084	-0.0885529518
29	-0.2272865176	0.3999486566	0.0379718542
30	-0.0442254469	0.2948326766	0.0723552704
31	0.0450129583	0.2533800602	0.1198816299
32	0.1129163355	0.2297098935	0.1954535246
33	0.1518224329	0.1440050602	0.3369451165
34	0.3536116779	0.0978622437	0.2686299086
35	0.3428944647	0.1023089886	0.3887893260
36	0.4010559022	0.1011475921	0.4624586403
37	0.4433895350	0.1553801894	0.5215559006
38	0.4983410835	0.2290201783	0.5920002460
39	0.5963876843	0.2703251541	0.6862732172
40	0.7465131879	0.2189815044	0.8072959781
41	0.8885478973	0.2612728775	0.8998641968
42	1.0776052475	0.4263577461	0.9607759118

Acronyms and abbreviations

.

Name	Description
AMI	Active Microwave Instrument
ASCAT	Advanced scatterometer
AWDP	Ascat Wind Data Processor
BUFR	Binary Universal Form for Representation (of meteorological data)
CMOD	C-band geophysical model function used for ERS and ASCAT
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA40	ECMWF 40 year reanalysis
ERS	European Remote sensing Satellite
ESA	European Space Agency
ESDP	ERS Scatterometer Data Processor
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GMF	geophysical model function
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
METOP	Meteorological Operational satellite
MLE	maximum likelihood estimator (used for distance to cone)
NWP	numerical weather prediction
QC	Quality Control (inversion and ambiguity removal)
SD	standard deviation
WVC	wind vector cell, also known as node or cell

Table 1 - List of acronyms and abbreviations

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