Ocean and Sea Ice SAF

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ASCAT Calibration and Validation

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Summary

In this report we present normalisation corrections to the current experimental L1B backscatter data as provided by EUMETSAT during the commissioning phase of MetOp-A. Based on the OSI SAF cone visualisation tools at KNMI and the CMOD5 wind sensitivity, improved calibration of the ASCAT scatterometer is attempted. Indeed, the ASCAT wind product shows similar characteristics to the ERS 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 +0.4 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.

An experimental ASCAT level 2 wind product stream is set up at KNMI using the pre-operational ASCAT level 1b stream at 25 km sampling as input. The level 1b σ^0 stream is corrected using linear scaling factors in the transformed z domain, which correspond 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).

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

An experimental ASCAT level 2 wind product stream is set up at KNMI using the experimental ASCAT level 1b stream at 25 km sampling as input. The level 1b 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 still 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) ss from 19 October 2006 until 29 January 2007;
2) zz from 30 January 2007 until 12 February 2007;
3) zzz from 13 February 2007 onwards.

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 and 7, the wind processing statistics and the ocean calibration results are discussed, respectively. The conclusions and outlook are presented in section 8. Note that all correction tables are listed in appendix A.

This report is written within the framework of the OSI SAF IOP work package on ASCAT Calibration and Validation tools and activities. Moreover, it provides input to the OSI SAF CDOP work package 23110 (Improvement of wind product monitoring and control tools)

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.

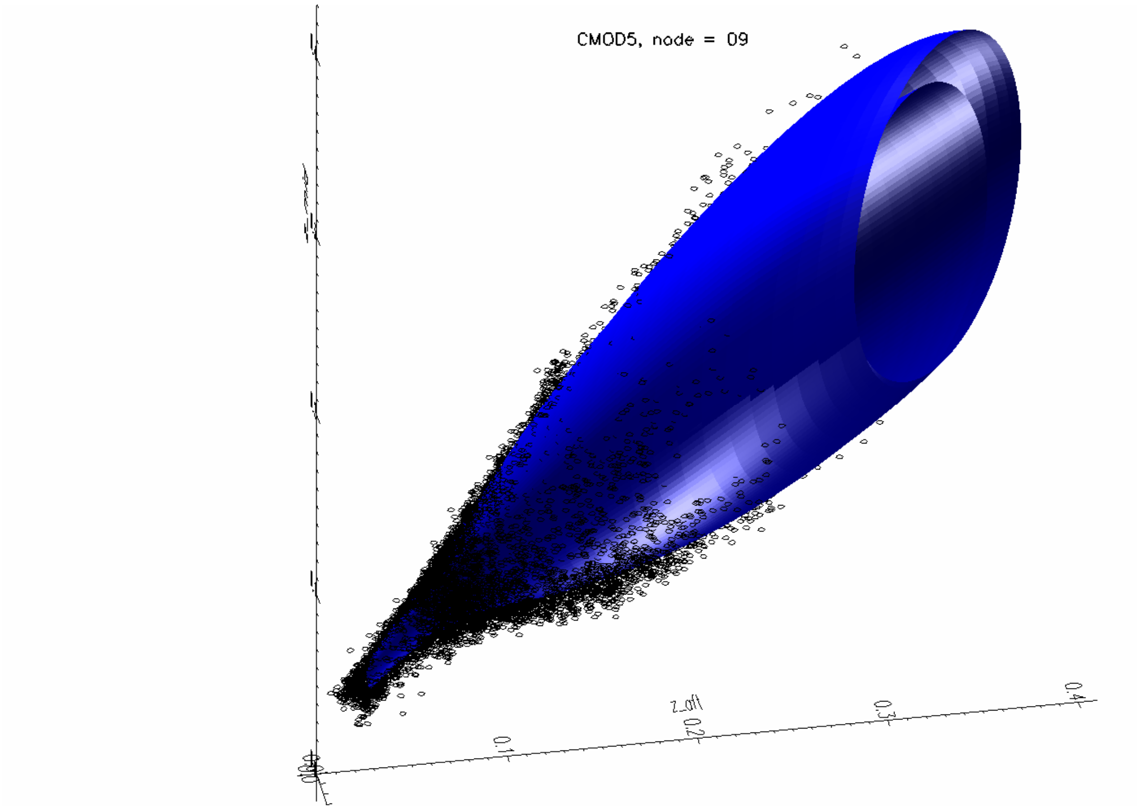


Figure 1 – CMOD5 wind cone with measured data points for WVC 9 (ERS).

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:

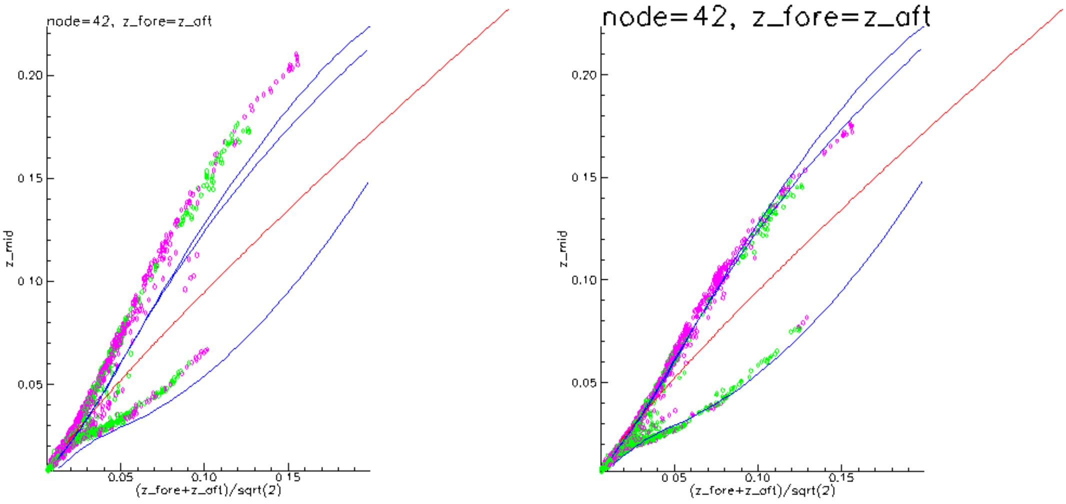
$$z^{corr}_{fore} = 1/z^{corr}_{aft}$$

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).

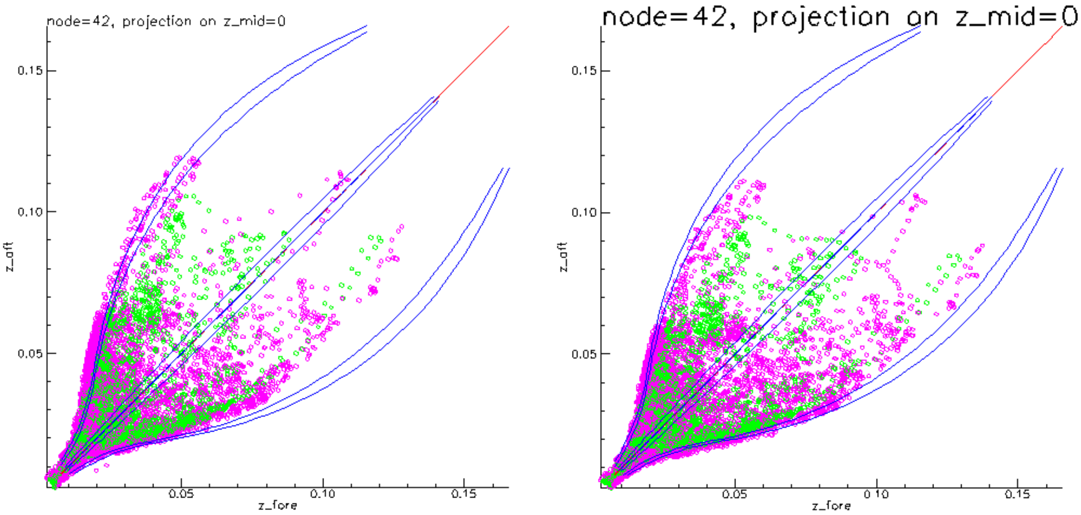
Figure 2 shows the visualisation plots (z_{fore}=z_{aft}) for WVC 42 , i.e., the outer WVC of the right swath. Green points belong to the downwind sheet of the GMF cone surface, while purple points belong to the upwind sheet of the GMF surface. The retrieved wind is the wind solution that has a wind 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

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.



a) b)

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 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.

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 ($\Phi = 0°$), downwind ($\Phi = 180°$) and the two crosswind values ($\Phi = 90°$ and $\Phi = 270°$). 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, A3 and A4 for tables related to the wind speed bias normalisation 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.

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

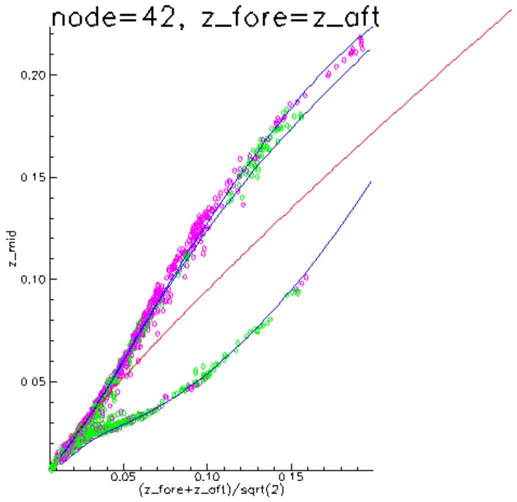


Figure 4 - Same as figure 2b, but with the windspeed bias correction also applied.

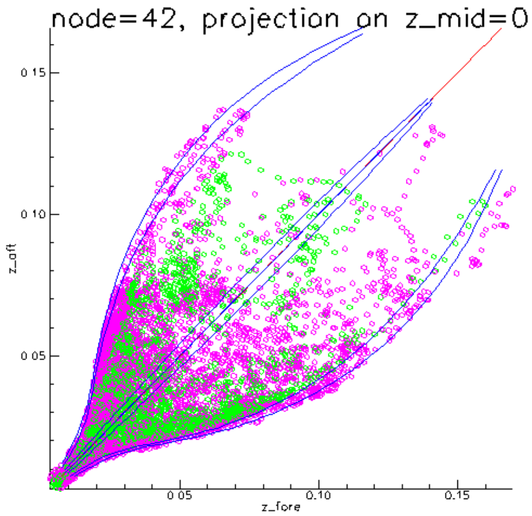


Figure 5 -Same as figure3b, but with the windspeed bias correction also applied.

Figure 6 shows the wind speed bias as a function of WVC for the corrected (visual + wind speed bias) and uncorrected (zzz) case. Here the statistics are accumulated over 2 days of data from 8 February 2007 to 9 February 2007. Note that after correction the wind speed bias is virtually removed.

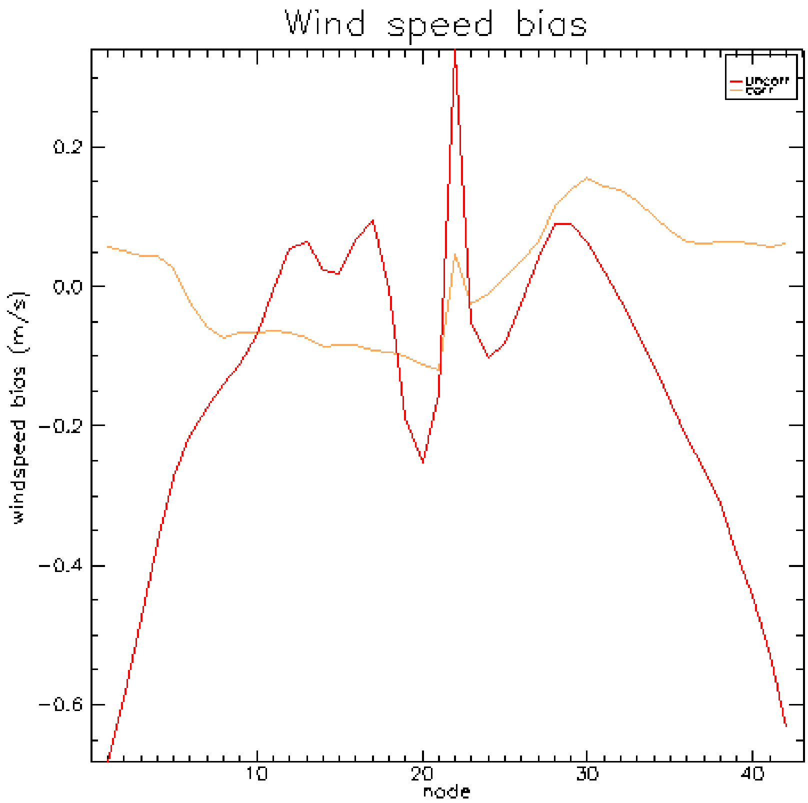
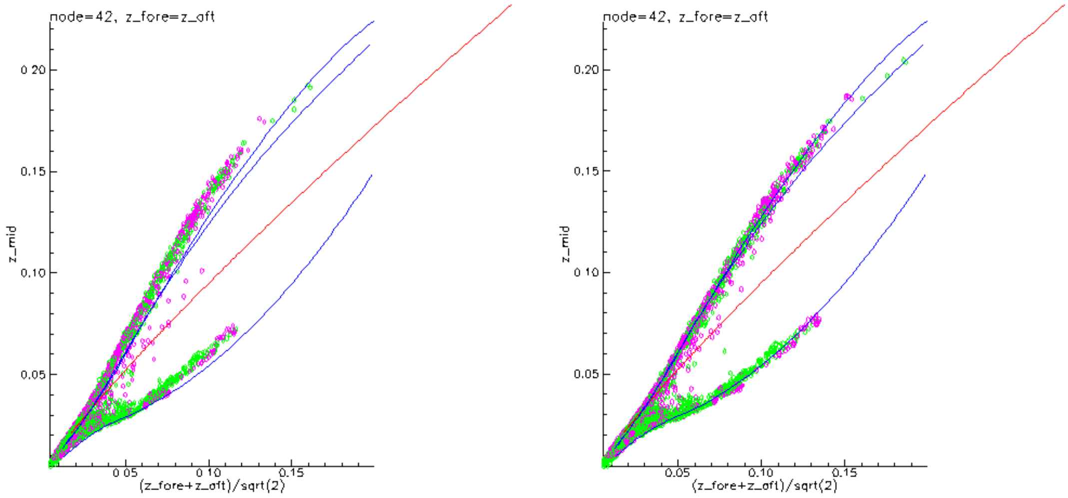


Figure 6 – Wind speed bias per WVC for the uncorrected (zzz normalisation) and corrected (visual + wind speed bias) case

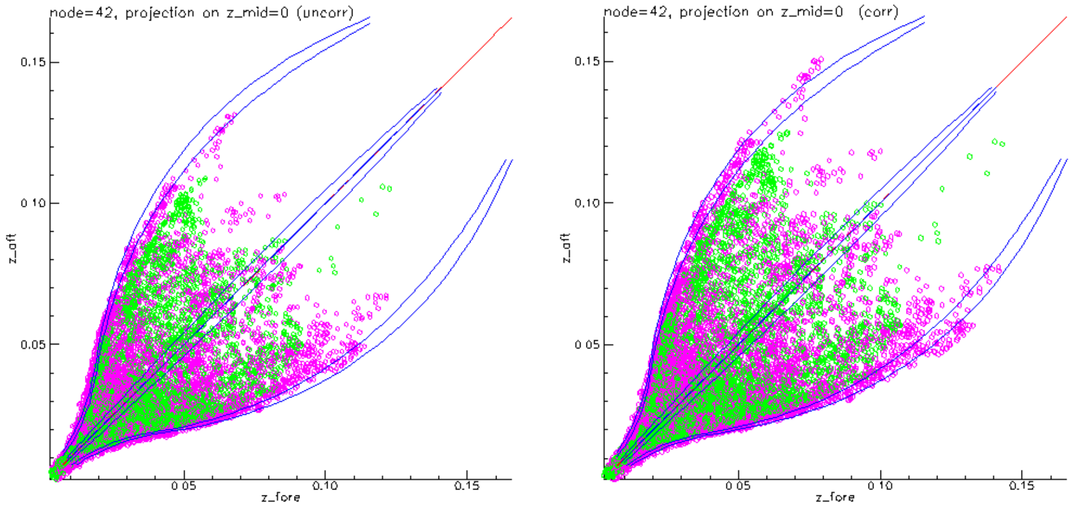
4 Normalisation correction

A total correction is applied to adapt the backscatter values in the level 1b stream, which consists of the visualisation and the wind speed bias corrections discussed in sections 2 and 3. They are performed on the original data (denoted with ss). Later on, EUMETSAT twice improved their normalisation tables in the level 1b 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 7a) shows the data from the uncorrected zzz-normalisation. Figure 7b) shows the same data after the total correction has been applied. The zzz-data is transformed back to ss-data using the normalisation correction, and then the visualisation and windspeed bias corrections are applied. Figure 8 shows the same as Figure 7 but with a different projection of the wind cone and data points.



a) b)

Figure 7 - Projection of the CMOD5 wind cone (blue), ice line (red) and data points on the plane $z_{fore} = z_{aft}$
a) zzz uncorrected data
b) zzz with KNMI total correction applied



a) b)

Figure 8- Projection of the CMOD5 wind cone (blue), ice line (red) and data points on the plane $z_{mid} = 0$
a) zzz uncorrected data
b) zzz with KNMI total correction applied

The correction factors are again determined per wind vector cell (WVC) and beam. See appendix A5 and A6 for normalisation correction factor tables.

5 Total correction factors

Figure 9 shows the total (visual + wind speed bias) correction factors per WVC and per antenna. For the outer WVCs of the swath the highest correction factors are applied. These WVCs have higher incidence angles than were present for ERS and will receive extra attention in the cal/val phase.

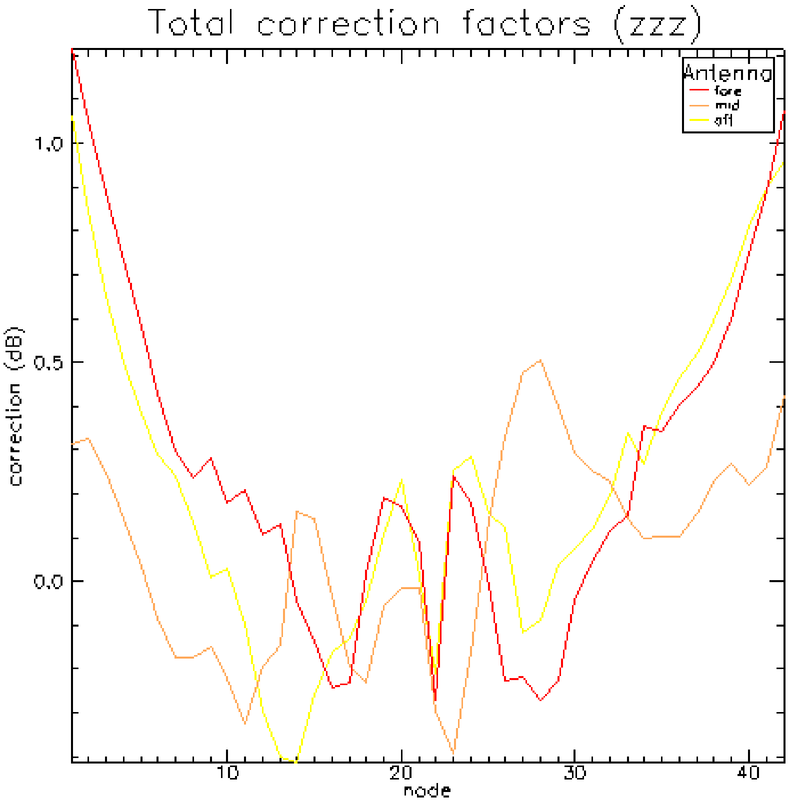


Figure 9 – Total correction factors per WVC and per antenna.

6 Level 2 monitoring statistics

The corrected and uncorrected (zzz normalisation) level 1b input are both processed with the ASCAT wind data processor (AWDP) to get the 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 appendix B the statistics from one orbit are shown per WVC for both the corrected and uncorrected case. Largest improvements can be seen in the distance to cone (ave_mle) and the wind speed bias (avg_wspd_diff). For other parameters the results are merely comparable.

The table with total correction factors can be found in appendix A7.

Figure 10 and Figure 11 show the wind speed comparison between scatterometer wind speed and prior ECMWF wind speed. Figure 10 shows the uncorrected (zzz) case and Figure 11 the wind speed bias for the KNMI corrected case for WVC 42, the outermost WVC of the right swath. This WVC is chosen because it has a large wind speed bias (see Figure 6). The upper left picture of Figure 10 shows clearly off-diagonal contours corresponding to a wind bias where the scatterometer winds are underestimated with respect to the NWP winds (bias 0.62 m/s). In the corresponding picture in Figure 11 the bias has almost disappeared (0.08 m/s). The standard deviation of the wind speed difference shows a slight decrease for the uncorrected case from 1.47 m/s to 1.37 m/s. The decrease can be explained by the fact that by scaling (increasing) the σ^0 values in the corrected case also the error in the σ^0 is scaled (increased). Thus removing the wind speed bias gives a higher standard deviation [STOFFELEN 1997 section IV]. The upper right pictures show the wind direction comparison. The deviation from the diagonal and the standard deviation of the difference is slightly better for the KNMI corrected case compared to the uncorrected case (zzz). The pictures in the lower half show the comparisons of the wind vector components u and v. They have comparable statistics for the uncorrected and corrected case. The SD scores of u and v are low in both cases.

For the applied wind speed biases of ECMWF and CMOD5 we refer to the comments in section 5.

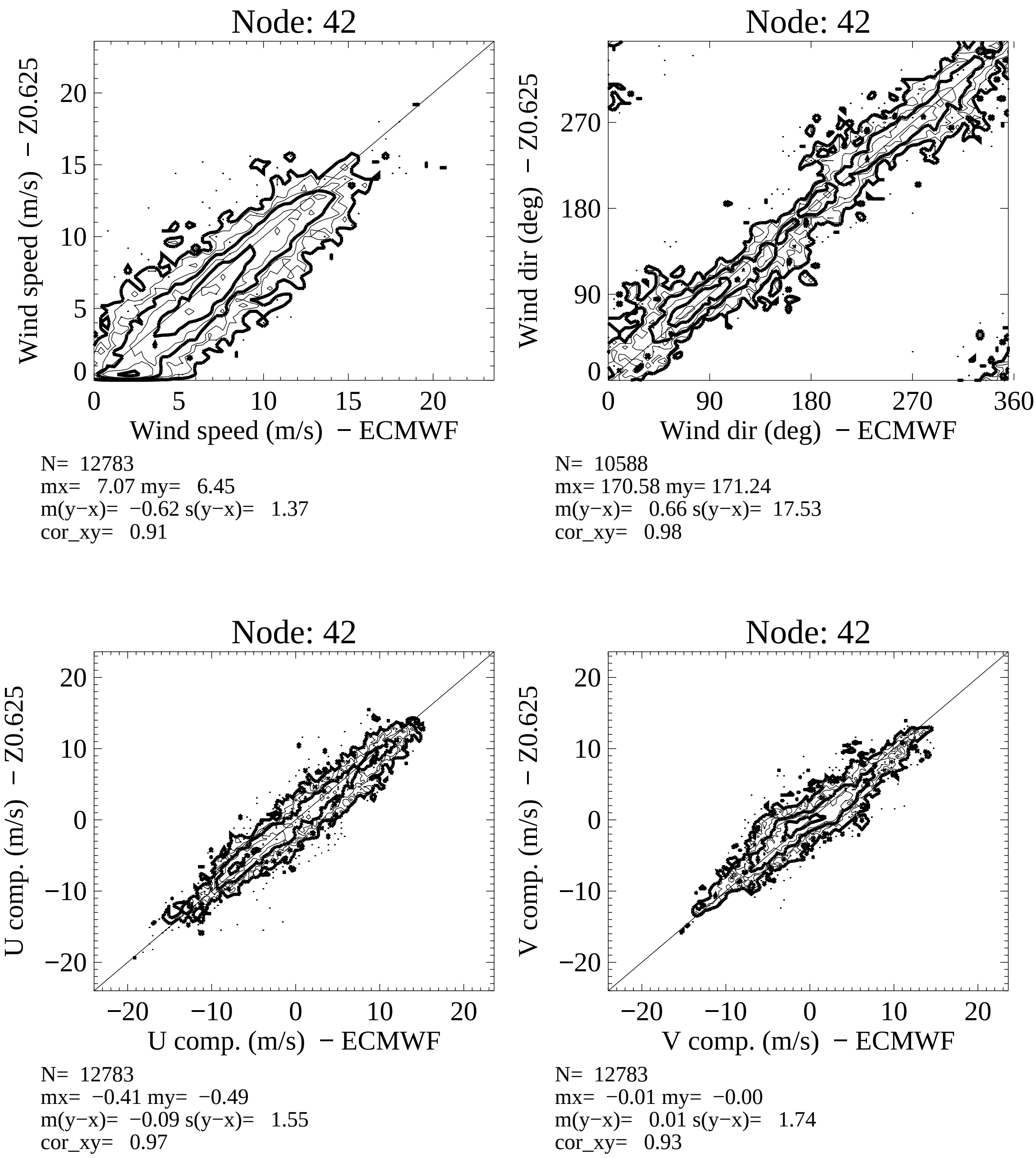


Figure 10 – Two-dimensional histogram of the closest to background KNMI-retrieved wind solution versus ECMWF wind for WVC 42. The upper left plot correspond to wind speed (bins of 0.4 m/s) and the upper right plot to wind direction (bins of 2.5°). The latter is computed for ECMWF winds larger than 4 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.

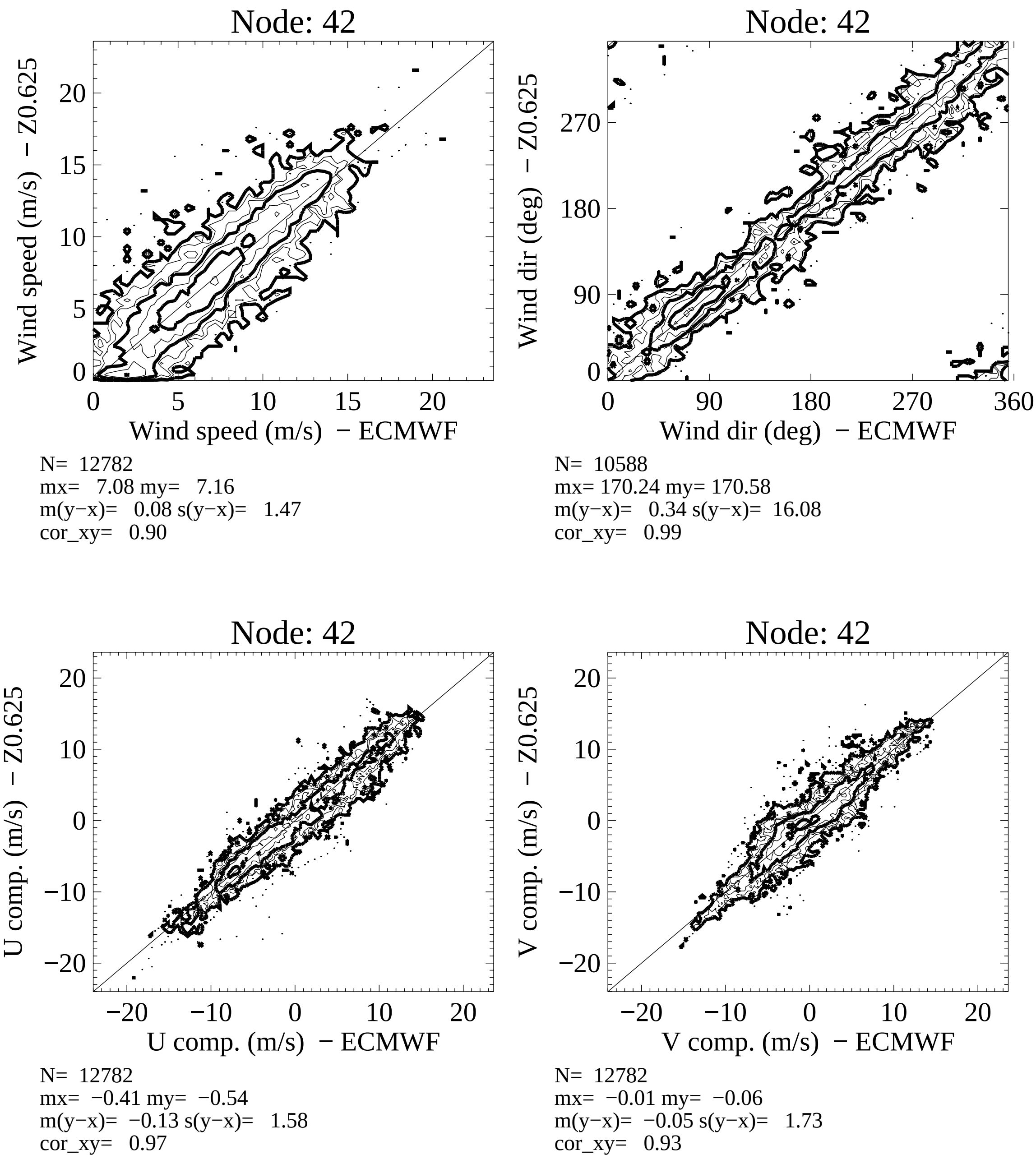
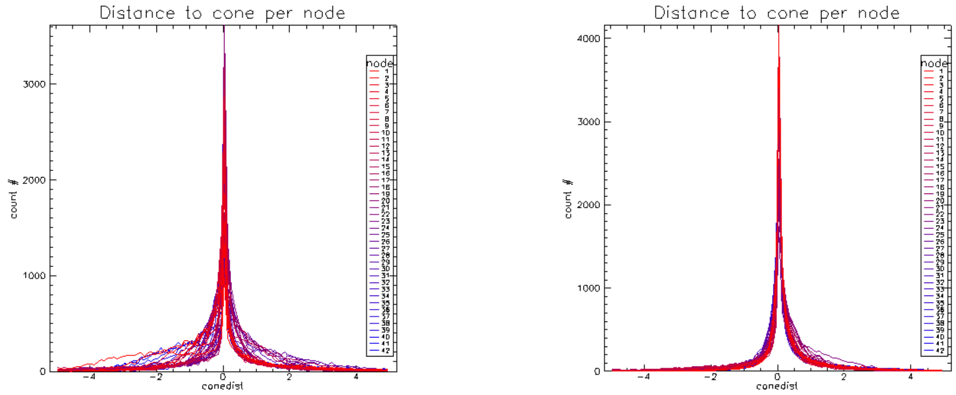


Figure 11 – Same as Figure 10 but now for the KNMI corrected input

Figure 12 shows the normalised distance to cone [PORTABELLA and STOFFELEN 2006] as a function of WVC for the corrected and uncorrected cases. Here the statistics are also accumulated over 2 days of data. 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.



a) b)

Figure 12 – Cone distance distribution per WVC
a) Processed zzz measurement triplets
b) KNMI corrected

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

7 Ocean calibration results

A preliminary ocean calibration [VERSPEEK 2006] is performed with the zzz level 1b data, both for the corrected and uncorrected (zzz) case in order to see whether the results improve. Figure 13 shows the results. Figure 13a) shows the uncorrected case where the difference between the measured averaged σ^0 values and the averaged σ^0 values simulated from the NWP winds (using CMOD5 with speed bias correction as specified in section 5) is depicted. The difference ranges from +0.4 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. Figure 13b) shows the same plot for the corrected σ^0 values. The difference ranges from -0.2 dB to +0.3 dB. This is a clear improvement with respect to the uncorrected case. 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. More data needs to be acquired to provide additional improvement.

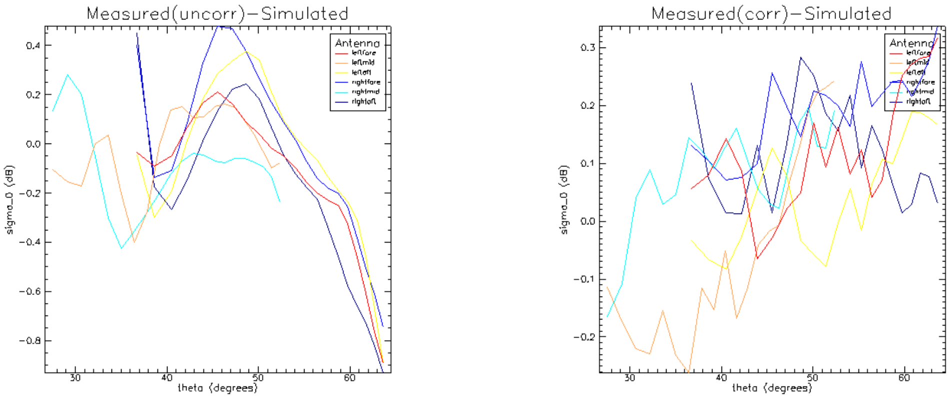
8 Conclusions

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 10th of a m/s; which results in a few 10th of dB uncertainties in backscatter as well, however, rather uniformly spread over the WVCs [STOFFELEN 1999].

These and other more detailed aspects of the ASCAT scatterometer L1B product and L2 product are currently tested as more ASCAT products become available.



a) b)

Figure 13 – Ocean calibration results for the zzz level 1b data from 2007-02-08.. to 2007-02-09
a) Uncorrected (zzz)
b) KNMI corrected

Appendix A1 – calibration correction factors – visualisation space

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# 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 – 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

Appendix A3 – windspeed bias

```
# 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
```

Appendix A4 – calibration correction factors – windspeed bias

```
# 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 A5 – normalisation correction zzz-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
```

Appendix A6 – normalisation correction

zz-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 A7 – calibration correction table – total

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

Appendix B – level 2 monitoring statistics

knmi_flag - fraction rejected in KNMI level 2 processing
avg_mle - average MLE
ave_wspd_diff - average wind speed difference (Meas-NWP) (m/s)
rms_dir_diff - RMS value of wind direction difference (Meas-NWP)
rms_wspd-diff - RMS value of wind speed difference (Meas-NWP) (m/s)

uncorr

WVC	knmi_flag	avg_mle	avg_wspd_diff	rms_dir_diff	rms_wspd_diff
1	0.014	2.614	-0.933	15.853	1.533
2	0.015	1.819	-0.842	15.684	1.489
3	0.013	1.472	-0.701	16.323	1.641
4	0.014	1.091	-0.587	15.493	1.406
5	0.007	1.065	-0.449	16.306	1.327
6	0.006	1.056	-0.349	15.119	1.247
7	0.005	1.007	-0.250	14.809	1.155
8	0.003	0.746	-0.179	14.917	1.101
9	0.000	0.649	-0.130	13.718	1.128
10	0.001	0.582	-0.078	12.664	1.208
11	0.002	0.641	-0.035	12.710	1.178
12	0.002	0.607	0.010	11.883	1.110
13	0.003	0.630	0.029	11.934	1.105
14	0.011	1.061	-0.036	13.676	1.041
15	0.025	1.471	-0.076	15.322	0.988
16	0.020	0.911	-0.006	13.073	0.965
17	0.009	0.489	0.037	10.804	0.960
18	0.012	0.422	-0.076	11.339	0.977
19	0.013	0.425	-0.263	12.123	1.022
20	0.011	0.330	-0.288	14.093	1.083
21	0.006	0.398	-0.108	17.730	1.091
22	0.004	0.516	0.359	17.499	1.144
23	0.008	0.585	-0.009	18.701	1.088
24	0.008	0.561	-0.067	16.942	1.101
25	0.006	0.460	-0.083	14.553	1.091
26	0.024	1.222	-0.044	15.378	1.191
27	0.053	1.872	0.001	16.346	1.186
28	0.023	1.747	0.067	15.478	1.225
29	0.012	1.208	0.110	15.688	1.274
30	0.008	0.720	0.103	16.511	1.293
31	0.002	0.484	0.046	16.098	1.329
32	0.007	0.405	-0.009	16.094	1.380
33	0.005	0.449	-0.022	15.113	1.461
34	0.004	0.490	-0.053	13.888	1.528
35	0.001	0.588	-0.134	12.789	1.475
36	0.004	0.570	-0.192	14.307	1.381
37	0.004	0.706	-0.249	13.201	1.311
38	0.004	0.762	-0.326	13.355	1.237
39	0.007	0.838	-0.422	14.566	1.232
40	0.001	1.083	-0.502	15.105	1.251
41	0.004	1.191	-0.587	14.338	1.358
42	0.002	1.239	-0.683	14.683	1.462

corr

#WVC	# knmi_flag	avg_mle	avg_wspd_diff	rms_dir_diff	rms_wspd_diff
1	0.018	0.898	-0.204	15.283	1.259
2	0.018	0.729	-0.216	15.133	1.297
3	0.013	0.644	-0.187	15.067	1.576
4	0.014	0.608	-0.188	14.805	1.330
5	0.008	0.655	-0.161	15.793	1.288
6	0.008	0.632	-0.165	14.908	1.223
7	0.005	0.700	-0.142	14.457	1.149
8	0.003	0.489	-0.129	14.876	1.103
9	0.000	0.493	-0.095	13.989	1.132
10	0.001	0.532	-0.086	13.283	1.220
11	0.001	0.673	-0.103	13.575	1.211
12	0.001	0.527	-0.117	12.475	1.133
13	0.003	0.567	-0.130	12.219	1.103
14	0.003	0.495	-0.158	12.009	1.024
15	0.008	0.742	-0.182	12.577	0.989
16	0.011	0.701	-0.159	12.435	0.965
17	0.010	0.551	-0.158	10.955	0.967
18	0.020	0.650	-0.178	12.226	0.998
19	0.020	0.609	-0.181	13.318	1.019
20	0.012	0.441	-0.149	15.292	1.074
21	0.008	0.424	-0.079	18.207	1.092
22	0.004	0.681	0.055	19.075	1.094
23	0.000	0.560	0.012	15.794	1.124
24	0.004	0.363	0.021	15.552	1.128
25	0.003	0.402	0.019	14.595	1.095
26	0.004	0.453	0.031	15.022	1.144
27	0.006	0.481	0.050	14.720	1.115
28	0.003	0.437	0.101	14.756	1.146
29	0.003	0.442	0.166	16.254	1.238
30	0.002	0.426	0.200	15.972	1.285
31	0.001	0.421	0.182	16.107	1.338
32	0.007	0.406	0.159	16.042	1.389
33	0.006	0.417	0.174	15.717	1.482
34	0.004	0.415	0.172	14.185	1.563
35	0.001	0.502	0.120	13.705	1.502
36	0.002	0.549	0.102	13.488	1.401
37	0.004	0.463	0.095	13.248	1.322
38	0.005	0.405	0.053	13.658	1.195
39	0.006	0.421	0.035	13.783	1.169
40	0.005	0.492	0.006	13.999	1.164
41	0.004	0.493	0.007	13.842	1.240
42	0.010	0.543	0.002	13.701	1.318

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 E.1 List of acronyms and abbreviations

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