The EUMETSAT Network of Satellite Application Facilities

NWC SAF
Support to Nowcasting and Very Short Range Forecasting

Intercomparison of ASCAT sea surface winds and NWC/GEO-HRW Atmospheric Motion Vectors

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TABLE OF CONTENTS

List of Figures and Tables

1. INTRODUCTION

In order to forecast the weather, conventional observations are sparse, whereas satellite based observations provide near global coverage at regular time intervals.

On one side, Atmospheric Motion Vectors (AMVs) calculate winds through the displacement of cloud features or water vapor gradient features in consecutive satellite images. This is an important source of global wind information, especially over the oceans and remote continental areas. Traditionally, AMVs are generated using imagery from geostationary satellites, which monitor a constant region of the Earth. More recently, satellite winds have also been produced using imagery from polar orbiters, as they provide coverage in polar regions. The Atmospheric Motion Vector general calculation process is composed of several steps:

1. The location of suitable tracers in an initial image.
2. The correlation between images to locate the same features in a later image, in order to determine the displacement vector for the feature. Clouds can change shape or even disappear, but enough tracers survive to produce AMVs. With shorter time intervals up to 15 minutes, the problem is smaller and more vectors are produced.
3. The height assignment of the AMVs, to locate the AMVs in the tridimensional atmosphere.
4. A Quality control. A selection of AMVs is performed, so that only the AMVs with a better quality are accepted.

AMVs have been generated for long with NWCSAF High Resolution Winds algorithm, considering MSG image data. NWC/GEO-HRW is an operational product which is actively used by many of the NWCSAF users, among which many National Meteorological Services. It is useful in Nowcasting applications, used in synergy with other data available to the forecaster. It can also be used in form of objectively derived fields, and assimilated in Numerical Weather Prediction Models (together with many other data), as an input to Analysis, Nowcasting and Very short range forecasting applications.

On the other side, scatterometers are known to provide accurate mesoscale (25-km or 12.5-km sampled) sea surface wind field information, used in a wide variety of applications, including Numerical Weather Prediction (NWP) data assimilation, nowcasting, oceanography and climate studies. Moreover, in contrast with NWP output, C-band scatterometer winds have proven to be very effective in capturing small-scale dynamical features and are only slightly degraded under rainy conditions [RD. 1].

ASCAT shows that small scale structures produced by moist convection near the ocean surface have large convergence, divergence and positive and negative vorticity. This implies strong updrafts and downdrafts and thus intensive vertical exchanges of momentum, heat and moisture. In addition, these have a large impact on turbulent air-sea fluxes, which in turn have an important impact on convective organization and on ocean circulation. C-band scatterometer derived sea surface wind fields are actually routinely superimposed to MSG infrared images (see http://projects.knmi.nl/scatterometer/osisaf/), often showing striking consistency. However, this consistency has not been quantified to date.

This project carries out a preliminary analysis of the differences between ASCAT winds and AMVs generated by NWC/GEO-HRW algorithm. In Section 2 the data and the collocation methodology are presented. In Section 3 the AMV/ASCAT intercomparison is shown in both wind distribution and wind vector differences. Conclusions are given in Section 4.

2. DATA AND COLLOCATION METHODOLOGY

The ASCAT and AMV wind products used in this study correspond to the month of April 2017.

The provided AMV winds are related to the operational region for which NWC/GEO products are calculated in the NWCSAF Helpdesk (www.nwcsaf.org), and are mostly located in the area of the North Atlantic Ocean and Europe. Within a day, the AMV winds are provided every 15 min, corresponding to the time of the MSG image acquisition, tracer computation and AMV calculation. For each tracer, several AMV winds are available and a correlation test as well as an applied quality test is run for each wind measurement, in order to provide the corresponding quality flag.

An AMV data reader developed by ICM is used to extract the AMV relevant information contained in the ASCII data files provided by AEMET. In particular, the wind speed and direction, along with the 27 fields associated to each measurement are sorted in files corresponding to 15-min time slots. A description of these fields can be found in [RD. 2]. Such data arrangement has been done to directly identify those AMV winds to be processed in the temporal collocation. The AMV data selected for this study are those having the correlation flag and the quality flag values equal to 3, which correspond to those winds with the best correlation and quality tests, among the winds calculated for a specific tracer. In addition, AMVs with orographic flag set to 6 have been chosen, so that the wind measurements are not compromised by land contamination. From this dataset, the AMV winds with pressure level lower than 700 hPa have been discarded, as they are expected to be not comparable with the ASCAT surface winds.

ASCAT data have been processed with the ASCAT Wind Data Processor (AWDP), which is software package developed by the Royal Netherlands Meteorological Institute (KNMI), in the context of the EUMETSAT Numerical Weather Prediction Satellite Application Facility (NWP SAF). The input of AWDP is a set of Normalized Radar Cross Section (NRCS) or backscatter measurements from each of the three ASCAT beams (i.e., fore, mid, and aft), organized in a regular grid across the satellite flight direction, i.e., in Wind Vector Cells (WVCs). The different ASCAT wind products have a WVC grid spacing of 25 km and 12.5 km, corresponding to a spatial resolution of 50 km and 25 km, respectively.

The scatterometer wind output is referred to as 10-m equivalent neutral winds [RD. 3], although it has been more recently interpreted as stress-equivalent winds [RD. 4]. Note also that European Centre for Medium-range Weather Forecasts (ECMWF) model output is also available in the ASCAT wind product files.

In particular, the collocated ECMWF winds are estimated by interpolating three 3-hourly ECMWF forecasts (selected from +3 to +18 h in 3-h steps) both in space and time to the ASCAT WVC acquisition. The ECMWF wind output refers to 10-m real winds, and as such, a global systematic difference of 0.2 m/s between ECMWF10-m real winds and ASCAT 10-m neutral winds is expected when compared one to one [RD. 4].

In order to speed up the collocation processing, the ASCAT dataset has been restricted to the area of the North Atlantic Ocean and Europe, where the AMVs are located. In particular, data with longitude ranging between 55W and 0W and latitude between 20N and 70N have been considered. From this restricted dataset, only the ASCAT winds selected by the ambiguity removal step have been used. In addition, only wind data with KNMI quality control flag equal to 0 have been selected, in order to avoid considering those wind vector cells with poor backscatter information and suspicious wind solutions.

The collocation has been performed in two steps. The first step consists of gathering, for each ASCAT WVC, those AMV winds within 30 min from the WVC time and 6.25√2 km distance from the WVC location. By using 12.5-km ASCAT wind products, such spatial threshold reduces the amount of AMV data, which could potentially be collocated with different ASCAT WVCs. In addition, since the AMV winds are not located in a regular grid, such spatial threshold ensures that no AMV winds are skipped in the analysis.

After Step 1, the collocation dataset still contains some redundancy. On the one hand, one AMV grid point can be collocated with more than one ASCAT WVC and, on the other hand, different AMV grid points can share the same collocated ASCAT WVC. While the latter is not a real issue (neighbouring AMV grid points usually correspond to wind estimates at different height levels, and are therefore important to keep since they provide different information content), the former can be avoided since such redundancy does not add any new information in our analysis. The second step of the collocation processing is then to assign for each AMV grid point of the Step 1 collocated dataset, the closest ASCAT WVC in space. Such criterion guarantees that each AMV grid point is collocated with only one ASCAT WVC, but it also allows to have more than one AMV grid point collocated with the same ASCAT WVC.

In the Step 2 collocation, another redundancy from the AMV data files has been taken into account. When the ASCAT wind with minimum distance from the AMV point is selected, more than one AMV wind appear to have the same minimum distance. Such result reveals that there are AMVs with same latitude/longitude and pressure level, but different identification (ID) number. When this event occurs, only the AMV wind with best correlation value is kept. If the correlation values are also the same, then the AMV with best quality index with forecast (QI with forecast) is kept. If the QI with forecast values are also the same, then the AMV with best QI without forecast is kept. If all the fields are identical (except for the ID), then the first AMV wind is kept.

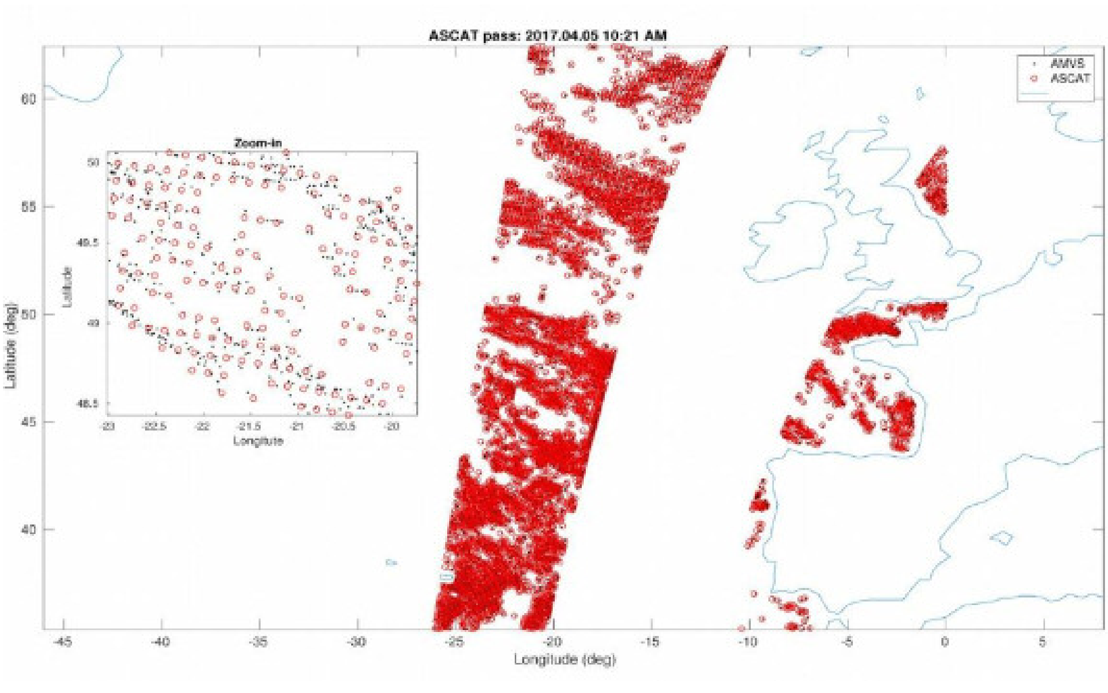

Figure 1: ASCAT winds (red) from April 05, 2017 at 10:21 AM, together with collocated AMVs (black). A zoom in of the right ASCAT swath is included to better show the output data from the Step-2 collocation.

3. AMV/ASCAT INTERCOMPARISON

3.1 COLLOCATED WIND DISTRIBUTIONS

The analysis of the ASCAT/AMVs differences in both wind speed and wind direction has been mainly performed as function of the AMV pressure level. In particular, the analysis is split in four different pressure level (P) ranges from 700 hPa to 900 hPa in intervals of 50 hPa. An additional low-pressure level layer above 900 hPa is used. Due to the small amount of AMVs with P values higher than 900 hPa, no upper threshold has been set. In general, all P level values are below 950 hPa, although a few AMVs up to 970 hPa are found.

As mentioned in Section 2, a third collocated wind source, i.e., ECMWF sea surface wind, is also used in this analysis.

Fig. 2 shows the mean of the wind speed for each wind source, as a function of AMV P level. As expected, the AMV level winds are higher than those at the surface (i.e., ECMWF and ASCAT). Note also that, the ASCAT 10-m neutral winds are slightly higher than the ECMWF 10-m real winds (see section 2). It is interesting to note that the mean sea surface winds significantly decrease with height, from about 7.5 m/s (highest level) to about 5 m/s (lowest level). Because of this, we could speculate that higher wind conditions may generate higher level clouds, but to be assumed, this is something which needs further work in the future.

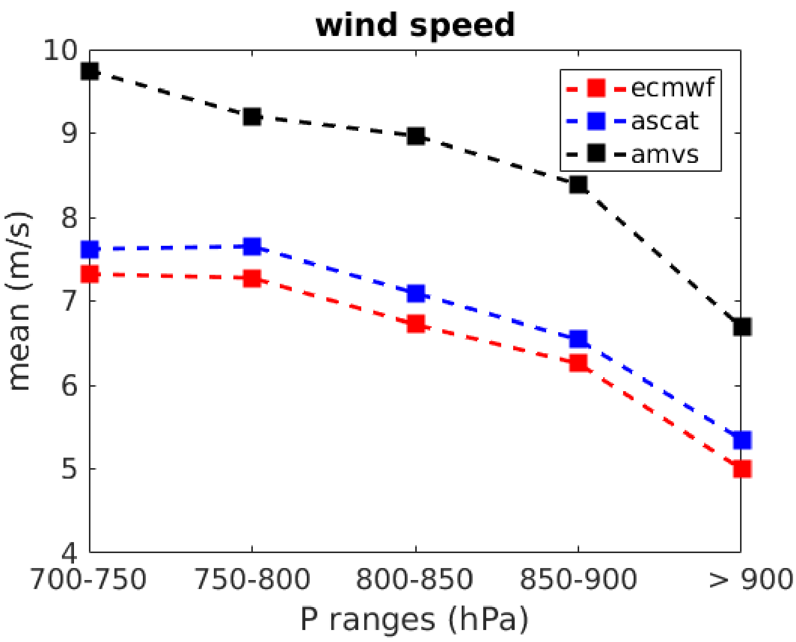

Figure 2: Mean of the AMVS (black) wind speed for different pressure level ranges. Comparison is done with the collocated ASCAT (blue) and ECMWF (red) winds.

The wind speed and wind direction distributions for the collocated AMV/ASCAT/ECMWF datasets are shown in Figs. 3 and 4, respectively. As in Fig. 2, Fig. 3 shows that AMV winds are generally higher than ASCAT and ECMWF winds. Also in line with Fig. 2, Fig. 3 shows that although the ASCAT and ECMWF wind speed distributions for the AMV lower pressure level categories (Figs. 3a and 3b) are similar to that of the global ocean sea surface (i.e., a Rayleigh distribution centered around 7.8 m/s), this is not the case for the AMV higher pressure level categories (Figs. 3d and 3e), where both ASCAT and ECMWF wind speed distributions are centered at lower wind speed values (around 5 m/s) and truncated approximately above 10 m/s.

Regarding the wind direction distributions, it is clear that the AMVs are mostly accumulated at the Northwesterlies and Northeasterlies quadrants, notably the latter (i.e., between 250°-360°), at all P levels. In contrast, this accumulation is less evident in the ASCAT and ECMWF distributions, except for the AMV pressure level category of 850-900 hPa (see blue and red lines of Fig. 4d).

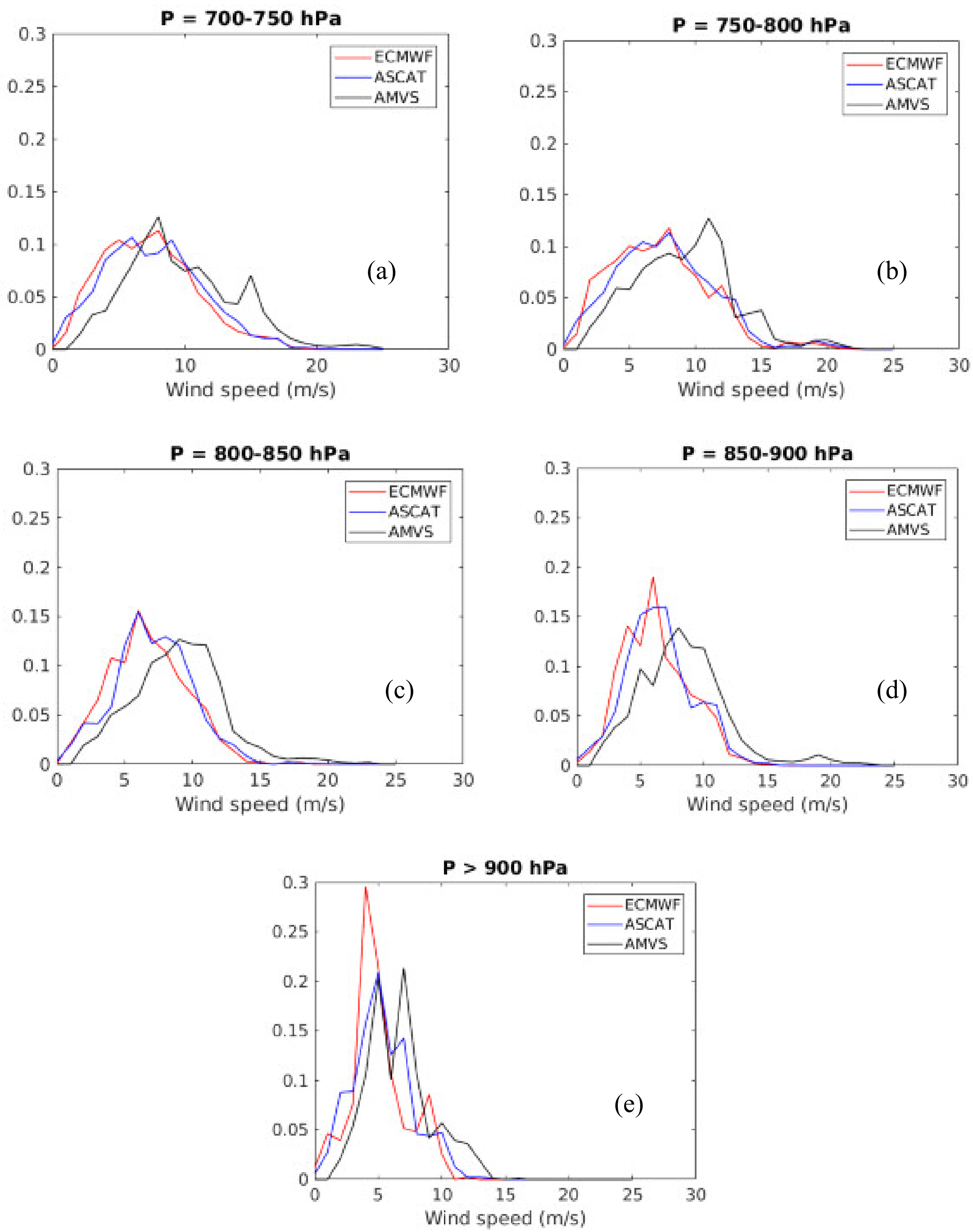

Figure 3: Wind speed distributions for different pressure level ranges. The AMVs distribution (black) is compared to the distribution of the collocated ASCAT (blue) and ECMWF (red) wind speeds, for different AMV pressure level categories: 700-750 hPa (a), 750-800 hPa (b), 800-850 hPa (c), 850-900 hPa (d), and above 900 hPa (e).

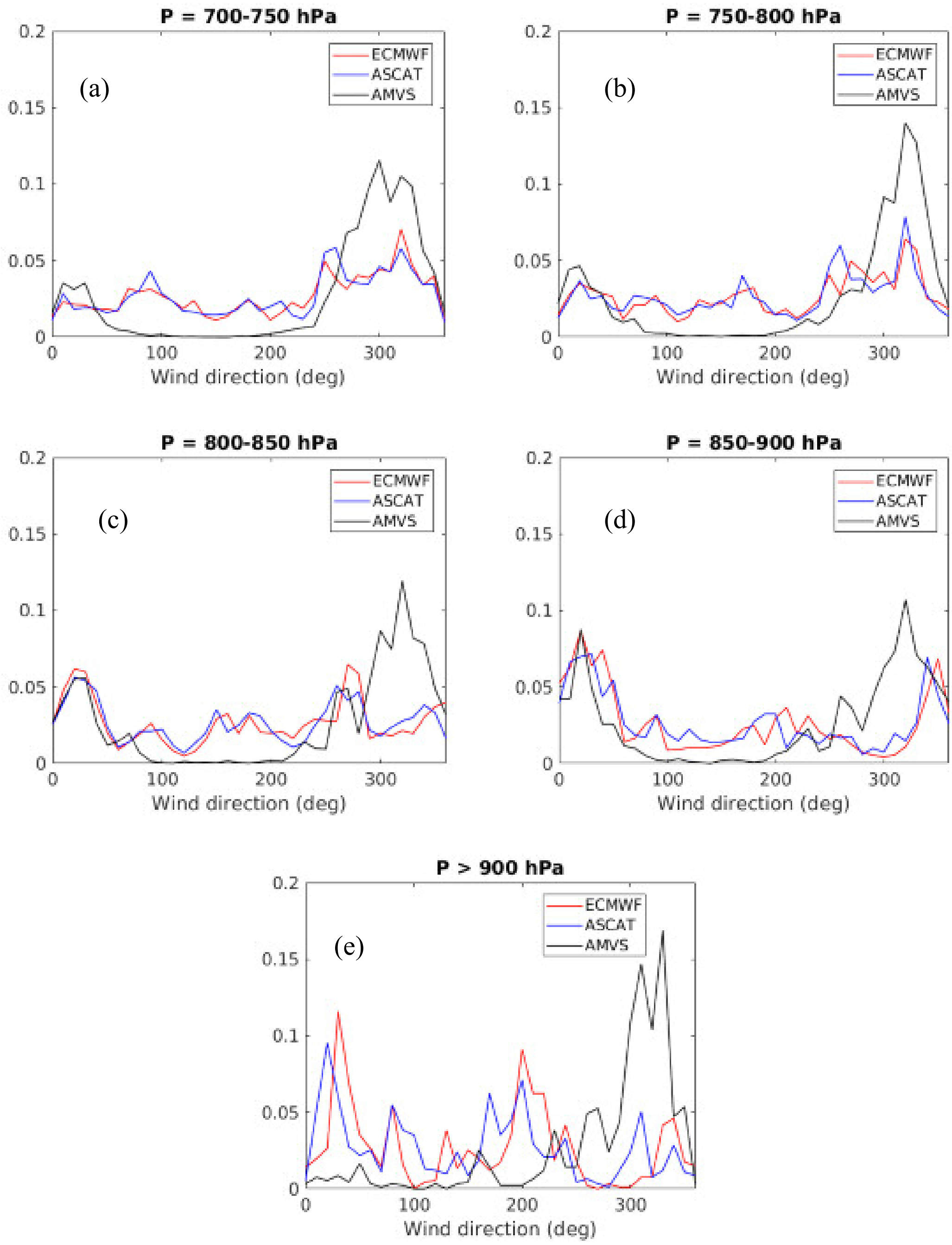

Figure 4: Same as Figure 3 but for wind direction distributions.

3.2 WIND VECTOR DIFFERENCES

Figures 5-9 show the two-dimensional (2D) histograms of AMV winds versus ASCAT winds, for both wind speed (left) and wind direction (right), and for the different AMV pressure level categories, i.e., 700-750 hPa (Fig. 5), 750-800 hPa (Fig. 6), 800-850 hPa (Fig. 7), 850-900 hPa (Fig. 8), and above 900 hPa (Fig. 9).

As expected, at P levels ranging between 700-850 hPa, the wind speed histograms have almost a circular shape with very low (cc) correlation values, showing that, as expected, high-level AMV winds and sea surface ASCAT winds are substantially different.

On the other hand, for P > 850 hPa, the AMV and ASCAT winds tend to be closer to the diagonal. Note though that the correlation value is also very low at high pressure levels, but this can be ascribed to the fact that the wind distribution is narrower and truncated above 10 m/s (see discussion in Section 3.1), and as such, it does not cover all the wind speed range. It can be shown that when the scatter along the diagonal is comparable to that across the diagonal, the correlation value will tend to zero. Therefore, for truncated wind distributions like those of Figs. 8 and 9, lower correlation values are expected.

In such cases, a more representative way to quantify the agreement between AMVs and ASCAT winds is to compute the standard deviation (SD) of the differences between the AMVs and the ASCAT wind speed and direction. Indeed, it is clear that, as the AMV winds get closer to the surface, the SD value decreases from about 5 m/s (Fig. 5) to about 3 m/s (Fig. 9). These AMV/ASCAT wind speed differences are in line with those found in previous studies [RD. 5]. However, note the substantial disagreement between AMV and ASCAT wind directions, even at the highest pressure levels. As mentioned in Section 3.1, the AMV wind direction distribution shows in general larger accumulation around northerly winds, while ASCAT and ECMWF distributions are more spread.

Note also that the number of collocations is rather small at high pressure levels. More robust statistical results would be obtained with a larger number of collocations and, in particular, with full wind speed and direction distributions (notably at high pressure levels).

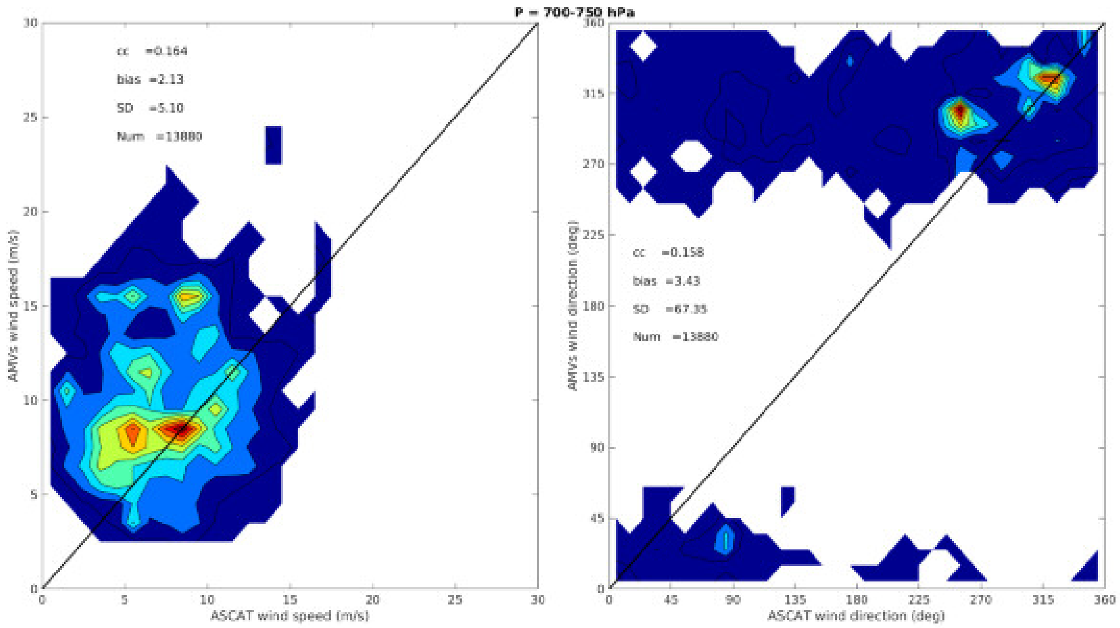

Figure 5: 2D histogram of AMV winds versus ASCAT winds, for both wind speed (left) and wind direction (right), and for the AMV pressure level of 700-750 hPA. The legend shows the correlation (cc), bias (bias) and standard deviation (SD) of the AMV-ASCAT differences, along with the number of collocations (Num) used.

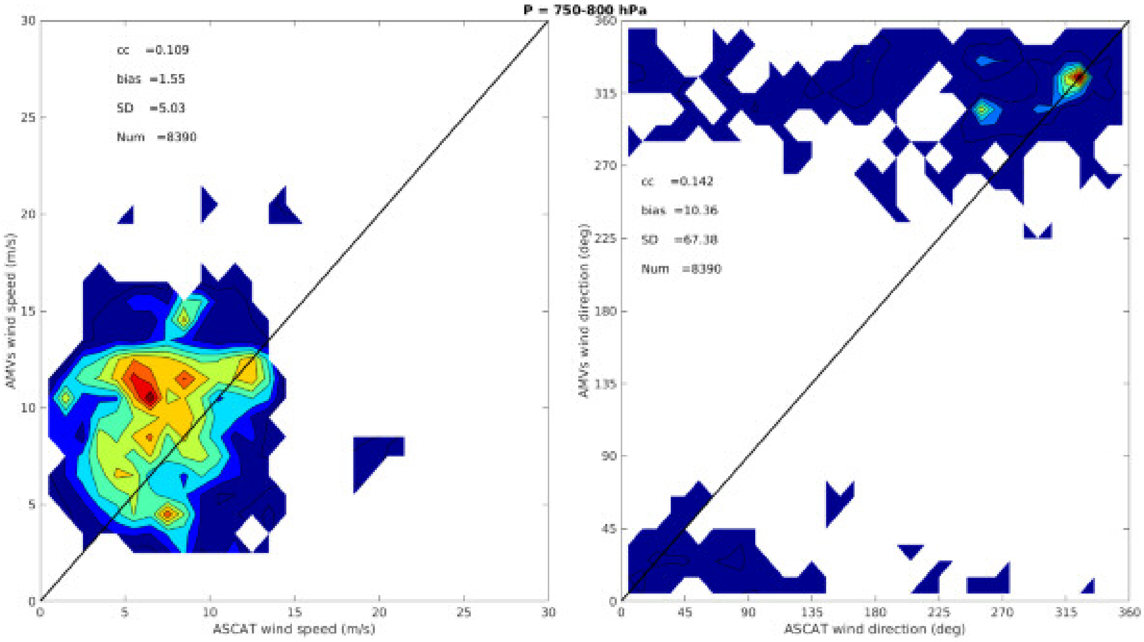

Figure 6: Same as Figure 5, but for the AMV pressure level of 750-800 hPa.

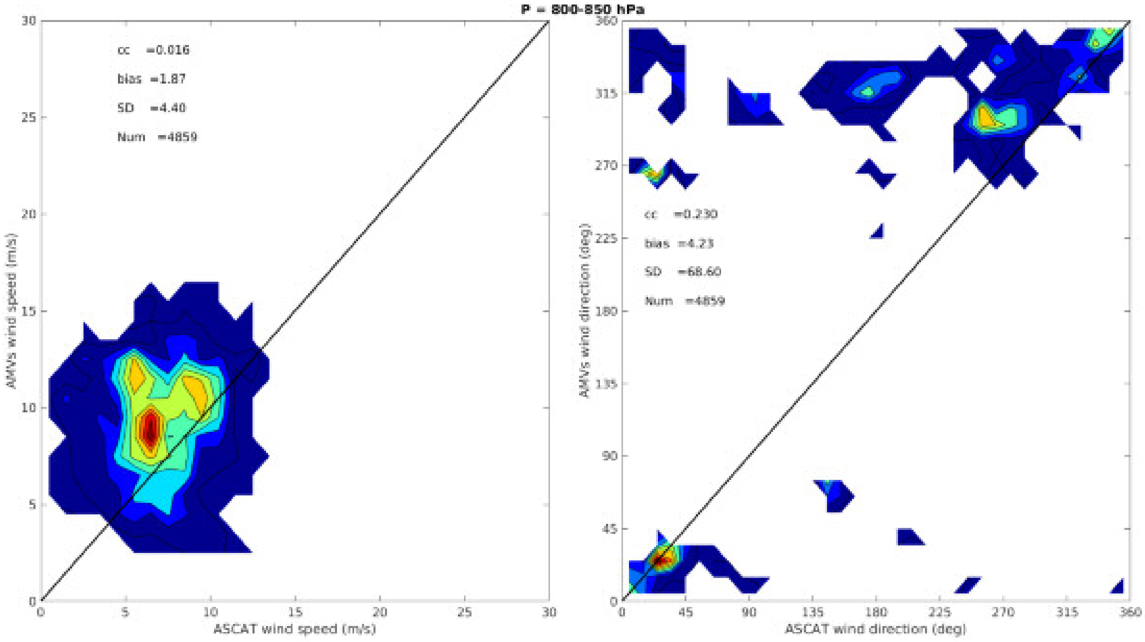

Figure 7: Same as Figure 5, but for the AMV pressure level of 800-850 hPa.

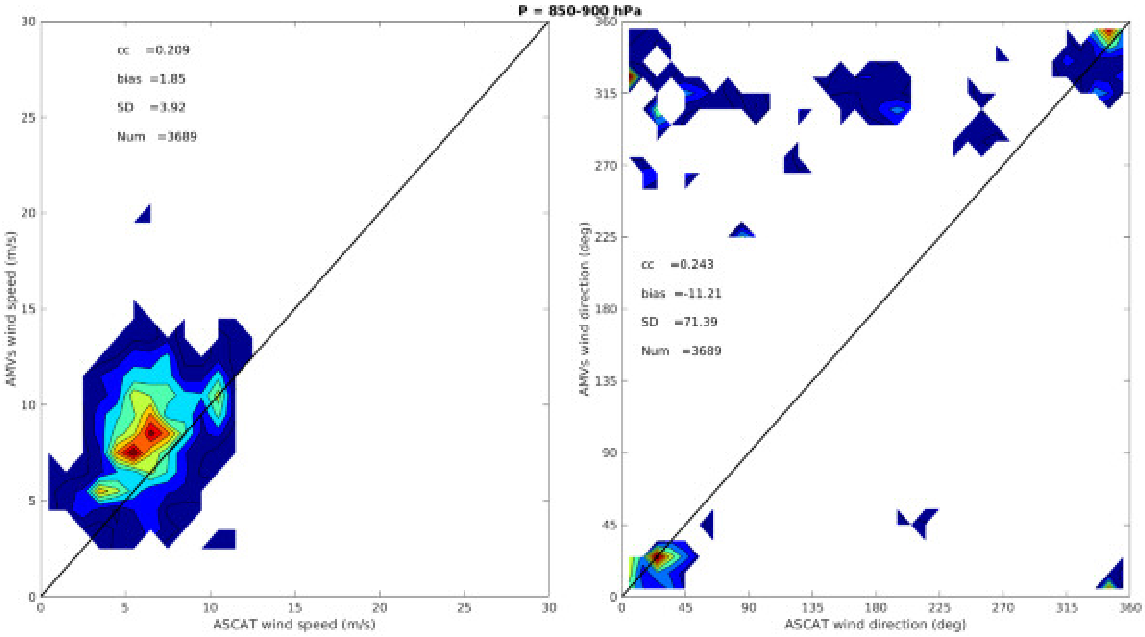

Figure 8: Same as Figure 5, but for the AMV pressure level of 850-900 hPa.

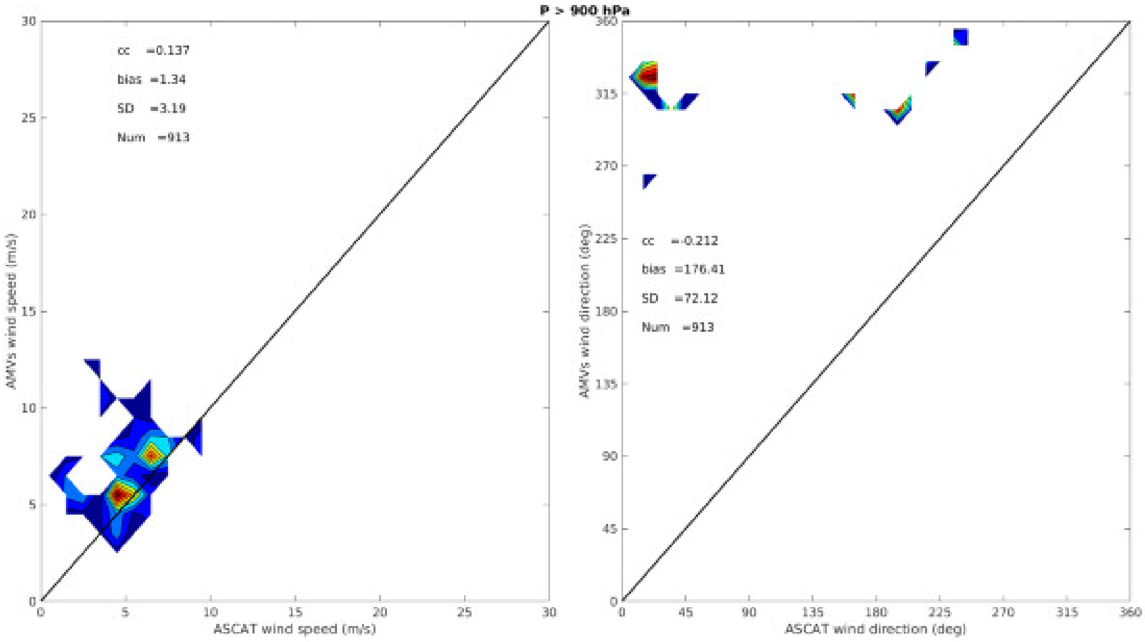

Figure 9: Same as Figure 5, but for the AMV pressure level above 900 hPa.

The analysis of the AMV/ASCAT differences as well as of the AMV/ECMWF differences is also carried out as a function of two other parameters related to the AMV data quality: the AMVs QI with forecast, representing the QI with the contribution of the forecast consistency test [RD. 2], and the MSG satellite channel from which the AMVs are generated. For such comparisons, only the AMV/ASCAT/ECMWF collocations corresponding to the highest pressure level categories, i.e., P > 850 hPa, are used.

Tables 1 and 3 show the mean bias (BIAS), the mean vector difference (MVD), the standard deviation of the vector difference (VSD) and the root-mean-square vector difference (RMSVD) for different QIs and satellite channels respectively. The description of these validation parameters is as follows:

1. $BIAS = \frac{1}{N}\sum_{i=1}^{N}\left(\sqrt{u_i^{a\,2} + v_i^{a\,2}} - \sqrt{u_i^{r\,2} + v_i^{r\,2}}\right)$

2. $MVD = \frac{1}{N}\sum_{i=1}^{N}(VD_i)$ with $VD_i = \sqrt{(u_i^a - u_i^r)^2 + (v_i^a - v_i^r)^2}$

3. $VSD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(VD_i - MVD)^2}$

4. $RMSVD = \sqrt{MVD^2 + VSD^2}$

where (u^a, v^a) and (u^r, v^r) are the wind components of the AMVs and the reference winds, respectively.

In addition, the corresponding normalized parameters with respect to the mean of the reference wind speed (SPD) have been calculated: Normalized BIAS (NBIAS = BIAS/SPD), Normalized MVD (NMVD = NMVD/SPD) and Normalized RMSVD (NRMSVD = RMSVD/SPD). *Tables 2* and *4* show the values of these normalized parameters as a function of the QI and the satellite channel, respectively.

In particular, to study the differences as a function of the QI, the AMV data have been collected by separating those AMVs with QI values higher than 70%, 80% and 90%. The results in Tables 1 and 2 show that the quality of the AMVs has a small impact on the statistics. Indeed, the MVD/RMSVD values as well as the NMVD/NRMSVD slightly decrease when considering AMVs with the highest QI values (i.e., 90%) and this effect is visible in both comparisons, i.e., against ASCAT and ECMWF winds. Note though that the BIAS and NBIAS values are slightly higher for QI > 90% than for lower QI thresholds. Note also that the very large RMSVD values (as compared to the relatively small wind speed SD values shown in the left panels of Figs. 8 and 9) are dominated by the large wind direction differences seen in the right panels of Figs. 8 and 9.

When looking at the differences with respect to WCH (Tables 3 and 4), the high resolution visible (HRVIS) channel produces slightly lower RMSVD values than the other channels, mostly due to the decrease of the corresponding MVD. However, the BIAS and the VSD values are lower for the VIS08 channel. Note that the mean speed for HRVIS is about 2 m/s higher than for the other channels, leading to substantially smaller normalized scores (Table 4). However, there are very few collocations for the HRVIS channel, leading to scores of low statistical significance. A larger amount of collocations is needed to draw more solid conclusions.

AMVs w.r.t. ASCAT/ECMWF	N	BIAS	VSD	MVD	RMSVD
QI >= 70%	4602	1.614/1.938	5.133/4.777	8.620/8.115	10.033/9.417
QI >= 80%	4063	1.759/2.087	5.153/4.775	8.557/8.048	9.989/9.357
QI >= 90%	3047	2.046/2.363	5.137/4.720	8.178/7.711	9.657/9.041

Table 1. Validation parameters calculated for the AMVs intercomparison with respect to ASCAT and ECMWF winds. The bias (BIAS), the Mean Vector Difference (MVD) and the Root-Mean-Square Vector Difference (RMSVD), are shown. The statistics are only performed for those collocations at the highest pressure levels, i.e., P above 850 hPa, and for the following QI with forecast values: higher than 70%, 80% and 90%. The number of corresponding collocations is also provided (N).

AMVs w.r.t. ASCAT/ECMWF	N	SPD (m/s)	NBIAS	NMVD	NRMSVD
QI >= 70%	4602	6.720/6.366	0.240/0.304	1.283/1.275	1.493/1.479
QI >= 80%	4063	6.725/6.371	0.261/0.328	1.272/1.263	1.485/1.469
QI >= 90%	3047	6.701/6.367	0.305/0.371	1.220/1.211	1.441/1.420

Table 2. Same as Table 1 but with Normalized values of the bias (NBIAS), mean vector difference (NMVD), and Root-Mean-Square Vector Difference (NRMSVD), with respect to the mean wind speed (SPD) of the reference wind (i.e. ASCAT and ECMWF).

AMVs w.r.t. ASCAT/ECMWF	N	BIAS	VSD	MVD	RMSVD
HRVIS	248	1.545/1.325	5.273/4.796	6.672/5.748	8.504/7.486
VIS08	2187	0.839/1.290	4.792/4.212	9.267/8.682	10.433/9.650
IR120	2167	2.357/2.634	5.329/5.167	8.236/7.833	9.810/9.384

Table 3. Validation parameters calculated for the AMVs intercomparison with respect to ASCAT and ECMWF winds. The bias (BIAS), the Mean Vector Difference (MVD) and the Root-Mean-Square Vector Difference (RMSVD), are shown. The statistics are only performed for those collocations at the highest pressure levels, i.e. P above 850 hPA, and the following satellite channels (WCH): HRVIS, VIS08 and IR120 (AMV data with other channels are not available in the collocated subset). The number of corresponding collocations is provided (N).

AMVs w.r.t. ASCAT/ECMWF	N	SPD (m/s)	NBIAS	NMVD	NRMSVD
HRVIS	248	8.383/8.425	0.184/0157	0.796/0.682	1.014/0.888
VIS08	2187	6.440/5.971	0.130/0.216	1.439/1.454	1.620/1.616
IR120	2167	6.788/6.515	0.347/0.404	1.213/1.202	1.445/1.440

Table 4. Same as Table 3 but with Normalized values of the bias (NBIAS), mean vector difference (NMVD), and Root-Mean-Square Vector Difference (NRMSVD), with respect to the mean wind speed (SPD) of the reference wind (i.e. ASCAT and ECMWF).

4. CONCLUSIONS

An intercomparison has been carried out between the NWC/GEO-HRW AMV and ASCAT winds. Specifically, the low level AMVs related to the month of April 2017 have been compared to the sea surface winds from the OSI SAF 12.5 km ASCAT product. The collocation has been performed by assigning the closest ASCAT WVC in space to each AMV grid point, within a spatial and temporal threshold of 6.25√2 km and 30 min, respectively. A third wind reference, i.e., ECMWF sea surface winds, which are already interpolated in space and time to the ASCAT winds within the ASCAT L2 product, has been also used in the analysis.

The results shown in this work refer to those AMVs having the correlation flag and applied quality flags equal to 3, which correspond to the highest quality wind among those calculated for each specific tracer. This substantially reduces the number of collocations. Note that, by including all AMVs with correlation flag and quality flag equal to 2, which correspond to those AMVs whose correlation test and quality test is up to 20% worse than the best quality wind (according to the product description), the number of collocated winds increase by a factor of 2.7, although the analysis results do not change significantly (not shown).

The analysis is carried out as a function of the pressure level (P), only considering AMVs with P > 700 hPa. In order to increase the number of collocations at the lower levels (i.e. P > 900 hPa), the spatial collocation criteria have been extended, by extending the spatial distance to 25 km and allowing multiple ASCAT WVCs (within the mentioned distance) for each AMV grid point. This increases the number of available collocations by a factor of 8, but again, the analysis results do not change significantly since we mainly add neighbouring ASCAT WVCs, which only adds redundancy to the analysis.

The main results of the AMV/ASCAT/ECMWF intercomparison are summarized hereafter.

The AMV level wind speeds are generally higher than the ASCAT and ECMWF sea surface winds. In particular, at P levels ranging between 700-850 hPa, the correlation value is very low, showing that, as expected, the low-pressure level AMV winds and the sea surface ASCAT winds are substantially different. On the other hand, for P > 850 hPa, there is a better agreement between AMV and ASCAT winds, but the correlation value is also very low. Such correlation values are mostly due to the wind distribution, which is narrower and truncated above 10 m/s, and as such, it does not cover all the wind speed range. For this reason, a more representative parameter to quantify the agreement between AMVs and ASCAT winds is the standard deviation (SD) of the differences between the AMVs and the ASCAT winds. Indeed, the results show that as the AMV winds get closer to the surface, the SD value decreases from about 5 m/s to about 3 m/s. Such result is in line with those found in previous studies [RD. 5]. In addition, it is interesting to note that the mean sea surface winds significantly decrease with height, from about 7.5 m/s at the lowest pressure level to about 5 m/s at the highest pressure level.

Regarding the wind direction, there is a substantial disagreement between AMV and ASCAT winds, even at the highest pressure levels. In particular, the AMVs are mostly accumulated at the Northwesterlies and Northeasterlies quadrants, (i.e., mostly between 250°-360°), at all P levels, and such accumulation is less evident in the ASCAT and ECMWF wind direction distributions, except for the AMV pressure levels ranging between 850-900 hPa.

The statistics have been also calculated as function of the quality index with forecast (QI with forecast) and the MSG satellite channel for the AMV calculation. The results show that the quality of the AMVs has only a small impact on the statistics. Indeed, the MVD/RMSVD values as well as the corresponding normalized values slightly decrease when considering AMVs with the highest QI values. In addition, the high resolution visible (HRVIS) channel appears to produce slightly lower RMSVD values than the other channels, mostly due to the decrease of the corresponding MVD. Moreover, the mean speed for HRVIS is about 2 m/s higher than for the other channels, leading to substantially smaller normalized scores. However, the number of collocations for the HRVIS channel is very low compared to that of the other two channels, so that the statistics may also be affected by that.

This AMVs/ASCAT/ECMWF intercomparison shows interesting features which would certainly benefit of further investigations. However, more robust statistical results would be obtained with a larger number of collocations and, in particular, with wind speed and direction distributions which do not depend on pressure level and are close to the global sea surface wind distributions.

5. REFERENCES

Ref.	Title
[RD.1]	Lin, W., Portabella, M., Stoffelen, A., Verhoef, A., and Turiel, A., "ASCAT wind quality control near rain *(IEEE Trans. Geosci. Rem. Sens,* vol. 53, n. 8, pp. 4165-4177, doi: 10.1109/TGRS.2015.2392372, 2015).
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[RD.3]	Portabella M. and A. Stoffelen, 2009: On Scatterometer Ocean Stress (*J. Atmos. Oceanic Technology*, vol. 26, pp. 368-382)
[RD.4]	J. De Kloe, A. Stoffelen, A. Verhoef, 2017: Improved Use of Scatterometer Measurements by Using Stress-Equivalent Reference Winds (*IEEE J. Sel. Topics in Appl Earth Obs. and Remote Sens.* vol. 10, n. 5, pp. 2340-2347).
[RD.5]	K. Nonaka, K. Shimoji, K. Kato, 2016: Estimation of the Sea Surface Wind in the Vicinity of Typhoon Using Himawari-8 Low Level AMVs (*13th International Winds Workshop*, Jun. 27-Jul.1 2017, Monterey, CA, USA)

Table 5. List of Reference Documents