Advances in Ku-band scatterometer Quality Control

All Ku-band based scatterometer wind products in the ranges
OSI-100 to OSI-115 and OSI-150 to OSI-159

Version: 1.1

Date: 15/9/2021

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EUMETSAT OSI SAF

Document Change record

Document version	Software version	Date	Author	Change description
1.0		Jun 2021	AV	Initial version
1.1		Sep 2021	AV	Modified according to Xingou's feedback

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1. Introduction

The Satellite Application Facilities (SAFs) are dedicated centres of excellence for processing satellite data – hosted by a National Meteorological Service – which utilise specialist expertise from institutes based in Member States. EUMETSAT created Satellite Application Facilities (SAFs) to complement its Central Facilities capability in Darmstadt. The Ocean and Sea Ice Satellite Application Facility (OSI SAF, http://osi-saf.eumetsat.int/) is one of eight EUMETSAT SAFs, which provide users with operational data and software products. More on SAFs can be read at https://www.eumetsat.int.

The objective of the OSI SAF is the operational near real-time production and distribution of a coherent set of information, derived from earth observation satellites, and characterising the ocean surface and the energy fluxes through it: sea surface temperature, radiative fluxes, wind vector and sea ice characteristics. For some variables, the OSI SAF is also aiming at providing long term data records for climate applications, based on reprocessing activities. KNMI is involved in the OSI SAF as the centre where the level 1 to level 2 scatterometer wind processing is carried out.

The scatterometer is an instrument that provides information on the wind field near the ocean surface, and scatterometry is the knowledge of extracting this information from the instrument's output [1].

KNMI has a long experience in scatterometer processing and is developing generic software for this purpose. Processing systems have been developed for the ERS, SeaWinds, ASCAT, Oceansat-2/OSCAT, RapidScat, Haiyang 2(HY-2)/HSCAT, ScatSat-1/OSCAT, and CFOSAT scatterometers. This documents summarises algorithm improvements in Quality Control (QC) for Ku-band wind scatterometry, leading to the implementation of two new QC flags for the wind products.

Following the introduction, section 2 of this document provides some background and motivation for this work, section 3 introduces the new QC algorithms and section 4 provides validation results and comparisons of the old and new QC methods. The conclusions are summarised in section 5.

2. Background and motivation

Ku-band scatterometers like ScatSat-1, Haiyang-2A/B/C, and QuikSCAT are sensitive to rain, in rainy areas the retrieved winds are usually not reliable [2]. This is contrary to C-band scatterometers like ASCAT which are hardly sensitive to rain. To illustrate this, Figure 1 shows the ScatSat-1 wind speed vs. ASCAT wind speed when no Quality Control (QC) is applied at all for ScatSat-1 winds. There is clearly a large 'lobe' to the upper left of the diagonal, these Ku-band winds are affected by rain and not reliable. Generally, spurious winds with speeds between 15 and 20 m/s are obtained in case of heavy rain. Therefore a Quality Control mechanism is necessary to filter out these winds. On the other hand the good quality winds should not be filtered, the 'false alarm rate' should be as low as possible.

For the OSI SAF wind products (both C-band and Ku-band) currently a Quality Control is used which is based on the Maximum Likelihood Estimator (MLE). MLE is the distance of the measured radar backscatter values to the Geophysical Model Function that describes the empirical relationship between wind speed and direction on one hand and radar backscatter on the other hand. Whenever the backscatter measurements are too far away from the Geophysical Model Function, the Wind Vector Cell is flagged. The MLE threshold which is used to set the flag was determined by Portabella et al. [2] using QuikSCAT – ECMWF winds collocations. The MLE threshold is speed dependent, it increases from ~1% rejections at very low wind speeds up to ~35% rejections at 20 m/s and above. The threshold is probably too high for high wind speeds but it was set in a conservative way since ECMWF does not contain reliable information of local wind variability, downbursts, rain patches and so on. Overall, 5 to 6% of the Ku-band winds are currently rejected which is much higher than the ~0.5% rejections that are obtained for ASCAT

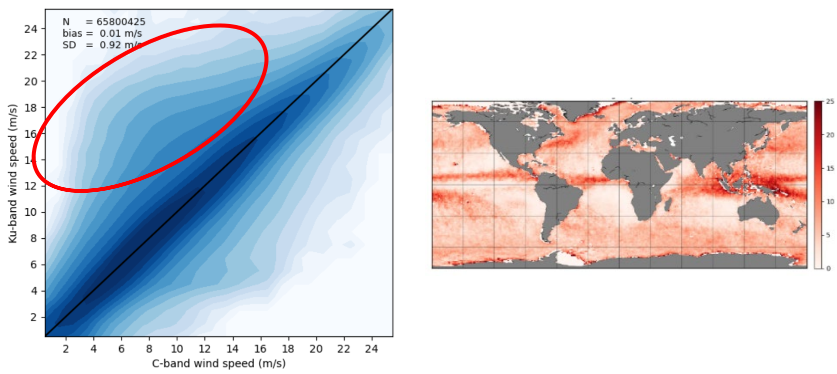

Figure 1: ScatSat-1 vs. ASCAT-A wind speed bias without applying any quality control, the red ellipse indicates the area where winds are affected by rain (left); spatial distribution of ScatSat-1 MLE quality control rejections, the colour indicates the rejection rate percentage (right).

Contrary to the QuikSCAT era, today a large amount of collocated Ku-band and C-band winds are available since ScatSat-1 and the three Metop satellites carrying the C-band ASCAT scatterometer are in almost the same orbit. Hence ASCAT winds can be used as a reference to improve the quality control for ScatSat-1 and subsequently for all Ku-band instruments. ASCAT provides better winds than ECMWF for this purpose since it has a similar spatial resolution and it observes the small scale wind variability in the same way as ScatSat-1.

Another motivation for assessing Ku-band QC is that several QC indicators other than MLE have been proposed in the past years. These new indicators are more sensitive to spatial inconsistencies in the wind field, contrary to MLE which working locally in one Wind Vector Cell and as such is affected by e.g., noise in the local backscatter observations. Lin and Portabella [3] used collocations of ASCAT and RapidScat winds to show that both an MLE value which is spatially averaged over multiple Wind Vector Cells (MLE_m), and the singularity exponents (SE) derived from an image processing technique, are sensitive to the quality of the retrieved winds. Xu and Stoffelen [4] use J_{oss}, the speed component of the observation cost-function (J_o) in 2DVAR, to accept extra WVCs which are rejected by the MLE QC. In the 2DVAR Ambiguity Removal a wind field is constructed from the scat wind ambiguities and ECMWF model winds by minimizing a cost function with constraints on meteorological consistency, this is called the analysis wind field. J_{oss}, is defined as

$$J_{oss} = f - f_s,$$

the analysis wind speed minus the selected scat wind speed. The method was further refined in an abstract submitted to IGARSS 2021 [5] with extra acceptance of winds above 11 m/s.

Xu shows that J_{oss} is very effective in detecting rainy Wind Vector Cells, however with the thresholds used in this work only ~1% of the winds are rejected which is probably too optimistic and not suitable for NWP assimilation. For this work, it was decided to establish a new QC method which makes use of both the MLE and the J_{oss} parameter. In this way, both local and information (MLE) and spatial consistence (J_{oss}) are taken into account. The new QC method can be well validated using the collocated ASCAT winds that are very reliable.

To assess the skill of different QC methods, 10 months of ScatSat-1 and Metop-A ASCAT collocations from Oct 2016 to July 2017 were used. The ScatSat-1 winds were retrieved using the NSCAT-4 Geophysical Model Function and the ASCAT winds were retrieved using the CMOD7 Geophysical Model Function. As such, the wind products are the same as those that are available in near-real time in the OSI SAF [6], [7].

A QC method is defined to have a good skill when the rejected winds have high biases and standard deviations with respect to the ASCAT winds, whereas the accepted winds have low biases and standard deviations with respect to the ASCAT winds. Hence both the accepted and the rejected wind statistics are assessed.

Two new QC flags are proposed:

1. A strict flag which replaces the current MLE KNMI QC flagging but taking advantage of the benefits of J_{oss}; it will be suitable for NWP applications. The accepted winds shall have equal or better statistics of ScatSat-1 winds vs. ASCAT winds and vs. ECMWF winds. This flag will have a rejection rate somewhat lower than the current 5 to 6 % which are rejected by the current MLE QC.
2. A relaxed flag which is suitable for nowcasting and visual applications where a slight deterioration of the winds is acceptable, it will have a lower a rejection rate of around 2 %.

3. QC algorithm description

In Figure 2 (left plot), the ScatSat-1 wind retrievals, per ScatSat-1 wind speed, have been ordered by their MLE values in bins of 1%: the first bin contains the 1% highest MLEs, the second bin the next 1% highest MLEs and so on to the 100th bin which contains the 1% lowest MLEs. For each bin, the average wind speed bias (ScatSat-1 – ASCAT) was computed and plotted in a colour scale. The right plot of Figure 2 is the same, but then for J_{oss}. Here the values are sorted from low to high since a lower J_{oss} value corresponds to a larger deviation from the analysis speed, i.e., a larger rain contamination.

The black lines in the plots show the operational QC threshold fraction, as expected it appears to be very conservative in particular at high wind speeds. Many winds with zero wind speed bias are rejected by applying this threshold. Therefore a new MLE rejection rate for the percentiles corresponding to a bias of 0.60 m/s was chosen, this leads to a rejection rate of ~2.6%, see the grey line in the left hand side plot. Note that for wind speeds above 20 m/s a constant rejection rate was chosen, the number of available collocations in the data set is quite low here and we assume the MLE and bias characteristics to be fairly constant for these wind speeds. The MLE-based rejection is performed like before using a lookup table with the MLE threshold values as a function of wind speed and WVC number. This table is generated by computing the MLE value for which the defined percentage (according to the grey curve in the left hand side plot in Figure 2) is rejected.

The J_{oss} rejection rate was established corresponding to a bias of 1.10 m/s, this also leads to a rejection rate of ~2.6%. We allow slightly higher wind speed biases of up to around 2 m/s above ~20 m/s, where rain appears to play a smaller role, this is reflected in the grey line in the right hand side plot of Figure 2. Contrary to the MLE-based QC, the J_{oss}-based is only wind speed dependent and independent of the swath location / WVC number.

The final J_{oss} threshold $J_{oss,lim}$ as a function of ScatSat-1 wind speed v is modelled by three straight lines in the wind speed domain and set to

$J_{oss,lim} = 0.3 * v - 4.2$ $\quad v < 9$ m/s

$J_{oss,lim} = -1.5$ $\quad 9$ m/s $<= v < 18$ m/s

$J_{oss,lim} = -0.4 * v + 5.7$ $\quad v > 18$ m/s

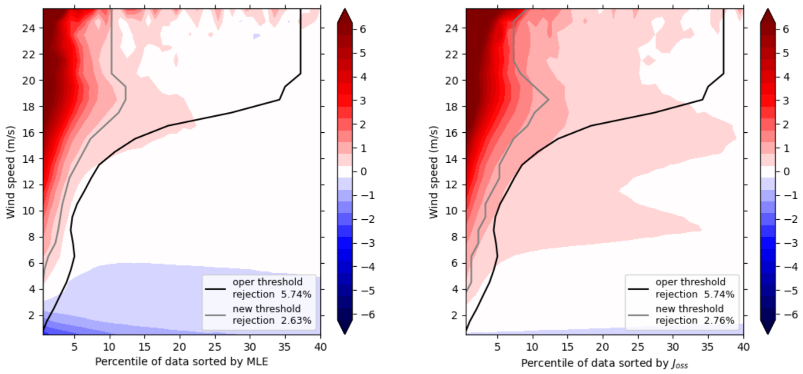

Figure 2: Wind speed bias (m/s according to colour scale) of ScatSat-1 vs. ASCAT as a function of ScatSat-1 wind speed and the sorted percentiles by MLE (left) and J_{oss} (right).

The new proposed QC flags are raised in the following circumstances

1. The strict flag is set whenever either the MLE exceeds the threshold or J_{oss} is lower than the threshold; this leads to a (combined) rejection rate of ~3.9%. We call this flag the 'KNMI Quality Control data rejection for NWP', in the data products it will replace the KNMI flag.
2. The relaxed flag is set whenever J_{oss} is lower than the threshold, i.e., MLE is not considered; this leads to a rejection rate of ~2.6%. We call this flag the 'Quality Control data rejection for visualisation and nowcasting', in the data products it will be implemented in an unused bit flag of the WVC quality parameter.

4. Validation results

4.1. KNMI Quality Control data rejection for NWP

Figure 3 and Figure 4 show the wind speed bias statistics of ScatSat-1 versus ASCAT for the existing MLE QC and for the NWP QC, respectively. The new QC has a lower rejection rate (3.9% vs. 5.7%), still accepted winds have a lower bias than MLE-accepted winds and a narrower contour along the diagonal (left hand side plots); on the other hand the contour of the rejected winds is more clearly above the diagonal for NWP QC than for MLE QC (middle plots). A good QC skill is indicated by a low bias/SD for accepted winds and a high bias/SD for rejected winds, in this respect the NWP QC has a better skill than the MLE QC.

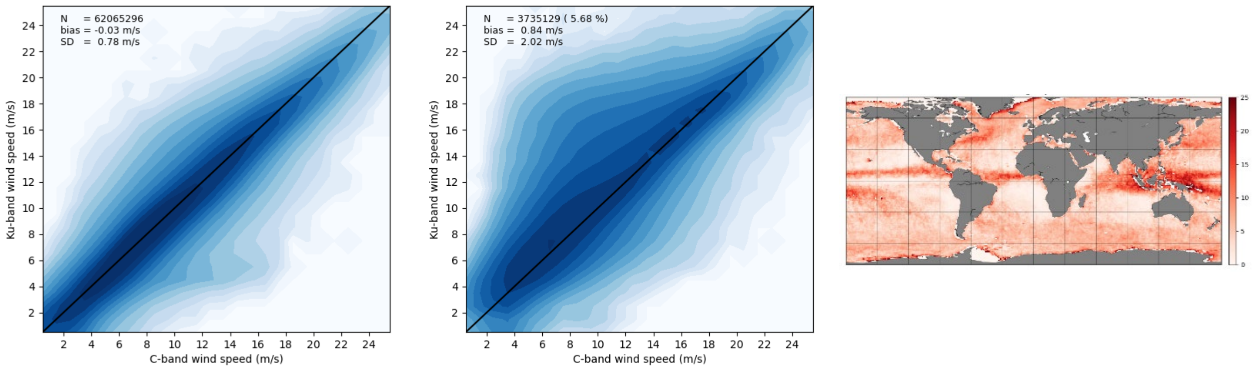

Figure 3: Wind speed bias of ScatSat-1 vs. ASCAT for accepted winds by MLE QC (left), for rejected winds by MLE QC (middle) and spatial distribution of the rejected winds, the colour indicates the rejection rate percentage (right).

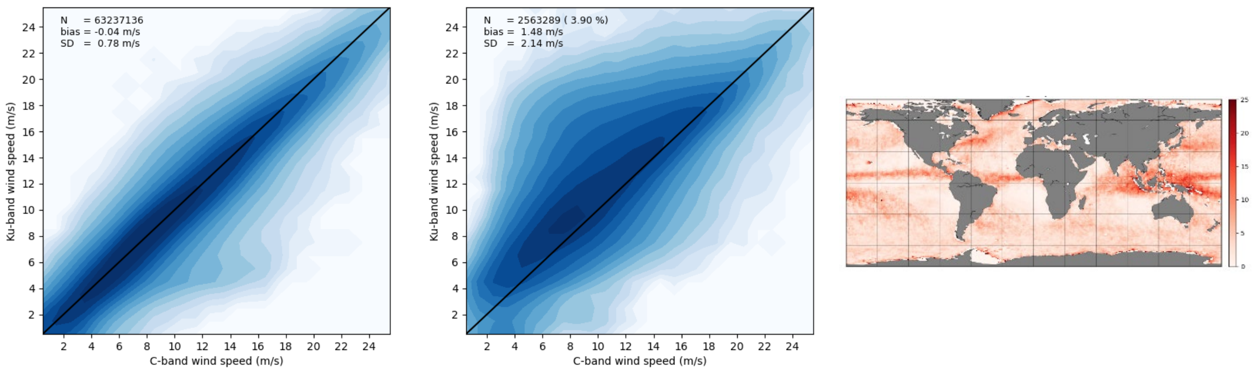

Figure 4: Wind speed bias of ScatSat-1 vs. ASCAT for accepted winds by NWP QC (left), for rejected winds by NWP QC (middle) and spatial distribution of the rejected winds, the colour indicates the rejection rate percentage (right).

Figure 5 shows another way to assess the difference between the two MLE methods. Here the wind statistics for the data sets where the two methods have a different flag setting are shown. The left hand plot shows the winds which were rejected by MLE QC, but are accepted by NWP QC. The right hand plots shows the winds which were accepted by MLE QC, but are rejected by NWP QC. The new accepted winds have a low bias (0.05 m/s, left plot) whereas the new rejected winds have a quite high bias (1.13 m/s, right plot) indicating that the new QC has a better skill. So, we conclude that this new QC has a better skill and can replace the current KNMI QC flag

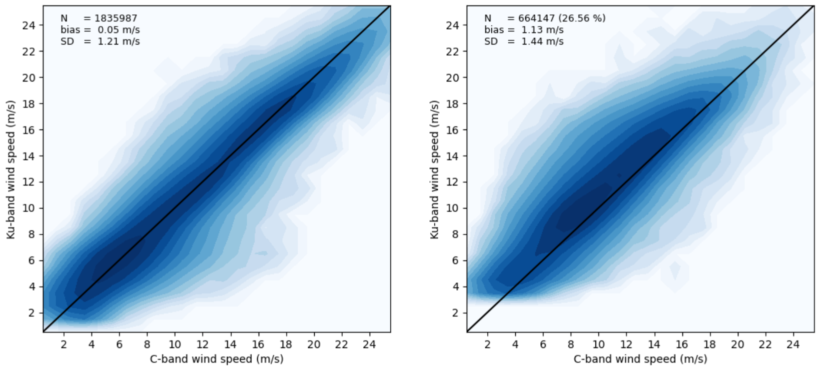

Figure 5: Wind speed bias between ScatSat-1 and ASCAT for winds accepted by NWP QC and rejected by MLE QC (left) and wind speed bias for winds rejected by NWP QC and accepted by MLE QC (right).

Finally it is relevant to investigate if the new NWP QC performs better than an MLE-only or J_{oss}-only QC with the same speed dependent rejection rate, leading to a total rejection rate of 3.9%. In other words, does the use of two QC parameters have added value above using only one of them? Figure 6 and Figure 7 show the wind statistics for an MLE-only and J_{oss}-only QC with such rejection rates. These plots can be compared to Figure 4.

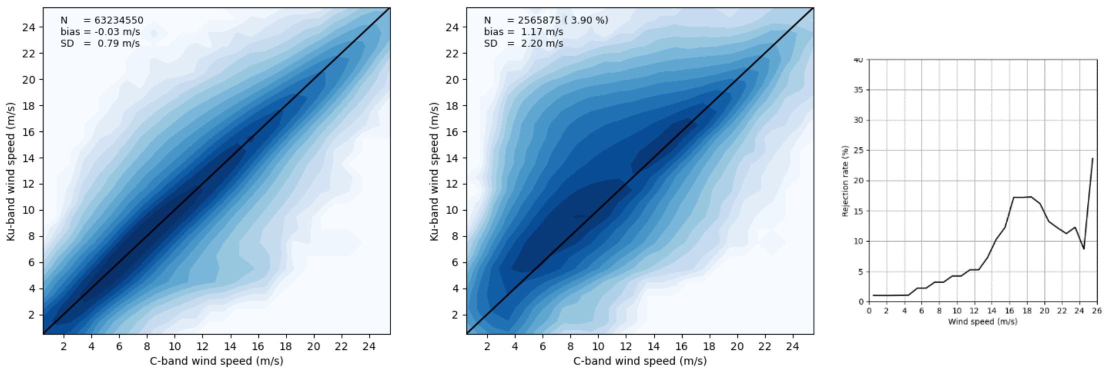

Figure 6: Wind speed bias between ScatSat-1 and ASCAT for winds accepted (left) and rejected (middle) by an MLE QC with identical rejection rate as NWP QC; the speed dependent rejection rate is shown in the right hand plot.

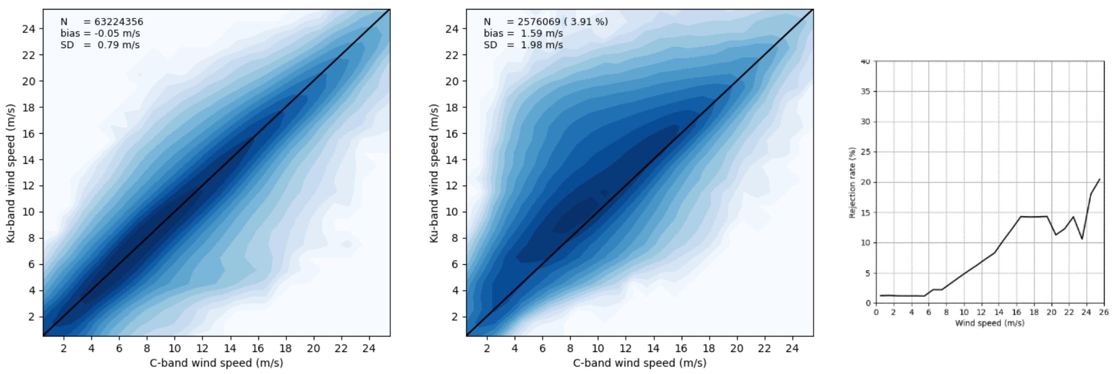

Figure 7: Wind speed bias between ScatSat-1 and ASCAT for winds accepted (left) and rejected (middle) by a J_{oss} QC with identical rejection rate as NWP QC; the speed dependent rejection rate is shown in the right hand plot.

The accepted winds of MLE QC (reduced rejection rate, Figure 6) have higher bias and standard deviation, whereas the rejected winds have lower bias, the contour of rejections is closer to the diagonal so indeed the NWP QC performs better. For the J_{oss}-only QC (Figure 7) it is more difficult to decide, but the contour of accepted winds for Joss QC appears to be somewhat broader which indicates a slightly lower skill

4.2. KNMI Quality Control data rejection for visualisation and nowcasting

Figure 8 shows the wind speed bias statistics of ScatSat-1 versus ASCAT for the nowcasting QC. The new QC has a lower rejection rate (2.6%) than the NWP QC (3.9%) and the MLE QC (5.7%). Accepted winds have slightly lower bias for nowcasting QC as compared to MLE QC but on the other hand a somewhat higher standard deviation. The accepted winds have comparable bias and standard deviation as the accepted winds from the old MLE QC so it is still very well usable for nowcasting applications.

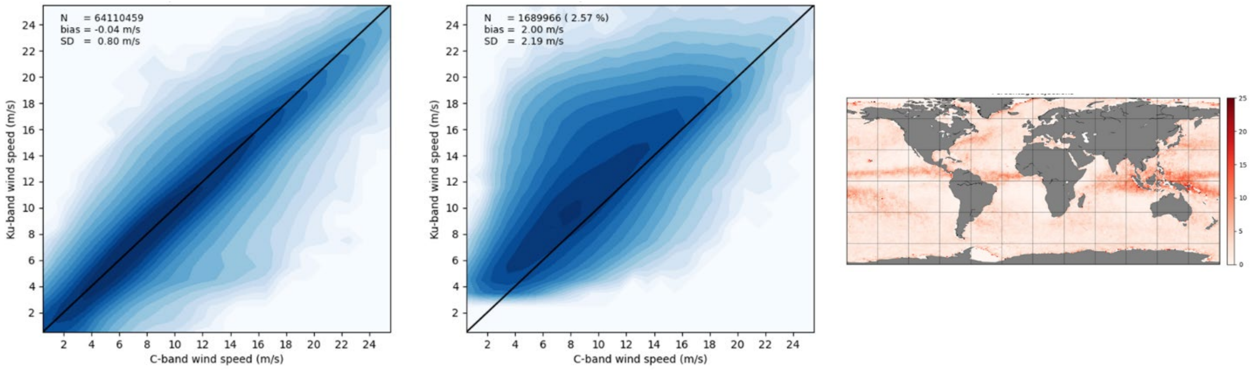

Figure 8: Wind speed bias of ScatSat-1 vs. ASCAT for accepted winds by visualisation/nowcasting QC (left), for rejected winds by visualisation/nowcasting QC (middle) and spatial distribution of the rejected winds, the colour indicates the rejection rate percentage (right).

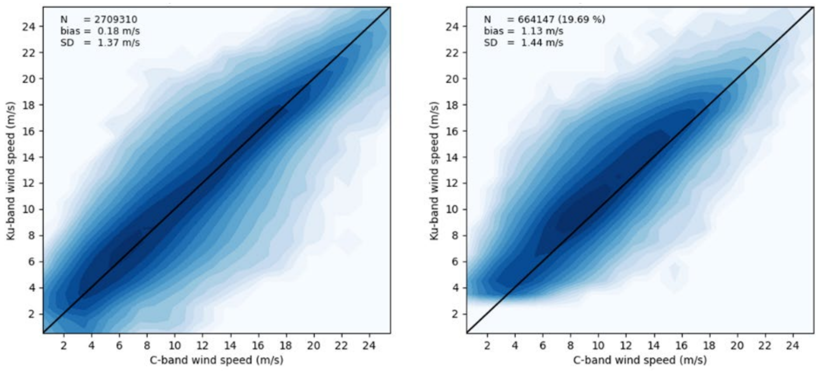

Figure 9: Wind speed bias between ScatSat-1 and ASCAT for winds accepted by visualisation/nowcasting QC and rejected by MLE QC (left) and vice versa (right).

Figure 9 compares the nowcasting QC and MLE QC in the same way as was done in the previous section for NWP QC and MLE QC. The wind statistics for the data sets where the two methods have a different flag setting are shown. The left hand plot shows the winds which were rejected by MLE QC, but are accepted by nowcasting QC. The right hand plots shows the winds which were accepted by MLE QC, but are rejected by nowcasting QC. The new accepted winds have a reasonably low bias (0.18 m/s, left plot), somewhat higher than the bias of the new accepted winds by mixed QC (0.05 m/s).

4.3. Comparison with ECMWF winds

The accepted winds of the three QC methods have also been compared to forecast winds from the ECMWF model. This comparison was not only done for ScatSat-1 winds, but also for HY-2B winds [8]. Since every retrieved wind is collocated to spatially and temporally interpolated model data, two days of data is sufficient to obtain reliable statistics. The ECMWF winds are stress equivalent 10 m winds to best represent the retrieved scatterometer winds. The results are compiled in Table 1. In all cases the biases and standard deviations are lower when NWP QC is compared with MLE QC for the same instrument. For nowcasting QC the statistics are comparable to those of MLE QC.

It is remarkable that the HY-2B rejection rates for NWP QC and nowcasting QC are lower than those for ScatSat-1. The reason for this is not clear, it may be related to the fact that HY-2B wind retrieval uses full radar footprints whereas for ScatSat-1 high resolution backscatter 'slices' are used. This may lead to a slightly noisier wind field with less spatial consistency and hence a higher rejection rate by the J_{oss} QC.

	speed bias	stdev *u*	stdev *v*	stdev wind dir	rejection rate
ScatSat-1 MLE QC	-0.05	1.28	1.23	10.14	5.44%
ScatSat-1 NWP QC	-0.08	1.26	1.21	10.14	3.85%
ScatSat-1 nowcasting QC	-0.07	1.27	1.22	10.19	2.63%
HY-2B MLE QC	-0.04	1.21	1.21	9.57	5.47%
HY-2B NWP QC	-0.05	1.20	1.20	9.60	3.16%
HY-2B nowcasting QC	-0.04	1.22	1.22	9.66	1.74%

Table 1: ECMWF comparison results of ScatSat-1 25 km winds (23 and 24 March 2018) and HY-2B 25 km winds (1 and 2 January 2019). Numbers are shown for the wind speed bias, the standard deviations of the zonal (u) and meridional (v) wind components, the standard deviations of the wind direction difference, and the rejection rates.

4.4. Wind field examples

In Figure 10 and Figure 11 some wind field examples are shown. The same HY-2B wind fields are shown in each plot, only the applied QC methods differ.

In Figure 10 the NWP QC rejects less scattered winds and less winds near the front in the middle right, whereas the nowcasting QC rejects even less winds. The region north-east of the cyclonic structure is still rejected by NWP QC and nowcasting QC and apparently heavily contaminated with rain.

The scene in Figure 11 is from the same HY-2B orbit but more to the north. The NWP QC rejects less winds along the frontal structure and almost no scattered winds north of the front. The nowcasting QC rejects even less winds along the front and the extra accepted winds appear to be fully consistent.

Generally it appears from these examples that the NWP QC accepts more winds than MLE QC, whereas nowcasting QC accepts even more winds. In all cases, the newly accepted winds appear to be consistent and in that respect they are useful for a better coverage of the wind field.

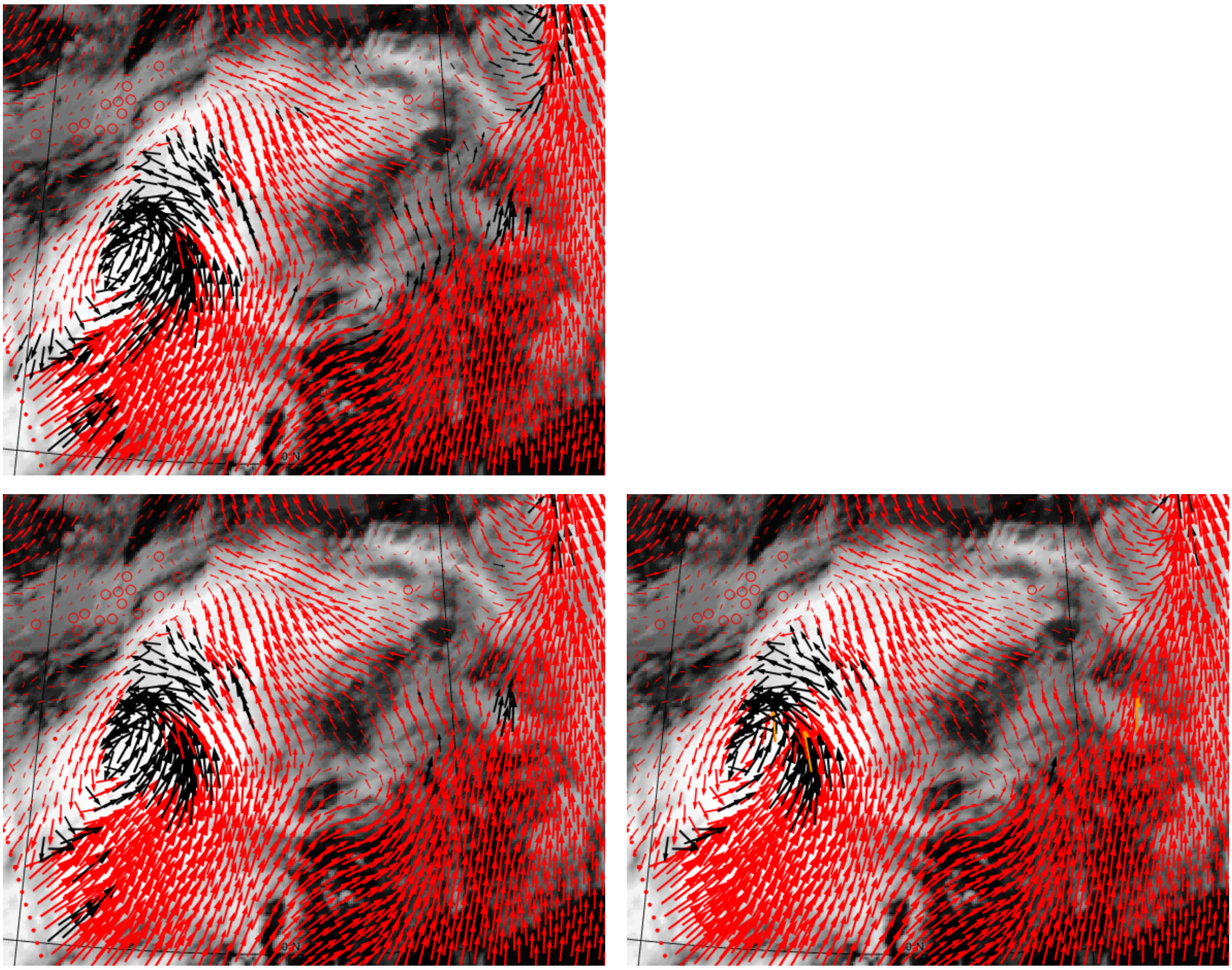

Figure 10: HY-2B wind field from 29 April 2021 ~20:00 UTC over the North Atlantic around 44° N, 45° W using MLE QC (top), NWP QC (bottom, left) and nowcasting QC (bottom, right). Rejected winds are in black.

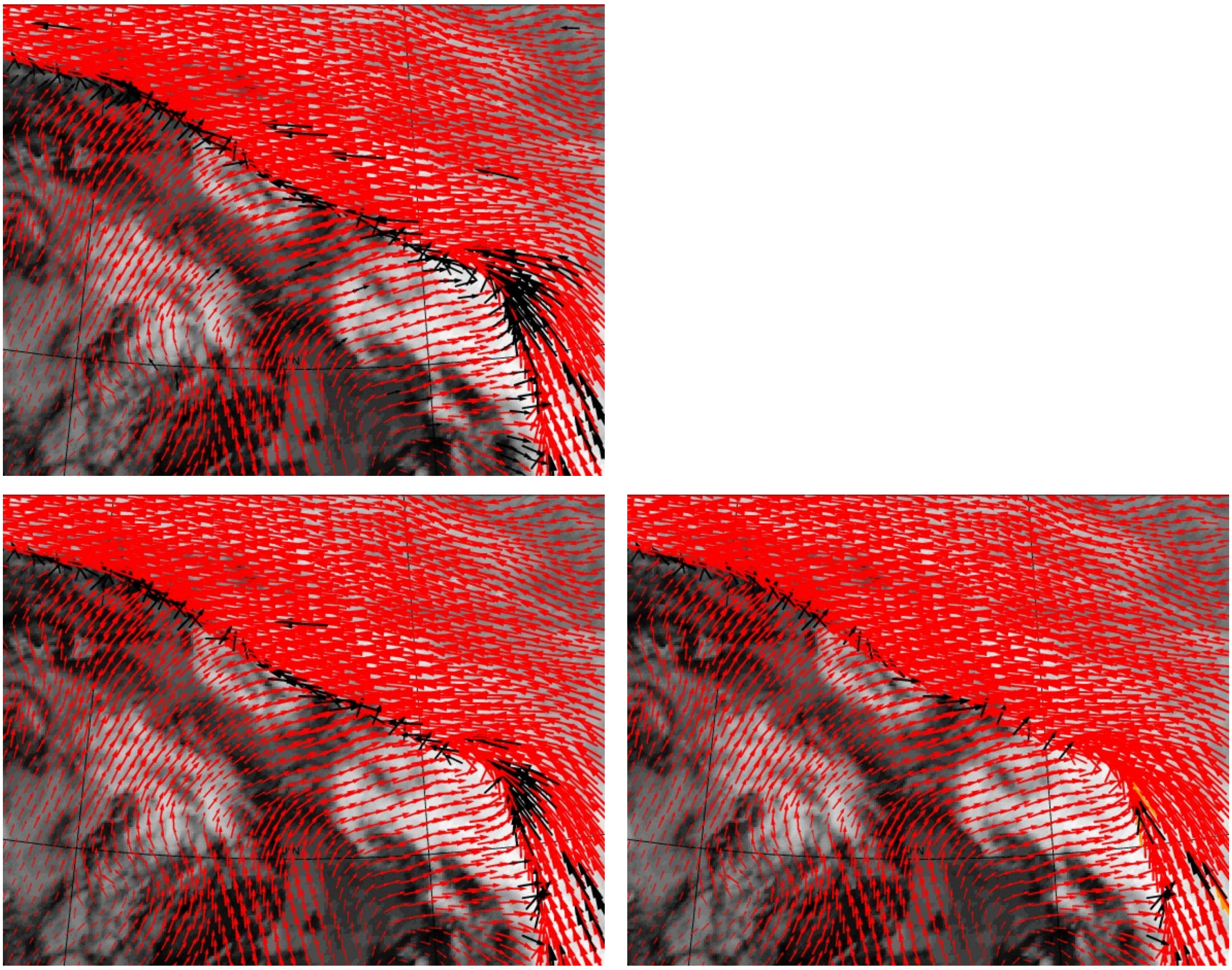

Figure 11: HY-2B wind field from 29 April 2021 ~20:00 UTC over the North Atlantic around 52° N, 45° W using MLE QC (top), NWP QC (bottom, left) and nowcasting QC (bottom, right). Rejected winds are in black.

5. Conclusions

The availability of abundant ScatSat-1 and ASCAT wind collocations has helped to get a better insight into the true characteristics of Ku-band wind retrievals in rainy and dynamic situations. This gives the opportunity to refine the Ku-band Quality Control. In this work, two new QC flags for Ku-band wind scatterometry are proposed, a conservative (NWP QC) flag to replace the current KNMI MLE flag for NWP applications, and a new, less conservative (nowcasting QC) flag for nowcasting applications.

Both QC flags have been validated using ASCAT and ECMWF reference winds, and inspection of wind field example plots. The NWP QC flag shows a better QC skill than the old MLE flag but at the same time it rejects significantly less winds (3.9% vs. 5.7%). The nowcasting QC flag shows a comparable skill as the old MLE flag and it rejects even less winds (2.6%).

6. References

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[5] Xu, X. and A. Stoffelen, A further evaluation of the quality indicator J_{oss} for Ku-band wind scatterometry in tropical regions, *IEEE IGARSS,* 2021, Brussels, Belgium

[6] EUMETSAT OSI SAF/EARS, ASCAT Wind Product User Manual, SAF/OSI/CDOP/KNMI/TEC/MA/126

[7] EUMETSAT OSI SAF, ScatSat-1 wind Product User Manual, SAF/OSI/CDOP2/KNMI/TEC/MA/287

[8] EUMETSAT OSI SAF, Product User Manual (PUM) for the HY-2 winds, SAF/OSI/CDOP3/KNMI/TEC/MA/392

7. Abbreviations and acronyms

2DVAR	Two-dimensional Variational Ambiguity Removal
AR	Ambiguity Removal
ASCAT	Advanced Scatterometer
CFOSAT	China-France Oceanography SATellite
ERS	European Remote-Sensing Satellite
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GMF	Geophysical Model Function
HSCAT	Scatterometer on-board the Chinese Haiyang satellites
KNMI	Royal Netherlands Meteorological Institute
MLE	Maximum Likelihood Estimator
NWP	Numerical Weather Prediction
OSCAT	Scatterometer on-board the Indian Oceansat-2 and ScatSat-1 satellites
OSI SAF	Ocean and Sea Ice SAF
QC	Quality Control
QuikSCAT	USA dedicated scatterometer mission
RapidScat	SeaWinds-like scatterometer on-board the International Space Station
SAF	Satellite Application Facility
SE	Stress Equivalent
SeaWinds	Scatterometer on-board QuikSCAT platform (USA)
u	West-to-east wind component
v	South-to-north wind component
WVC	Wind Vector Cell