CONSOLIDATION OF QUALITY CONTROL PROCEDURES FOR SCATTEROMETERS

Marcos Portabella[1], Wenming Lin[2], Ad Stoffelen[3], Xingou Xu[4], Xiaolong Dong[4]

[1]Institute of Marine Sciences (ICM-CSIC), 08003, Barcelona, Spain
[2]School of Marine Sciences, Nanjing University of Information Science and Technology, 210044, Nanjing, China
[3]Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands
[4]Key Laboratory of Microwave Remote Sensing, National Space Science Center, Chinese Academy of Sciences, Beijing 100190, China

ABSTRACT

With the advent of the golden era of scatterometry, with seven scatterometers currently operating in orbit and a few others to be launched in the near future, a wide variety of scientific and operational applications will certainly benefit from consolidated wind retrieval procedures. In particular, an important component of the scatterometer wind processing is the quality control (QC) procedure. Over the last two decades, several QC indicators have been developed for C-band and Ku-band scatterometers, and used in the operational generation of sea surface wind products. Such indicators mostly aim at identifying and filtering retrieved wind quality degradation due to high wind variability and/or rain contamination effects. As such, the different QC indicators may be applied for different oceanographic and meteorological applications. The methods will be presented at the conference to motivate a discussion on their application-dependent use and come up with a consolidated view from the different user communities.

Index Terms— Scatterometer, wind, quality control, rain, wind variability.

1. INTRODUCTION

Scatterometers are known to provide accurate mesoscale (25-50 km resolution) sea surface wind field information used in a wide variety of applications, including Numerical Weather Prediction (NWP) data assimilation, nowcasting, ocean forcing and climate studies. The impact of scatterometry in such applications is expected to boost with the currently growing scatterometer constellation. In particular, the following scatterometers are currently operating: the three C-band Advanced Scatterometers, ASCAT-A, -B & -C onboard the European Metop-A, -B, and -C, respectively; the OSCAT-2 onboard the Indian SCATSat-1; the HSCAT-B and HSCAT-C onboard the Chinese HY-B and HY-2C, respectively; and the rotating fan-beam scatterometer CSCAT onboard the Chinese-French CFOSAT. Moreover, in the near future, OSCAT-3 onboard the Indian Oceansat-3 and WINDRAD onboard the Chinese FY-3E will also be launched. While the ASCATs are operating in C-band with fixed viewing geometry, the others are Ku-band with varying viewing geometry (except for the upcoming WINDRAD which will operate at both C- and Ku-band).

Within the Committee on Earth Observation Satellites (CEOS) virtual constellation of ocean surface vector wind project, a particular effort is currently undergoing on the standardization/best practices of scatterometer wind retrieval approaches for optimized scientific and operational applications. An essential component of the scatterometer wind processing is the quality control procedure. Scatterometers are sensitive to geophysical phenomena other than the area or wind vector cell (WVC) mean stress-equivalent wind and SST [1], such as rain, local wind variability, confused sea state, and the radar footprint contamination by land or ice. Some attempts were made to either correct the radar backscatter for rain contamination effects [2], [3] or to use a neural network approach to relate the backscatter to the sea surface winds in all weather conditions [4], However, these phenomena distort the WVC-mean wind signal, leading to poor-quality retrieved winds. As such, detection and then correction or elimination of poor-quality data is a prerequisite for the successful use of scatterometer winds.

Hence in scatterometry quality indicators are developed for flagging poor-quality retrieved winds. Over the past two decades, three different flagging methodologies have been consolidated: 1) one based on the inversion residual [5]-[7]; 2) another one based on the local decorrelation of neighbouring WVC winds [7]-[11]; 3) and a third method based on the consistency between the retrieved wind and that obtained in the 2DVAR ambiguity removal step [12],

[13]. The three QC indicators are presented in Section 2. A discussion about the main results of the mentioned indicators and their different application domains can be found in Section 3.

2. QC INDICATORS

a) MLE

The inversion residual or Maximum Likelihood Estimator (MLE) can be interpreted as the closest distance of the scatterometer set of backscatter measurements in a WVC (corresponding to the different antenna beams) to the Geophysical Model Function (GMF). For example, for a given WVC position across the swath, the ASCAT measured backscatter triplets (corresponding to the fore, mid, and aft beams) are distributed around a well-defined "conical" surface and hence the signal largely depends on just two geophysical parameters, i.e., wind speed and direction. Such cone, as constructed from the so-called CMOD7 Geophysical Model Function (GMF) [14], represents the best known fit to the measured triplets and can in turn be used for Quality Control (QC) purposes.

In general, the scatterometer measurements lay close to the GMF surface (i.e., have low MLE values), further validating the wind GMF and low noise characteristics of the scatterometer systems. A large inconsistency with the GMF results in a large MLE, which indicates geophysical conditions other than those modelled by the wind GMF, such as rain, local wind variability, etc. As such, the MLE provides a good indication for the quality of the retrieved winds [5]-[7]. For Ku-band scatterometers, with lower signal-to-noise ratio than C-band scatterometers, the averaged MLE over the nearest 8 WVCs, MLE_m, is a more effective QC indicator than the rather noisy MLE [10].

b) Singularity analysis

Singularity analysis is an effective tool to measure the wind de-correlation of a particular WVC with its neighboring WVCs [9]. The derived singularity exponent (SE) depicts the degree of local regularity (spatial gradient) around a given WVC for a given signal. The wavelet projections of the gradient measurements of the inversion residual (MLE) and the retrieved wind components (speed and direction) are examined in order to assess the irregularities of scatterometer winds. Note that the MLE is a local measure, whereas SE is based on spatial derivatives between WVCs and are therefore complementary. This is shown in Fig. 1, where the largest discrepancies between ASCAT and ECMWF winds are found for both large positive MLE values and large negative SE values. Note that although ECMWF does not resolve spatial gradients on the scatterometer scale, a similar pattern is found against buoy winds (not shown). In general, SE is particularly effective in filtering increased wind variability conditions for both C-

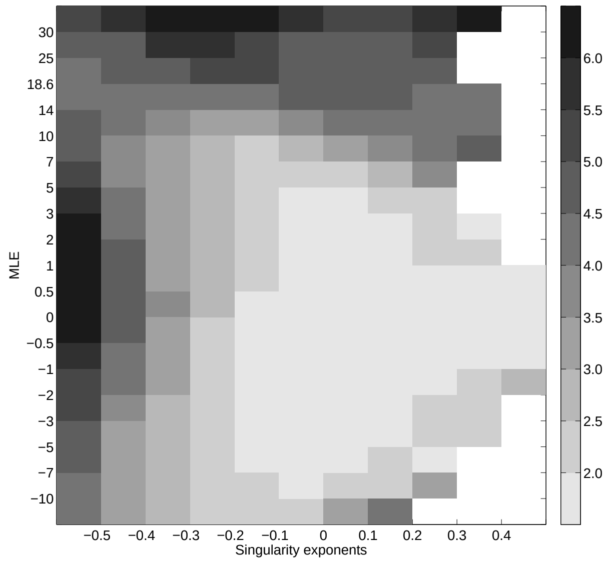

Fig. 1 Mean vector difference (MVD) between ASCAT and ECMWF winds as a function of SE and MLE. The blank area is due to the lack of data in the corresponding bins. The grayscale corresponds to different MVD values (see the legend) [9].

band and Ku-band systems [9], [10], while less effective than MLE/MLE_m in detecting the presence of rain [10], [11] (see Fig. 2).

c) 2DVAR analysis

The 2DVAR analysis wind field is derived in the 2DVAR procedure during the wind product generation, where it constructs an optimal wind field from the ambiguous scatterometer information and background winds obtained from a Numerical Weather Prediction (NWP) model, considering empirically-based spatial background error structure functions [15]. In the final 2DVAR step, the WVC wind vector solution closest to the local 2DVAR field is selected as the unambiguous locally observed scatterometer wind, with the objective to provide a unique observed wind field. A new QC indicator, J_{OSS}, is defined as the local wind speed difference of the 2DVAR analysis speed and the retrieved (inverted) wind speed. Since the 2DVAR speed field is smooth, it essentially measures the spatial differences of wind speeds due to the presence of rain.

In contrast with C-band scatterometers, whose quality is mainly degraded by increased wind variability conditions, Ku-band scatterometers are sensitive to rain contamination (mainly attenuation and volume scattering). However, the retrieved wind quality is found to be little affected by low/moderate rain conditions. The J_{OSS} QC indicator is essentially used to reduce the false alarm rate (FAR) of the MLE-based filtered WVCs for Ku-band scatterometers, i.e., to recruit those WVC winds initially filtered by MLE (due to rain), but which are mainly affected by local wind variability and low to moderate rain conditions [12].

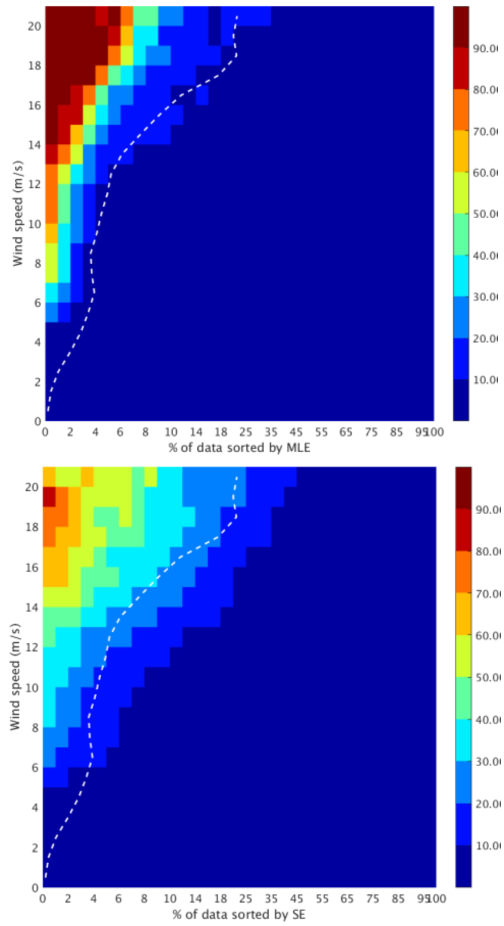

Fig. 2 Percentage of rain-contaminated data (GMI RR > 1 mm/h) as a function OSCAT-2 wind speed and the sorted percentiles by MLE (top) and SE (bottom). Only sweet-swath WVCs are analyzed. The white dashed curve indicates the rejection ratio of the operational MLE-based QC [11].

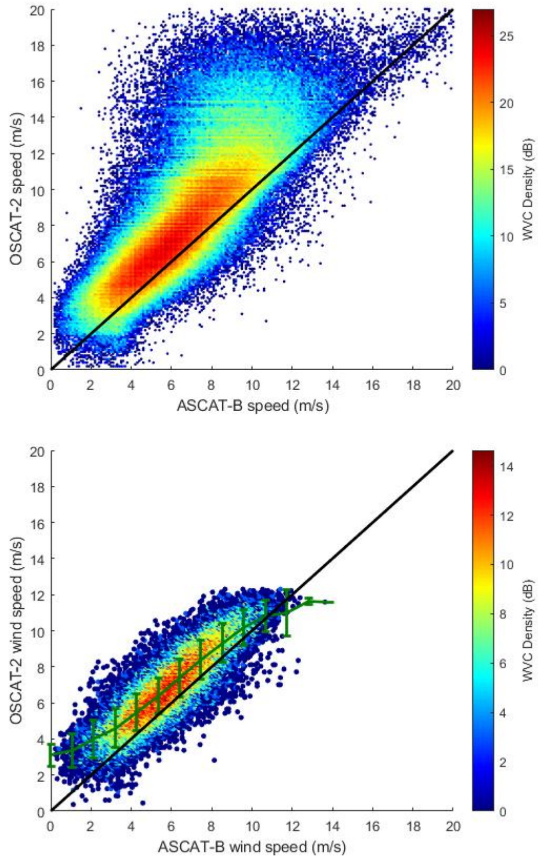

Fig. 3 Wind speeds from collocated OSCAT-2 rejected and ASCAT-B accepted WVCs by MLE QC (top); same plot but for OSCAT-2 FAR WVCs recruited by Joss (bottom). Only sweet-swath WVCs in tropical regions (latitude ∈ [-20°, 20°]) are analyzed [12].

3. DISCUSSION AND CONCLUSIONS

For optimized QC, it is important to discern between C-band fixed viewing geometry and Ku-band varying viewing geometry systems. As already mentioned, C-band systems are little affected by rain contamination, while Ku-band systems suffer mostly from signal attenuation and volume scattering by droplets. Also, the C-band ASCATs optimized fixed viewing geometry makes their inversion residual (MLE) a good noise (and thus QC) indicator across the entire swath [9]. In contrast, the QC effectiveness of the MLE derived from varying geometry systems varies across swath. In particular, in the outer swath region where only two views (beams) are available, the MLE is less effective as noise indicator [5], [10].

The correlation between the ASCAT wind quality and the MLE and SE derived parameters is demonstrated in [9], and mainly driven by wind variability effects. Moreover, the SE is proven to be a complementary parameter to MLE for ASCAT QC purposes, particularly in finding large sub-WVC variability cases under rainy conditions. The QC method is further refined by taking the K_p and wind speed parameters into account. By choice, the combined SE/MLE and multi-parameter-based QC approaches filter, respectively, twice and three times as many poor-quality WVCs than the current MLE-based QC, for ASCAT wind speeds above 4 m/s. In particular, more data are rejected by the new methods near moist convection, i.e,., wind downburst areas (near rain cells). Depending on the method used, the percentage of quality controlled (QC'ed) WVCs for C-band systems ranges between 0.3% (MLE-based) to 1% (multi-parameter approach).

For Ku-band QC development purposes, collocated and QC'ed ASCAT winds are used as reference, since the latter are little affected by rain contamination effects. MLE and MLE_m appear the most effective in the inner swath to uniquely detect rain, according to collocated GMI data, while SE is ineffective here for rain detection (see Fig. 2). In the outer swath region, SE and MLE_m are most effective for rain detection, but the MLEs are generally much less effective for QC here than in the inner swath. It turns out that the SE is generally more effective than the MLE_m and the MLE in flagging the most discrepant Ku-band derived and ASCAT winds, notably in the outer swath. Since SE seeks for spatial wind singularities, this discrepancy between ASCAT and Ku-band winds is mainly due to Ku-band wind quality degradation, caused by increased local wind variability.

A particularly effective scheme is the so-called J_{OSS}. As seen in Fig. 3 (top), a large amount of Ku-band MLE-based QC'ed WVCs are in good agreement with collocated ASCAT-derived winds (see high data density along the diagonal), and therefore of good quality. According to collocated GPM IMERG-F [16] rain data, most of these WVCs are only under low to moderate rain conditions [12]. J_{OSS} proves to be well correlated to rain after MLE-based QC labeling, and as such, can be used for FAR reduction. Based on J_{OSS}, FAR in the current MLE-based QC can be reduced by over 75%. Such percentage of recruited WVCs are indeed in good agreement with collocated ASCAT winds, as shown in Fig. 3 (bottom). While the MLE-based QC leads to about 5-7% of rejections, the combined MLE & J_{OSS} QC leads to only about 2% of rejections, which include the most rain contaminated WVCs and the most discrepant winds (against ASCAT) from the MLE-based QC set.

In conclusion, for C-band scatterometers the aim is to develop the most effective method in flagging extreme wind variability conditions, which includes both MLE and SE QC indicators. For Ku-band scatterometers, the aim is to filter rain-contaminated WVCs, for which the combined $MLE_{(m)}$ and J_{OSS} (and possible inclusion of SE in the outer swath regions) is the preferred option. Moreover, SE, being the most effective indicator for increased wind variability conditions, should be further considered for specific applications. Variable winds are a potential hazard in some applications, such as data assimilation and the methods developed here may be useful for those applications. For other applications though, such as nowcasting and oceanography, it may be relevant to keep the "high wind variability" flagged WVCs since its winds provide essential information on (highly variable) air-sea interaction processes that cannot be captured by any other wind observing system. These results will be presented at the conference to initiate a discussion with the wide user community and find consensus on whether different QC methods should be used for different applications.

REFERENCES

[1] Wang, Z., Stoffelen, A., Zhao, C., Vogelzang, J. Verhoef, A., Verspeek, J., Lin, M., and Chen, G., "A SST-dependent Ku-band geophysical model function for RapidScat," *J. Geophys. Res. Oceans*, 122(4), 3461-3480, 2017.

[2] Draper, D.W. and D.G. Long, "Evaluating the Effect of Rain on SeaWinds Scatterometer Measurements," *Journal of Geophysical Research*, Vol. 109, No. C02005, 2004.

[3] Owen, M. and D.G. Long, "Towards an Improved Wind and Rain Backscatter Model for ASCAT," *Proc. of IGARSS*, Honolulu, HI, 25-30 July, 2010.

[4] Stiles, B.W., and R. Scott Dunbar, "A Neural Network Technique for Improving the Accuracy of Scatterometer Winds in Rainy Conditions," *IEEE Trans. Geosci. Remote Sens.*, 48 (8), pp 3114-3122, 2010.

[5] M. Portabella and A. Stoffelen, "Rain detection and quality control of SeaWinds," *J. Atm. and Ocean Techn*., 18 (7), pp. 1171-1183, 2001.

[6] M. Portabella, A. Stoffelen, A. Verhoef, and J. Verspeek, "A new method for improving scatterometer wind quality control," *IEEE Geosci. Rem. Sens. Lett.*, 9 (4), pp. 579-583, 2012.

[7] M. Portabella, A. Stoffelen, W. Lin, A. Turiel, A. Verhoef, J. Verspeek, and J. Ballabrera-Poy, "Rain effects on ASCAT wind retrieval: Towards an improved quality control," *IEEE Trans. Geosci. Remote Sens.*, vol. 50, no. 7, pp. 2495–2506, 2012.

[8] W. Lin, M. Portabella, A. Stoffelen, A. Turiel, and A. Verhoef, "Rain identification in ASCAT winds using singularity analysis," *IEEE Geosci. Rem. Sens. Lett.*, 11 (9), pp. 1519-1523, 2014.

[9] W. Lin, M. Portabella, A. Stoffelen, A. Verhoef, and A. Turiel, "ASCAT wind quality control near rain," *IEEE Trans. Geosci. Rem. Sens.*, 53 (8), pp. 4165-4177, 2015.

[10] W. Lin, and M. Portabella, "Towards an improved wind quality control for RapidScat," *IEEE Trans. Geosci. Rem. Sens.*, 55 (7), pp. 3922-3930, 2017.

[11] Portabella, M., Lin, W., Stoffelen, A., Verhoef, A., and Wang, Z., "Extension of the validation of the NSCAT-5 Geophysical model function," *Associated Scientist report for the EUMETSAT OSI SAF*, SAF/OSI/CDOP3/KNMI/SCI/RP/344, March 2019.

[12] X. Xu and A. Stoffelen, "Improved rain screening for ku-band wind scatterometry," *IEEE Trans. Geosci. Remote Sens.*, 58 (4), pp. 2494–2503, 2020.

[13] X. Xu, A. Stoffelen, W. Lin, X. Dong, "Rain False-Alarm-Rate Reduction for CSCAT," *IEEE Geosci. Rem. Sens. Lett.*, https://doi.org/10.1109/LGRS.2020.3039622, in press 2021.

[14] A. Stoffelen, J. A. Verspeek, J. Vogelzang, and A. Verhoef,"The CMOD7 geophysical model function for ASCAT and ERS wind retrievals," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, 10 (5), pp. 2123–2134, May 2017.

[15] J. Vogelzang, "Two dimensional variational ambiguity removal (2DVAR)," KNMI Tech. Note NWP SAF NWPSAF-KN-TR-004, 2017.

[16] G. J. Huffman, D. T. Bolvin, and E. J. Nelkin, "Integrated Multi-satellitE Retrievals for GPM (IMERG) technical documentation," NASA/GSFC Code, vol. 612, p. 47, Jun. 2015.