Extreme-Wind Observation Capability for a Next Generation Satellite Wind Scatterometer Instrument

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Abstract. Ocean surface vector wind information, derived from satellite-based wind scatterometer observations, is one of the essential inputs for operational weather forecasting, in particular for extreme marine weather. It also provides eddy-scale ocean forcing, determining ocean circulation, wave and surge forecasting services. The current generation of European scatterometer instruments operate at C-band with a single vertical polarisation (VV). This co-polarised radar backscatter saturates above a wind speed of about 25 to 30 m/s, particularly at low incidence angles, which imposes a serious limitation on the capability of these observation systems. Recently, observations of storm events along the North American coasts by RadarSAT-2 and comparisons with in-situ buoy data revealed a high sensitivity of C-band cross-polarised backscatter signal intensity (i.e. VH or HV) with high wind speeds. This prompted the ocean vector wind community to further explore the limit of the cross-polar response. Establishing a new Geophysical Model Function (GMF) requires accurate in-situ information of the vector wind field together with collocated scatterometer observation data, but these are rare at extreme winds. A more successful collocation approach consists of making use of the wind field information from global Numerical Weather Prediction (NWP) analysis data collocated with RadarSAT-2 observations. The result is however affected by inherent NWP model errors and systematic underestimation of peak extreme winds due to limitations in the NWP model spatial resolution. For obtaining independent verification from in-situ wind field information, data from the stepped frequency microwave radiometers (SFMR) instrument flown on board NOAA's Orion P3 'Hurricane Hunter' aircraft were collocated with the available RadarSAT-2 observations. A high level of correlation has been confirmed between both the NWP model and the in-situ wind speed and the measured cross-polarised radar backscatter up to the extreme wind regime. In parallel to the above-described scientific effort for establishing the new GMF and a corresponding wind vector retrieval, an engineering design of a new generation of wind scatterometer instrument was elaborated in the frame of the MetOp Second Generation preparatory programme, jointly undertaken by the ESA and EUMETSAT. The new design features a higher spatial resolution product than the one provided by the ASCAT instrument on board the MetOp series of satellites in orbit, and an additional VH channel for measuring cross-polarised radar backscatter in order to extend the wind speed dynamic range of the next generation system.

Keywords. Ocean vector wind, scatterometer, geophysical model function, extreme-wind, C-band, cross-polarised backscatter, MetOp Second Generation.

1. Introduction

Wind speeds and directions over oceans are routinely measured with high temporal resolution by scatterometers. The ocean surface vector winds can be inferred from the measured Normalized Radar Cross Section (NRCS) signal strength (σ 0) as these are linked to the ocean roughness and its azimuthal variation. The vector wind can be retrieved using three collocated measurements from different azimuth viewing angles combined with the Geophysical C-band Model (CMOD) Function (GMF) that empirically links the radar backscatter to the local wind vector and incidence angle [1]. The near-real-time global wind estimates from the different scatterometer instruments, at a spatial resolution in the order of tens of kilometers prove very accurate [2] and are used in diverse applications, such as marine meteorology, Numerical Weather Prediction (NWP), oceanography and climate. A main limitation of the current fan-beam scatterometer ASCAT [3] is the low sensitivity of co-polarised signal strength with respect to severe wind speeds (> 25 m/s). This reduces the usefulness of the winds in case of severe wind situations like Hurricanes and Typhoons. In recent years, the cross-polarised signals (VH) over the oceans have been studied in more detail after the launch of the RadarSAT-2 satellite, which showed a rather simple relationship to the wind speed with useful sensitivity in the severe wind regime [4]. The operational use of cross-polarised signals for wind retrievals over the ocean will only be possible in future meteorological satellite systems.

The Meteorological Operational satellite programme Second Generation (MetOp-SG) satellites [5] will replace the current MetOp system in the 2020+ time frame. One instrument to be carried on-board the MetOP-SG is a C-band scatterometer (ASCAT-SG), similar to ASCAT on MetOp, but with a designed higher spatial resolution, increased coverage and stability [6]. Another innovation in the design of ASCAT-SG is the inclusion of a single cross-polarised beam, which can be used for the retrieval of severe wind speeds and therefore be a prime improvement in the nowcasting of hurricane intensities. The latter can subsequently be used for a more accurate forecasting of hurricane intensities and benefit hurricane warnings for the protection of coastal residents and infrastructure. In preparation for ASCAT-SG, the cross-polarization (VH) data from the RadarSAT-2 SAR satellite are compared to wind speeds measured by NOAA's 'Hurricane Hunter' flights and to wind speeds provided by ECMWF forecasts. The results indicate that VH backscatter is capable of retrieving strong to extreme/severe wind speeds without any dependence on wind direction. As such, VH backscatter could be used to complement the standard VV products by extending wind speed retrieval beyond 25 m/s.

2. Geophysical Model Function for C-band cross-polarised backscatter

In the low-to-strong wind speed regime (<20 m/s), the cross-polarised backscatter by RadarSAT-2 fine quad-polarization (HH, HV, VH, and VV) mode has been compared to wind vectors measured at buoys [4]. It was found that the cross-polarised backscatter was insensitive to incidence angle and wind direction, resulting in a simple linear geophysical relationships that may be directly used to derive absolute wind speeds:

$$VH[dB] = 0.592\ U_{10}[m/s] - 35.6$$

There were however only a very limited number of collocated RadarSAT-2/buoy strong wind events (> 20 m/s). To link the VH backscatter signals to the strong-to-severe wind regime, images of hurricanes were combined with aircraft and NWP data. A total of 19 RadarSAT-2 dual polarized C-band SAR images (co-polar: VV and cross-polarisation: VH) backscatter signals were acquired, through the Canadian Space Agency's Hurricane Watch program during strong-to-severe wind events between 2008 and 2011. Hurricane transects and hurricane surface winds were also obtained from the NOAA WP-3D 'Hurricane Hunter" research aircraft carrying the airborne Stepped-

Frequency Microwave Radiometer (SFMR) instrument [7]. The retrieval of the SFMR wind velocity is based on nadir microwave emissions from the sea surface in 6 C-band frequencies along the flight track. As the SFMR measures the wind speed below the aircraft, the data provides transects/tracks of the wind speeds through the individual hurricanes and not the full wind speed pattern throughout the hurricane system.

The NOAA Hurricane Hunters flew a total of 18 collocated flight tracks through 9 of the 19 available hurricanes with the SFMR instrument. A typical NOAA flight takes around 6 hours and within this time a number of flight legs are flown through the eye of the hurricane. Compared to the near instantaneous measurements of RadarSAT-2, both data streams will never be fully collocated in time and space, especially when taking into account the hurricane's intrinsic movement during the flight. Therefore, each of the individual legs (lasting about 20 minutes) has been collocated separately. The VH backscatter to wind speed distribution shows a different behavior in the low-to-strong wind speed regime (U10 < 20 m/s) compared to the strong-to-severe wind speed regime (U10 > 20 m/s) , where each of the regimes depicts an approximate linear relationship (Figure 1). The validity of the linear relationship has been evaluated by comparing the cross- polarized data to two additional independent wind speed datasets, i.e., the short-range ECMWF model forecast (blue lines in Figure 1) and the NOAA best estimate one-minute maximum sustained winds from their GIS database .

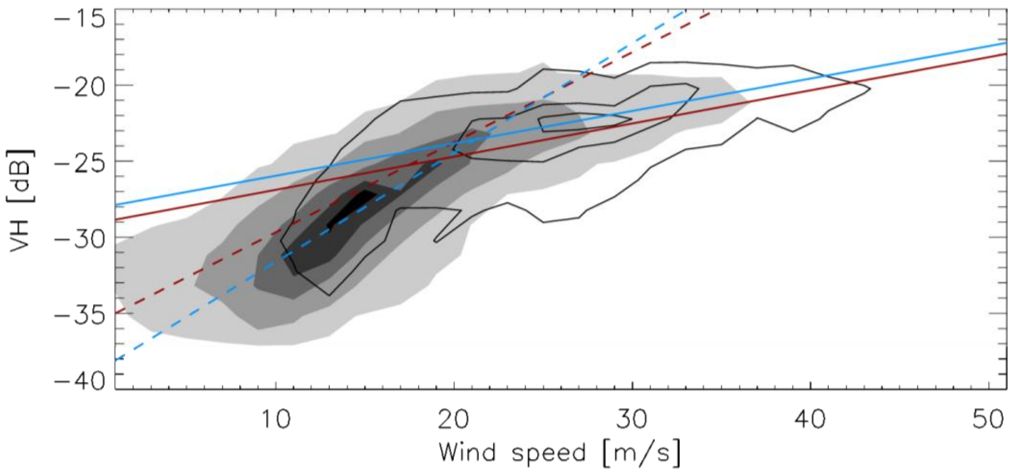


Figure 1. The above graph combines the ECMWF-VH (represented by the grayscale contours) and the SFMR-VH distributions (represented by the contoured lines). The four lines overlaid depict four linear fits that define the VH-GMF. The dashed red line is the Vachon and Wolfe [4] linear fit, the two blue lines are the linear fits based on the ECMWF data and the solid red line the linear fit based on the SFMR data.

The SFMR distribution is well defined up to 40 m/s with a correlation of 0.70. From this data set, a relationship for wind speed retrieval using VH-polarization backscatter for strong-to-severe wind speeds (i.e. 21 m/s < U10 < 40 m/s) was derived. Within this wind speed regime, the cross-polarised data showed no distinguishable loss of sensitivity and, as such, cross-polarised signals are a good candidate for the retrieval of severe wind speeds from satellite instruments. The upper limit of 40 m/s is set by the currently available collocated data and can be related to VH in between 21 and 40 m/s as:

$$VH(21 < U10 < 40 \text{ m/s}) = 0.218\, U10[\text{m/s}] - 29.07$$

The VH-GMF, based on the available data, can be described by two linear relationships. In the low-strong winds by the wind speed relationship from Vachon and Wolfe [4], and strong-severe wind speeds by the relation found using the SFMR data. The apparent transition between the low-to-strong wind speeds and the strong-to-severe wind speeds needs to be taken into account in the VH-GMF.

The comparison to the ECMWF data indicates that the cross-polarised backscatter was insensitive to wind direction and shows a modest incidence angle dependence. This means that absolute (severe) ocean wind speeds can be directly retrieved from a single VH channel in the C-band.

Both the ECMWF and SFMR data provide data up to ~45 m/s and shows no loss of sensitivity up to that point. In order to improve hurricane forecast warnings and hurricane model run initialisation, it is useful to know up to which wind speed the cross-polarised backscatter signals will be able to retrieve a robust value. To enable this check, the VH measurements are compared to the Tropical Cyclone Best Track Information product from the NHC GIS Archive. This Best Track is a subjectively-smoothed representation of the tropical cyclone's location and intensity. The intensity is described as its maximum 1-minute sustained surface wind speed and minimum sea-level pressure at 6 hour intervals over its lifetime. The VH images and their retrieved velocities are independent of the NOAA best track assessment data and describe the hurricane in a very different way. For the VH-GMF, only the tail of the image distribution is important since this describes the highest wind velocities. In the case of the one-minute maximum sustained winds, the most important issue is its stability in time, since this describes how stable the wind speed estimate is at the time of the RadarSAT-2 overpass.

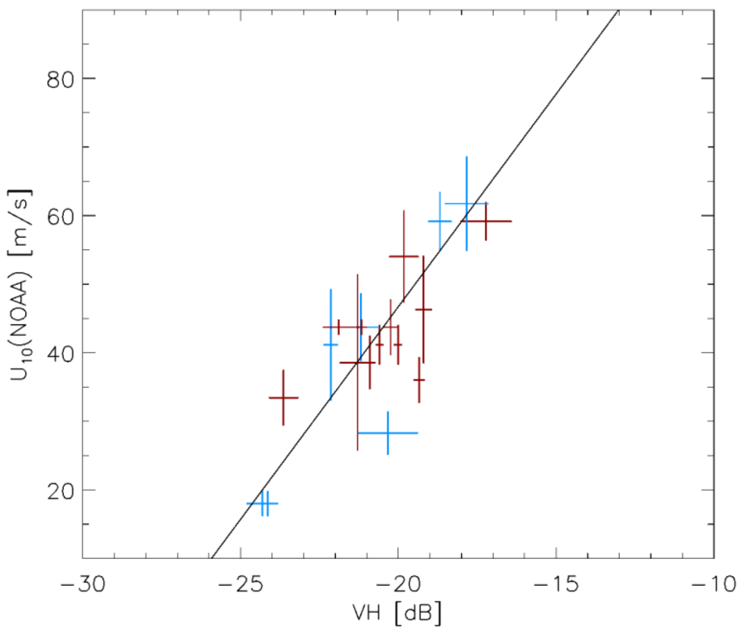


Figure 2. Comparison of the maximum 1-minute sustained surface wind speed best track estimates versus the averaged sum of the 0.995 and 0.9995 VH-value percentiles for each of the 19 hurricanes. The error estimates in the x-direction show the two percentile values and represent the variability close to the eye within the image, the y-direction error bar shows the standard deviation within a 24 hour window around the RadarSAT-2 overpass time. The red color indicates those hurricanes which did not have collocated SFMR flights around the time of the satellite overpass, the remaining (blue) points indicate the images which were used to create the SFMRVH distribution.

To ensure that the high VH returns are not from non-sea-surface targets, e.g., coastlines or small islands, the 0.995 and 0.9995 percentile values are retrieved (horizontal error bars). The vertical error bars are defined as the standard deviation of the 5 closest 6-hour points of the NOAA track (~24 hour window). The 19 hurricane points/images indicate that wind speeds up to 60 m/s can be retrieved routinely by including a cross-polarisation channel to the ASCAT-SG.

Toward the lower end of the wind speed, Fig. 1 shows a cross-polarised backscatter level of -30 dB at the wind speed range of 10 – 15 m/s, which is still well within the nominal measurement dynamic range of existing scatterometers such as ASCAT (however without the VH-channel).

3. Extreme-wind retrieval approach and expected accuracy

The performance enhancement that results from adding a cross-polarised (VH) capability to the baseline ASCAT-SG scatterometer is quantified using an end-to-end wind retrieval simulator such as shown in Fig. 3. The general methodology for quantifying the wind retrieval performance of scatterometer systems is described in [8]. Wind retrieval simulations are carried out after introducing a VH-channel to the existing VV channel in the Mid-beam, and the results compared against the case without the VH measurement. In this first assessment, the GMF is assumed to be defined by the linear relations as described in Section 2.

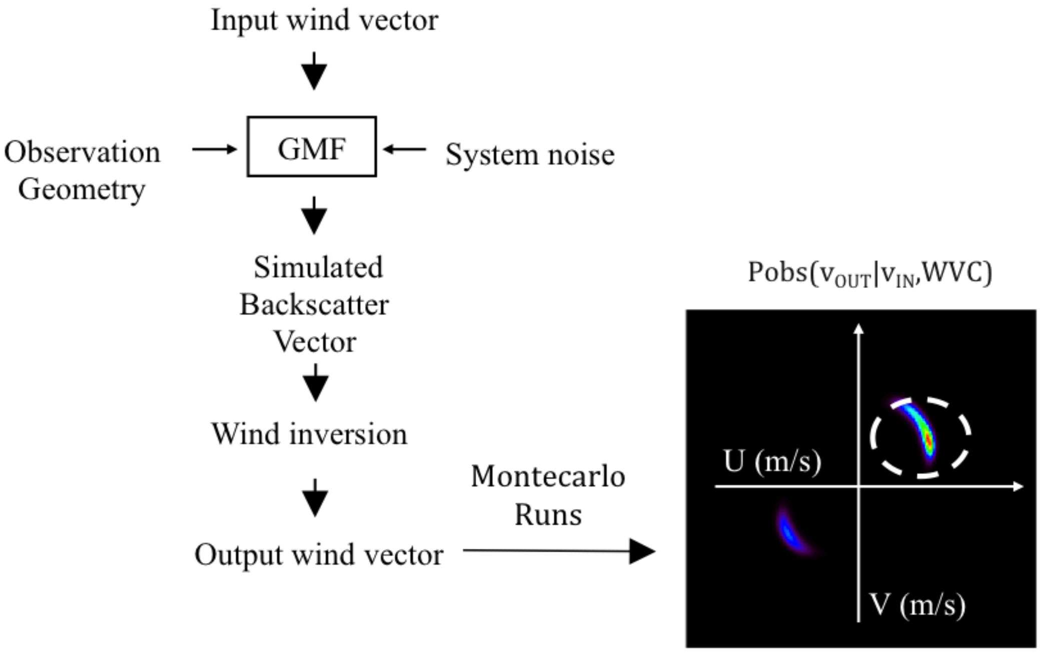


Figure 3. End-to-end performance simulation with a resulting output wind probability array

The simulated wind solutions are collected and binned into output wind probability arrays $P_{obs}(v_{OUT}|v_{IN},WVC)$, which describe the dispersion of wind solutions (v_{OUT}) about the true wind (v_{IN}) for a given cross-track location (WVC or wind vector cell). The output wind probability arrays allow the characterization of the retrieval error via mean statistics such as the wind vector root-mean-square (VRMS) error, defined as:

$$VRMS(\vec{v}_{true},WVC)=\left(\int\left|\vec{v}-\vec{v}_{true}\right|^2 P_{obs}(\vec{v}\,|\,\vec{v}_{true},WVC)P_{NWP}(\vec{v}-\vec{v}_{true})\,d\vec{v}\right)^{1/2}$$

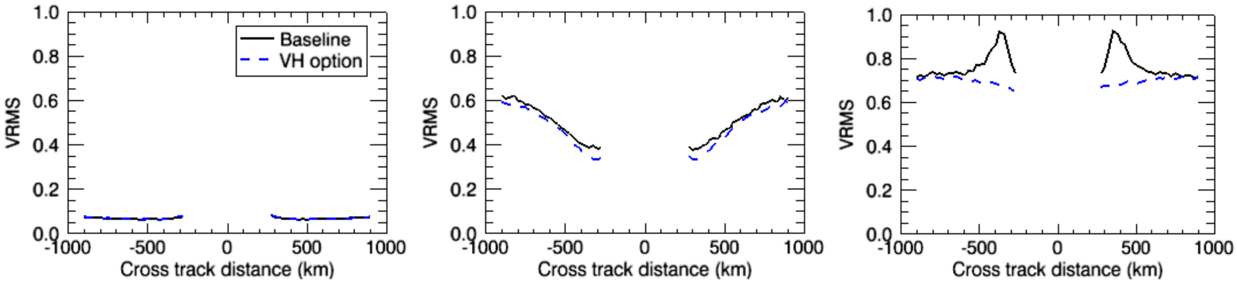
Or the wind speed root-mean-square (WSRMS) error defined as:

$$WSRMS(\vec{v}_{true},WVC)=\left(\int\left(\left|\vec{v}\right|-\left|\vec{v}_{true}\right|\right)^2 P_{obs}(\vec{v}\,|\,\vec{v}_{true},WVC)\,d^2v\right)^{1/2}$$

The postulated *a priori* wind knowledge $P_{prior}(V_{out} - V_{in})$, which is a Gaussian function centered about the true wind with a 10 m/s standard deviation, is introduced in the VRMS definition to help discard ambiguous wind solutions, usually 180 degrees separated from the input wind for an ASCAT-like system. Note that the first figure of metric (VRMS) measures the quality of the retrieved wind vector (including both wind speed and direction), whereas the second figure of merit only evaluates the wind magnitude regardless of wind direction.

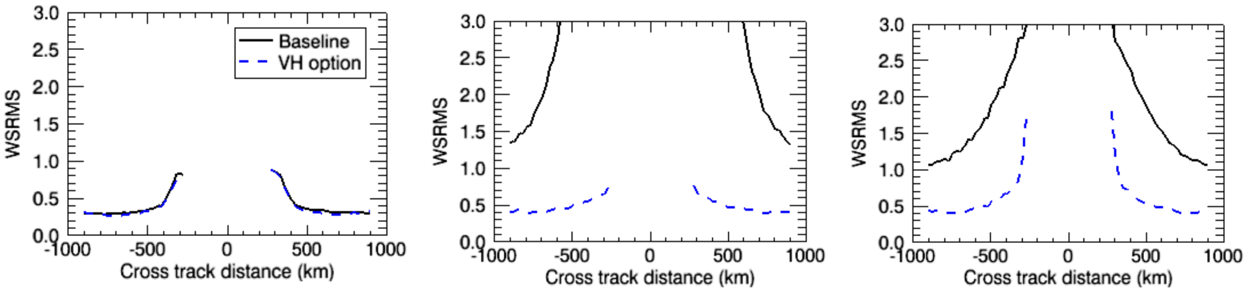
The performance scores for the baseline ASCAT-SG with and without a VH capability are shown in Figs. 4 and 5 as a function of cross-track location for different wind speeds (25, 45 and 65 m/s). The WSRMS scores in Fig. 5 suggest that adding a VH capability definitely helps improve the determination of the wind magnitude at extreme wind speeds. This improvement, which begins to be felt at wind speeds larger than the saturation level (> 25 m/s), is rather uniform across the swath and limits the wind speed error to 0.5 m/s.

The determination of the wind vector in VRMS scores (scaled by $\sqrt{2}\times\sigma_{NWP}$) in Fig. 4 improves only marginally relative to the case without the VH-channel, with wind vector errors as large as 7 m/s at 45 m/s. This is a reasonable result, considering that the cross-pol. GMF does not carry any information about wind direction. The fact that the VRMS error approaches the standard deviation of the NWP condition (e.g., 10 m/s) indicates that at extreme wind speeds, the wind direction is determined mostly from the *a priori* condition. This is best illustrated in Figs. 6 and 7 below, which show that wind retrieval errors at extreme wind are dominated by uncertainty in wind direction. Introducing a cross-pol. VH capability helps constrain retrieval errors in wind magnitude to below 0.5 m/s, without necessitating additional information about wind direction.



a) 25 m/s b) 45 m/s c) 65 m/s

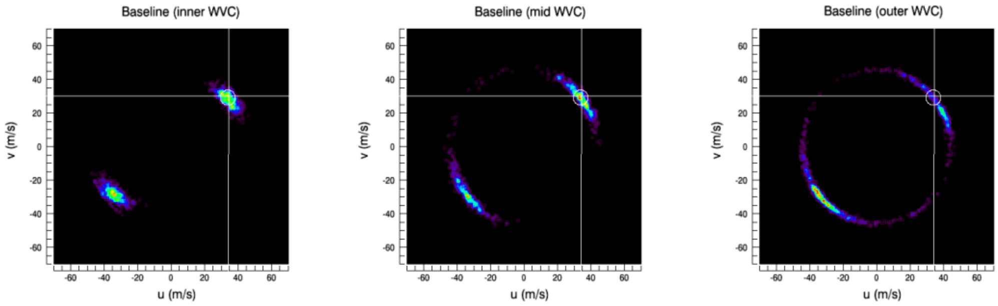
Figure 4. VRMS scores (scaled by $\sqrt{2}\times\sigma$NWP) for the ASCAT-SG with and without a VH option



a) 25 m/s b) 45 m/s c) 65 m/s

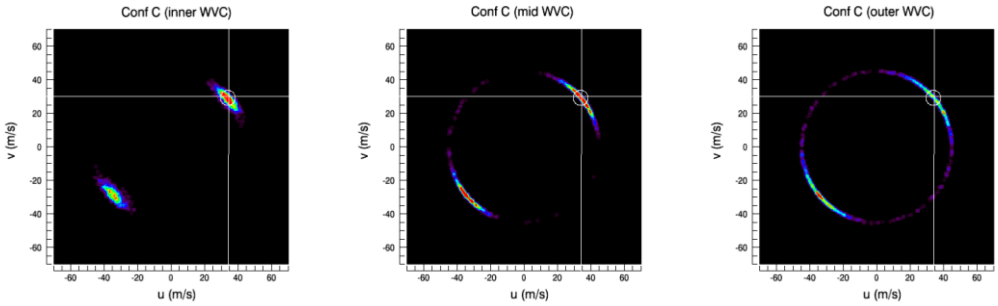
Figure 5. WSRMS scores for the ASCAT-SG with (dashed line) and without a VH option (solid line)

a) ASCAT-SG without VH



inner WVC mid WVC outer WVC

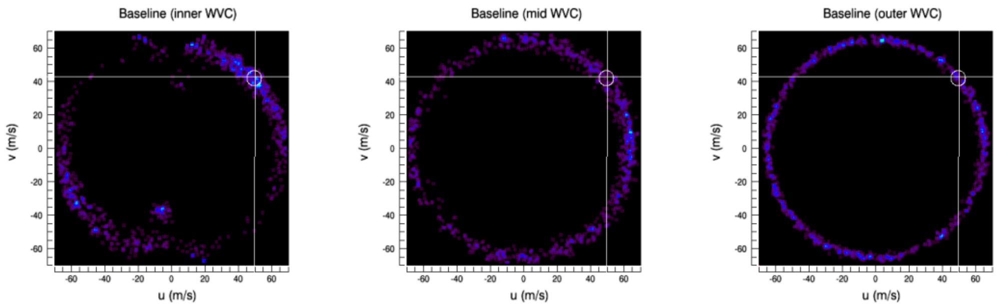
b) ASCAT-SG with VH in Mid-beam



inner WVC mid WVC outer WVC

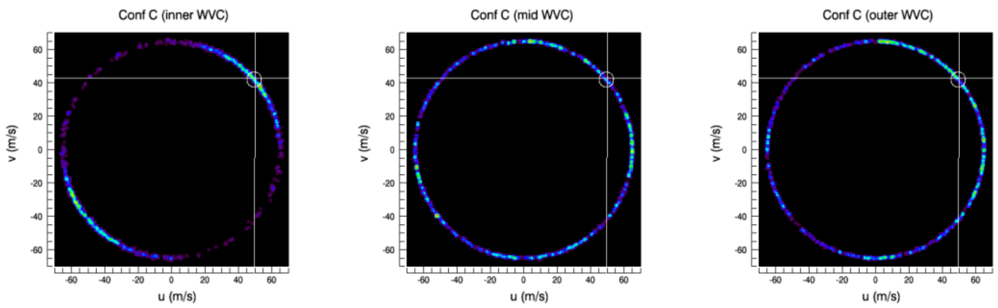
Figure 6. Sample output wind probability arrays (true wind is marked at 45 m/s @ 45 deg) for the ASCAT-SG with (bottom) and without VH channel (top)

a) ASCAT-SG without VH



inner WVC mid WVC outer WVC

b) ASCAT-SG with VH in Mid-beam



inner WVC mid WVC outer WVC

Figure 7. Sample output wind probability arrays (true wind is marked at 65 m/s @ 45 deg) for the ASCAT-SG with (bottom) and without VH channel (top)

4. MetOp-SG scatterometer instrument

The new EUMETSAT EPS-Second-Generation (EPS-SG) polar orbiting system will be implemented with a space segment developed by ESA (*MetOp*-Second-Generation or *MetOp*-SG) and the ground segment by EUMETSAT. The EPS-SG mission will consist of a constellation of two satellites (Sat-A and Sat-B), with ESA-developed instruments on Sat-A (MicroWave atmospheric Sounder or MWS, Multi-directional Multi-polarization Multispectral Imager or 3MI and Radio Occultation or RO) and Sat-B (Wind Scatterometer or ASCAT-SG, MicroWave Imager or MWI, Ice-Cloud Imager or ICI and RO) [5]. The new system will ensure continuity of the meteorological services currently offered by the EPS/*MetOp* system by around 2020.

The ASCAT-SG [6] will be flown on Sat-B as an evolution of the ASCAT instrument [3] on board *MetOp*. The instrument concept trade-offs, carried out during the Phase 0, are summarised in [8]. As a result of the concept trade-offs and design elaboration, the ASCAT-SG instrument will provide better spatial resolution (≤ 25 km) and higher radiometric stability (0.1 dB) than ASCAT. The instrument will operate in C-band with 8 waveguide-array antennas configured in 3 antenna-pair assemblies similar to those of ASCAT. In this configuration, the principal elevation planes of the SCA antenna beams are oriented at 45° (Fore-left), 90° (Mid-left), 135° (Aft-left), 225° (Aft-right), 270° (Mid-right) and 315° (Fore-right) with respect to the flight direction, similar to MetOp's ASCAT as shown in Fig. 8. Each of the SCA beams shall acquire a continuous image of the normalised (per-unit-surface) radar backscatter coefficient of the ocean surface over a swath. Both sides of the sub-satellite track are imaged each with three azimuth views, with an unavoidable observation gap below the satellite. A large number of independent looks are summed in range and azimuth (multi-looking), for each azimuth view, in order to achieve the specified radiometric resolution of the σ^0-estimate on each measurement pixel. The three σ^0 measurements (σ^0-triplet) are uniquely related to the 10-m vector wind through the Geophysical Model Function (GMF) [1].

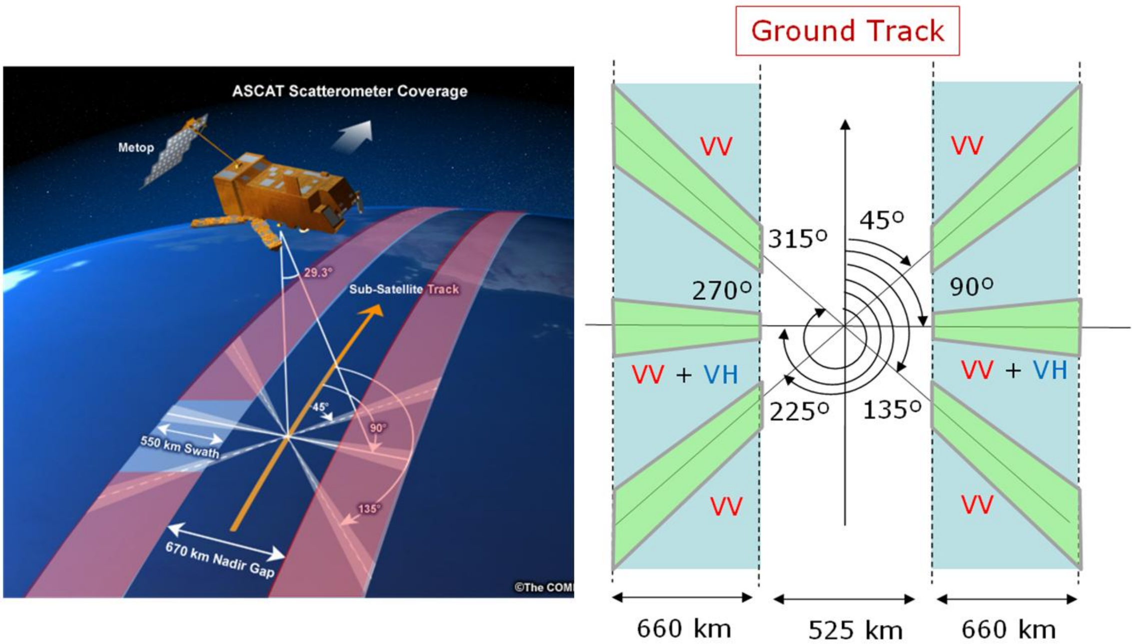


Figure 8. Measurement geometry of ASCAT (left) versus ASCAT-SG (right)

As compared to ASCAT, ASCAT-SG shall have a smaller nadir gap by reducing the minimum incidence angle from 25° (ASCAT) to 20°. The main technical requirements of ASCAT-SG are reported in Table 1 and compared to the ones of ASCAT. The major improvements to be brought by SCA with respect to ASCAT are the spatial resolution of 25 km × 25 km with the sampling of 12.5 km × 12.5 km, the radiometric stability of ≤ 0.1 dB and the addition of VH polarisation channels on

Mid-beams. A high resolution product will also be provided with a sampling distance of 6.25 km × 6.25 km with a spatial resolution of 17 to 22 km, depending on the swath position. The radiometric resolution of the high resolution product would be degraded with respect to that of the nominal resolution product.

Table 1. Main technical requirements of ASCAT-SG versus ASCAT

Parameter	ASCAT	MetOp-SG SCA
Frequency	5.3 GHz	
Polarisation	VV for all beams	VV for all beams + VH for Mid-beams
Azimuth views	45°, 90° and 135° w.r.t. satellite track	
Min. incidence	25°	20°
Horizontal resolution	Nom: $(50\ km)^2$ High res.: $(25 - 35\ km)^2$	Nom: $(25\ km)^2$ High res.: $(17 - 22\ km)^2$
Horizontal sampling	Nom: $(25\ km)^2$ High res.: $(12.5\ km)^2$	Nom: $(12.5\ km)^2$ High res.: $(6.25\ km)^2$
Radiometric resolution	≤ 3 % for $\theta_i \leq 25°$ at 4 m/s cross-wind (VV) $(0.175\times\theta_i - 1.375)$ % for $\theta_i > 25°$ at 4 m/s cross-wind (VV) ≤ 3 % at 25 m/s up-wind	
Radiometric Stability	≤ 0.2 dB	≤ 0.1 dB
Coverage	97 % in 48 hrs.	99 % in 48 hrs.

The sketches of two possible Sat-B configurations at the end of phase 0 are shown in Fig. 9, which were elaborated separately by two industrial satellite design teams. Each of the antenna assemblies has the form of an elongated roof-top with its faces oriented towards the imaged swath. The Mid-beam antenna assembly is fixed on the satellite nadir face, whereas the other two are stowed side-by-side to the former during launch, and deployed to their respective positions once in orbit. The difference between the two configurations comes from the location of the Fore-left & Aft-right antenna assembly, whether it is located symmetrically to the Mid-beam assembly (Y-shape), or on the same side as the Fore-right & Aft-left one (K-shape). The Mid-beam assembly actually contains four antennas, i.e. V- and H-polarisations for the left and right side imaging. The antenna beams for the two polarisations can be implemented in respectively two separate apertures side-by-side, or combined into a shared aperture. Both concepts are currently pursued, and this has significant impacts on the accommodation on the platform, overall satellite volume and mass.

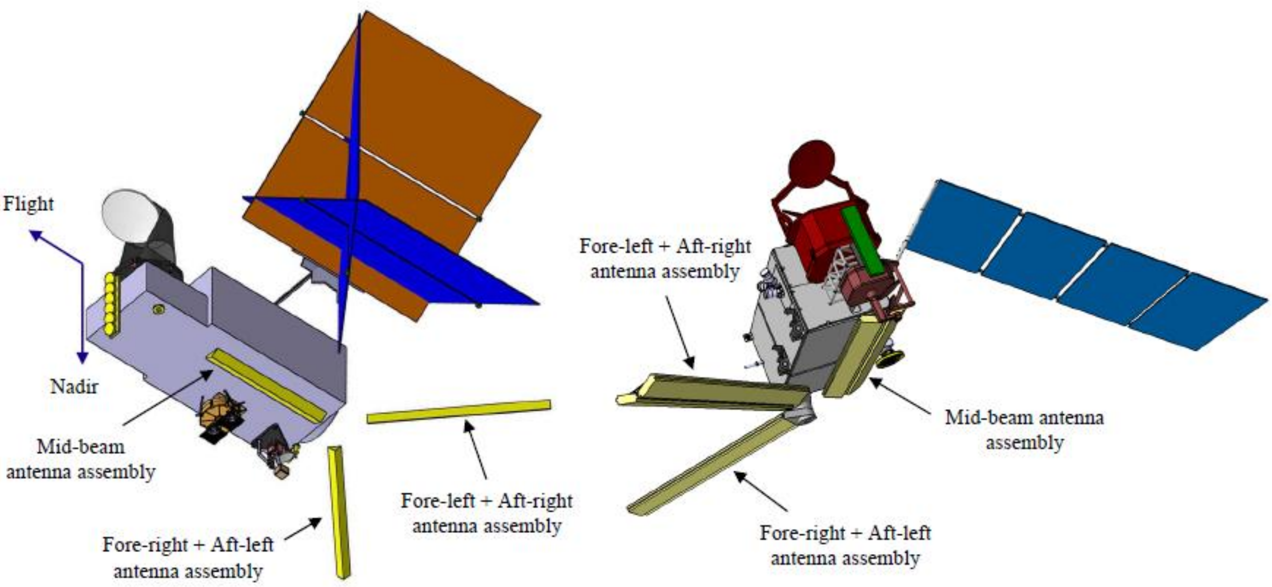


Figure 9. Two possible Sat-B configurations: Antenna assemblies in Y-shape (left); in K-shape (right)

It was shown in Section 2 that the cross-polarised (VH) radar backscatter of the ocean surface is generally much weaker than the co-polarised ones (i.e. VV and HH). However, no attempt was made in the instrument design to achieve a higher sensitivity for the VH channel as compared to the VV one. This limitation in the VH channel sensitivity is justified by the fact that this channel is useful for observing extreme-winds, under which condition the VH backscatter would be sufficiently strong to become measurable as already explained in the previous section. From the examination of the preliminary VH-GMF as depicted in Fig. 2, one can anticipate that high quality VH data would be acquired for wind speeds stronger than 15 m/s, which would ensure a large overlap with the accurately measurable wind range using the VV channels (25 m/s maximum).

5. Conclusion

In this paper, the potential of observing extreme/severe winds from space using the next generation operational scatterometer instrument, ASCAT-SG, was described. RadarSAT-2 C-band SAR imagery of cross-polarised (VH) backscatter signals acquired during severe wind speed (hurricane) events were compared to time and space collocated SFMR wind measurements acquired by NOAA's Hurricane Hunter aircrafts. From this data set, a VH-polarization backscatter GMF for strong to severe wind speeds (i.e. 20 m/s < U10 < 45 m/s) was obtained [9]. Within this wind speed regime, the cross polarization data showed no distinguishable loss of sensitivity and the use of these type of signals can be considered as a good candidate for the retrieval of severe wind speeds from satellite instruments [10]. The upper limit of 45 m/s is set by the currently available collocated data. The validity of the linear relationship has been evaluated by comparing the cross polarization to two additional, independent wind speed data sets, i.e., the short-range ECMWF model forecast and the NOAA best estimate one-minute maximum sustained winds from their GIS database. Combination of the findings on the three comparison data sets, result in the following main conclusions:

- The VH backscatter relationship to wind speed shows a different behaviour in the low-to-strong wind speed regime (U10 < 20 m/s) and the strong-to-severe wind speed regime (U10 > 20 m/s). The low-to-strong wind speed regime is described by the relationship found by Vachon and Wolfe [4], and the strong-to-severe wind regime by the relationship described in Section 2.
- The VH backscatter shows a modest incidence angle dependence. A correction for this dependence is only feasible for wind speeds up to 20 m/s due to the low amount of severe wind speed data above that value. Additional data is needed to determine the incidence-angle dependence in the strong-to-severe wind regime.
- There is no wind direction dependence in the VH backscatter signals. This means that ocean wind speeds can be directly retrieved from a VH-channel in the C-band. In case of an operational wind product, three additional VV or HH beams are required to retrieve the wind speed and direction up to 25 m/s. The combination of the information in both the VV and VH signals should enable the calculation of wind direction for larger wind speeds by advanced wind retrieval algorithms. In the case of hurricane force winds, the knowledge of wind speeds is more important than the wind direction, as the former denotes the class and devastation of hurricanes. In those cases, the wind direction can be defined by the general flow pattern (e.g., in the case of hurricanes and typhoons the wind rotates around the eye).
- There is a strong correlation between the highest VH measurements within a hurricane SAR image and the one-minute maximum sustained wind speeds from the NOAA best track product. This correlation can be described by a linear relationship. Since this relationship is only based on a combination of the most extreme VH measurements, it is different from the more general VH-GMF found by comparing all available SFMR collocated measurements.

- The ASCAT-SG with a cross-pol. VH-channel will be able to retrieve in near real time the one-minute maximum sustained wind speed from a hurricane or typhoon, as well as be able to make an assessment of the spatial wind speed distribution. Wind retrieval simulations up to 65 m/s shows that the cross-pol. VH capability helps constrain retrieval errors in wind magnitude to below 0.5 m/s. For reference, wind speed errors without the VH-channel are predicted to range from 1 to 5 m/s at extreme wind speeds. The determination of wind direction, which remains the largest error component in the wind vector retrieval at extreme wind speeds, is only marginally improved by this change.

References

[1] Stoffelen, A. and M. Portabella. *On Bayesian scatterometer wind inversion*. IEEE Transactions on Geoscience and Remote Sensing, Vol. 44, 1523 – 1533, doi:10.1109/TGRS.2005.862502, 2006.

[2] Vogelzang, J., A. Stoffelen, A. Verhoef, and J. Figa-Saldaa. On the quality of high-resolution scatterometer winds. Journal of Geophysical Research: Oceans, 116, n/a–n/a, doi:10.1029/2010JC006640, http://dx.doi.org/10.1029/2010JC006640, 2011.

[3] Gelsthorpe R.V., E. Schied, J.J.W. Wilson. *ASCAT – Metop's Advanced Scatterometer*: http://www.esa.int/esapub/bulletin/bullet102/Gelsthorpe102.pdf

[4] Vachon, P. W. and J. Wolfe. *C-Band Cross-Polarization Wind Speed Retrieval*. IEEE Geosci. Remote Sensing Lett., 8, 456–459, 2011.

[5] Banfi, S., P. Schlüssel, D. Diebel, P. Clarke, M. Betto, C.C. Lin, V. Kangas, S. Kraft, P. Bensi, I. Zerfowski, M. Saccoccio, T. Maciaszek. *Feasibility Studies for the follow-on EUMETSAT Polar System*. SPIE Remote Sensing Conference 2010, Toulouse, France, Sept. 2010.

[6] Fois F, C.C. Lin, H. Barré, M. Betto, M. Loiselet, G Mason. *MetOp Second Generation Sscatterometer Mission*. Proc. EUMETSAT Meteorological Satellite Conference 2012, Sopot, Poland, Sept. 2012: http://www.eumetsat.int/Home/Main/AboutEUMETSAT/Publications/ConferenceandWorkshopProceedings/2012/groups/cps/documents/document/pdf_conf_p61_s1_01_fois_v.pdf

[7] Uhlhorn, E. W., P.G. Black, J.L. Franklin, M. Goodberlet, J. Carswell, and A.S. Goldstein. *Hurricane Surface Wind Measurements from an Operational Stepped Frequency Microwave Radiometer*. Monthly Weather Review, 135, 3070–3085, doi:10.1175/MWR3454.1, http://dx.doi.org/10.1175/MWR3454.1, 2007.

[8] Lin C.C., M. Betto, M. Belmonte Rivas, A. Stoffelen, J. de Kloe. *EPS-SG Windscatterometer Concept Tradeoffs and Wind Retrieval Performance Assessment*. IEEE Trans. Geosc. and Remote Sensing, Vol. 50, No. 7, July 2012, pp. 2458-2472.

[9] van Zadelhoff, G.-J., A. Stoffelen, P. Vachon, J. Wolfe, J. Horstmann, and M. Belmonte Rivas. *Scatterometer Hurricane Wind Speed Retrievals using Cross Polarization*. Submitted for publication.

[10] Belmonte Rivas, M., A. Stoffelen, G.-J. v. Zadelhoff. *The benefit of HH and VH polarization in retrieving extreme wind speeds for an ASCAT-type scatterometer*. Submitted for publication.