Response to the review comments by Xiao-Ming Li

Gerd-Jan van Zadelhoff, A Stoffelen, P. W. Vachon, J. Wolfe, J. Horstmann, and M. Belmonte Rivas

We thank the referee for his thorough review of our paper. Below we start with a point by point response to the review comments. When referring to the original manuscript (amtd-2013-139) the abbreviation van Zadelhoff et al. 2013 is used, the abbreviation Li 2013 is used for the comments made by Xiao-Ming Li (amtd-6-C3085-2013-supplement).

Q.1. It is understood the primary purpose of the study is to demonstrate the necessarily to establish a VH channel in the next generation scatterometer instruments. However, the presented study is fully based on RADARSAT-2 data. Please consider whether the title matches well with the contents.

Your comment makes apparent that our internal project title was used as title for the paper. You are right that the title does not completely matches with the contents. We propose to update the title to

Retrieving Hurricane Wind Speeds using Cross Polarization C-band Measurements

Q.2. Pp. 7947, line 13, "In the case of SAR instruments, additional wind direction (or speed) information…". The referee would like to know why "additional wind speed information" is needed for SAR to retrieve the absolute wind speed using co-polarization data.

The original intention of the sentence was to indicate that to retrieve both the wind direction and wind speed at a given resolution, one of the two is needed a priori. This got lost in a rewrite of the sentence at a later point. The sentence will be changed to make more sense.

Q.3. Pp. 7947, line 21-22, "provided the prevailing wind direction is uniform…". This argument is not always. Wind direction can be derived from SAR using kinds of methods, e.g., FFT, local gradient, and Doppler centroid shift, even the prevailing wind is not uniform, which, on the other hand, is the advantage of using SAR to retrieve sea surface wind field in high spatial resolution. Among many typical examples, tropical cyclone is a nice one showing wind direction with significant spatial resolution can be derived from SAR.

Indeed, it depends on the spatial scale whether alternative (to backscatter strength) wind information may be retrieved from SAR. Portabella et al (2012) considered FFT SAR wind retrieval methods and other authors later on studied Doppler information. These methods have serious limitations, one of which is that they cannot retrieve information in a small spatial context. So, indeed, in several cases, wind vector information may be retrieved from SAR on the resolution of these alternative information sources, but generally not on the SAR (km) scale. Since the atmospheric wind spectrum is rather uniform in along and across-track wind components, one generally expects both components to vary equally strong on these small scales.

> 'The high spatial resolution (about hundred meter) provided by SAR instruments, can be used to determine local wind speed phenomena in bays, fjords and along the coast line provided the prevailing wind direction is uniform (Portabella et al., 2002).'

Q.4. Pp. 7947, line 24. The referee doubts the argument "SAR systems typically achieve< 2dB". It might be true for the SAR sensors which had operated for a long extended-life (after 10 years or so), e.g., ERS-2/SAR. However, for the new generation SAR systems, e.g., RADARSAT-2 and TerraSAR-X, the radiometric stability is very good. For instance, after its launch of three years, radiometric stability of TerraSAR-X is only 0.15 dB. Therefore, please be sure on this value.

Within this comment we combined the knowledge of the radiometric stability and the knowledge of the instrument noise floor. The RADARSAT-2 noise floor is not particularly well known and variable, and is estimated to have a 1dB accuracy (Vachon 2011). The radiometric uncertainty is better, but difficult to determine due to the noise floor variations. The remark was intended to comment on the noise floor uncertainty and introduced here to indicate why only measurement values >NESZ+1dB are adopted. The sentence in the paper will be rewritten to make this more clear.

Q.5. Pp. 7951, line 26. If the NESZ is of around -30dB, why Fig.3 (top panel) shows so many data pairs with sigma naught of VH between -30dB and -35 dB? Are they noise?

The dual polarization RADARSAT-2 measurements provided contain the sum of the measured geophysical signal (σ_0) and the Noise Equivalent Sigma Zero (NESZ). The NESZ is also provided separately. To retrieve the $\sigma_{0,}$ the two signals have to be subtracted. In Figure 1, a cross section along the viewing direction through Hurricane Adrian is shown to visualize the different signals. The provided sum of the VH+NESZ signals (black) show, for low signals, the shape of the NESZ itself (wave-structure beyond longitude 255.5). By subtracting the NESZ from the combined signals a more realistic signal structure (blue) becomes apparent. The 1dB remark referred to in Q4 becomes important here. Since the NESZ has an uncertainty of 1dB all combined signals below NESZ+1dB are not taken into account within the analysis performed within the manuscript. The lower signals referred to in Li 2013 Q5 are therefore not noise, but signals above the noise floor.

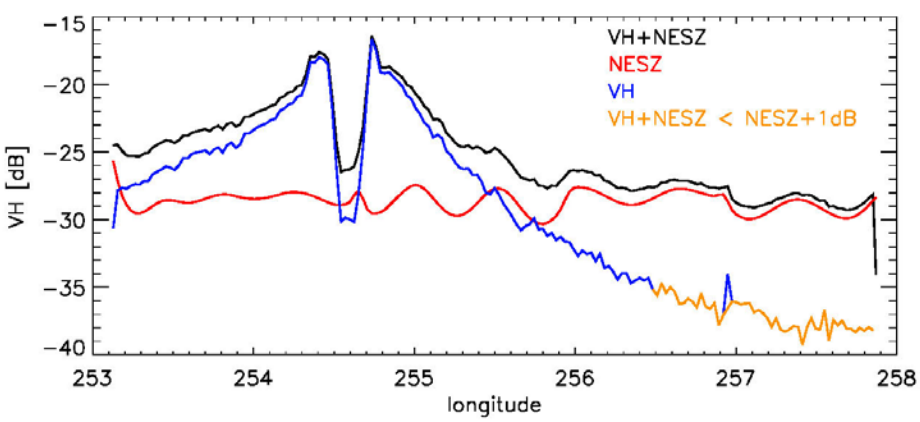

Figure 1: Cross section through the center of Hurricane Adrian (June 10th, 2011) in the viewing direction of the RADARSAT-2 imager. The black line shows the output signals as delivered by the RADARSAT-2 team. This signal is a combination of the measured σ_0 and the NESZ. The red line depicts the NESZ and the blue line the retrieved VH signal after the NESZ has been subtracted. The orange points are discarded from our statistics since they lie within 1dB of the original combined (σ_0+NESZ) signal strength.

Q.6. Pp. 7953, line 17. How the "wind speed ambiguity" is resolved to retrieve high wind speed *cases using CMOD5 from VV polarization data? This question is related with the orange curve shown in the top panel in Fig. 3.*

The wind speeds used to derive the orange curve, are calculated using the CMOD5.n function (Hersbach 2009), without taking into account a speed ambiguity correction as for instance described by Shen et. al. 2009. The orange curve is only provided as an indication of what the co-polar signals from RadarSAT-2 would give. The CMOD5n calculation themselves are not used within the paper.

Q.7. The wide ScanSAR has a nominal pixel size of 50 x 50 m in both azimuth and range directions. According to the description, e.g., pp.7956, line 9, the EMCWF wind field results in 25 km scale are up-scaled to the Radarsat-2 resolution (100m) for matching up. This assumes that the averaged σ_0 in two SAR pixels is considered to be related with real wind at the locations of the two pixels. However, one has to realize that the study deals with wind speed retrieval but not a single SAR pixel.
An individual SAR pixel is not naturally corresponded to wind in the pixel location. To retrieve wind field from SAR, a regular grid with a size generally larger than 500 m should be considered (e.g., Horstmann et al., 2000), in order to: 1) reduce the speckle effect in SAR image; and 2) average the tilt modulation induced by long surface waves. Although the spatial resolution of retrieved wind speed can be further increased to be less than 500 m in some special cases (e.g., 250 m used in the study by Li and Lehner (2013)), a spatial resolution of 100 m (only averaging two pixels!) used in the present study tends to bring many problems.

Thank you for pointing out this value of 100 meter resolution. The referee is absolutely right that use of a 100 meter resolution introduces noise as is kindly explained in the question. The value of a 100 meter is a typo. The provided RADARSAT-2 images have been averaged to a resolution of 3km and any up-scaling and collocations takes place at this resolution throughout our analysis. The value will be updated in the text.

Q8 (see Li 2013)

The main differences seen in Fig R1 (Li 2013) have in our mind to do with dealing with the noise floor (NESZ). In Figure 1, within this document, we show the difference between using the VH+NESZ and VH signals. Since the NESZ has a value of approximately -30dB this is the lower limit you can achieve when using the combined signals (e.g. the blue dots in Fig R1). In the top panel of Figure 2, we show the same results when using the VH+NESZ signals. The blue solid line, depicts the fit to the ECMWF data above 20m/s (using VH signals), and it indeed seems to represent a fit of the entire wind speed regime (> 5m/s). If one looks more closely into the shape of the darkest two contours, there is still a change in slope at around 20m/s but this is not as clear as shown in Figure 8, van Zadelhoff et. al. 2013. In the bottom panel the same distribution is provided but now based on the noise floor corrected VH measurements. The slope of the distribution shows the change described in the manuscript. In both panels the same two fits using the ECMWF wind speeds and the Vachon et al. 2011 relationships are overplotted to guide the eye.

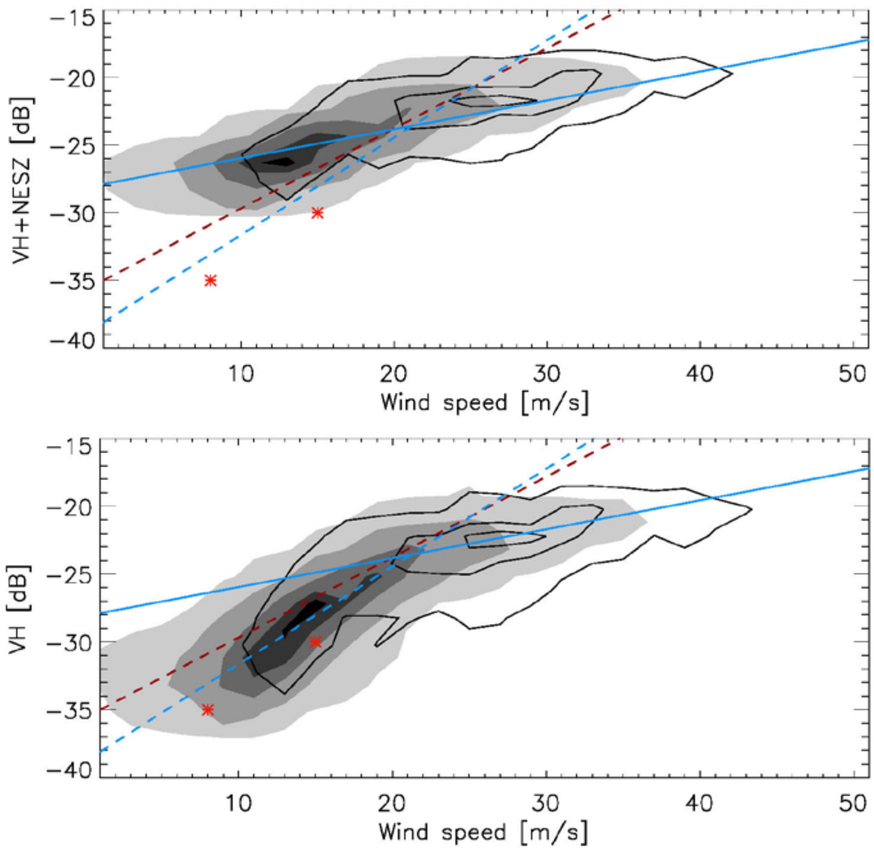

Figure 2: Top panel shows the observed distribution using the combined signals of σ_0 and NESZ. It indeed looks like the ECMWF fit made for wind speeds between 20 and 40m/s does describe the entire velocity range. However, the shape of the darkest contours show that this is not the case and that there is a slope change around 20m/s. The bottom panel shows the distribution after the NESZ has been subtracted (see Figure 1). The red line, in both panels, indicates the Vachon 2011 & Zhang 2011 results and the blue lines the fits based on the ECMWF wind speeds for the NESZ corrected distribution. The orange symbols represent two approximate distribution center values, estimated from the quad-pol measurements in Fig. R1, Li 2013.

If we now compare two quad-pol values (orange symbols representing the approx. centers of the distributions estimated from Fig. R1, Li 2013):

Wind speed	VH quad-pol: Fig R1
8	-35
15	-30

to the distribution in Figure 2 , they lie close to the blue dashed line indicating the fit based on the ECMWF data for winds < 20 m/s and well within the presented U_{10}-VH distribution. In both cases the distribution lie slightly to the right of the Zhang 2011 & Vachon 2011 results. This analysis, is clearly not a full description of the potential differences between the dual-pol and quad-pol signals, but that is beyond the scope of this manuscript. What this does indicate is that there are no major differences between the two polarization settings as long as the signals have been corrected for the additional noise levels (NESZ).

Within the paper this procedure is currently described in van Zadelhoff et. al. 2013 (P7951 s24- P7952 s2). We will re-evaluate whether this has to be made more clear in the text.

Additional References

- Hui Shen, Yijun He, W. Perrie , 'Speed ambiguity in hurricane wind retrieval from SAR imagery', International Journal of Remote Sensing, Vol. 30, Iss. 11, 2009
- Hersbach, H.: Comparison of C-Band Scatterometer CMOD5.N Equivalent Neutral Winds with ECMWF, Journal of Atmospheric and Oceanic Technology, 27, 721–736, doi:10.1175/2009JTECHO698.1, http://dx.doi.org/10.1175/2009JTECHO698.1, 2009.
- Vachon, P. W. and Wolfe, J.: C-Band Cross-Polarization Wind Speed Retrieval, IEEE Geosci. Remote Sensing Lett., 8, 456–459, 2011.
- Zhang, B., Perrie, W., and He, Y.: Wind speed retrieval from RADARSAT-2 quad-polarization images using a new polarization ratio model, J. Geophys. Res., 116, C08 008, doi:10.1029/2010JC006522, http://dx.doi.org/10.1029/2010JC006522, 2011.