Reprocessed QuikSCAT (V04) Wind Vectors with Ku-2011 Geophysical Model Function

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Introduction

In April 2011, we reprocessed the QuikSCAT ocean wind vectors using a new geophysical model function. The primary objective of the reprocessed QuikSCAT V04 was to improve wind speed retrievals at high wind speeds.

1. The new Geophysical Model Function Ku2011

In March 2011, we finalized the new Geophysical Model Function (GMF) for QuikSCAT wind vector retrievals, which we refer to as Ku-2011. When the original GMF for QuikSCAT was developed in 2001 (Ku-2001), validation data for winds higher than 20 m/s were extremely limited. Recent analyses showed that high winds derived using Ku-2001 were significantly overestimated.

The new GMF Ku-2011 relies on a recent advancement in satellite wind vector retrieval for the WindSat polarimetric radiometer. Meissner and Wentz (2009) recently developed an all-weather WindSat algorithm capable of global wind vector retrievals even in rainy and stormy conditions. The all-weather WindSat winds have been trained using the NOAA Hurricane Research Division (HRD) dataset. The WindSat mission started in 2003 and is still active. The new GMF uses WindSat retrievals as calibration ground truth for wind speed. The WindSat retrievals are considered reliable for winds up to 30 m/s, and therefore are an optimal calibration target for QuikSCAT in the range 20-30 m/s. The new WindSat products were developed at Remote Sensing Systems (RSS). WindSat gridded maps for 8 environmental parameters were released to the public on the Remote Sensing Systems website (www.remss.com) in April 2011. In addition to wind speed, WindSat retrievals include wind direction, water vapor, sea surface temperature, cloud water, rain rate, and a new all-weather wind product which includes wind retrievals in rain. We extensively validated the WindSat winds before using them to develop the Ku-2011 GMF for QuikSCAT.

The Ku-2011 GMF is a transfer function that relates the radar backscatter ratio σ_0 to ocean surface wind speed and direction. The transfer function depends on the radar beam incidence angle. QuikSCAT is a conical scanner, and has a fixed incidence angle for each polarization, 46 and 53 deg for h-pol and v-pol, respectively. Therefore, for each polarization, the σ_0 depends only on wind speed w and direction. It can be easily expressed as a summation of harmonic functions of the wind direction φ_R relative to the looking angle (azimuth):

$$\sigma_0 = f(w,\varphi_R)_{pol} \cong \sum_{i=0}^{N} A_i(w)\cos(i\varphi_R)$$

We developed the new GMF Ku-2011 by collocating 7 years of radar backscatter ratio σ_0 from QuikSCAT with WindSat wind speeds. The global QuikSCAT and WindSat retrievals were collocated within a time-window of 90 minutes (~ hundreds of millions collocations). It is very important to exclude any possibility of rain contaminated data at this stage, as rain impacts the σ_0 and would bias the GMF. For this reason, we used WindSat rain retrievals to discard σ_0 observations in proximity of rain. The coefficients A_j *(w)* of the expansion (up to N=5) are calculated using WindSat wind speeds as ground truth. For wind direction, we used those from the Cross-Calibrated Multi-Platform dataset (CCMP; Atlas et al., IEEE TGRS, 2008), as we found these data to have slightly lower noise than NCEP. After this first step, some fine-tuning was necessary to adjust the coefficients at very low winds (below 5 m/s) and very high winds (above 25 m/s). This was done because the noise in the retrievals (both of σ_0 and of the validation winds) in these wind regimes has the effect of artificially altering the coefficients of the harmonic analysis of binned σ_0. In particular, the uncertainty in wind direction impacts the calculation of harmonic expansion coefficients at low wind speeds, resulting in underestimated coefficients by an amount proportional to the noise in wind direction. In order to account for this uncertainty, we applied a correction to the A_j *(w)* coefficients similar to the one described in Wentz and Smith (JGR, 1999), but determined using 9 years of σ_0 differences collocated with CCMP wind directions. Additional fine tuning of the coefficients was based on validation studies involving several years of the new QuikSCAT wind retrievals compared to buoys, and other satellite retrievals.

Our goal during the fine-tuning phase has been to make sure that: 1) A multi-year comparison with global buoys shows no global bias and displays a very similar probability distribution function of wind speeds (Figure 1). 2) There is no across-track bias in QuikSCAT retrievals compared to other validation data (Figure 2). 3) The global maps of wind bias compared to validation data do not show any unexplained regional patterns (Figures 3a-b). 4) The high wind speeds from the new QuikSCAT match the WindSat retrievals up to about 35 m/s (Figure 4). 5) The histograms of QuikSCAT wind direction match NCEP, at all winds (Figures 5 and 6). The latter is a particular challenging problem at low winds (Figure 5), because the non-directional coefficients in the GMF are very small, and very sensitive to small errors due to noise. Figures 1-6 also display results from similar analyses performed using winds from the Ku-2001 GMF.

It would be ideal to have an independent data of very high winds to validate our final GMF. So far, the only reliable one we found is provided by aircraft wind measurements taken during the GFDex experiment off the tip of Greenland (Renfrew et al., QRJMS 2009). The maximum wind speed observed during flights that collocated with QuikSCAT retrievals is 25 m/s. In this range of wind speeds the new QuikSCAT retrievals match very well the aircraft winds, both for wind speed and wind direction (Figure 7). In particular, Figure 7 illustrates a significant improvement in the new QuikSCAT wind direction, represented by the direction root mean square (RMS) difference with aircraft measurements. This was due to the improved directional coefficients (A_1, A_2) at high winds in the new GMF compared to the old one (Ku-2001).

We hope to have additional high wind observations for an independent validation of QuikSCAT (i.e. from oil rigs, rain-free aircraft measurements in extratropical storms, or dropsondes). So far, none of these data have been made available to us or they have not been validated at those high winds. Therefore, we decided to proceed and finalize our GMF. We will continue to validate the new QuikSCAT high winds as soon as any additional validation data becomes available. If necessary, we will refine our GMF at high winds in the next few years, based on results of additional validation studies.

In April 2011, we reprocessed the complete QuikSCAT winds (1999-2009) using the final version of our new model function, which we called Ku-2011. Daily, weekly, and monthly gridded maps of Ku-2011 QuikSCAT were produced and released to the public on www.remss.com in May 2011.

2. Comparison of passive (radiometer) versus active (scatterometer) winds

We performed an extensive analysis of the strengths and weaknesses of wind retrievals from passive radiometers (WindSat) and active scatterometers (QuikSCAT) by comparing the skill of wind speed and direction retrievals at different wind and rain regimes. The analysis showed that WindSat wind speeds from the new all-weather algorithm are sufficiently accurate in rain, but the wind direction is degraded. On the other hand, rain has a significant impact on QuikSCAT wind speeds, but not on wind direction, except for very high rain rates. The results are summarized in the Tables 1 and 2.

Table 1: Wind speed bias and standard deviation for WindSat and QuikSCAT Ku-2011 compared to global buoys.

Rain Rate	Satellite – BUOY Wind Speed [m/s] Bias Standard Deviation			
	WindSat all-weather algorithm		QuikSCAT Ku 2011	
No rain	0.04	0.9	0.01	0.9
Light rain 0 – 3 mm/h	0.7	1.6	1.7	2.3
Moderate rain 3 – 8 mm/h	0.02	2.0	4.8	3.6
Heavy rain > 8 mm/h	-0.5	2.2	7.1	4.5

Table 2: Strengths and weaknesses of passive versus active satellite wind retrievals

	Condition	Passive WindSat V7	Active QuikSCAT Ku2011 GMF
Wind speed	no rain low – moderate winds	+ +	+ +
	no rain high winds	+ +	+
	rain	+	–
Wind direction	moderate – high winds no - moderate rain	+ +	+ +
	low winds	–	+
	high rain	–	+
Rain detection		+ +	–

\+ + very good

\+ slightly degraded

– strongly degraded / impossible

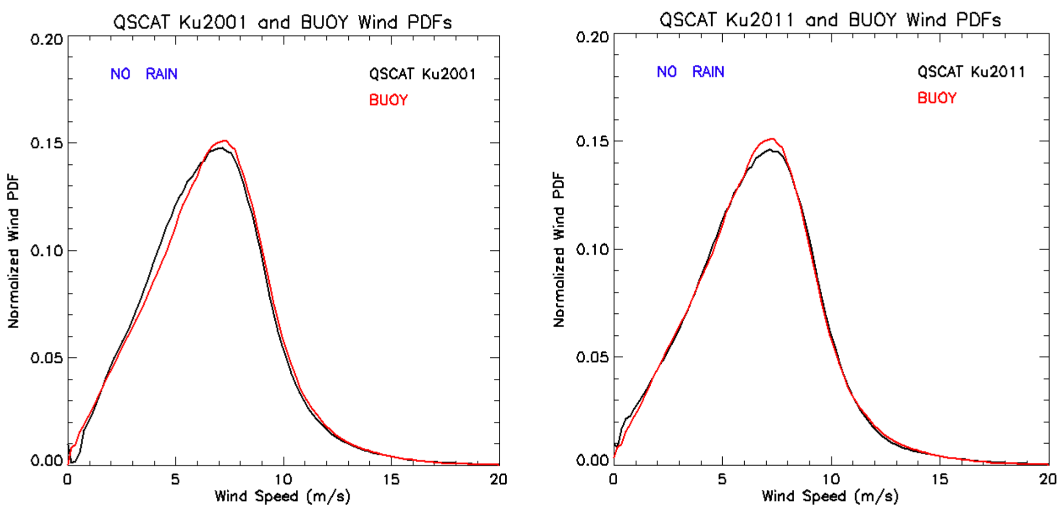

Figure 1: Wind speed Probability Distribution Function (PDF) for QuikSCAT Ku-2001 (left) and Ku-2011 (right) compared to buoys (200 global buoys, 5 year statistics).

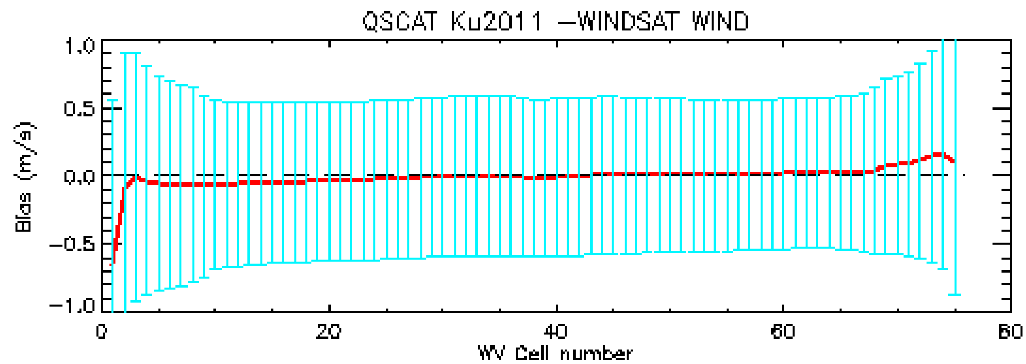

Figure 2: Across-track bias (red line) and standard deviation (blue bars) of QuikSCAT-WindSat wind speeds for moderate winds (6-12 m/s), as a function of wind vector cell number (5 yr validation, rain-free).

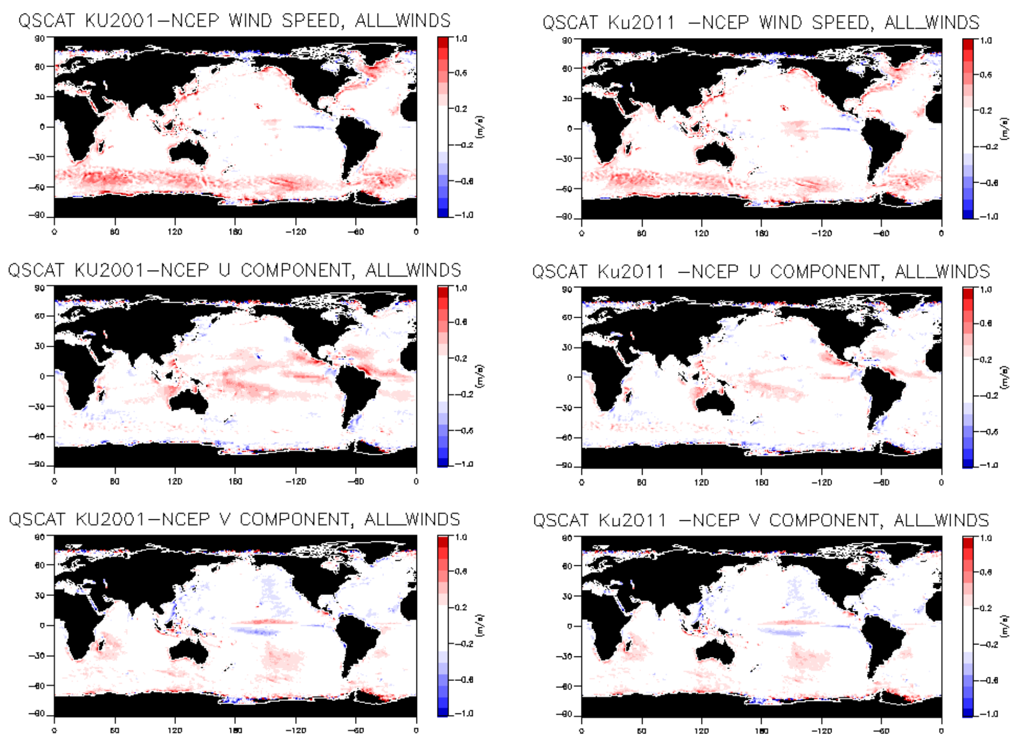

Figure 3a: Global maps of QuikSCAT-NCEP bias, for wind speed (top), U component (center) and V component (bottom). The panels on the left refer to QSCAT Ku-2001, and those on the right to the new QuikSCAT Ku-2011. All wind regimes were included.

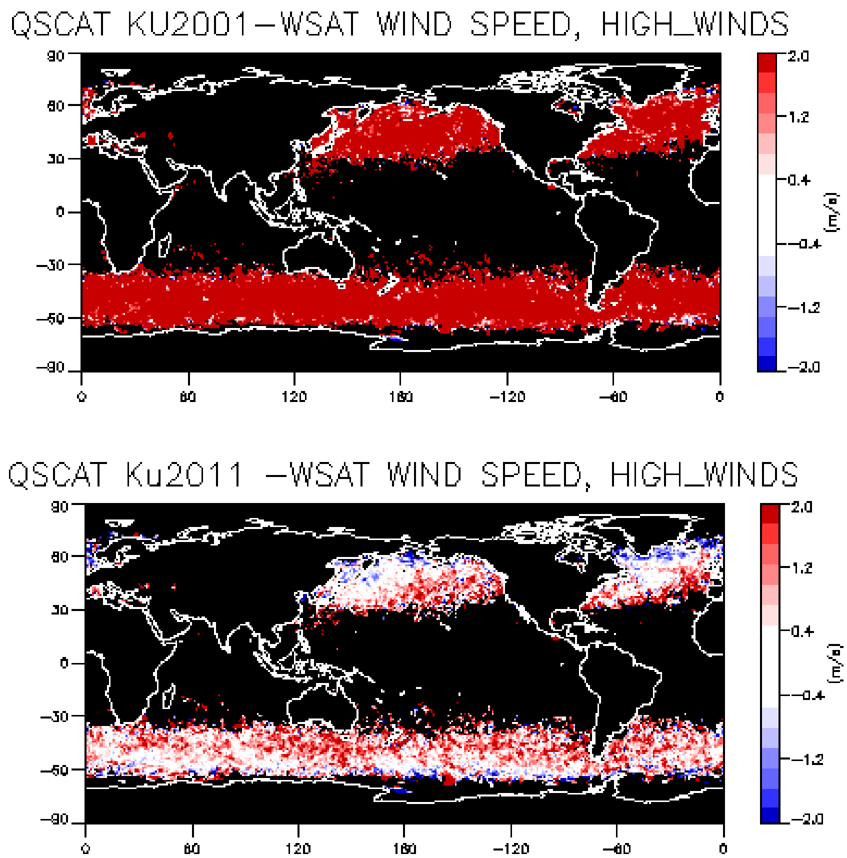

Figure 3b: Global map of QuikSCAT- WindSat bias, for high wind speed only (above 20 m/s). The top panel refers to QSCAT Ku-2001, and the bottom one to the new QuikSCAT Ku-2011.

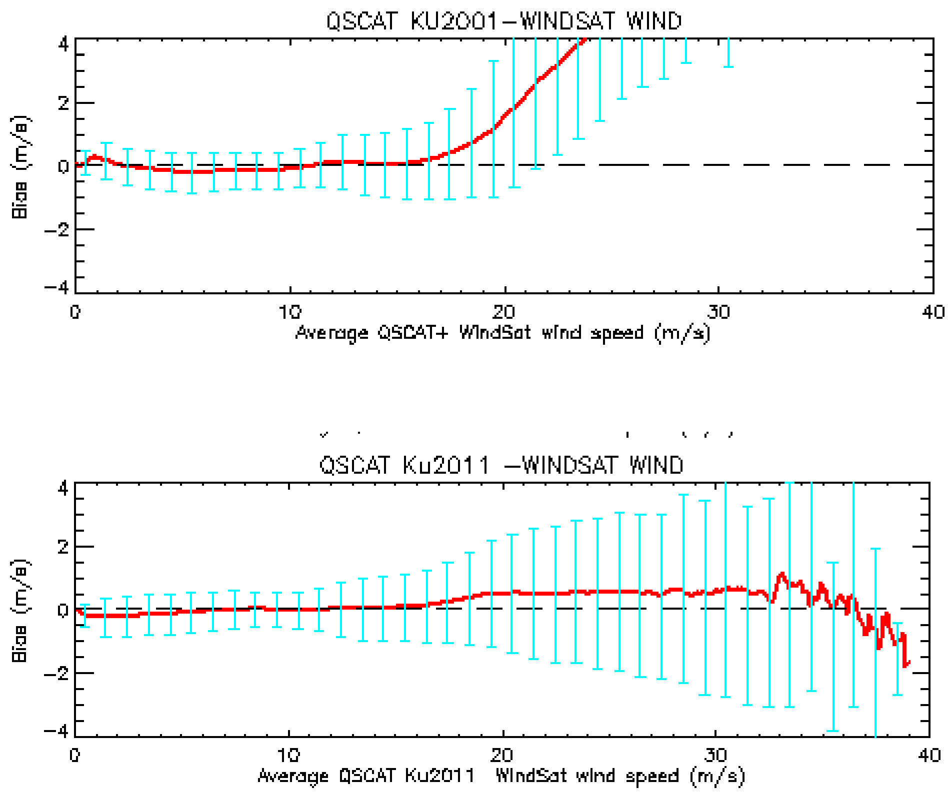

Figure 4: QuikSCAT- WindSat bias (red line) and standard deviation (blue bars) as a function of the average QuikSCAT+WindSat wind speed. The top panel refers to QSCAT Ku-2001, the bottom panel to Ku-2011.

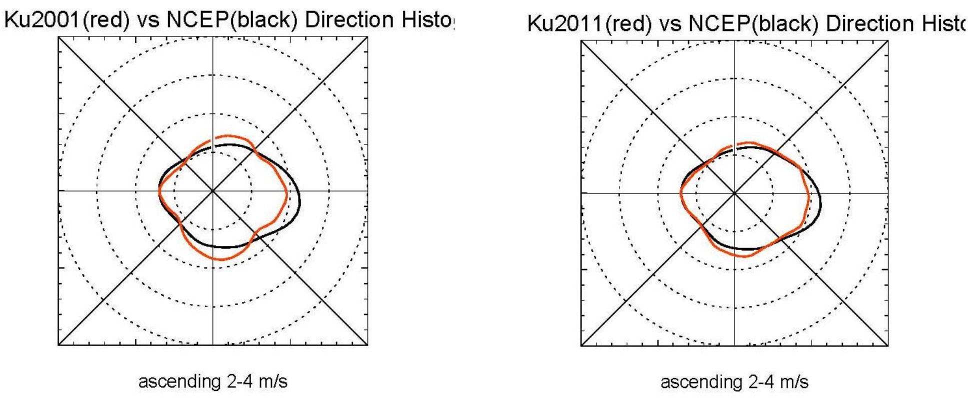

Figure 5: QuikSCAT (red) versus NCEP (black) histograms of wind direction (relative to the satellite track) at very low wind speed (2-4 m/s, ascending passes). Left and right panels refer to QuikSCAT Ku-2001 and Ku-2011, respectively.

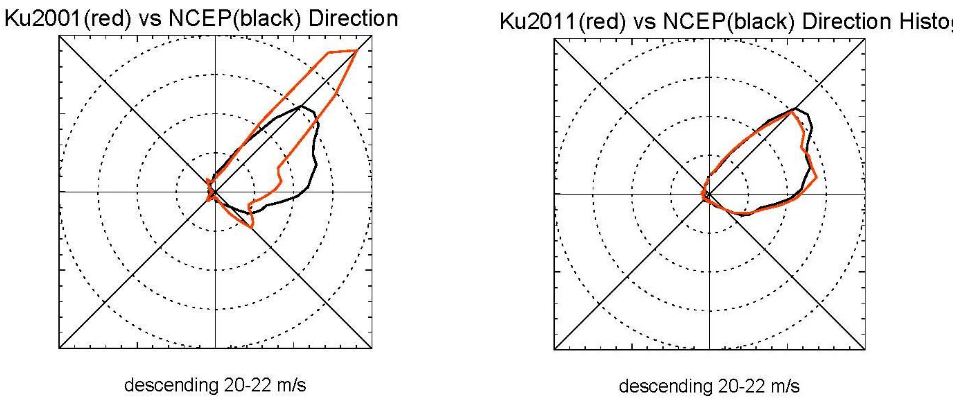

Figure 6: Similar to Fig. 5, but for high wind speeds (20-22 m/s, descending passes).

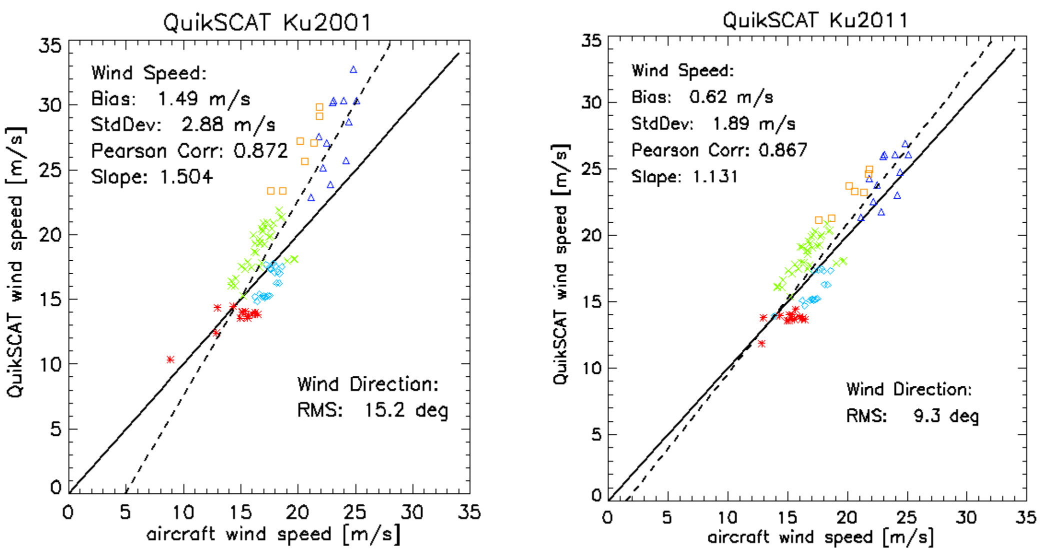

Figure 7: Aircraft winds for the GFDex experiment compared to QuikSCAT Ku-2001 (left), and the new Ku-2011 (right). Each color refers to a different mission flight. Also illustrated are wind speed bias and standard deviation compared to aircraft measurements, and root-mean-square (RMS) difference in wind direction.