ALL-WEATHER WIND VECTOR MEASUREMENTS FROM INTERCALIBRATED ACTIVE AND PASSIVE MICROWAVE SATELLITE SENSORS

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1 BACKGROUND

Accurate observations of high winds over the oceans are important for analyses of phenomena that range from regional (tropical and extratropical storms) to global scales (air-sea exchanges, ocean circulation). However, so far a lack of in-situ observations of winds above 20 m/s posed severe limitations to the accuracy of satellite-retrieved high winds as insufficient data were available for training and validation of wind speed retrieval algorithms. An additional difficulty is the fact that many high wind observations are contaminated by rain. This leads to a strong degradation in the accuracy of wind speed measurements by active sensors (scatterometers) and a complete breakdown of the wind speed retrieval by passive sensors (radiometers) if the standard algorithms, which have been trained in rain-free conditions, are used.

2 WINDSAT ALL-WEATHER WIND RETRIEVALS

A recent advancement in satellite radiometer retrievals of winds in rain has been achieved by Meissner and Wentz [1] who developed an all-weather wind vector retrieval algorithm for the WindSat polarimetric radiometer. The new algorithm is a blending between the standard physical wind algorithm for non-raining atmospheres and a new wind-through-rain algorithm. The latter one is a combination between a physical and a statistical algorithm that has been trained in rainy conditions. Its key feature is the utilization of C-band and X-band frequencies. Their spectral signatures allow to find combinations between different channels in these bands that are sufficiently sensitive to wind speed but less sensitive to rain. This basic principle has been employed successfully for a long time by the airborne Step Frequency Microwave Radiometer (SFMR) [2] for measuring wind speeds in hurricanes. WindSat all-weather wind vector retrievals are now available starting from 2003 to present, as part of Remote Sensing Systems (RSS) new Version 7 intercalibrated ocean suite.

3 IMPROVED QUIKSCAT KU 2011 GEOPHYSICAL MODEL FUNCTION

Scatterometer wind vector retrievals are based on a Geophysical Model Function (GMF), which relates the radar backscatter cross section σ_0 to surface wind speed W and relative wind direction φ by means of the harmonic expansion:

$$\sigma_0 = f(W,\varphi) = A_0(W) + A_1(W)\cdot\cos(\varphi) + A_2(W)\cdot\cos(2\varphi) + \ldots$$

The Ku2001 GMF, which has been used so far to retrieve QuikSCAT wind fields, had been developed using buoy wind speed measurements and wind fields from numerical weather prediction models as ground truth [3]. At high winds, where ground truth data are sparse or non-existent, the Ku2001 GMF had to be extrapolated. Recent aircraft measurements have shown that above 15 m/s scatterometer wind speeds that were derived from the extrapolated Ku2001 GMF are about 20 – 25% too large [4]. This warrants a recalibration of the scatterometer GMF at high winds.

An additional problem is that above 15 m/s the scatterometer σ_0 starts to lose sensitivity to wind speed, which makes scatterometer high wind speed measurements more difficult and prone to error. In contrast, the radiometer emissivity model function keeps increasing linearly even at high wind speeds. Therefore the radiometer seems to be the more reliable instrument for measuring high wind speeds. We therefore use the new WindSat retrievals as a reference in order to develop a new GMF for QuikSCAT (Ku2011) with the specific goal of improving high wind retrievals. The new GMF is based on 7 years of QuikSCAT Ku-band σ_0 that were collocated within 90 minutes with rain-free WindSat winds.

Figure 1shows the Ku2001 and Ku2011 GMF for the coefficients A_0 and A_2 at v-pol.

The whole QuikSCAT wind vector data set has been reprocessed using the new improved Ku2011 GMF.

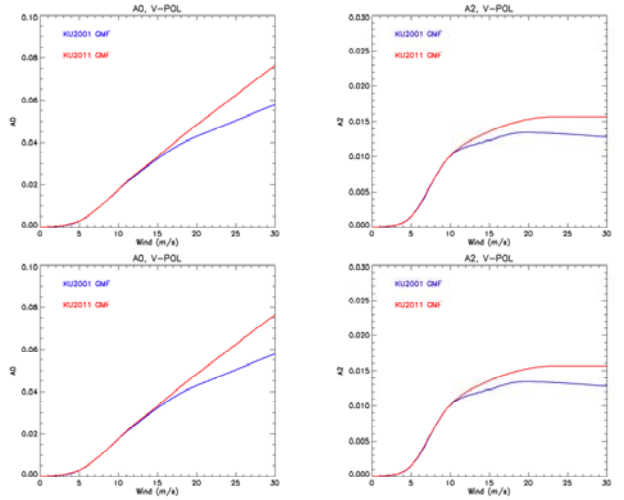

Figure 1: V-pol A_0 and A_2 coefficients of the Ku2001 and Ku2011 GMF.

4 Validation Study

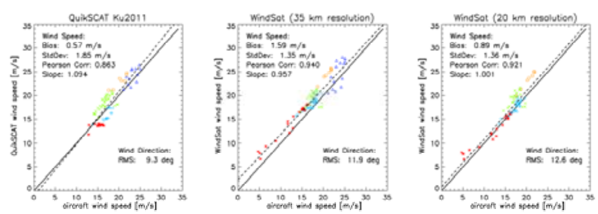

Figure 2: Comparison of wind speeds form QuikSCAT Ku2011 GMF and WindSat with the aircraft measurements from [4].

We have undertaken an extensive validation study for both the WindSat and the new QuikSCAT wind vector products comparing to ground truth observations from buoys and aircrafts, other microwave satellites (e.g.: SSM/I) and wind fields from numerical weather prediction (NCEP GDAS) and data assimilation models (CCMP [5]) and the NOAA Hurricane Research Division (HRD). Examples are shown in Figure 2 and Figure 3.

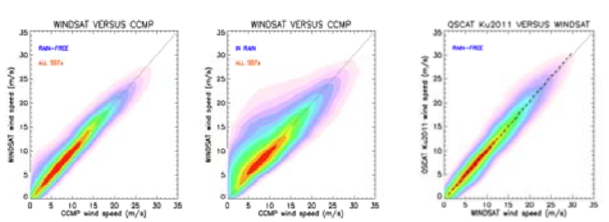

Figure 3: Joint wind PDF for WindSat rain-free or in-rain compared to CCMP [5] and for rain-free QSCAT Ku2011 compared to WindSat.

5 Degradation in Rain

Table 1 and Figure 4 demonstrate how the WindSat all-weather and QuikSCAT Ku2011 wind speeds degrade as a function of rain rate. The residual degradation of the all-weather radiometer wind speeds in rain constitutes a significant improvement over the standard radiometer wind retrievals that have been available so far. The all-weather radiometer wind speed retrieval undercorrects at very low wind speeds and slightly overcorrects at very high winds. Its overall bias is almost zero.

Table 1: Wind speed bias and standard deviation for WindSat all-weather and QSCAT Ku2011 winds compared to buoys.

Rain Rate	Satellite – Buoy Wind Speed [m/s]			
	WindSat All Weather		QuikSCAT Ku 2011	
	Bias	Std. Dev.	Bias	Std. Dev.
no rain	0.04	0.9	0.01	0.9
light rain 0 – 3 mm/h	0.70	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	-0.05	2.5	7.1	4.5

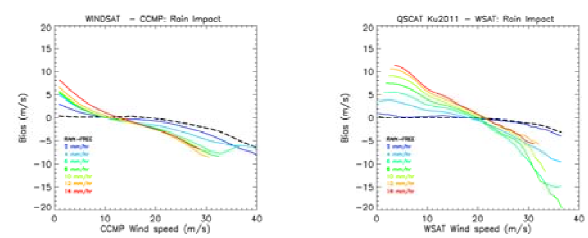

Figure 4: Statistics using 5 years of all-weather WindSat wind speeds collocated with CCMP (figure on left) and with QuikSCAT Ku2011 winds (right) The figures show the biases as a function of wind speed for different rain regimes.

6 Summary: Passive Versus Active Wind Vectors

A summary of the strengths and weaknesses of passive (radiometers) versus active (scatterometer) wind retrievals is presented in Table 2.

The radiometer provides a reliable rain detection and keeps better sensitivity at high wind speeds. Rain impacts scatterometer wind retrievals, especially at high winds. On the other hand, the scatterometer has significantly better sensitivity to wind direction than the radiometer especially in wind speeds below 6 m/s and in moderate or high rain.

Daily gridded maps of the all-weather WindSat winds together with other WindSat products are available at **www.remss.com** from 2003 until current. The reprocessed QuikSCAT winds using the Ku2011 model function for the complete dataset (1999-2009) can be found on the same website.

Table 2: Performance overview of wind speed and direction retrievals from passive (radiometer) and active (scatterometer) microwave sensors: green (++) = very good performance, yellow (+) = slightly degraded performance, red (–) = strongly degraded performance or retrieval impossible.

	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		+ +	–

7 References

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