PRELIMINARY INVESTIGATION OF SPLASH EFFECT ON HIGH WIND C-BAND HH-POL MODEL FUNCTION

James R. Carswell[1], Dragana Perkovic[2], Tao Chu[3], Stephen J. Frasier[3], Paul S. Chang[4], Zorana Jelenak[4]

[1] Remote Sensing Solutions, Barnstable, MA 02630, USA

[2] Radar Science and Engineering Dept., Jet Propulsion Laboratory, Pasadena, CA 91109, USA

[3] University of Massachusetts, Amherst, MA 01003, USA

[4] NOAA/NESDIS/STAR-UCAR, Camp Springs, MD 20746, USA

The National Research Council Decadal Survey [1] identified a need for a future mission that would provide accurate real-time observations of ocean wind vectors from calm to tropical cyclone wind conditions with and without presence of rain. Tasked by National Oceanic and Atmospheric Administration (NOAA), the Jet Propulsion Laboratory (JPL) developed a future scatterometer design that would leverage its success on the heritage of QuikSCAT but would provide more accurate measurements under all weather conditions through use of Ku- and C-band coincident measurements of the ocean surface. To design a cost effective instrument for all weather operations from space the existing risks need to be mitigated. The work described in this paper attempts to validate results reported at hurricane strength winds in [2] and investigate the effects of precipitation on the scatterometer wind estimation.

1. INTRODUCTION

A scatterometer transmits a precisely known amount of power and receives an echo from the ocean surface accurately measuring the backscattered return. The University of Massachusetts airborne conically scanning scatterometer IWRAP is capable of measuring the ocean surface return at two wavelengths and at different sizes of illumination footprints. To correlate such measurements a dimensionless quantity known as Normalized Radar Cross Section, NRCS, is defined as:

$$\sigma^0 = \frac{(4\pi)^3 P_r}{P_t \lambda^2 \int_{A_{ill}} \left(G^2/R^4\right) dA}$$

where, σ^0 denotes NRCS, P_r is the received power, P_t is the transmitted power, λ is the radar wavelength, A_{ill} is the area of the ocean surface illuminated by the antenna footprint, G is the antenna gain and R is the distance to the ocean surface. The NRCS is highly correlated to near ocean surface wind speed and direction. There are a number of empirical models relating strength of ocean radar backscatter to the equivalent neutral stability wind at 10 m height above the ocean surface [3], [4]. Off nadir the predominant scattering mechanism is Bragg scattering and the model function relating the wind at 10 m height and NRCS is:

$$\sigma^0 = M\left(U_{10N}, \chi, \theta, p, \lambda\right)$$

where, U_{10N} is the neutral wind at 10 m height, χ the relative angle between electromagnetic radiation of the radar and wind direction, θ is the incidence angle, and p is the polarization of the electromagnetic wave. Presently the two models used in the scientific community are 1) NSCAT2 for Ku-band which was derived from Seawinds scatterometer aboard QSCAT satellite and 2) CMOD5 model function for C-band VV-pol developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the Royal Netherlands Meteorological Institute (KNMI) for use with ERS and ASCAT scatterometers. The empirical models developed so far follow the cosine Fourier series expansion to model the NRCS response to the ocean wind.

$$\sigma^0 = A_0 + A_1 \cos\chi + A_2 \cos 2\chi$$

The A_0, mean NRCS, A_1, the first harmonic and A_2 second harmonic are dependant on radar wavelength, polarization and incidence angle and follow a power law with respect to the wind speed. The NSCAT2 model function describes the relationship between NRCS and low to moderate wind speeds, while CMOD5 extends the relationship at C-band to high-wind cases. A new model function was developed based on IWRAP measurements to relate hurricane-strength winds to the NRCS at Ku-band and C-band HH-pol by D. Estaban-Fernandez [1]. In this paper we attempt to verify the IWRAP model function and investigate effects of splash at high wind speeds.

2. RESULTS

We investigate the effects of rain on the surface of the ocean during high-wind events and the subsequent effect of splash on the geophysical model function at C-band horizontal polarization. The data used for this investigation were collected by University of Massachusetts and NOAA/NESDIS/STAR during the 2008 hurricane season using a dual wavelength scatterometer IWRAP [5], and a stepped frequency microwave radiometer AOC SFMR.

During 2008 the IWRAP system was operated at Ku-band VV-pol and C-band HH-pol configurations and collected ocean backscatter measurements under varying wind and rain conditions. The AOC SFMR is a passive device that operates at C-band (4.7 – 7.2 GHz) and produces estimates of wind speed and rain rate through measurement of brightness temperature.

In the past the SFMR data was used for flagging of rain events in IWRAP data, the issue with this is that SFMR is a nadir looking instrument and the volume that it samples differs from the volume sampled by IWRAP. On the other hand the SFMR is less sensitive to lower rain rates and it may omit certain events. The new rain flag was developed solely from IWRAP data using the pulse-pair correlation coefficient profile given by:

$$\rho = \frac{\sum_{M}\left(V_{i-1}V_i^*\right)}{MS_{i-1}S_i}$$

where, V_{i-1} is the voltage of the pulse $i-1$ and V_i^* is the complex conjugate of voltage of pulse i, and the S_i is the estimate of the signal power.

The correlation coefficient depends on the signal to noise of the volume backscatter measurement and the spectral width. It is a better alternative to using reflectivity as it is not affected by calibration errors and it is very sensitive to low rain rates. Since IWRAP samples the volume from the flight level to the ocean surface the value of the correlation coefficient is calculated over ten range gates uncontaminated by the surface backscatter. A simple threshold method is used for detection of rain events. With no precipitation present the value of the correlation coefficient is approx 5%, setting the threshold at 10% enables detection of very weak precipitation events. Once the data are processed to a 500 m along track grid and rain flagged we can proceed to verify the high wind model function at C-band HH-pol.

The data used for validation were collected over three days, August 31, September 6 and 7, 2008. The data was normalized to 50 degrees incidence, the measurements that fell within the same along track bin were accumulated and averaged. The first five Fourier cosine terms were derived from averaged NRCS conical scans for each along track cell. The measurements were then binned into 3 m/s wind speed bins according to the wind speed derived from the corresponding SFMR measurement. The mean and standard deviation of these measurements were calculated and outliers whose value was greater than 3 sigma standard deviation of the binned measurements were removed and marked as outliers. This filtering removed about 4% of the overall data, which we deemed sufficiently small for validation purposes while the further investigation is ongoing.

Figure 1a plots the wind speed bin averaged C-band HH-pol mean NRCS at 50 degrees incidence versus averaged SFMR wind speed estimate. The measured standard deviation is plotted as a vertical line about the point and the number of measurements used for each bin is labeled on top. The solid line is the IWRAP gmf function remapped for changes in emissivity model corrections for SFMR data. The bias of 4.9 dB was detected between the data points and the predicted IWRAP gmf curve. The data have been corrected for this bias whose most likely source are errors in data calibration being investigated.

Figure 1a shows that the remapped IWRAP gmf correctly predicts measured NRCS sensitivity to wind speed at C-band horizontal polarization.

To study the influence of precipitation at high wind speeds we study the residual between the measured and mean NRCS values for a particular wind speed by subtracting the predicted mean NRCS from measured, shown in Figure 1b.

Each point is color coded based on the SFMR wind speed. The residual measurements are binned into 3 dB bins and the mean and standard deviation of each bin shown (black circle and line) with the number of samples per bin displayed. A linear fit to the measurements is plotted as a dashed line. This plot shows a downward trend, which can most likely be attributed to atmospheric attenuation rather than effects from splash at higher rain rates and wind speeds.

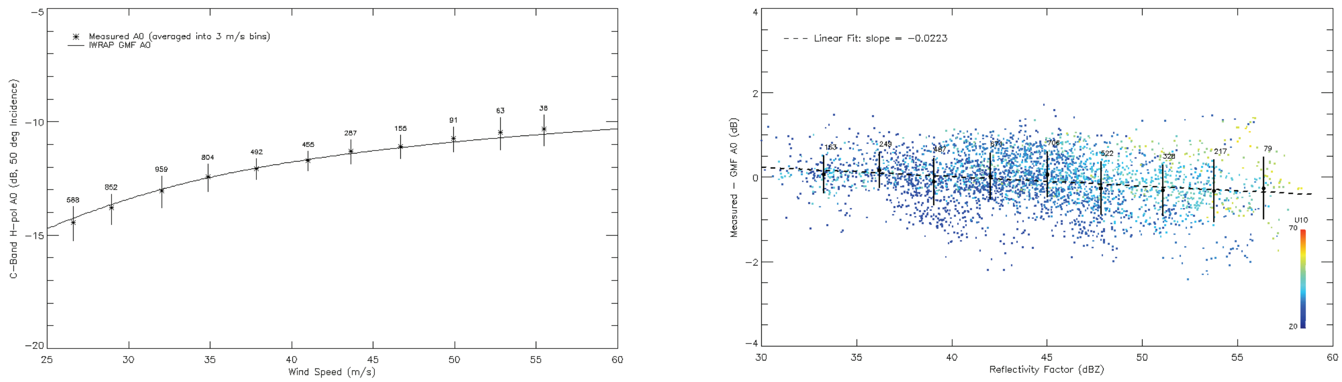

Figure 1. a) Left: C-band HH-pol IWRAP mean NRCS (A0) measurements obtained at 50 degrees incidence are plotted versus wind speed, b) right: Using the IWRAP GMF, the difference between the measured C-band mean NRCS versus the modeled mean NRCS (HH-pol, 50 degrees incidence) is plotted versus the IWRAP reflectivity factor.

3. CONCLUSIONS

Preliminary study of IWRAP data from hurricane season 2008 verifies the IWRAP high speed model function for C-band HH-pol. Furthermore the study of residual between measurements and predicted mean NRCS values show a inverse linear relationship with the wind speed that is explained by the atmospheric attenuation.

4. BIBLIOGRAPHY

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