COMBINED ACTIVE AND PASSIVE REMOTE SENSING OF HURRICANE OCEAN WINDS

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ABSTRACT: The synergism of active and passive microwave techniques for hurricane ocean wind remote sensing is explored. We performed the analysis of Windsat data for Atlantic hurricanes in 2003-2005. The polarimetric third Stokes parameter observations from the Windsat 10, 18 and 37 GHz channels were collocated with the ocean surface winds from the Holland wind model, the NOAA HWind wind vectors and the Global Data Assimilation System (GDAS) operated by the National Center for Environmental Prediction (NCEP). The collocated data were binned as a function of wind speed and wind direction, and were expanded by sinusoidal series of the relative azimuth angles between wind and observation directions. The coefficients of the sinusoidal series, corrected for atmospheric attenuation, have been used to develop an empirical geophysical model function (GMF). The Windsat GMF for extreme high wind compares very well with the aircraft radiometer and radar measurements.

KEY WORDS: Sea surface wind; microwave polarimetry; hurricanes

1. INTRODUCTION

The near surface ocean wind, generating the momentum flux affecting ocean circulation and mixing, is the key driving force in air-sea interaction processes. Global mapping of near surface ocean wind vectors is crucial for many oceanographic and atmospheric studies. To obtain this key measurement, scientific satellite scatterometers have been launched to acquire a time-series of global ocean surface winds.

Response of radar measurements to ocean surface wind under extreme wind conditions has been under active investigation to improve the capability of hurricane tracking and predictions using spaceborne scatterometer observations (Yueh et al., 2001, 2003). The analysis of QuikSCAT data indicated the response of radar echoes from ocean surfaces to hurricane wind speed and direction. However, the impact of rain has to be corrected using passive microwave rain products to enable accurate retrieval (Yueh et al., 2003).

In addition to aiding the correction of rain effects on active radar data, the passive microwave has the potential to provide additional information regarding the surface winds for hurricanes. Figure 1 provides airborne demonstration of complementary wind direction information in coincident active and passive microwave data. The passive microwave polarimetry for surface wind vector measurements has been investigated in the range of wind speed from 3 to 15 m/s by many aircraft field campaigns (Irisov et al., 1991; Yueh et al, 1995; Yueh et al., 1997; Yueh et al., 1999; Laursen and Skou, 2001; Piepmeier and Gasiewski, 2001; Lahtinen et al, 2003). Based on these experimental observations, the US Navy together with the National Polar Orbiting Environmental Satellite System (NPOESS) launched the WindSat with multi-frequency polarimetric radiometers in January 2003 to demonstrate the passive polarimetry for large spatial coverage of ocean surface wind vector measurements from space.

The first step toward the retrieval of ocean surface winds from WindSat brightness temperatures is to develop a geophysical model function, relating the polarimetric brightness temperatures to ocean surface wind speed and direction. The initial development of WindSat GMF was based on the airborne measurements and theoretical analysis. The spaceborne GMFs were derived from the WindSat 10, 18 and 37 GHz data collocated with the NCEP GDAS winds for up to about 25 m/s wind speed (Yueh et al., 2006).

However, the WindSat polarimetric GMF for tropical cyclones cannot be established through the collocated GDAS analysis due to the deficiencies of GDAS predictions for tropical cyclones. To assess the response of the WindSat data to extreme high winds, we analyzed the WindSat polarimetric data acquired from Atlantic hurricanes in 2003-2005. The approach and results of our analysis are described in the following sections.

2. WINDSAT HIGH WIND GEOPHYSICAL MODEL FUNCTION

We examined the WindSat data from satellite passes over Atlantic hurricanes in 2003-2005. These data contained hurricanes reaching category 4 and 5 strength and offered excellent opportunity to examine the characteristics of the WindSat polarimetric data for up to 60-70 m/s wind speeds. Figure 2 illustrates the color-coded WindSat third Stokes parameter data from rev 3510 and the best track (piece-wised red curve) analysis

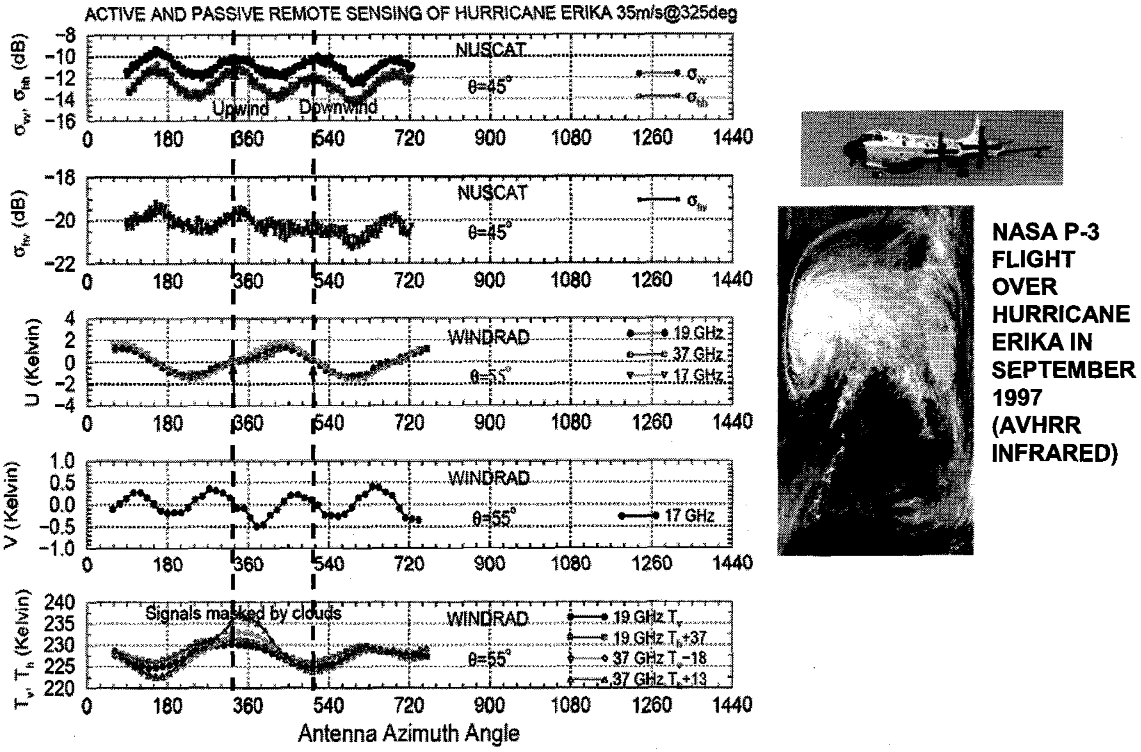


Figure 1. Coincident radar and radiometer observations of hurricane Erika were acquired with NASA P-3 flights in September 1997 The active and passive microwave data show complementary response to wind direction at 35 m/s wind speed.

from the National Hurricane Center. The vertically and horizontally polarized brightness temperatures (T_v and T_h) show clear influence of rain near the eye of the hurricane, while the third Stokes parameter (U) shows asymmetric variations around the eye, indicative of the signature of wind direction.

To quantify the dependence of the third Stokes parameter on wind speed and direction, we applied the technique described in (Yueh et al., 2001; Yueh et al., 2003) to examine the information in the WindSat polarimetric data for hurricanes. This technique, proved effective for the extension of QuikSCAT GMF to hurricane force winds, used National Oceanic and Atmospheric Administration HWind analysis (Hwind) and Holland's model winds for tropical cyclones to estimate the wind speed and direction at each WindSat footprint location.

We subsequently binned the WindSat data as a function of the Hwind wind speed and direction. For example, the WindSat 10-GHz U data for 2003-2005 Atlantic hurricanes are illustrated versus wind direction for each wind speed bin in Figure 3.

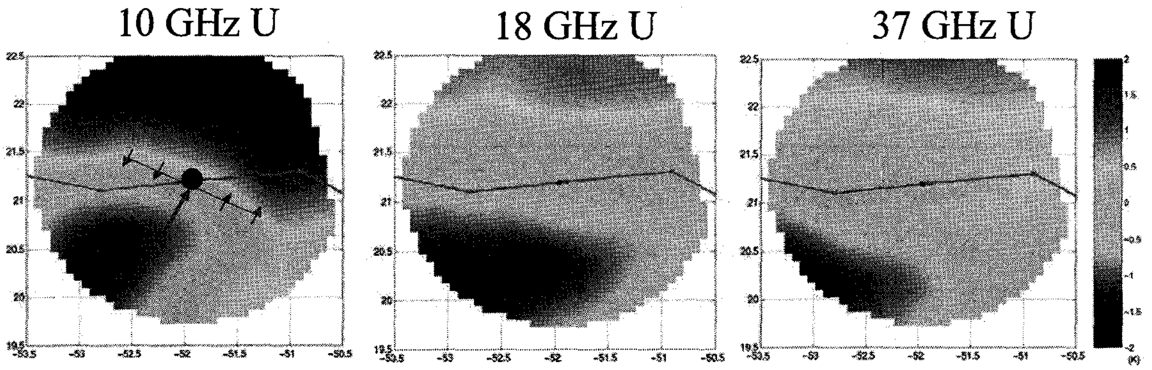
We find a few Kelvin directional variations in the WindSat third Stokes parameter data near the eye of hurricanes. The directional signals, well correlated with the wind direction, have amplitude in the range of 5 Kelvin peak-to-peak for 20-30 m/s wind speed and 2 Kelvin peak-to-peak for up to 60 m/s wind speeds. In addition, the WindSat 10-GHz third Stokes channel appears to be less affected by rain than the 18 and 37 GHz channels (Fig. 2).

To remove the impact of atmosphere, we applied a technique that we developed in the past to estimate the atmospheric attenuation from the data set itself (Yueh et al., 2006). The attenuation is estimated using the vertically and horizontally polarized brightness temperatures. The estimates from both polarizations are very consistent, indicative of the relative consistency of brightness temperature measurements for both polarizations. From the attenuation estimates, we correct the impact of atmosphere on the third (U) Stokes parameter measurements from WindSat.

To derive the geophysical model function for the WindSat measurements, we fit the data by a sine series of relative wind direction (φ) for each wind speed (w) (Yueh et al., 2006).

$$U(w,\varphi)=\Sigma\, U_n(w)\, \sin(n\varphi)$$

Figure 4 illustrates the first and second sine series coefficients for 18-GHz U versus wind speed. The coefficients from <25 m/s wind speed were derived from six months of WINDSAT and GDAS match-up data (Yueh et al., 2006). The first harmonic coefficients (U_1) increase with increasing wind speed for up to about 20 m/s. The second harmonic coefficients (U_2), having a



10 GHz U

18 GHz U

37 GHz U

Figure 2. WindSat polarimetric data for rev 3510 show the spatial features of the third Stokes parameter U around the eye of hurricane Isabel (black dot in the left panel). The WindSat look direction is indicated by the long red arrow, while the shorter arrows roughly correspond to the win d direction. U signals were close to zero when WindSat looked parallel to the wind direction, and reached to +/- 2 Kelvin at 10 GHz when WindSat looked away from the wind direction.

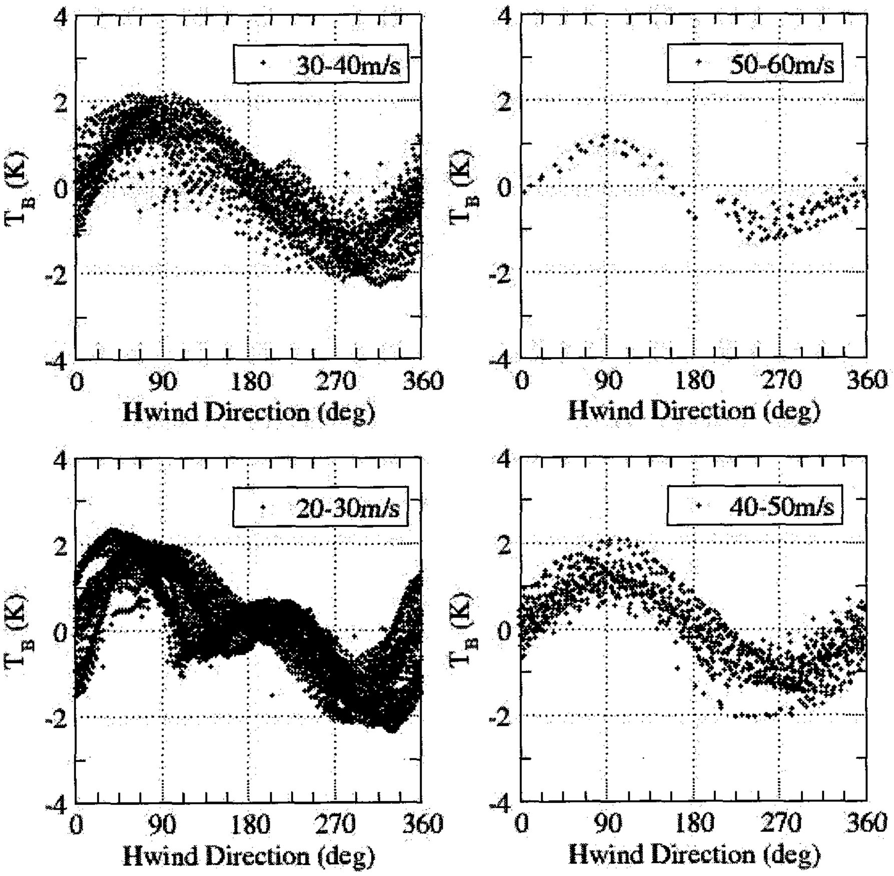


Figure 3. WindSat U Signals Versus Hwind Direction at 10 GHz for Atlantic Hurricanes 2003-2005. WindSAT 10 GHz U had 2 K peak to peak sinusoidal signals at 50-60 m/s wind speeds. The direction signals are dominated by the first harmonics.

different feature, increase with wind speed from light to moderately high wind speed (<15 m/s) and then display a decreasing trend beyond about 15 m/s wind speed. From these harmonics data, we establish an empirical WindSat

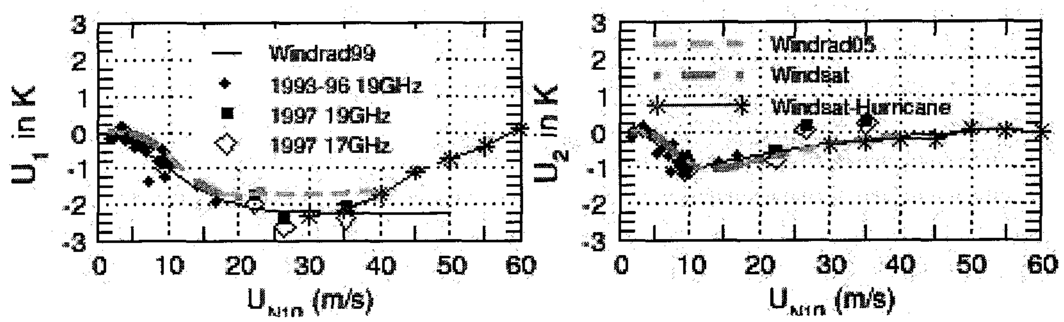


Figure 4. Comparison of the WindSat 18-GHz U data with the airborne observations acquired using the JPL WindRad in 1997.

GMF for hurricanes. Figure 4 shows that the WindSat data at 18 GHz agree very well with the JPL aircraft polarimetric radiometer measurements for 20-35 m/s winds from the Hurricane Ocean Wind Experiment (HOWE) in 1997 (Yueh et al., 2006).

3. SUMMARY

We have analyzed the Windsat data for Atlantic hurricanes in 2003-2005, and binned the polarimetric U data as a function of the Holland wind speed at 10-m/s steps and wind direction at 20-degree steps. The WindSat U data at 10, 18 and 37 GHz frequencies show clear sinusoidal dependence on wind direction for wind speed up to 60 m/s. The 10 GHz channel appears to be more robust to rain impact than the higher frequency channels.

We performed sinusoidal analysis of the WindSat data and extended the geophysical model function for the Windsat polarimetric channels to extreme high wind speeds (60-70 m/s). The Windsat data and the resulting GMF have a very good agreement with the JPL aircraft wind radiometer (WINDRAD) observations acquired over 1993-2003.

It is noted that the directional response of the third Stokes parameter data behaves like a sine function, which complements very well the cosine dependence of the scatterometer backscatter data (Figure 1). This clearly demonstrates the synergistism of active and passive remote sensing techniques for accurate determination of the ocean wind direction for hurricanes.

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