Polarimetric Microwave Remote Sensing of Hurricane Ocean Winds

Simon H. Yueh
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, USA
Simon.Yueh@jpl.nasa.gov

Abstract— **We presented the analysis of Windsat data for hurricanes Isabel and Fabian in 2003. The polarimetric third and fourth 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 QuikSCAT 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.**

Keywords: Sea surface wind; microwave polarimetry; hurricanes

I. 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.

With the potential of being an alternate technique to active microwave radar, 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 [1-7]. 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. In [8], the 10, 18 and 37 GHz GMFs were derived from the Windsat data collocated with the NCEP GDAS winds for up to about 25 m/s wind speed.

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 if there is wind direction information in the WindSat data for extreme high winds, we analyzed the WindSat polarimetric data acquired from hurricanes Isabel and Fabian in September 2003. The approach and results of our analysis are described in the following sections.

II. WINDSAT HIGH WIND GEOPHYSICAL MODEL FUNCTION

We examined the WindSat data from eight satellite passes over hurricanes Isabel and Fabian. These two hurricanes reached category 4 and 5 strength over an extended period of their lifetime and offered excellent opportunity to examine the characteristics of the WindSat poalrimetric data for up to 60-70 m/s wind speeds. Figure 1 illustrates the color-coded WindSat data from rev 3510 and the best track (red curve) analysis 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 (black dot) 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 [9,10] 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 Holland's model field for tropical cyclones

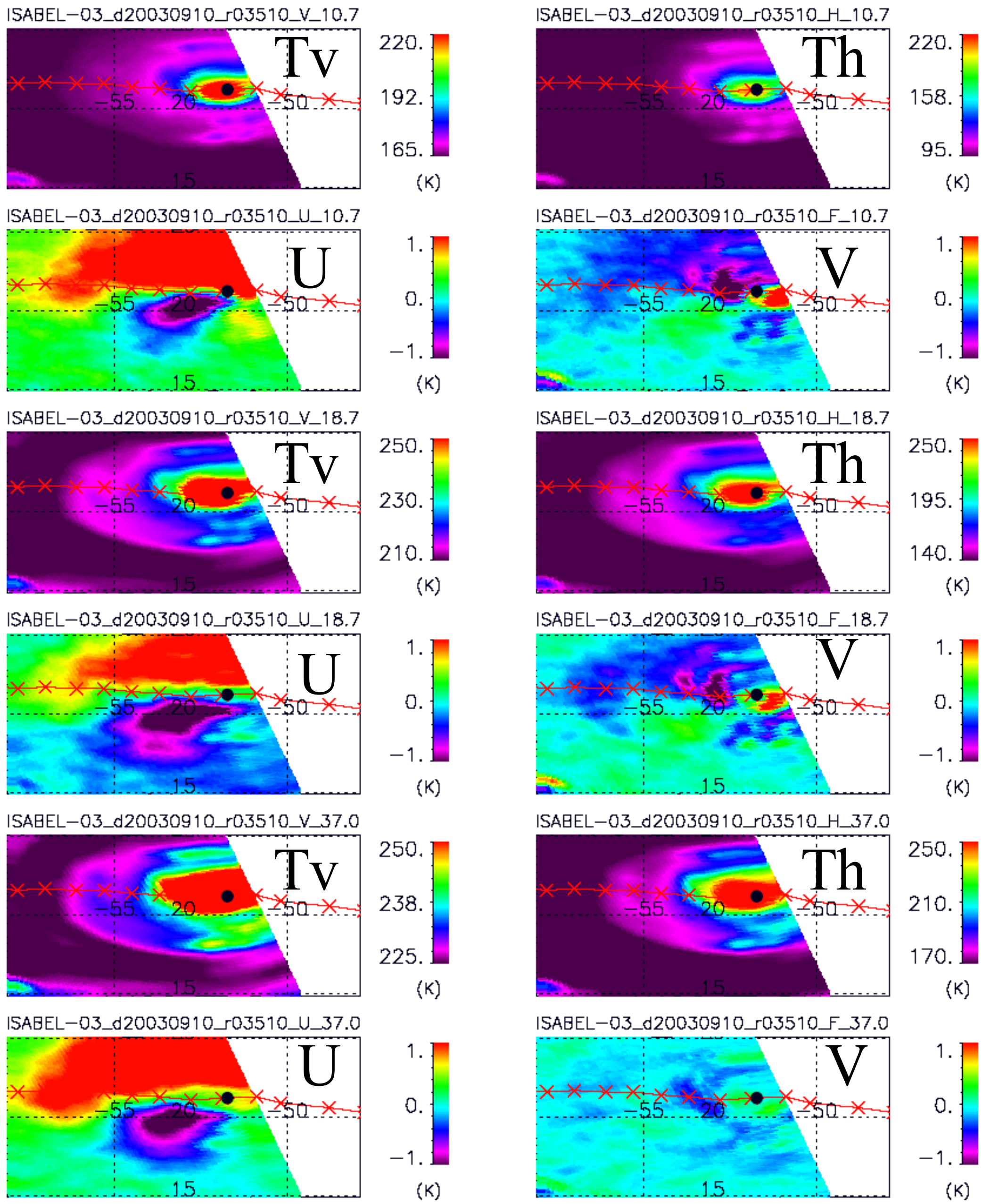

Figure 1. The WINDSAT rev 3510 data for hurricane Isabel in September 2003 show the response of the polarimetric data to ocean surface wind direction to extreme wind velocities. The upper four images show the spatial distribution for the 10.7 GHz data, the middle four images for the 18 GHz data , and the bottom four for the 37 GHz data.

to estimate the wind speed and direction at each WindSat footprint location. The details of the procedure are described in [9,10].

We subsequently binned the WindSat data as a function of the wind speed and direction. For example, the WindSat data from rev 3510 are illustrated versus wind direction for each wind speed bin in Figure 2. The data from other revs show similar features.

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 directions, have amplitude in the range of 5 Kelvin peak-to-peak for 20-30 m/s wind speed and 1 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. There were also directional signals in the WindSat fourth Stokes parameter channel for these two hurricanes. The amplitude approaches 2 Kelvin level, significantly greater than the directional signal observed for lower than 20 m/s wind speeds. However, the fourth Stokes parameter signals appear to be influenced by rain bands, rather than wind direction.

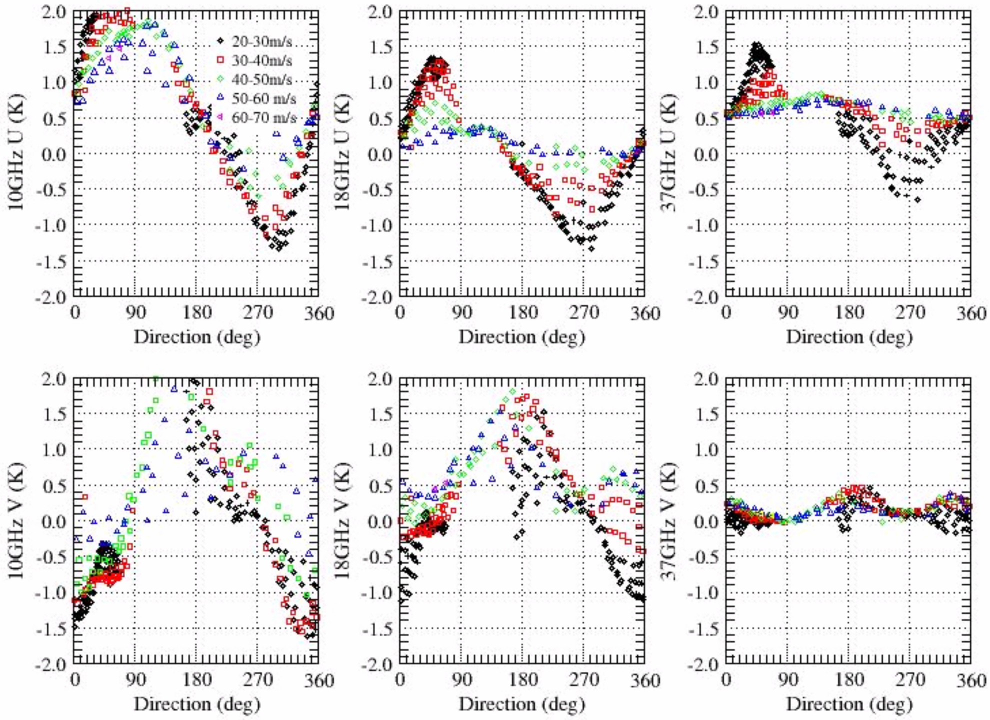

Figure 2. WindSat polarimetric data for rev 3510 show the dependence of U and V Stokes parameters on wind direction.

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 [5]. 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) and fourth (V) 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) [12].

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

Figure 3 illustrates the first and second sine series coefficients for U versus wind speed. The coefficients from <25 m/s wind speed were derived from six months of WINDSAT and GDAS match-up data [8]. The first harmonic coefficients (U_1) at 18 and 37 GHz increase with increasing wind speed for up to about 20 m/s. The second harmonic coefficients (U_2), having a 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 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 [8].

III. SUMMARY

We have analyzed the Windsat data for hurricanes Isabel and Fabian, and binned the polarimetric U and V data as a function of the Holland wind speed at 5-m/s step and wind direction at 20-degree step. 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 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 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 QukSCAT scatterometer backscatter data. This clearly suggests that the synergistic use of active and passive remote sensing techniques for accurate determination of the ocean wind direction for hurricanes.

ACKNOWLEDGMENT

The research carried out in this paper is performed by the Jet Propulsion Laboratory under a contract with the National Aeronautics and Space Administration. The work was funded by the National Polar Orbiting Environmental Satellite System.

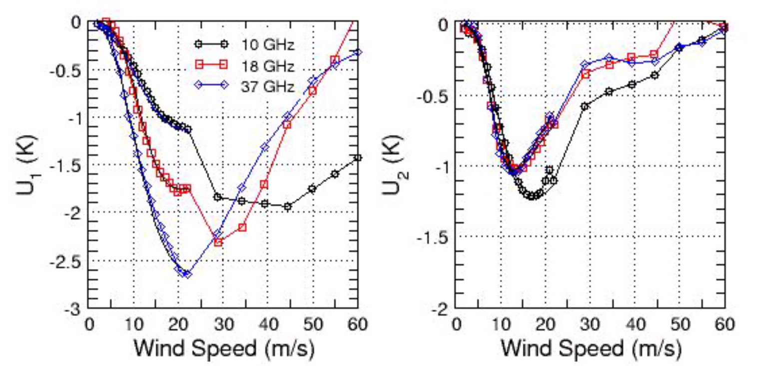

Figure 3. The variations of WindSat U data with wind direction are expanded as a function of sine series. The coefficients of the first and second harmonics show the show decreasing response to wind speed for extreme high winds.

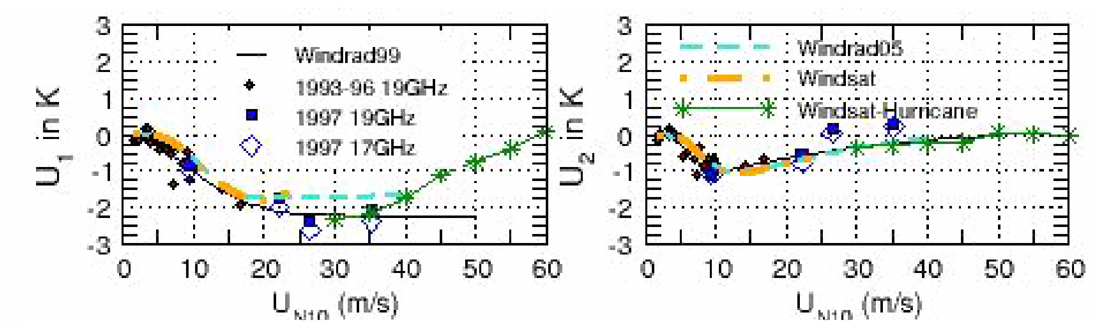

Figure 4. Comparison of the WindSat 18-GHz U data with the airborne observations acquired using the JPL WindRad in 1997.

REFERENCES

[1] V. G. Irisov, A. V. Kuzmin, M. N. Pospelov, J. G. Trokhimovsky, and V. S. Etkin, ``The dependence of sea brightness temperature on surface wind direction and speed. Theory and Experiment.,'' IEEE, Proceedings of International Geoscience and Remote Sensing Symposium, pp.1297-1300, Espoo, Finland, 1991.

[2] S. H. Yueh, W. J. Wilson, F. K. Li, W. B. Ricketts, and S. V. Nghiem, ``Polarimetric measurements of sea surface brightness temperatures using an aircraft K-band radiometer,'' IEEE Trans. Geosci. Remote Sensing, Vol. 33, No. 1, 85-92, 1995.

[3] S. H. Yueh, W. J. Wilson, F. K. Li, W. B. Ricketts, and S. V. Nghiem, ``Polarimetric brightness temperatures of sea surfaces measured with aircraft K- and Ka-band radiometers,'' IEEE Trans. Geosci. Remote Sensing, Vol. 35, No. 5, 1997.

[4] S. H. Yueh, W. J. Wilson, S. Dinardo, and F. K. Li, ``Polarimetric microwave brightness signatures of ocean wind directions,'' IEEE Trans. Geosci. Remote Sensing, Vol. 37, No. 2, 1999.

[5] J. R. Piepmeier and A. J. Gasiewski, "High-resolution passive polarimetric microwave mapping of ocean surface wind vector fields," IEEE Trans. Geosci Remote Sensing, Vol. 39, No. 3, pp. 606-622, Mar 2001.

[6] B. Laursen and N. Skou, "Wind direction over the ocean determined by an airborne, imaging, polarimetric radiometer system," IEEE Trans. Geosci Remote Sens., Vol. 39, No. 7, pp. 1547-1555, July 2001.

[7] J. Lahtinen, J. Pihlflyckt, K. Mononen, S. J. Tauriainen, M. Kemppinen, and M. T. Hallikainen, "Fully polarimetric microwave radiometer for remote sensing, " IEEE Trans. Geosci. Remote Sens., Vol. 41, No. 8, pp. 1869-1878, August 2003.

[8] Simon H. Yueh, William Wilson, Steve Dinardo, and S. V. Hsiao , "Polarimetric Microwave Wind Radiometer Model Function and Retrieval Testing for WindSat", IEEE Trans. Geosci. And Remote Sensing, Vol. 44, No. 2, 584-596, March 2006.

[9] Yueh, S.H., B. Stiles, W. T. Liu, "QuikSCAT wind retrievals for tropical cyclones," IEEE Trans. Geosci and Remote Sens.,41 (11): 2616-2628 Part 1, Nov 2003.

[10] Yueh, Simon H., B. W. Stiles, W.-Y Tsai, Hua Hu, and W. T. Liu, QuikSCAT Geophysical Model Function for Tropical Cyclones and Applications to Hurricane Floyd, IEEE Trans. Geosci. Remote Sens., 39, 2601-2612, Dec 2001.

[11] Yueh, S. H., R. Kwok, and S. V. Nghiem, ``Polarimetric scattering and emission properties of targets with reflection symmetry,'' Radio Science, Vol. 29, No. 6, 1409-1420, November-December, 1994.