New Microwave Technology for Ocean Wind Measurements

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Abstract - Global mapping of near surface ocean winds is crucial for many meteorological, oceanographic and atmospheric studies. The microwave emission from the ocean surface is elliptically polarized and the degree of polarization and angle is a function of the surface wind speed and direction. JPL has developed a set of microwave polarimetric radiometers at 19 and 37 GHz (WINDRAD), which have been used on the NASA DC-8 aircraft for remote measurements of ocean surface wind vectors. A summary of all the ocean polarimetric data vs. wind speed and incidence angle from three flights in 1994 and eight flights in 1995 is presented. These data show clear wind direction signals at wind speeds from 3 to 24 m/s and incidence angles of 45" to 65". Based on these data, a design for a spaceborne polarimetric wind radiometer has is presented.

1. INTRODUCTION

Global mapping of near surface ocean winds is crucial for many meteorological, oceanographic and atmospheric studies. In the past from Seasat, ERS-1, to the present development of NASA's Scatterometer (NSCAT, to be launched in 1996), spaceborne wind radars have been the only instruments to provide a global monitoring of ocean surface wind vectors with frequent and adequate temporal-spatial coverage. The principle of wind scatterometry is based on the fact that electromagnetic backscatter varies periodically as a function of the azimuthal angle between the wind direction and the radar look direction. This is because the water ripples (capillaries) induced by ocean wind are smoother in the crosswind direction and rougher in the up- or downwind direction. Recently however, experimental observations and analysis [Etkin et al., 1991; Wentz, 199?; Yueh et al., 1995, 1996] have shown that the directional features of water ripples also cause the emitted thermal radiation, or the radiometric brightness temperatures, to be elliptically polarized. The degree of polarization and angle is a function of the surface wind speed and direction and will cause the brightness temperature to vary over azimuth angles by a few degrees Kelvin. This azimuthal dependence of brightness temperatures thus make it possible for passive microwave radiometers to provide both wind speed and wind direction measurements over the ocean surface.

II. AIRCRAFT MEASUREMENTS

JPL has had a strong interest in measuring wine{ vectors from space and has been responsible for developing the NASA scatterometer installments NSCAT and SEAWINDS. When it was discovered that a passive radiometer instrument could be 2-3 time less expensive than a scatterometer instrument, JPL began a program to study this technique. This program included the development of 19 GHz and 37 GHz polarimetric radiometers (WINDRAD) which have heen used on the NASA DC-8 aircraft to study this technique. Fifteen (15) successful Wind radiometer aircraft flights have been made since November 1993 -- four in 1993, three in 1994 and eight in 1995. These data show that there is a clear wind direction signal at wind speeds from 3 to 24 m/s and incidence angles from 45°-65°.

A set of measured 19- and 37-GHz polarimetric data taken on April 17, 1995 at moderate wind speed is shown in Figure 1 for 45" incidence angle. Data are plotted continuously in azimuth angle with increments of 360° added for each additional circle flight around the NDBC buoy 46005 located off the Oregon coast. (These data are typical of the aircraft data with wind speeds from 3 to 14 m/s.) The top curve is the vertical polarization (T_v), the second is the horizontal polarization (T_h), the third is the second Stokes parameter, Q (= T, - T_h), and the fourth curve is the third Stokes parameter, U (= T_{45} - T_{-45}), The instrument noise is <0.05 K. Thus, all the "noise" on the data is from the atmosphere or ocean surface. Note that in clear weather, the 19- and 37-GHz signals have similar amplitudes, which shows that the wind signals have a broad frequency range.

At 45° incidence angle, the T_h , Q and U azimuth signals have a strong second harmonic component -- peaks in the upwind and downwind directions. The Q azimuth signal has even symmetry [cos (AZ)] about the wind direction, with the upwind direction having the largest value, The U azimuth signal has odd symmetry [sin (AZ)] and has a 90° azimuth phase difference relative to the Q signal. This suggests that there will be excellent ambiguity selection skill in estimating wind direction. Also notice that the U data has significantly less "atmospheric noise" than the T., T_h , and Q data, especially near -630° azimuth. The fact that the U azimuth signal is more insensitive to clouds, suggests that it will be possible to use this signal for wind direction measurements even with moderate cloud cover. Aircraft polarimetric measurements have also been made at incipience angles of 55° and 65°.

A summary of the 1994 and 1995 polarimetric U azimuth data, with low atmospheric attenuation, is shown in Figure 2. This plot shows the peak-to-peak azimuth signal for the U Stokes parameter vs. wind speed for the 45°, 55° and 65° incidence angles. It is likely that the scatter in the data is mainly due to errors in the reported buoy wind speed due to time and location differences.

These summaries show that the 45” incidence angle azimuth data has the largest peak-to-peak signal and has detectable signals for wind speeds above 3 m/s. The 55° incidence angle data has a lower signal amplitude and would be detectable only for winds above 4-5 m/s. At wind speeds > 5 m/s, the 65° incidence angle data only has a first harmonic, anti its peak-to-peak amplitude is lower by a factor of ~2 from the 45° incidence angle I-he amplitude of this data goes through zero near 5 m/s and shows a strong second harmonic component for winds < 5 m/s. The 65° incidence angle data is also more sensitive to the atmospheric attenuation because of the longer path through the atmosphere.

III. SPACE INSTRUMENT

The aircraft results show that passive polarimetric radiometers have a strong potential for global ocean wind measurements. The aircraft measurements and the analysis of the data have also narrowed the instrument parameters for a spaceborne radiometric sensor for measuring wind vectors. The next step will be to demonstrate this instrument in space, to show how well it will measure wind vectors under a wide variety of wind and weather conditions.

Based on the aircraft measurements, a passive radiometric instrument for space has been designed to satisfy the science requirements in Table 1. The characteristics of the proposed instrument are listed in Table 2. A three frequency: 18, 22, and 37 GH7 radiometer system, similar to those on SSM/I and Topex Poseidon, was chosen to get the polarimetric wind data and provide the capability to correct for atmospheric moisture effects. The 37 GHz channel will provide the best spatial resolution with good sensitivity and will operate in clear weather and with thin clouds. The 18 GH7 channel will have moderate spatial resolution over a wide range of wind speeds and will operate in conditions with thicker clouds. The 22 GHz radiometer will be used to correct for atmospheric water vapor and cloud effects.

Another key design parameter for a spaceborne instrument is the antenna scan geometry, Based on the **model simulations using the aircraft data, a full conical circular scan** will be required to achieve the wind direction accuracy specified in Table 1. The aircraft data demonstrated that a conically scanning antenna with a constant incidence angle ranging between 45° and 65° provides a detectable wind-direction signal. The lower incidence angle of 45° has the largest signal, and thus best accuracy for the wind direction retrievals for wind speeds >4 m/s. However, the larger incidence angle of 65° may have a larger signal for winds <5 m/s and would provide the largest coverage and the shortest repeat time between subsequent satellite overpasses. As noted above though, the 65° incidence angle has a lower wind direction signal strength for speeds > 5/ins, and will be more affected by atmospheric attenuation because of the longer path through the atmosphere, and has a more complex geophysical model function. Therefore, in this instrument, it is proposed to design an antenna system with two beams at 45° and 65°.

The Polarimetric Wind Radiometer instrument has been designed to have a small size (1 x 1 x 1 m), a low mass (< 50 kg), and low power requirements of < 50 Watts. The polarimetric wind radiometer could be flown either as an instrument of opportunity on an already scheduled space mission, or flown on a small free-flyer -- e.g. small satellite and small launch vehicle.

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TABLE 1. OCEAN WIND MEASUREMENT REQUIREMENTS	
Wind Speed Range	2-30 m/s
Wind Speed Accuracy	* 2 m/s or 10%
Wind Direction Accuracy	± 20°
Spatial Resolution	<50 km
Global Coverage	2 days (90% of the ice-free oceans)
Weather Capability	**Clear sky** and clouds

Table 2. POLARIMETRIC WIN	RADIOMETER CHARACTERISTICS
Frequencies	18, 22, 37 GHz
Antenna Diameter	0.75 m
Antenna Beamwidth	1.8°, 1.5°, 0.9°
Polarization	4 **Stokes** parameters
Spacecraft Altitude	525 km
Antenna Scan	Conical, Circular (two looks)
Beam Incidence Angle	45° and 65°
Footprints	15 to 50 km
Swath Width	940 to 1800 **km**
RMS Noise per Footprint	<0.1 K
Absolute Calibration Accuracy	≤1 K
Instrument Power	50 Watts
Instrument Mass	20 kg
Instrument Data Rate	50 kb/s

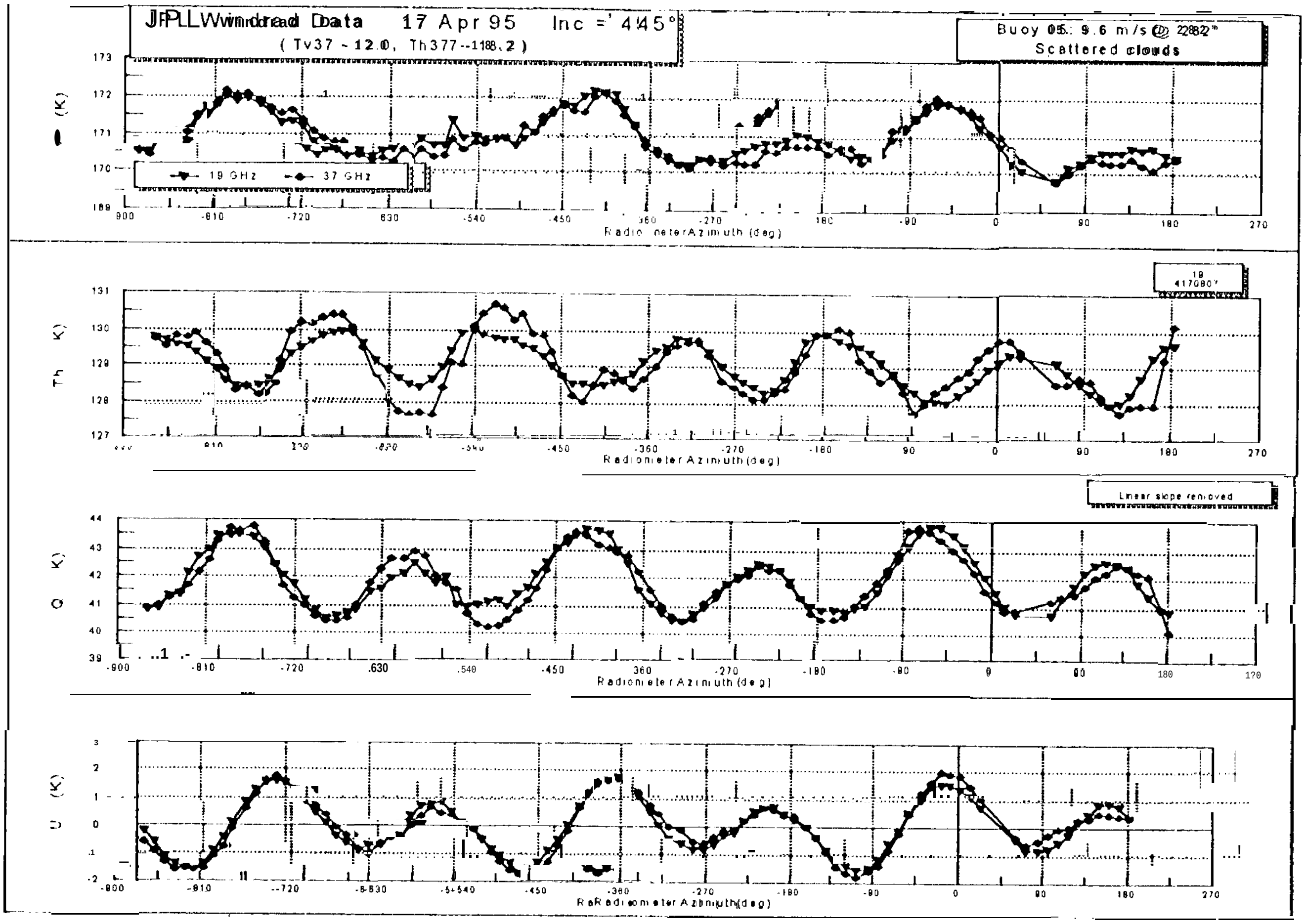

Figure 1. Measured 19 and 37 GHz polarimetric data on April 17, 1995, as a function of azimuth angle for an incidence angle of 45°. The wind speed was 9.6 m/s at 5 m height, the direction was 282, and the weather was scattered clouds. T_v is the vertical polarization, T_h is the horizontal, Q is their difference (TV - Th), and U is the difference between T_{+45} and T_{-45}. Notice the 90° phase difference in azimuth between Q and U. Data are plotted continuously in azimuth angle with increments of 360° added for each additional circle flight arOUnd the NDBC buoy 46005. The 37 GHz T_v and T_h have been plotted using an offset of -12.0 and -18.2 K respectively, for ease of comparison.

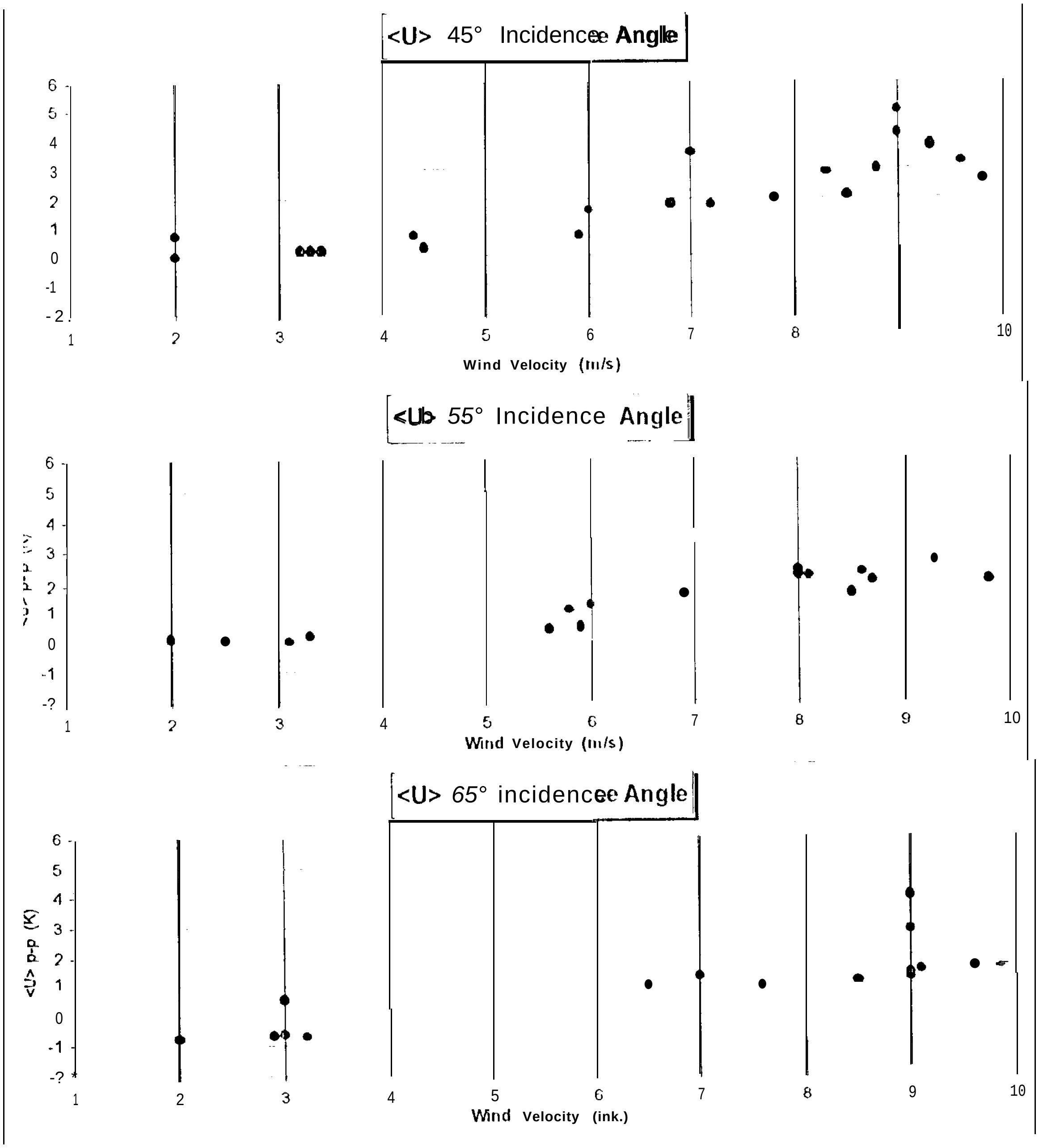

Figure 2. Summary of the peak-to-peak U azimuth signal data vs. wind velocity for the 1994 and 1995 WINDRAD data. The negative values in the 65° incidence angle data < 5 m/s, represent a 180° phase shift from the > 5 m/s data.