REMOTE SENSING OF OCEAN WIND USING POLARIMETRIC MICROWAVE RADIOMETERS

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Abstract

Winds over the ocean modulate the air-sea fluxes of heat, moisture, gases and particulates, regulating the crucial coupling between atmosphere and ocean that establishes and maintains global and regional climate. Global mapping of ocean wind is crucial for many oceanographic and atmospheric studies. Numerous spaceborne scatterometers have been and will be launched to perform global "wind field measurements. Besides the scatterometer technology, the Jet Propulsion Laboratory (JPL) is investigating a new technology for wind measurements using polarimetric microwave radiometers. This paper will provide an overview of the polarimetric wind radiometer research activities at JPL. Recent results from aircraft multi-frequency polarimetric radiometer flights will be presented along with their implications. Future research plan will be described.

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 winds is crucial for many oceanographic and atmospheric studies. The Seasat-A Satellite Scatterometer operating from June to October 1978 was the first spaceborne scatterometer demonstrating that accurate wind velocity measurements could be made from space. A single-swath scatterometer operating at C-band is presently flying on the European Space Agency's Remote Sensing Satellite mission. Numerous spaceborne wind scatterometer missions are being planned in the future. To be launched as part of the Japanese Advanced Earth Observation System (ADEOS-1) mission in 1996, NSCAT will be the first dual-swath, Ku-band scatterometer to fly since Seasat. Follow on to the NSCAT is the SeaWinds scatterometer to be launched on the second ADEOS mission in 1999.

Besides active wind scatterometers, JPL is developing a polarimetric radiometer technology for ocean wind velocity (speed and direction) measurements. Previous applications of passive microwave radiometers were limited to wind speed measurements. However, recent experimental observations [1, 2, 3, 4] indicated that ocean microwave thermal radiation could vary over azimuthal angles relative to the wind direction by a few Kelvin.

The aircraft radiometer experiments conducted by the Russian scientists at the Spare Research Institute measured the sea surface brightness temperatures at near normal incidence angles [1, 3]. They found a few Kelvin wind direction signal in the brightness temperatures. Unfortunately, those measurements did not cover the range of incidence angle traditionally used by spaceborne microwave radiometers (incidence angles of 45° to 60°) for large swath coverage. In contrast, the Special Sensor Microwave/Imager (SSM/I) has measured the brightness temperatures at an incidence angle of 53°. Wentz's SSM/I model function [2] indicated that T_h and T_v at both 19 and 37 GHz could vary with the wind direction by a few Kelvin.

In addition to T_v and T_h measured by conventional radiometers, the third and the fourth Stokes parameters (U and V) are required to fully characterize polarized electromagnetic radiation [5]. To explore the potential of polarimetric radiometry for spaceborne remote sensing applications, a K-band multi-polarization radiometer (WINDRAD) was built and deployed on the NASA DC-8 aircraft with circle flights over several ocean buoys to study sea surface radio emissions by Yueh et, al. [4] in November 1993. These measurements were the first experimental evidence indicating that the first three Stokes parameters of sea surface emissions are sensitive to ocean wind direction in the incidence angle range of 30° to 50°.

However, these experimental data are not yet adequate to design a spaceborne sensor for ocean wind measurements. To obtain a better understanding of the frequency dependence, a Ka-band (37 GHz) polarimetric radiometer was built and integrated with the K-band (19 GHz) radiometer used in the 1993 WINDRAD experiments. The dual- frequency system was flown in July and August 1994 and March-May 1995 over ocean buoys to obtain a more extensive measurement. The results arc reported in this paper.

2 Aircraft Wind Radiometer Flight Experiments

Eight successful aircraft flights were performed by .11'1, over the National Data Buoy Center (NDBC) moored buoys deployed in the East Pacific in summer 1994 and spring 1995. The wind speeds encountered during the experiments range from 2 m/s to 11 m/s. The radiometer antenna horns were fixed mounted on the DC-8 windows at an angle of 80 degrees from nadir. To measure the data at 45°, 55°, and 65° incidence angles, the DC-8 was banked at 35°, 25°, and 15°, respectively. At each bank angle, DC-8 performed circle flights, allowing the radiometers to acquire data from all azimuth angles with respect to the surface wind direction. Aircraft altitude for the circle flights at 25 and 35 degree bank angles was about 27K feet, and was about 31 K feet for the 15 degree bank. The flight altitude was chosen so that the location of antenna footprint would be close to the center of the circles. This ensured that the data were collected over nearly the same area, hence reducing the uncertainty due to potential spatial surface variations.

Here arc the key results of the flight experiments. (1) Clear Wind Direction Signals: The sea surface brightness temperatures vary with the wind direction by a few Kelvins in all polarizations. In particular, the symmetry of the U is complementary to those of Tv and Th, indicating a significant potential for unambiguous wind direction measurements. ('2) Broad Frequency Dependence: The wind direction signals are comparable at 19 and 37 GHz. This weak frequency dependence implies that 19 and 37 GHz radiometers would provide similar accuracies for the wind direction measurement under clear sky condition. It should, however, be expected that 19 GHz channel would be less sensitive to atmospheric effects than 37 GHz channel, while 37 GHz spaceborne radiometer typically would give a better spatial resolution than 19 GHz radiometers for the same antenna size. (3) Strong Incidence Angle Dependence: The data, collected in the incidence angle range of 30 to 65 degrees, showed that the the directional signals in Th have a weak incidence angle dependence, while Tv and U may have significant changes over incidence angles. (4) Observable Signals at Low Winds: preliminary data indicate that there are 0.8 to 1 Kelvin signals in U at 2-3 m/s winds at 65 degree incidence angle.

3 Summary

In conclusion, our aircraft radiometer flight experiments have provided the experimental evidence that all Stokes parameters of thermal radiation from sea surfaces are sensitive to wind direction in the range of incidence angles from 30 to 65 degrees. The successful experiments have indicated the strong potential of passive microwave radiometers to be a low-cost operational instrument for global ocean wind measurements.

Following is our future WINDRAD research plan:

1. Conduct one set of flights each year in 1996 and 1997 to collect data over a more variety of atmospheric and oceanic conditions, in particular low and high wind conditions.

2. Develop the preliminary WINDRAD geophysical model function. WINDRAD data will be assimilated into a preliminary geophysical model function relating sea surface brightness temperatures to ocean wind velocity. The sensitivity of geophysical model function on incidence angle, frequency, polarization, atmospheric water vapor/liquid water, air and sea surface temperatures, and swells will be investigated.

We are currently conducting spaceborne wind radiometer design to determine cost and configuration along with the platform of opportunity.

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