Passive Polarimetric Remote Sensing of the Ocean Surface during the Rough Evaporation Duct Experiment (RED 2001)

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Abstract: **This paper describes the deployment of a fully polarimetric K-band radiometer in the Rough Evaporation Duct (RED) experiment, which was conducted during August and September of 2001. The calibration of the four Stokes parameters is described, along with a comparison of the measurements with results of both the Klein-Swift and Ellison *et al.* sea surface dielectric models. The purpose of the experiment was to improve physical forward models of the ocean surface emission in order to improve wind vector retrieval algorithms.**

I. INTRODUCTION

In the past few years there has been an increased interest in the passive remote sensing of the wind vector, i.e. wind speed and direction, over the ocean surface.

Efforts in measurements and modeling were intensified in preparation for the recent launch of WindSat, the first polarimetric radiometer in space, developed by the Naval Research Laboratory (NRL) for the U.S. Navy, and by the National Polar orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office. The principal objective of WindSat is to validate the feasibility of measuring wind direction over the ocean surface using microwave radiometry to obtain global wind vector maps.

Accurate retrieval of ocean wind speed and direction from space-borne microwave radiometers requires knowledge of how changes in surface properties affect the brightness temperature measured by passive remote sensing instruments. Wind roughening of the ocean in form of small scale (capillary) waves, large scale (gravity) waves, and whitecaps (with resulting foam) allow such instruments to remotely sense the wind vector. However, near-surface radiometric observations are still very much needed to improve the quantitative knowledge of the effects of changing surface conditions, including foam and roughness, on microwave emissivity [1].

II. EXPERIMENT DESCRIPTION

The Rough Evaporation Duct (RED) experiment, sponsored by the Office of Naval Research, focused on the effects of the air-sea boundary layer, including evaporation ducts, on the propagation of microwave and electro-optical signals near the sea surface. It was conducted near the northeast coast of Oahu, Hawaii, during August and September of 2001.

A suite of instruments was deployed for this experiment, including RF and electro-optical link receivers, and a K-band (18.7 GHz) polarimetric radiometer (KPR) designed and fabricated at the Microwave Remote Sensing Laboratory at the University of Massachusetts Amherst.

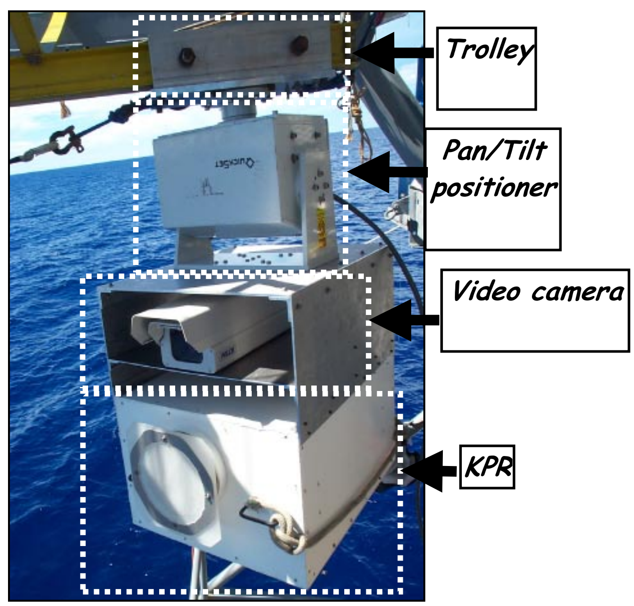

Fig. 1. KPR radiometer with a video camera and pan-tilt positioner deployed during the RED experiment. A rexolite radome was used to protect the antenna and the radio frequency components from the corrosive operational environment.

The 18.7 GHz window frequency was chosen to provide quantitative information on sea surface emission in a frequency band commonly used for satellite radiometer measurements.

KPR is a Dicke radiometer with a narrow band conical-corrugated horn antenna. The circular waveguide at the output of the antenna is connected to an orthomode transducer (OMT) that splits the incident thermal radiation into two orthogonal linearly polarized components (vertical and horizontal).The radiometer was deployed under the face boom (Fig. 1) of the Research Platform (R/P) FLIP, moored 10 Km off the northeast shore of Oahu, Hawaii.

Two different data sets were measured during the field experiment. In the first one, the brightness temperature of the sea surface was measured at a specific azimuth angle and different incidence angles (30º, 35º, 40º, 45º, and 50º), in order to characterize the sea-surface emissivity at a variety of incidence angles. The second set of data was aimed to improve knowledge of the azimuthal wind direction dependence by setting the radiometer at several fixed incidence angles (35º, 45º, and 55º) and scanning it at six different azimuth angles with respect to the prevailing wind direction, namely (-55º, -100º, -145º, 170º, 125º, and 85º). A remotely controlled pan and tilt positioner was used to point the radiometer in the desired direction with an accuracy of 0.25º. A set of three sensitive clinometers (resolution <0.15º), two for the elevation angle and one for the tilt angle, was used to provide the instantaneous fine pointing position of the antenna.

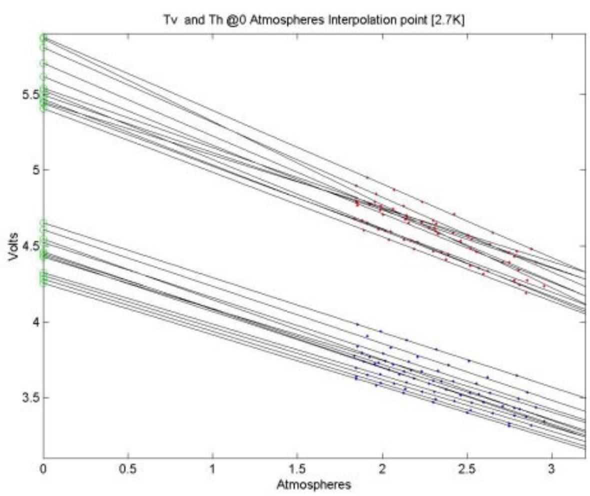

Fig. 2. Set of tip curves at both H (red dots) and V (blue dots) polarizations.

III. INSTRUMENT CALIBRATION

Prior to each scan, the first two Stokes parameters were calibrated by means of tip curves and a microwave absorber at known physical temperature. Fig. 2 depicts a set of tip curves in both *H* and *V* polarizations from different days. From Fig. 2, the vertical polarization tip curves (blue dots) seem to be consistent in terms of gain and exhibit only offset changes. On the other hand, the gain of the H channel (red dots) shows larger gain differences mainly induced by the larger temperature sensitivity in some of the key components, like the low noise amplifier (LNA).

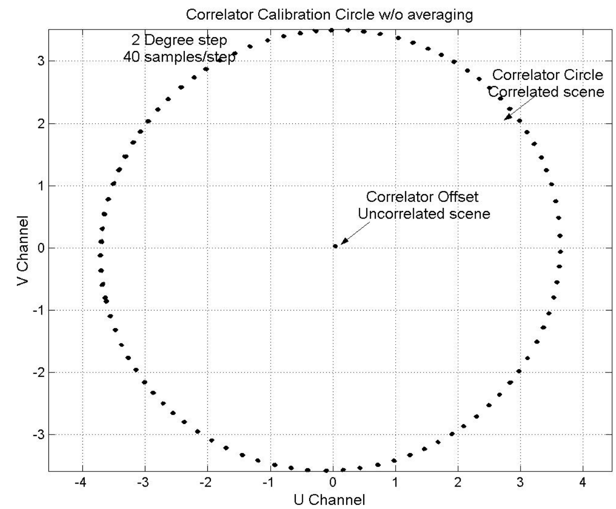

Fig. 3. Correlator calibration circle.

For a polarimetric radiometer, the third and fourth Stokes parameters must be calibrated as well. Since the operational environment did not allow the use of an external polarized target, an internal noise injection loop was used to calibrate the correlator [2]. It consisted of a noise source divided into two correlated noise signals, one per polarization, and a digitally controlled phase shifter at the local oscillator of one of the polarization channels. Fig. 3 shows the in-phase (U) and quadrature (V) outputs of the correlator in the complex plane, when the phase shifter was stepped from 0º to 360º in 2º steps. The shape of the ellipse contains information that allows removing four possible error sources: offset, in-phase, amplitude, and quadrature errors. Once corrected, the phase shifter will be used to phase synchronize both H and V polarizations at the input to the complex correlator.

IV. EXPERIMENTAL RESULTS

Several sources such as downwelling atmospheric radiation (T_{DN}) reflected from the sea-surface contribute to the measured brightness temperature (T_B). When the antenna temperature is measured near the surface, two effects are negligible, the upwelling radiation and the attenuation of the surface emission and reflected downwelling radiation during upward propagation. The measured antenna temperature is then

$$T_A = e_i T_w + (1 - e_i) T_{SKY}, \tag{1}$$

where:

- T_A is the measured antenna temperature;
- e_i is the emissivity at *i* polarization;
- T_w is the physical temperature of the water; and
- T_{SKY} is the unpolarized downwelling radiation.

Since the antenna beamwidth is narrow (7º), the antenna temperature is due principally to the sea surface emission and reflected downwelling, and the emissivity can be obtained from

$$e_i = \frac{T_A - T_{SKY}}{T_W - T_{SKY}}, \quad (2)$$

where:

- The downwelling radiation (T_{SKY}) is approximated by the antenna temperature measurement obtained by pointing the radiometer upward at the specular angle [1];
- T_A is the antenna temperature at the radiometer, and a temperature sensor on a buoy constantly measured T_w.

Two ocean dielectric models have been compared with the measured data, the Klein-Swift [3] and Ellison *et al.* [4] models. Although widely used at these frequencies, model [3] provides an accurate result only up to 10 GHz. Therefore, a recently developed model with very low error up to 40 GHz, was used as a baseline for comparison. As depicted in Figs. 4 and 5, the measurement compares better with model results using the Ellison *et al.* emissivities than those using the Klein-Swift emissivities, both using the Kirchoff method with stationary phase approximation to account for wind speed effects [5].

Figs. 4 and 5 show close agreement between measurements and the Ellison *et al.* model, within about 2-3 K. For Fig. 5 showing the comparison for vertical polarization, one sees that the instantaneous slope with incidence angle differs between the measurements and the model results, which may result from small inaccuracies in characterization of the effects of roughening of the sea surface due to wind [5].

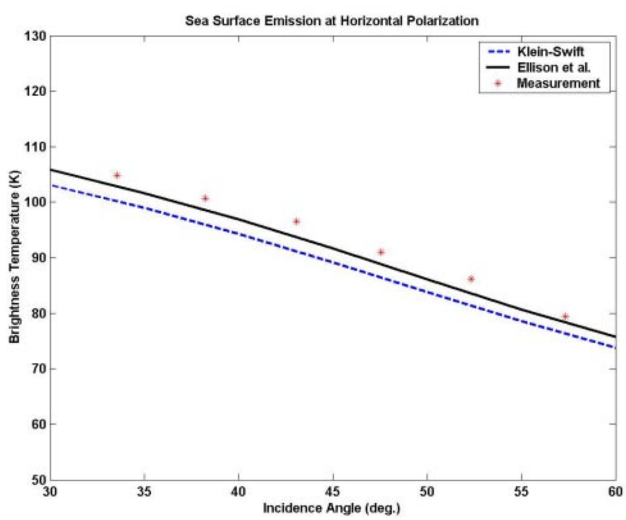

Fig. 4. Comparison of measurements and models at horizontal polarization (Klein-Swift dielectric model--blue dashed line, Ellison et al. model--black solid line, Measurements—red asterisks). SST = 26 ˚C, SSS =36 psu, WS = 8 m/s.

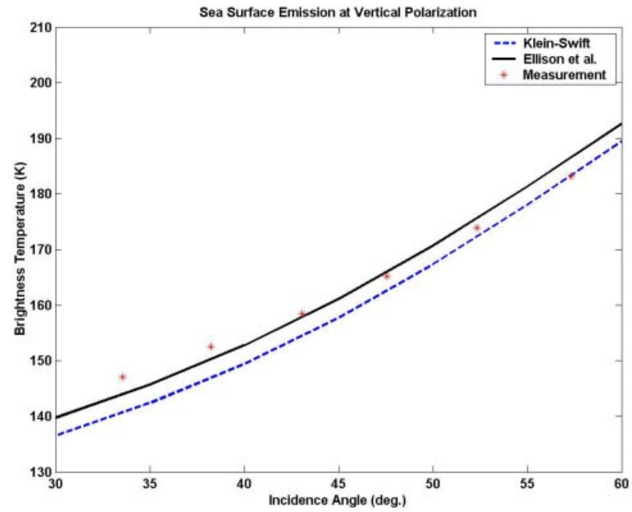

Fig. 5. Comparison at vertical polarization (Klein-Swift model--blue dashed line, Ellison model--black solid line, Measurements—red asterisks). SST = 26 ˚C, SSS =36 psu, WS = 8 m/s.

V. SUMMARY

A fully polarimetric K-band radiometer fabricated at the University of Massachusetts was deployed at the Rough Duct Evaporation (RED) campaign during August and September 2001. A successful comparison with the Ellison *et al.* ocean dielectric model has been shown along the successful calibration of the four Stokes parameters. Future work will focus on wind vector retrieval at different azimuth angles, with a specific elevation angle.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

[1] L.A. Rose, W.E. Asher, S.C. Reising, P.W. Gaiser, K.M. St. Germain, et al., "Radiometric measurements of the microwave emissivity of foam". *IEEE Trans. Geoscience and Remote Sensing*, vol. 40, no. 12, pp. 2619-2625, Dec. 2002.

[2] A. Camps, F. Torres, I.Corbella, J. Bara, X. Soler, "Calibration and experimental results of a two-dimensional interferometric radiometer", *Radio Science*, vol. 32, pp. 1821-1832, 1997.

[3] L.A. Klein and C.T. Swift, "An improved model for the dielectric constant of sea water at microwave frequencies", *IEEE Trans. Antennas Propagat.*, vol. AP-25(1), pp. 104-111, 1977.

[4] W. Ellison, A. Balana, G. Delbos, K. Lamkaouchi, L. Eymard, C. Guillou, and C. Prigent, "New permittivity measurements of seawater," *Radio Science*, vol. 33, no. 3, pp. 639-648, 1998.

[5] A. Camps and S.C. Reising, "Wind direction azimuthal signature in the Stokes emission vector from the ocean surface at microwave frequencies," *Microwave Optical Tech. Lett.*, vol. 29, no. 6, pp. 426-432, 2001.