MICROWAVE SCATTERING FROM THE OCEAN SURFACE

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Abstract

This paper is a review of current aircraft and satellite microwave remote sensing programs concerned with the measurement of ocean wave and surface wind conditions. These particular measurements have been identified by the user community as offering significant economic and technological benefits. Active microwave remote sensing techniques for these applications have been described theoretically and verified experimentally. The results of recent aircraft and satellite experimental programs are presented herein along with plans for the SeaSat-A Satellite Scatterometer.

Introduction

A current need for knowledge of ocean wave and ocean surface-wind vector conditions has been identified by many private and government organizations. Potential areas of use for this information include maritime shipping, coastal water usage, meteorology and tactical military operations to name a few. In fact, a recent NASA study[1] has shown that significant economic and technological benefits would result from a dedicated satellite to perform these measurements bidaily on a global scale. Several active microwave techniques have been shown, both theoretically and experimentally, to be applicable for aircraft and/or satellite ocean measurements. Other radar techniques, in lesser stages of development, promise improved or expanded ocean remote sensing capabilities. This paper reviews several of the above techniques including recent aircraft and satellite ocean measurements and presents plans for the SeaSat-A Satellite Scatterometer (SASS).

Wave Measurements

A dual frequency correlation technique has been developed by Weissman[2] for measuring the rms wave height averaged over an area of the sea that is much greater than any horizontal scale of the surface waves. This measurement involves a near-nadir looking radar that transmits and then receives two monochromatic signals simultaneously. At the receiver, the two radar returns are correlated as a function of their variable frequency separation. The resulting cross correlation $R(\Delta f)$ depends primarily on the rms wave height. An aircraft instrument, the Dual Frequency Scatterometer (DFS), was developed by NASA-LaRC and flight tested in 1974. Results reported by Johnson[3] for low and moderate sea states are in good agreement with Weissman's theory. Additional measurements with wave heights of up to 20 feet (figure 1) also showed good agreement for low and moderate sea states. The high sea state data however showed significant deviations from theory. It is hypothesized that this effect may be the result of an inadequate number of scattering points in the antenna footprint. In figure 1, the rms wave height (σ) is a calculated best fit to the data. Laser profilometer wave data were taken on these flights and are presently being processed to yield rms wave height for comparison with the radar inferred values.

For off-nadir measurements, Barrick[4,5] has developed a theoretical model which indicates that the dual frequency correlation $R(\Delta f)$ yields the dominant ocean wave length and the directional wave slope spectrum. Experiments were conducted with the DFS to test this theory but the data reduction is not yet completed. Jackson[6] has performed an analysis of the Barrick approach as well as a short pulse approach suggested by Tomiyasu[7]. Jackson finds that the two approaches are essentially the same (different hardware configurations) and that they both appear feasible when properly implemented. In the Tomiyasu technique, the time varying amplitude of the backscattered signal is used to infer directional wave slope spectrum. This idea was conceptually developed into a satellite ocean wave length sensor by Eckerman[8]. In this instrument, a short transmitted pulse sweeps across the ocean surface producing a backscattered signal which is essentially the impulse response of the waves. Ocean wave spectrum can then be resolved by signal processing. The development of this technique is being pursued by NASA-GSFC in cooperation with the Naval Research Laboratory (NRL).

Wind Vector Measurements

Extensive measurements of the radar sea return from aircraft were performed by Guinard, Daley, and Valenzuela of NRL[9-11]. The scattering coefficient σ^o was obtained as a function of polarization, incidence angle, and azimuth angle using four radars operating at 428, 1228, 4455, and 8910 MHz. Other aircraft measurements[12-14] taken by NASA-JSC at 13.3 GHz used a fan-beam doppler radar technique to obtain σ^o_{vv} for incidence angles between ± 60° (near-nadir data were excluded). More recently measurements[15,16] have also been obtained by NASA-LaRC using a 13.9 GHz pencil beam scatterometer (AAFE RADSCAT) installed in a NASA-JSC aircraft.

An analysis of NRL and NASA-JSC data has been performed by Apel[17] to determine the dependence of σ^o on ocean surface wind speed. To remove instrument biases, σ^o at 35° incidence normalized to σ^o at 10° incidence was used. When these data are plotted as in figure 2, the result suggests a power law relationship such that

$$\sigma^o = AU^{\nu}$$

where A - is a constant
U - is wind speed
ν - is the wind speed power coefficient

Daley[11] has curve-fitted power law responses to NRL measurements. Bradley[13] and Claassen[14] of the University of Kansas and Jones, Schroeder, Mitchell and Grantham[15,16] of NASA-LaRC have performed similar analyses for the 13.3 GHz fan beam scatterometer and the 13.9 GHz AAFE RADSCAT respectively. Tables of wind speed power coefficients for upwind, downwind, and crosswind observations are given in figure 3. Previous observations indicated an azimuthal variation (wind direction dependence) of scattering coefficient at incidence angles well off the nadir. To examine this effect, the AAFE RADSCAT was pointed to the nadir and then the aircraft flown in high banked circles thereby producing a conical scan of the ocean's surface. Results for three flights (figure 4) imply that both wind speed and direction may be inferred from multi-look radar observations.

The first satellite measurements of ocean scattering coefficient were obtained during the NASA-JSC Skylab program. The Skylab earth resources package contained a mechanically scanned pencil-beam 13.9 GHz scatterometer (similar to AAFE RADSCAT) known as S-193 RADSCAT. Preliminary results[18] of ocean scattering coefficient versus wind speed are shown in figure 5 for 50° incidence angle. These data support the backscattering power law response to wind speed as do results at other incidence angles for both polarizations.

SeaSat-A Satellite Scatterometer

A microwave scatterometer will provide the measurement of ocean surface wind speed and direction for the SeaSat-A oceanographic satellite (1978 launch). This fan beam scatterometer incorporates four antennas which produce a star-like illumination on the surface (figure 6). Dual polarized backscatter measurements are performed using each antenna consecutively. Doppler filtering and range gating are used to subdivide the footprint into separate cells at different incidence angles. Since the scattering coefficient is a function of wind direction as well as wind speed, both the forward and aft looking antennas are required for each resolution cell. An optimum implementation is for the forward and aft beams each squinted 45° off the subsatellite track to provide measurements which are separated in azimuth by 90°. In this configuration, the mean of the two measurements for a given resolution cell is nearly independent of wind direction. After determining wind speed from σ^{o} values taken at orthogonal azimuth angles, individual forward and aft measurements can be used to determine wind direction. If necessary an iterative procedure can be used to improve wind speed and direction estimate.

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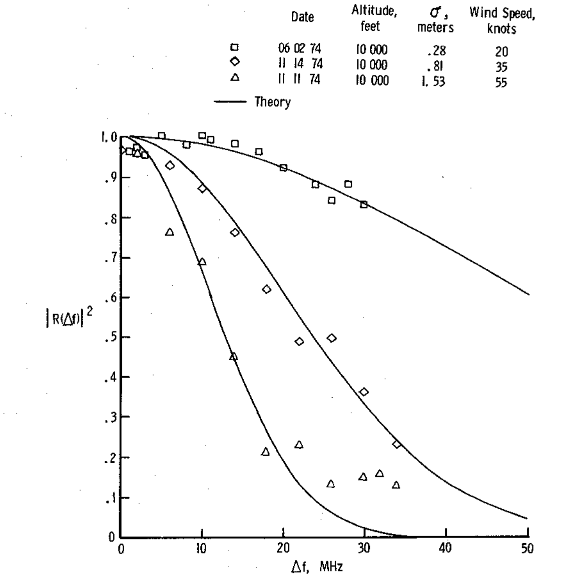

Fig. 1. Dual frequency scatterometer correlation coefficient for low, moderate and high sea states.

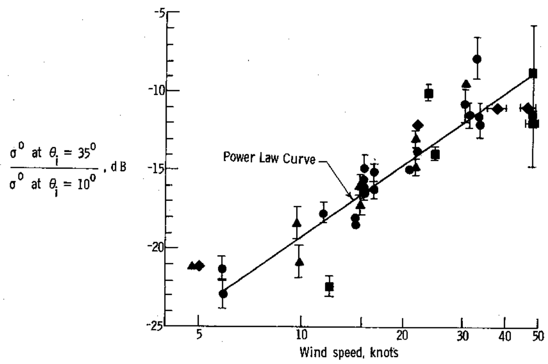

Fig. 2. Normalized scattering coefficient data from JSC and NRL (log-log plot).

NRL

Freq.	Direction	Polarization	Exponent	Incidence Angle				
				20°	25°	30°	40°	50°
8.9 GHz	Upwind	VV	ν	0.20	0.25	0.37	0.66	0.73
	Downwind	VV	ν	0.20	0.29	0.36	0.80	0.80
	Upwind	HH	ν	0.00	0.33	0.58	0.87	1.03
	Downwind	HH	ν	0.00	0.29	0.52	1.04	1.30

NASA-JSC

Freq.	Direction	Polarization	Exponent	Incidence Angle, θ_i	
				25°	35°
13.3 GHz	Upwind	VV	ν	1.12	1.49
	Downwind	VV	ν	1.15	1.60
	Crosswind	VV	ν	1.00	1.40

AAFE RADSCAT

Freq.	Direction	Polarization	Exponent	Incidence Angle, θ_i			
				20°	30°	40°	50°
13.9 GHz	Upwind	VV	ν	1.05	1.68	1.77	1.66
	Downwind			.98	1.56	1.62	1.55
	Crosswind			.98	1.49	1.52	1.51
13.9 GHz	Upwind	HH	ν	1.00	1.65	1.98	1.93
	Downwind			.94	1.68	1.97	1.96
	Crosswind			.75	1.45	1.46	1.48

Fig. 3. Tables of wind speed power coefficient.

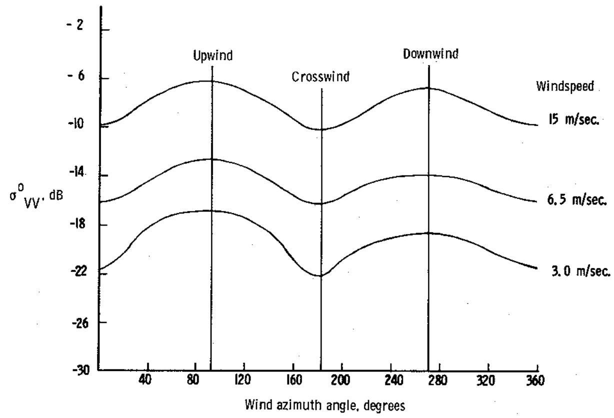

Fig. 4. AAFE Radscat scatterometer wind direction sensitivity.

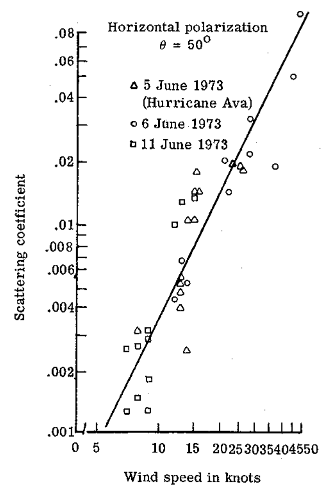

Fig. 5. Skylab S-193 scatterometer response to wind at sea (from congressional presentation by Dr. R. K. Moore, Feb. 20, 1974).

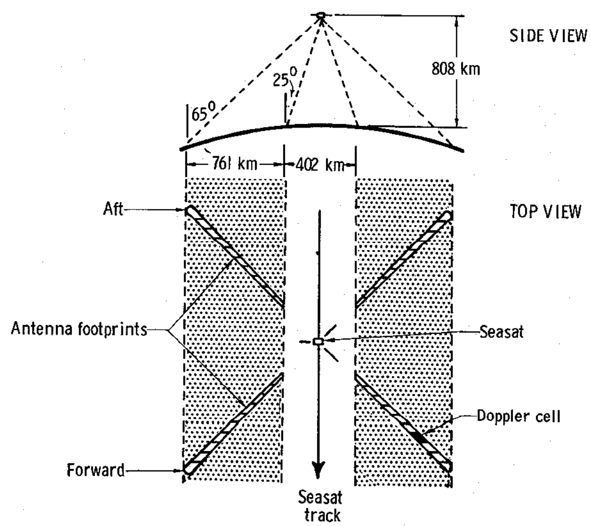

Fig. 6. Seasat-A satellite scatterometer (SASS).