Def Sci J, Vol 35, No 4, October 1985, pp 383–389

Wind Dependence of L-Band Radar Backscatter

ABHIJIT SARKAR, LAKSHMI BHADURI & RAJ KUMAR
Space Applications Centre, Ahmedabad-380053

Received 27 March 1984 ; revised 13 March 1985

Abstract. Like other microwave frequency bands, L-band scattering coefficient (σ°) measurements have shown a definite dependence on ocean surface wind speed (W). The relationship between the two depends on the observation angle of the radar. The satellite-borne L-band radars SEASAT-SAR and SIR-A made observations at fixed incidence angles, while the just completed SIR-B mission has made observations at multiple incidence angles. The present work uses the theory of scattering from a composite surface and generates an analytic function of σ° — W relationship for varying incidence angle at L-band by the method of empirical curve fitting.

1. Introduction

The utility of microwave sensors in ocean studies, stems from their response to specific ocean surface structures, which are composed primarily of capillary and short gravity waves. It is the wind vector in the surface boundary layer over oceans which mainly determines the physical nature of the underlying ocean surface, which in its turn is responsible for modulating any microwave radar signal returned by such a surface. Thus the backscattered microwave signal power or the backscattering coefficient of the sea exhibits a dependence on the sea surface wind vector and a microwave radar becomes a potential remote sensor of sea surface wind vector.

During the last two decades, the scattering coefficient of the ocean has been measured using various airborne and spaceborne radars operating over a wide range of frequency bands and incidence angles. Analysis of these data have shown that the backscattering coefficient is proportional to the ocean surface wind speed raised to some power, the value of the exponent and the coefficient, however, remain to be correctly defined. For the angles, θ, near the vertical (quasi specular range of angles), expressions of the type $\tan\left(\sum_{i=0}^{3} b_i\theta^i\right)$ and $\exp\left(\sum_{i=0}^{3} a_i\theta^i\right)$ have been found appropriate for the exponent and the coefficient respectively[1]. Attempts to develop similar expressions for the mid angular range were undertaken in this work.

The sea spectrum model as suggested by Daley[2] and the corresponding expression for the scattering coefficient by the composite surface approach are relatively simple and used in the derivation. The power law dependence of the scattering coefficient thus derived has been found fairly accurate for *L* and *P*-bands. SEASAT-SAR and SIR-A acquired *L*-band radar images at fixed incidence angles of 20 and 47 degrees respectively, revealing the important role played by the incidence angle in the radar sea response[3]. The just completed SIR-B mission also operating at *L*-band has made measurements at multiple incidence angles.

The relationship derived in this work applies to *L*-band and the incidence angle in the mid angular range (30°—70°). Attempts to generate a generalized relationship, applicable to the full spectrum of microwave frequencies are underway.

2. Sea Spectrum and Scattering Coefficient

Perhaps the most extensive measurements of the radar sea return observed from the aircraft were performed by Naval Research Laboratory of USA during the period 1965 to 1971. The four frequency radar (4–FR) mostly used was an airborne coherent-pulsed radar capable of transmitting and receiving a sequence of four frequencies in *X*, *C*, *L* and *P* bands. Using the radar measurements, ocean wave spectrum is derived by using standard least square fit procedures[2]. When the averaged data are used, the spectra in terms of the ocean wave numbers assume the forms as represented in Fig. 1.

Following Valenzuela[4], the scattering coefficient for a composite surface can be related to the two-dimensional energy density spectrum of surface height variations of the ocean surface $S_j(k)$ by the expression :

$$[\sigma_j^0]_{vv} = 4\pi\beta^4 \cos^4\theta \, \alpha_{vv} \, S_j(k)$$

where the spectrum is assumed to have the form

$$S_j(k) = B_j \, g^{-\nu_j} \, W^{2\nu_j} \, k^{-(4-\nu_j)}$$

where

j = upwind (u), crosswind (c) or downwind (d)

vv = vertically polarized transmitted and received signal

β = radar wave number = $25.71917\,\mathrm{m}^{-1}$

θ = angle of incidence

$$\alpha_{vv} = \left| \frac{(\epsilon - 1)[\epsilon(\sin^2\theta + 1) - \sin^2\theta]}{[\epsilon\cos\theta + (\epsilon - \sin^2\theta)^{1/2}]^2} \right|^2$$

ϵ = complex dielectric constant

$k = 2\beta\sin\theta$ = oceanic wave number

$B_u = 4.92 \times 10^{-4}$, $B_c = 9.26 \times 10^{-4}$, $B_d = 6.28 \times 10^{-4}$

g = acceleration due to gravity

$2\nu_j$ = wind speed exponent

W = wind speed in meters per second

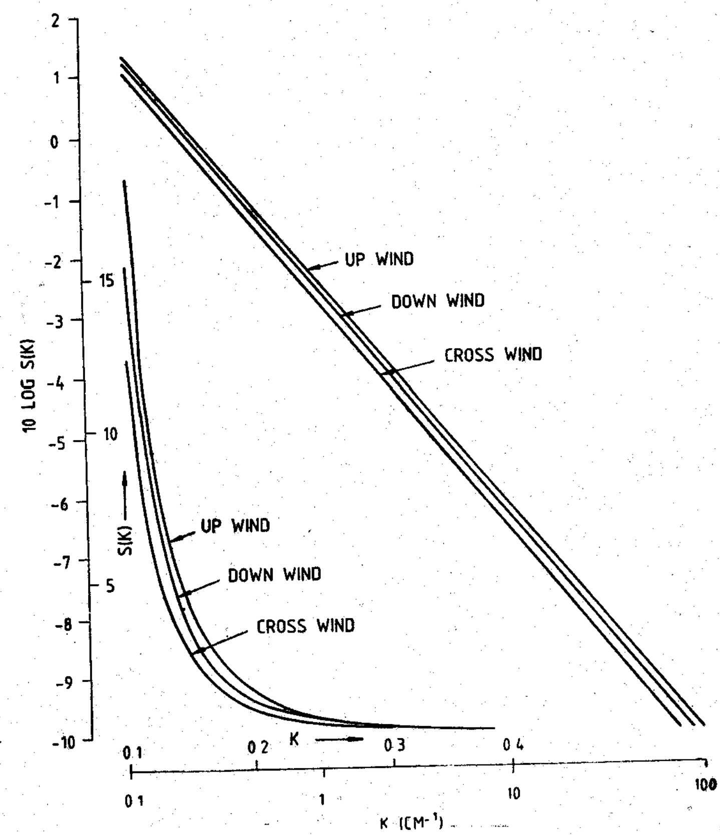

Figure 1. Ocean spectra as a function of ocean wave number.

Substitution of the expression of the spectrum in $(\sigma_j^0)_{vv}$ results in the final expression of the scattering coefficient, subsequently used in our computations :

$$\left[\sigma_j^0\right]_{vv} = \frac{\pi}{4} B_j g^{-\nu_j} \alpha_{vv} \cot^4\theta (2\beta \sin\theta)^{\nu_j} W^{2\nu_j}$$

The dielectric constant, computed for salinity value of 35ppt an temperature of 26°C of sea water is 67.0666 — i 82.8795.

3. Results and Discussions

3.1 *Angular Variation of the Coefficient*

The wind dependence of the scattering coefficient for the angles of incidence of 30, 40, 50, 60 and 70 degrees are shown in the Figs. 2 – 4 for three different cases of the wind azimuth angle namely upwind, crosswind and downwind. The values of the exponent used are 0.56, 0.34 and 0.46 for the above cases respectively. The lines in Figs. 2 – 4 suggest that the values of intercepts decrease with increasing angles of incidence. By

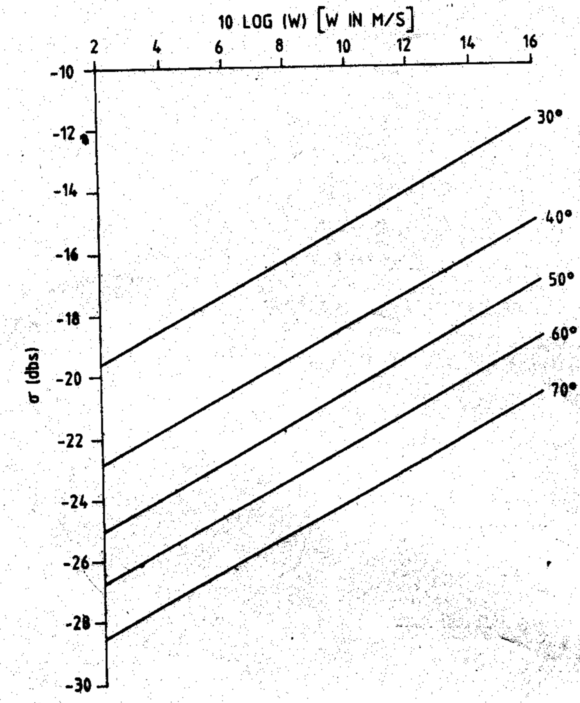

Figure 2. Dependence of σ^0 on W for different incidence angles (upwind case).

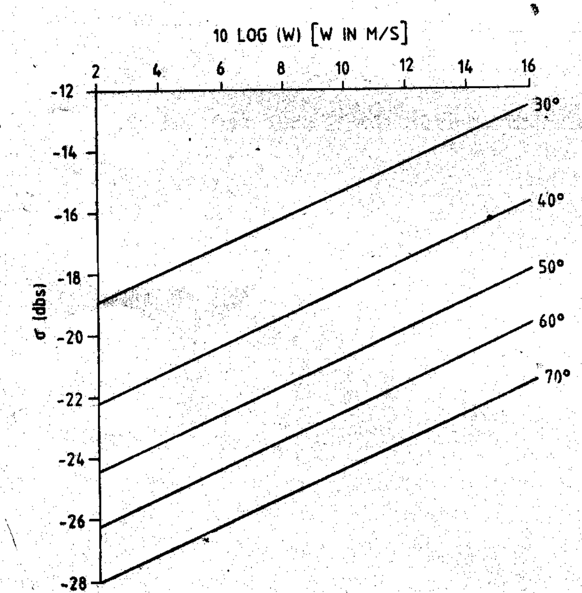

Figure 3. Dependence of σ^0 on W for different incidence angles (downwind case).

the method of empirical curve fitting of data for every half degree of incidence angle, it has been found that three degree polynomials of the type $\sum_{i=0}^{3} a_i\theta^i$ give excellent fits

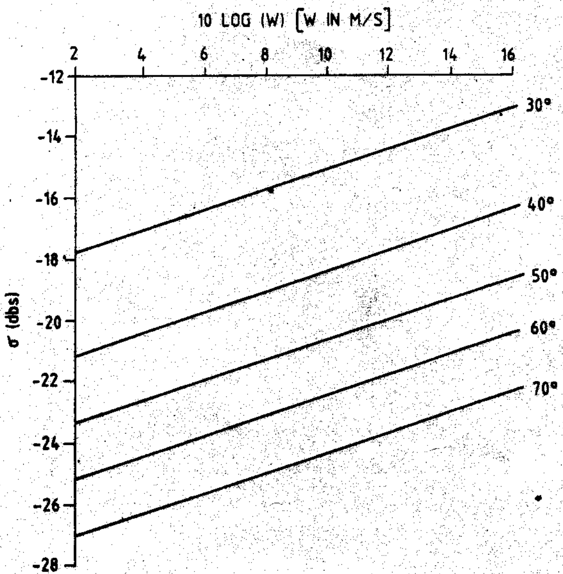

Figure 4. Dependence of σ^0 on W for different incidence angles (crosswind case).

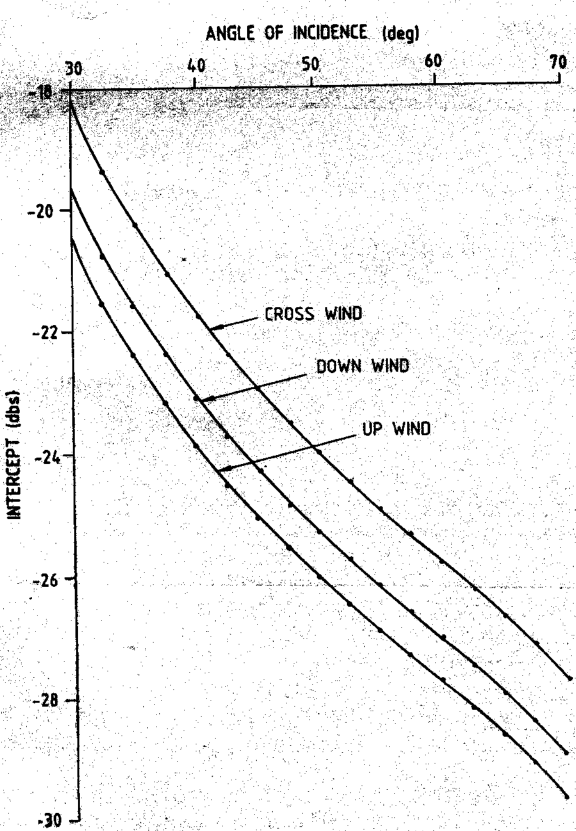

Figure 5. Dependence of intercept on angle of incidence.

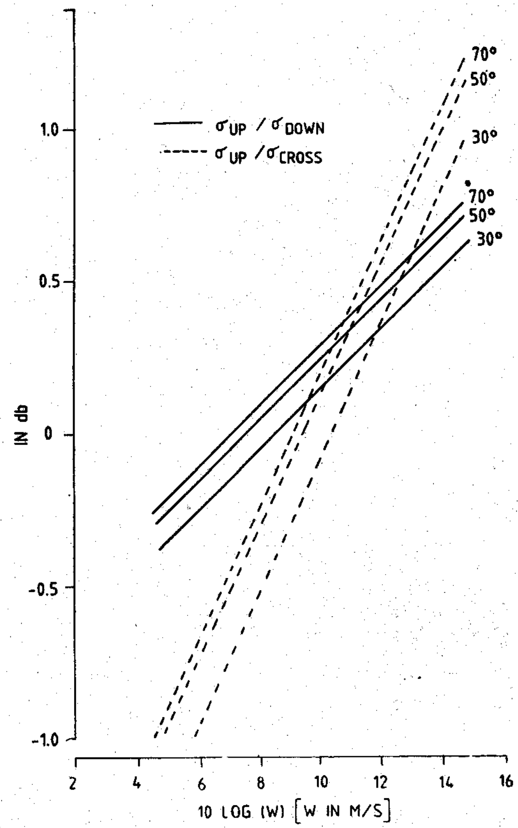

Figure 6. Scattering coefficient anisotropy as a function of wind speed for different incidence angles.

for the intercepts (Fig. 5). Hence, the scattering coefficient could be expressed as follows :

$$\sigma_j^0 = 10^{\frac{1}{10}\sum_{i=0}^{3} a_{ji}\theta^i} W^{2b_j}$$

where θ is the angle of incidence in degrees. The values of *a* and *b* as computed by our program are as follows (Table 1) :

Table 1. Values of *a* and *b* in power law relationship

	u	*c*	*d*
a_{j_0}	0.493277	3.48302	1.47656
a_{j_1}	—1.112540	—1.14670	—1.11613
a_{j_2}	0.0163022	0.16716×10^{-1}	0.162458×10^{-1}
a_{j_3}	-0.9385×10^{-4}	-0.95727×10^{-4}	-0.930884×10^{-4}
b_j	0.28000	0.17000	0.23000

The RMS errors of the fits for the cases of upwind, cross-wind and downwind are 0.581038×10^{-2}, 0.555053×10^{-2} and 0.687944×10^{-2}, respectively thereby exhibiting excellent fits.

3.2 *Wind Anisotropy Effect*

Variations in the scattering coefficient due to variation in the azimuth angle with respect to the wind direction results in anisotropic effect of the scattering coefficient. The computations of σ_u^0/σ_c^0 and σ_u^0/σ_d^0 have confirmed that there is a greater variability between σ_u^0 and σ_c^0 than between σ_u^0 and σ_d^0 as expected. A marked wind dependence of scattering coefficient anisotropy is also noticed (Fig. 6), suggesting that wind direction retrieval will require the knowledge of wind speed.

4. Conclusion

L-band radar's response shows wind speed dependence of the power law type. The proportionality coefficient of the $\sigma - W$ relationship is well approximated by a three degree polynomial of the incidence angle which can be used for analysing multiple incidence angle measurement data, or for computing the scattering coefficient of an area covering a range of incidence angles.

Acknowledgements

The authors wish to thank Dr. T. A. Hariharan for his constant encouragement and guidance. They also wish to thank Dr. P. C. Pandey and other colleagues of the Meteorology Division, Space Applications Centre, Ahmedabad for useful discussions and comments.

References

1. Sarkar, A. & Bhaduri, L., *Proc. Ind. Acad. Sci. (EPS)*, **93** (1984), 111–116.
2. Daley, J. C., *J. Geophys. Res.*, **78** (1973), 7823–7833.
3. Thompson, T. W., Weissman, D. E. & Gonzalez, F. I., *J. Geophys. Res.*, **88** (1983), 1727–1735.
4. Valenzuela, G. R., Laing, M. B. & Daley, J. C., *J. Mar. Res.*, **29** (1971), 69–84.