Characterization of Fluctuation Statistics of Radar Clutter for Indian Terrain

K. Rajalakshmi Menon, N. Balakrishnan, M. Janakiraman, and K. Ramchand

Abstract— **In this paper, characterization of the fluctuation statistics of radar clutter using Weibull and lognormal distribution models, is presented. Both farmland and sea clutter data measured using a noncoherent, airborne S-band radar are used in the analysis. The clutter data represent the first measurements from an airborne platform over Indian terrain. The values of the distribution parameters estimated using two different techniques, have also been presented along with the different criteria used to classify the clutter.**

I. Introduction

RADAR clutter is the vector sum at the radar antenna of many echo signals from many small scatterers which are located within the radar resolution cell. Owing to the movement of these scatterers, the amplitude and phase of these echo signals will change, giving rise to fluctuating signals. In view of this, the clutter signals become a stationary and sometimes even a nonstationary random sequence [5]. The amplitude distribution of radar clutter depends upon the type of terrain, the size of the resolution cell and the grazing angle of the antenna beam.

The variability in the clutter signal in general, is much more than that of noise even when the mean clutter level is lower than the noise level [1]. Hence, at times the target detection capability of a radar becomes clutter limited instead of being noise limited. To estimate the radar performance, it is therefore essential to quantify the clutter distribution by suitable probability density functions. Such characterizations would also be useful in the classification of terrain types and also in evolving optimum algorithms for rejection of clutter interference in the design of airborne radars.

Various statistical distributions are used to fit the temporal and spatial distributions of clutter data. Rayleigh, Ricean, lognormal, Weibull, Chi-Square are a few of these [3]. The radar designer is concerned with clutter distribution in time, frequency and space, and in short time intervals, of the order of, pulse, inter-pulse and long scan-to-scan intervals.

The clutter distribution from many sources of comparable strength, independent of one another is frequently described by a Rayleigh distribution in accordance with the central limit theorem [2]. Hence, the clutter returns from a long pulse-width ($\geq 1\ \mu$ s) radar can be modeled by a Rayleigh distribution.

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The clutter data measured with practical airborne radars are often observed to give distributions that are different from Rayleigh [3]. This is attributed to addition of small number of large scatterers (of large Radar Cross Section (RCS)) or deletion of large number of small scatterers from the resolution cell. Sea spikes or man-made structures add large cross-sections whereas the shadowing mechanism removes small scatterers, leading to non-Rayleigh distributions. Further, due to the motion of the platform, the echo signals measured by airborne radars reflect the combined effect of temporal and spatial variations of the terrain. When the period of observation is small, of the order of 50 ms, the echoes can be considered to represent purely the temporal characteristics of the terrain. For longer periods, of the order of a second, the echoes represent a mix of both temporal and spatial variations. Appropriate averaging over finite windows could help in isolating only the spatial variations.

The area covered by a normal radar flight is vast unlike a ground-based low range radar. Hence, the land clutter is classified as farmland, snow covered mountain, marshy land, woods etc., and the sea surface is characterized by the sea state.

Land clutter is commonly described by Ricean distribution as the sum of a constant component (due to the presence of echo from a fixed target) and fluctuating components (described by Rayleigh distribution). Depending on the strength of the constant component (which is a function of wind speed and type of terrain), the probability distribution curve varies from exponential to a distribution approximated by a narrow Gaussian, centered around the intensity of the steady echo [4].

Large terrain undulations result in locally larger grazing angles for some of the scatterers within the radar beam. This causes the reflectivity of those scatterers to be larger resulting in a distribution that has a long tail. Lognormal distributions are highly suited for describing such data with long tail distributions [3]. In low resolution radars, lognormal distributions are observed at low grazing angles. In high resolution radars, lognormal distributions are observed even at moderate grazing angles.

In general, experimental clutter data show the tail of the distribution to be in between that of Rayleigh and lognormal. To fit such clutter data, Weibull distribution has been used, as it has a mathematically tractable form. The different values of shape parameter of the Weibull distribution can be chosen to suit the extent of the tail. The value of this parameter characterizes the nature of the experimental clutter data [5].

The K distribution is used to model terrain composed of a mixture of locally homogeneous terrain patches [6].

The characterization of fluctuation statistics of radar clutter has received considerable attention in the past. Notable amongst them are those by [2], [4], [10]. They have used ground based radar system and therefore have reported the temporal clutter fluctuation statistics. The first airborne measurements were carried out using the 4 Frequency Radar (4FR) system at (P, L, X and C) bands over Arizona (desert) mountains, farmlands and urban areas. Reference [11] have reported the echo fluctuations measured using the 4FR system by Rayleigh and Ricean distribution. The first airborne measurements at "S" band were carried out through a program called the Overland Radar Technology program conducted by the U.S. Air force. Reference [9] have reported the results of the measurements and have characterized the fluctuation statistics using Weibull distribution function only for sea clutter. The mean values of the backscatter coefficient have been reported with no reference to the statistical characteristics of echoes for farmland type of terrain.

In this paper, clutter data collected from an "S" band airborne radar flown over Indian farmland and sea are presented. The distribution parameters of the clutter echo are estimated using two different techniques and the results of the analysis are discussed.

II. Radar Data

A noncoherent "S" band radar with a pulse width of 800ns and an azimuth beam width of 1.6° was used for the measurements. The radar was calibrated against the standard trihedral corner reflector placed at different ranges. The radar sensitivity constant R_k was determined during the calibration of the radar using the relation,

$$R_k = \frac{P_r R^4}{G^2 \sigma_{cr}} \quad (1)$$

where, P_r is the received echo power in watts from the corner reflector placed at range R in meters from the radar. G is the antenna gain corrected for range dependence because of large beam-width in elevation and σ_{cr} is the cross-section of corner reflector (46.2dBm^2). During the calibration process, the radar was mounted on a hill top (at Nandi Hills, near Bangalore, approximately 1 Km above the fixed ground). The backscatter coefficient σ^o for a particular terrain can then be calculated using the following equation:

$$\sigma^o = \frac{P_r R^4}{G^2 R_k} \frac{1}{\delta A} \quad (2)$$

where,

δA = Area of the foot-print, calculated from the geometry.
P_r = Clutter Power received from range R.
G = Antenna gain corrected for range dependence.
R_k = Radar sensitivity constant derived from calibration.

After calibration, the radar was mounted on a modified HS-748 aircraft with the antenna inside a radome located at $\approx$ 3.3 m above the fuselage.

In order to characterize the clutter from Indian terrain, measurements were conducted over Kolar (a farmland tract near Bangalore) and over sea (Bay of Bengal) using the airborne radar. Two sorties were flown over Kolar on July 16, 1992. Sortie-I was flown at an altitude of 2.28 km above the ground and the sortie-II at approximately 1.67 km above the ground. On Sept. 7, 1992, another sortie (sortie-III) was flown at an altitude of approximately 1 km. The measurements from this sortie yielded data from as low as 2.8° grazing angle. The sea clutter data was measured on July 17, 1992 using the airborne radar flown at an altitude of 2.28 km above the sea level. The wind speed was around 10-12 Kts and the sea state was one in the Beaufort scale during the measurements. During the airborne measurements, the aircraft was flown in an orbit of 4 Km radius at 1° s turn rate.

In this work, clutter echoes from about 20 different grazing angles have been measured and are used for analysis. For each grazing angle, approximately 355 sets, each comprising of 40 contiguous echo samples are recorded. In other words, order of 14000 echo samples are analyzed for each grazing angle. Each clutter echo sample is separated by the radar Pulse Repetition Time (PRT) of 1.25 ms, and the sets are separated by 2.5 s. The latter parameter has been fixed by the data measurement scheme chosen.

The variations of mean backscatter coefficient $\bar{\sigma}^o$ with grazing angle were found to agree well with [3]. The statistical fluctuations due to transmitter jitter and noise are estimated to be less than 0.27 dB during calibration. This level of fluctuations is smaller than the fluctuations due to the terrain, which was found to be greater than 3 dB.

In the following sections, the details of the clutter data analysis and the results are presented.

III. Characterization of Clutter Distribution

In order to get an overview of the variability in the backscatter coefficient, σ^o, (defined as the clutter cross-section per unit area) the 5, 25, 50, 75, and 95 percentiles of σ^o for various grazing angles have been plotted in the Fig. 1 for Kolar (farmland). Similar trends were observed for sea data collected over Bay of Bengal. This plot establishes the variability in the clutter backscatter coefficient which need to be quantified in some parametric form.

To quantify this variability of clutter signal, we describe the fluctuation statistics of the clutter around the mean by suitable probability density functions. The Weibull and lognormal distributions have been chosen to describe the distribution of measured values of σ^o of Kolar and Bay of Bengal. This choice has been made because the Weibull probability density function has the advantage of having a mathematically tractable form and the lognormal distribution function has chosen to cater for the long tailed distribution, of the measured data. As the Rayleigh probability distribution is a special case of the Weibull family of curves, the deviation from the Rayleigh model can also be analyzed by fitting a Weibull distribution. The variation in the shape parameter value from one (corresponding to Rayleigh distribution) is an indicator of the non-Rayleigh nature of the distributions.

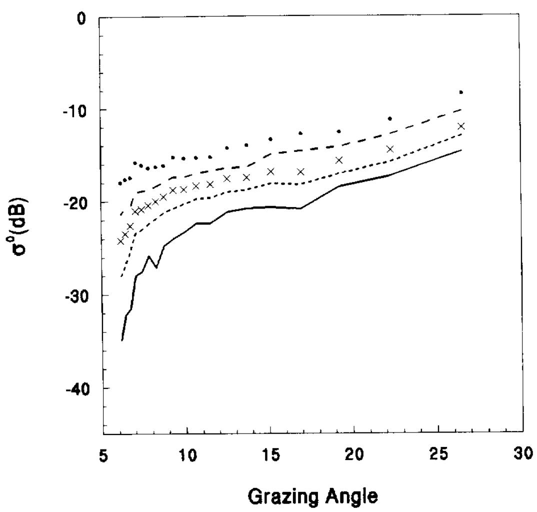

Fig. 1. Variability of σ^o with grazing angle of farmland terrain (Kolar). — 5 percentile value, - - - 25 percentile value, xxxx 50 percentile (median) value, - · - 75 percentile value, and ··· 95 percentile value.

The K distribution was not used to model the clutter distribution because it is very similar to Weibull distribution [5].

The Weibull Probability density function $p(x)$ is given by [5],

$$p(x) = \frac{c}{a} x^{c-1} \exp(-\frac{x^c}{a}) \quad (3)$$

and Weibull probability distribution function $P(x)$ is given by,

$$P(x) = 1 - \exp(-\frac{x^c}{a}) \quad (4)$$

where, c is the shape parameter and a is the scale parameter.

The mean $\bar{x}$ for a Weibull variate x is given by

$$\bar{x} = a^{\frac{1}{c}} \Gamma(1 + \frac{1}{c}) \quad (5)$$

where, Γ is the gamma function.

The lognormal density function $p(x)$ is given by [5],

$$p(x) = \frac{1}{\sqrt{2\pi} x \sigma} \exp\left[-\frac{1}{2\sigma^2}\left(\ln\left(\frac{x}{x_m}\right)\right)^2\right] \quad (6)$$

and the lognormal distribution function $P(x)$ is given by

$$P(x) = \frac{1}{2}\left[1 + \frac{1}{\sqrt{2}\sigma} \text{erf}(\ln(x) - \ln(x_m))\right] \quad (7)$$

where, σ is the standard-deviation of the $\ln(\frac{x}{x_m})$ value, x_m is the median value of x, and erf(x) is the error function. The mean value $\bar{x}$ for lognormal distribution function is given by

$$\bar{x} = \exp\left(\ln(x_m) + \frac{1}{2}\sigma^2\right). \quad (8)$$

The characterization of the fluctuation statistics thus gets reduced to estimation of the values of the parameters of the distribution function, which can model the set of measured clutter from different types of terrain and at various grazing angles.

IV. Estimation of the Distribution Parameters

A. Estimation

In this paper, two techniques to estimate the values of the distribution parameters for the chosen distribution functions namely, lognormal and Weibull distribution have been presented.

Plotting on Probability Paper (PPP) Technique: In the first technique, the cumulative distribution of data is first plotted in a Weibull probability paper ($\ln\left(\ln\left(\frac{1}{1-P}\right)\right)$ versus $\ln \sigma^o$, where P is the cumulative probability of the data). A linear fit is then made on the plotted points using the least square criteria. The slope of the fitted line gives the shape parameter and the intercept gives the scale parameter. The Root Mean Square Error (RMSE) of the regression fit is a measure of the goodness of fit [5].

A similar approach has been adopted for estimating the mean and standard deviation of the lognormal distribution by plotting $\text{erf}^{-1}(2P-1)$ versus $\ln \sigma^o$. The slope of the linear fit gives the standard deviation (σ) and the mean (x_m) is obtained from the intercept of the line [5].

In the linear regression fit, only data between $P = 0.001$ to 0.999 have been considered since the sample size of our measurements is of the order of tens of thousands. Reference [7] has calculated the number of samples to be of the order of one million to fit long tailed distributions.

Maximum Likelihood Estimator (MLE) Technique: In the second technique, a point parametric estimation technique has been used to obtain MLE estimators for Weibull and lognormal distribution parameters. The MLE estimators denoted by ^ are given by the following expressions:

For Weibull distribution, $\hat{c}$ is obtained from the equation

$$\frac{n}{\hat{c}} + \sum_{i=1}^{n} \ln(\sigma_i^o) - \frac{n \sum_{i=1}^{n} \sigma_i^{o\hat{c}} \ln(\sigma_i^o)}{\sum_{i=1}^{n} \sigma_i^{o\hat{c}}} = 0 \quad (9)$$

and $\hat{a}$ is obtained from

$$\hat{a} = \frac{1}{n} \sum_{i=1}^{n} \sigma_i^{o\hat{c}}. \quad (10)$$

For the lognormal distribution,

$$\hat{x}_m = \exp\left[\frac{1}{n} \sum_{i=1}^{n} \ln(\sigma_i^o)\right] \quad (11)$$

$$\hat{\sigma} = \left[\frac{1}{n} \sum_{i=1}^{n} \left(\ln(\frac{\sigma_i^o}{x_m})\right)^2\right]^{\frac{1}{2}}. \quad (12)$$

B. Hypothesis Testing

Kolmogrov-Smirnov goodness of fit test has been used to determine which of the two distribution (lognormal or Weibull) fits the data better. Consider the statistic D_n, given by

$$D_n = \sup_{-\infty < x < \infty} |P_n(x) - P(x)| \quad (13)$$

where, $P_n(x)$ is the cumulative distribution of the n data $P(x)$ is the probability distribution function under test.

Since the statistic D_n is a distribution free statistic [8], the distribution with a lower value for the statistic is considered to be a better fit. This technique has been used for estimating the best distribution (out of Weibull and lognormal) that fit the data when the estimators have been obtained using MLE estimation technique.

When the estimation has been obtained using the plotting on probability paper (PPP) technique, the distribution with lowest RMSE is considered to be the best fit. The Y-axis of the lognormal and Weibull probability paper gets transformed to approximately the same range of values and hence RMSE can be considered to be a distribution free statistic for hypothesis testing of these two given distribution functions. In particular, lower RMSE criteria can be used to find the best distribution out of lognormal and Weibull distribution.

V. Results of the Clutter Measurements from Airborne Radar

The measured clutter data has been analyzed to find out the suitability of Weibull and lognormal over the grazing angles of interest for the types of terrain over which measurements have been conducted. The RMSE and the D_n values for the two distribution models for various grazing angles have been compared. The nature of variations of the values of the distribution parameter with grazing angle has also been studied.

The clutter data obtained from the non coherent "S" band airborne radar in nonscanning mode from Kolar (farmland) and Bay of Bengal (sea) exhibits the combined effect of temporal and spatial variations. This mixed effect is observed because the 40 contiguous samples collected from each range yield temporal characteristics, since during this time the echoes are from the same patch, while due to the orbital coverage, many sets of 40 contiguous samples of data are collected from several spatially separated patches which depict spatial characteristics. All the samples from a particular grazing angle has been used in the analysis to study this combined effect by estimating the probability distribution parameters.

A. Distribution of Backscatter Coefficient

The numerical values of the distribution parameters for Weibull and lognormal distributions are presented in this section.

Farmland terrain: The distribution characteristics of σ^o for farmland (Kolar) can be seen from the histograms of the data as shown in Figs. 2–5. The X-axis in these plots are the σ^o values normalized with $\bar{\sigma}^o/10$. This normalization aids in visual comparison of the nature of probability distribution of σ^o for various grazing angles irrespective of the signal strength.

The Fig. 2 shows the probability density function of the data measured from Kolar at a grazing angle of 7°. The probability density function of the estimated distribution parameters for lognormal and Weibull, using both the techniques have also been superimposed on the histogram of the measured data in Fig. 2. The distribution parameter values have been summarized in Table I for farmland clutter at grazing angles of 7°, 8.8° and 4.6°.

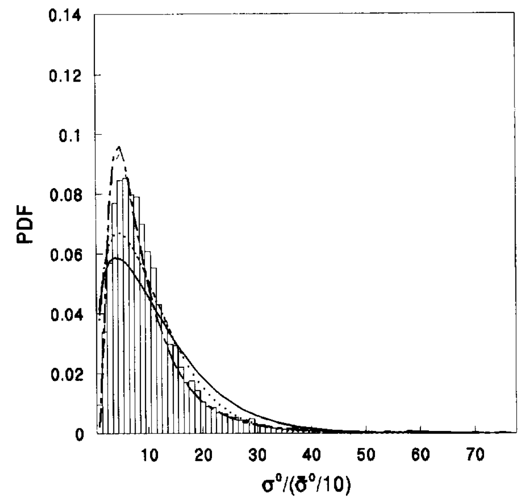

Fig. 2. Plot of lognormal fit for a grazing angle of 7° for farmland with estimated parameters on the histogram of the data. X-axis is σ^o normalized with $\bar{\sigma}^o/10$. - - - lognormal fit with MLE estimators. - · - lognormal fit with PPP estimators. — Weibull fit with PPP estimators. ··· Weibull fit with MLE estimators.

TABLE I
Distribution Parameters for Farmland

Grazing Angle	PDF	Parameter	PPP Technique	MLE Technique
7° Sortie-I	Lognormal	Std-dev	0.746	0.754
		Mean	-4.871	-4.796
		RMSE/D_n	0.102	0.036
	Weibull	Shape	1.27	1.38
		Scale	0.004354	0.002251
		RMSE/D_n	0.29	0.085
8.8° Sortie-I	Lognormal	Std-dev	0.513	0.565
		Mean	-4.612	-4.512
		RMSE/D_n	0.1742	0.095
	Weibull	Shape	2.059	2.04
		Scale	0.000178	0.000172
		RMSE/D_n	0.164	0.086
4.6° Sortie-III	Lognormal	Std-dev	1.124	1.163
		Mean	-4.887	-4.883
		RMSE/D_n	0.040	0.024
	Weibull	Shape	0.723	0.867
		Scale	0.04178	0.02391
		RMSE/D_n	0.141	0.121

From the table, it is seen that the value of the distribution parameters obtained, using both the techniques are in close agreement with each other. Therefore, only the values of the distribution parameters obtained using the PPP technique have been presented further in Fig. 3–5. It is clearly seen from Fig. 2 that lognormal density function fits the histogram better than Weibull density function. This fact can also be confirmed by comparing the RMSE and D_n values given in Table I.

A plot similar to Fig. 2 is given in Fig. 3 for a grazing angle of 8.8° for farmland clutter. The shorter tail as compared to the Fig. 2 is evident from the Fig. 3. It has been observed in general that the extent of the tail decreases for increasing grazing angles and hence a Weibull distribution fits the clutter data better for high grazing angles, whereas lognormal distribution is a better fit for the clutter fluctuations for low grazing angles. This behavior at low grazing angles is as expected, because, at

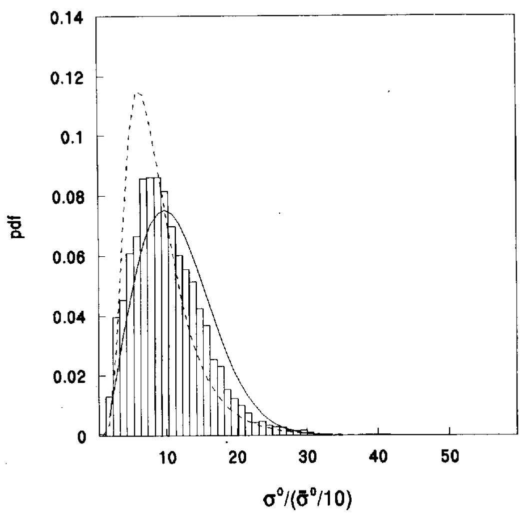

Fig. 3. Plot of Weibull and lognormal fit for a grazing angle of 8.8° for farmland with estimated parameters on the histogram of the data. X-axis is σ^o normalized with $\bar{\sigma^o}/10$. — Weibull fit. - - - lognormal fit.

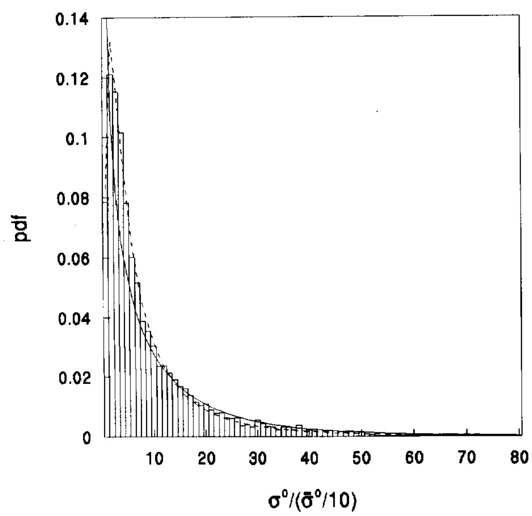

Fig. 4. Plot of Weibull and lognormal fit for a grazing angle of 4.6° for farmland with estimated parameters on the histogram of the data. X-axis is σ^o normalized with $\bar{\sigma^o}/10$. — Weibull fit. - - - lognormal fit.

low grazing angles, due to the terrain undulations, shadowing effect is predominant and also the grazing angles are higher at some local intercepting point on the rough surface resulting in stronger reflectivity from these localized points. This strong reflectivity causes the distribution to be long tailed at low grazing angles. These effects are lessened at higher grazing, resulting in Weibull distributions with shorter tail (higher value of shape parameter).

In order to further validate the above assertions, data from lower grazing angles collected during sortie-III are analyzed. The histogram of the data obtained from the sortie-III has been plotted in Fig. 4 for a grazing angle of 4.6°. This graph also confirms the trend of longer tail for lower grazing angles. The nature of variations of the histogram from a grazing angle of

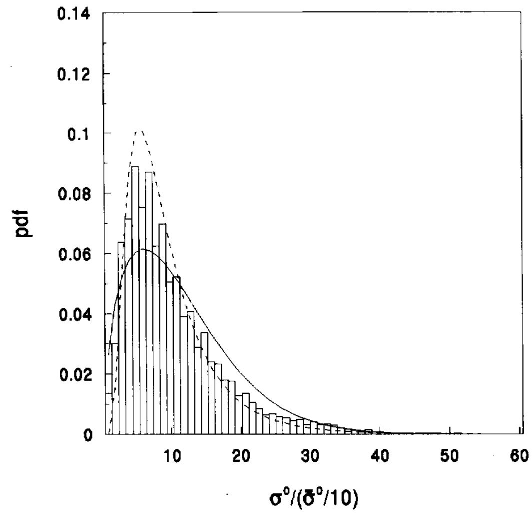

Fig. 5. Plot of Weibull and lognormal fit for a grazing angle of 15° for sea with estimated parameters on the histogram of the data. X-axis is σ^o normalized with $\bar{\sigma^o}/10$. — Weibull fit. - - - lognormal fit.

TABLE II
DISTRIBUTION PARAMETERS FOR SEA

Grazing Angle	PDF	Parameter	PPP Technique	MLE Technique
15°	Lognormal	Std-dev	0.6359	0.77
		Mean	-7.39	-7.37
		RMSE/D_n	0.1866	0.031
	Weibull	Shape	1.475	1.454
		Scale	3.7e-5	3.8e-5
		RMSE/D_n	0.1994	0.089

4° to 6° depicts the transition from a long tailed non-Rayleigh distribution to a near Rayleigh distribution.

Sea: Due to the calm sea state that prevailed during the measurements, the reflectivity from the sea was low and hence valid data has been obtained only in the grazing region of 11° to 20°. The histogram of sea clutter data has been plotted in Fig. 5 for a grazing angle of 15°. The lognormal density function fits the data better for this grazing angle for the case of sea clutter. This has been found true for all the grazing angles as the sea clutter distribution in general exhibits a long tail distribution. The values of the distribution parameters for a grazing angle of 15° for sea is given in Table II.

B. Variation of Distribution Parameters with Grazing Angle

The experimental setup and the chosen measurement scheme enabled us to collect data from various grazing angles for farmland and sea. The nature of variation of the distribution parameters with grazing angle is of interest for characterization of clutter fluctuation statistics.

Farmland Terrain: The curves in Figs. 6 and 7 show the variation of the Weibull shape parameter and the lognormal standard deviation parameter with grazing angle respectively for farmland (Kolar) clutter.

A third order polynomial fit of the following form has been made on these curves to characterize the nature of variations.

$$k = a_0 + a_1\theta + a_2\theta^2 + a_3\theta^3 \qquad (14)$$

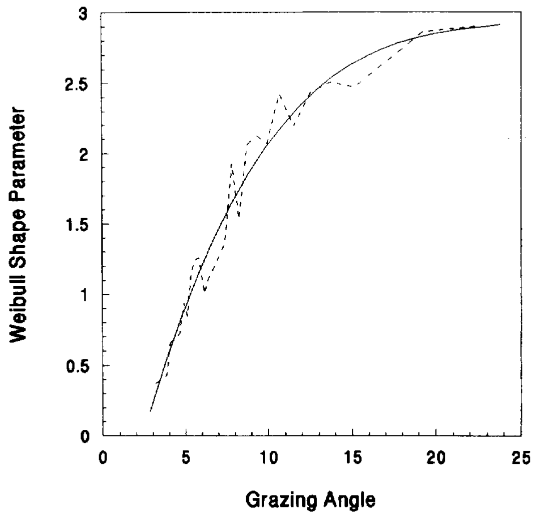

Fig. 6. Plot of variation of Weibull shape parameter values with grazing angle for farmland. - - - Estimated values. — Third order polynomial fit to the curve.

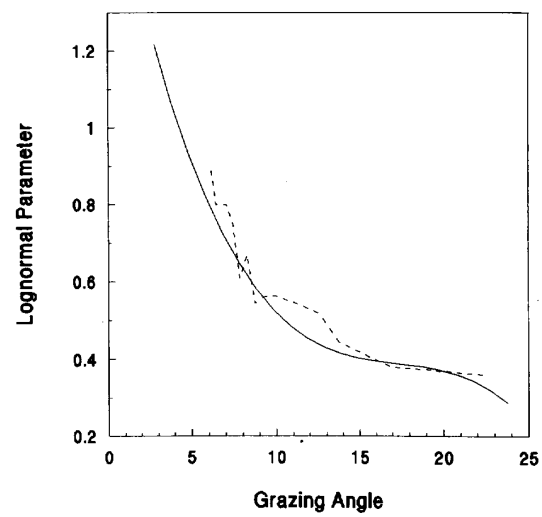

Fig. 7. Plot of variation of lognormal standard-deviation parameter values with grazing angle for farmland. - - - Estimated values. — Third order polynomial fit to the curve.

where, θ is the grazing angle, k is the shape parameter or the lognormal standard-deviation parameter and a_0,a_1,a_2 and a_3 are constants.

The Fig. 6 shows that the shape parameter value increases from 6° to 17° and then attains a constant value.

The fact that the shape parameter decreases with decreasing grazing angle could be due to the following reasons [5]:

(a) the undulating terrain seems to the radar as rougher with decreasing grazing angle.

(b) the lowlands are shadowed (masked) by the highlands, therefore the tail of the distribution curve becomes larger, which can be fitted by a Weibull distribution function with lower shape parameter value.

These observations also agree with the results obtained from the measurements made during sortie-II which establishes the repeatability of the clutter measurement scheme.

The data from sortie-III were analyzed for the grazing angle from 2.8° to 4.6°. For these grazing angles, the Weibull shape parameter decreases further and reaches a value of 0.34 at 2.86°. The measurements have shown consistency in the nature of variation of the shape parameter with grazing angles for different sets of measurements.

The lognormal standard deviation parameter value decreases from a value of 1.7 at a grazing angle of 2.8° to 0.4 at 15° and then attains a constant value for farmland terrain clutter. The nature of the variations in this case has been observed to exhibit this trend for the various sets of measured data collected from farmland (Kolar) terrain during the various sorties conducted over different days.

Sea: The nature of variation of the distribution parameters with grazing angle for sea clutter data has been plotted in Figs. 8 and 9 for Weibull shape parameter and the lognormal standard-deviation parameter respectively along with the third order polynomial fit of the form (14).

The Fig. 8 shows that the shape parameter attains a value of 1.5 at 20° which is lower than the value of 3.0 attained

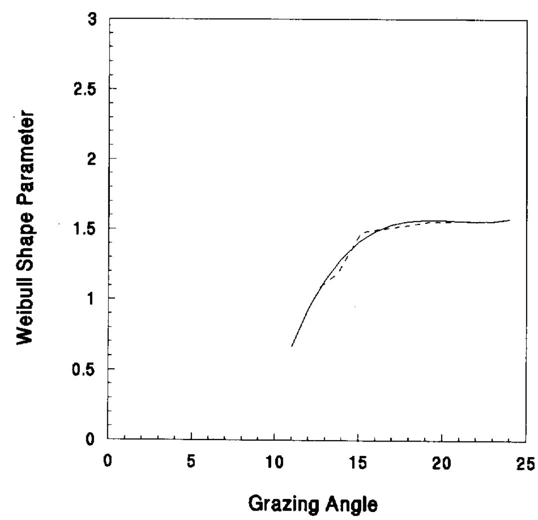

Fig. 8. Plot of variation of Weibull shape parameter values with grazing angle for sea. - - - Estimated values. — Third order polynomial fit to the curve.

by the land clutter. It can be concluded from the graph that the variation in the nature of fluctuation, with grazing angle, is comparatively lower for sea data than the land clutter. This is due to the calm sea state that prevailed during the measurements. As is shown, had the sea been at a higher sea state, the model parameters (a_0, a_1, a_2, a_3) would tend to be approaching that of land.

In Table III, the values of the constants a_0,a_1, a_2 and a_3 (14) have been compared for farmland type of terrain and sea for Weibull and lognormal distributions.

VI. Conclusions

The first clutter measurements carried out from an airborne platform over India have been analyzed to characterize

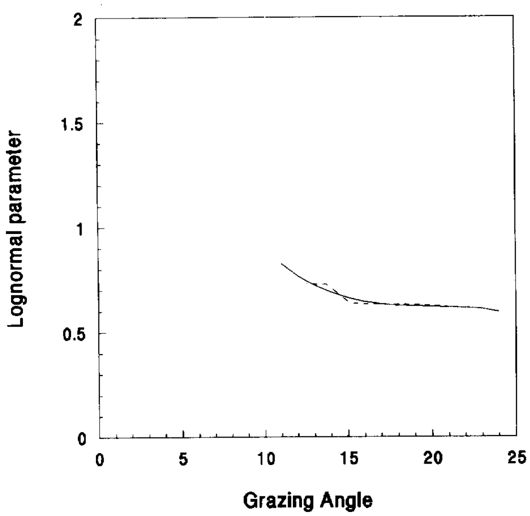

Fig. 9. Plot of variation of lognormal standard-deviation parameter values with grazing angle for sea. - - - Estimated values. — Third order polynomial fit to the curve.

TABLE III
VALUES OF THE CONSTANTS

	Farmland		Sea	
	shape	std-dev	shape	std-dev
a_0	-1.03662	1.76373	-7.65817	2.71358
a_1	0.48648	-0.22923	1.35088	-0.30935
a_2	-0.02061	0.01299	-0.06564	0.01533
a_3	0.0003	-0.00025	0.00106	-0.00026

the variability in the values of backscatter coefficient. This variability has been quantified using Weibull and lognormal distributions.

It is seen that the land clutter can be modeled using a lognormal distribution for low grazing angles <6° and Weibull distribution for higher grazing angles. The repeatability of the measurements have also been established through the analysis of the data collected from the same terrain during different sorties. The value of the Weibull shape parameter increases with grazing angle and reaches a value of approximately 2.8 for grazing angle of 22° for the land. The lognormal distribution model fits the sea clutter better for the grazing angles of 12° to 20°.

The nature of variation of the distribution parameters with the grazing angle has been modeled by a third order polynomial fit for farmland and sea clutter and has been presented.

The angles at which the RMSE values are high, attempts must be made to model the clutter distribution using a combination of more than one distribution.

The distribution parameter values have been obtained using two different techniques and the values are found to be in close agreement with each other.

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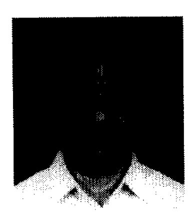

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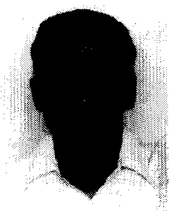

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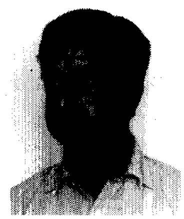

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