Comparison Of A Trans-Horizon Littoral Clutter Model With Shipboard Radar Data

George LeFurjah, NSWCDD, Dahlgren, VA
Donald de Forest Boyer, TSC, Dahlgren, VA
Terry Foreman Ph.D., NSWCDD, Dahlgren, VA

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SUMMARY & CONCLUSIONS

Standard radar clutter reflectivity models such as the GIT sea clutter model [1,2] and the Billingsley land clutter model [3,4] are based upon many measurements, in part to remove the effects of varying propagation environment, in order to predict radar reflectivity for standard propagation. It has been known for some time that radars on ships operating in regions near land are often subject to clutter amplitudes that vary significantly from these models, and this is due to anomalous propagation, or ducting [5,6]. This paper describes the Littoral Clutter Model (LCM) developed by Naval Surface Warfare Center Dahlgren Division and its validation against recorded radar data. LCM includes propagation modeling and is an extension of both the GIT sea clutter, and Billingsley land clutter models. The model compares favorably to measured land and sea clutter amplitudes in the presence of ducting.

1. *INTRODUCTION*

In order to accurately assess the performance of shipboard radar against low-flying cruise missiles, in a coastal environment, it is necessary to model the effects of electromagnetic wave propagation. Low grazing angle scatter from both the land and sea are subject to the effects of anomalous propagation. Electromagnetic energy, such as transmitted radar energy, becomes partially trapped when atmospheric boundary layers form with sufficient height and extent to create refractivity gradient reversals. These conditions are referred to as ducts.

Parabolic Wave Equation models or PWE-models, which solve the electromagnetic wave equation for propagation over any surface very efficiently, under quite general refractivity and boundary conditions, have been created and refined [7,8]. These models allow a radar analyst to include the effects of multipath and ducting, as well as diffraction and terrain shadowing, in the simulation of the radar return from targets and clutter over both land and sea.

A site-specific model of the backscatter from both land and sea for a ship-based radar in a littoral environment, in the presence of ducting, has been developed at the Naval Surface Warfare Center Dahlgren Division. The inputs to the model are: the geographic location of the sensor; the maximum range and angular width of the azimuth sector over which the radar is to transmit; the radar parameters, such as frequency, antenna height, and beam-width and elevation angles. In order to evaluate the effect of the atmosphere and the sea surface on both propagation and clutter, timely estimates of the atmospheric refractivity over the region, and the sea state are also needed. The principal output from the model is simulated clutter power versus range, along each azimuth in the sector, which may be plotted as the PPI display of a clutter map.

In order to simulate the diffraction and shadowing of a clutter patch over variable height, site-specific terrain, a PWE-Model is executed with terrain contours from Digital Terrain Elevation Data (DTED) files provided by National Imagery and Mapping Agency (NIMA). The PWE models compute the propagation factor $\mathbf{F}^4$, which allows the model to estimate land and sea clutter in the presence of surface based ducting, as well as subrefraction.

USGS provides a global land cover database, Advanced Very High Resolution Radiometer (AVHRR), with 24 terrain type classifications, and with a latitude and longitude worldwide reference. The terrain types are correlated with the DTED data, to associate appropriate electrical properties and surface roughness values with each patch of terrain. With the terrain heights, electrical properties, surface roughness, and atmospheric refractivity, as inputs, the PWE-Model is able to compute a propagation factor for each clutter patch along each propagation path.

In order to model backscatter from patches of terrain or ocean surface, it is usually necessary to employ an empirical clutter model, rather than a conceptual, or physics based clutter model. This is especially true in the case of low-angle radar clutter, where this model applies. The empirical models employed, provide distributed clutter amplitude statistics, in terms of Weibull means and spreads, to represent the normalized clutter reflectivity, σ^0. The radar cross section of a patch of surface clutter is computed as σ^0 times the propagation factor, multiplied by the area of the clutter cell. The Navy-Standard GIT model provides σ^0 for sea clutter, and the low-angle radar empirical land clutter model designed by

J. Barrie Billingsley at MIT Lincoln Labs provides σ^0 for land clutter.

The Billingsley land clutter model that was chosen for very low-angle radar land clutter is based upon extensive land clutter measurements conducted by MIT Lincoln Laboratories of a large range of terrain types over a range of depression angles and surface slopes, for both vertical and horizontal polarization, and over the band from VHF to X Band, approximately 200 MHz to 10 GHz.

It is commonly agreed that most land clutter backscatter comes from discrete objects within the radar resolution cell. Such objects, often called point clutter to distinguish them from reflectivity that is distributed more or less homogeneously throughout the cell, are sometimes modeled separately from the distributed component. Billingsley [3] argues convincingly that this approach is unnecessary, and furthermore not easily derived from the empirical database. A constant mean Weibull model with a spread parameter that varies as a function of cell size is all that is needed to account for this case, and others. Hence the Billingsley land clutter model is an empirically based fit of mean reflectivity based upon depression angle, surface slope, and terrain type, combined with a Weibull distributed amplitude whose spread parameter is a function of cell area.

2. *ANOMALOUS PROPAGATION IN A LITTORAL CLUTTER MODEL*

By the late 1980's, it was clear that in order to include rough surface effects, as well as range varying refractivity, in the range performance of shipboard radars, the Parabolic Wave Equation (PWE) approximation to the Helmholz equation, and its implementation using the Fast Fourier Transform, was the technique that showed the most promise. The atmospheric refractivity may vary with respect to range and height. The surface boundary may include roughness, and may be ocean, or variable height terrain of range varying composition.

There are two PWE models that in common use in the Navy Radar Community:

TEMPER (Tropospheric ElectroMagnetic Parabolic Equation Routine) was developed at the Johns Hopkins University Applied Physics Laboratory, primarily by G. Daniel Dockery and Dr. Michael Newkirk

APM (Advanced Propagation Model) was developed by Amalia Barrios at SPAWAR Systems Center, San Diego (SSC-SD).

The importance of ducting to low angle radar performance was underscored by extensive experiments conducted by NSWC in 1998 and 2000 [10], Microwave Propagation Measurement Experiments (MPME), that evaluated radar propagation path loss by direct measurement coupled with detailed meteorological measurements. These experiments provided significant confidence in the PWE models.

3. *TRANSHORIZON LAND AND SEA CLUTTER*

The depression angle used in Billingsley's low angle radar land clutter model is the angle below the radar at which a clutter patch is observed by the radar. See figures 1 and 2. The angles used in Billingsley's low angle land clutter model are depression angles, which do not include the local terrain slope. Many land clutter modelers, including Barton [9], have used the grazing angle, which Billingsley defines as the depression angle plus the terrain slope, in figures 1 and 2.

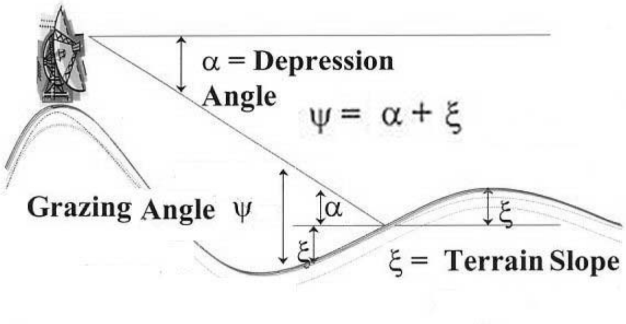

Figure 1 Billingsley Grazing Angle

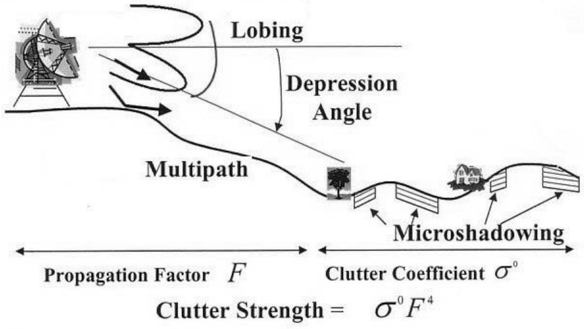

Figure 2 Billingsley Clutter Physics

Ducting causes significant clutter backscatter from well beyond the horizon. Figure 3 illustrates the simplest type of surface based duct. Along the horizontal axis refractivity in modified M-units are plotted, where:

$$\mathbf{M} = \left[(\mathbf{n} - \mathbf{1}) + \frac{\mathbf{z}}{\mathbf{a}} \right] \mathbf{x10^6} \tag{1}$$

n is the index of refraction, **z** the altitude and **a** the radius of the earth. If the slope of the **M** function is negative over a portion of the axis, a trapping layer exists.

The parameters that determine how much of a radar beam's vertical beam width is trapped in a duct, are the duct height, **dh**, and the **M**-deficit across the duct, **ΔM** (see Figure 3). The height of the trapping layer and the trapping angle are given, respectively, by

$$\text{dhcrit} = \left(\frac{1572}{\text{fGHz}}\right)^{\frac{1}{1.8}} \textit{meters, and } \theta_c = \sqrt{2\Delta M} \qquad (2)$$

Clearly, it is only those depression angles smaller than the critical angle illustrated in Figure 4 that will return to the radar as backscatter.

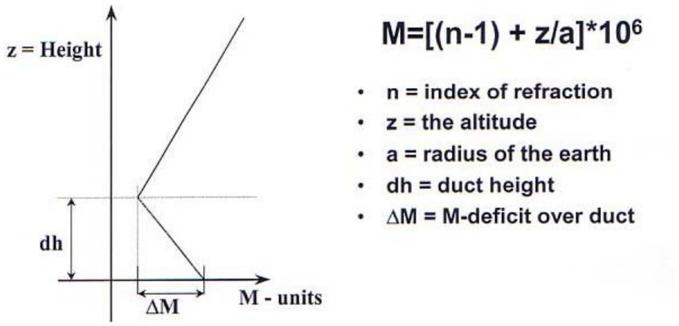

Figure 3 - Simple Surface Based Duct

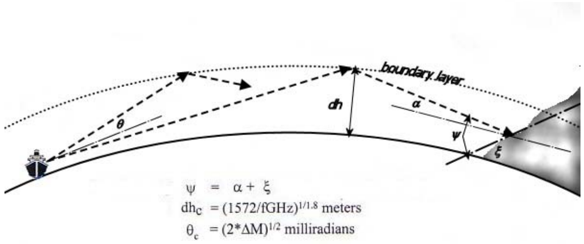

Figure 4 Transhorizon Clutter Physics

4. *MATLAB IMPLEMENTATION OF THE MODEL*

The first action taken by the model is to generate a terrain map of the simulated region. The map is created using the user supplied maximum range, range step, azimuth sector, and azimuth spacing. The terrain map is extracted from NIMA's DTED map data using the MATLAB mapping toolbox.

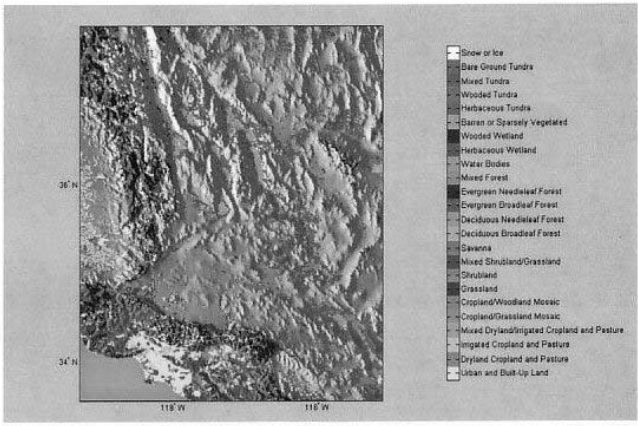

Figure 5. USGS Land Use map combined with DTED terrain heights of Southern California.

The terrain types are generated by extracting terrain types from the USGS AVHRR Land Use database. Figure 5 shows a converted terrain map combined with the DTED terrain.

The matrix of AVHRR terrain types have to be converted into the terrain types for which Billingsley has specified normalized clutter reflectivity (see Figure 6). The Billingsley terrain types consist of Water, Agricultural, Forest, Desert, Shrub lands, Grassland, Wetland, Mountain, and Urban. Agricultural, Forest, Desert, Shrub lands, and Grassland all have both high and low relief determined by their terrain slope.

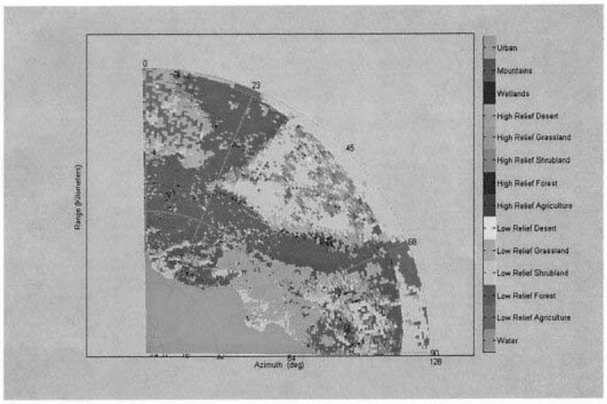

Figure 6. Map of terrain types of Southern California.

The propagation factors for the simulated region are generated by either TEMPER or APM. TEMPER and APM are coded in FORTRAN90, and in the simulation, they are executed in MATLAB as "mex-files". A PPI display of propagation factors is shown below in Figure 7.

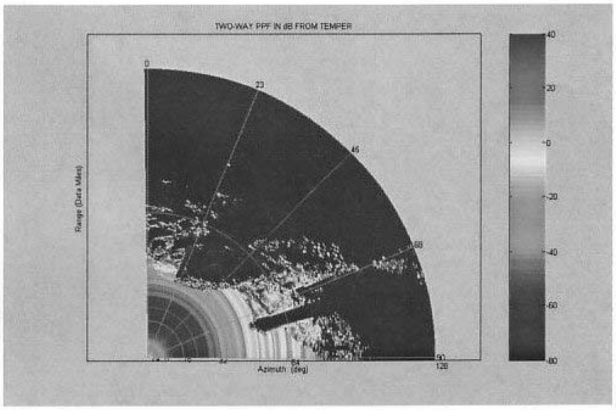

Figure 7. PPI display of the propagation factors generated using TEMPER for Southern California.

The model uses the radar range equation, as implemented in Equation 3, to calculate the clutter-to-noise values for each range bin.

$$C/N = \left(R_0/R\right)^4 D_0 A_c \sigma^0 F^4 \qquad (3)$$

Where: $\boldsymbol{F}$ is the propagation factor collected from the PE Model. $\boldsymbol{\sigma^0}$ is the normalized clutter reflectivity. $\boldsymbol{A_c}$ is the area covered by a given range bin, $\boldsymbol{R_0}$ is the minimum detectable range for a target with a radar cross section of 1 m^2 in the center of the beam, under free space propagation. $\boldsymbol{D_0}$ is the detectability threshold of the radar, and $\boldsymbol{R}$ is the radar range.

5. *MODEL VALIDATION*

LCM has been validated by comparison with data recorded using the US Navy's AN/SPY-1A radar off the coast of southern California. Simultaneously with the collection of wide dynamic range intermediate frequency radar data, atmospheric refractivity data were collected at a single location. By employing measured refractivity as an input to TEMPER realistic ducting propagation factors were computed within LCM. As an example, the results of this comparison for a single data file collected off Los Angeles are demonstrated through Figures 8 through 10. Figure 8 illustrates a direct PPI comparison of model and data. Figure 9 summarizes statistical comparisons of model and data for the entire range-angle space of the model. The Inverse Distributions show a credible similarity, and the model accurately predicts maxima and the corresponding positions of those maxima. Earlier models have under predicted CNR maxima consistently. Figure 10 shows Inverse Distributions for subsets in azimuth. Note that the model under predicts in some azimuths and over predicts in others to some extent. This is to be expected because the propagation is modeled as homogeneous in azimuth, due to limited refractivity data, and actual propagation inhomogeneities are known to exist in littoral regions. *The model accurately predicts the overall maximum CNR extent for this run, important in that earlier models have under-predicted CNR in similar scenarios.* This can be attributed to the use of the wide Weibull spread parameter for urban clutter, which results in large CNR values typical of large discretes in these environments. Furthermore, with hundreds of Weibull draws per kilometer there is an associated statistical stability of the maxima from model run to model run.

Figures 11 and 12 illustrate further direct comparisons of model results and data from this test, this time data that was collected on two different days off of Monterey. In both cases the model predictions pick up the terrain features well. However, the meteorological measurements predict less ducting than was clearly present. This is due to both the timing and location of those measurements. This data was collected off shore at times further separated from the radar data than that reflected in Figures 8-10. MPME [10] results clearly showed the dynamic, fast changing character of the propagation environment in offshore or littoral environments.

In general the model results are a credible prediction of CNR for this data set.

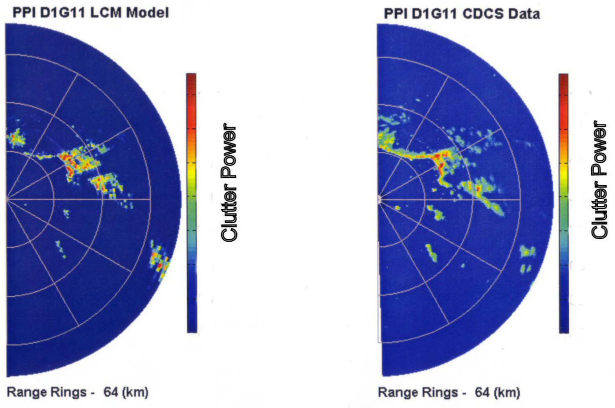

Figure 8 PPI Comparisons Los Angeles

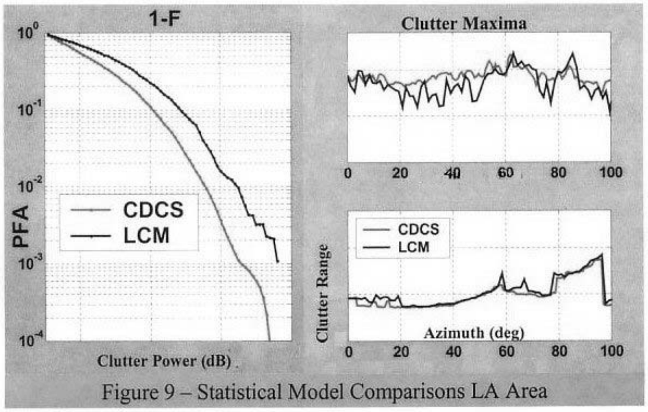

Figure 9 – Statistical Model Comparisons LA Area

Comparative Clutter Power Histograms

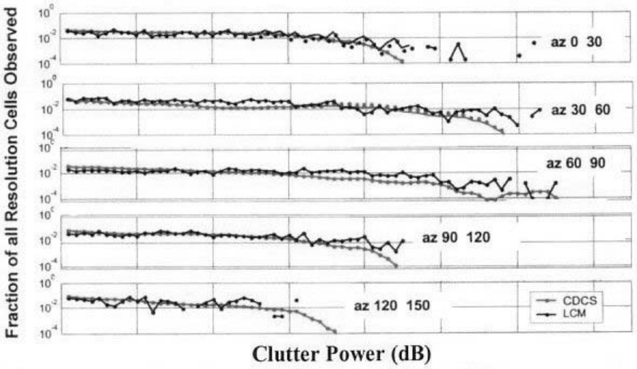

Figure 10 – Comparative Clutter Power Histograms

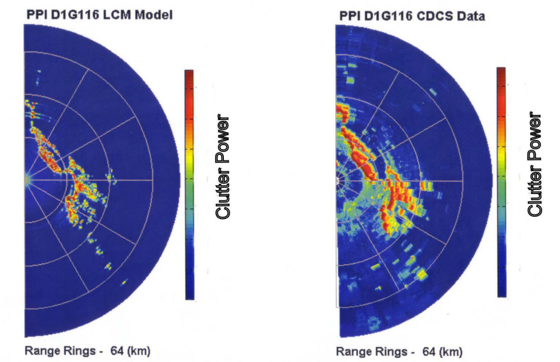

Figure 11 PPI Comparisons Monterey

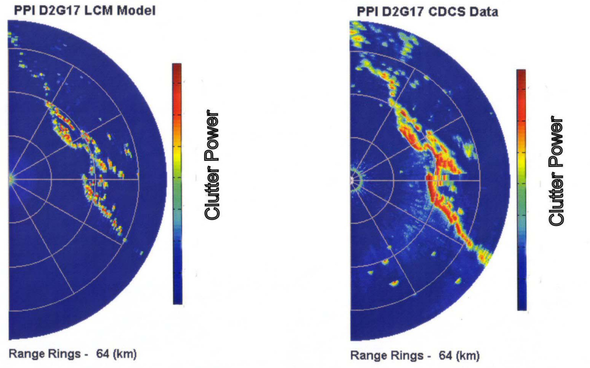

Figure 12 PPI Comparisons Monterey

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BIOGRAPHIES

George LeFurjah earned the B.S.E.E. (1968) and M.S.E.E (1975) from Rutgers University. He is currently employed by the Naval Surface Warfare Center Dahlgren Division. He has also worked for Technology Service Corporation in Silver Spring Md. His work experience includes all aspects of radar systems design, analysis, and testing, including over twenty years of experience with the AN/SPY-1 radar family. His primary contributions have been in the areas of radar signal processing, radar modeling, and radar phenomenological modeling. His current work includes radar clutter mitigation processing and radar clutter modeling.

Donald de Forest Boyer earned a BA (1958) and MA (1963) in mathematics from The George Washington University. From 1982 to July 2004 he was a scientist at the Naval Surface Warfare Center Dahlgren Division. He worked for seven years in the area of numerical methods in statistical estimation, and filtering for the Trident II Test Flight Analysis in the SLBM Systems Accuracy Branch. Prior to joining NSWC, he worked for two years with Sperry Univac Dahlgren, on contract to the Gun Fire Control Branch, where he developed a nonlinear numerical estimation technique for determining initial alignment parameters from the track of a projectile. Since 1990, Mr. Boyer has been involved with modeling of radar wave propagation and clutter. He developed the Littoral Clutter Model that has been used by NSWC and Technology Service Corporation. Since August of 2004, when he retired from NSWC, he has been a consultant at Technology Service Corporation. He is presently working on radar simulation, and nonlinear trajectory estimation problems.

Dr. Terry L. Foreman has a B.S.E.E from West Virginia Institute of Technology (1975), an M.E.E.E from University of Virginia (1992) and a Ph.D. in electrical engineering from the University of Virginia (2000). He has worked for EG&G and Syscon and is currently employed by the Naval Surface Warfare Center Dahlgren Division. His work experience includes radar system design/development, electromagnetic compatibility and combat system design. He was involved in the development and testing of the AN/SPY-1B/D and AN/SPY-1D (V) radars. His current research interests are in the areas of detection theory; clutter processing, clutter modeling and radar signal processing.