Spatial Aspects of Sea and Land Clutter from S, C, and X Band Radar Due to Non-Standard Radio Frequency Propagation During a Coastal Sea Breeze

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Abstract

Sea breeze circulations create a spatio-temporally heterogeneous radio frequency (RF) propagation environment that enhances land and sea clutter returns for ship borne radar. Clutter, so influenced by a heterogeneous refractivity field is difficult to model by a single refractivity profile. Mesoscale numerical weather prediction (NWP) is an improving technology that resolves sea breeze circulations with vertical profiles of refractivity every 3km in the area of illumination. This paper will describe the clutter to noise ratio maps at three wavelengths produced by driving a littoral clutter model (LCM) with three dimensional refractivity profiles provided by a mesoscale NWP model.

1. Introduction

It has long been recognized that sharp vertical gradients atmospheric thermodynamic variables impact the propagation of RF energy. Modified refractivity is most commonly employed by RF engineers to describe propagation because it includes a term that accounts for the curvature of the earth [1]. This relationship is given in (1) where M is modified refractivity, T is atmospheric temperature in degrees Kelvin, P is atmospheric pressure in millibars, e is water vapor pressure in millibars and z is the height above the surface in meters:

$$M = \left(\frac{77.6}{T}\right)\left(P + \frac{4810e}{T}\right) + 0.157z \tag{1}$$

The vertical gradient of M determines the propagation category and these are displayed in table 1.

Table 1. Propagation Categories

Behavior (dM/dz) m^{-1}	Range 1	Range 2
Standard	= 0.118	
Ducting	< 0.000	
Super-refractive	0.000	0.079
Normal	> 0.079	0.157
Sub-refractive	> 0.157	

The standard value of the vertical gradient of M of $0.118m^{-1}$ falls within the normal range, results in normal radar horizons, but is rare near the coast. Ducting, or the more demonstrative term trapping, results in RF energy reflecting over great distances between the top of the ducting layer and the surface with resulting folded land and sea clutter. Super-refraction causes the RF energy to follow the curvature of the earth and extends radar horizon. Sub-refraction rapidly propagates RF energy away from the surface, reduces radar horizon, and places strong ameliorating engineering demands on radar design.

2. Mesoscale Numerical Weather Prediction

Mesoscale numerical weather prediction (NWP) numerically and simultaneously solves prognostic equations based on Newton's second law of motion, the equation of state for an ideal gas, the first law of thermodynamics, conservation of mass, and conservation of moisture to model vertical profiles of pressure, temperature, water vapor,

winds and modified refractivity on a horizontal grid from the surface layer to the tropopause. Mesoscale refers to meteorological phenomena that range in size from a few kilometers to about 100 km. This includes local winds such as the sea breeze circulation that significantly alters the performance of littoral radars. Mesoscale models typically have a 1 to 10km horizontal resolution in order to resolve local meteorological patterns [2]. This is as if a vertical sounding of refractivity is taken every hour out to 48 hours at the horizontal resolution of the NWP model.

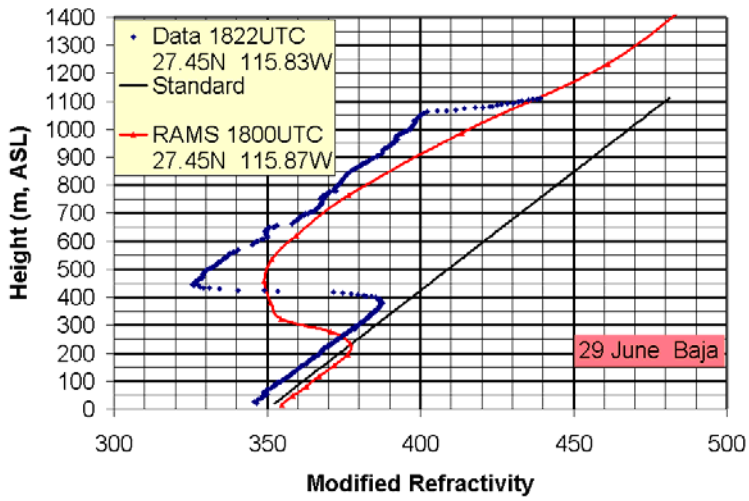

Figure 1: Modified Refractivity Comparison

The Regional Atmospheric Modeling System (RAMS) was used to model a sea breeze along the California Baja Sur in June of 2005 [3]. The horizontal grid spacing is 4km. Figure 1 is a vertical profile of modified refractivity for both a RAMS profile and a measured profile 40km off the coast. RAMS resolved the sea breeze circulation, but did not perfectly resolve the height and strength of the duct (dM/dz < 0.0). This is representative of the state of the art for mesoscale NWP as applied to refractivity fields.

A southwest to northeast cut was made through the RAMS refractivity field as shown in figure 2. This is along the mean wind direction of the sea breeze. Notional radars are placed at the X in figure 2 and modeled in the next section. Figure 3 is a series of modified refractivity profiles taken along this cut every 20km at the height of the sea breeze, 30 minutes after solar noon. The solid red curve indicates a strong duct at the ship. The solid green curve is 20km away towards land and indicates a slightly lower and stronger duct. 40km away, the solid blue curve indicates strong super-refraction. The solid gold and brown curves are over land, 60 and 80km from the radar respectively and indicate normal propagation. This is due to the sun heating the earth, producing convective turbulence, and mixing the thermodynamic gradients to near zero. The solid black curve is a reference for a standard atmosphere.

Figure 2. Location of Modeled Ship Borne Radars

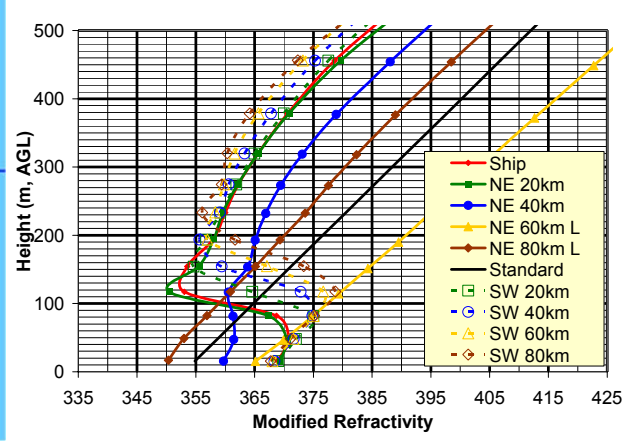

Figure 3. Modified Refractivity Profiles NE and SW of the Ship Location in Figure 2.

Southwest of the ship, the dashed lines indicate increased duct height and weakening ducts with range. RAMS has resolved the basic structure of the sea breeze circulation and demonstrated the heterogeneous nature of refractivity during local coastal circulations

3. Littoral Clutter Model

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. Littoral Clutter Model (LCM) is such a model [4]. The empirical models employed in LCM 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 supplied by the parabolic equation model, Tropospheric Electromagnetic Parabolic Equation Routine (TEMPER), [5] and mesoscale NWP, multiplied by the area of the clutter cell. The Navy-Standard Georgia Institute of Technology model provides σ^0 for sea clutter. The low-angle radar empirical land clutter model, designed by J. Barrie Billingsley at MIT, Lincoln Labs provides σ^0 for land clutter. LCM was employed to model the land and sea clutter for notional S, C and X band radars at the height of the sea breeze. The radars were designed to have equal probability of detection of a notional target in a free atmosphere thus allowing for wavelength dependent refractivity features to be observed. The radars were placed on a notional ship at the location indicated by the X in figure 2. RAMS provided the three dimensional refractivity field as well as the surface winds used to model wave height at each grid point.

The resulting modeled clutter to noise ratio in dB for the notional S-band radar is shown in figure 4. Notice the sea clutter out to 400km in the northwest quadrant. This is in contrast to the same modeled radar clutter in a standard atmosphere displayed in figure 5 where the clutter is mainly due to the topography along the peninsula and exposed mainland to the southeast. Due to the ducting and super-refraction towards shore, the peninsula is well illuminated during the sea breeze.

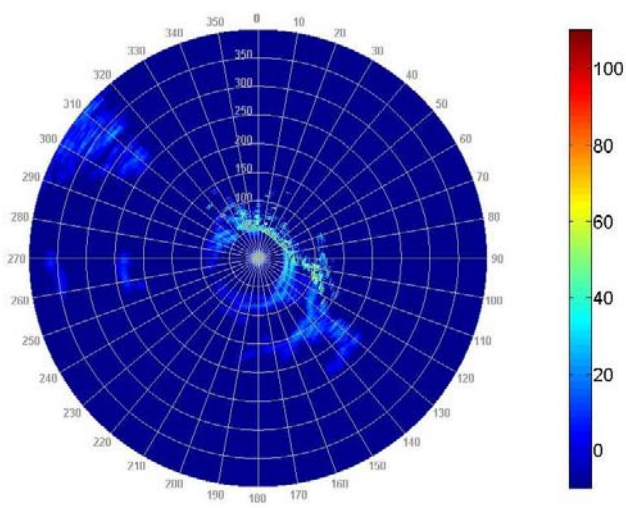

Figure 4. Modeled S-band CNR During the Sea Breeze

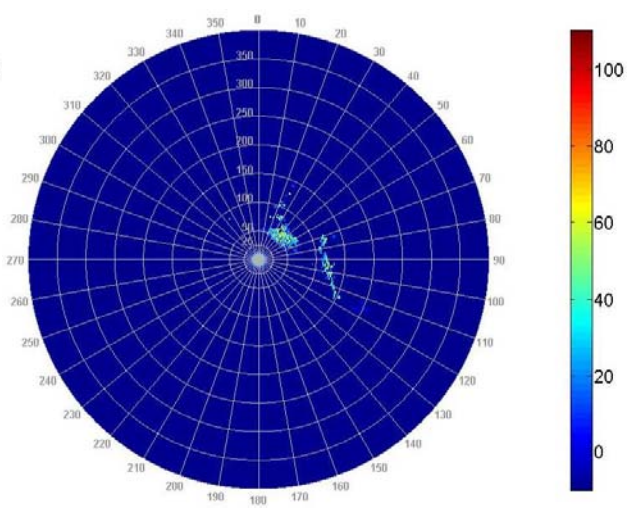

Figure 5. Modeled S-band CNR in a Standard Atmosphere

The same RAMS data were employed to drive LCM with notional C-band and X-band radars in figures 6 and 7 respectively. The planar images are similar to that of the S-band, however, the smaller scale wavelength differences are observable. In general, the spatial distribution of the clutter is similar at all wavelengths and the clutter to noise ratio increases with frequency.

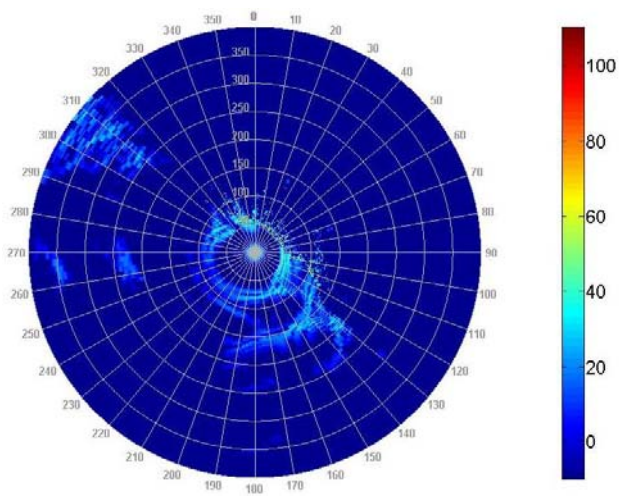

Figure 6. Modeled C-band CNR During the Sea Breeze

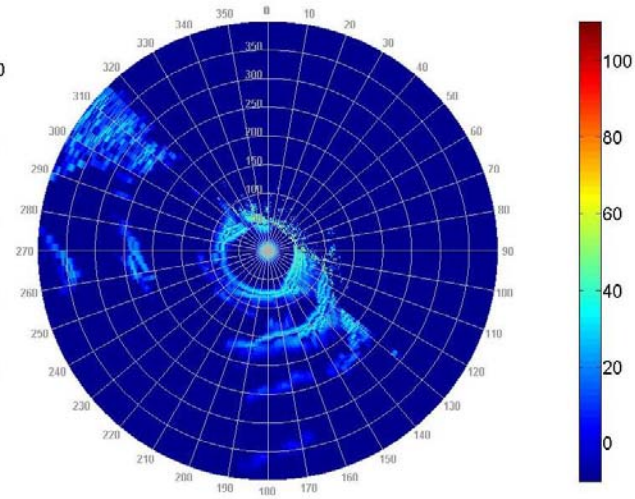

Figure 7. Modeled X-band CNR During the Sea Breeze

The reason for employing a three dimensional refractivity grid to drive LCM is supported by the image in figure 8 that is the result of driving LCM at S-band with the single RAMS refractivity profile at the ship. The assumption that the strong duct in red in figure 3 is homogeneous throughout the area of illumination, leads to the prediction of non physical concentric clutter rings.

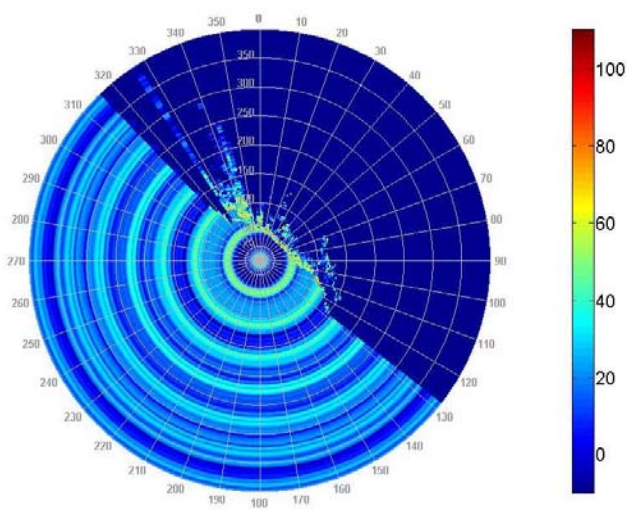

Figure 8. Modeled S-band with single profile

4. Conclusions

It has been shown that mesoscale NWP can capture the three dimensional essence of the refractivity field that develops during a sea breeze. Sea breezes result in heterogeneous sea and land clutter for ship borne radar. CNR appears to increase with frequency. The use of a single refractivity profile at the ship results in non realistic clutter rings.

5. References

1. Bean, B. R. and E. J. Dutton, 1966, *Radio Meteorology*, National Bureau of Standards Monograph 92

2. Pielke, R. A., Sr., *Mesoscale Meteorological Modeling*, Academic Press, 2002

3. Saleeby, S.M., W.Y.Y. Cheng, and W.R. Cotton, "New developments in the regional atmospheric modeling system suitable for simulations of snowpack augmentation over complex terrain", Journal of Weather Modification, 39, 37-49, 2007

4. LeFurjah, G.. R. E. Marshall, T. S. Casey, T. Haack, D. Boyer, "Clutter Forcast-A Symthesis of Mesocale Numerical Weather Prediction and Empirical Site Specific Radar Clutter Model", IEEE Radar Conference, Boston, MA, 2007