17A.5 A RADAR CHARACTERIZATION OF THE TRADEWIND BOUNDARY LAYER

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1. INTRODUCTION

The Rain In Cumulus over the Ocean (RICO) experiment took place from November 24, 2004 to January 24, 2005. Operations for the experiment were based off the islands of Antigua and Barbuda in the Caribbean Sea. RICO was designed to sample the pristine trade wind environment across a wide range of scales. One major component of RICO was NCAR's SPOLka radar which was located on the island of Barbuda during the campaign.

Longer wavelength radars such as the 10 cm radars have the benefit of being able to resolve echoes from a clear sky through Bragg scattering. In order to achieve Bragg scattering, there must be turbulent mixing of air with different refractive indices at scales on the order of half the wavelength of the radar. Water – whether in vapor or liquid form – is the most significant factor in determining air's index of refraction (n). This is especially true in the RICO environment which consists of the tropical marine boundary layer below and a dry air source above the tradewind inversion. Another controlling parameter on n is temperature, although it is less significant than moisture (e.g., Doviak and Zrnić, 1984).

Although the RICO radar scanning strategy was designed to sample clouds, layers of Bragg scattering were commonly observed. At upper levels, these layers showed up as rings in most of the radar fields when the radar was scanning in PPI mode (e.g., see Fig. 1.). The Bragg scattering layers were separated by areas of "no-echo" in the radar reflectivity field. For this investigation, we found the average vertical location of these layers and tracked them as a function of time. We chose to carry this analysis out on spectral width (SW).

2. ANALYSIS TECHNIQUE

In order to determine the vertical location of the layers, we employed wavelet analysis using the Haar function as our base function. The Haar base function is a simple step function given by

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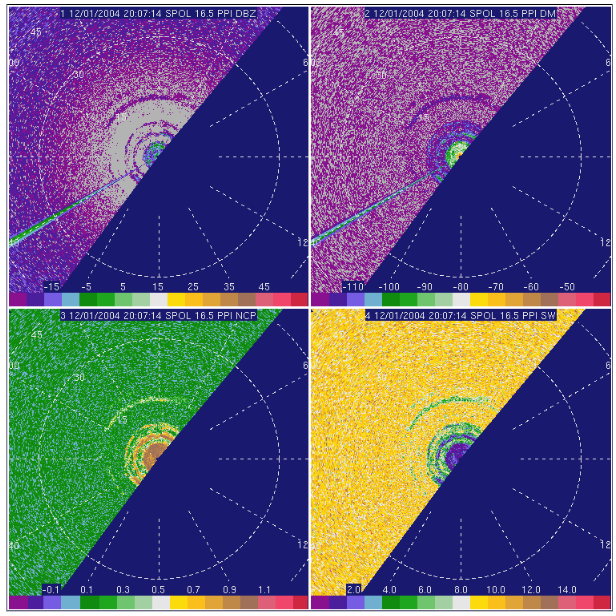


Fig. 1. Clear air echoes of 10cm radar data for the same scan are shown for 4 different variables (DBZ – upper left, DM – upper right, NCP – lower left, and SW – lower right). Layers of Bragg scattering show up as rings separated by regions of "no-echo."

$$h\left(\frac{t-b}{a}\right)=\begin{cases}1, & b-\frac{a}{2}\le t\le b\\ -1, & b\le t\le b+\frac{a}{2}\\ 0, & elsewhere,\end{cases}$$

where t represents the original data points, b is the translation term, and a is the dilation term. When the Haar function is used for wavelet analysis, the resulting details are proportional to the slope of the original data. Because of this, elementary calculus relationships such as the first and second derivative tests can be applied to the results. Namely, maxima and minima in the analysis results are located at the inflection points in the original data. Physically, the inflection points are located at the ring edges.

For one elevation angle and a single PPI scan, wavelet analysis was carried out along each beam. The results for all the beams in the scan were then averaged together. Thresholds were determined for noise, and maxima and minima were found whenever the average results exceeded the threshold range. The location of the maxima and minima (i.e., the average heights of

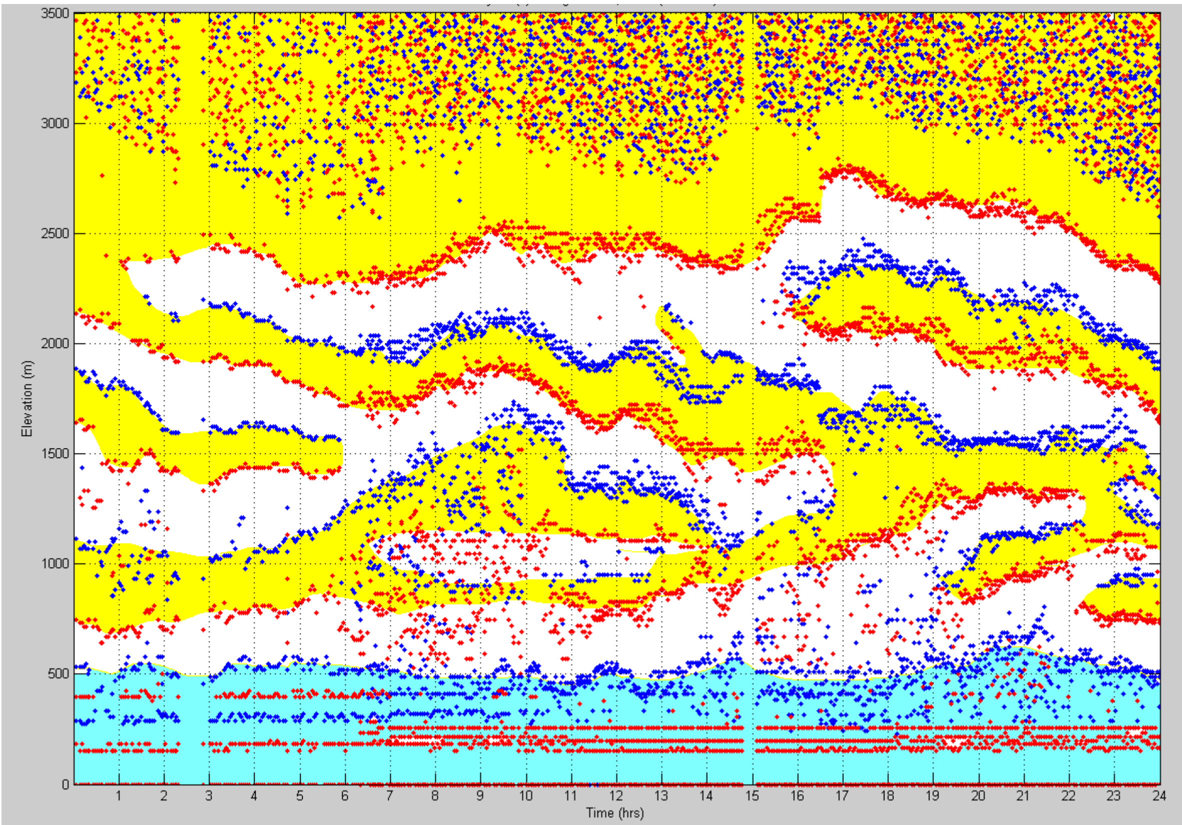


Fig. 2. A time height diagram of the layered structure of the atmosphere for Dec 5, 2004. Time shown is in UTC, with local noon at 16 UTC. Red (blue) dots correspond to boundaries with Bragg Scattering regions below (above) and "no-echo" regions above (below). Shading was done by hand for ease of interpretation. Yellow (white) shading corresponds to "no-echo" (Bragg scattering) regions. The blue shading along the bottom of the figure indicates the extent of the mixed layer. Intermittent dots are most likely due to remaining cloud contamination. This figure is a composite of the results from the 5.8°, 7.5°, and 9.8° elevation angles. (Layer results from 0-6 UTC are the results of 5.8° only, since there were no 7.5° or 9.8° scans done during this time period.) The top-most line formed by red dots represents the height of the tropical inversion.

the layers' boundaries) were then plotted as a function of time (see Fig. 2.). This analysis was carried out separately for all PPI scans whose elevation angle exceeded 4.5°.

Prior to analysis, range gates with dBZ values greater than ten were filtered out. The reason for filtering was to remove the majority of clouds which occur independently from the layer structure. Since detrainment of cloudy air was often seen to enhance existing Bragg scattering layer structure, we chose not to remove clouds from the analysis all together.

3. INTERPRETATION OF RESULTS

The results from different elevation angles can be combined as is shown in Figure 2. There are several advantages to combining elevation angles. Good co-location of the layers is an indication that genuine layers are being detected. The compactness of each layer boundary indicates how homogenous and uniform the layer is within the radar domain. Spread in a layer's location can result from non-uniform thickness, layer slant, or uneven distribution of the layer across the radar domain. Since the radar did not always scan at the same angles, gaps where there were no results from one elevation angle can be filled in by the results from another elevation angle. There are disadvantages to composites as well. Results with heavy cloud contamination at one elevation angle can mask genuine layers which are detected at another elevation angle. In addition, due to the geometry of the radar measurements, layers at higher elevations cannot always be detected by the lower elevation angles.

4. COMPARISON WITH SOUNDINGS

In order to more fully understand the physical meaning of the layer diagrams, comparisons were made with soundings taken at the same time. The soundings were launched from the island of Barbuda. Three examples from the same day are shown in Figure 3 (b)-(d). These three soundings represent the range of quality found throughout all such comparisons for the entire RICO data set. Overall, the general trend was for relative humidity (RH) minima in the soundings to correspond to red dots (upper limits of Bragg scattering regions) while RH maxima in the soundings correspond with blue dots (lower limit of Bragg scattering regions). This can easily be seen with the third sounding comparison. The multi-layer structure in the RH profile is clearly detected by the layer analysis. While the lowest moist/dry layer couplet is not seen in the radar layer excerpt on the sounding figure comparison itself, it is resolved at times just prior to the sounding on the day-long layer composite image show in Figure 3 (a).

5. DISCUSSION

The implications of the link between RH maxima and minima and layer boundaries are primarily two-fold. The first implication is that the behavior of RH profile in the atmosphere between RICO soundings can be tracked whenever there is radar data at appropriate elevation angles available. In other words, good estimates of the average inversion height and mixed layer height will be available at much higher temporal resolution – not just at sounding times. In addition, growth and subsidence of layers can be tracked, providing a much more descriptive and complete environmental characterization in which to address research questions surrounding individual RICO case studies.

The second implication is in reference to how

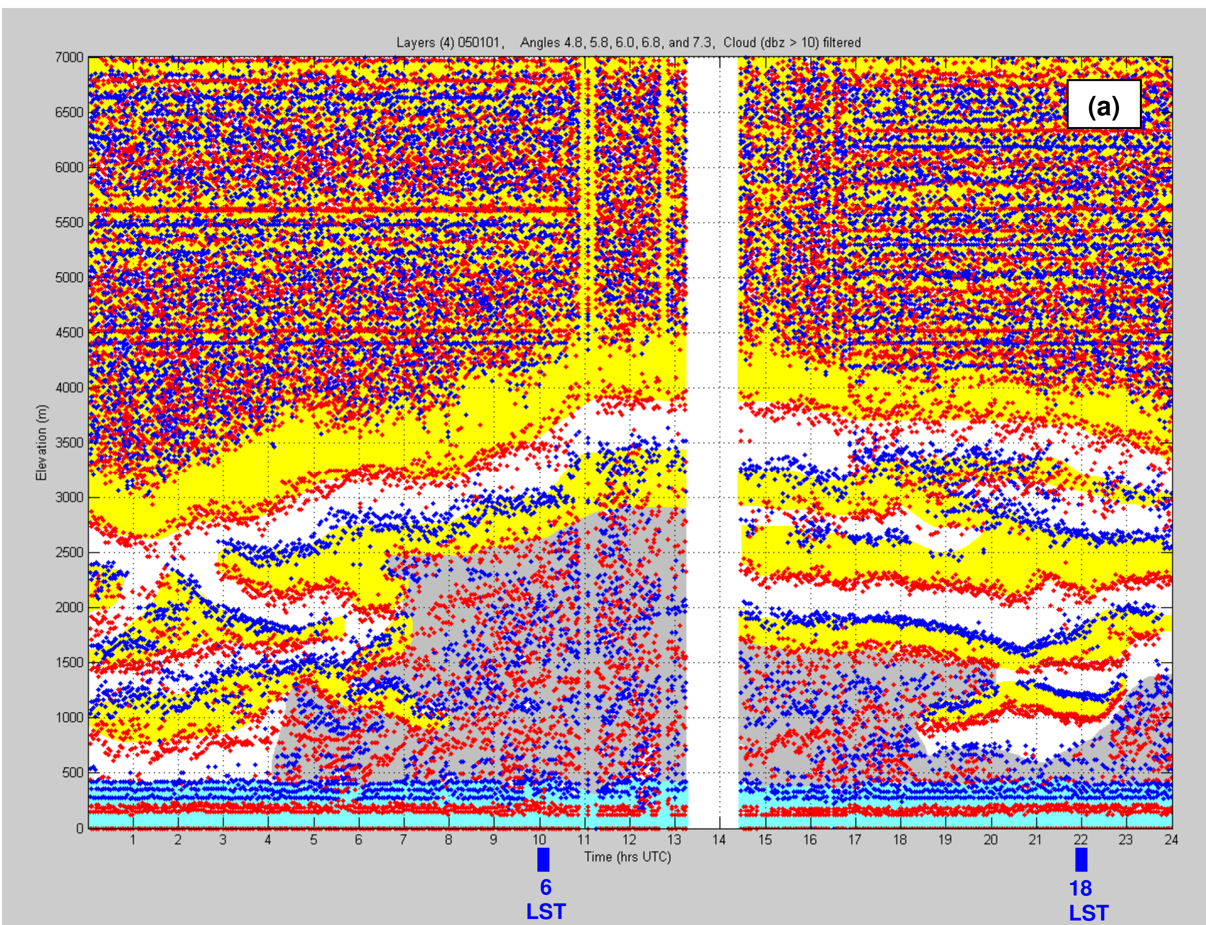
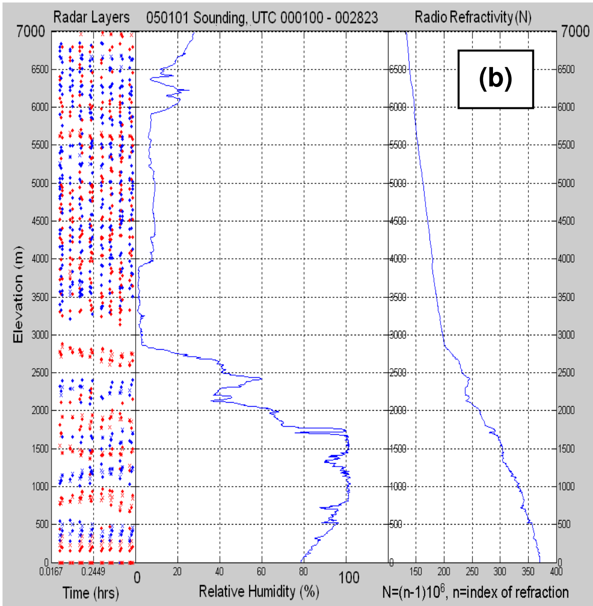
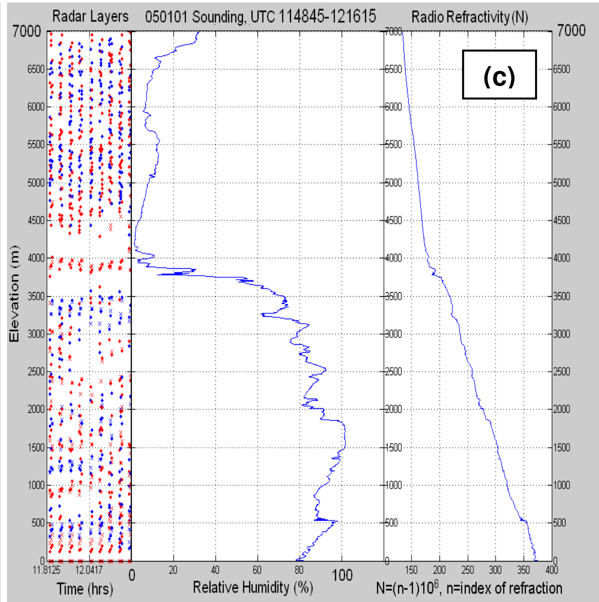
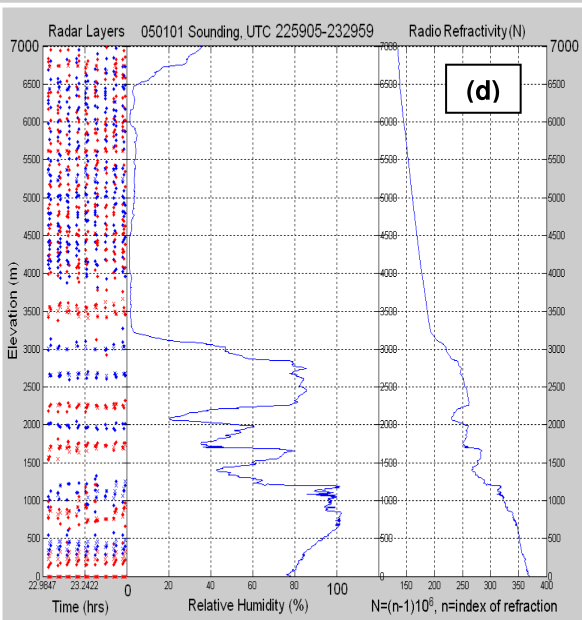


Fig. 3. (a) Layer analysis results from Jan 1, 2005. (b)–(d) Excerpts of radar layer results for the times between when sounding was launched and 7000 m elevation are shown in the left most profiles. RH values, as measured by the soundings, are in the center profiles. The radio refractivity (N) calculated based upon the soundings is shown in the right most profiles.







the air observed was being turbulently mixed. Humidity gradients exist on both sides of RH maxima and minima. The apparent link between these maxima and minima and the Bragg scattering layer edges implies that turbulent mixing of these gradients only occurs when there is a dry layer over a moist layer – not when there is a moist layer over a dry layer.

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References

Doviak, R. J. and D. S. Zrnić, 1984: *Doppler Radar and Weather Observations.* Academic Press, 458 pp.