

# Puerto Rico Deployable Radar Network Design; Site Survey

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***Abstract*** -- The Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts and the Cloud Microwave Measurements of Atmospheric Events (CLiMMATE) Laboratory at the University of Puerto Rico at Mayagüez are collaborating to modify a MK2 marine radar donated by Raytheon for use as meteorological radar nodes in a proposed weather radar network. This will be the first network to measure lower atmospheric phenomena in Puerto Rico. The radar consists of an antenna, a rotator, and a transceiver that will be placed at top of a tower or building, along with a data processing system. This paper derives two important equations describing the curved earth effect on beam propagation for radar range calculation. It also describes the method used to survey the MIRSL Tilson Farm field site, and the eleven campuses of the University of Puerto Rico backbone and justifies their fixed offset antennas' elevation angle and location.

## I. INTRODUCTION

The purpose of this study is to develop methodology for conducting site surveys to deploy low cost, high resolution weather radars to measure lower atmospheric phenomena in Puerto Rico. The proposed network will serve as a complement to currently used NEXRAD (next generation weather radar). NetRad will overcome the curved earth problem and obtain enhanced spatial resolution.

The radar beamwidth spreads with distance causing a degradation of the spatial resolution. For the case of NEXRAD it has a maximum range of 200 km which results in a spatial resolution of 3.3 km with a beamwidth of 1 degree [2]. For the

proposed network, radars nodes will have a maximum horizontal range between 20 to 30 km (0.5 km spatial resolution) to fix the problem of spatial resolution and lack of visibility of atmospheric phenomena at the lower atmosphere that NEXRAD presents. In addition, the radars will be observing the lower troposphere with a dual polarization measurement capability.

The Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts and the University of Puerto Rico are collaborating to modify a commercially manufactured Raytheon marine single polarization radar to have dual polarization (polarimetric) and Doppler capability allowing them to function as meteorological radar nodes. In polarimetric radars, the polarization is switched sequentially between linear vertical and linear horizontal, which provides several advantages in precipitation measurements over conventional single polarization radars [1]. Dual polarization radars can discriminate between hail and rain, detect mixed phase precipitation and estimate more accurately the rainfall rate [2].

However, before the radars are installed a study of the site and the earth propagation problem must be conducted in order to decide the height of the radar tower and the inclination angle that the antenna must have, in order for the beam to point above clutter from trees and buildings. For the survey the eleven campuses of the University of Puerto Rico were chosen due to accessibility since University network can be used to manage data, electric power exists, easier maintenance, among other advantages.

Mathematical relationships to describe the curved earth problem and analysis of survey data from the eleven campuses of the University of Puerto Rico field site will be discussed.

## II. CURVED EARTH EFFECT

The earth's curvature impedes that the lower boundary layer can be observed at far distances from the radar [3]. Most of the atmospheric phenomena occur at the boundary layer in the lower atmosphere. Radars have a tilted beam which increases in height as distance increases, missing important information of atmospheric events. To explain that problem a sketch was created with all the wave propagation, distance parameters, and earth curvature effects (Fig 1).

In the diagram **h1** is the perpendicular distance from the earth to the radar horizontal range, and **h2** is the distance (aligned with the Earth's radius **D/2** and with **h1**) between **R** and radar beam and **D** is the Earth's diameter (12756.272 km). Parameters **h1** and **h2** were derived working with the geometry of the problem and we obtained,

$$h1 = \frac{\sqrt{4R + (2H + D)^2} - D}{2} \quad (1)$$

$$h2 = \frac{R \sin(\theta) \sqrt{4R^2 + (D + 2H)^2}}{(D + 2H) \cos(\theta) - 2R \sin(\theta)} \quad (2)$$

It is easy to observe from the equations that both depend on the antenna height **H**, the earth's diameter **D** and the radar range distance **R**. We can also notice that **h2** depends on  $\theta$ . The **h1** equation does not depend on  $\theta$  because it does not take the antenna tilt angle into consideration.

Figure 1. Curved earth problem for weather radar

## III. SURVEY MATERIALS AND PROCEDURE

In each campus, the location of the radar was selected on the tallest building in order to get an obstruction free view angle.

To determine the height and fixed elevation offset of the antenna we measured the minimum elevation angle over a full 360 degree azimuth swath (in 5 degree increments from North to West) using a distance range meter telescope, a digital level, and a compass. The geographic coordinates were obtained using a Global Positioning System (GPS).

## IV. PRELIMINARY RESULTS AND DISCUSSION

Figure 2 depicts a plot of minimum obstruction angle vs. azimuth angle with its respective 360 degree swath panorama. One was made for each of the eleven campuses. It can be noticed from the plot that some minimum angles are required to surpass the obstructions. In the Puerto Rico case the far hills establish the minimum antenna vertical angle for each campus.

The radar range can be obtained for each campus by plotting the sum of equations 1 and 2 with respect to horizontal distance (Fig. 3). The plot has two curves with the one in solid having no antenna height and tilted and the dashed one with antenna height over sea level and the same tilt angle ( $\theta$ ). Looking at this plot you can determine at what height from the earth the radar beam will be at a specific distance or range point from the antenna. It can also be observed that the two curves behave like one curve after a significant distance.

The point where the height of the radar beam is at 4 km was marked on the plot to identify the height where the ice layer starts and consequentially establishing the maximum range distance.

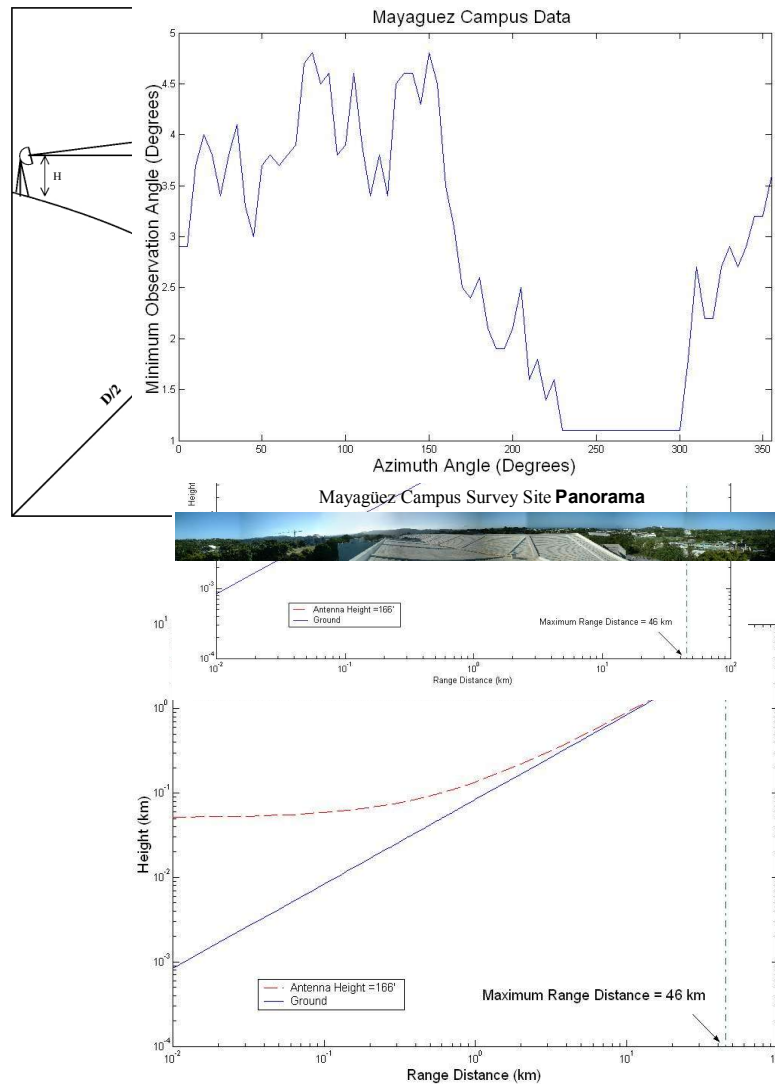


Figure 3. Combined effect of curved earth and tilted beam (Mayagüez Campus)

As a preliminary result, Table 1 summarizes the data of the eleven campuses. It shows the antenna minimum vertical angle, height, and the maximum radar range distance. A map of Puerto Rico with the eleven campus sites is also shown in Fig. 4. The red points (Cayey, Carolina, Utuado) mean that a radar in that point will be not feasible because of the high antenna tilt angle required to surpass the obstacles, while Bayamón and Medical Sciences campuses are in red because Rio Piedras Campus will cover the area and they will cause unnecessary overlapping. The circles have a radius of the maximum range shown in the Table 1.

TABLE 1  
SURVEY RESULTS

Site	Minimum Vertical Angle (Degrees)	Antenna Height Over Sea Level (Feet)	Maximum Radar Range (Km)
Aguadilla	4	171	52
Arecibo	5	71	44
Bayamón	5	282	44
Carolina	14.1	177	19.5
Cayey	16	230	13.5
Humacao	6	219	37
Mayagüez	4.8	238	46
Medical Sciences	3.5	1384	60.5
Ponce	5.2	643	42
Rio Piedras	3.3	295	62
Utuado	11.3	207	19.5

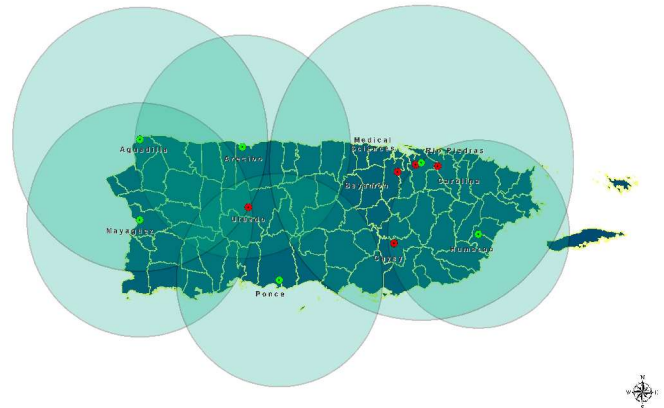


Figure 4. Deployable radar network

## V. CONCLUSIONS AND FUTURE PLANS

The procedure to survey the eleven campuses of the University of Puerto Rico was explained, resulting in the coverage depicted in Figure 4. From the figure we can observe that using six (Aguadilla, Arecibo, Humacao, Mayagüez, Ponce, Rio Piedras) of the eleven campuses there is full coverage of the island. The circles are shown using the maximum range of the radars, which exceeds the 30 km required to obtain good spatial resolution. If a radar range of 30 km was used, more radars would be needed to obtain a complete coverage of the Island.

The first kilometer of the atmosphere, for which an angle of one to two degrees is needed, is of interest in the design of the network. Due to the geography of the island, the vertical angles required to exceed the hills are very high, which leads us to find higher locations to reduce these angles.

As a future work new sites with more height will be surveyed to reduce the minimum antenna vertical angle with the purpose of the observation of the lowest part of the atmosphere. Also the Raytheon marine radar rotator, transceiver, and antenna will be installed and the data processing system will be designed for testing purposes.

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