

# THREE-RADAR NETWORK DEPLOYMENT SITE SURVEY FOR THE WESTERN REGION OF PUERTO RICO

by

Ricardo Ríos-Olmo

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Approved by:

---

Sandra L. Cruz-Pol, PhD  
President, Graduate Committee

---

Date

---

José Colom-Ustáriz, PhD  
Member, Graduate Committee

---

Date

---

Rafael Rodríguez-Solís, PhD  
Member, Graduate Committee

---

Date

---

Victor Huérfano-Moreno, PhD  
Representative of Graduate Studies

---

Date

---

Isodoro Couvertier-Reyes, PhD  
Chairperson of the Department

---

Date

## ABSTRACT

Due to the lack of reliable weather data, necessary for the estimation of precipitation in the western part of Puerto Rico, an interest in developing a meteorological radar network within this region has arisen. As part of the Engineering Research Center (ERC) for Collaborative Adaptive Sensing of the Atmosphere (CASA) different radar technologies at X-band frequencies have been developed and are being considered for deployment within the mentioned region of the island. Prior to installation, site surveys and simulations to determine the optimal location for the deployment of these radars have been performed by means of a Matlab tool developed in this project. These studies take into consideration several factors including technical considerations such as beam blockage, tower height, and performance of radar network products, such as multi-Doppler. In addition, considerations include social aspects such as the vulnerability of the population in the region of coverage. The sites are studied from a single radar perspective in order to determine them as favorable or not. They are then analyzed from a three-radar network perspective, finalizing with a recommendation of the optimal location for the deployment of the radar network.

## RESUMEN

Dada a la escasez de data meteorológica confiable, necesaria para la estimación de precipitación en la región oeste de Puerto Rico, un interés en el desarrollo de una red de radares meteorológicos para esta región ha surgido. Como parte del Centro de Investigación en Ingeniería (ERC, por sus siglas en inglés) del Muestreo Adaptivo y Colaborativo de la Atmósfera (CASA, por sus siglas en inglés) diferentes tecnologías de radares a frecuencias de banda-X se han desarrollado y están siendo consideradas para despliegue dentro de la región mencionada de la isla. Antes de la instalación, estudios de localidades y simulaciones para la localización óptima de estos radares fueron realizadas a través de una herramienta en Matlab desarrollada en este proyecto. Estos estudios toman en consideración varios factores incluyendo consideraciones técnicas como lo es el bloqueo del haz, la altura de la torre y el desempeño de productos de redes de radares, como lo es el “multi-Doppler”. En adición, las consideraciones incluyen aspectos sociales como lo es la vulnerabilidad de la población dentro de la región de cobertura. Las localidades son estudiadas desde la perspectiva de un sólo radar para así determinarlas como favorable o no. Estas luego son evaluadas desde la perspectiva de una red de tres radares, finalizando con una recomendación de la localización óptima para el despliegue de la red de radares.

To God & my family . . .

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# 1. INTRODUCTION

## 1.1 PROBLEM STATEMENT

CASA is an Engineering Research Center (ERC) focusing on the Collaborative, Adaptive Sensing of the Atmosphere. The center seeks to revolutionize the way the atmosphere is sensed today. Presently, the most common weather radar used in the United States is the WSR-88D, commonly known as NEXRAD. It is an S-Band (2GHz - 4GHz), Doppler weather radar used by the National Weather Service throughout the US and PR. One limitation encountered with this system is that since NEXRAD is a long-range radar, the farther away the signal travels from it, the higher in the atmosphere the sampling takes place. This effect is enhanced by the earth's curvature resulting in coverage problems in distant areas, which is the case in Puerto Rico's west coast. The NEXRAD radar at Puerto Rico is located in Cayey (eastern part of the island). It is at an elevation of approximately 850m and by the time the beam reaches the western region of the island it is sampling 1.4km over the area of Mayagüez (major city in the western part of the island). This is the problem CASA in general and especially in Puerto Rico is currently trying to compensate. Monitoring the atmosphere in the lower kilometers is of great interest in order to generate accurate quantitative precipitation estimates (QPE) which is one of the center's goals. This centered CASA in developing a new technology called Distributed Collaborative and Adaptive Sensing (DCAS) which will be implemented to improve the way the atmosphere is to be monitored at the lower troposphere [1]. The technology will be tested using a network of low-powered, short-

range radars. Using a network of radars which overlap each other, given their close proximity, eliminates the earth's curvature effect and it is then possible to sample at a desirable altitude in the atmosphere. This technology has been employed and successfully tested in CASA's Integrated Project No. 1 (IP-1). [2] IP-1 consists of a four-radar x-band (8GHz - 12GHz), Doppler, and polarimetric network; it is located in Oklahoma and is currently under operation.

A similar network is desired in the western part of Puerto Rico, the network will complement NEXRAD measurements and can be composed of radars currently under development at UPRM. The network could be a combination of off-the-grid radars plus radars similar to CASA's IP-1. It is expected in the near future that at least three IP-1 type radars will be deployed in the western region of Puerto Rico, and in addition two OTG radars could be integrated to the network as well. Its deployment within this region encounters additional challenges given to Puerto Rico's complex topography. Suggesting the best possible location for the networks configuration is this thesis's goal. Since the OTG radars are designed for easy mobility and portability, this work will only focus in the analysis of locations for fixed radars that will become permanently located in strategic points of the west coast.

## 1.2 MOTIVATION

Creating a positive impact on the world around us is every researcher's goal. Knowing that the work done is impacting people's lives to the better fills anyone with satisfaction and fulfillment. The goals behind this project are no different and seek to improve people's lives which are affected by weather on a day to day basis. The radar

network technology proposed to be deployed in the western part of Puerto Rico seeks to innovate the way the atmosphere is sensed in the island. Puerto Rico has a diverse and variable climate which makes it important to have a system observing rapidly developing weather events.

### 1.2.1 PUERTO RICO'S PRECIPITATION CLIMATOLOGY

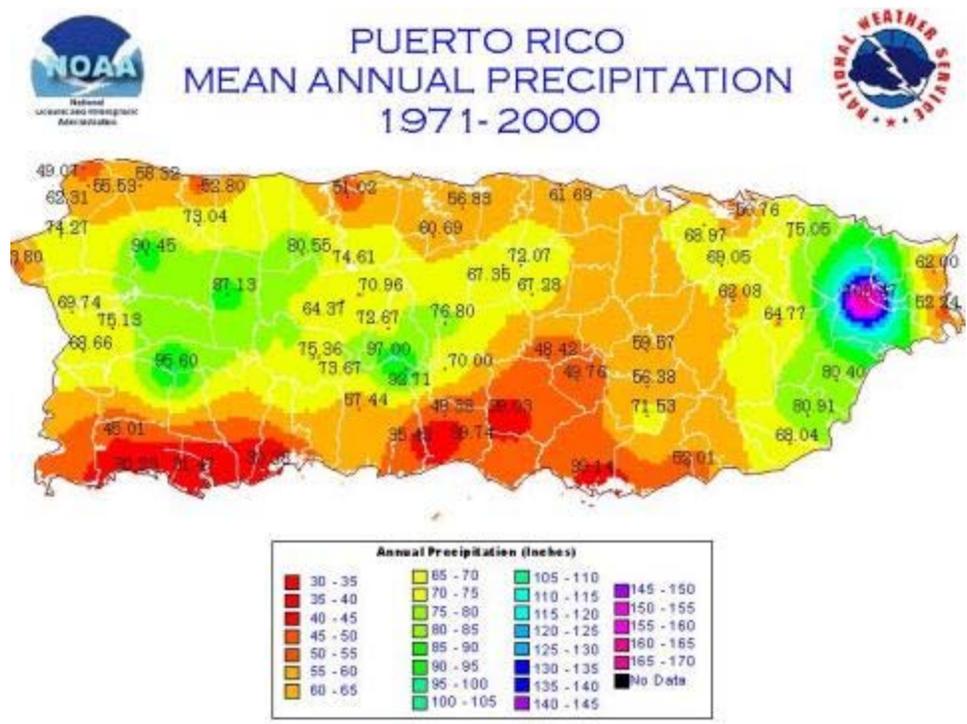
[3] Puerto Rico's climate falls into the tropical climatic zone. Throughout the year, temperatures average 80°F (27° C) in low elevations and average 70°F (21°C) in the mountain regions which run along the middle of the island and are known as the Cordillera Central. These mountains are the main cause of the variations on the temperature and rainfall that occur over very short distances. They also cause wide variations in local wind speed and direction due to their sheltering and channeling effects adding to climatic variations. Easterly trade winds pass across the island year round. Puerto Rico's rainy season stretches from May to November. Although it rains regularly all year round, during the rainy season precipitation increases considerably. On average, about a quarter of the annual rainfall for the island occurs during tropical cyclones; meaning tropical depressions, tropical storms, and hurricanes. These mentioned events are more frequent during the presence of La Niña. La Niña along with El Niño are important temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean. The name for El Niño, from the Spanish "the little boy" and similarly La Niña means "the little girl" [4].

Although geographically Puerto Rico is a relatively small island its climate varies greatly within. The northern region of the Island has good rainfall averages all year.

Within this region lies the only tropical rain forest in the United States National Forest System [5]. It is known as “El Yunque National Forest” or just simply “El Yunque” it is located on the slopes of the Sierra de Luquillo Mountains, this area gets the most amount of rain year round than anywhere else in the island.

The southern region of the island, on the other hand, is a dry region. So dry, in fact, that within this region lies the Guánica State Forest, subtropical dry forest/desert located in the southwest. This area was designated as a forest in 1919 and a United Nations Biosphere Reserve in 1981. It is considered the best preserved subtropical forest and the best example of a dry forest in the Caribbean [6].

It is necessary to mention the above in order to understand the variability of Puerto Rico’s climate. *Figure 1.1* shows the mean annual precipitation model from 1971 to 2000 provided by the National Oceanic and Atmospheric Administration and the National Weather Service.



**Figure 1.1 Mean Annual Precipitation of Puerto Rico 1971-2000.**

It is of great concern to accurately estimate the amount of precipitation falling at any given moment. It is so in order to help the proper authorities like the National Weather Service in San Juan or any emergency management personnel make important decisions as to evacuate people that may be in harm's way from flash floods or overflowing rivers, for example. People throughout the island depending on their geographical location and social standings may be more vulnerable to hazardous events than others. This is also an important matter to take into consideration and that the proper authorities should be aware of. Vulnerability studies have been performed in the western coast of the Island and are of concern for the work done in this project.

### 1.2.2 VULNERABILITY IN THE WEST COAST

Puerto Rico experienced rapid industrialization during the 1950's greatly due to Operation Bootstrap which aimed to transform the island's economy from agricultural based to manufacturing-based. [7] The industrialization of the island, particularly of its coastal municipalities, encouraged the citizens of the island to migrate to the coastal regions. This caused an increase on the population living in areas exposed to coastal hazards particularly in the west. The west coast of the island has become the region with the largest portion of the population residing in areas exposed to hazardous events. It is in these situations that disasters may occur, when a vulnerable population is exposed to a hazardous event. Vulnerability is not only defined as the harm that is presented depending on your geographical location. [7] defines vulnerability as "the characteristics of a group and their situation that influences their capacity to anticipate,

cope with, resist, and recover from the impact of a natural hazard; an extreme natural event or process”.

It is evident that the combination of a vulnerable population and hazardous events are the recipe for disasters. Given Puerto Rico’s topography, climatology, and geographical location, hazardous events varying from hurricanes and landslides, all the way to tsunamis are definitely potential scenarios for Puerto Rico. Determining the vulnerability of the population of the island is key in understanding the probability of a disaster occurring. Clearly defining this will help the corresponding authorities to better prevent, respond and cope with any event occurring.

The occurrence of disasters in Puerto Rico is not a surprising subject; anyone that has lived in the island for a while can be easily familiarized with this. Taking a look into the past, many events classified as disasters in Puerto Rico can be encountered. The most common hazardous events occurring in the Island may seem to be Hurricanes. Hurricane season stretches usually from June to November. One of the latest disasters due to the event of a hurricane was Hurricane Georges, the second major hurricane of the 1998 Atlantic Hurricane Season. It caused terrible damage across the island; according to the National Climatic Data Center they exceeded two billion dollars in damages, claiming 12 lives as well. This being one of the latest disasters in the island’s history is just one of the many in the past. Since 1956, Puerto Rico has received 20 federal declarations of major disasters and four federal emergency declarations [7]. This establishes the high probability of Puerto Rico facing natural hazards putting its population in harm’s way and creating the need to study their vulnerability, as it serves as the motivation for the author of [7].

From a technical aspect it is certainly important to include these studies when designing or developing technology that directly interacts with the environment around. The radar network proposed to be deployed in the western region of Puerto Rico, which is the primary focus of this project, seeks to provide high resolution precipitation data both in time and space within this region. Current weather observation instruments within the island are incapable of providing this important data.

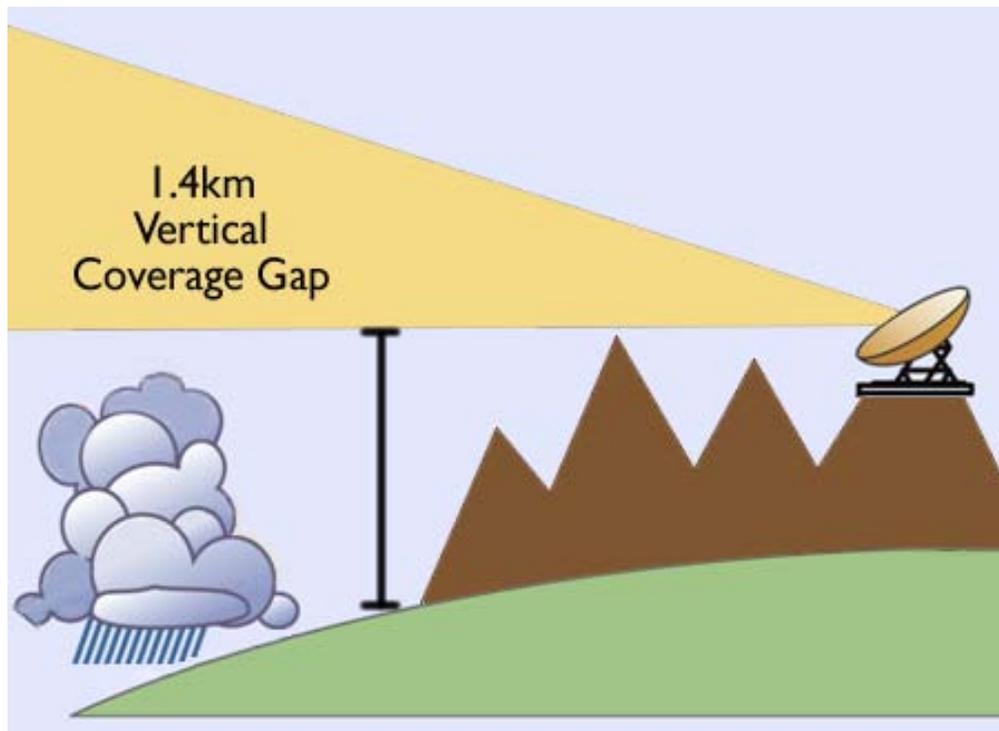
### 1.2.3 PUERTO RICO'S CURRENT RADAR COVERAGE

Currently the island is served by one weather radar belonging to the National Weather Service (NWS) in San Juan, known as NEXRAD radar. It has been known by NWS and emergency management personnel that precipitation over the western region of the island is underestimated. This compromises their response to any hazardous event such as a flash flood within this region since the severity of the same may not be well determined. Consequently this endangers the lives of the population living in this location.

There are several aspects underlying to the underestimation of the NEXRAD radar in Puerto Rico. The location of this radar within the island puts it in high elevations above sea level, approximately 850m. NEXRAD, being a long range radar (up to 240 km), introduces limitations due to the earth's curvature. As the range increases further away from the radar the beam climbs higher in the atmosphere. This creates an inability to observe the atmosphere close to the earth's surface, causing the radar to miss events that are under the area of observation of the radar. *Figure 1.2* presents an image illustrating the location of NEXRAD on a mountain top and

demonstrating the effect of the earth's curvature on the radar's beam. While establishing NEXRAD's limitation to observe atmosphere near the earth's surface it also encounters problems with low resolution at long ranges. Due to Puerto Rico's complex topography, the mountains may present themselves as obstacles to the radar. This blinds the radar from any event that may be behind those obstacles.

The deployment of the new X-band short range radar network in the western area will provide the coverage necessary to complement the NEXRAD radar providing the NWS with accurate, high resolution data of the highly variable weather events that occur within this region. This will give them the ability to better identify and respond to threats affecting vulnerable populations.



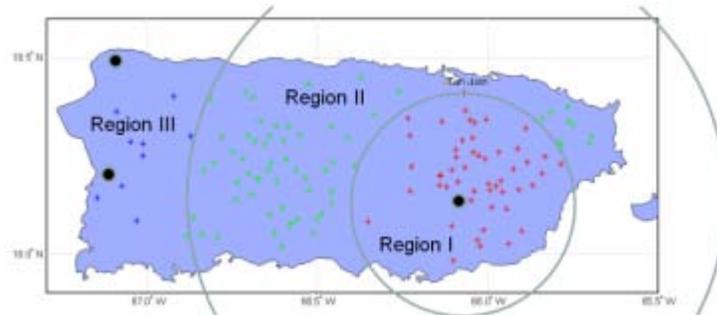
**Figure 1.2 Diagram demonstrating NEXRAD's beam with earth's curvature effect over the western region of Puerto Rico.**

### 1.3 LITERATURE REVIEW

The National Weather Service (NWS) currently uses the NEXRAD (WSR-88D) Radar as its primary weather radar. It is a long-range (over 200 Km), S-Band, Doppler radar installed in over fifty locations in the US and one in Puerto Rico. It has been one of the greatest cornerstones for weather radar technology. Still, it leaves broader fields for new advances in this area as everyday new technologies are developed [8]. These radars are not only used for storm detection and warnings, they are also used for estimation of rain and prediction of rain rates [9] [10]. Every day people research on new ways to provide these estimates using different types of radars and techniques [11]. This is how far radar meteorology has come with the new technologies developed. In order to establish reliable rain estimates weather radars need to provide very accurate readings. In [12] it is established that the precision needed for radar measurements in hydrology - such as issuing flood warnings is far more demanding than for following and extrapolating echoes in time and space. As the field in weather radars grows, there is a demanding need, like higher accuracy data, that also continues to grow. In response to these needs the CASA project developed new ideas and techniques to better sample the lower atmosphere [1].

CASA addresses some issues that currently are causing inaccurate rain estimates, such as the earth curvature problem. Long-range radar like NEXRAD have a limitation mentioned earlier, as the beam goes farther in range, the earth's surface separates from it. Studies were performed in [13] validating NEXRAD's readings with ground point measurements obtained with rain gauges. These validation results are

based on five heavy storms that seriously impacted human life and the economy of PR from 2003 to 2005. In this study Puerto Rico was divided into zones shown in *Figure 1.3*. Results for the validation efforts of this paper showed that the NEXRAD exhibit underestimation within all three regions but it is greater within Region III (farthest region from the radar location). [13] states that radar measurements over the western part of PR are frequently inaccurate because reflectivity measurements are retrieved high in the atmosphere. It can be observed through this validation effort, that NEXRAD's data loses accuracy while it is retrieved farther from the radar.



**Figure 1.3 Location of rain gauges (stars) within 3 different zones in Puerto Rico and Nexrad (black dot within Region I).**

One of the interests in meteorology is to improve the sampling in the lower atmosphere, in the layer called the Troposphere. This is the layer of the atmosphere where weather phenomena occur (being the layer which most impacts living beings) and its thickness varies around the globe. It reaches heights in excess of 16km in the tropics, but in polar-regions, it is more, subdued, extending to 9 km or less. The troposphere is the chief focus of meteorologists because it is in this layer of the atmosphere that essentially all of the important weather phenomena occur. Almost all

clouds and certainly all precipitation, as well as violent storms, are born in this lowermost layer. This layer is often called the “weather sphere” [14].

CASA proposes using short-range, low-powered, X-Band radars to eliminate the Earth’s curvature effect and other issues. One of the greatest advantages of working in the X-Band frequency is that the size of the radar units is reduced dramatically, contrary to NEXRAD large system. CASA currently has several test-beds directed to different issues; the Oklahoma test bed (IP-1) for example is directed more in the forecasting of tornados and the quantitative precipitation estimation (QPE). The radars deployed are what they call the NetRad [2]. These radars are already operational and have already begun collecting data. Preliminary comparisons with the NEXRAD have been performed [15]. Another important test bed for CASA is the Puerto Rico Student Test bed (IP-3) [16]. Its goal is to establish a network of solar-powered radars that are capable for QPE [17]. There is an additional project associated to CASA [18] which seeks to bring the radar technology of IP-1 to Puerto Rico. This proposal granted by NSF will deploy a three-radar network rather than a four-radar network as the one in Oklahoma. It is interesting to say that it is a challenging task since Puerto Rico is a very mountainous region. Deploying any radar within such a complex terrain is subject to beam blockage due to ground clutter. As a tool to aid in choosing the deployment sites for the radars this thesis is focused in the analysis of multiple radars with coverage overlapping over the west coast taking into consideration the geography of the island and previous vulnerability analysis of the region. This survey will provide the minimum observation angle to avoid ground clutter for each site, and will provide analysis from a single-radar perspective to a network perspective.

Having a network of radars in the western region of Puerto Rico will not only complement NEXRAD providing coverage in the areas with limitations. It will also provide meteorological products not available from single radars since it permits the use of Distributed Collaborative Adaptive Sensing (DCAS) technology introduced by CASA. Different techniques can be applied to higher quality data such as techniques for radar reflectivity retrieval. Since all of the radars comprising the radar network to be deployed operate at X-band frequencies, attenuation is a problem that needs to be addressed. With the employment of network retrieval algorithms the path attenuation can be corrected and reflectivity data can be retrieved [19]. In order to employ network reflectivity retrieval algorithms it is necessary to have observations of the same event from multiple radars. This means that this is performed within radar overlap regions. Another benefits offered by networked radars among many is the possibility of multi Doppler retrieval. As explained in [20] the essence of multi-Doppler radar wind retrieval from a network is the transfer from non-orthogonal radial velocities to the orthogonal Cartesian wind components. This is highly dependent on the radars' perspective angles. All of the products that will be available from the radars deployed in the western region will provide the NWS and emergency management with necessary data that will help them accurately inform people that may be in harm's way.

Understanding the local population will also help in the deployment of the radar networks. It is important to provide good coverage over populations that are highly vulnerable to disasters. In her study, Santos, J. the author of [7] addresses this issue utilizing data from the 1990 and 2000 U.S. Census of Population and Housing of Puerto Rico. Her work explored the issues related to the development, vulnerability and

hazards in the West Coast of Puerto Rico comprised of the following municipalities: Aguadilla, Aguada, Rincón, Añasco, Mayagüez, and Cabo Rojo. *Figure 1.4* highlights the municipalities in this study. Particular interest arises in the municipality of Mayagüez since three rivers lie within easily flooded areas. This can cause serious flooding in the event of heavy precipitation. The data was analyzed at a block group level. According to the U.S. Decennial Census Geographic Glossary Manual (2005), block groups are the smallest geographic division for which all data is tabulated or made publicly available. With this, vulnerability indexes were obtained for the people residing within these regions. Understanding all of these elements is an important key in decision making and contributes greatly to the site survey performed in this project.

With all of the key contributing components in order a decision as to determining a location as suitable for a radar or not can be made, ranging from a single radar to a network of multiple radars which is the ultimate product of this thesis.



**Figure 1.4** Municipalities where vulnerability studies were performed.

## 2. Theoretical Background

### 2.1 INTRODUCTION

Nature most certainly affects people's lives in a day-to-day basis influencing their everyday activities, jobs, health, and comfort. It is a part of living on Earth and it can be seen in natural hazards all over the world. Everyday natural hazards adversely affect millions of people and are responsible for innumerable damages to homes, agriculture, economy, and lives. Some hazards such as earthquakes and volcanic eruptions are geological events. But a greater number are related to the events in the atmosphere. It is safe to say that there are few aspects of the physical environment that affects lives more than the phenomena we collectively called *weather*.

As learned from [14], weather is highly dynamic, sometimes changing from hour to hour. It is a term that refers to the state of the environment at a given time and place. Since it greatly affects lives, it has always caught the interest of scientists and the general public as far back as the seventeenth century. It was then that the scientific study of the atmosphere began in response to the development of instruments to measure different elements. These instruments provided data that helped observers formulate laws applying to the atmosphere. For example, Galileo invented an early version of the thermometer in 1593, and Torricelli built the first barometer in 1643. During the eighteenth century, instruments were improved and standardized; this is when extensive data collection began. The acquisition of data was fundamental to the study of physical processes and the development of explanations about atmospheric

phenomena. As the years passed new technological advances were developed in this area. A widely and very useful tool developed was the radiosonde [14]. It has been deployed since the late 1920s using balloons. These instruments are equipped with radio transmitters that send back temperature, pressure, and relative humidity data in the lower points of the atmosphere. Radiosondes are deployed two times a day and are still currently used worldwide by several governmental agencies, for instance, the National Weather Service in the United States and Puerto Rico. Rain gauges also provide meteorological data, but similar to radiosonde, they provide data for a specific point in space.

Among the methods of studying the atmosphere that are best known to the general public and most useful for to atmospheric scientists are weather satellites and radars. Meteorological satellites give a perspective of the atmosphere that is unique and invaluable by providing images that cover large areas which allow the study of the distribution of clouds and circulation patterns. They also help track and detect storms with great precision. An example of a meteorological satellite is National Aeronautics and Space Administration's (NASA) Tropical Rainfall Measuring Mission (TRMM). It is a joint mission between NASA and the JAXA (Japan Aerospace Exploration Agency). TRMM is the first mission dedicated to the measuring of rainfall in the tropic and sub-tropic areas. [21]

Recent technological developments greatly enhance the advances of the weather radar for the purpose of storm detection, warning, and research. Radar technology is currently a field of rapid growth and in the interest of this project.

## 2.2 RADAR THEORY

The term RADAR originally is a contraction of the words *radio detection and ranging*. It is an electromagnetic system for the detection and the location of reflecting objects such as aircrafts, ships, spacecrafts, vehicles, people, and the natural environment. It operates by radiating energy into space and detecting the echo signal reflected from an object or target. One of the most important attributes of radars is the ability to measure distance with high accuracy under any current weather condition for a large coverage area. Radars can operate under conditions in which normally infrared and optical sensors cannot operate as in darkness, fog, and rain for example. All of the mentioned attributes make radars very valuable as a measuring instrument [22].

As mentioned, radars provide useful information such as distance and intensity. The basic performance of a radar can be described in detail observing *Figure 2.1*. An electromagnetic signal is generated in the transmitter and is radiated to the atmosphere by the radar antenna. The transmitted signal is intercepted by the target affecting its path. Depending on the type of target, a portion of the signal may be absorbed, another portion may be scattered in all directions. The portion of the signal that is scattered back towards the radar is collected by the radar antenna, which delivers it to the receiver where it is then processed and analyzed.

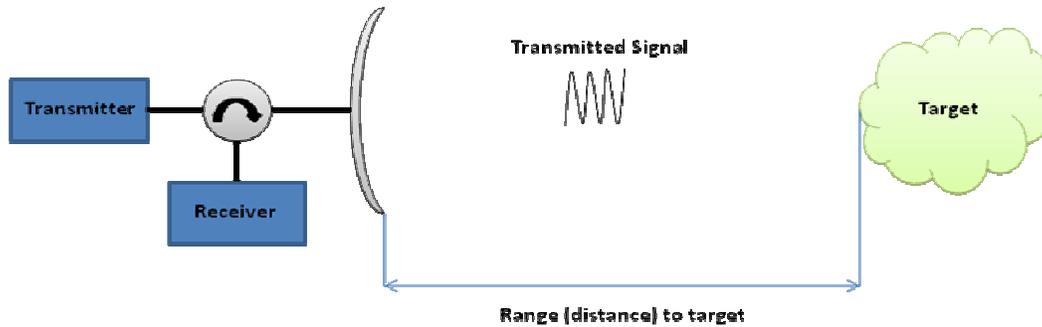


Figure 2.1 Basic Radar Diagram.

Understanding and performing the measurement of distance with radars is fairly easily analyzed. The electromagnetic signal radiated by the radar travels at the velocity of light ( $c = 3.8 \times 10^8$ ), travels a distance  $D$  (two-way path) in a time  $T_r$ . Equation 2.1 is a simple equation derived to calculate this distance or range ( $R$ ).

$$R = \frac{cT_R}{2}$$

Equation 2.1

An ambiguity in range when working with pulse radars exists when transmitting and receiving a signal. When a pulse has been transmitted by the radar, enough time has to elapse in order for the reflections from all of the different targets within wanted ranges are received back. This has to occur before transmitting the second pulse. If a target far away reflects the signal and the signal is received after transmitting the second pulse, it may seem that the reflection is due to a target close by the radar creating a “false” target nearby. In order to avoid ambiguity with range measurements, an unambiguous range ( $R_{un}$ ) can be calculated using Equation 2.2. Where  $T_p$  is the pulse repetition period, and its inverse ( $1/T_p$ ) is similarly known as the pulse repetition frequency ( $f_p$ ).

$$R_{un} = \frac{cT_p}{2} = \frac{c}{2f_p}$$

**Equation 2.2**

It is useful to relate the radar maximum range with other component characteristics at the transmitter, receiver, antenna, target, and the environment. With this not only can you determine maximum range, it can serve as a mean to understanding the factors that affect the radars performance. This is known as the radar equation and it is very helpful in aiding in the design of a radar as well.

$$R_{max}^4 = \left[ \frac{P_t G^2 \lambda^3 \sigma}{(4\pi)^3 S_{min}} \right]$$

**Equation 2.3**

Where  $P_t$  is the transmitted power,  $G$  is the radar antenna's gain,  $\lambda$  is the wavelength ( $\lambda = c/f$ ), where  $c$  is the velocity of propagation and  $f$  is the frequency of operation), and  $\sigma$  is the radar cross section (RCS) of the target. The RCS determines the power density returned to the radar for a particular power density incident on the target. The last term of *Equation 2.3* is  $S_{min}$ , it is the minimum detectable signal at which point  $R_{max}$  occurs. *Equation 2.3* is the fundamental form of the radar equation; more terms may be added further on to account for other contributing factors such as attenuation among many others.

There are various applications for radars, varying from military, air traffic control, and remote sensing among others. Targets may vary in many aspects as well depending on the application. The radar may be used to detect a point target, meaning

that it is interested in just one item in the area of observation, like an airplane in the sky. It may also be the interest of the radar operator to detect a volume target, in which case, the interest of observation lies within a volume of space as is the case of rain detection with weather radars. For weather radars the targets are hydrometeors, being rain, snow, hail, etc. These hydrometeors scatter the energy from the emitted radiation back to the radar which is then detected.

Depending on their application radars have different operating frequencies. Some common operating frequencies for weather radars are the L, S, C, X, and K bands [23]. Each has different applications:

- L band radars operate on a frequency of 1-2 GHz. They are mostly used for clear air turbulence studies, ocean salinity and soil moisture.
- S band radars operate on a frequency of 2-4 GHz. Because of the wavelength and frequency, S band radars are not easily attenuated in the atmosphere. This makes them useful for near and far range weather observation.
- C band radars operate on a frequency of 4-8 GHz. The signal is more easily attenuated, so this type of radar is best used for short-range weather observation.
- X band radars operate on a frequency of 8-12 GHz. Because of the smaller wavelength, it is more sensitive and can detect smaller particles. X band radars also attenuate very easily, so they are used for only short-range weather observation. Yet the higher frequency provides more advantages in terms of overall equipment size and weight.

- K band radars operate on a corresponding frequency of 27-40 GHz and 12-18 GHz. This band is split down the middle due to a strong absorption line in water vapor. This band is similar to the X band but is just more sensitive.

Attenuation due to the atmosphere and rain increases proportional to the increase in frequency. Some weather radars such as NEXRAD use the S-Band since they do not experience much attenuation and are capable of working at long ranges. Although higher frequencies offer better resolution they are not often employed due to the problems encountered with attenuation. Short-wavelength (e.g.,  $\lambda \leq 3$  cm) radars suffer echo power loss that can be 100 times larger than that of radars operated with  $\lambda \leq 10$  cm [24]. Even though attenuation can be a problem at X-Band ( $\lambda \leq 3$  cm), CASA has chosen this frequency for the network radar they have proposed since it is a short range radar network. In addition, the decision is based on component size being smaller and cheaper at X-Band and also for providing higher resolution than on lower frequencies. Different attenuation correction algorithms were developed in order to cope with problems due to attenuation.

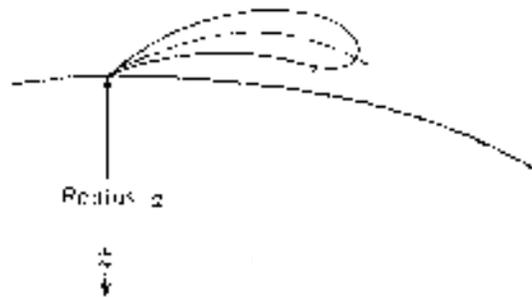
### 2.3 RADAR BEAM PROPAGATION, BLOCKAGE AND CLUTTER

Normally radar's beam propagation is thought of traveling in a straight line. This is true in free space since the dielectric permittivity  $\epsilon_0$  and magnetic permeability  $\mu_0$  are constants related to speed of propagation defined by *Equation 2.4*:

$$c = \sqrt{\mu_0 \epsilon_0}$$

Equation 2.4

This is not so in the earth's atmosphere where its permittivity  $\epsilon$  is larger than  $\epsilon_0$  and it varies vertically throughout it [24]. This means that electromagnetic waves propagate at a velocity smaller than the velocity of light at free space ( $v < c$ ) along curved lines. Refraction occurs due to the earth's atmosphere which means that the radar's beam may be bent back towards the surface. This can be observed in *Figure 2.2*. Normally the effect of bending caused by atmospheric refraction is favorable because it causes the radar's horizon to be extended and increase coverage beyond the geometrical horizon. However, the bending of rays by the atmosphere can introduce errors in the measurement of elevation angles [22].



**Figure 2.2 Radar beam propagation due to refraction.**

Atmospheric refractivity depends on pressure, water vapor, and temperature. Among these, the most influencing element is water vapor at microwave frequencies. It is the most variable with time and space. It immensely affects the speed at which the electromagnetic wave propagates. Major changes in atmospheric refractivity occur in the vertical dimension. Although some changes occur in the horizontal dimension, these are generally small so propagation can be considered independent of the azimuth direction.

A simple method exists to account for the effects of atmospheric refraction; it is to assume that the gradient of the index of refraction is constant with height at least over the lower part of the atmosphere (area of interest of this project). This allows the actual radius of the earth and its non-uniform atmosphere to be replaced with an earth having a different radius known as the *effective radius of the earth*. Assuming the earth to have this effective radius and a uniform atmosphere radar waves can propagate in a straight line rather than along paths. This can be observed in Figure 2.3 where now as mentioned, the earth's radius is substituted for an effective radius and the beam now propagates in a straight line.

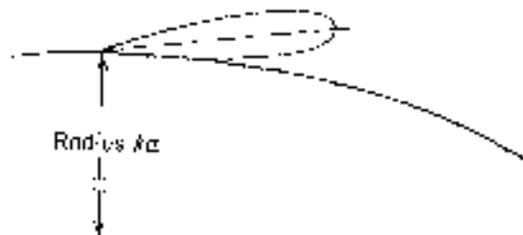


Figure 2.3: Radar's beam propagation using effective radius of the earth.

The earth's effective radius is given by:

$$\text{Effective Radius, } a_e = ka$$

Equation 2.5

Where  $a$  is the earth's radius and  $k$  is a factor dependent on the refractivity gradient at the surface. It is calculated using:

$$k = \frac{1}{1 + a\left(\frac{dn}{dh}\right)}$$

Equation 2.6

The gradient of  $n$  ( $\frac{dn}{dh}$ ) is the rate of change of the refractive index with height.

Substituting *Equation 2.6* in *Equation 2.5* yields,

$$a_e = ak = \frac{a}{1 + a\left(\frac{dn}{dh}\right)}$$

Equation 2.7

Researchers have found that the gradient of  $n$  ( $\frac{dn}{dh}$ ) within the first two kilometers of the atmosphere is typically  $-1/4a$  [25]. Substituting this in equation *Equation 2.7* gives,

$$a_e = \frac{4}{3}a$$

Equation 2.8

This is the long-term average value of the gradient of  $n$  over the United States. The use of  $k = 4/3$  effective earth's radius to account for normal atmospheric refraction is conveniently and widely used keeping in mind that it is an approximation.

*Equation 2.9* is used to determine the minimum height ( $h$ ) of the radar's beam at any point in range depending on the elevation angle ( $\theta_e$ ) and range ( $r$ ),

$$h = \sqrt{r^2 + a_e^2 + 2rk_e a \sin \theta_e} - a_e$$

Equation 2.9

As can be observed, in the previous equation the effective radius of the earth is used to take into account refraction due to the atmosphere. For the purpose of this

thesis project radar's beam propagation using the effective radius of the earth as  $k = 4/3$  will be calculated. Beam's propagation of the earth using  $k = 1$  will also be used and afterwards both models will be compared.

Other than atmospheric refraction there are other factors that can affect radar's performance. Since the earth's atmosphere is always changing the radar's transmitted signal can return echoes other than from the object of interest [22]. These unwanted echoes are referred to as clutter. It implies that these echoes "clutter" the radar and make the detection of wanted targets difficult. Usual clutter includes echoes from land, sea, weather (particularly rain), birds and insects. Even echoes from ionized meteor trails and aurora can produce clutter at lower frequencies. Of course the type of clutter encountered depends on the application of the radar. For a radar which its application is to detect airplanes in the sky, weather can cause serious clutter. But, for a weather radar which its application is to detect precipitation, other types of clutter can occur. For example, since it is in interest that weather radars sample as close to the earth's surface as possible land clutter can occur.

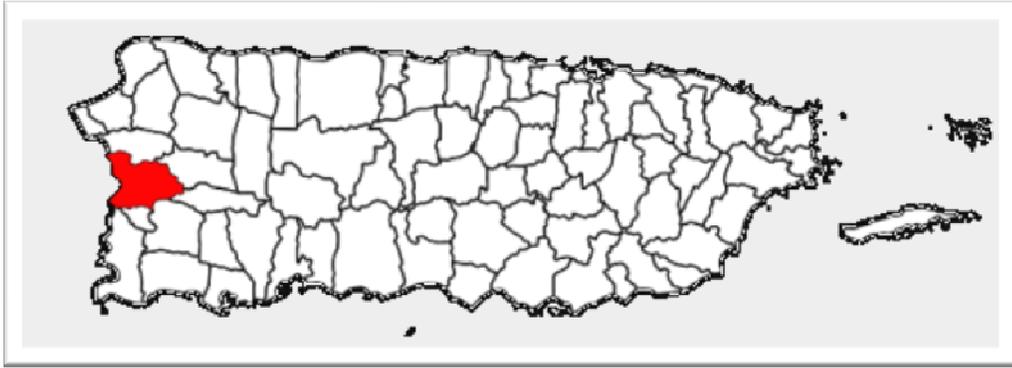
Ground clutter is a serious problem for radars that wish to observe close to the earth's surface. Land produces from unwanted echoes to complete beam blockage. Complete beam blockage may occur when the radar beam's path is completely obstructed by an object for example a high mountain. This brings forth challenges for the deployment of these types of radars and is enhanced when having complex topography as is the case in Puerto Rico. These are the challenges this thesis project wishes to address in order to provide best performance to radars that will be deployed in the western region of the island.

## 3. CONSIDERATIONS FOR RADAR DEPLOYMENT

### 3.1 RADAR SITE SELECTIONS

As part of the Engineering Research Center (ERC) for Collaborative, Adaptive Sensing of the Atmosphere (CASA), a site survey has been performed to determine the optimum location for the deployment of a radar network in the western part of the Island of Puerto Rico. Several locations were suggested for considerations, all of which are territories belonging to the University of Puerto Rico at Mayagüez (UPRM). UPRM is one of four core universities that form the ERC. Other core universities are Colorado State University (CSU), University of Massachusetts (UMASS), and Oklahoma University (OU). Seeking university property is key in the deployment for the radar network since it provides ease of access to acquire a part of the property for the radar installation. This thesis project seeks to determine all of the possible locations as being an option for deployment or not. Several key factors are taken into consideration, among them, radar coverage area, ground clutter, and hydrological considerations.

Other than the campus property located in Mayagüez, PR shown in *Figure 3.1*, the university possesses different locations within the western region of the island. Overall eleven different locations were identified for the site survey; each of them evaluated individually. These eleven locations can be observed in *Figure 3.2*. The locations that are found to be favorable for the deployment will then be evaluated for optimum performance as networks of three radars which is ultimately the product this thesis project offers.



**Figure 3.1: Puerto Rico map highlighting the municipality of Mayagüez in red.**

The selected sites for the survey are located within different municipalities in the western region of the island. This region of the island has been chosen for the radar deployment location since it is the area farthest from the island's NEXRAD hence, it is provided with poor coverage. Within this area, NEXRAD has been found to provide poor coverage. The eleven locations are within seven different municipalities as can be appreciated in *Figure 3.2*. These municipalities are: Aguadilla, Isabela, Mayagüez, Cabo Rojo, Lajas, Sabana Grande, and Adjuntas.



Figure 3.2: Site locations map.

Current conditions of the sites are an important part of the survey. Each of the sites were visited and evaluated for different elements important for a radar installation, for example, electricity access, internet access, and security. Site surroundings were also evaluated at each site. This is an important element since the immediate surroundings of the point of installation such as trees, buildings, and other existing infrastructure are most influential in the tower height needed for the radar deployment. Following, a description of all the sites and the infrastructure within is provided.

### 3.1.1 R & D CENTER OF UPRM (CID)

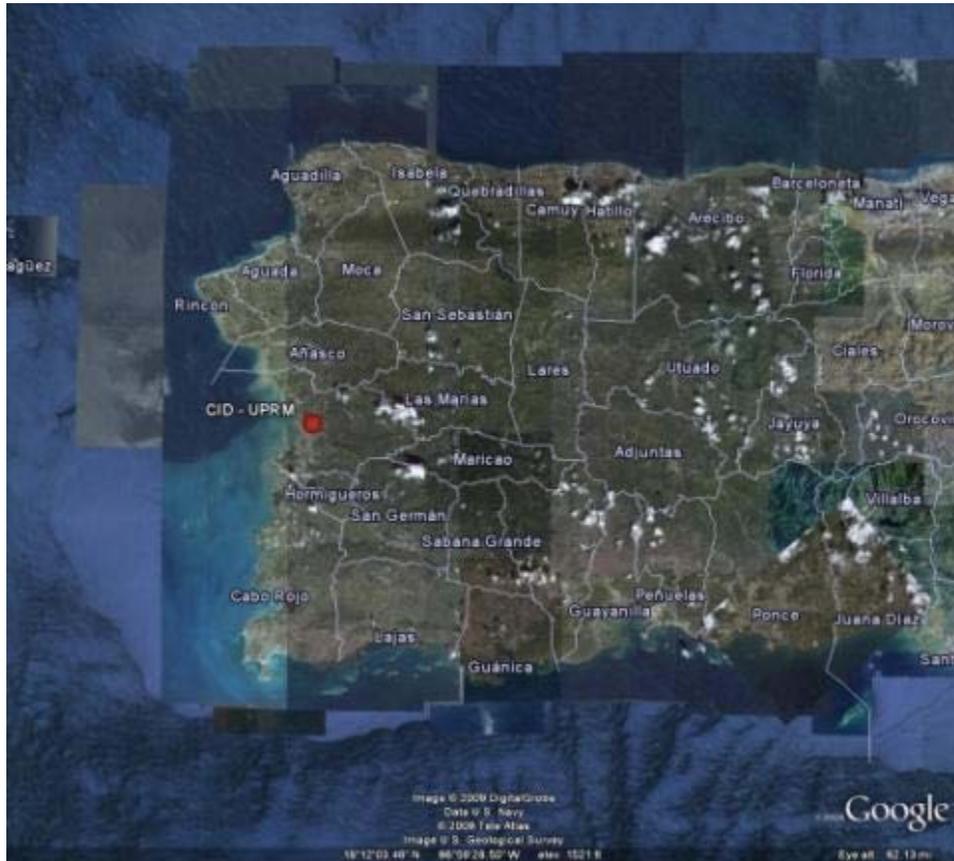


Figure 3.3: CID site map location.



Figure 3.4: Research and Development Center (CID) site panoramic picture at UPRM.

The first site under consideration is located within campus grounds on top of the Research and Development Center (CID, for its Spanish acronym: “Centro de Investigación y Desarrollo”) building. A panoramic picture of this site can be observed in *Figure 3.4*. Since its location is within campus grounds twenty four hour security is

provided. Access to electrical power grid and to high speed internet is also available at this location. *Table 3.1* provides a summary of the availability of infrastructure requirements on this site.

**Table 3.1: CID infrastructure evaluation.**

Infrastructure Considerations	Availability
<b>Security</b>	YES
<b>Electricity</b>	YES
<b>Internet Access</b>	YES
<b>Tower</b>	NO

Although the CID site does not have an existing tower for the installation of the radar, it does have a platform where a small tower can be constructed upon. This platform can be observed in *Figure 3.5*. A small tower is needed in order to overcome all obstacles immediately encountered around the radar location. The highest obstacle was measured on-site.

On-site measurements for tower height were performed using different tools. The first was a manual angle measuring tool (reads elevation and azimuth angles); it can be seen in *Figure 3.6*. The second tool used, measured the distance to the obstacle; this tool can be observed in *Figure 3.7*. If the distance was greater than 200 meters (maximum range of the tool), Google Earth’s measuring tool was used to determine this distance.



**Figure 3.5: CID building platform.**



**Figure 3.6: Angle measuring tool.**



**Figure 3.7: On-site distance measuring tool.**

The instruments mentioned before are hand-held instruments and therefore can introduce errors in the measurements. Because of this, only approximate tower heights can be calculated. CID on-site measurements were performed and an approximate minimum tower height was determined. The highest obstacle measured was a radar dome also located on the rooftop of the CID building. Calculations for the tower height can be observed on *Figure 3.8*. The distance to the target was determined to be approximately 24 meters using the tool in *Figure 3.7*. This value was verified using Google Earth's measuring tool which gave a value of approximately 25 meters.

The measurements show that a 10 ft (3.05m) tower is needed to be installed over the platform. Although only a 10 ft tower is needed for the deployment of the radar on this site if it is found to be a favorable location, a 20 ft (6.1m) tower will be constructed instead. The reason for this is that in order to reduce infrastructure costs tower building

materials have been donated by the Arecibo Observatory. The tower legs donated are 20-ft in length determining the minimum height of the tower at this height. Simulations performed for this site in chapters IV and V, will be performed using a 20ft tower.

## CID Tower Height

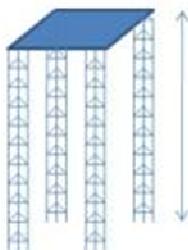
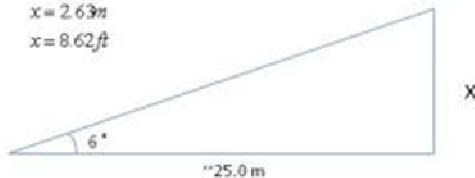
Minimum elevation angle of highest obstacle:  $6^\circ$

Azimuth location of obstacle:  $\sim 315^\circ$  (MN)

$$x = 25.0 * \tan(6)$$

$$x = 2.63m$$

$$x = 8.62ft$$



$\sim 10ft$

Minimum recommended height is  $\sim 10ft$

Figure 3.8: CID Tower height calculations.

Similarly all other sites were evaluated for infrastructure and site measurements were performed to determine approximate minimum tower heights. These analyses can be observed in Appendix 1.

## 4. ANALYSIS OF CANDIDATE SITES

### 4.1 INTRODUCTION

Determining a location favorable for the installation of a radar is critical especially in a complex terrain like the one encountered in Puerto Rico. The performance of the radar at a specified location is analyzed using a tool developed in Matlab. This tool demonstrates how the terrain can affect the radar's beam causing blockage. These simulations will provide the user with the minimum angle of observation for the radar's antenna. This angle is determined as the values which provides with no beam blockage due to the elevated terrain within the area of coverage.

As mentioned before, this site survey is being performed as part of the ERC CASA; more specifically, as part of the CASA IP-3 test bed. This testbed seeks to deploy what is known as "Off-the-Grid" radars (OTG). What it means is that they are small, portable, low-powered radars that can be deployed easily at any site. More importantly they will be solar-powered, not depending on the electrical power grid, hence the name: "Off the Grid". These radars are still under development at UPRM. Other radar technology CASA possesses and could be deployed in Puerto Rico is the IP-1 testbed radars in Oklahoma. These radars are more robust and are highly capable having Doppler and dual-polarimetric capabilities.

Although one of the primary tasks for IP-3 is deploying the "Off-the-Grid" radars, the simulations performed in this chapter and the next will go beyond the reach of these radars. Due to the high capability the IP-1 radars offer, a more complete analysis can be

performed for the site survey using the Matlab tool. This developed tool will then be useful to determine the performance for off-the-grid radars as well as more complex systems such as the IP-1 radars.

Puerto Rico's digital elevation models (DEMs) were obtained in order to perform these analyses. DEMs contain the terrain's elevation at a specified resolution. The DEM's resolution obtained for the simulations performed in this thesis project is 90 meters. This means that each pixel contains an area of 8100 m<sup>2</sup>. The DEMs were imported to Matlab as a map and then analyzed. Being geo-referenced, each site's location was then determined within the map.

Each candidate site location was simulated using the developed Matlab tool to determine if beam blockage is encountered at that site. This was performed for various tower heights and antenna elevation angles. The results for each site was viewed and evaluated according to required criteria. Every site was then determined as a favorable location for radar deployment assigning a PASS or NO-PASS status to each.

The individual simulations performed for the candidate sites were evaluated using the minimum tower height determined in the previous section. Because of the complexity of Puerto Rico's terrain, the antenna elevation angle cannot be as small as half of the beam-width because extreme beam blockage will occur. The beam-width used for the simulations is 1.8°; this being the beam-width for the IP-1 radars. The minimum antenna elevation angle used for all simulations will start at 2° and will be incremented from there on.

## 4.2 DEVELOPED MATLAB TOOL (STAGE I)

A tool which evaluates the performance of a radar depending on its location was developed using Matlab. This tool uses digital elevation models for the location where the radar is being considered for installation and determines if the terrain will cause any beam blockage. This is performed for a given set of configuration parameters such as tower height and beam elevation angle analyzing also coverage of critical areas such as watersheds. This developed tool consists of two stages of analyses (see A1.1 through A1.3 for Matlab tool codes). The first accounts for the performance of a single radar at a single location. The second stage evaluates the performance of a network of three radars, although it can be modified to any number of radars. The first stage of this tool was used for the analyses performed in the following sections and will be the one discussed in this section. A diagram of the first stage can be observed in *Figure 4.1*.

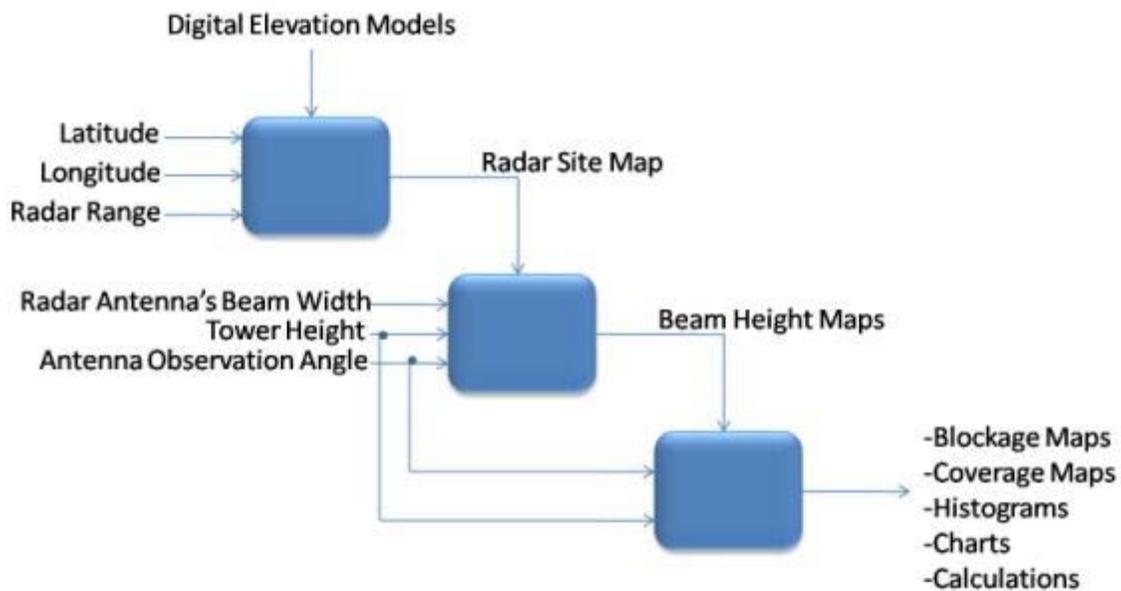


Figure 4.1 Diagram for the first stage of the developed Matlab tool.

As can be observed from the diagram in *Figure 4.1*, the first stage of the Matlab tool can be divided into three parts. One will create a map centering it on the radar site under evaluation given by the geographical coordinates (in degrees) provided as an input by the user. This map will be saved to a desired directory for future use and it is used as an input for the second part of the program. The second part will then compute the height of the beam over the entire map area. It determines the height of the bottom portion of the beam. This will be performed for user defined radar parameters; the antenna's beam width, its angle of observation and tower height. As the previous map created, the beam height maps will be saved to a desired directory and are inputted to the next part of the program. The third part of the tool will then determine the blockage points encountered on the map. When a blocked pixel is found, the program will block the radial where that pixel is found from its location until the maximum range of the radar. It is then that the blockage maps are formed and plotted. Along with the blockage maps other results are provided in the form of charts and figures containing coverage calculations.

Special areas of coverage were included as part of the coverage analyses of this tool. Coverage of areas with high vulnerability indices given by J. Santos study in [7] is analyzed. Important watersheds for the western region of Puerto Rico are evaluated for proper coverage as well.

All of these analyses can be observed in the following sections of this chapter where the Research and Development Center (CID) of UPRM is evaluated as a possible radar site. This tool can be used for similar studies in any part of the world, given that the user has available topographic data and the parameters of the radars.

### 4.3 SITE ANALYSIS (CID)

The CID site was located within the map using its geographical coordinates listed in *Table 4.1*. *Figure 4.2* shows the location of the site and the yellow circle around determines the radars range at 40km.

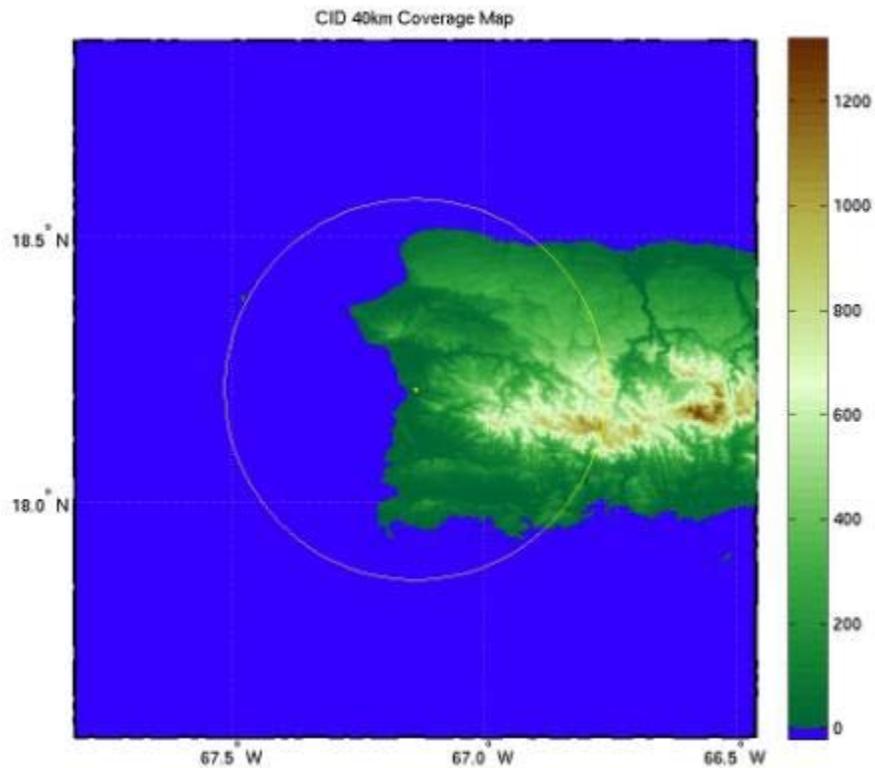


Figure 4.2 CID 40km coverage map.

Table 4.1 CID geographical coordinates.

CID Geographical Coordinates (degrees)	
Latitude	18.21125
Longitude	-67.13676

As stated previously in this chapter, simulations for all of the sites under consideration were performed starting at 2° of antenna elevation angle and at the minimum tower height established in the previous chapter. The value for the minimum tower height for this site was stated to be 20ft. *Figure 4.3* shows the blockage analysis at these values. Beam blockage is depicted in black as can be observed from the figure. Note that the area beyond the 40km range circle around the site is masked in black, stating that this is the maximum range of the radar. This is performed over the map created using the DEMs uploaded into Matlab. The color bar defines the value of the terrain's height in meters. As can be observed, negative values are given to the sea and blocked areas; blocked areas being the most negative value (exactly -40m).

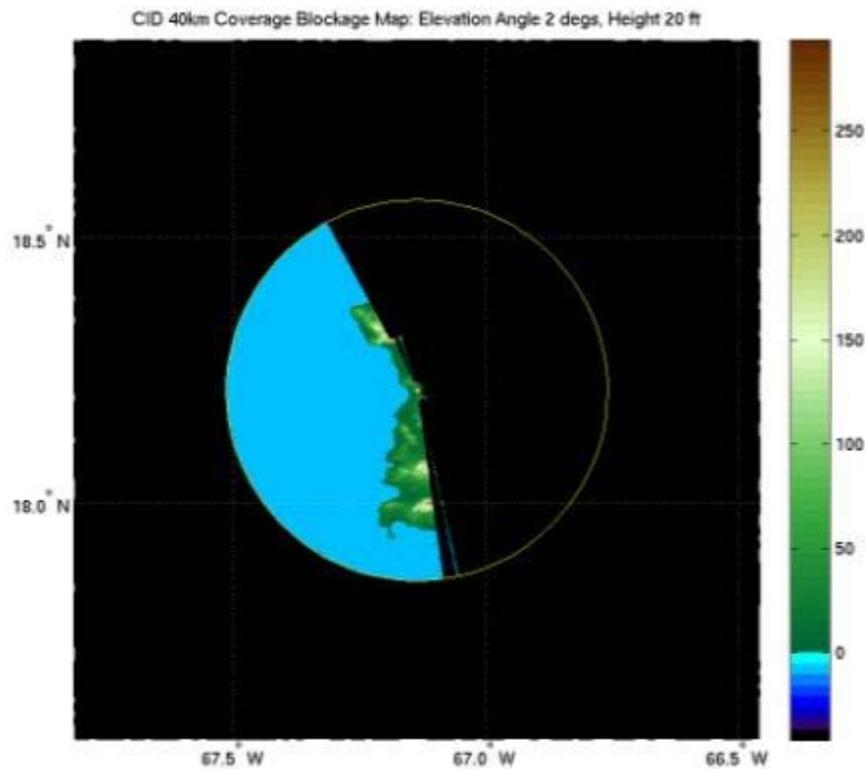


Figure 4.3 CID coverage blockage map.

CID Coverage Pie Chart: Elevation Angle 2 degs, Height 20 ft

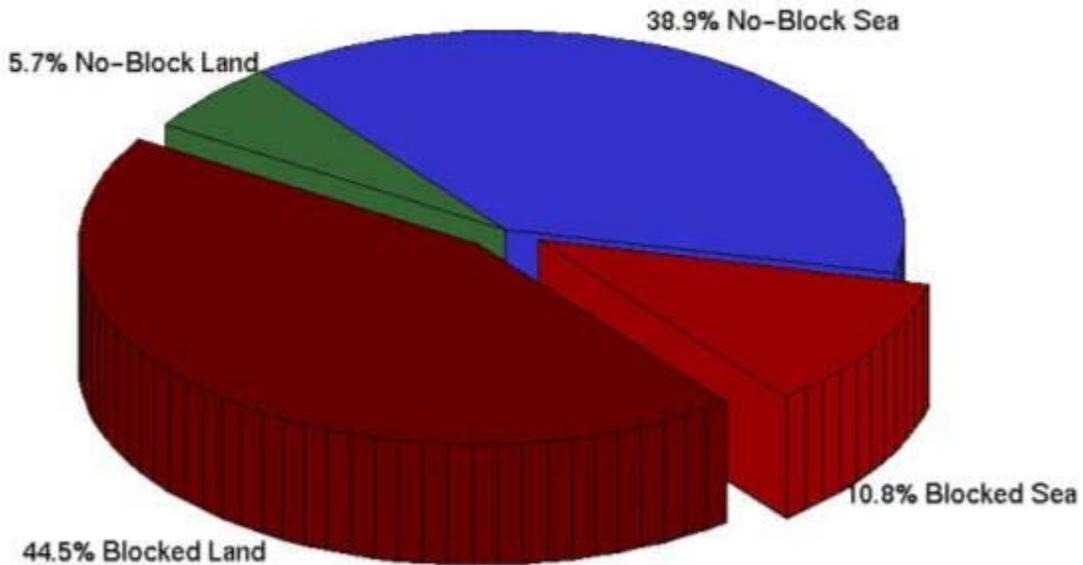


Figure 4.4 CID blockage area pie chart.

A pie chart of the analysis of the area of coverage at the mentioned radar parameters can be observed in *Figure 4.4*. The percentages of blocked and un-blocked land and sea areas within the radar's range are presented within the pie chart. It shows that of all the land mass within the radar's range, 44.5% is blocked. For the portion of sea, 10.8% is blocked. Due to serious beam blockage encountered almost half of the land covered by the radar is blocked and cannot be observed by the radar. The quantified values of coverage for the land and sea areas under the radar's range can be observed in *Figure 4.5*.

Coverage Area Calculations:  
CID Elevation Angle 2 degs, Height 20 ft

Total Area of Coverage: 4991.8923 km<sup>2</sup>

Total Area of Land Coverage: 287.4609 km<sup>2</sup> --> 5.7586%

Blocked Land Area: 2221.3602 km<sup>2</sup> --> 88.542%

Total Area of Water Coverage: 1942.7121 km<sup>2</sup> --> 38.9173%

Blocked Water Area: 540.3591 km<sup>2</sup> --> 0.21762%

Figure 4.5 CID coverage area calculations.

Different products are provided for this analysis through the use of the developed tools in Matlab. The following images shown in *Figure 4.6*, present the height of the beam over land and sea areas within radar range. Color bar to the right of each of the images represents the height of the beam in meters going from red (smaller values of height) to blue (larger values of height).

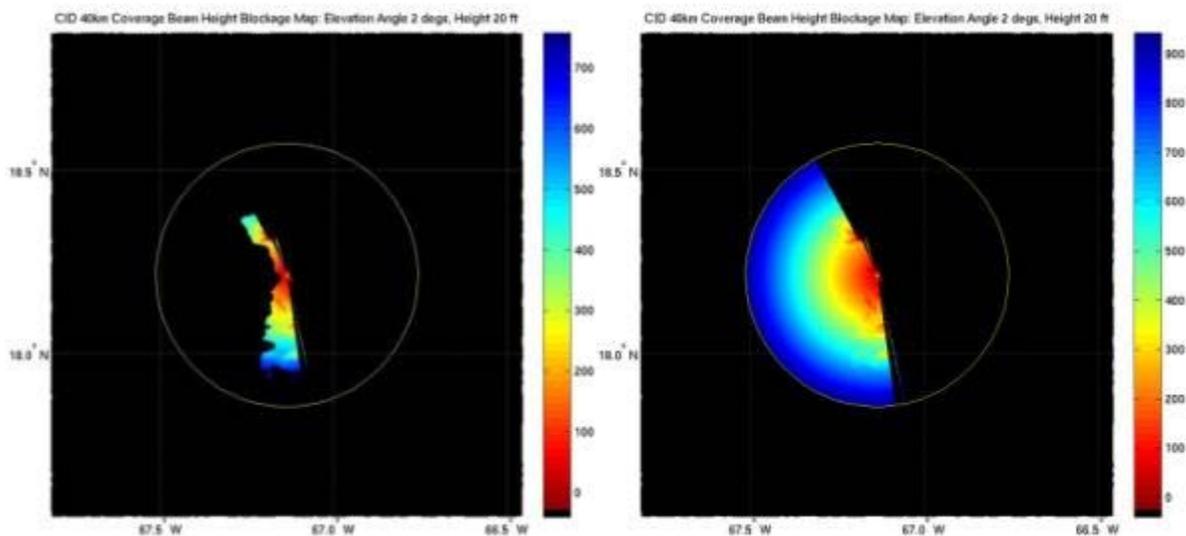


Figure 4.6 CID coverage beam height blockage diagrams.

Two different images are shown in *Figure 4.6*; the difference lies in that, the first image, shows the beam height over the terrain but not over the sea. The sea values for this image are masked in black. This accentuates the coastline of the island so that it is easily defined and better visualized. The second image shows beam height over both, land and sea. The beam heights used in the analysis is the bottom portion of the beam providing with the worst case scenario.

A distribution of the beam heights over the area within range can be seen in *Figure 4.7*. This histogram shows the occurrence of all of the height value measuring from the terrain to the bottom portion of the beam. As mentioned before, blocked values are given a negative value. Observing the histogram in the figure, note that a large number of occurrences for these blocked areas exists.

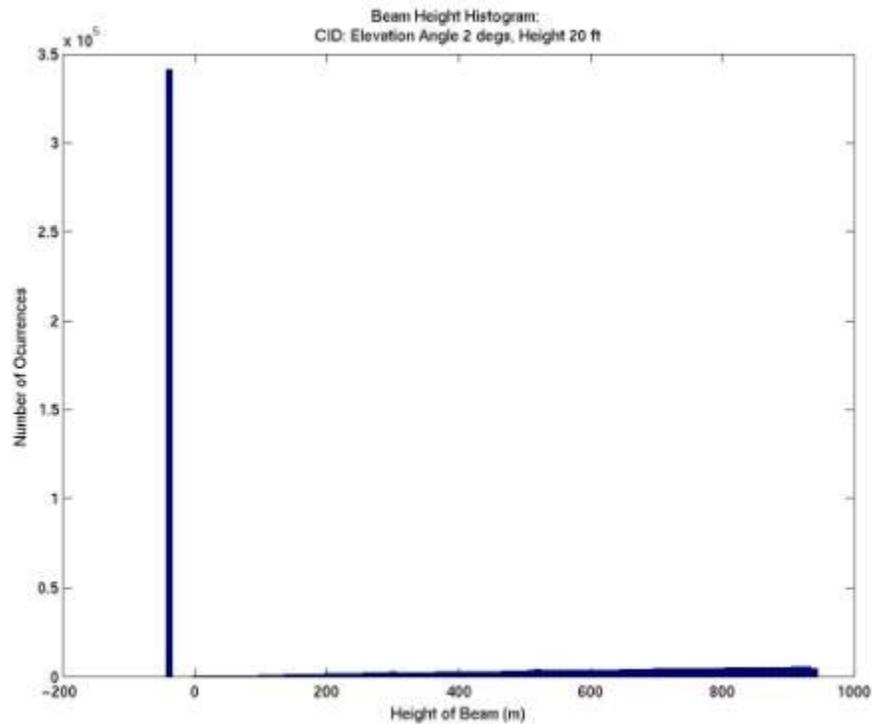
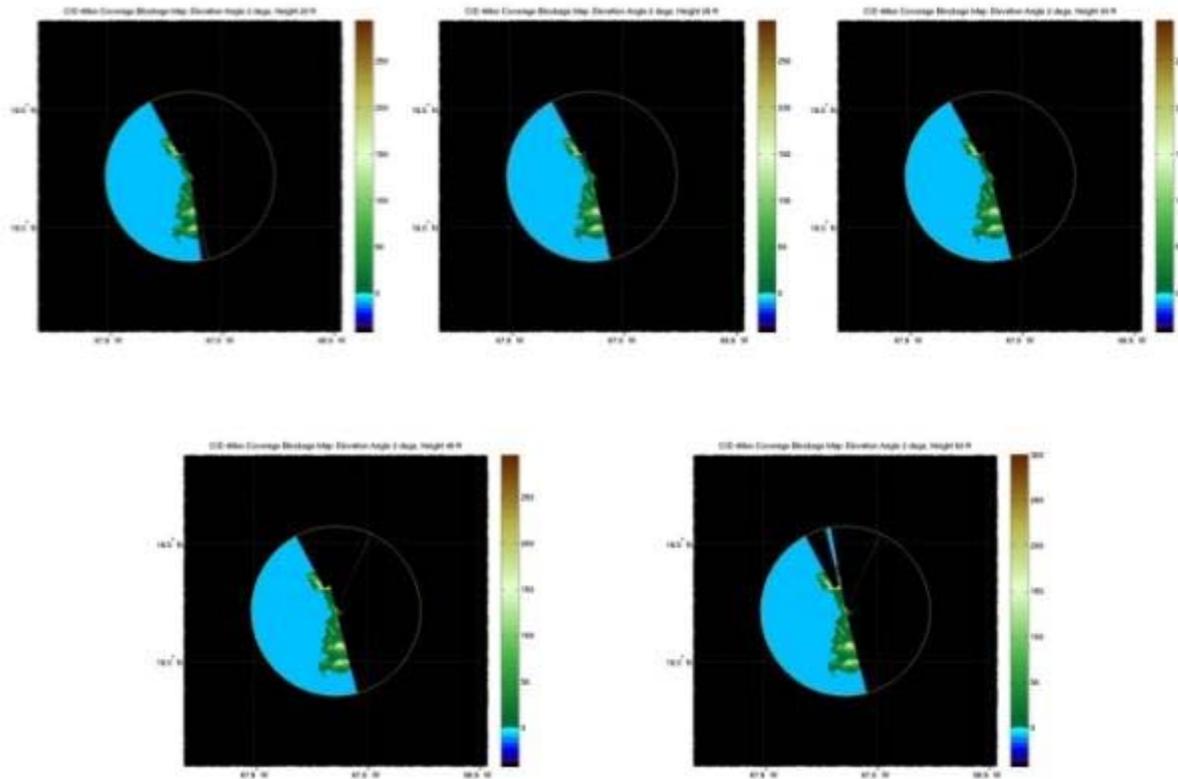


Figure 4.7 CID beam height histogram.

Up to this part of the analysis, the value of the tower height was calculated by on-site measurements performed for each location under consideration. While keeping the elevation angle of the antenna constant at 2.0°, the tower height will be increased to determine the effect of this variable upon the blockage encountered by the radar's beam. Progressions of the simulations incrementing the tower's height are shown in *Figure 4.8*. The current tower height for this site is 20ft and it will be incremented up to 50ft. This value is the largest tower height being considered for radar deployment in this site survey.



**Figure 4.8 CID tower height variation simulation results.**

*Table 4.2* shows how the change in percentages of coverage when varying the tower heights used in the simulation.

**Table 4.2 CID coverage variations as function of tower height.**

Tower Height	Coverage over Land	Coverage over Sea
20	5.7156 %	38.9173 %
25	6.3490 %	39.4669 %
30	6.6416 %	39.7610 %
40	6.9226 %	39.7723 %
50	7.2029 %	40.4157 %

From *Table 4.2* little variability in the percentages of coverage can be observed. Less than 1% is observed in change when varying the tower height. Tower heights are mainly affected by the immediate surroundings of the radar's location within the site. They are affected by trees, buildings, and other natural or man-made obstacles surrounding the radar. Though for this site, tower height had minimal effect, this may not necessarily hold true for other radar locations in which small hills may be easily overcome increasing tower heights. This being the case, the recommended tower height for this site is 20ft.

The tower heights effect on the blockage encountered by the radar was determined. Now, the tower's height will be constant and a new variable will be incremented to determine its effect upon blockage. The antenna's elevation angle will be incremented from 2° to 5°. Since one of the goals is to observe the atmosphere close to the earth's surface, 5° is the maximum elevation angle being considered for the radar in this analysis. Progressions of the simulations incrementing the antenna's angle of observation are shown in *Figure 4.9*.

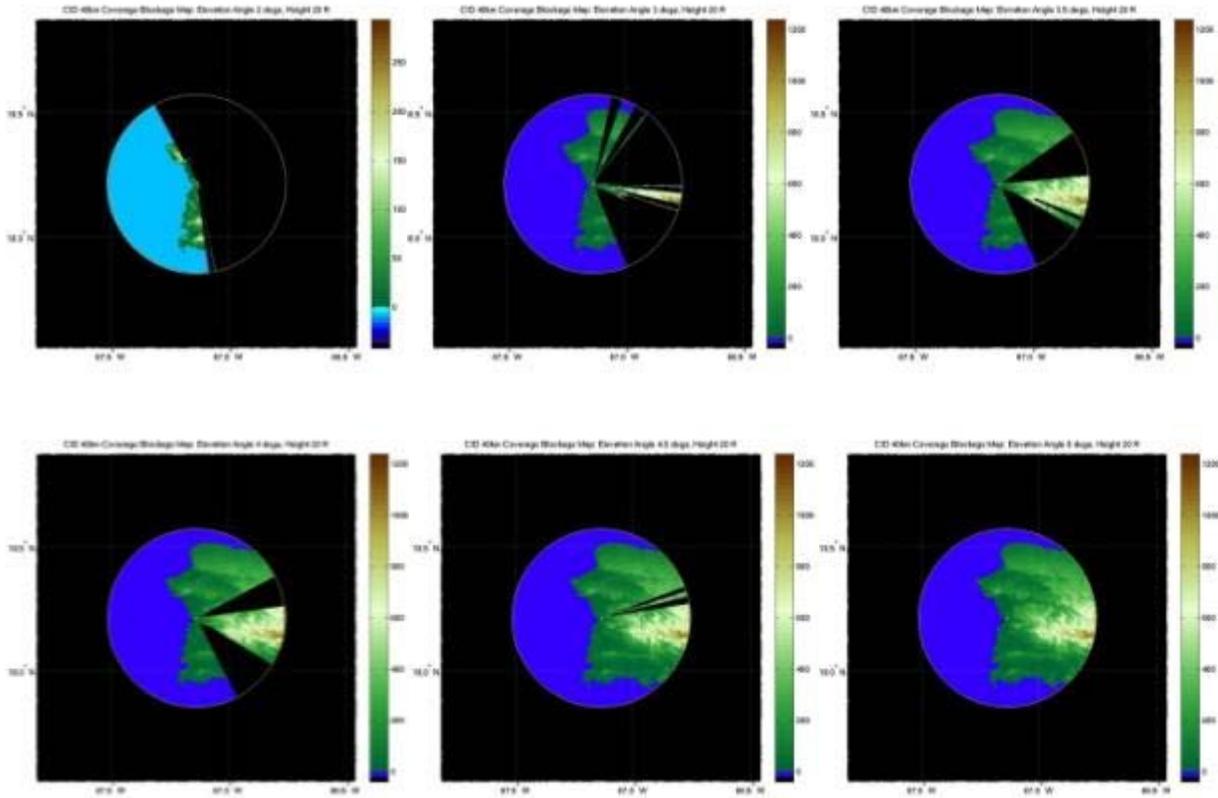


Figure 4.9 CID angle of observation variation simulation results.

The antenna's angle of observation has great effect on the encountered beam blockage from what can be observed in *Figure 4.9*. Six different elevation angles were simulated in this analysis. Through these, it was determined that in order to avoid beam blockage for this site, an antenna observation angle needs to be at least 5°.

From previous analyses different parameters within the simulations were modified to determine their effect. Through these new parameters were developed for which no beam blockage occurs. These are for a tower height of 20ft and a minimum observation angle of 5°. The simulations results for these new determined parameters are presented in the following figures.

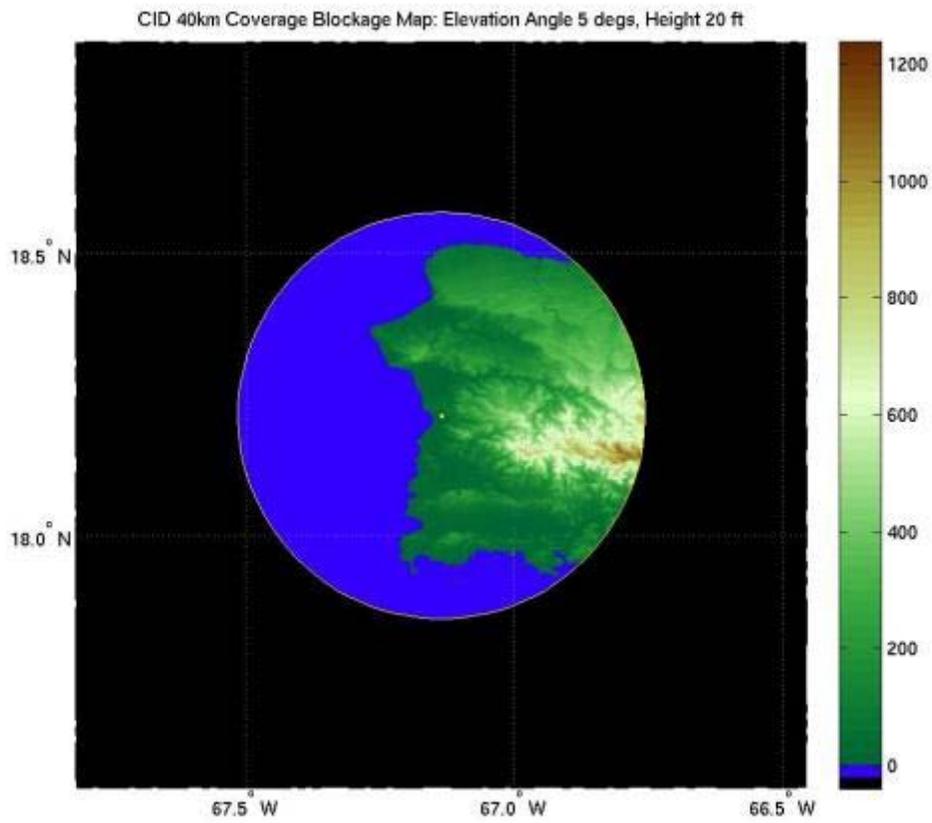


Figure 4.10 CID no blockage coverage map.

CID Coverage Pie Chart: Elevation Angle 5 degs, Height 20 ft

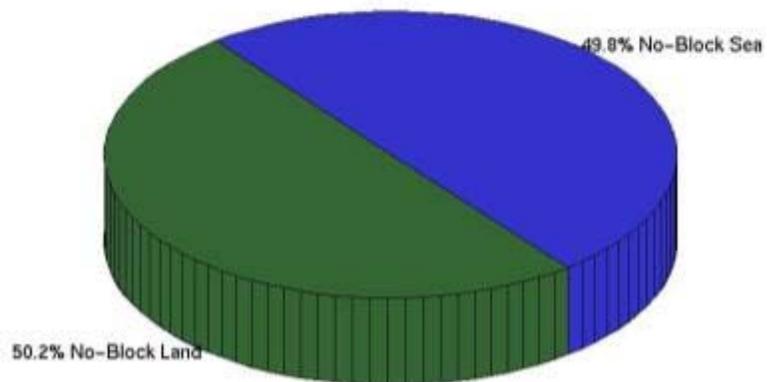


Figure 4.11 CID no blockage coverage area pie chart.

From the pie chart shown in *Figure 4.11*, no blockage portions can be observed and only land and sea coverage percentages are presented. The quantified values for these areas of coverage are shown in *Figure 4.12*.

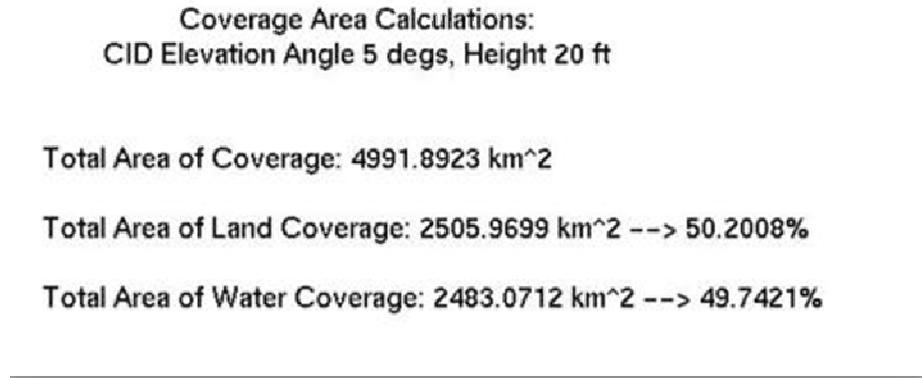


Figure 4.12 CID coverage area calculations.

Beam height images were also obtained with these parameters and can be observed in *Figure 4.13*.

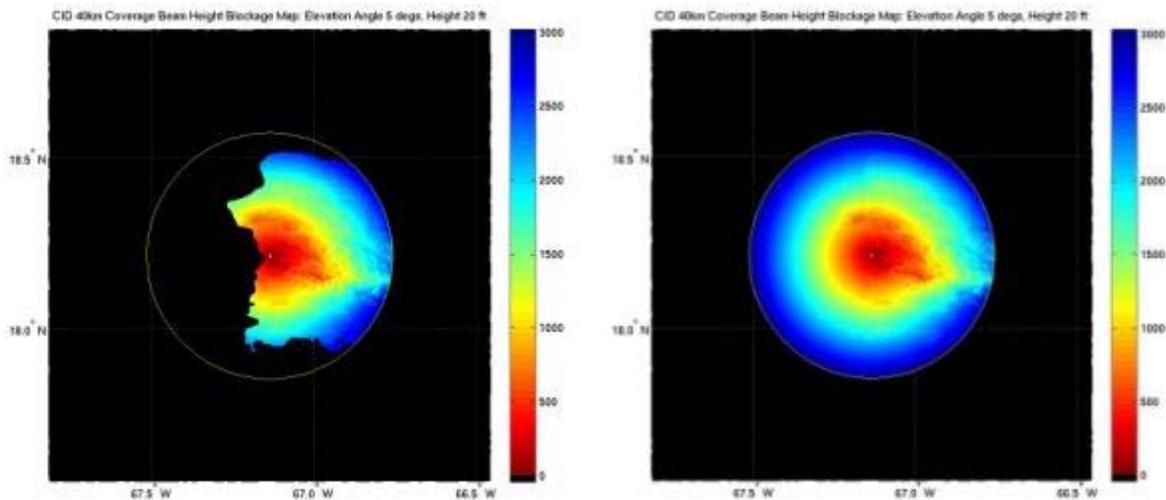
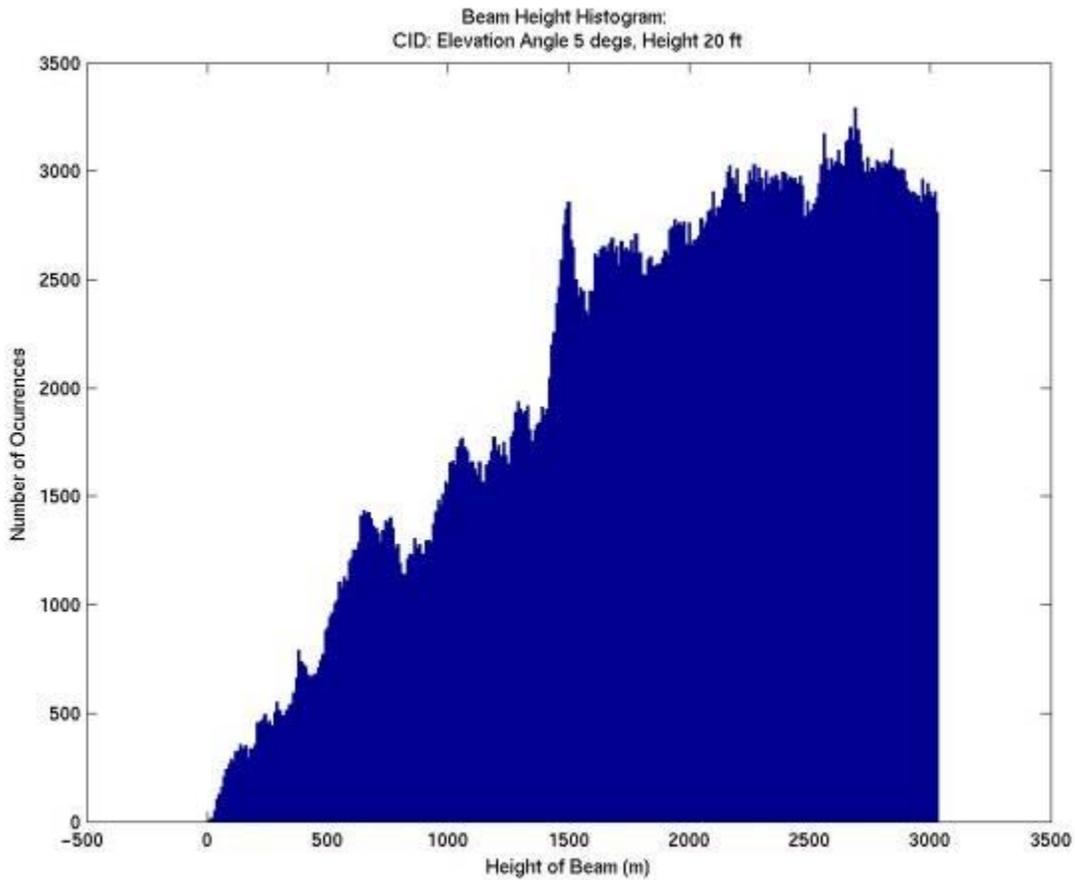


Figure 4.13 CID no blockage beam height diagrams.

The distribution of beam heights over the terrain can be observed in *Figure 4.14*. Note that no negative values are observed in the histogram since no blockage is encountered at these simulated parameters.



**Figure 4.14** CID no blockage beam height histogram.

As part of the site analysis, coverage of vulnerable populated areas and important watersheds for the western region of Puerto Rico were determined. The coverage of the different municipalities composing this vulnerable populated area can be observed in *Figure 4.15*. All municipalities within the vulnerable area are shaded in red all of which are provided with proper coverage by this radar site as observed in the

figure. The Pie chart in *Figure 4.16* confirms that a 100% of coverage is provided to this area.

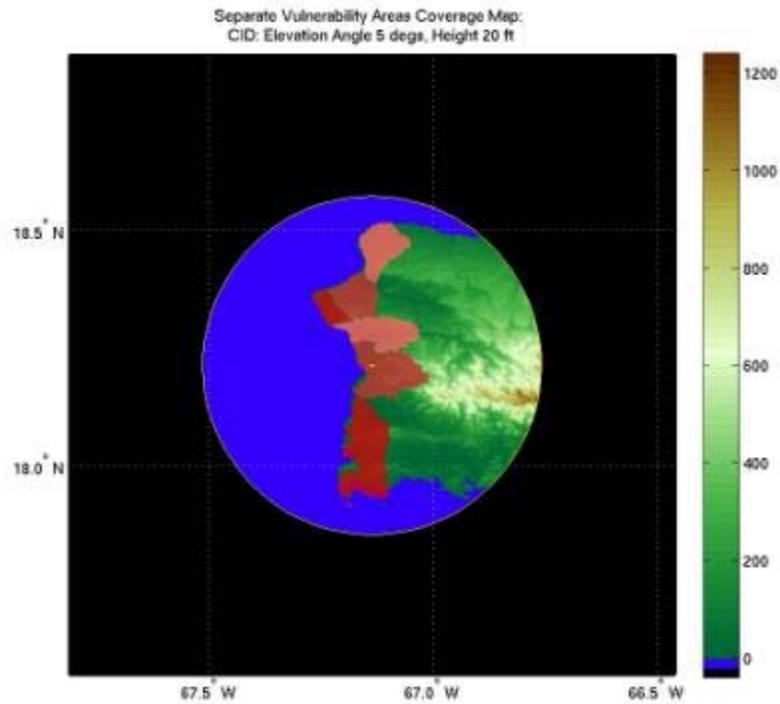


Figure 4.15 CID vulnerable population area coverage.

Vulnerability Coverage Pie Chart:  
CID: Elevation Angle 5 degs, Height 20 ft

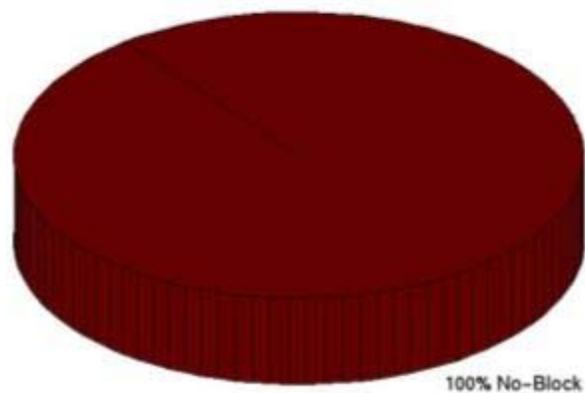


Figure 4.16 CID vulnerable population area coverage pie chart.

Coverage area calculations for the vulnerable population areas can be observed in *Figure 4.17*. These calculations were performed for the entire vulnerable populated area and for each individual municipality. This also confirms that the complete area (697.086 km<sup>2</sup>) is properly provided coverage by the radar.

**CID Vulnerability Area Coverage Calculations:  
Elevation Angle 5 degs, Height 20 ft**

**Total Vulnerability Area: 697.086 km<sup>2</sup>**

**In-Range Vulnerability Area: 697.086 km<sup>2</sup> --> 100%**

**Aguadilla: 102.5379 km<sup>2</sup> --> 100%**

**Aguada: 87.1317 km<sup>2</sup> --> 100%**

**Rincon: 39.8358 km<sup>2</sup> --> 100%**

**Anasco: 110.9214 km<sup>2</sup> --> 100%**

**Mayaguez: 154.7991 km<sup>2</sup> --> 100%**

**Cabo Rojo: 201.8601 km<sup>2</sup> --> 100%**

**Out-of-Range Vulnerability Area: 0 km<sup>2</sup> --> 0%**

**Figure 4.17 CID vulnerable population area coverage calculations.**

Four different watersheds are being considered for this analysis. The watersheds observed are Culebrinas, Rio Grande de Añasco, Yagüez, and Guanajibo. These are plotted in different shades of blue in *Figure 4.18*.

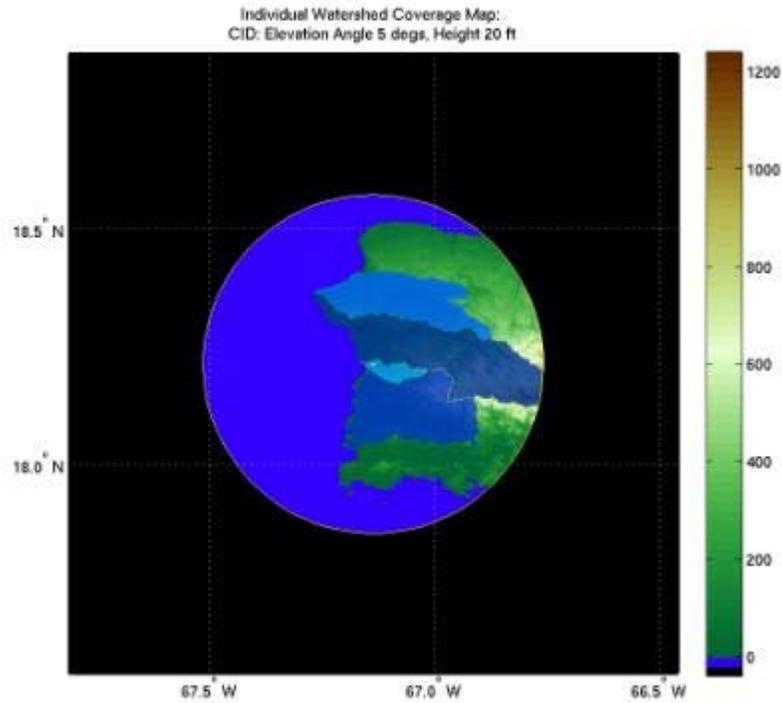


Figure 4.18 CID watershed area coverage map.

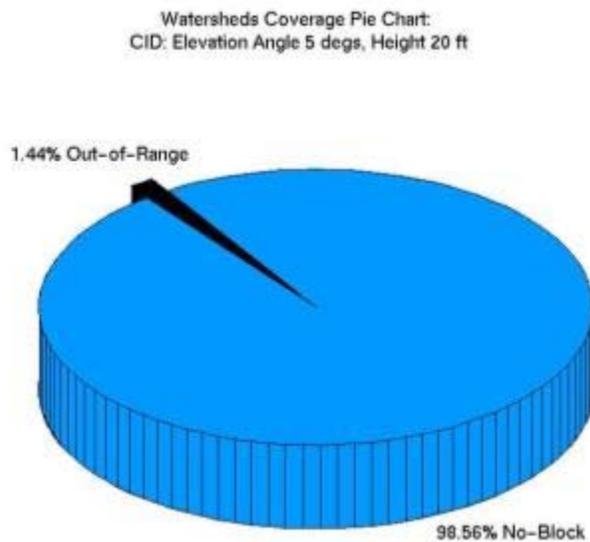


Figure 4.19 CID watershed area coverage pie chart.

The pie chart in *Figure 4.19* shows that 1.44% of the watersheds area is not within the radar's maximum range. Watershed coverage calculations can be observed in *Figure 4.20*. The watersheds area is covered 98.56%. This is because a portion of the Rio Grande de Añasco watershed is located out of the radar's maximum range. In *Figure 4.20* the percentage of coverage for the Rio Grande de Añasco watershed is stated to be 96.58%. This leaves a 3.42% of this individual watershed area without coverage.

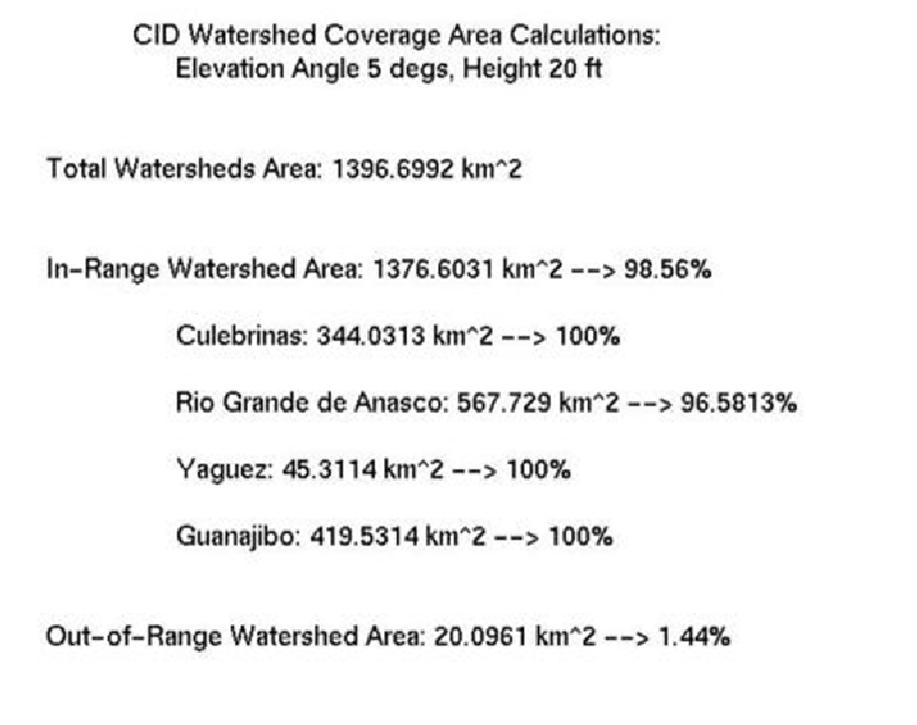


Figure 4.20 CID watershed area coverage calculations.

Although the observation angle determined for this site is a relatively large value (the largest under consideration), provided the infrastructure and area of coverage it offers, the status assigned to this site is: **PASS**.

This analysis was performed for all site locations under consideration. These analyses for each individual site are presented in Appendix 2 of this thesis project. A summary of the PASS/NO-PASS status for each candidate sites can be observed in *Table 4.3*. In *Table 4.4* a summary of the final minimum angle of observation and minimum tower height can be observed as well. These final parameters are presented for only those sites found favorable for radar deployment.

**Table 4.3 Summary of PASS/NO-PASS assigned status to candidate sites.**

Site Location	Status Assigned
CID	PASS
CROEM	PASS
Cerro las Mesas	<b>NO-PASS</b>
Cornelia	PASS
Finca Montaña I	PASS
Finca Montaña II	PASS
Isabela	PASS
Adjuntas	<b>NO-PASS</b>
Lajas	PASS
Isla Magueyes	<b>NO-PASS</b>
Sabana Grande	<b>NO-PASS</b>

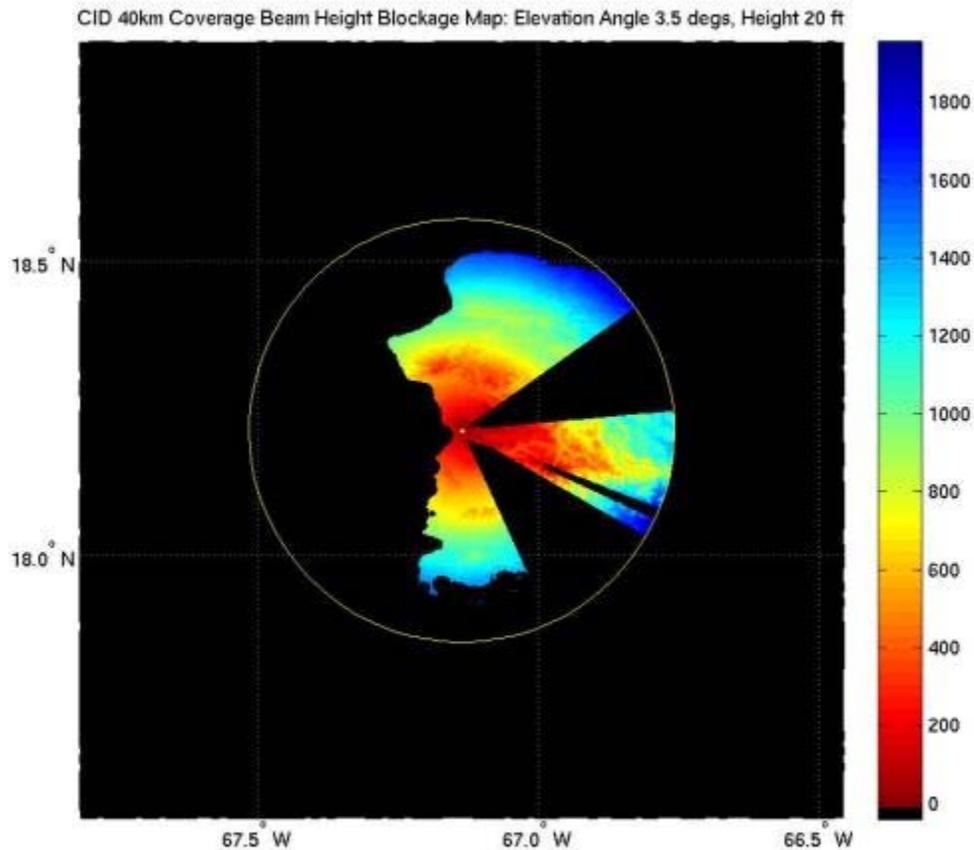
**Table 4.4 Summary of site parameters at which no blockage will occur.**

Site Location	Minimum Tower Height (ft)	Minimum Elevation Angle (°)
CID	20ft	5.0°
CROEM	50ft	3.5°
Cornelia	50ft	3.5°
Finca Montaña I	40ft	3.0°
Finca Montaña II	40ft	3.5°
Isabela	40ft	3.0°
Lajas	30ft	4.0°

#### 4.4 PROPAGATION MODEL COMPARISON

The analyses performed in the previous section for the CID site and for all site locations under considerations in Appendix 2, were performed calculating the height of the beam using *Equation 2.9*. The effective radius of the earth was used for  $k=1$  in *Equation 2.7*. This means that the effective radius equals the actual radius of the earth. To determine the effect of using a different effective radius of the earth to account for atmospheric diffraction simulations were performed for  $k=4/3$ . Blockage analyses were performed and compared in order to determine if this parameter has any effect on the beam blockage encountered. Analyses performed on the CID site were chosen for this comparison. The parameters at which the simulations were performed are: using tower height of 20ft and an antenna elevation angle of 3.5°.

The simulation for the CID site using  $k=1$  can be observed in *Figure 4.21*. In this figure the beam height map presenting blockage is used. This image has been chosen due to the fact that beam elevations can be observed and compared.



**Figure 4.21** CID beam height diagram for angle of beam height propagation model for  $k = 1$ .

As can be observed, considerable blockage occurs over land. This blockage will be quantified and compared to a  $4/3$  effective Earth radius propagation model in order to determine the effect the propagation model has on beam blockage.

Quantified values of the blockage observed in the simulation of *Figure 4.21* can be observed in *Figure 4.22*. A blocked area of  $883.16 \text{ km}^2$  can be observed over land, this is a 35.20% of all the land area within the radar's range. The sea area presenting

blockage cannot be appreciated in this image since sea area is masked-off in black in order to define the Island's coastline. Nevertheless this area was calculated and presented in *Figure 4.22*. It states that an area of 55.64 km<sup>2</sup> being this only a 0.022% of all the sea area within the radars range. This is a very small portion that is being blocked due to ground clutter.

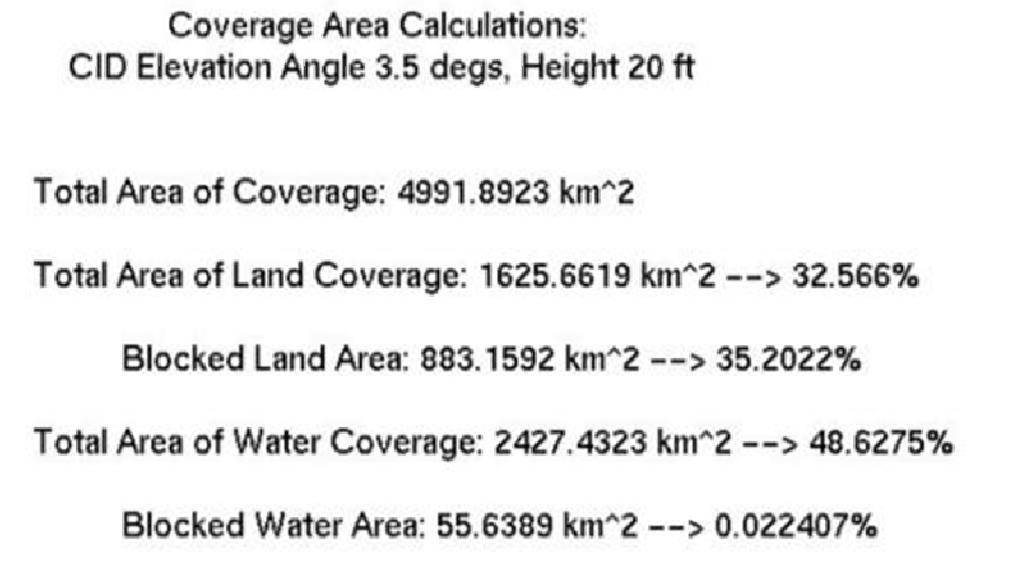


Figure 4.22 CID coverage area calculations for beam propagation model,  $k = 1$ .

The simulations for the  $4/3$  propagation model can be observed in *Figure 4.23*. This means that  $k=4/3$  in the effective radius equation in *Equation 2.7*. Same parameters as for the previous simulations are used in these simulations.

4/3 Propagation Model CID 40km Coverage Beam Height Blockage Map: Elevation Angle 3.5 degs, Height 20 ft

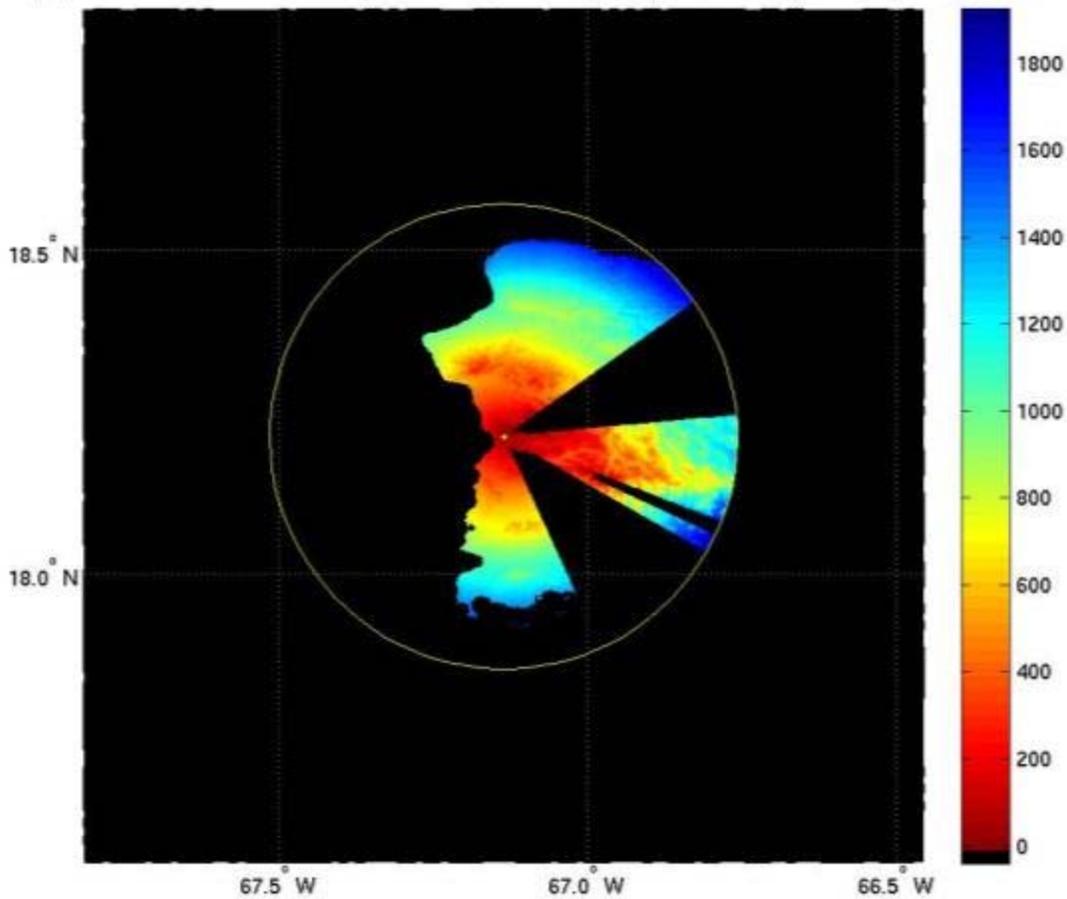


Figure 4.23 CID blockage diagram for beam propagation,  $k = 4/3$ .

From simple observation of the images of the simulations in *Figure 4.21* and *Figure 4.23*, no difference can be easily noted. The areas presenting blockage were quantified for this simulation as well. These calculations can be observed in *Figure 4.24*. It states that for this method of propagation used the calculated blocked area is  $891.63 \text{ km}^2$  which determines that a 35.54% of all land within the radar's range presents blockage. The water area presenting blockage is  $55.6389 \text{ km}^2$ , which is a 0.02% of all the sea area within the radar's range.

**Coverage Area Calculations:  
CID Elevation Angle 3.5 degs, Height 20 ft**

**Total Area of Coverage: 4991.8923 km<sup>2</sup>**

**Total Area of Land Coverage: 1617.1893 km<sup>2</sup> --> 32.3963%**

**Blocked Land Area: 891.6318 km<sup>2</sup> --> 35.5399%**

**Total Area of Water Coverage: 2427.4323 km<sup>2</sup> --> 48.6275%**

**Blocked Water Area: 55.6389 km<sup>2</sup> --> 0.022407%**

Figure 4.24 CID coverage area calculations for beam propagation model,  $k = 4/3$ .

*Table 4.5* shows the comparison between both methods of propagation. Since the  $4/3$  propagation model accounts for diffraction of the beam towards the surface of the earth, more blockage can be expected. Though this can be observed in *Table 4.5*, the difference is little, only 0.3377%.

**Table 4.5 Blockage area coverage comparison.**

	Propagation Model K = 1	Propagation Model K = 4/3	Difference
<b>Blocked Land</b>	883.1592 km <sup>2</sup>	891.6318 km <sup>2</sup>	8.4726 km <sup>2</sup>
	35.2022 %	35.5399 %	0.3377 %
<b>Blocked Water</b>	55.6389 km <sup>2</sup>	55.6389 km <sup>2</sup>	0
	0.0224 %	0.0224 %	0

This is observed not only in analyses for the CID site, but for all of the candidate sites under consideration. In an effort to understand the difference between both propagation models, a plot was created where both models are graphed together as a function of range. This plot can be observed in *Figure 4.25*.

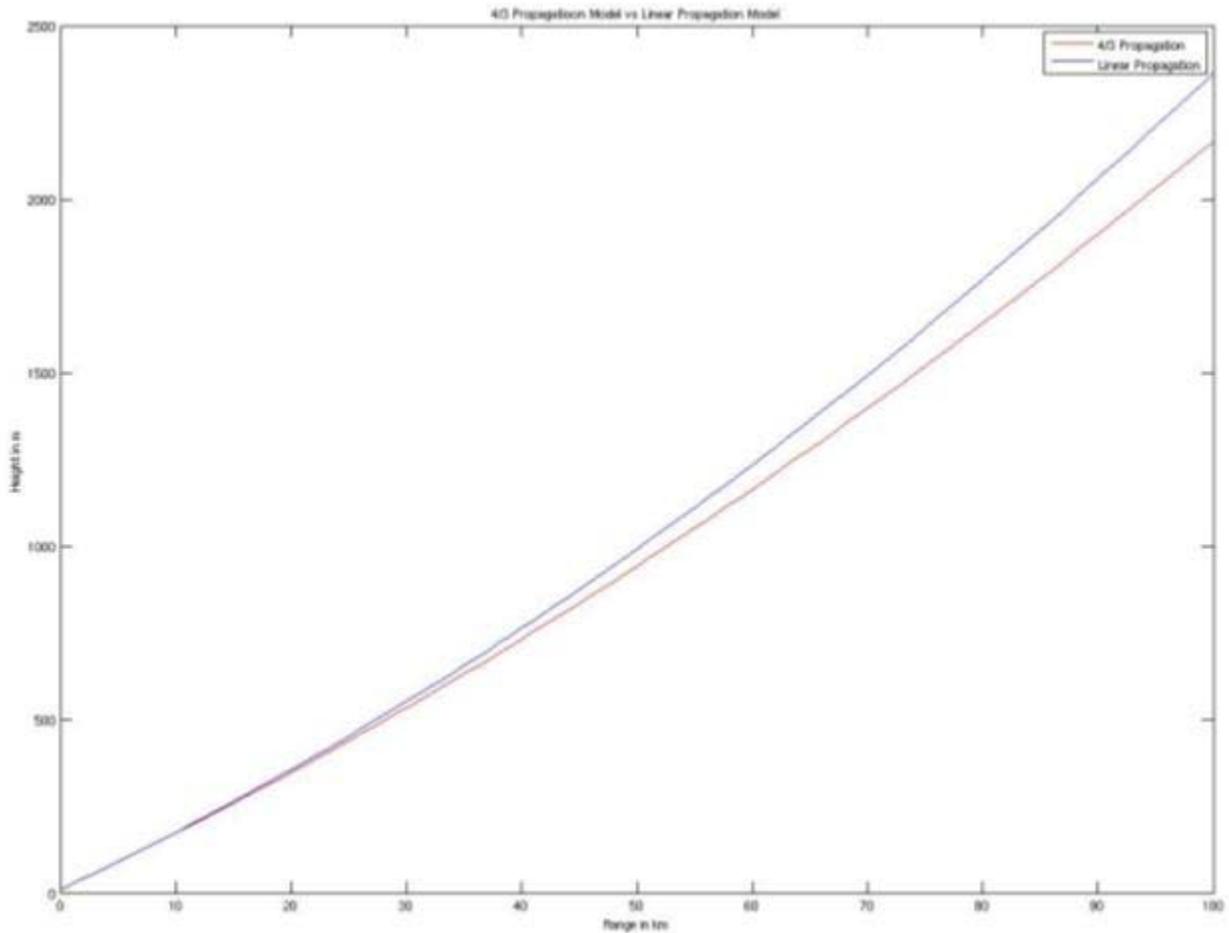


Figure 4.25 Propagation model comparison plot.

The plot in the figure shows that both models were plotted up to a range of 100km. It can be observed that the effects of the 4/3 propagation model on the radar's beam propagation increases with range. Since the maximum range of the radars being considered in this site survey is 40km, the difference between both methods of propagation is minimal.

## 5. DESCRIPTION OF CANDIDATE CONFIGURATIONS

Site locations under consideration were all analyzed in previous chapters. Not all of them however, were determined favorable for radar deployment. The site locations that were found favorable for radar deployment were involved in a second stage of analyses. This second stage of analyses consists in evaluating sites in groups. Since this site survey serves as a tool to determine the location for a network of radars, different configurations formed from the sites found favorable will be evaluated. These will be comprised by three different sites since the number of radars for the network to be deployed in the western region of Puerto Rico is three.

### 5.1 SELECTING SITE CONFIGURATIONS

Different three-radar networks configurations can be built from the candidate sites that were considered favorable for radar deployment. Although a large number of combinations can be built, not all were evaluated. It is favorable for the radar network to have specified geometrical configurations. The interest for this site survey is to define a network configuration for three radars that would yield the best performance. The performance for this radar network will be measured in terms of area of coverage, network retrieval capability, and multi-Doppler capabilities. Overlap of the radars forming the network is a vital key in providing best performance for the network. Not only this but, the individual perspective angle of each of the radars to observe an event at the same time is important as well. In order to satisfy these requirements, the best possible geometrical configuration this radar network can have is the shape of a

triangle. Although a linear configuration can provide with a large area of coverage (larger than for a triangle) it does not provide for best overlap areas for 2 or more radars. This is where a triangular configuration excels a linear one.

Although a geometrical configuration for the radar is known, there is a limitation encountered. This project's ability to provide a triangular configuration for the radar network is bound by the geographical location of the selected candidate sites.



Figure 5.1 Selected candidate sites map location.

The candidate sites to form these configurations can be divided in three groups of regions given their geographical location. *Figure 5.1* shows the location of the selected candidate sites. The radar sites can be separated into northern region sites, center region sites and southern region sites. These can be observed in *Table 5.1*.

**Table 5.1 Selected candidate sites divided into regions.**

Northern Region	Center Region	Southern Region
Finca Montaña I	CID	Lajas
Finca Montaña II	CROEM	
Isabela	CORNELIA	

The three sites for each configuration will be built choosing one site from within each region. The formed configurations are listed in *Table 5.2*.

**Table 5.2 Candidate configurations.**

	Northern Region	Center Region	Southern Region
<b>1</b>	Finca Montaña I	CID	Lajas
<b>2</b>	Finca Montaña I	CROEM	Lajas
<b>3</b>	Finca Montaña I	Cornelia	Lajas
<b>4</b>	Finca Montaña II	CID	Lajas
<b>5</b>	Finca Montaña II	CROEM	Lajas
<b>6</b>	Finca Montaña II	Cornelia	Lajas
<b>7</b>	Isabela	CID	Lajas
<b>8</b>	Isabela	CROEM	Lajas
<b>9</b>	Isabela	Cornelia	Lajas
<b>10</b>	CID	CROEM	Lajas

One exception can be observed in *Table 5.2*. Configuration number 10 is formed from the three radars within the center region. This configuration was chosen due to the fact that it forms a triangle. It is a small triangle meaning that the distance between radars is small. Nevertheless, it will be evaluated for performance. Some of the configurations can be observed in *Figure 5.2* through *Figure 5.7*.

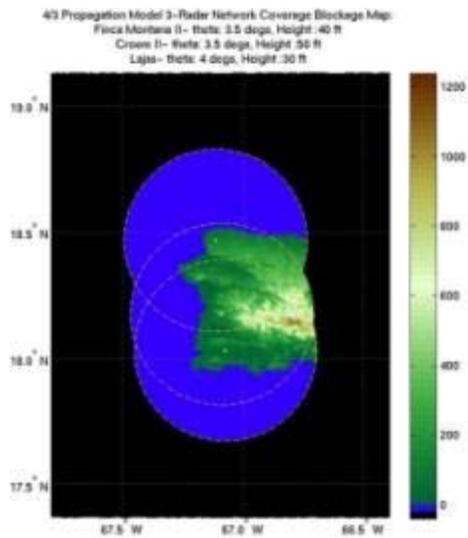


Figure 5.2 Finca Montaña II, CROEM, and Lajas configuration.

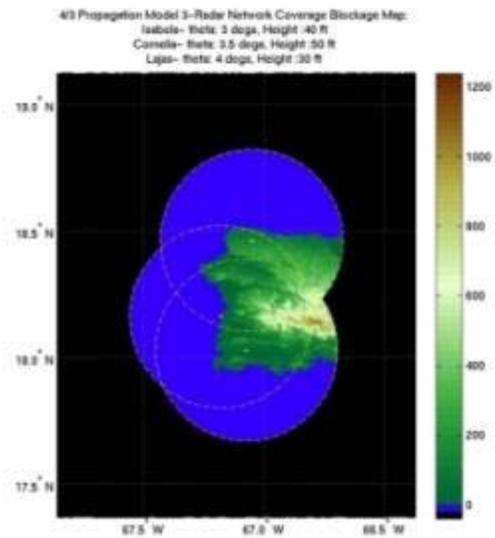


Figure 5.4 Isabela, Cornelia, and Lajas configuration.

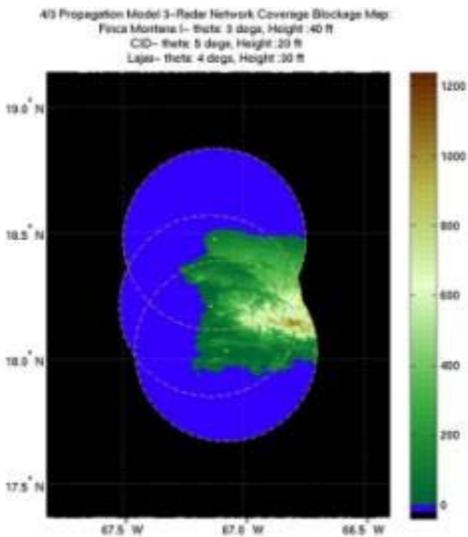


Figure 5.3 Finca Montaña I, CID, and Lajas configuration.

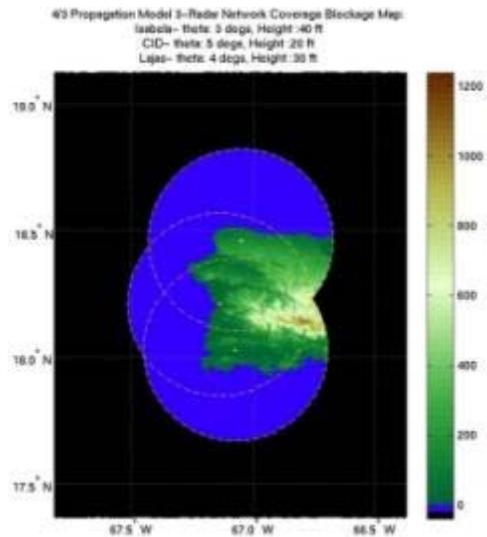


Figure 5.5 Isabela, CID, and Lajas configuration.

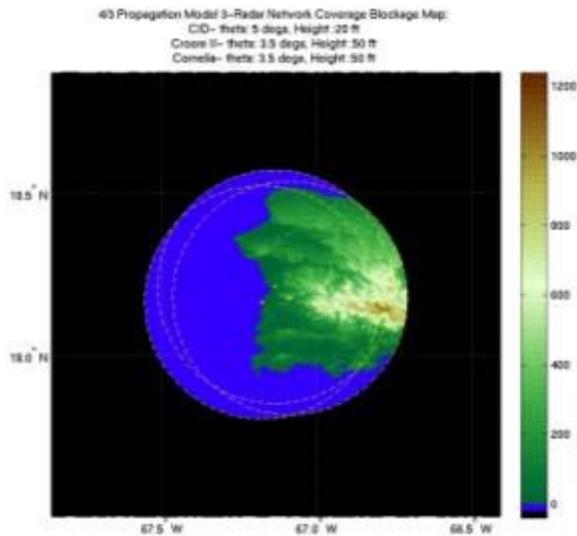


Figure 5.6 CID, CROEM, and Cornelia configuration.

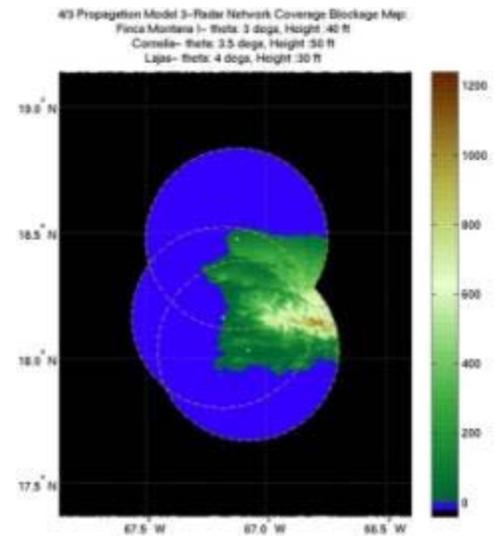


Figure 5.7 Finca Montaña I, Cornelia, and Lajas configuration.

## 5.2 DEVELOPED MATLAB TOOL (STAGE II)

In the previous chapter the analyses for a single radar location were determined using the first stage of the Matlab tool. Using the results from those analyses, selected radar sites were formed into configurations. The second stage of this tool evaluates the performance and capabilities of the radar network configuration. A diagram for the second stage of the developed Matlab tool can be observed in *Figure 5.8*.

The first part of the second stage of the tool prepares a map taking into consideration the location of the three sites forming the network. The three inputs for this part are the geographical coordinates corresponding to each site. This part outputs a map containing the three radar sites then saving it to a desired directory and inputting it to the next part of the program. The second part of this stage finds the stored maps of the three sites selected. It loads the coverage maps, the blockage maps, and the beam

height maps for each site. It subsequently determines the size of the input map (from part one) and equals all map sizes to that of the new map maintaining the geographical location within it. This enables calculations and analyses performed further on the program.

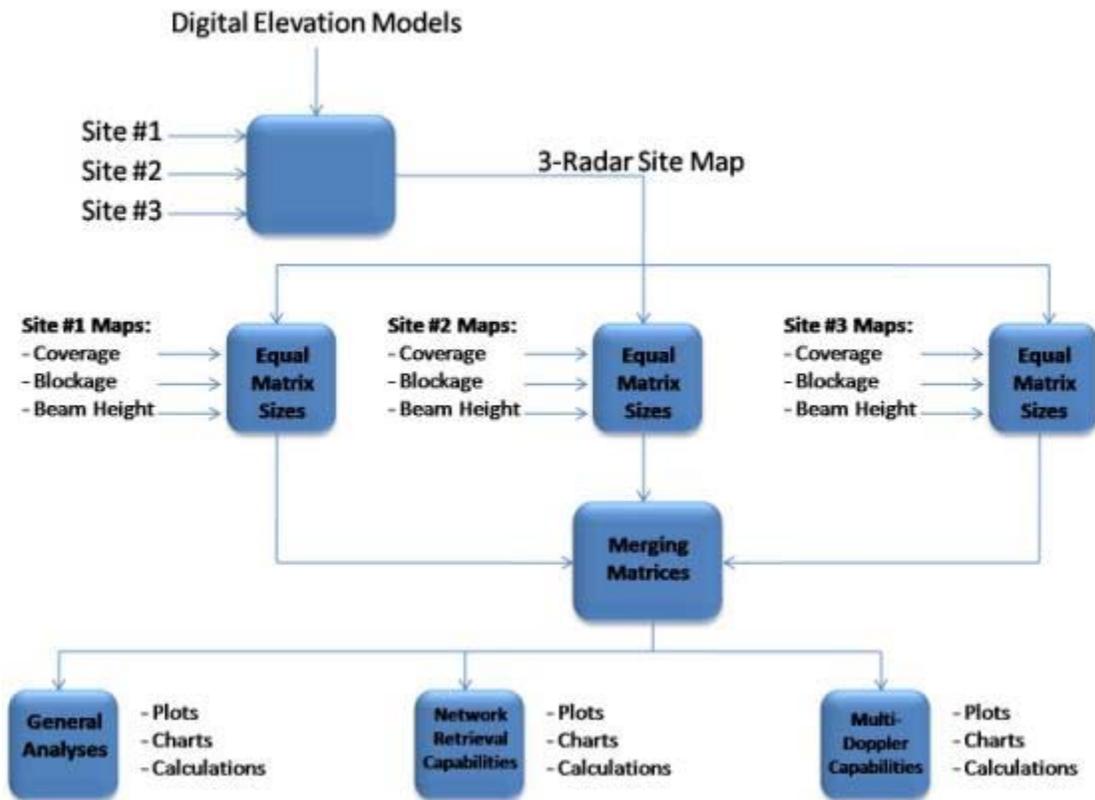


Figure 5.8 Diagram for the second stage of the developed Matlab tool.

After the program has equaled the sizes of all of the loaded maps in the previous part, it merges these maps into one from which the program outputs general coverage plots, charts, and calculations. The next part evaluates two different network derived capabilities. The first one of these is the capability of network retrieval which is analyzed and results are provided to the user with plots, charts, and calculations. Similarly the capability of retrieving multi-Doppler from the network configuration is

determined and the results are returned to the user in plots, charts, and calculations as well.

All of these analyses can be observed in the following sections of this chapter in which a three-radar configuration will be evaluated using this second stage of the developed Matlab tool.

As in the first stage of analyses, in this second stage the performance of the radar network was evaluated over areas of interest. This stage not only determines proper coverage over areas of population with high indices of vulnerability and over important watersheds, but it also evaluates the capabilities of the network over these regions.

This developed Matlab tool can be used by the scientific community as an aid in developing radar networks where currently no coverage is provided. Having good performance simulations is an essential first step in the deployment of any radar network. It can be ideally used for areas with irregular topography.

### 5.3 SITE CONFIGURATION ANALYSES

From *Table 5.2* and *Figure 5.2* through *Figure 5.7* , the best geometrically shaped networks are configurations 9 (*Figure 5.4*) and 10 (*Figure 5.6*).

The analyses for each of the configurations were performed using the parameters for each individual site that produces no beam blockage. For example configuration 9 is comprised of Isabela, Cornelia, and Lajas. The parameters determined from previous analyses for these are listed in *Table 4.4*. For example

configuration 9 requires that for Isabela the tower height used is 40ft and antenna elevation angle is 3.0°.

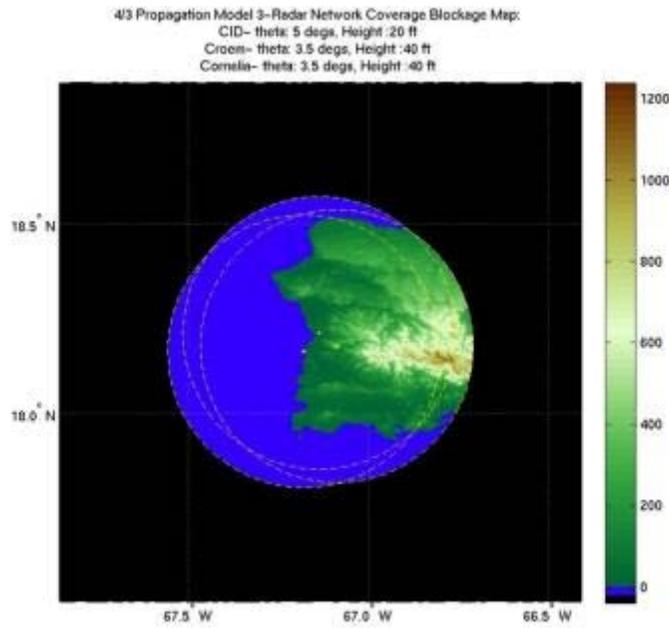


Figure 5.9 CID, CROEM, and Cornelia configuration.

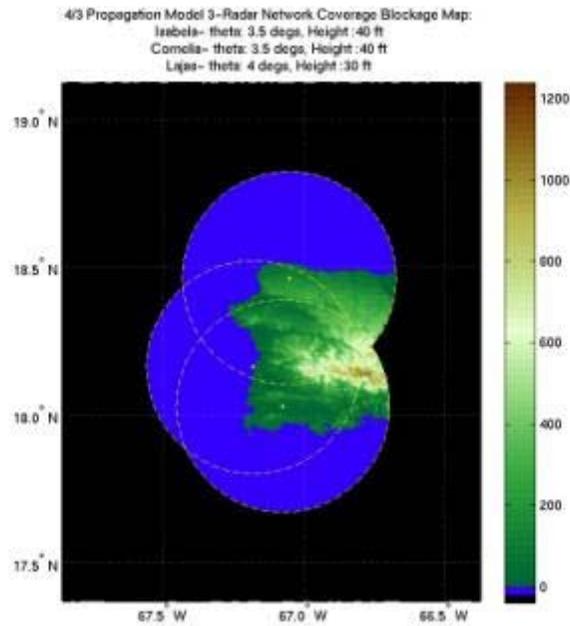


Figure 5.10 Isabela, Cornelia, and Lajas configuration.

### 5.3.1 AREA OF COVERAGE

Given their geographical locations the different configurations yield different areas of coverage. *Figure 5.11* shows the calculations performed for the Isabela, Cornelia, and Lajas configuration. It states that the total area of coverage within the networks range is 9168.60 km<sup>2</sup>. Of this, 33.12% is composed of land area and 66.88% is composed of sea area.

#### **4/3 Propagation Model 3–Radar Network Coverage:**

**Isabela– theta: 3 degs, Height :40 ft**

**Cornelia– theta: 3.5 degs, Height :50 ft**

**Lajas– theta: 4 degs, Height :30 ft**

**Total Area of Coverage: 9168.6006 km<sup>2</sup>**

**Total Area of Land Coverage: 3036.3012 km<sup>2</sup> --> 33.1163%**

**Total Area of Water Coverage: 6132.2994 km<sup>2</sup> --> 66.8837%**

**Figure 5.11 Isabela, Cornelia, Lajas surface area calculations.**

The surface area calculations for the CID, CROEM, and Cornelia configuration are shown in *Figure 5.12*. It shows that the area total area of coverage is 5936.74 km<sup>2</sup>. This area is composed of 46.78% land area and 53.21% sea area.

4/3 Propagation Model 3–Radar Network Coverage:

CID– theta: 5 degs, Height :20 ft

Croem II– theta: 3.5 degs, Height :50 ft

Cornelia– theta: 3.5 degs, Height :50 ft

Total Area of Coverage: 5936.7411 km<sup>2</sup>

Total Area of Land Coverage: 2777.3199 km<sup>2</sup> --> 46.7819%

Total Area of Water Coverage: 3159.4212 km<sup>2</sup> --> 53.2181%

Figure 5.12 CID, CROEM, Cornelia surface area calculations.

Table 5.3 shows the comparison of surface area coverage provided by each network. It can be observed that the Isabela, Cornelia and Lajas configuration covers more area than the CID, CROEM, and Cornelia. Although the Isabela, Cornelia, & Lajas configuration covers more land area, the main difference between both configurations is in sea area coverage.

Table 5.3 Configuration comparison of surface area coverage.

	Isabela, Cornelia, & Lajas	CID, CROEM, & Cornelia	Difference
Total Area of Coverage	9168.60 km <sup>2</sup>	5936.74 km <sup>2</sup>	3231.86 km <sup>2</sup>
Land Area	3036.30 km <sup>2</sup>	2777.32 km <sup>2</sup>	258.98 km <sup>2</sup>
Sea Area	6132.30 km <sup>2</sup>	3159.42 km <sup>2</sup>	2972.88 km <sup>2</sup>

### 5.3.2 MINIMUM BEAM HEIGHT

Using the tool developed in Matlab, the radar network's beam height within the area of coverage for each radar was determined and plotted. The beam height plots for the Isabela, Cornelia, and Lajas configuration can be observed in *Figure 5.13* and *Figure 5.14*. Within radar overlap regions, the lowest beam height between the radars is used and are the values shown in the diagram. The color bar to the right of each diagram shows the elevation of the beam in meters.

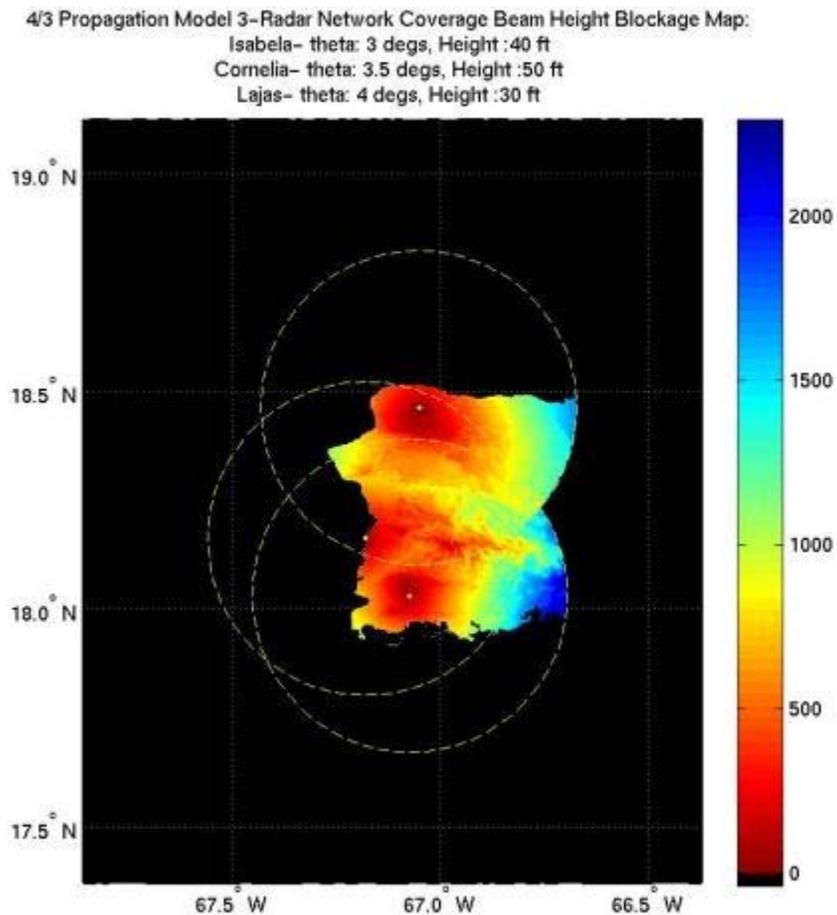
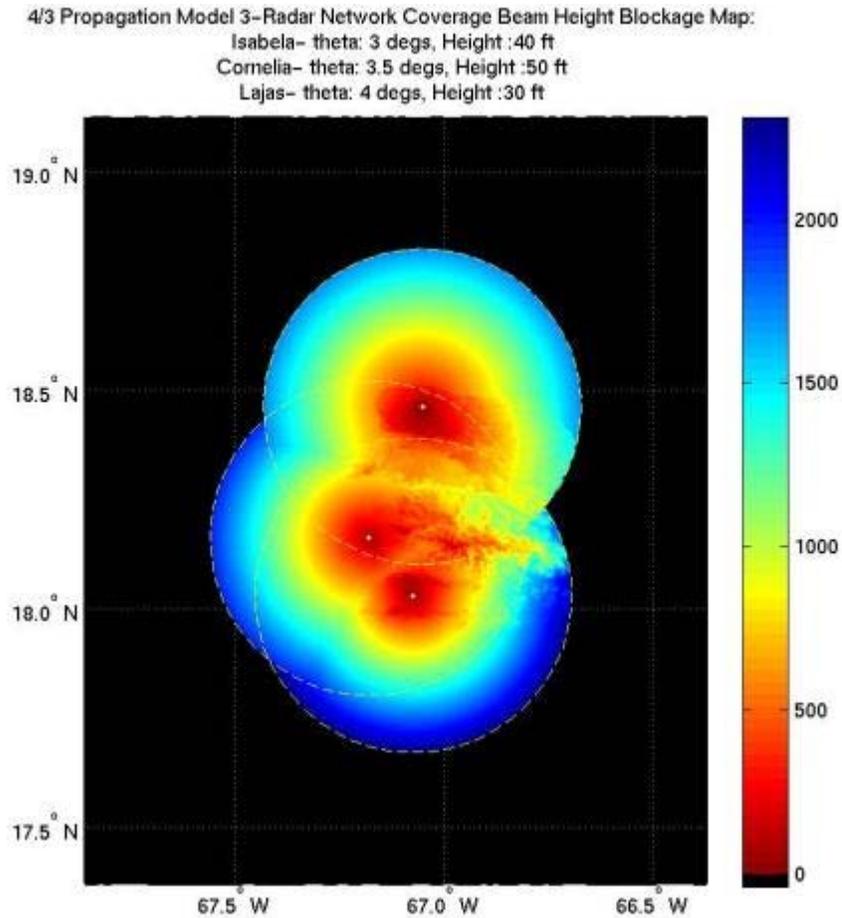


Figure 5.13 Isabela, Cornelia, & Lajas beam height diagram (masked sea area).



**Figure 5.14 Isabela, Cornelia, & Lajas beam height diagram.**

As in the analyses in previous chapters, the diagram images in *Figure 5.13* and *Figure 5.14* show the same beam height plot. The difference between them is that in order to visualize the island's coastline, the sea area is masked of in black. This is the case for *Figure 5.13*. These same simulations were performed for the CID, CROEM, and Cornelia configuration. These can be observed in *Figure 5.15* and *Figure 5.16*.

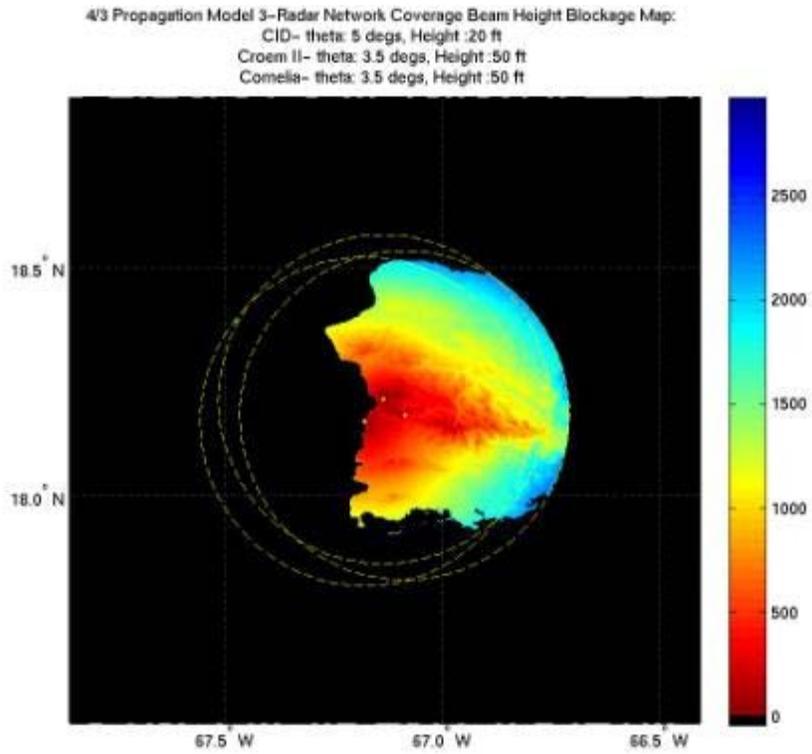


Figure 5.15 CID, CROEM, & Lajas beam height diagram (masked sea area).

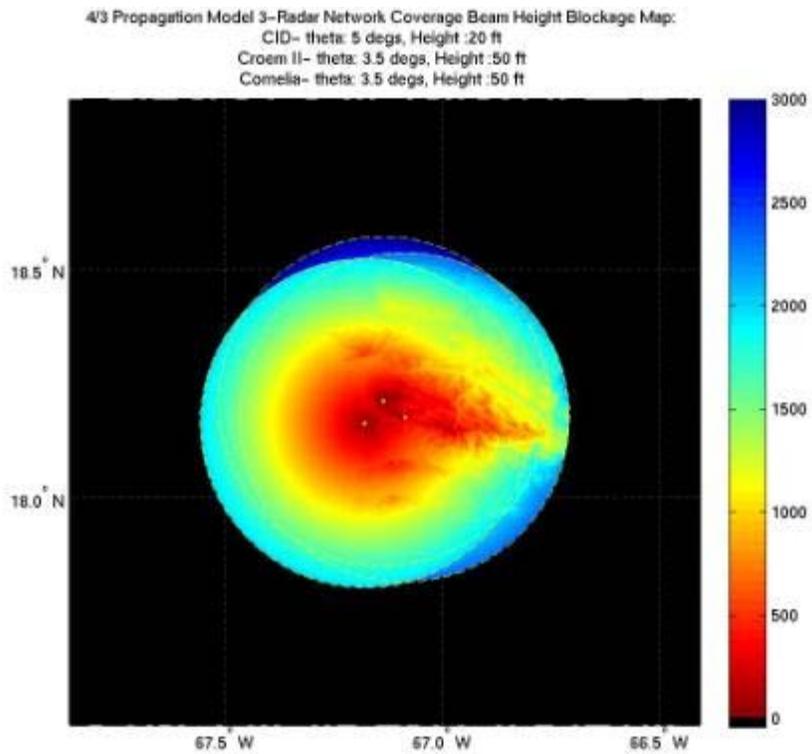
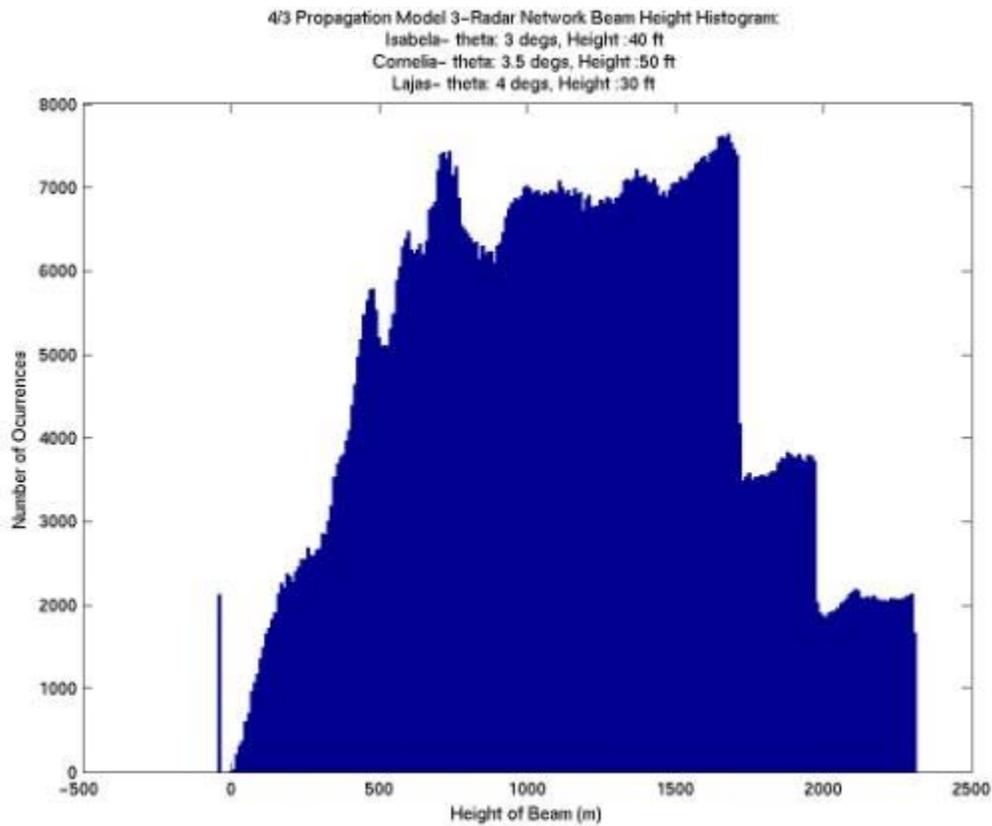
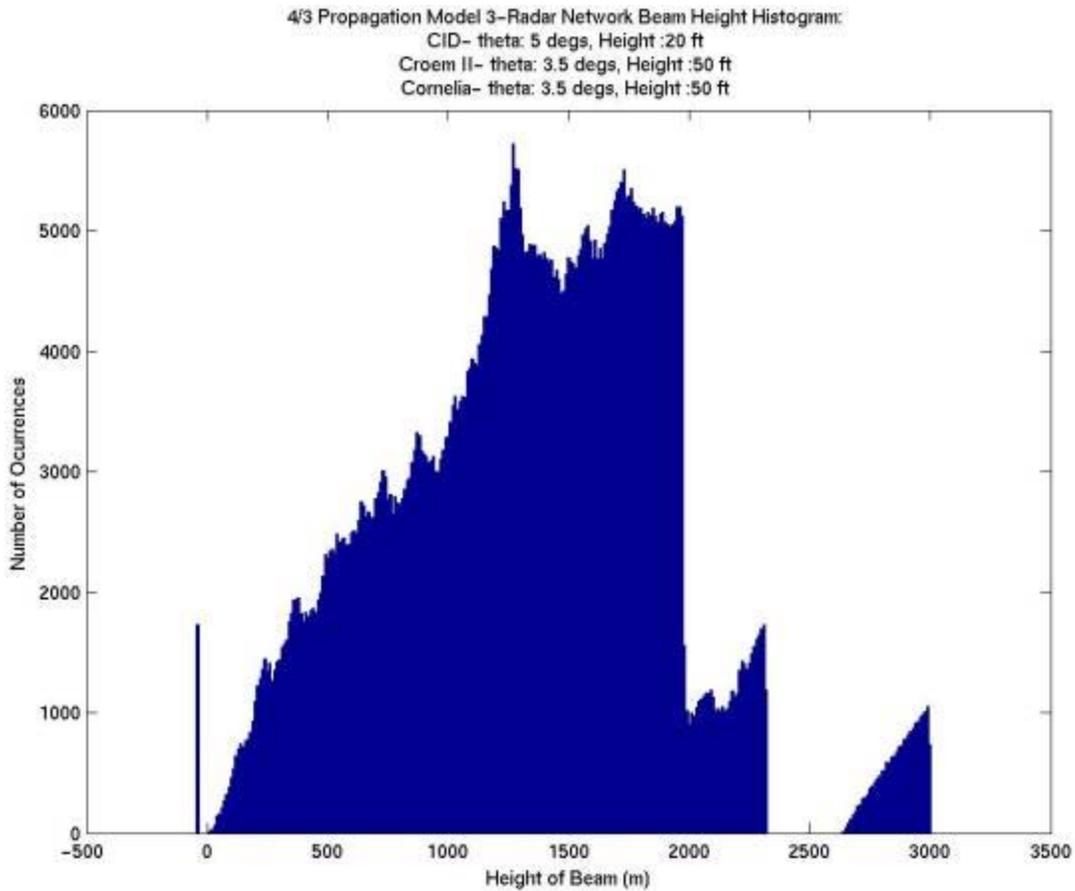


Figure 5.16 CID, CROEM, & Lajas beam height diagram.

Some visual analyses can be performed for these simulation results. Given that the color bar for each of the diagrams goes from red (lesser values of beam heights) to blue (higher values of beam heights) some conclusions can be derived. By looking at *Figure 5.13* a greater distribution of reddish colors can be observed over the surface. This means that a greater number of lower beam heights exist over land. This is the interest of this project since one of the goals is to be able to sense the atmosphere close to the surface of the earth. These results can be confirmed by observing the histograms in *Figure 5.17* and *Figure 5.18*. These histograms plot the occurrences of beam height values over the total area of coverage.



**Figure 5.17 Isabela, Comelia, & Lajas beam height histogram.**

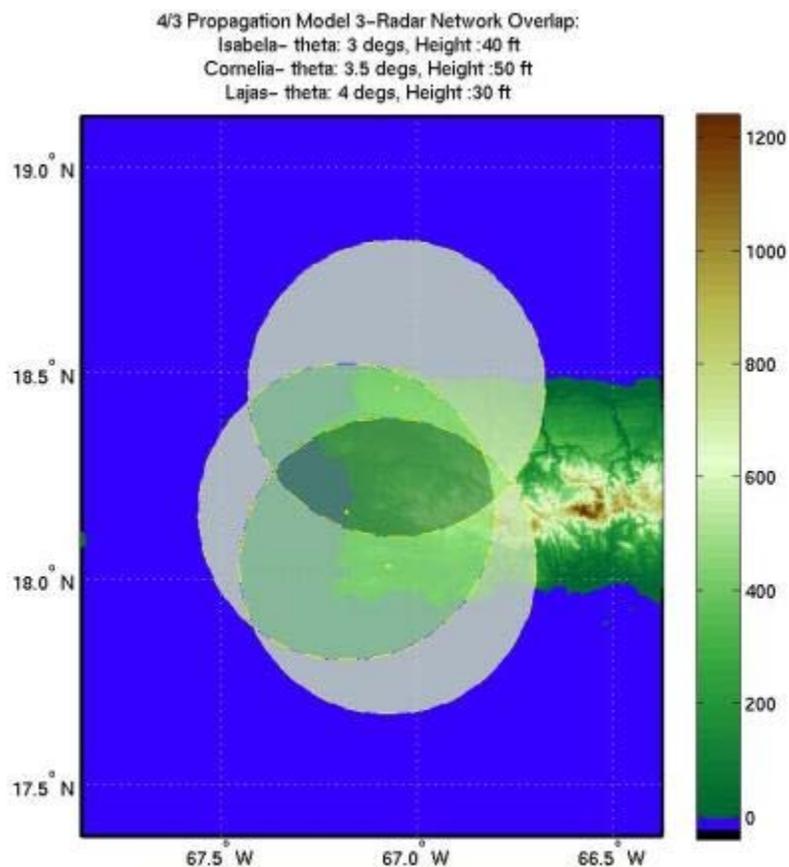


**Figure 5.18 CID, CROEM, & Lajas beam height histogram.**

For the Isabela, Cornelia and Lajas configuration a large number of occurrences can be observed for beam height values less than 1000 m. One of the largest number of occurrences for this configuration can be observed to occur for the beam height value of around 750m. This excels what can be observed in the histogram for the CID, CROEM, and Cornelia configuration. Evidently, these histograms confirm what was visually analyzed from the diagrams.

### 5.3.3 NETWORK RETRIEVAL CAPABILITIES

Network retrieval capabilities are determined by the overlap area of the radar network. This is so, since that network retrieval algorithms depend in the simultaneous observation of the same event by two or more radars. This capability was evaluated with the developed Matlab tool. The results for the Isabela, Cornelia, & Lajas configurations are shown in *Figure 5.19* through *Figure 5.21*. *Figure 5.19* shows the coverage of the network of radars over the Island. The overlap regions are identified by different shades of green, the darker green being the region of overlap by three-radars.



**Figure 5.19** Isabela, Cornelia, and Lajas overlap regions.

4/3 Propagation Model 3-Radar Network Overlap Pie Chart:  
 Isabela- theta: 3 degs, Height :40 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft  
 Lajas- theta: 4 degs, Height :30 ft

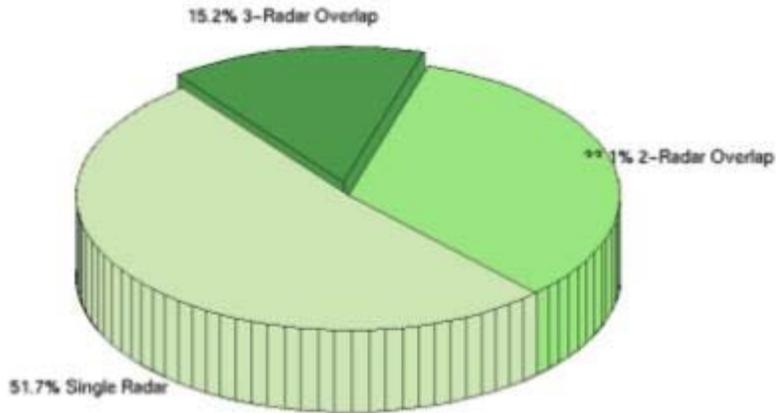


Figure 5.20 Isabela, Cornelia, and Lajas pie chart of overlap regions.

4/3 Propagation Model 3-Radar Network Overlap:  
 Isabela- theta: 3 degs, Height :40 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft  
 Lajas- theta: 4 degs, Height :30 ft

Total Radar Network Area of Coverage: 9168.6006 km<sup>2</sup>

Single-Radar Area of Coverage: 4740.687 km<sup>2</sup>

Land : 816.5853 km<sup>2</sup> --> 17.225%  
 Water : 3924.1017 km<sup>2</sup> --> 82.775%

Two-Radar Overlap Area of Land Coverage: 3036.2607 km<sup>2</sup>

Land : 1115.0298 km<sup>2</sup> --> 36.7238%  
 Water : 1919.0115 km<sup>2</sup> --> 63.2031%

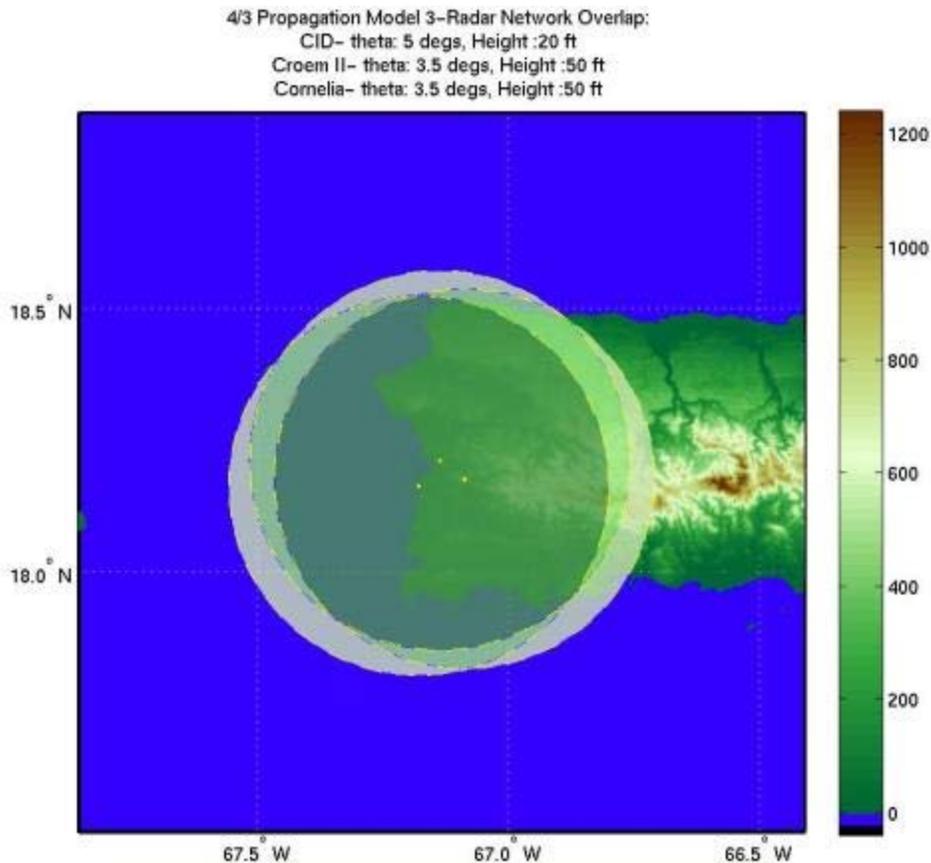
3-Radar Area of Coverage: 1391.6691 km<sup>2</sup>

Land : 1101.9078 km<sup>2</sup> --> 79.1789%  
 Water : 289.2024 km<sup>2</sup> --> 20.781%

Figure 5.21 Isabela, Cornelia, and Lajas overlap area calculations.

The result of these simulation show that the area within range of the Isabela, Cornelia, and Lajas configuration has a 15.2% of three-radar overlap area, a 33.1% of two-radar overlap area, and a 51.7% of single radar coverage. *Figure 5.21* also lists the distribution of land and sea area within each of the overlap regions. For example, for the three-radar overlap region, 79.18% occurs over land and 20.78% occurs over the sea.

These evaluations were also performed for the CID, CROEM, and Cornelia site configuration. These simulation results can be observed in *Figure 5.22* through *Figure 5.24*. The results for this configuration are later on compared to the results from the Isabela, Cornelia, and Lajas configuration.



**Figure 5.22 CID, CROEM, and Cornelia overlap regions.**

4/3 Propagation Model 3-Radar Network Overlap Pie Chart:  
 CID- theta: 5 degs, Height :20 ft  
 Croem II- theta: 3.5 degs, Height :50 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft

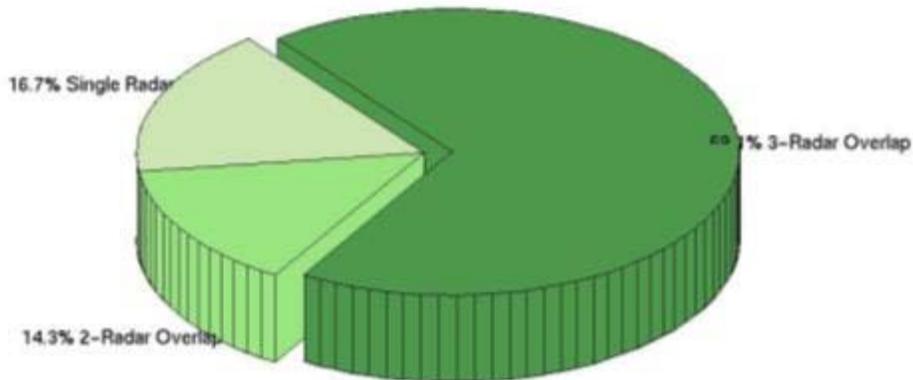


Figure 5.23 CID, CROEM, and Cornelia pie chart of overlap regions.

4/3 Propagation Model 3-Radar Network Overlap:  
 CID- theta: 5 degs, Height :20 ft  
 Croem II- theta: 3.5 degs, Height :50 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft

Total Radar Network Area of Coverage: 5936.7411 km<sup>2</sup>

Single-Radar Area of Coverage: 989.2773 km<sup>2</sup>

Land : 273.5532 km<sup>2</sup> --> 27.6518%  
 Water : 715.7241 km<sup>2</sup> --> 72.3482%

Two-Radar Overlap Area of Land Coverage: 847.2114 km<sup>2</sup>

Land : 318.8646 km<sup>2</sup> --> 37.637%  
 Water : 528.2577 km<sup>2</sup> --> 62.3525%

3-Radar Area of Coverage: 4100.301 km<sup>2</sup>

Land : 2182.0428 km<sup>2</sup> --> 53.2166%  
 Water : 1915.488 km<sup>2</sup> --> 46.7158%

Figure 5.24CID, CROEM, and Cornelia overlap region calculations.

**Table 5.4 Site configurations under evaluation overlap region comparison.**

Overlap Regions	Isabela, Cornelia, & Lajas	CID, CROEM, & Cornelia	Difference
Single-Radar	4740.69 km <sup>2</sup>	989.28 km <sup>2</sup>	3751.41 km <sup>2</sup>
Two-Radar	3036.26 km <sup>2</sup>	847.21 km <sup>2</sup>	2189.05 km <sup>2</sup>
Three-Radar	1391.67 km <sup>2</sup>	4100.3 km <sup>2</sup>	2708.63 km <sup>2</sup>

From the simulation results for both configurations under evaluation and area comparison calculations listed in *Table 5.4*, it can be determined that the second configuration (CID, CROEM, and Cornelia) offers the most area of coverage for three-radar overlap regions. This is due to the fact that the sites that compose this configuration are located very near to one another. It offers a three radar overlap region of approximately 4100 km<sup>2</sup> (69.07% of all its area) while the first configuration offers one of approximately 1391 km<sup>2</sup>. This gives a difference in area of approximately 2708 km<sup>2</sup>, a considerable amount. For two-radar overlap regions, the second configuration offers a coverage of approximately 847 km<sup>2</sup>, while the first configuration's coverage is of approximately 3036 km<sup>2</sup>. Although the first configuration offers more two-radar overlap regions, it is more favorable to have more three-radar overlap regions. This is because three radars can be observing the event simultaneously thus providing better performance. In this case, the second configuration offers better performance than the first site configuration. Note that in regions that are observed by a single radar, no network retrieval is possible.

### 5.3.4 MULTI-DOPPLER CAPABILITIES

For multi-Doppler capabilities, the crossbeam angles between two radar beams while simultaneously observing the same event are analyzed. Here, not only the ability of two or more radars observing the same event simultaneously (overlap regions) is important, but the perspective angles at which each radar observes the same event are important as well. It has been previously determined that multi-Doppler retrieval is possible for crossbeam angles equal or greater than  $30^\circ$ .

The Matlab tool developed for this site survey provides the evaluation for multi-Doppler capabilities as well. The simulation results for the Isabela, Cornelia, and Lajas configuration can be observed in *Figure 5.25* through *Figure 5.27*.

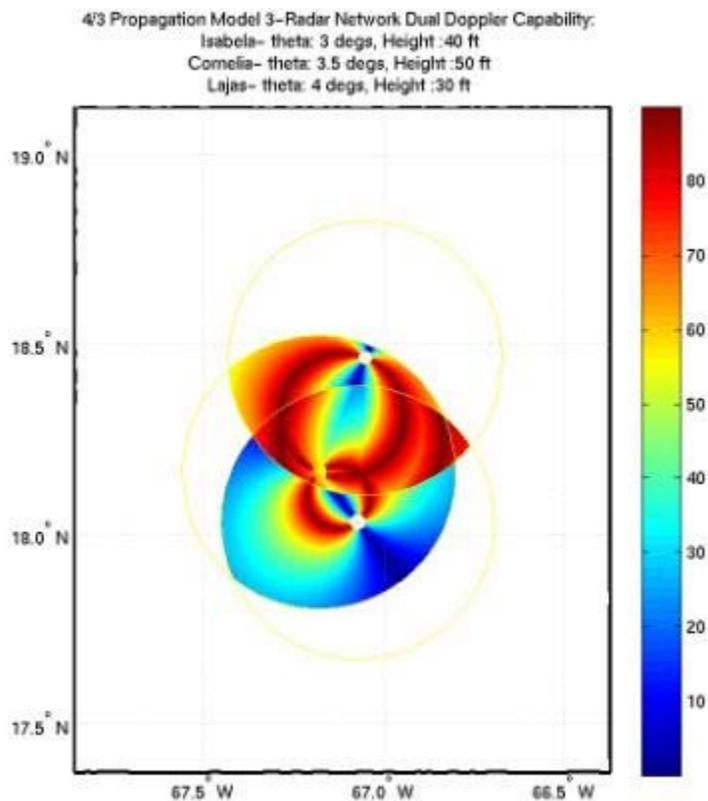


Figure 5.25 Isabela, Cornelia, and Lajas crossbeam angle diagram.

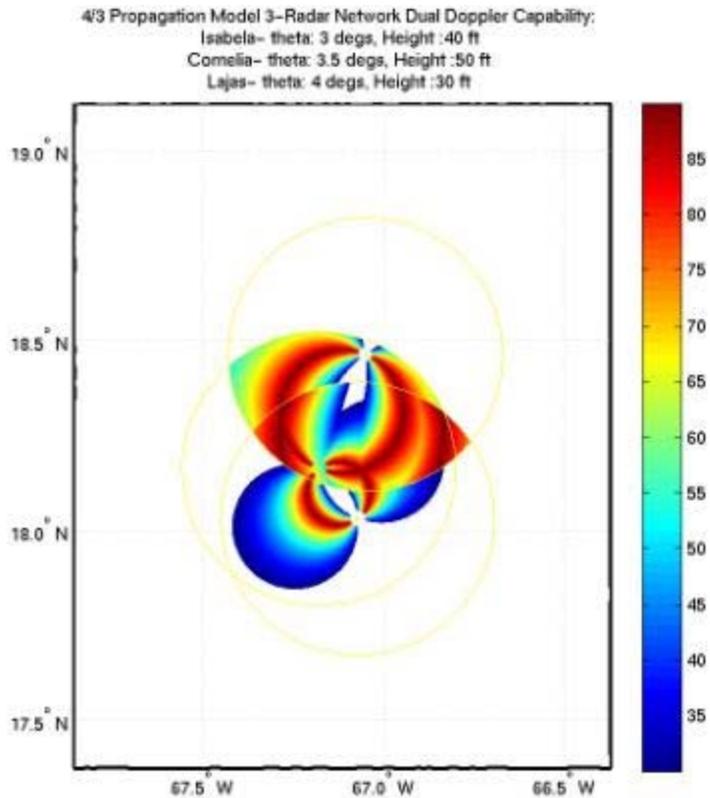


Figure 5.26 Isabela, Cornelia, and Lajas multi-Doppler capability diagram.

4/3 Propagation Model 3-Radar Network Multi Doppler Capabilities:  
 Isabela- theta: 3 degs, Height :40 ft  
 Comelia- theta: 3.5 degs, Height :50 ft  
 Lajas- theta: 4 degs, Height :30 ft

Total Area of Coverage: 9168.6006 km<sup>2</sup>

Multi Doppler Capability Area: 3363.0714 km<sup>2</sup>

- Over Land Capability: 1796.661 km<sup>2</sup> --> 53.4232%

- Over Water Capability: 1566.4104 km<sup>2</sup> --> 46.5768%

Figure 5.27 Isabela, Cornelia, and Lajas multi-Doppler capable region calculations.

Figure 5.25 shows the crossbeam angles formed by two radars observing the same location in the network's overlap regions. The Matlab tool developed calculates these crossbeam angles within a layer of the atmosphere. For these simulations it was between 1 km and 2.5 km of height. Figure 5.26 shows multi-Doppler the multi-Doppler capability region by eliminating all crossbeam angles less than 30°. The calculations of the area with multi-Doppler capability can be observed in Figure 5.27. It states that this configuration offers an area of 3363.07 km<sup>2</sup> capable of multi-Doppler, this is a 36.68% of the networks total area of coverage. The evaluations for multi-Doppler capabilities for the CID, CROEM, and Cornelia configuration can be observed in Figure 5.28 through Figure 5.30.

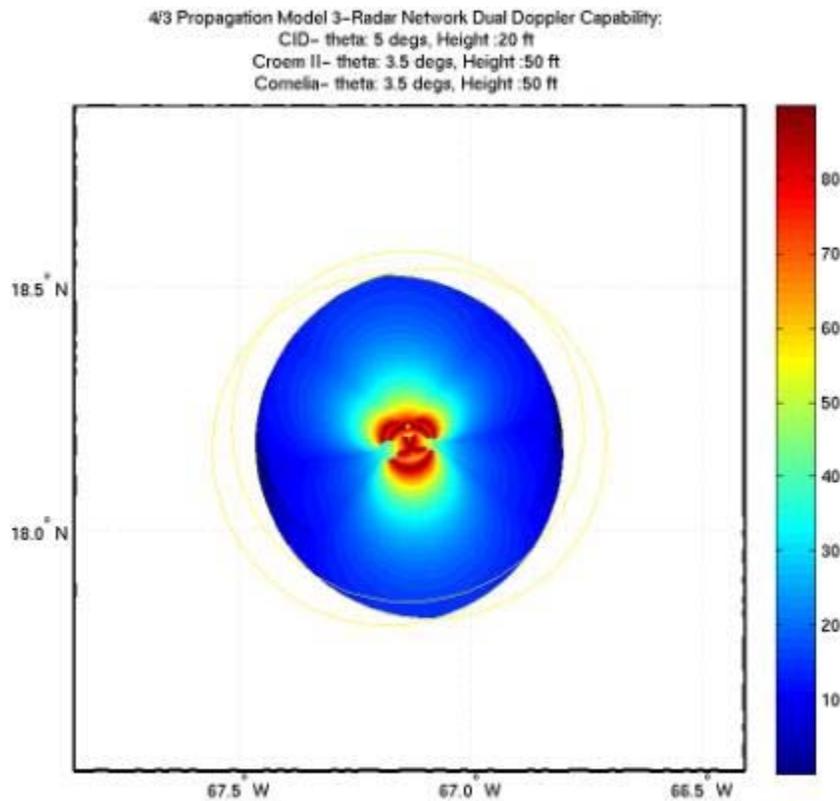


Figure 5.28 CID, CROEM, and Cornelia crossbeam angle diagram.

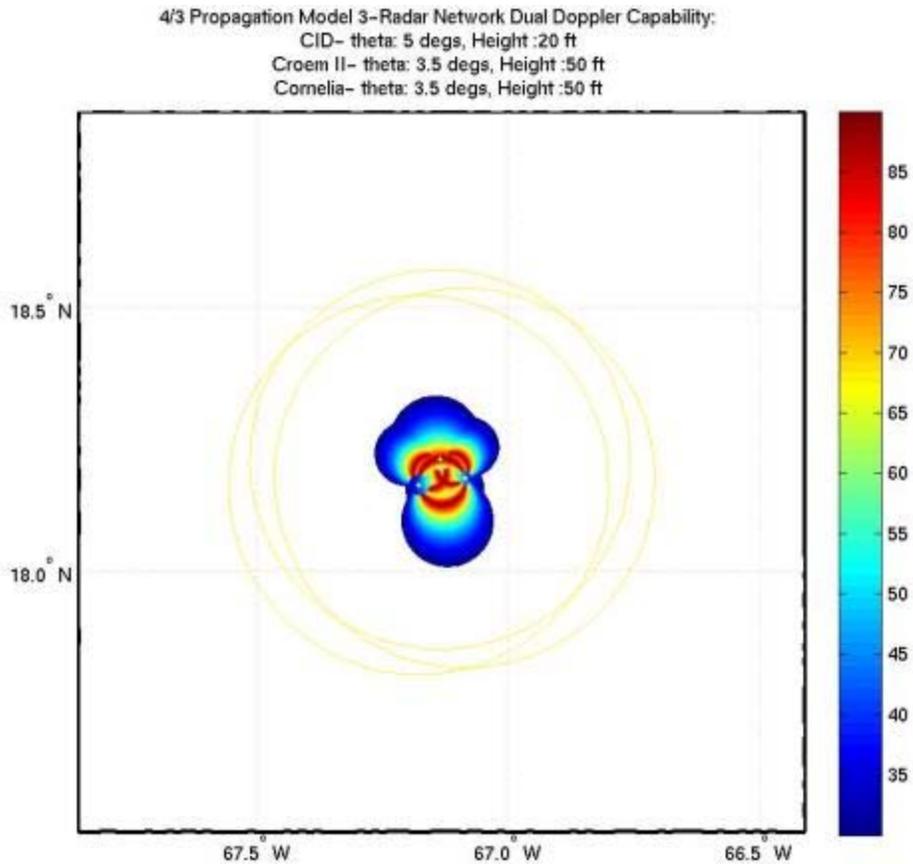


Figure 5.29 CID, CROEM, and Cornelia multi-Doppler capability region.

4/3 Propagation Model 3-Radar Network Multi Doppler Capabilities:

CID- theta: 5 degs, Height :20 ft  
 Croem II- theta: 3.5 degs, Height :50 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft

Total Area of Coverage: 5936.7411 km<sup>2</sup>

Multi Doppler Capability Area: 672.0165 km<sup>2</sup>

- Over Land Capability: 520.3764 km<sup>2</sup> --> 77.4351%

- Over Water Capability: 151.6401 km<sup>2</sup> --> 22.5649%

Figure 5.30 CID, CROEM, and Cornelia multi-Doppler capable region calculations.

**Table 5.5 Site configurations multi-Doppler capability area calculations.**

Multi-Doppler Regions	Isabela, Cornelia, & Lajas	CID, CROEM, & Cornelia	Difference
Total Area	3363.07 km <sup>2</sup>	672.02 km <sup>2</sup>	2691.05 km <sup>2</sup>
Land Area	1796.66 km <sup>2</sup>	520.38 km <sup>2</sup>	1276.28 km <sup>2</sup>
Sea Area	1566.41 km <sup>2</sup>	151.64 km <sup>2</sup>	1414.77 km <sup>2</sup>

Although the CID, CROEM, and Cornelia configuration offers more three-radar overlap region, due to their proximity, very little area is capable of multi-Doppler. This is so because as the range increases, the difference between the angles of observation of the radars towards the event decreases, resulting in low crossbeam angle values. This can be observed in *Figure 5.29* which shows the area capable of multi-Doppler after eliminating all angle values less than 30°. The total area capable of multi-Doppler for this site configuration is 672.02 km<sup>2</sup> of which 77.4% occurs over land while 22.6% occurs over the sea. This is very little compares to the Isabela, Cornelia, and Lajas configuration which offers a total area of capability of 3363.07 km<sup>2</sup> of which 53.4% occurs over land and 46.6% occurs over the sea. These calculations can be observed in *Figure 5.27* and *Figure 5.30*. The difference of multi-Doppler capable areas between the two configurations under evaluation can be observed in *Table 5.5*.

### 5.3.5 COVERAGE OF VULNERABLE POPULATION AREAS

In terms of general areas, the performance of the two configurations in comparison was evaluated. Now, the performance of the site configurations for the radar network deployment will be evaluated within specified areas of interest. The radar

network should provide proper coverage to regions where population vulnerable to disasters live in. The vulnerable populated locations under observation are the municipalities along the west coast. These are the area for which vulnerability studies have been performed by J. Santos in [7]. The municipalities that comprise this region (from north to south) are Aguadilla, Aguada, Rincón, Añasco, Mayagüez, and Cabo Rojo. The network's performance in network retrieval capabilities and multi-Doppler capabilities will be evaluated.

### 5.3.5.1 Network Retrieval Capability

The simulation results for the evaluation of network retrieval capability for the Isabela, Cornelia, and Lajas configuration can be observed in *Figure 5.31 through Figure 5.33*.

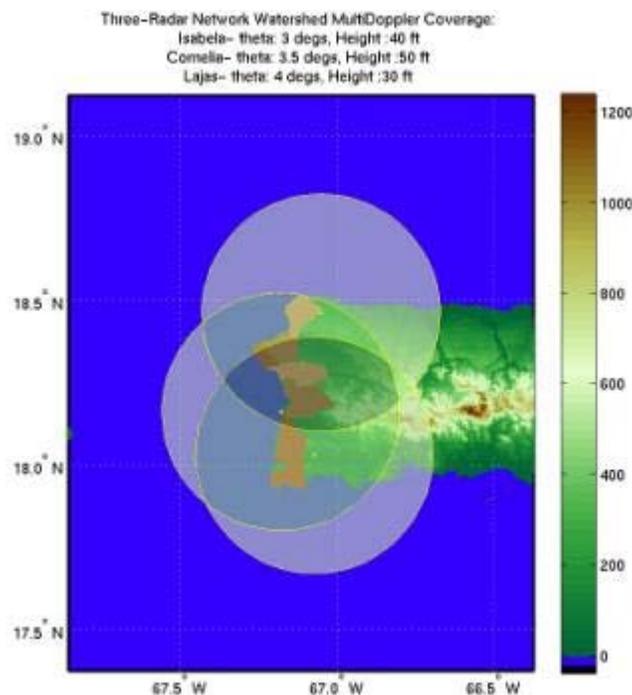


Figure 5.31 Isabela, Cornelia, and Lajas overlap regions over vulnerable areas.

Network Retrieval Capability Vulnerability Area Coverage Calculations:

Isabela- theta: 3 degs, Height :40 ft

Cornelia- theta: 3.5 degs, Height :50 ft

Lajas- theta: 4 degs, Height :30 ft

One-Radar Vulnerability Area Coverage: 0.0567 km<sup>2</sup> --> 0.01%

Aguadilla: 0.0567 km<sup>2</sup> --> 0.06%

Aguada: 0 km<sup>2</sup> --> 0%

Rincon: 0 km<sup>2</sup> --> 0%

Anasco: 0 km<sup>2</sup> --> 0%

Mayaguez: 0 km<sup>2</sup> --> 0%

Cabo Rojo: 0 km<sup>2</sup> --> 0%

Two-Radar Vulnerability Area Coverage: 319.7799 km<sup>2</sup> --> 45.87%

Aguadilla: 102.1329 km<sup>2</sup> --> 99.61%

Aguada: 19.3833 km<sup>2</sup> --> 22.25%

Rincon: 7.7598 km<sup>2</sup> --> 19.48%

Anasco: 0 km<sup>2</sup> --> 0%

Mayaguez: 0 km<sup>2</sup> --> 0%

Cabo Rojo: 190.5039 km<sup>2</sup> --> 94.37%

Three-Radar Vulnerability Area Coverage: 377.2494 km<sup>2</sup> --> 54.12%

Aguadilla: 0.3483 km<sup>2</sup> --> 0.34%

Aguada: 67.7484 km<sup>2</sup> --> 77.75%

Rincon: 32.076 km<sup>2</sup> --> 80.52%

Anasco: 110.9214 km<sup>2</sup> --> 100%

Mayaguez: 154.7991 km<sup>2</sup> --> 100%

Cabo Rojo: 11.3562 km<sup>2</sup> --> 5.63%

Figure 5.32 Isabela, Cornelia, and Lajas overlap regions over vulnerable area calculations.

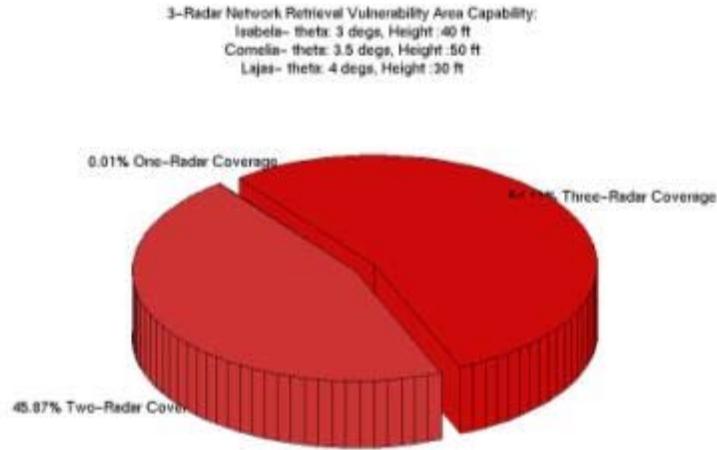


Figure 5.33 Isabela, Cornelia, and Lajas overlap regions over vulnerable area pie chart.

The simulation results show that all of the vulnerable populated regions are provided with good coverage by two or more radars. The region provided with single-radar coverage is minimal, only a 0.01% which is 0.06 km<sup>2</sup>. The results for the CID, CROEM, and Cornelia configuration are shown in *Figure 5.34* through *Figure 5.36*.

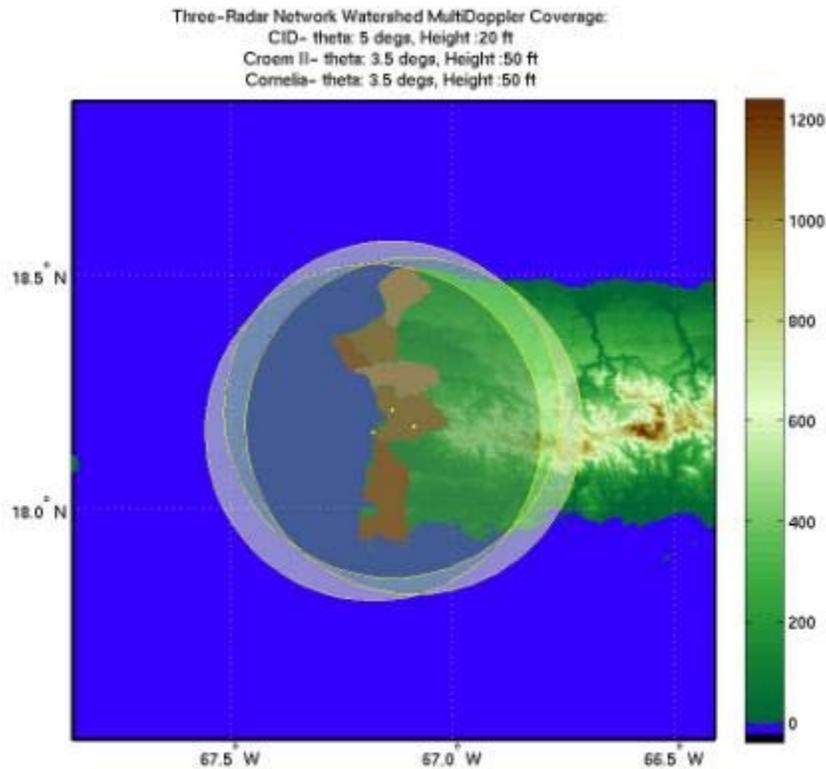


Figure 5.34 CID, CROEM, and Cornelia overlap region over vulnerable area.

Network Retrieval Capability Vulnerability Area Coverage Calculations:

CID- theta: 5 degs, Height :20 ft

Croem II- theta: 3.5 degs, Height :50 ft

Cornelia- theta: 3.5 degs, Height :50 ft

One-Radar Vulnerability Area Coverage: 0 km<sup>2</sup> --> 0%

Aguadilla: 0 km<sup>2</sup> --> 0%

Aguada: 0 km<sup>2</sup> --> 0%

Rincon: 0 km<sup>2</sup> --> 0%

Anasco: 0 km<sup>2</sup> --> 0%

Mayaguez: 0 km<sup>2</sup> --> 0%

Cabo Rojo: 0 km<sup>2</sup> --> 0%

Two-Radar Vulnerability Area Coverage: 0.0567 km<sup>2</sup> --> 0.01%

Aguadilla: 0.0567 km<sup>2</sup> --> 0.06%

Aguada: 0 km<sup>2</sup> --> 0%

Rincon: 0 km<sup>2</sup> --> 0%

Anasco: 0 km<sup>2</sup> --> 0%

Mayaguez: 0 km<sup>2</sup> --> 0%

Cabo Rojo: 0 km<sup>2</sup> --> 0%

Three-Radar Vulnerability Area Coverage: 697.0293 km<sup>2</sup> --> 99.99%

Aguadilla: 102.4812 km<sup>2</sup> --> 99.94%

Aguada: 87.1317 km<sup>2</sup> --> 100%

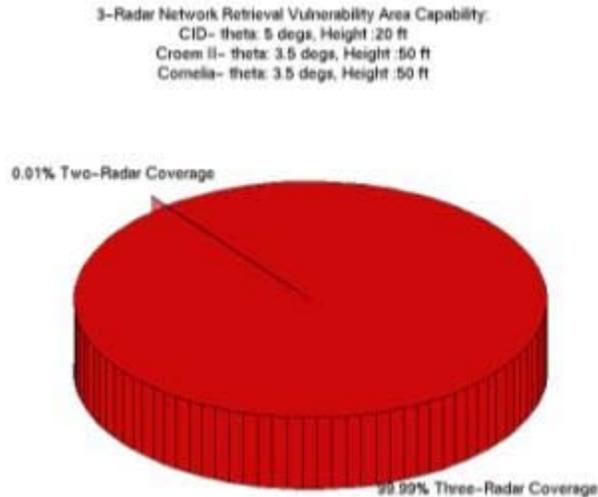
Rincon: 39.8358 km<sup>2</sup> --> 100%

Anasco: 110.9214 km<sup>2</sup> --> 100%

Mayaguez: 154.7991 km<sup>2</sup> --> 100%

Cabo Rojo: 201.8601 km<sup>2</sup> --> 100%

Figure 5.35 CID, CROEM, and Cornelia overlap region over vulnerable area calculations



**Figure 5.36 CID, CROEM, and Cornelia overlap region over vulnerable area pie chart.**

These simulation results show that both networks possess network retrieval capabilities over vulnerable populated areas. The difference is that the CID, CROEM, and Cornelia configuration offers three-radar overlap over 99.99% of the areas of interest. Meanwhile the Isabela, Cornelia and Lajas configuration offers 54.12% of the area with three-radar overlap regions and 45.87% with two radar overlap.

### 5.3.5.2 Multi-Doppler Capability

Other than for network retrieval capabilities over the vulnerable populated areas, the performance of both networks will be evaluated in multi-Doppler capabilities. The simulation results for the Isabela, Cornelia, and Lajas configurations can be observed in *Figure 5.37* through *Figure 5.39*. In these simulations the white shaded area over the map determines the area with multi-Doppler capabilities.

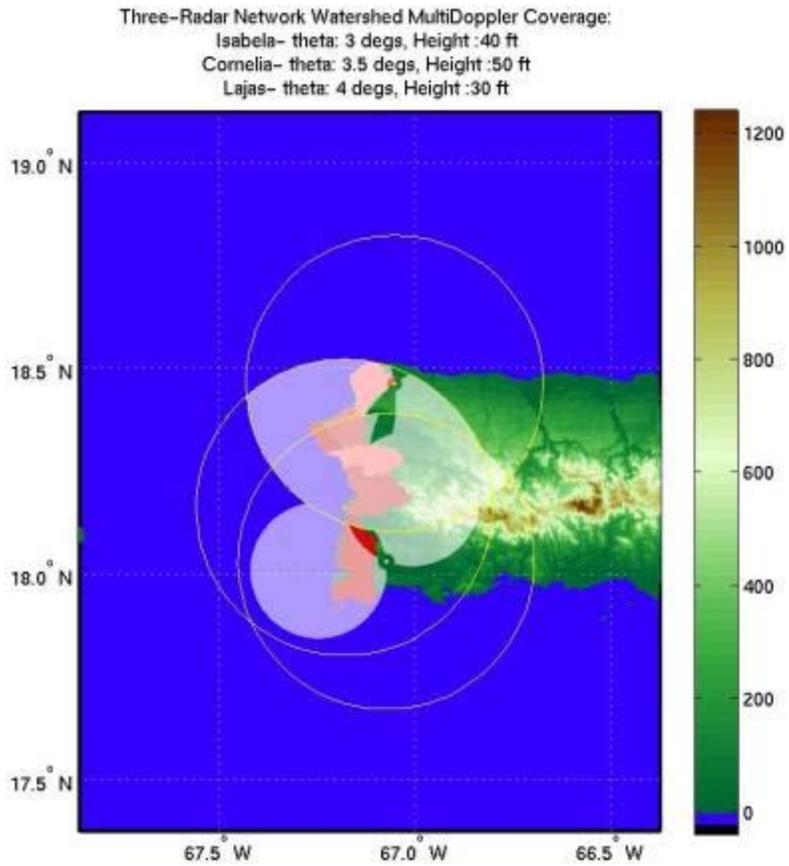


Figure 5.37 Isabela, Cornelia, and Lajas multi-Doppler capability over vulnerable areas.

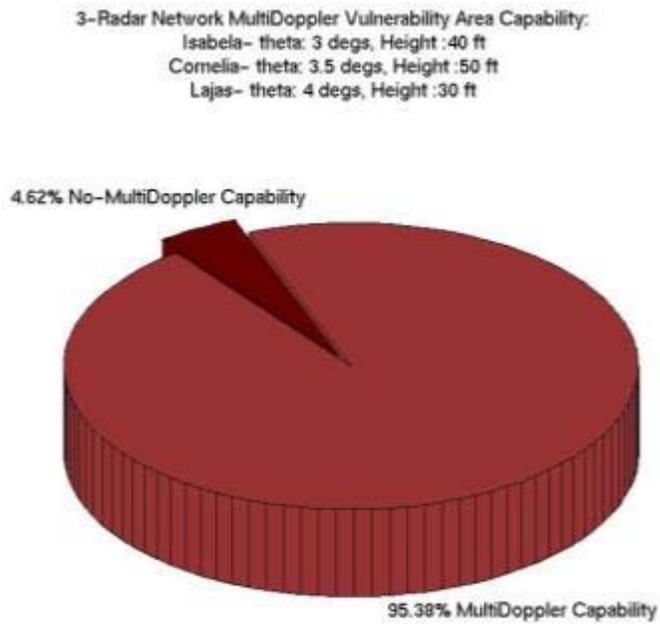


Figure 5.38 Isabela, Cornelia, and Lajas multi-Doppler capability over vulnerable area pie chart.

MultiDoppler Capability Vulnerability Area Coverage Calculations:

Isabela- theta: 3 degs, Height :40 ft

Cornelia- theta: 3.5 degs, Height :50 ft

Lajas- theta: 4 degs, Height :30 ft

MultiDoppler Capability Vulnerability Area: 664.848 km<sup>2</sup> --> 95.38%

Aguadilla: 98.0424 km<sup>2</sup> --> 95.62%

Aguada: 87.1317 km<sup>2</sup> --> 100%

Rincon: 39.8358 km<sup>2</sup> --> 100%

Anasco: 110.8242 km<sup>2</sup> --> 100%

Mayaguez: 154.7991 km<sup>2</sup> --> 100%

Cabo Rojo: 174.2148 km<sup>2</sup> --> 86.3%

NoMultiDoppler Capability Vulnerability Area: 32.238 km<sup>2</sup> --> 4.62%

Aguadilla: 4.4955 km<sup>2</sup> --> 4.38%

Aguada: 0 km<sup>2</sup> --> 0%

Rincon: 0 km<sup>2</sup> --> 0%

Anasco: 0.0972 km<sup>2</sup> --> 0.09%

Mayaguez: 0 km<sup>2</sup> --> 0%

Cabo Rojo: 27.6453 km<sup>2</sup> --> 13.7%

Figure 5.39 Isabela, Cornelia, and Lajas multi-Doppler capability over vulnerable area calculations.

From these simulations, it can be observed that the Isabela, Cornelia, and Lajas configuration has multi-Doppler capabilities over most of the vulnerable populated areas. *Figure 5.39* states that only two municipalities are partially covered by multi-

Doppler capable regions. These are Aguadilla, which is provided 95.62% of capability, and Rincon which is provided 86.3% of coverage with this capability.

The simulation results for the CID, CROEM, and Cornelia configuration can be observed in *Figure 5.40* through *Figure 5.42*.

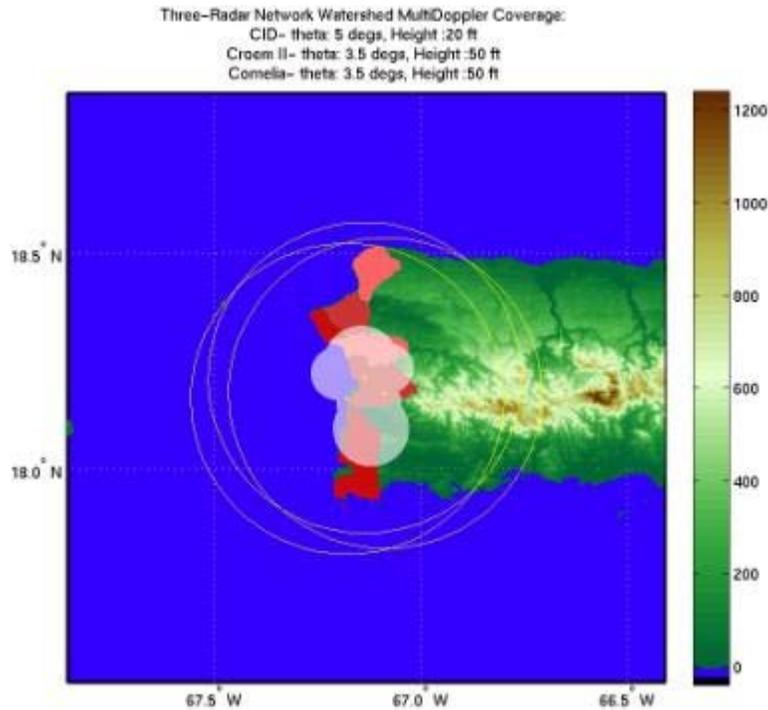


Figure 5.40 CID, CROEM, and Cornelia multi-Doppler capability over vulnerable area.

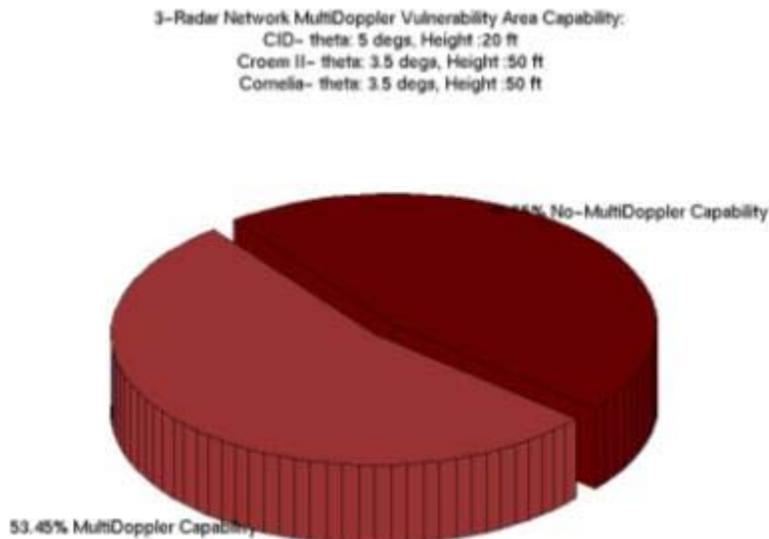


Figure 5.41 CID, CROEM, and Cornelia multi-Doppler capability over vulnerable area pie chart.

MultiDoppler Capability Vulnerability Area Coverage Calculations:  
 CID- theta: 5 degs, Height :20 ft  
 Croem II- theta: 3.5 degs, Height :50 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft

MultiDoppler Capability Vulnerability Area: 372.5919 km<sup>2</sup> --> 53.45%

Aguadilla: 0 km<sup>2</sup> --> 0%

Aguada: 13.041 km<sup>2</sup> --> 14.97%

Rincon: 4.1229 km<sup>2</sup> --> 10.35%

Anasco: 101.2581 km<sup>2</sup> --> 10.35%

Mayaguez: 142.3089 km<sup>2</sup> --> 91.93%

Cabo Rojo: 111.861 km<sup>2</sup> --> 55.42%

NoMultiDoppler Capability Vulnerability Area: 324.4941 km<sup>2</sup> --> 46.55%

Aguadilla: 102.5379 km<sup>2</sup> --> 100%

Aguada: 74.0907 km<sup>2</sup> --> 85.03%

Rincon: 35.7129 km<sup>2</sup> --> 89.65%

Anasco: 9.6633 km<sup>2</sup> --> 8.71%

Mayaguez: 12.4902 km<sup>2</sup> --> 8.07%

Cabo Rojo: 89.9991 km<sup>2</sup> --> 44.58%

Figure 5.42 CID, CROEM, and Cornelia multi-Doppler capability over vulnerable area calculations.

Although the CID, CROEM, and Cornelia configuration has multi-Doppler capabilities over the vulnerable populated areas, it is not nearly as good as for the Isabela, Cornelia, and Lajas configuration. It only provides multi-Doppler capability coverage over 53.45% of the vulnerable area.

### 5.3.6 COVERAGE OF WATERSHED AREAS

Important watersheds for the western region of Puerto Rico were pointed out. These are the Rio Culebrinas watershed, the Rio Grande de Añasco watershed, the Rio Yagüez watershed, and the Rio Guanajibo watershed. It is important to provide good coverage and for the radars to have good performance over the region containing these 4 watersheds. This is why the site configurations were evaluated over this region for network retrieval capabilities and multi-Doppler capabilities as well.

#### 5.3.6.1 Network Retrieval Capability

The simulation results for the Isabela, Cornelia, and Lajas configuration can be observed in *Figure 5.43* through *Figure 5.45*.

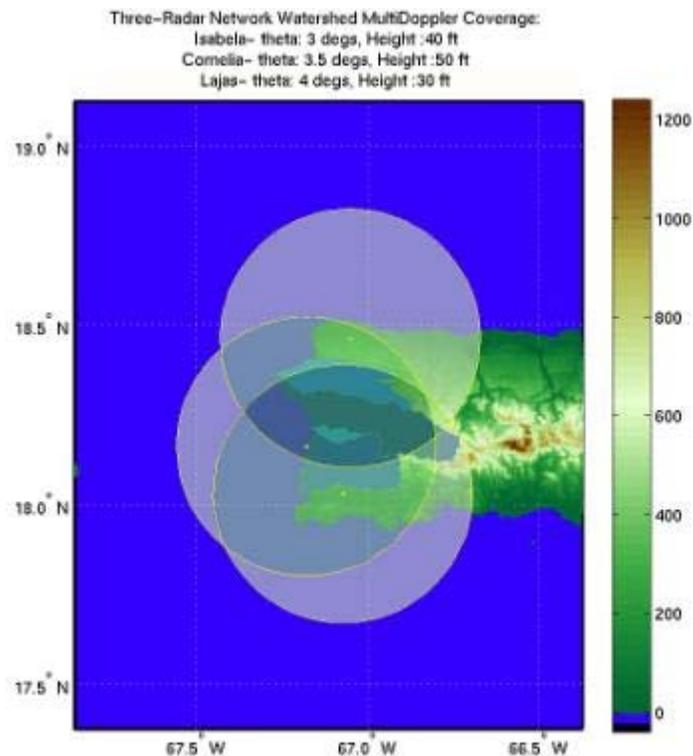


Figure 5.43 Isabela, Cornelia, and Lajas overlap region over watershed areas.

Watershed Network Retrieval Capability Coverage Area Calculations:  
 Isabela- theta: 3 degs, Height :40 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft  
 Lajas- theta: 4 degs, Height :30 ft

One-Radar Coverage Watershed Area: 57.5667 km<sup>2</sup> --> 4.1216%

Culebrinas: 0 km<sup>2</sup> --> 0%

Rio Grande de Anasco: 57.5667 km<sup>2</sup> --> 9.79%

Yaguez: 0 km<sup>2</sup> --> 0%

Guanajibo: 0 km<sup>2</sup> --> 0%

Two-Radar Coverage Watershed Area: 316.8639 km<sup>2</sup> --> 22.6866%

Culebrinas: 56.0682 km<sup>2</sup> --> 16.3%

Rio Grande de Anasco: 40.9293 km<sup>2</sup> --> 6.96%

Yaguez: 0 km<sup>2</sup> --> 0%

Guanajibo: 219.8664 km<sup>2</sup> --> 52.41%

Three-Radar Coverage Watershed Area: 1022.2686 km<sup>2</sup> --> 73.1918%

Culebrinas: 287.9631 km<sup>2</sup> --> 83.7%

Rio Grande de Anasco: 489.3291 km<sup>2</sup> --> 83.24%

Yaguez: 45.3114 km<sup>2</sup> --> 100%

Guanajibo: 199.665 km<sup>2</sup> --> 47.59%

Figure 5.44 Isabela, Cornelia, and Lajas overlap regions over watershed areas calculations.

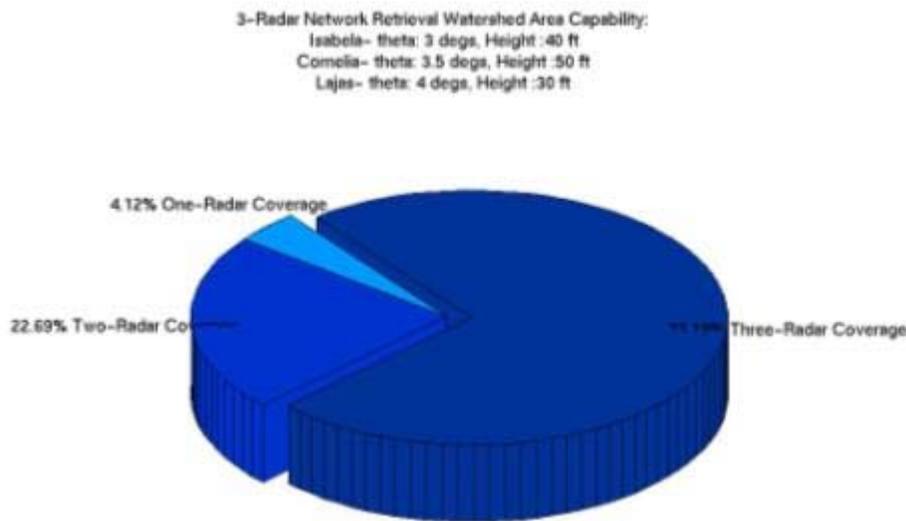
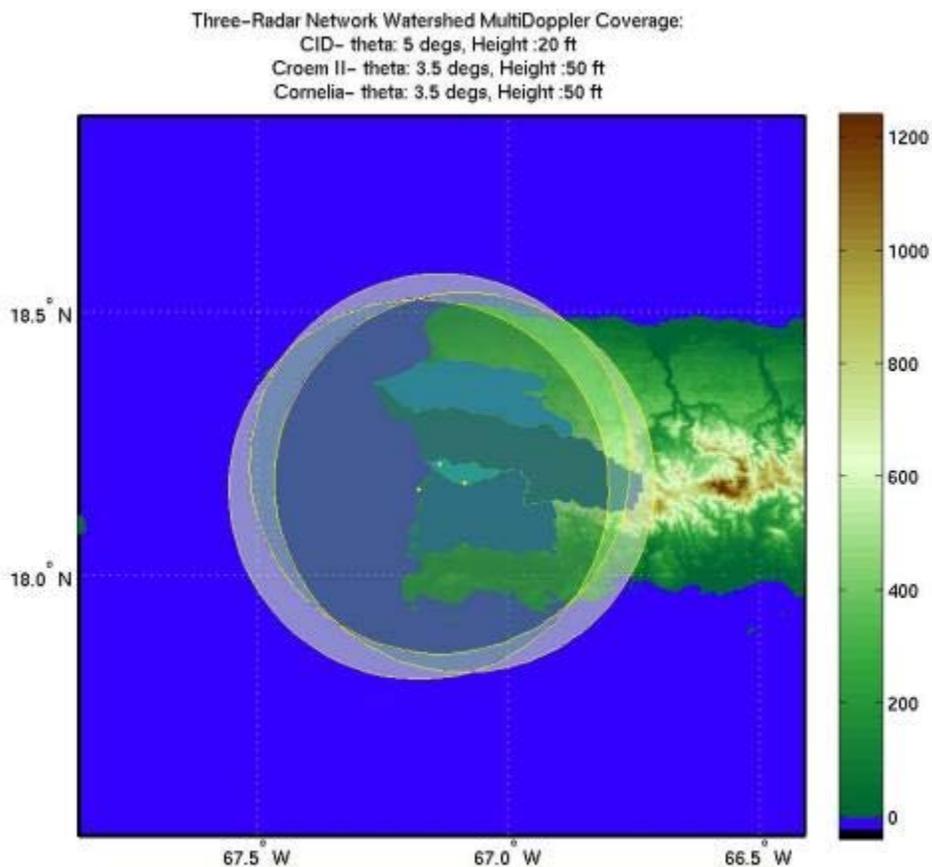


Figure 5.45 Isabela, Cornelia, and Lajas overlap region over watershed areas pie chart.

The simulations for this site configuration show that it provides good coverage with two or more radar overlap regions. It provides a three-radar overlap coverage over 73.19% and two-radar coverage of 22.69% over the watershed area. This configuration does not provide network retrieval capabilities over 4.12% of the entire watershed area. The simulation results for the CID, CROEM, and Cornelia configuration can be observed in *Figure 5.46 through Figure 5.48*.



**Figure 5.46** CID, CROEM, and Cornelia overlap region over watershed area.

Watershed Network Retrieval Capability Coverage Area Calculations:  
 CID- theta: 5 degs, Height :20 ft  
 Croem II- theta: 3.5 degs, Height :50 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft

One-Radar Coverage Watershed Area: 20.8251 km<sup>2</sup> --> 1.491%

Culebrinas: 0 km<sup>2</sup> --> 0%

Rio Grande de Anasco: 20.8251 km<sup>2</sup> --> 3.54%

Yaguez: 0 km<sup>2</sup> --> 0%

Guanajibo: 0 km<sup>2</sup> --> 0%

Two-Radar Coverage Watershed Area: 41.5935 km<sup>2</sup> --> 2.976%

Culebrinas: 0 km<sup>2</sup> --> 0%

Rio Grande de Anasco: 41.5935 km<sup>2</sup> --> 7.08%

Yaguez: 0 km<sup>2</sup> --> 0%

Guanajibo: 0 km<sup>2</sup> --> 0%

Three-Radar Coverage Watershed Area: 1334.2806 km<sup>2</sup> --> 95.531%

Culebrinas: 344.0313 km<sup>2</sup> --> 100%

Rio Grande de Anasco: 525.4065 km<sup>2</sup> --> 89.38%

Yaguez: 45.3114 km<sup>2</sup> --> 100%

Guanajibo: 419.5314 km<sup>2</sup> --> 100%

Figure 5.47 CID, CROEM, and Cornelia overlap region over watershed area calculations.

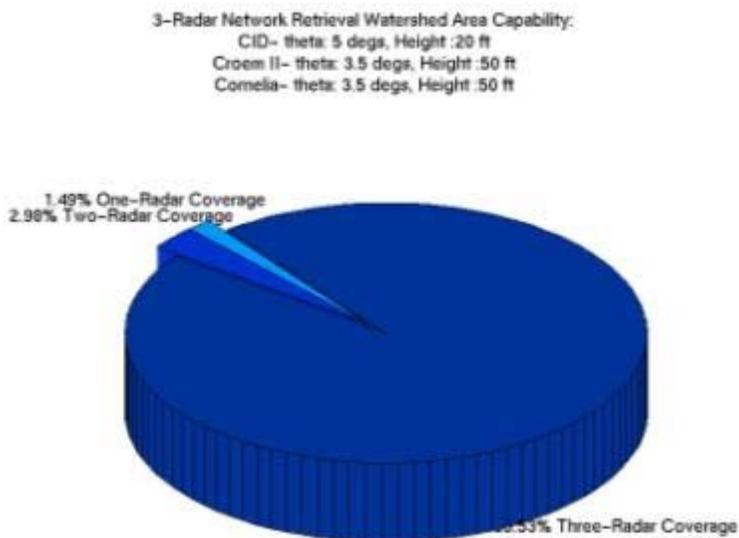


Figure 5.48 CID, CROEM, and Cornelia overlap region over watershed area pie chart.

Similarly to the Isabela, Cornelia, and Lajas configuration, the CID, CROEM, and Cornelia configuration offers excellent coverage over the watershed area with network retrieval capabilities. For this configuration, 95.53% of the entire watershed area is provided coverage with network retrieval capabilities and only 1.49% is not provided with such capabilities.

### 5.3.6.2 Multi-Doppler Capability

Muti-Doppler capabilities are also evaluated for both configurations over the watershed area. The simulation results for the Isabela, Cornelia, and Lajas configuration can be observed in *Figure 5.49* through *Figure 5.51* .

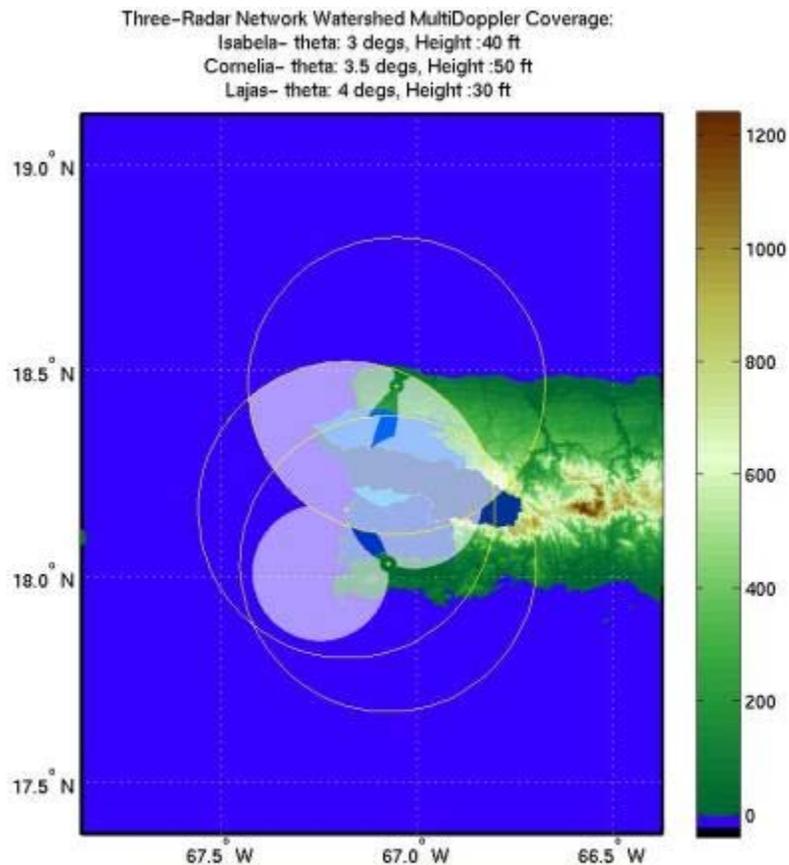


Figure 5.49 Isabela, Cornelia, and Lajas multi-Doppler capability region over watershed area.

3-Radar Network MultiDoppler Watershed Area Capability:  
 Isabela- theta: 3 degs, Height :40 ft  
 Comelia- theta: 3.5 degs, Height :50 ft  
 Lajas- theta: 4 degs, Height :30 ft

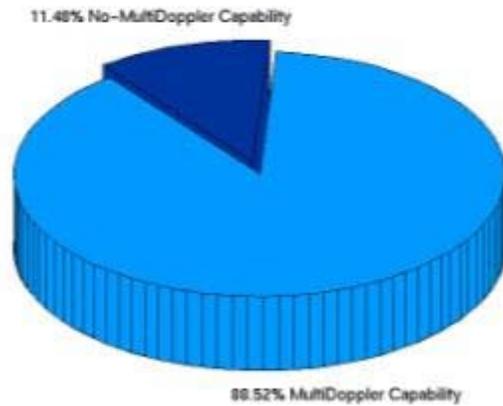


Figure 5.50 Isabela, Cornelia, and Lajas multi-Doppler capability region over watershed area pie chart.

Watershed Multi-Doppler Capability Coverage Area Calculations:

Isabela- theta: 3 degs, Height :40 ft  
 Comelia- theta: 3.5 degs, Height :50 ft  
 Lajas- theta: 4 degs, Height :30 ft

MultiDoppler Capability Watershed Area: 1236.303 km<sup>2</sup> --> 88.5161%

Culebrinas: 299.0601 km<sup>2</sup> --> 86.93%

Rio Grande de Anasco: 508.2588 km<sup>2</sup> --> 86.46%

Yaguez: 45.3114 km<sup>2</sup> --> 100%

Guanajibo: 383.6727 km<sup>2</sup> --> 91.45%

No-MultiDoppler Capability Watershed Area: 160.3962 km<sup>2</sup> --> 0.11484%

Culebrinas: 44.9712 km<sup>2</sup> --> 13.07%

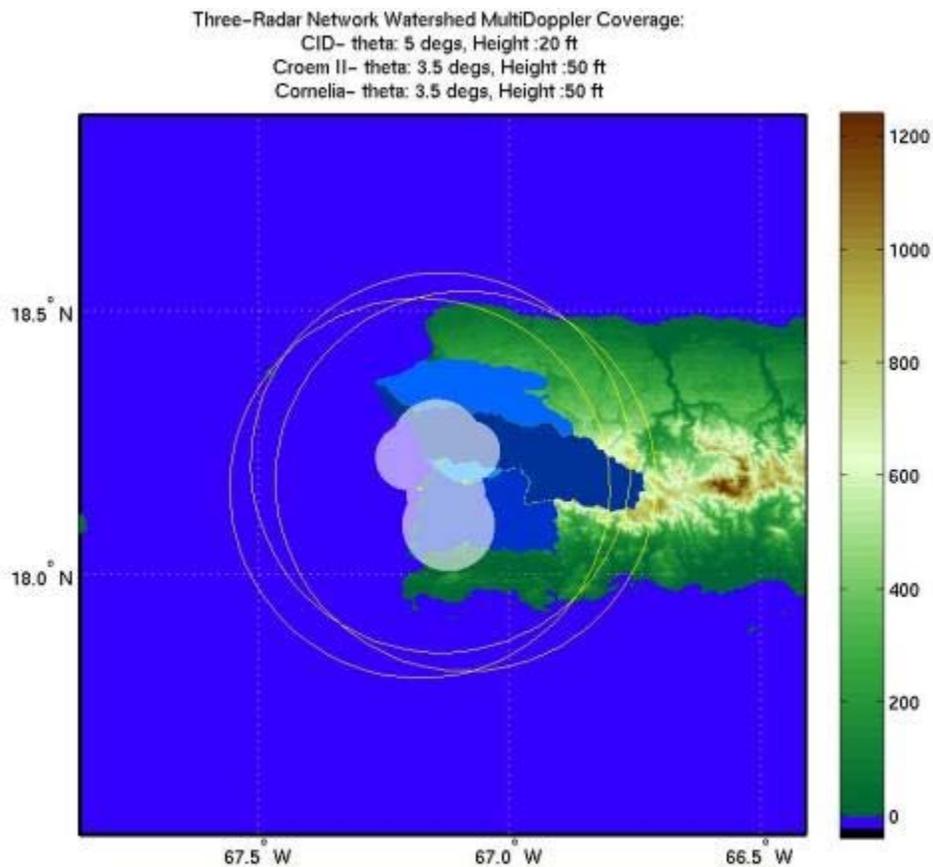
Rio Grande de Anasco: 79.5663 km<sup>2</sup> --> 13.54%

Yaguez: 0 km<sup>2</sup> --> 0%

Guanajibo: 35.8587 km<sup>2</sup> --> 8.55%

Figure 5.51 Isabela, Cornelia, and Lajas multi-Doppler capability region over watershed area calculations.

The results for this configuration show that 88.52% of the entire watershed areas is provided coverage with multi-Doppler capabilities. This leaves 11.48% of the watershed area without coverage with these capabilities. The CID, CROEM, and Cornelia configuration was evaluated as well. These simulation results can be observed in *Figure 5.52* through *Figure 5.54*.



**Figure 5.52** CID, CROEM, and Cornelia multi-Doppler capability region over watershed area.

3-Radar Network MultiDoppler Watershed Area Capability:  
 CID- theta: 5 degs, Height :20 ft  
 Croem II- theta: 3.5 degs, Height :50 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft

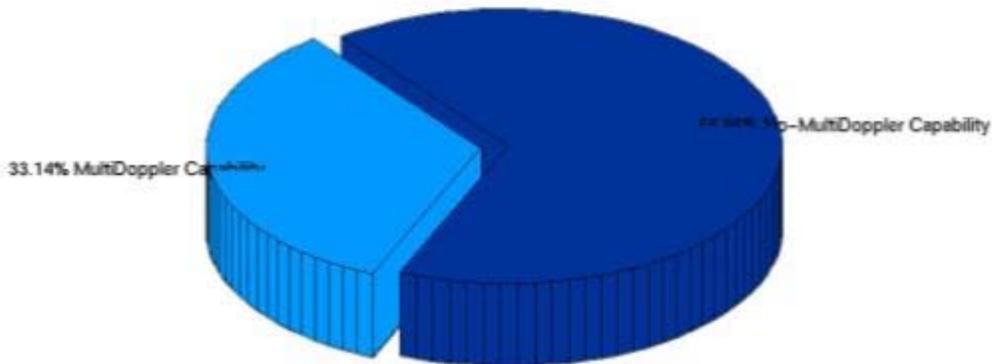


Figure 5.53 CID, CROEM, and Cornelia multi-Doppler capability over watershed area pie chart.

Watershed Multi-Doppler Capability Coverage Area Calculations:  
 CID- theta: 5 degs, Height :20 ft  
 Croem II- theta: 3.5 degs, Height :50 ft  
 Cornelia- theta: 3.5 degs, Height :50 ft

MultiDoppler Capability Watershed Area: 462.9069 km<sup>2</sup> --> 33.1429%

Culebrinas: 14.8068 km<sup>2</sup> --> 4.3%

Rio Grande de Anasco: 178.9857 km<sup>2</sup> --> 30.45%

Yaguez: 42.4278 km<sup>2</sup> --> 93.64%

Guanajibo: 226.6866 km<sup>2</sup> --> 54.03%

No-MultiDoppler Capability Watershed Area: 933.7923 km<sup>2</sup> --> 66.8571%

Culebrinas: 329.2245 km<sup>2</sup> --> 95.7%

Rio Grande de Anasco: 408.8394 km<sup>2</sup> --> 69.55%

Yaguez: 2.8836 km<sup>2</sup> --> 6.36%

Guanajibo: 192.8448 km<sup>2</sup> --> 45.97%

Figure 5.54 CID, CROEM, and Cornelia multi-Doppler capability over watershed area calculations.

The CID, CROEM, and Cornelia configuration only provides for 33.14% of coverage with multi-Doppler capabilities over the watersheds area. This means that the Isabela, Cornelia, and Lajas configuration has better performance over this region.

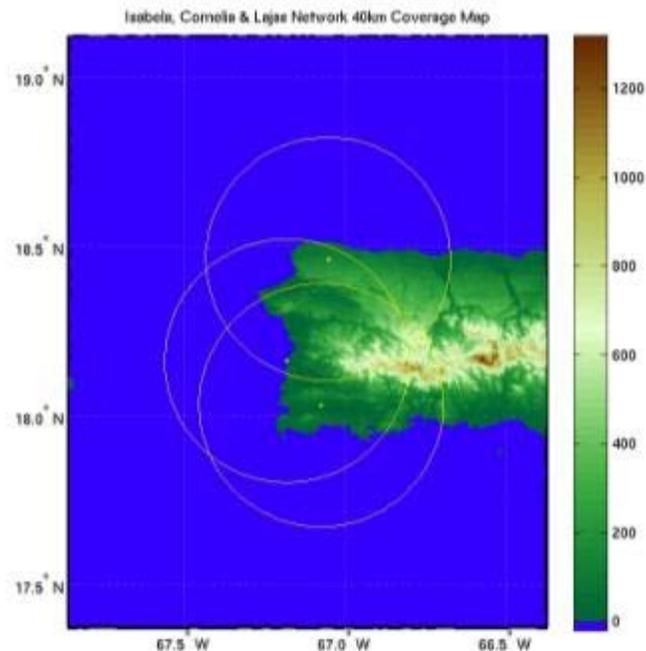
Overall, it is safe to say that the best performance in many aspects in which the configurations were evaluated was provided by the Isabela, Cornelia, and Lajas site configuration. This is why this configuration is recommended for the three-radar deployment in the western region of Puerto Rico.

## **6. Summary and Future Work**

Different analyses were performed through the course of this thesis project. First, the candidate sites were selected, most of which are property of UPRM because of ease of access. Afterwards, these candidate sites were evaluated in two different ways. On-site measurements were performed in order to determine obstacles surrounding the location for radar deployment. These pre-determined the radar tower's minimum tower height. Then, these sites were simulated for radar performance through the use of Matlab through which the minimum antenna angle of observation was determined. All of the candidate sites were then determined as favorable for radar deployment assigning a status of "PASS" or "NO-PASS".

The sites that were identified with the "PASS" status were evaluated forming configurations of three radar sites. Although many different three-radar site configurations could be constructed, not all were evaluated. Because of the performance requirements expected from the three-radar network, the geometry of the

radar's site location played an important role in the selection of the configuration. Being limited by this, only two radar configurations were evaluated and compared. Finally a recommendation of the deployment location for the three-radar network was provided. It has been determined that the best radar-site configuration was the Isabela, Cornelia, and Lajas configuration. This configuration can be observed in *Figure 6.1*.



**Figure 6.1 Recommended configuration: Isabela, Cornelia, and Lajas.**

This thesis project was bound by the locations that the UPRM possessed. Within its limitations and to its best understanding, this project has recommended the best possible site configuration for the radar network deployment. In order to broaden the performance of this radar network, other sites should be evaluated; not necessarily being sites that belong to the university. For which ever being the case, the Matlab tool developed for this radar site survey can be used for future site analyses within the island. If the analysis is performed for other sites within the island, only geographical coordinates for the new location are needed.

## 7. CONTRIBUTIONS

A unique Matlab tool was developed to aid in radar site survey analyses. This Matlab tool is capable of determining any blockage encountered by the radar's beam due to elevated terrain surrounding the site. Although this tool was originally developed for a site survey in the western region of Puerto Rico it can be easily used for surveys at different locations in and outside of Puerto Rico. This holds true as long as digital elevation models are available for the desired location in ASCII format.

As observed throughout this thesis project, the developed Matlab tool is useful in evaluating single radar sites as well as evaluating the performance of a network of radars. For single radar analyses the program returns several map plots in which the user can observe the radar coverage, beam height over coverage area, and blockage maps along with different charts and calculations. The same holds true for analyses of radar configurations adding the network capability performance results. These include network retrieval and Multi-Doppler capabilities. These analyses are essential in determining the optimal location of a radar network especially in complex terrain areas like the one encountered in Puerto Rico.

Using the developed tool in Matlab, special areas of coverage could be taken into consideration. These are the areas of population presenting high vulnerability indices and coverage over important watersheds for the western region. This provided the survey with not only technical aspects, but also added a social and hydrological component.

The analyses performed in this thesis project had never before been performed for the western region of Puerto for which a location for the radar network configuration has been suggested. Although our main focus was centered in the mentioned region of the island, it may be so that in a near future the radar network could be expanded to the entire Island. There, the tool can be used to determine the location for the new radars and a network of more than three radars can be evaluated.

These new radars which are going to be deployed in Puerto Rico, as part of a granted NSF proposal and CASA, will compliment the island's NEXRAD providing the necessary personnel such as the National Weather Service in San Juan and emergency management officials with the accuracy in weather data they need in order to provide the residents of the island with accurate predictions and courses of action in order to prevent disasters.

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# APPENDIX 1: DEVELOPED MATLAB TOOL CODE

## A1.1 CREATING BEAM HEIGHT MATRICES

### A1.1.1 bhMatMake.m

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%  
%                               Beam Height Matrices                               %  
%                                                                                   %  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%                               University of Puerto Rico at Mayaguez                %  
%                               Department of Electrical and Computer Engineering    %  
%                               Created By: Ricardo Rios-Olmo                       %  
%                                                                                   %  
% Purpose:                                                                       %  
% This program calculates the height of the bottom beam. It does not take        %  
% into consideration the refraction proposed by Doviak the commonly known       %  
% 4/3Re (radius of the Earth).                                                    %  
%                                                                                   %  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%                               Radar Locations in the Map                          %  
%                                                                                   %  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
  
for locVar = 1:11  
  
    if locVar == 1  
        % CID  
        CidStr = 'CID';  
        lat_CID = 18.21125;  
        lon_CID = -67.13676;  
        height_CID = 41.10;  
  
        radrStr = 'CID';  
        radrFlStr = 'CID';  
        radr_lat = 18.21125;  
        radr_lon = -67.13676;  
  
    elseif locVar == 2  
        % Aguadilla - Finca Montana  
        AguadillaStr = 'Finca Montana';  
        lat_Aguadilla = 18.4751;  
        lon_Aguadilla = -67.1206;  
  
        radrStr = 'Finca Montana I';  
        radrFlStr = 'Aguadilla';  
        radr_lat = 18.4751;  
        radr_lon = -67.1206;  
  
    elseif locVar == 3  
        % Croem  
        CroemStr = 'Croem II';
```

```

lat_Croem = 18.1759;
lon_Croem = -67.0876;
height_Croem = 394.04;

radrStr = 'Croem II';
radrFlStr = 'Croem';
radr_lat = 18.1759;
radr_lon = -67.0876;

elseif locVar == 4
% Cerro las Mesas
CMesasStr = 'Cerro las Mesas';
lat_CMesas = 18.1809;
lon_CMesas = -67.0889;
height_CMesas = 407.06;

radrStr = 'Cerro las Mesas';
radrFlStr = 'CMesas';
radr_lat = 18.1809;
radr_lon = -67.0889;

elseif locVar == 5
% Estacion Experimental - Lajas
LajasStr = 'Lajas';
lat_Lajas = 18.03181;
lon_Lajas = -67.07284;
height_Lajas = 31.23;

radrStr = 'Lajas';
radrFlStr = 'Lajas';
radr_lat = 18.03181;
radr_lon = -67.07284;

elseif locVar == 6
% Cornelia (Joyuda)
Joyudastr = 'Cornelia';
lat_Joyuda = 18.16302;
lon_Joyuda = -67.17920;
height_Joyuda = 54;

radrStr = 'Cornelia';
radrFlStr = 'Cornelia';
radr_lat = 18.16302;
radr_lon = -67.17920;

elseif locVar == 7
% Subestacion Experimental - Adjuntas
Adjuntastr = 'Adjuntas';
lat_Joyuda = 18.17865;
lon_Joyuda = -66.79737;
height_Adjuntas = 654.15;

radrStr = 'Adjuntas';
radrFlStr = 'Adjuntas';
radr_lat = 18.17865;
radr_lon = -66.79737;

elseif locVar == 8
% Isla Magueyues
SGrandeStr = 'Isla Magueyues';
lat_SGrande = 17.96948;
lon_SGrande = -67.04419;
height_Magueyues = 29.89;

radrStr = 'Isla Magueyues';
radrFlStr = 'Magueyues';
radr_lat = 17.96948;
radr_lon = -67.04419;

elseif locVar == 9
% Estacion Experimental - Isabela

```

```

IsabelaStr = 'Isabela';
lat_Isabela = 18.4632;
lon_Isabela = -67.0515;

radrStr = 'Isabela';
radrFlStr = 'Isabela';
radr_lat = 18.4632;
radr_lon = -67.0515;

elseif locVar == 10
% Charcas UPRM - Sabana Grande
SGrandeStr = 'Sabana Grande';
lat_SGrande = 18.04763;
lon_SGrande = -66.97992;
height_SGrande = 43.60;

radrStr = 'Sabana Grande';
radrFlStr = 'SGrande';
radr_lat = 18.04763;
radr_lon = -66.97992;

elseif locVar == 11
% CROEM
SGrandeStr = 'Croem';
lat_SGrande = 18.17667;
lon_SGrande = -67.08833;
height_SGrande = 43.60;

radrStr = 'Croem';
radrFlStr = 'CroemII';
radr_lat = 18.17667;
radr_lon = -67.08833;

elseif locVar == 12
% Mogotes Aguadilla
MogoteStr = 'FincaMonatanaII';
lat_SGrande = 18.466717;
lon_SGrande = -67.113367;
height_SGrande = 43.60;

radrStr = 'Finca Montana II';
radrFlStr = 'FMontana';
radr_lat = 18.466717;
radr_lon = -67.113367;

elseif locVar == 13
% Stefani
SGrandeStr = 'Stefani';
lat_SGrande = 18.20955;
lon_SGrande = -67.140031;
height_SGrande = 43.60;

radrStr = 'Stefani';
radrFlStr = 'Stefani';
radr_lat = 18.20955;
radr_lon = -67.140031;

else

f = errordlg('No record of location found', 'LocationError');

end

```

```

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Setting location Dir to save data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

CurrentDir = pwd;

savefiledir = strcat(CurrentDir, '/', 'Linear Propagation', '/', radrStr, '/');

if ~isdir(savefiledir)
    mkdir(savefiledir)
end

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Load 90m Resolution Data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Verify if a previous map has been created for this location

filename = strcat('medMapData', radrFlStr, '.mat');

radrMapFile = fullfile(savefiledir, filename);

if ~exist(radrMapFile, 'file')

    % Create new map data for desired location.
    [map, maplegend, latlim, lonlim] =
radrMapRead(radrMapFile, radrFlStr, radrStr, radr_lat, radr_lon);

else

    % Load Medium Resolution map data
    load(radrMapFile)

end

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Create Matrices
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

matSaveFileName = strcat('allMats', radrFlStr, '.mat');
matSaveFile = fullfile(savefiledir, matSaveFileName);

if ~exist(matSaveFile, 'file')

% Obtaining the correct starting lat/lon
[lat, lon] = pix2latlon(maplegend, 1, 1);

%Creating lat vector
latRefVec = lat + (0:length(map(:, 1))-1)*maplegend(1, 2);

%Creating lon vector
lonRefVec = lon - (0:length(map(1, :))-1)*maplegend(1, 2);

%Expand lat/lon vectors to matrices of equal sizes.
sizeVec = size(map);
latMat = repmat(latRefVec', 1, sizeVec(2));
lonMat = repmat(lonRefVec, sizeVec(1), 1);

%Obtain all ranges and azimuths within map... with respect to CID.

tic

```

```

[allRange,allAz] = distance(radr_lat,radr_lon,latMat,lonMat);
toc

%Convert ranges from degrees of arc length to km.
allRange = deg2km(allRange);

%Round all azimuth to the nearest hundreaths
allAz = roundn(allAz,-1);

save(matSaveFile,'latMat','lonMat','allRange','allAz')

else

    load(matSaveFile)

end

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Create BH Matrices
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radar Stats %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% This is going to be performed for
% h = 10,15,20,25,30,40,50 feet
% theta = 0.9,1.2,1.8,2.0,2.6 degrees

hVec = [10 15 20 25 30 40 50];
thetaVec = [0.9 1.2 1.8 2.0 2.6 3.0 3.5 4 4.5 5];

for hIndex = 1: length(hVec)

    for thetaIndex = 1: length(thetaVec)

        % Height of radar including terrain and tower height.
        h_radr = distdim(hVec(hIndex),'ft','m') + llheight(map,maplegend,radr_lat,radr_lon);

        %Beam Width
        bw = 1.8;

        %Elevation Angle
        theta = thetaVec(thetaIndex);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% BH Matrix %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        bhfilename =
strcat(radrFlStr,num2str(hVec(hIndex)),num2str(thetaIndex),'_', 'bhMat.mat');
        bhfile = fullfile(savefiledir,bhfilename);

        if ~exist(bhfile,'file')

            %Calculate bh matrix... using for loop for now.
            sizeVec = size(map);
            bhMat = nan(sizeVec);

            tic

            bhMat = bhCalc(allRange,h_radr,bw,theta);
            save(bhfile, 'bhMat')

            toc

```

```

        else
            load(bhfile)
        end
    end
end
end
end
end

```

## A1.1.2 radrMapRead.m

```

function [map,maplegend,latlim,lonlim] =
radrMapRead(radrMapFile,radrFlStr,radrStr,radr_lat,radr_lon)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           Read 90m Resolution Data and Plot Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%           University of Puerto Rico at Mayaguez
%           Department of Electrical and Computer Engineering
%           Created By: Ricardo Rios-Olmo
%
% Purpose:
% This program reads DEM data (ASCII) and creates map pertaining to a
% radar site location.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tic
%Read Elevation Data (ASCII)
[map,maplegend] = arcgridread('srtm_23_09.asc');
toc

% Convert few pixels with negative values to 0 height
map(find(map < 0)) = 0;

% Water surrounding the island is given a negative value
map(isnan(map)) = -10;

% Determining coordinates for points in space given by rng and az.
[lat0, lon0] = reckon(radr_lat, radr_lon, km2deg(40),0);
[lat90, lon90] = reckon(radr_lat, radr_lon, km2deg(40),90);
[lat180, lon180] = reckon(radr_lat, radr_lon, km2deg(40),180);
[lat270, lon270] = reckon(radr_lat, radr_lon, km2deg(40),270);

% Establish lat/lon limits
latlim = [lat180-0.3 lat0+0.3];
lonlim = [lon270-0.3 lon90+0.3];

% Clip map matrix... too large!
[x1,y1] = latlon2pix(maplegend, latlim(2), lonlim(1));
[x2,y2] = latlon2pix(maplegend, latlim(1), lonlim(2));

newmap = map(round(x1):round(x2),round(y1):round(y2));

[lat, lon] = pix2latlon(maplegend,round(x1),round(y1));

```

```

maplegend(3,1) = lon;
maplegend(3,2) = lat;

map = newmap;

% Just in case
map(isnan(map)) = -10;

tic
%Plot map
figStr = [radrStr ' Map'];
figHndl = figure('Name',figStr);
ax = worldmap(latlim,lonlim);
geoshow(map,maplegend,'DisplayType','surface')
demcmap(map)
% daspectm('m',1)
% view(3)
colorbar
axis off
hold on

tightmap
hold on

X = colormap;
X(1,2) = 0;
X(1,1) = 0.2;
colormap(X);
toc

% Figure Title
title([radrStr ' 40km Coverage Map'])
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(rad_r_lat,rad_r_lon,1400,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(rad_r_lat,rad_r_lon,km2deg(40));
plot3m(Cirlat,Cirlon,1400,'y')

% Creating file path and name to save map figure.
[path, name, ext] = fileparts(rad_r_map_file);
filename = fullfile(path,'/', ['medMap' rad_r_map_file '.jpg']);

saveas(gcf,filename)
close(figHndl)

save (rad_r_map_file,'map', 'maplegend', 'latlim', 'lonlim')

```

### A1.1.3 llheight.m

```

function [height] = llheight(map, maplegend, lat, lon)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           Calculate Radar Terrain Height at Site
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           University of Puerto Rico at Mayaguez
%           Department of Electrical and Computer Engineering
%           Created By: Ricardo Rios-Olmo
%
% Description:

```

```

% This program returns the terrain height at the radar location in meters.
%
%
% Input Variables :
%           map           current map matrix
%           maplegend     map reference matrix
%           lat           radar location latitude
%           lon           radar location longitude
%
% Output Variables :
%           height        height of terrain at radar site. (m)
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Check if maplegend is a reference vector or matrix

SizeVec = size(maplegend);

if SizeVec(1) == 1

    %Calculates the terrain height at selected lat,lon.

    heightIndex = setpostn(map, maplegend,lat,lon);
    height = map(heightIndex);

else

    % Calculate the terrain height at selected lat, lon.
    [row, col] = latlon2pix(maplegend,lat,lon);
    height = map(round(row),round(col));

end

```

### A1.1.4 bhCalc.m

```

function [bh] = bhCalc(r,h,beamwidth,theta)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           Beam Height Function
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This program calculates the height of the bottom beam. It does not take
% into consideration the refraction proposed by Doviak the commonly known
% 4/3Re (radius of the Earth).
%
% Input Variables :
%           theta         antenna elevation angle
%           bw            beamwidth = 1.8
%           h             Height of radar including tower
%           r             range of the radar
%
% Output Variables :
%           bh            beam height at bottom of beam
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Range of radar in meters
r = distdim(r,'km','m');

% Earth radius at Equator at mean sea level, in meters
Re=6378135;

% Effective beam elevation at 3db beam bottom
be=(theta-beamwidth/2)*(pi/180)+pi/2;

% lower beam height

```

```
bh=( (Re+h)^2+r.^2-2*(Re+h)*r.*cos(be)).^0.5-Re;
```

## A1.2 DETERMINING BLOCKAGE

### A1.2.1 medResMain.m

```
clc
clear
close all

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Radar Beam Blockage and Coverage
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               University of Puerto Rico at Mayaguez
%                               Department of Electrical and Computer Engineering
%                               Created By: Ricardo Rios-Olmo
%
% Purpose:
% This program determines areas of beam blockage due to high terrain.
% Provides calculations for area of coverage.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Radar Locations in the Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for locVar = 1:12

    %   locVec = {'Aguadilla'; 'Croem'; 'Cerro las Mesas'; 'Lajas'; 'Cornelia'; 'CID'};

    if locVar == 1
        % CID
        CidStr = 'CID';
        lat_CID = 18.21125;
        lon_CID = -67.13676;
        height_CID = 41.10;

        radrStr = 'CID';
        radrFlStr = 'CID';
        radr_lat = 18.21125;
        radr_lon = -67.13676;

    elseif locVar == 2
        % Aguadilla - Finca Montana
        AguadillaStr = 'Finca Montana';
        lat_Aguadilla = 18.4751;
        lon_Aguadilla = -67.1206;

        radrStr = 'Finca Montana I';
        radrFlStr = 'Aguadilla';
        radr_lat = 18.4751;
        radr_lon = -67.1206;

    elseif locVar == 3
```

```

% Croem
CroemStr = 'Croem II';
lat_Croem = 18.1759;
lon_Croem = -67.0876;
height_Croem = 394.04;

radrStr = 'Croem II';
radrFlStr = 'Croem';
radr_lat = 18.1759;
radr_lon = -67.0876;

elseif locVar == 4
% Cerro las Mesas
CMesasStr = 'Cerro las Mesas';
lat_CMesas = 18.1809;
lon_CMesas = -67.0889;
height_CMesas = 407.06;

radrStr = 'Cerro las Mesas';
radrFlStr = 'CMesas';
radr_lat = 18.1809;
radr_lon = -67.0889;

elseif locVar == 5
% Estacion Experimental - Lajas
LajasStr = 'Lajas';
lat_Lajas = 18.03181;
lon_Lajas = -67.07284;
height_Lajas = 31.23;

radrStr = 'Lajas';
radrFlStr = 'Lajas';
radr_lat = 18.03181;
radr_lon = -67.07284;

elseif locVar == 6
% Cornelia (Joyuda)
Joyudastr = 'Cornelia';
lat_Joyuda = 18.16302;
lon_Joyuda = -67.17920;
height_Joyuda = 54;

radrStr = 'Cornelia';
radrFlStr = 'Cornelia';
radr_lat = 18.16302;
radr_lon = -67.17920;

elseif locVar == 7
% Subestacion Experimental - Adjuntas
Adjuntastr = 'Adjuntas';
lat_Joyuda = 18.17865;
lon_Joyuda = -66.79737;
height_Adjuntas = 654.15;

radrStr = 'Adjuntas';
radrFlStr = 'Adjuntas';
radr_lat = 18.17865;
radr_lon = -66.79737;

elseif locVar == 8
% Isla Magueyues
SGrandeStr = 'Isla Magueyues';
lat_SGrande = 17.96948;
lon_SGrande = -67.04419;
height_Magueyues = 29.89;

radrStr = 'Isla Magueyues';
radrFlStr = 'Magueyues';
radr_lat = 17.96948;
radr_lon = -67.04419;

```

```

elseif locVar == 9
    % Estacion Experimental - Isabela
    IsabelaStr = 'Isabela';
    lat_Isabela = 18.4632;
    lon_Isabela = -67.0515;

    radrStr = 'Isabela';
    radrFlStr = 'Isabela';
    radr_lat = 18.4632;
    radr_lon = -67.0515;

elseif locVar == 10
    % Charcas UPRM - Sabana Grande
    SGrandeStr = 'Sabana Grande';
    lat_SGrande = 18.04763;
    lon_SGrande = -66.97992;
    height_SGrande = 43.60;

    radrStr = 'Sabana Grande';
    radrFlStr = 'SGrande';
    radr_lat = 18.04763;
    radr_lon = -66.97992;

elseif locVar == 11
    % CROEM
    SGrandeStr = 'Croem';
    lat_SGrande = 18.17667;
    lon_SGrande = -67.08833;
    height_SGrande = 43.60;

    radrStr = 'Croem';
    radrFlStr = 'CroemII';
    radr_lat = 18.17667;
    radr_lon = -67.08833;

elseif locVar == 12
    % Mogotes Aguadilla
    MogoteStr = 'FincaMonatanaII';
    lat_SGrande = 18.466717;
    lon_SGrande = -67.113367;
    height_SGrande = 43.60;

    radrStr = 'Finca Montana II';
    radrFlStr = 'FMontana';
    radr_lat = 18.466717;
    radr_lon = -67.113367;

elseif locVar == 13
    % Stefani
    SGrandeStr = 'Stefani';
    lat_SGrande = 18.20955;
    lon_SGrande = -67.140031;
    height_SGrande = 43.60;

    radrStr = 'Stefani';
    radrFlStr = 'Stefani';
    radr_lat = 18.20955;
    radr_lon = -67.140031;

else

    f = errordlg('No record of location found', 'LocationError');

end

```

```

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Setting location Dir to save data
%

```

```

%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

CurrentDir = pwd;

savefiledir = strcat(CurrentDir,'/', 'Linear Propagation','/',radrStr,'/');

if ~isdir(savefiledir)
    mkdir(savefiledir)
end

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Load 90m Resolution Data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

filename = strcat('medMapData',radrFlStr, '.mat');
radrMapFile = fullfile(savefiledir,filename);

load(radrMapFile)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Load previously Created Matrices
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

matSaveFileName = strcat('allMats',radrFlStr, '.mat');
matSaveFile = fullfile(savefiledir,matSaveFileName);

load(matSaveFile)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Load previously Created BH Matrices
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

hVec = [10 15 20 25 30 40 50];
thetaVec = [0.9 1.2 1.8 2.0 2.6 3.0 3.5 4 4.5 5];

for hIndex = 3:length(hVec)

    for thetaIndex = 4:length(thetaVec)

bhfilename = strcat(radrFlStr,num2str(hVec(hIndex)),num2str(thetaIndex),'_','bhMat.mat');
bhfile = fullfile(savefiledir,bhfilename);

load(bhfile)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Determining Blockage
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

blkfilename = strcat(radrFlStr,'BlkData',num2str(hVec(hIndex)),num2str(thetaIndex),'.mat');
blkfile = fullfile(savefiledir,blkfilename);

%Find out if there is previously recorded block data
if ~exist(blkfile,'file')

```

```

%Create a new map and bhMat which will contain blocking pixels
blkMap = map;
blkBhMat = bhMat;

% Find all map pixels within radar coverage
outRng = find(allRange > 40);
blkMap(outRng) = -40;

% Determining points in map presenting blockage
blkMat = bhMat - map;
blkIndex = find(blkMat < 0);

% Creating another block Mat to modify later on and save.
compBlkMat = blkMat;
compBlkMat2 = blkMat;
compBlkMat(outRng) = -40;
compBlkMat2(outRng) = -40;

% Find all the water in map and give it black color in bhblkMat
watIndex = find(blkMap == -10);
compBlkMat(watIndex) = -40;

% Find Range and Azimuths of points presenting blockage
rngBlk = allRange(blkIndex);
azsBlk = allAz(blkIndex);

% Determine pixels that may be blocking in other azimuths aswell
lessRangeIndex = find(rngBlk <= 6);
lessAzs = azsBlk(lessRangeIndex);
lessRange = rngBlk(lessRangeIndex);

tic
wait3 = waitbar(0, 'Determining other blocking Azs...');
for indi = 1: length(lessRangeIndex)

    %Creating Azimuth vector
    newlessAz = (lessAzs(indi)-15:0.1:lessAzs(indi)+15);

    % Find negative angles and converting them to positive.
    negVarI = find(newlessAz < 0);
    newlessAz(negVarI) = newlessAz(negVarI) + 360;

    % Determining coordinates for point in space given by rng and az.
    [lat, lon] = reckon(radr_lat, radr_lon, km2deg(lessRange(indi)), newlessAz);

    % Determining map indices: row and col
    [row, col] = latlon2pix(maplegend, lat, lon);

    newBlks = (length(row));
    for i=1:length(row)
    % Finding blk values with found indices
    newBlks(i) = blkMat(round(row(i)), round(col(i)));
    end

    % Get all of the indices that contain a blocking value
    newAZI = find(newBlks < 0);

    % Add this found blocking azimuth and range to the previous found
    % blocking ranges and azimuths
    azsBlk = vertcat(azsBlk, (newlessAz(newAZI)'));
    rngBlk = vertcat(rngBlk, repmat(lessRange(indi), length(newAZI), 1) );

    waitbar(indi/length(lessRangeIndex), wait3)

end
toc
close(wait3)

```

```

% Get blk az/range. Filter ranges by azimuths and block map pixels.
tic
wait2 = waitbar(0, 'Blocking Pixels Determined...');

for i = 1:length(azsBlk)

    % Create vector containing +/- 0.9 degrees due to the radar's
    % beamwidth.
    someVar = [azsBlk(i)-0.9 azsBlk(i)+0.9];

    % Find negative angles and convert them to positive.
    negSomeVar = find(someVar < 0);
    someVar(negSomeVar) = someVar(negSomeVar) + 360;

    % Find all angles between radar's beamwidth
    blkAzIndex = find(allAz >= someVar(1) & allAz <= someVar(2));

    blkRngTemp1 = allRange(blkAzIndex);

    blkRngIndex = find(blkRngTemp1 >= rngBlk(i));

    blkMap(blkAzIndex(blkRngIndex)) = -40;
    blkBhMat(blkAzIndex(blkRngIndex)) = -40;
    compBlkMat(blkAzIndex(blkRngIndex)) = -40;
    compBlkMat2(blkAzIndex(blkRngIndex)) = -40;

    waitbar(i/length(azsBlk), wait2)

end
toc
close(wait2)

save(blkfile, 'blkMap', 'blkBhMat', 'compBlkMat', 'compBlkMat2')

else

    load(blkfile)

end

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                               %
%                               %
%                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Creating new directory to store the pics in.
picSavefiledir = strcat(savefiledir, '/', num2str(hVec(hIndex)),
    '/', num2str(thetaVec(thetaIndex)), '/');

if ~isdir(picSavefiledir)
    mkdir(picSavefiledir);
end

figStr = [radrStr ' Blockage Map'];
figHndl1 = figure('Name', figStr);
worldmap(latlim, lonlim);
geoshow(blkMap, maplegend, 'DisplayType', 'surface')
demcmap(blkMap)

colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;

```

```

X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

% Figure Title
title({'40km Coverage Blockage Map: ';...
      [radrStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft']})
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(rad_r_lat,rad_r_lon,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(rad_r_lat,rad_r_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y')

% Creating file path and name to save map figure.
mapPicFileName = strcat(rad_rFlStr,' medMapBlk',num2str(hVec(hIndex)),num2str(thetaIndex),'.jpg');
mapPicFile = fullfile(picSavefiledir,mapPicFileName);

saveas(figHndl1,mapPicFile)
close(figHndl1)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                               %
%                               %
%                               %
%                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Plot map
figStr = [radrStr ' Beam Height Blockage Map'];
figHndl2 = figure('Name',figStr);
ax = worldmap(latlim,lonlim);
geoshow(compBlkMat,maplegend,'DisplayType','surface')
colormap(jet)
%           colormap(jet)
colorbar
axis off
hold on

tightmap
hold on

%Modifying The Colormap
X = flipud(colormap);
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

% Figure Title
title({'40km Coverage Beam Height Blockage Map: ';...
      [radrStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft']})
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(rad_r_lat,rad_r_lon,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(rad_r_lat,rad_r_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y')

```

```

% Creating file path and name to save map figure.
BhMapPicFileName = strcat(radrlStr, '
BeamHeightBlkMap',num2str(hVec(hIndex)),num2str(thetaIndex), '.jpg');
BhMapPicFile = fullfile(picSavefiledir,BhMapPicFileName);

saveas(figHndl2,BhMapPicFile)
close(figHndl2)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Blk Beam Height Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Plot map
figStr = [radrlStr ' Beam Height Blockage Map'];
figHndl3 = figure('Name',figStr);
ax = worldmap(latlim,lonlim);
geoshow(compBlkMat2,maplegend,'DisplayType','surface')
colormap(jet)
%           colormap(jet)
colorbar
axis off
hold on

tightmap
hold on

%Modifying The Colormap
X = flipud(colormap);
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

% Figure Title
title(['40km Coverage Beam Height Blockage Map: ';...
      [radrlStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft']])
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radrl_lat,radrl_lon,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radrl_lat,radrl_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y')

% Creating file path and name to save map figure.
BhMapPicFileName = strcat(radrlStr, '
BeamHeightBlkMap2',num2str(hVec(hIndex)),num2str(thetaIndex), '.jpg');
BhMapPicFile = fullfile(picSavefiledir,BhMapPicFileName);

saveas(figHndl3,BhMapPicFile)
close(figHndl3)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Histogram
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% For map containing land and sea

```

```

inRng = find(allRange <= 40);
histVar2 = compBlkMat2(inRng);

figStr = [radrStr ' Beam Height Histogram'];
figHndl4 = figure('Name',figStr);
histVec2 = -40:10:max(histVar2);
hist(histVar2,histVec2)
ylabel('Number of Ocurrences')
xlabel('Height of Beam (m)')
title({'Beam Height Histogram: ';...
      [radrStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft']})

% Creating file path and name to save map figure.
histFileName = strcat(radrf1Str, ' Histogram',num2str(hVec(hIndex)),num2str(thetaIndex), '.jpg');
histFile = fullfile(picSavefiledir,histFileName);

saveas(figHndl4,histFile)
close(figHndl4)
pause(1)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Surface Area
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Puerto Rico's Surface Area = 9,104 sq km. It doesn't include Vieques or
% Culebra.

% Determine all of the area covered by the radar.
covSAMap = map(inRng);
covCompSAnumPix = length(covSAMap);
covCompSAArea = covCompSAnumPix * 90 * 90;
covCompSAArea = covCompSAArea * 1e-6; % Now in km^2

% Determine the area of land covered by the radar (m^2).
covLandSAVarIndex = find(covSAMap>=0);
covLandSANumPix = length(covLandSAVarIndex);
covLandSAArea = covLandSANumPix * 90 * 90;
covLandSAArea = covLandSAArea*1e-6; % Now in km^2

% Determine the area of land available from block map (m^2).
blkSAMap = blkMap(inRng);
noblkLandSAVarIndex = find(blkSAMap>=0);
noblkLandSANumPix = length(noblkLandSAVarIndex);
noblkLandSAArea = noblkLandSANumPix * 90 * 90;
noblkLandSAArea = noblkLandSAArea * 1e-6; %Now in km^2

% Determine the area of water covered by the radar (m^2).
covWtrSAVarIndex = find(covSAMap == -10);
covWtrSANumPix = length(covWtrSAVarIndex);
covWtrSAArea = covWtrSANumPix * 90 * 90;
covWtrSAArea = covWtrSAArea*1e-6; %Now in km^2

% Determine the area of water covered by the radar (m^2).
noblkWtrSAVarIndex = find(blkSAMap == -10);
noblkWtrSANumPix = length(noblkWtrSAVarIndex);
noblkWtrSAArea = noblkWtrSANumPix * 90 * 90;
noblkWtrSAArea = noblkWtrSAArea * 1e-6;

% Land Unblocked Coverage Percentage
landUnBlkd_PoC = noblkLandSAArea/covCompSAArea*100;

```

```

% Land Blocked Coverage Percentage
landBlkd_SA = covLandSArea - noblkLandSArea;
landBlkd_PoC = landBlkd_SA/covLandSArea*100;

% Water Unblocked Coverage Percentage
wtrUnBlkd_PoC = noblkWtrSArea/covCompSArea*100;

% Water Blocked Coverage Percentage
wtrBlkd_SA = covWtrSArea - noblkWtrSArea;
wtrBlkd_PoC = wtrBlkd_SA/covWtrSArea;

% Surface Area values in msg box

SACell = {'
          Coverage Area Calculations: '};...
['
          ' radrStr ' Elevation Angle ' num2str(thetaVec(thetaIndex)) '
degs, Height ' num2str(hVec(hIndex)) ' ft'];...
[' ' ' '];...
[' ' ' '];...
['
          Total Area of Coverage: ' num2str(covCompSArea) ' km^2'];...
[' ' ' '];...
['
          Total Area of Land Coverage: ' num2str(noblkLandSArea) ' km^2 --> '
num2str(landUnBlkd_PoC) '% '];...
[' ' ' '];...
['
          Blocked Land Area: ' num2str(landBlkd_SA) ' km^2 --> '
num2str(landBlkd_PoC) '% '];...
[' ' ' '];...
['
          Total Area of Water Coverage: ' num2str(noblkWtrSArea) ' km^2 --> '
num2str(wtrUnBlkd_PoC) '% '];...
[' ' ' '];...
['
          Blocked Water Area: ' num2str(wtrBlkd_SA) ' km^2 --> '
num2str(wtrBlkd_PoC) '% '];...
[' ' ' '];...
[' ' ' ']];

msghandle = msgbox(SACell);
set(msghandle,'Color',[1 1 1])
msgFileName = strcat(radrf1Str, ' SurfaceAreaCalc',num2str(hVec(hIndex)),num2str(thetaIndex),
'.jpg');
msgFile = fullfile(picSavefiledir,msgFileName);
saveas(msghandle,msgFile)
close(msghandle)

% Generate Pie Chart
blkLand = covLandSArea - noblkLandSArea;
noBlkLand = covLandSArea - blkLand;
blkWtr = covWtrSArea - noblkWtrSArea;
noBlkWtr = covWtrSArea - blkWtr;

figStr = [radrStr ' Coverage Pie Chart'];
figHndl5 = figure('Name',figStr);
pieVar = [noBlkLand blkLand blkWtr noBlkWtr];
explode = [0 1 1 0];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-1)) '% No-Block
Land'], [num2str(roundn(pieVar(2)/sum(pieVar)*100,-1)) '% Blocked Land'],...
[num2str(roundn(pieVar(3)/sum(pieVar)*100,-1)) '% Blocked
Sea'], [num2str(roundn(pieVar(4)/sum(pieVar)*100,-1)) '% No-Block Sea']];

pie3(pieVar, explode,label)

title({'Coverage Pie Chart: '};...
      [radrStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft']})

X2 = [051/255 102/255 051/255 ; 102/255 0/255 0/255 ; 153/255 0/255 0/255 ; 051/255 051/255
204/255];
colormap(X2)

% Creating file path and name to save map figure.

```

```

pieChartFileName = strcat(radrf1Str, ' PieChart',num2str(hVec(hIndex)),num2str(thetaIndex),
'.jpg');
pieChartFile = fullfile(picSavefiledir,pieChartFileName);

saveas(figHndl5,pieChartFile)
close(figHndl5)
pause(1)

%% WtrSheds
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Read Watershed Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[cuencasMap,cuencasMaplegend] = arcgridread('subcuencas_id2.asc');

% Equalling Watershed Map size to that of map
[tempCuencasMap] = eqMapSizev2(map,maplegend,latlim,lonlim,cuencasMap,cuencasMaplegend);

% Create new watersheds map full on NaNs
newCuencasMap = nan(size(tempCuencasMap));
CuencasMap = newCuencasMap;
CuencasI = find(tempCuencasMap >= 0);
newCuencasMap(CuencasI) = tempCuencasMap(CuencasI);

% Complete Watersheds Map
CuencasMap(CuencasI) = 1400;

% Create a map full of NaNs
nanmap = nan(size(newCuencasMap));

% Culebrinas
culebrinasMap = nanmap;
inRngCulebrinasMap = nanmap;
CuleI = find(newCuencasMap == 1);
culebrinasMap(CuleI) = 1400;
inRngCulebrinasMap(inRng) = culebrinasMap(inRng);

% Rio Grande de Anasco
rioGMap = nanmap;
inRngRioGMap = nanmap;
rioGI = find(newCuencasMap == 2);
rioGMap(rioGI) = 1400;
inRngRioGMap(inRng) = rioGMap(inRng);

% Rio Yaguez
yagMap = nanmap;
inRngYagMap = nanmap;
yagI = find(newCuencasMap == 4);
yagMap(yagI) = 1400;
inRngYagMap(inRng) = yagMap(inRng);

% Guanajibo
guanaMap = nanmap;
inRngGuanaMap = nanmap;
guanaI = find(newCuencasMap == 3);
guanaMap(guanaI) = 1400;
inRngGuanaMap(inRng) = guanaMap(inRng);

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Watershed Calculations
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Radar coverage over complete watershed area.

inRngWtrsheds = nanmap;
inRngWtrsheds(inRng) = CuencasMap(inRng);

```

```

% Surface Area of Complete Watershed area.
compWtrshedSA = length(CuencasI) * 90 * 90 * 1e-6;

% Surface Area of Watershed Area within radar range.
inRngWtrshedsSAI = find(inRngWtrsheds >= 0);
inRngWtrshedSA = length(inRngWtrshedsSAI) * 90 * 90 * 1e-6;
inRngWtrshedPoC = roundn(inRngWtrshedSA/compWtrshedSA * 100,-2);

% Surface Area of out of range watersheds.
outRngWtrshedSA = compWtrshedSA - inRngWtrshedSA;
outRngWtrshedPoC = roundn(outRngWtrshedSA/compWtrshedSA * 100,-2);

% Block/No-Block Watershed Surface Area
inRngBlkWtrsheds = nanmap;

noblockI = find(blkMap(inRngWtrshedsSAI) >= -10);

% Surface Area of No-Block Watershed Area
noBlkWtrshedSA = length(noblockI) * 90 * 90 * 1e-6;
noBlkWtrshedPoC = roundn(noBlkWtrshedSA/inRngWtrshedSA * 100,-2);

% Surface Area of Blocked Watershed Area
blkWtrshedSA = inRngWtrshedSA - noBlkWtrshedSA;
blkWtrshedPoC = roundn(blkWtrshedSA/inRngWtrshedSA * 100,-2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Individual Watersheds Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Culebrinas
compCuleSA = length(CuleI) * 90 * 90 * 1e-6;

inRngCuleI = find(inRngCulebrinasMap >= 0);
inRngCuleSA = length(inRngCuleI) * 90 * 90 * 1e-6;
inRngCulePoC = roundn(inRngCuleSA/compCuleSA * 100,-2);

inRngNoBlkCuleI = find(blkMap(inRngCuleI) >= -10);

inRngNoBlkCuleSA = length(inRngNoBlkCuleI) * 90 * 90 * 1e-6;
inRngNoBlkCulePoC = roundn(inRngNoBlkCuleSA/inRngCuleSA * 100,-2);

inRngBlkCuleSA = inRngCuleSA - inRngNoBlkCuleSA;
inRngBlkCulePoC = roundn(inRngBlkCuleSA/inRngCuleSA * 100,-2);

% Rio Grande de Anasco
compRioGSA = length(rioGI) * 90 * 90 * 1e-6;

inRngRioGI = find(inRngRioGMap >= 0);
inRngRioGSA = length(inRngRioGI) * 90 * 90 * 1e-6;
inRngRioGPoC = roundn(inRngRioGSA/compRioGSA * 100,-2);

inRngNoBlkRioGI = find(blkMap(inRngRioGI) >= -10);

inRngNoBlkRioGSA = length(inRngNoBlkRioGI) * 90 * 90 * 1e-6;
inRngNoBlkRioGPoC = roundn(inRngNoBlkRioGSA/inRngRioGSA * 100,-2);

inRngBlkRioGSA = inRngRioGSA - inRngNoBlkRioGSA;
inRngBlkRioGPoC = roundn(inRngBlkRioGSA/inRngRioGSA * 100,-2);

% Yaguez
compYagSA = length(yagI) * 90 * 90 * 1e-6;

inRngYagI = find(inRngYagMap >= 0);
inRngYagSA = length(inRngYagI) * 90 * 90 * 1e-6;
inRngYagPoC = roundn(inRngYagSA/compYagSA * 100,-2);

inRngNoBlkYagI = find(blkMap(inRngYagI) >= -10);

inRngNoBlkYagSA = length(inRngNoBlkYagI) * 90 * 90 * 1e-6;
inRngNoBlkYagPoC = roundn(inRngNoBlkYagSA/inRngYagSA * 100,-2);

```

```

inRngBlkYagSA = inRngYagSA - inRngNoBlkYagSA;
inRngBlkYagPoC = roundn(inRngBlkYagSA/inRngYagSA * 100,-2);

% Guanajibo
compGuanaSA = length(guanaI) * 90 * 90 * 1e-6;

inRngGuanaI = find(inRngGuanaMap >= 0);
inRngGuanaSA = length(inRngGuanaI) * 90 * 90 * 1e-6;
inRngGuanaPoC = roundn(inRngGuanaSA/compGuanaSA * 100,-2);

inRngNoBlkGuanaI = find(blkMap(inRngGuanaI) >= -10);

inRngNoBlkGuanaSA = length(inRngNoBlkGuanaI) * 90 * 90 * 1e-6;
inRngNoBlkGuanaPoC = roundn(inRngNoBlkGuanaSA/inRngGuanaSA * 100,-2);

inRngBlkGuanaSA = inRngGuanaSA - inRngNoBlkGuanaSA;
inRngBlkGuanaPoC = roundn(inRngBlkGuanaSA/inRngGuanaSA * 100,-2);

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Watershed Calculations MsgBox
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SACell12 = {'          ' radrStr ' Watershed Coverage Area Calculations: ' };...
['          ' Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft'];...
[' ' ' '];...
[' ' ' '];...
['          ' Total Watersheds Area: ' num2str(compWtrshedSA) ' km^2'];...
[' ' ' '];...
[' ' ' '];...
['          ' In-Range Watershed Area: ' num2str(inRngWtrshedSA) ' km^2 --> '
num2str(inRngWtrshedPoC) '% '];...
[' ' ' '];...
['          ' Watershed No-Block Area: ' num2str(noBlkWtrshedSA) ' km^2 --> '
num2str(noBlkWtrshedPoC) '% '];...
[' ' ' '];...
['          ' Culebrinas: ' num2str(inRngNoBlkCuleSA) ' km^2 --> '
num2str(inRngNoBlkCulePoC) '% '];...
[' ' ' '];...
['          ' Rio Grande de Anasco: ' num2str(inRngNoBlkRioGSA) ' km^2 -
-> ' num2str(inRngNoBlkRioGPoC) '% '];...
[' ' ' '];...
['          ' Yaguez: ' num2str(inRngNoBlkYagSA) ' km^2 --> '
num2str(inRngNoBlkYagPoC) '% '];...
[' ' ' '];...
['          ' Guanajibo: ' num2str(inRngNoBlkGuanaSA) ' km^2 --> '
num2str(inRngNoBlkGuanaPoC) '% '];...
[' ' ' '];...
['          ' Watershed Blocked Area: ' num2str(blkWtrshedSA) ' km^2 --> '
num2str(blkWtrshedPoC) '% '];...
[' ' ' '];...
['          ' Culebrinas: ' num2str(inRngBlkCuleSA) ' km^2 --> '
num2str(inRngBlkCulePoC) '% '];...
[' ' ' '];...
['          ' Rio Grande de Anasco: ' num2str(inRngBlkRioGSA) ' km^2 -->
' num2str(inRngBlkRioGPoC) '% '];...
[' ' ' '];...
['          ' Yaguez: ' num2str(inRngBlkYagSA) ' km^2 --> '
num2str(inRngBlkYagPoC) '% '];...
[' ' ' '];...
['          ' Guanajibo: ' num2str(inRngBlkGuanaSA) ' km^2 --> '
num2str(inRngBlkGuanaPoC) '% '];...
[' ' ' '];...
[' ' ' '];...
['          ' Out-of-Range Watershed Area: ' num2str(outRngWtrshedSA) ' km^2 --> '
num2str(outRngWtrshedPoC) '% '];...

```

```

        [' ' ' '];...
        [' ' ' ']];

msghandle2 = msgbox(SACell2);
set(msghandle2,'Color',[1 1 1])
msgFileName = strcat(radrf1Str, '
WtrshedSurfaceAreaCalc2',num2str(hVec(hIndex)),num2str(thetaIndex), '.jpg');
msgFile = fullfile(picSavefiledir,msgFileName);
saveas(msghandle2,msgFile)
close(msghandle2)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Watershed Calculations PieChart
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

blkLand = covLandSArea - noblkLandSArea;
noBlkLand = covLandSArea - blkLand;

blkWtr = covWtrSArea - noblkWtrSArea;
noBlkWtr = covWtrSArea - blkWtr;

figStr = [radrStr ' Watersheds Coverage Pie Chart'];
figHndl6 = figure('Name',figStr);
pieVar = [noBlkWtrshedSA blkWtrshedSA outRngWtrshedSA];
explode = [1 0 0];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-2)) '% No-Block
'],[num2str(roundn(pieVar(2)/sum(pieVar)*100,-2)) '% Blocked '],...
         [num2str(roundn(pieVar(3)/sum(pieVar)*100,-2)) '% Out-of-Range ']];

pie3(pieVar, explode,label)

title({'Watersheds Coverage Pie Chart: '};...
      [radrStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft'])

X2 = [0/255 153/255 255/255 ; 0/255 51/255 153/255 ; 0/255 0/255 0/255];
colormap(X2)

% Creating file path and name to save map figure.
pieChartFileName2 = strcat(radrf1Str, '
WatershedPieChart',num2str(hVec(hIndex)),num2str(thetaIndex), '.jpg');
pieChartFile2 = fullfile(picSavefiledir,pieChartFileName2);

saveas(figHndl6,pieChartFile2)
close(figHndl6)
pause(1)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Read Municipios Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[muniMap,muniMaplegend] = arcgridread('pr_countries.asc');

% Equalling Municipalities Map size to that of map
[tempMuniMap] = eqMapSizev2(map,maplegend,latlim,lonlim,muniMap,muniMaplegend);

% Create new Municipalities Map with NaNs
newMuniMap = nan(size(tempMuniMap));
MuniMap = newMuniMap;

MuniI = find(tempMuniMap >= 0);
newMuniMap(MuniI) = tempMuniMap(MuniI);

% Create a map full of Nans
nanmap = nan(size(newMuniMap));

```

```

% Aguadilla
AguadillaMap = nanmap;
inRngAguadillaMap = nanmap;
AguadillaI = find(newMuniMap == 72005);
AguadillaMap(AguadillaI) = 1400;
inRngAguadillaMap(inRng) = AguadillaMap(inRng);

% Aguada
AguadaMap = nanmap;
inRngAguadaMap = nanmap;
AguadaI = find(newMuniMap == 72003);
AguadaMap(AguadaI) = 1400;
inRngAguadaMap(inRng) = AguadaMap(inRng);

% Rincon
RinconMap = nanmap;
inRngRinconMap = nanmap;
RinconI = find(newMuniMap == 72117);
RinconMap(RinconI) = 1400;
inRngRinconMap(inRng) = RinconMap(inRng);

% Anasco
AnascoMap = nanmap;
inRngAnascoMap = nanmap;
AnascoI = find(newMuniMap == 72011);
AnascoMap(AnascoI) = 1400;
inRngAnascoMap(inRng) = AnascoMap(inRng);

% Mayaguez
MayaMap = nanmap;
inRngMayaMap = nanmap;
MayaI = find(newMuniMap == 72097);
MayaMap(MayaI) = 1400;
inRngMayaMap(inRng) = MayaMap(inRng);

% Cabo Rojo
CaboMap = nanmap;
inRngCaboMap = nanmap;
CaboI = find(newMuniMap == 72023);
CaboMap(CaboI) = 1400;
inRngCaboMap(inRng) = CaboMap(inRng);

% Merge all indices.
compMuniI = vertcat(AguadillaI, AguadaI, RinconI, AnascoI, MayaI, CaboI);

% Complete Municipalities Map
MuniMap(compMuniI) = 1400;

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Vulnerability Calculations
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Radar coverage over complete municipality area.

inRngMuniMap = nanmap;
inRngMuniMap(inRng) = MuniMap(inRng);

% Surface Area of Complete Municipality areas.
compMuniSA = length(compMuniI) * 90 * 90 * 1e-6;

% Surface Area of Municipality Areas within radar range.
inRngMuniSAI = find(inRngMuniMap >= 0);
inRngMuniSA = length(inRngMuniSAI) * 90 * 90 * 1e-6;
inRngMuniPoC = roundn(inRngMuniSA/compMuniSA * 100,-2);

% Surface Area of out of range vulnerability areas.
outRngMuniSA = compMuniSA - inRngMuniSA;

```

```

outRngMuniPoC = roundn(outRngMuniSA/compMuniSA * 100,-2);

% Block/No-Block Vulnerability Surface Area
inRngBlkMuni = nanmap;

noblockMuniI = find(blkMap(inRngMuniSAI) >= -10);

% Surface Area of No-Block Vulnerability Area
noBlkMuniSA = length(noblockMuniI) * 90 * 90 * 1e-6;
noBlkMuniPoC = roundn(noBlkMuniSA/inRngMuniSA * 100,-2);

% Surface Area of Blocked Vulnerability Area
blkMuniSA = inRngMuniSA - noBlkMuniSA;
blkMuniPoC = roundn(blkMuniSA/inRngMuniSA * 100,-2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Individual Municipality Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Aguadilla
compAguadillaSA = length(AguadillaI) * 90 * 90 * 1e-6;

inRngAguadillaI = find(inRngAguadillaMap >= 0);
inRngAguadillaSA = length(inRngAguadillaI) * 90 * 90 * 1e-6;
inRngAguadillaPoC = roundn(inRngAguadillaSA/compAguadillaSA * 100,-2);

inRngNoBlkAguadillaI = find(blkMap(inRngAguadillaI) >= -10);

inRngNoBlkAguadillaSA = length(inRngNoBlkAguadillaI) * 90 * 90 * 1e-6;
inRngNoBlkAguadillaPoC = roundn(inRngNoBlkAguadillaSA/inRngAguadillaSA * 100,-2);

inRngBlkAguadillaSA = inRngAguadillaSA - inRngNoBlkAguadillaSA;
inRngBlkAguadillaPoC = roundn(inRngBlkAguadillaSA/inRngAguadillaSA * 100,-2);

% Aguada
compAguadaSA = length(AguadaI) * 90 * 90 * 1e-6;

inRngAguadaI = find(inRngAguadaMap >= 0);
inRngAguadaSA = length(inRngAguadaI) * 90 * 90 * 1e-6;
inRngAguadaPoC = roundn(inRngAguadaSA/compAguadaSA * 100,-2);

inRngNoBlkAguadaI = find(blkMap(inRngAguadaI) >= -10);

inRngNoBlkAguadaSA = length(inRngNoBlkAguadaI) * 90 * 90 * 1e-6;
inRngNoBlkAguadaPoC = roundn(inRngNoBlkAguadaSA/inRngAguadaSA * 100,-2);

inRngBlkAguadaSA = inRngAguadaSA - inRngNoBlkAguadaSA;
inRngBlkAguadaPoC = roundn(inRngBlkAguadaSA/inRngAguadaSA * 100,-2);

% Rincon
compRinconSA = length(RinconI) * 90 * 90 * 1e-6;

inRngRinconI = find(inRngRinconMap >= 0);
inRngRinconSA = length(inRngRinconI) * 90 * 90 * 1e-6;
inRngRinconPoC = roundn(inRngRinconSA/compRinconSA * 100,-2);

inRngNoBlkRinconI = find(blkMap(inRngRinconI) >= -10);

inRngNoBlkRinconSA = length(inRngNoBlkRinconI) * 90 * 90 * 1e-6;
inRngNoBlkRinconPoC = roundn(inRngNoBlkRinconSA/inRngRinconSA * 100,-2);

inRngBlkRinconSA = inRngRinconSA - inRngNoBlkRinconSA;
inRngBlkRinconPoC = roundn(inRngBlkRinconSA/inRngRinconSA * 100,-2);

% Anasco
compAnascoSA = length(AnascoI) * 90 * 90 * 1e-6;

inRngAnascoI = find(inRngAnascoMap >= 0);
inRngAnascoSA = length(inRngAnascoI) * 90 * 90 * 1e-6;

```

```

inRngAnascoPoC = roundn(inRngAnascoSA/compAnascoSA * 100,-2);

inRngNoBlkAnascoI = find(blkMap(inRngAnascoI) >= -10);

inRngNoBlkAnascoSA = length(inRngNoBlkAnascoI) * 90 * 90 * 1e-6;
inRngNoBlkAnascoPoC = roundn(inRngNoBlkAnascoSA/inRngAnascoSA * 100,-2);

inRngBlkAnascoSA = inRngAnascoSA - inRngNoBlkAnascoSA;
inRngBlkAnascoPoC = roundn(inRngBlkAnascoSA/inRngAnascoSA * 100,-2);

% Mayaguez
compMayaSA = length(MayaI) * 90 * 90 * 1e-6;

inRngMayaI = find(inRngMayaMap >= 0);
inRngMayaSA = length(inRngMayaI) * 90 * 90 * 1e-6;
inRngMayaPoC = roundn(inRngMayaSA/compMayaSA * 100,-2);

inRngNoBlkMayaI = find(blkMap(inRngMayaI) >= -10);

inRngNoBlkMayaSA = length(inRngNoBlkMayaI) * 90 * 90 * 1e-6;
inRngNoBlkMayaPoC = roundn(inRngNoBlkMayaSA/inRngMayaSA * 100,-2);

inRngBlkMayaSA = inRngMayaSA - inRngNoBlkMayaSA;
inRngBlkMayaPoC = roundn(inRngBlkMayaSA/inRngMayaSA * 100,-2);

% Cabo Rojo
compCaboSA = length(CaboI) * 90 * 90 * 1e-6;

inRngCaboI = find(inRngCaboMap >= 0);
inRngCaboSA = length(inRngCaboI) * 90 * 90 * 1e-6;
inRngCaboPoC = roundn(inRngCaboSA/compCaboSA * 100,-2);

inRngNoBlkCaboI = find(blkMap(inRngCaboI) >= -10);

inRngNoBlkCaboSA = length(inRngNoBlkCaboI) * 90 * 90 * 1e-6;
inRngNoBlkCaboPoC = roundn(inRngNoBlkCaboSA/inRngCaboSA * 100,-2);

inRngBlkCaboSA = inRngCaboSA - inRngNoBlkCaboSA;
inRngBlkCaboPoC = roundn(inRngBlkCaboSA/inRngCaboSA * 100,-2);

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Vulnerability Calculations MsgBox                               %
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SACell13 = [{'          ' radrStr ' Vulnerability Area Coverage Calculations: ' };...
            ['          Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs,
Height ' num2str(hVec(hIndex)) ' ft'];...
            [' ' ' '];...
            [' ' ' '];...
            ['          Total Vulnerability Area: ' num2str(compMuniSA) ' km^2'];...
            [' ' ' '];...
            [' ' ' '];...
            ['          In-Range Vulnerability Area: ' num2str(inRngMuniSA) ' km^2 --> '
num2str(inRngMuniPoC) '%' ];...
            [' ' ' '];...
            ['          Vulnerability No-Block Area: ' num2str(noBlkMuniSA) ' km^2 --> '
num2str(noBlkMuniPoC) '%' ];...
            [' ' ' '];...
            ['          Aguadilla: ' num2str(inRngNoBlkAguadillaSA) ' km^2 --> '
num2str(inRngNoBlkAguadillaPoC) '%' ];...
            [' ' ' '];...
            ['          Aguada: ' num2str(inRngNoBlkAguadaSA) ' km^2 --> '
num2str(inRngNoBlkAguadaPoC) '%' ];...
            [' ' ' '];...

```

```

        ['          Rincon: ' num2str(inRngNoBlkRinconSA) ' km^2 --> '
num2str(inRngNoBlkRinconPoC) '%' ];...
        [' ' ' '];...
        ['          Anasco: ' num2str(inRngNoBlkAnascoSA) ' km^2 --> '
num2str(inRngNoBlkRinconPoC) '%' ];...
        [' ' ' '];...
        ['          Mayaguez: ' num2str(inRngNoBlkMayaSA) ' km^2 --> '
num2str(inRngNoBlkMayaPoC) '%' ];...
        [' ' ' '];...
        ['          Cabo Rojo: ' num2str(inRngNoBlkCaboSA) ' km^2 --> '
num2str(inRngNoBlkCaboPoC) '%' ];...
        [' ' ' '];...
        ['          Vulnerability Blocked Area: ' num2str(blkMuniSA) ' km^2 --> '
num2str(blkMuniPoC) '%' ];...
        [' ' ' '];...
        ['          Aguadilla: ' num2str(inRngBlkAguadillaSA) ' km^2 --> '
num2str(inRngBlkAguadillaPoC) '%' ];...
        [' ' ' '];...
        ['          Aguada: ' num2str(inRngBlkAguadaSA) ' km^2 --> '
num2str(inRngBlkAguadaPoC) '%' ];...
        [' ' ' '];...
        ['          Rincon: ' num2str(inRngBlkRinconSA) ' km^2 --> '
num2str(inRngBlkRinconPoC) '%' ];...
        [' ' ' '];...
        ['          Anasco: ' num2str(inRngBlkAnascoSA) ' km^2 --> '
num2str(inRngBlkAnascoPoC) '%' ];...
        [' ' ' '];...
        ['          Mayaguez: ' num2str(inRngBlkMayaSA) ' km^2 --> '
num2str(inRngBlkMayaPoC) '%' ];...
        [' ' ' '];...
        ['          Cabo Rojo: ' num2str(inRngBlkCaboSA) ' km^2 --> '
num2str(inRngBlkCaboPoC) '%' ];...
        [' ' ' '];...
        [' ' ' '];...
        ['          Out-of-Range Vulnerability Area: ' num2str(outRngMuniSA) ' km^2 --> '
num2str(outRngMuniPoC) '%' ];...
        [' ' ' '];...
        [' ' ' '];

```

```

msghandle3 = msgbox(SACell3);
set(msghandle3,'Color',[1 1 1])
msgFileName = strcat(radrf1Str, '
VulnerabilitySurfaceAreaCalc2',num2str(hVec(hIndex)),num2str(thetaIndex), '.jpg');
msgFile = fullfile(picSavefiledir,msgFileName);
saveas(msghandle3,msgFile)
close(msghandle3)

```

```

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%          Vulnerability Calculations PieChart
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

figStr = [radrf1Str ' Vulnerability Coverage Pie Chart'];
figHndl7 = figure('Name',figStr);
pieVar = [noBlkMuniSA blkMuniSA outRngMuniSA];
explode = [1 0 0];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-2)) '% No-Block
'],[num2str(roundn(pieVar(2)/sum(pieVar)*100,-2)) '% Blocked '],...
        [num2str(roundn(pieVar(3)/sum(pieVar)*100,-2)) '% Out-of-Range ']}];
pie3(pieVar, explode,label)
title({'Vulnerability Coverage Pie Chart: '};...
        [radrf1Str ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft'])

```

```

X2 = [153/255 51/255 51/255 ; 100/255 0/255 0/255 ; 0/255 0/255 0/255];

```

```

colormap(X2)

% Creating file path and name to save map figure.
pieChartFileName3 = strcat(radrf1Str, '
VulnerabilityPieChart',num2str(hVec(hIndex)),num2str(thetaIndex), '.jpg');
pieChartFile3 = fullfile(picSavefiledir,pieChartFileName3);

saveas(figHndl7,pieChartFile3)
close(figHndl7)
pause(1)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Separate Watersheds
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr 'Watershed Blockage Map'];
figHndl9 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(blkMap,maplegend,'DisplayType', 'surface')
demcmap(blkMap)

colorbar
axis off
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

hold on

% Plot Culebrinas Watershed Area
h_OLMap1 = geoshow(inRngCulebrinasMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 102/255 255/255])
set(figHndl9,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Rio Grande de Abasco Watershed Area
h_OLMap1 = geoshow(inRngRioGMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 51/255 153/255])
set(figHndl9,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Yaguez Watershed Area
h_OLMap1 = geoshow(inRngYagMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 153/255 255/255])
set(figHndl9,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Guanajibo Watershed Area
h_OLMap1 = geoshow(inRngGuanaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 51/255 204/255])
set(figHndl9,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

```

```

% Figure Title
title({'Individual Watershed Coverage Map: '};...
    [radrStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft'}})
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(rad_r_lat,rad_r_lon,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(rad_r_lat,rad_r_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y')

% Creating file path and name to save map figure.
mapPicFileName = strcat(rad_rFlStr, '
WatershedBlkMap2', num2str(hVec(hIndex)), num2str(thetaIndex), '.jpg');
mapPicFile = fullfile(picSavefiledir, mapPicFileName);

saveas(figHndl9, mapPicFile)
close(figHndl9)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Separate Municipalities
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' Vulnerability Area Blockage Map'];
figHndl11 = figure('Name', figStr);
worldmap(latlim, lonlim);
geoshow(blkMap, maplegend, 'DisplayType', 'surface')
demcmap(blkMap)

colorbar
axis off
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

% Figure Title
title({'Separate Vulnerability Areas Coverage Map: '};...
    [radrStr ': Elevation Angle ' num2str(thetaVec(thetaIndex)) ' degs, Height '
num2str(hVec(hIndex)) ' ft'}})
xlabel('Longitude')
ylabel('Latitude')

hold on

% Plot Aguadilla Area
h_OLMap1 = geoshow(inRngAguadillaMap, maplegend, 'DisplayType', 'surface');
set(h_OLMap1, 'FaceColor', [255/255 100/255 100/255])
set(figHndl11, 'Renderer', 'OpenGL')
set(h_OLMap1, 'FaceAlpha', 0.8)

hold on

% Plot Aguada Area
h_OLMap1 = geoshow(inRngAguadaMap, maplegend, 'DisplayType', 'surface');

```

```

set(h_OLMap1,'FaceColor',[204/255 51/255 51/255])
set(figHndl111,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Rincon Area
h_OLMap1 = geoshow(inRngRinconMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 10/255 10/255])
set(figHndl111,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Anasco Area
h_OLMap1 = geoshow(inRngAnascoMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[255/255 100/255 100/255])
set(figHndl111,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Mayaguez Area
h_OLMap1 = geoshow(inRngMayaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 51/255 51/255])
set(figHndl111,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Cabo Rojo Area
h_OLMap1 = geoshow(inRngCaboMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 10/255 10/255])
set(figHndl111,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y')

% Creating file path and name to save map figure.
mapPicFileName = strcat(radrFlStr,'
VulnerabilityBlkMap2',num2str(hVec(hIndex)),num2str(thetaIndex),'.jpg');
mapPicFile = fullfile(picSavefiledir,mapPicFileName);

saveas(figHndl111,mapPicFile)
close(figHndl111)

%%
    end

end

end

```

## A1.3 THREE-RADAR NETWORK EVALUATIONS

### A1.3.1 Radr3Main.m

```

clc
clear
close all

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               3-Radar Network Analyses
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               University of Puerto Rico at Mayaguez
%                               Department of Electrical and Computer Engineering
%                               Created By: Ricardo Rios-Olmo
%
% Purpose:
% This program evaluates the performance of a network of three radars.
% Capabilities such as network retrieval and multi-Doppler retrievals are
% evaluated.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%% Radar 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Radar Locations in the Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

locVarVec1 = [2 2 9 9 9 1 2];
locVarVec2 = [3 6 1 3 6 3 1];
locVarVec3 = [5 5 5 5 5 6 3];

hIndexVec1 = [6 6 6 6 6 3 6];
hIndexVec2 = [6 6 3 6 6 6 3];
hIndexVec3 = [5 5 5 5 5 6 6];

thetaIndexVec1 = [6 6 7 7 7 10 6];
thetaIndexVec2 = [7 7 10 7 7 7 10];
thetaIndexVec3 = [8 8 8 8 8 7 7];

for index = 1:length(locVarVec1);

locVar = locVarVec1(index);

    if locVar == 1
        % CID
        CidStr = 'CID';
        lat_CID = 18.21125;
        lon_CID = -67.13676;
        height_CID = 41.10;

        radrStr = 'CID';
        radrFlStr = 'CID';
        radr_lat = 18.21125;
        radr_lon = -67.13676;

    elseif locVar == 2
        % Aguadilla - Finca Montana
        AguadillaStr = 'Finca Montana';
        lat_Aguadilla = 18.4751;
        lon_Aguadilla = -67.1206;

        radrStr = 'Finca Montana I';
        radrFlStr = 'Aguadilla';
        radr_lat = 18.4751;
        radr_lon = -67.1206;

    elseif locVar == 3
        % Croem
        CroemStr = 'Croem II';

```

```

lat_Croem = 18.1759;
lon_Croem = -67.0876;
height_Croem = 394.04;

radrStr = 'Croem II';
radrFlStr = 'Croem';
radr_lat = 18.1759;
radr_lon = -67.0876;

elseif locVar == 4
% Cerro las Mesas
CMesasStr = 'Cerro las Mesas';
lat_CMesas = 18.1809;
lon_CMesas = -67.0889;
height_CMesas = 407.06;

radrStr = 'Cerro las Mesas';
radrFlStr = 'CMesas';
radr_lat = 18.1809;
radr_lon = -67.0889;

elseif locVar == 5
% Estacion Experimental - Lajas
LajasStr = 'Lajas';
lat_Lajas = 18.03181;
lon_Lajas = -67.07284;
height_Lajas = 31.23;

radrStr = 'Lajas';
radrFlStr = 'Lajas';
radr_lat = 18.03181;
radr_lon = -67.07284;

elseif locVar == 6
% Cornelia (Joyuda)
Joyudastr = 'Cornelia';
lat_Joyuda = 18.16302;
lon_Joyuda = -67.17920;
height_Joyuda = 54;

radrStr = 'Cornelia';
radrFlStr = 'Cornelia';
radr_lat = 18.16302;
radr_lon = -67.17920;

elseif locVar == 7
% Subestacion Experimental - Adjuntas
Adjuntastr = 'Adjuntas';
lat_Joyuda = 18.17865;
lon_Joyuda = -66.79737;
height_Adjuntas = 654.15;

radrStr = 'Adjuntas';
radrFlStr = 'Adjuntas';
radr_lat = 18.17865;
radr_lon = -66.79737;

elseif locVar == 8
% Isla Magueyues
SGrandeStr = 'Isla Magueyues';
lat_SGrande = 17.96948;
lon_SGrande = -67.04419;
height_Magueyues = 29.89;

radrStr = 'Isla Magueyues';
radrFlStr = 'Magueyues';
radr_lat = 17.96948;
radr_lon = -67.04419;

elseif locVar == 9
% Estacion Experimental - Isabela

```

```

    IsabelaStr = 'Isabela';
    lat_Isabela = 18.4632;
    lon_Isabela = -67.0515;

    radrStr = 'Isabela';
    radrFlStr = 'Isabela';
    radr_lat = 18.4632;
    radr_lon = -67.0515;

elseif locVar == 10
    % Charcas UPRM - Sabana Grande
    SGrandeStr = 'Sabana Grande';
    lat_SGrande = 18.04763;
    lon_SGrande = -66.97992;
    height_SGrande = 43.60;

    radrStr = 'Sabana Grande';
    radrFlStr = 'SGrande';
    radr_lat = 18.04763;
    radr_lon = -66.97992;

elseif locVar == 11
    % CROEM
    SGrandeStr = 'Croem';
    lat_SGrande = 18.17667;
    lon_SGrande = -67.08833;
    height_SGrande = 43.60;

    radrStr = 'Croem';
    radrFlStr = 'CroemII';
    radr_lat = 18.17667;
    radr_lon = -67.08833;

elseif locVar == 12
    % Mogotes Aguadilla
    MogoteStr = 'FincaMonatanaII';
    lat_SGrande = 18.466717;
    lon_SGrande = -67.113367;
    height_SGrande = 43.60;

    radrStr = 'Finca Montana II';
    radrFlStr = 'FMontana';
    radr_lat = 18.466717;
    radr_lon = -67.113367;

elseif locVar == 13
    % Stefani
    SGrandeStr = 'Stefani';
    lat_SGrande = 18.20955;
    lon_SGrande = -67.140031;
    height_SGrande = 43.60;

    radrStr = 'Stefani';
    radrFlStr = 'Stefani';
    radr_lat = 18.20955;
    radr_lon = -67.140031;

else

    f = errordlg('No record of location found', 'LocationError');

end

%% Radar 2
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               2nd Radar Locations in the Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

locVar2 = locVarVec2(index);

```

```

if locVar2 == 1
    % CID
    radrStr2 = 'CID';
    radrFlStr2 = 'CID';
    radr_lat2 = 18.21125;
    radr_lon2 = -67.13676;

elseif locVar2 == 2
    % Aguadilla - Finca Montaña
    radrStr2 = 'Finca Montana I';
    radrFlStr2 = 'Aguadilla';
    radr_lat2 = 18.4751;
    radr_lon2 = -67.1206;

elseif locVar2 == 3
    % Croem
    radrStr2 = 'Croem II';
    radrFlStr2 = 'Croem';
    radr_lat2 = 18.1759;
    radr_lon2 = -67.0876;

elseif locVar2 == 4
    % Cerro las Mesas
    radrStr2 = 'Cerro las Mesas';
    radrFlStr2 = 'CMesas';
    radr_lat2 = 18.1809;
    radr_lon2 = -67.0889;

elseif locVar2 == 5
    % Estacion Experimental - Lajas
    radrStr2 = 'Lajas';
    radrFlStr2 = 'Lajas';
    radr_lat2 = 18.03181;
    radr_lon2 = -67.07284;

elseif locVar2 == 6
    % Cornelia (Joyuda)
    radrStr2 = 'Cornelia';
    radrFlStr2 = 'Cornelia';
    radr_lat2 = 18.16302;
    radr_lon2 = -67.17920;

elseif locVar2 == 7
    % Subestacion Experimental - Adjuntas
    radrStr2 = 'Adjuntas';
    radrFlStr2 = 'Adjuntas';
    radr_lat2 = 18.17865;
    radr_lon2 = -66.79737;

elseif locVar2 == 8
    % Isla Magueyues
    radrStr2 = 'Isla Magueyues';
    radrFlStr2 = 'Magueyues';
    radr_lat2 = 17.96948;
    radr_lon2 = -67.04419;

elseif locVar2 == 9
    % Estacion Experimental - Isabela
    radrStr2 = 'Isabela';
    radrFlStr2 = 'Isabela';
    radr_lat2 = 18.4632;
    radr_lon2 = -67.0515;

elseif locVar2 == 10
    % Charcas UPRM - Sabana Grande
    radrStr2 = 'Sabana Grande';
    radrFlStr2 = 'SGrande';
    radr_lat2 = 18.04763;
    radr_lon2 = -66.97992;

```

```

elseif locVar2 == 11
    % CROEM
    radrStr2 = 'Croem';
    radrFlStr2 = 'CroemII';
    radr_lat2 = 18.17667;
    radr_lon2 = -67.08833;

elseif locVar2 == 12
    % Mogotes Aguadilla
    radrStr2 = 'Finca Montana II';
    radrFlStr2 = 'FMontana';
    radr_lat2 = 18.466717;
    radr_lon2 = -67.113367;

elseif locVar2 == 13
    % Stefani
    radrStr2 = 'Stefani';
    radrFlStr2 = 'Stefani';
    radr_lat2 = 18.20955;
    radr_lon2 = -67.140031;

else

    f = errordlg('No record of location found', 'LocationError');

end

%% Radar 3
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           3rd Radar Locations in the Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

locVar3 = locVarVec3(index);

if locVar3 == 1
    % CID
    radrStr3 = 'CID';
    radrFlStr3 = 'CID';
    radr_lat3 = 18.21125;
    radr_lon3 = -67.13676;

elseif locVar3 == 2
    % Aguadilla - Finca Montana I
    radrStr3 = 'Finca Montana I';
    radrFlStr3 = 'Aguadilla';
    radr_lat3 = 18.4751;
    radr_lon3 = -67.1206;

elseif locVar3 == 3
    % Croem
    radrStr3 = 'Croem II';
    radrFlStr3 = 'Croem';
    radr_lat3 = 18.1759;
    radr_lon3 = -67.0876;

elseif locVar3 == 4
    % Cerro las Mesas
    radrStr3 = 'Cerro las Mesas';
    radrFlStr3 = 'CMesas';
    radr_lat3 = 18.1809;
    radr_lon3 = -67.0889;

elseif locVar3 == 5
    % Estaci3n Experimental - Lajas
    radrStr3 = 'Lajas';
    radrFlStr3 = 'Lajas';
    radr_lat3 = 18.03181;

```

```

        radr_lon3 = -67.07284;

elseif locVar3 == 6
    % Cornelia (Joyuda)
    radrStr3 = 'Cornelia';
    radrFlStr3 = 'Cornelia';
    radr_lat3 = 18.16302;
    radr_lon3 = -67.17920;

elseif locVar3 == 7
    % Subestacion Experimental - Adjuntas
    radrStr3 = 'Adjuntas';
    radrFlStr3 = 'Adjuntas';
    radr_lat3 = 18.17865;
    radr_lon3 = -66.79737;

elseif locVar3 == 8
    % Isla Magueyues
    radrStr3 = 'Isla Magueyues';
    radrFlStr3 = 'Magueyues';
    radr_lat3 = 17.96948;
    radr_lon3 = -67.04419;

elseif locVar3 == 9
    % Estacion Experimental - Isabela
    radrStr3 = 'Isabela';
    radrFlStr3 = 'Isabela';
    radr_lat3 = 18.4632;
    radr_lon3 = -67.0515;

elseif locVar3 == 10
    % Charcas UPRM - Sabana Grande
    radrStr3 = 'Sabana Grande';
    radrFlStr3 = 'SGrande';
    radr_lat3 = 18.04763;
    radr_lon3 = -66.97992;

elseif locVar3 == 11
    % CROEM
    radrStr3 = 'Croem';
    radrFlStr3 = 'CroemII';
    radr_lat3 = 18.17667;
    radr_lon3 = -67.08833;

elseif locVar3 == 12
    % Mogotes Aguadilla
    radrStr3 = 'Finca Montana II';
    radrFlStr3 = 'FMontana';
    radr_lat3 = 18.466717;
    radr_lon3 = -67.113367;

elseif locVar3 == 13
    % Stefani
    radrStr3 = 'Stefani';
    radrFlStr3 = 'Stefani';
    radr_lat3 = 18.20955;
    radr_lon3 = -67.140031;

else

    f = errordlg('No record of location found', 'LocationError');

end

%% Save Dir
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Setting location Dir to save data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

CurrentDir = pwd;

filedir = strcat(CurrentDir,'/Tri-Radar Networks/Linear/');
savefiledir = strcat(filedir,radrStr,'_',radrStr2,'_',radrStr3,'/');

if ~isdir(savefiledir)

    mkdir(savefiledir)

end

%% Load Map
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Load 90m Resolution Data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Load Medium Resolution map data

filename = strcat('medMapData',radrFlStr,radrFlStr2,radrFlStr3,'.mat');
radrMapFile = fullfile(savefiledir,filename);

if ~exist(radrMapFile,'file')

    [map,maplegend,latlim,lonlim] =
radr3MapRead(radrMapFile,radrFlStr,radrStr,radr_lat,radr_lon,...
              radrStr2,radrFlStr2,radr_lat2,radr_lon2,...
              radrStr3,radrFlStr3,radr_lat3,radr_lon3);

else

load(radrMapFile)

end

%% Load Matrices
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Load previously Created Blk Matrices
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radar 1 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
hVec = [10 15 20 25 30 40 50];
thetaVec = [0.9 1.2 1.8 2.0 2.6 3.0 3.5 4 4.5 5];

hIndex = hIndexVec1(index);
thetaIndex = thetaIndexVec1(index);

% block data
blkfilename = strcat(radrFlStr,'BlkData',num2str(hVec(hIndex)),num2str(thetaIndex),'.mat');
openfiledir = strcat(CurrentDir,'/Linear Propagation/',radrStr,'/');
blkfile = fullfile(openfiledir,blkfilename);

load(blkfile)

% Change variable names before loading the next ones.
blkBhMatA = blkBhMat;
blkMapA = blkMap;
compBlkMatA = compBlkMat;
compBlkMat2A = compBlkMat2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radar 2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
hVec2 = [10 15 20 25 30 40 50];
thetaVec2 = [0.9 1.2 1.8 2.0 2.6 3.0 3.5 4 4.5 5];

hIndex2 = hIndexVec2(index);

```

```

thetaIndex2 = thetaIndexVec2(index);

blkfilename2 = strcat(radrFlStr2,'BlkData',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.mat');
openfiledir2 = strcat(CurrentDir,'/Linear Propagation/',radrStr2,'/');
blkfile2 = fullfile(openfiledir2,blkfilename2);

load(blkfile2)

% Change variable names before loading the next ones.
blkBhMatB = blkBhMat;
blkMapB = blkMap;
compBlkMatB = compBlkMat;
compBlkMat2B = compBlkMat2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radar 3 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
hVec3 = [10 15 20 25 30 40 50];
thetaVec3 = [0.9 1.2 1.8 2.0 2.6 3.0 3.5 4 4.5 5];

hIndex3 = hIndexVec3(index);
thetaIndex3 = thetaIndexVec3(index);

blkfilename3 = strcat(radrFlStr3,'BlkData',num2str(hVec3(hIndex3)),num2str(thetaIndex3),'.mat');
openfiledir3 = strcat(CurrentDir,'/Linear Propagation/',radrStr3,'/');
blkfile3 = fullfile(openfiledir3,blkfilename3);

load(blkfile3)

% Change variable names before loading the next ones.
blkBhMatC = blkBhMat;
blkMapC = blkMap;
compBlkMatC = compBlkMat;
compBlkMat2C = compBlkMat2;

%% Equal Matrices
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Equalling the size of the Matrices                               %
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radar 1 Matrices %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%blkMap
[nBlkMapA] = eqMapSize(map,maplegend,latlim,lonlim,blkMapA,openfiledir,radrFlStr,...
    radr_lat,radr_lon);

%compBlkMat
[nCompBlkMapA] = eqMapSize(map,maplegend,latlim,lonlim,compBlkMatA,openfiledir,radrFlStr,...
    radr_lat,radr_lon);

%compBlkMat2
[nCompBlkMap2A] = eqMapSize(map,maplegend,latlim,lonlim,compBlkMat2A,openfiledir,radrFlStr,...
    radr_lat,radr_lon);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radar 2 Matrices %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%blkMap
[nBlkMapB] = eqMapSize(map,maplegend,latlim,lonlim,blkMapB,openfiledir2,radrFlStr2,...
    radr_lat2,radr_lon2);

%compBlkMat
[nCompBlkMapB] = eqMapSize(map,maplegend,latlim,lonlim,compBlkMatB,openfiledir2,radrFlStr2,...
    radr_lat2,radr_lon2);

%compBlkMat2
[nCompBlkMap2B] = eqMapSize(map,maplegend,latlim,lonlim,compBlkMat2B,openfiledir2,radrFlStr2,...
    radr_lat2,radr_lon2);

```



```

small13 = find(nCompBlkMapA(eq1_3) > nCompBlkMapC(eq1_3));

triRadrCompBlkMap(eq1_3(small11b)) = nCompBlkMapA(eq1_3(small11b));
triRadrCompBlkMap(eq1_3(small13)) = nCompBlkMapC(eq1_3(small13));

% Overlap indices between radar 2 & 3.
eq2_3 = intersect(nCompBlkMapBI,nCompBlkMapCI);

% triRadrCompBlkMap2(eq2_3) = -40; % Test area overlapped by radars 2 & 3

small12b = find(nCompBlkMapB(eq2_3) < nCompBlkMapC(eq2_3));
small13b = find(nCompBlkMapB(eq2_3) > nCompBlkMapC(eq2_3));

triRadrCompBlkMap(eq2_3(small12b)) = nCompBlkMapB(eq2_3(small12b));
triRadrCompBlkMap(eq2_3(small13b)) = nCompBlkMapC(eq2_3(small13b));

% Overlap indices between radar 1, 2 & 3
eq1_2_3 = intersect(eq1_2,nCompBlkMapCI);

small11c = find(nCompBlkMapA(eq1_2_3) < nCompBlkMapB(eq1_2_3) & nCompBlkMapA(eq1_2_3) <
nCompBlkMapC(eq1_2_3));
small12c = find(nCompBlkMapB(eq1_2_3) < nCompBlkMapA(eq1_2_3) & nCompBlkMapB(eq1_2_3) <
nCompBlkMapC(eq1_2_3));
small13c = find(nCompBlkMapC(eq1_2_3) < nCompBlkMapA(eq1_2_3) & nCompBlkMapC(eq1_2_3) <
nCompBlkMapB(eq1_2_3));

triRadrCompBlkMap(eq1_2_3(small11c)) = nCompBlkMapA(eq1_2_3(small11c));
triRadrCompBlkMap(eq1_2_3(small12c)) = nCompBlkMapB(eq1_2_3(small12c));
triRadrCompBlkMap(eq1_2_3(small13c)) = nCompBlkMapC(eq1_2_3(small13c));

% triRadrCompBlkMap2(eq1_2_3) = -40; %Test Area Overlapped by 3 radars

%% Merge Comp Blk 2
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Merging nCompBlkMap2
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Find indices of all values larger than 0.
nCompBlkMap2AI = find(nCompBlkMap2A >= 0);
nCompBlkMap2BI = find(nCompBlkMap2B >= 0);
nCompBlkMap2CI = find(nCompBlkMap2C >= 0);

%Create a new map with all values = -40.
triRadrCompBlkMap2 = -40*(ones(size(map)));

%Merge the blk map data
triRadrCompBlkMap2(nCompBlkMap2AI) = nCompBlkMap2A(nCompBlkMap2AI);
triRadrCompBlkMap2(nCompBlkMap2BI) = nCompBlkMap2B(nCompBlkMap2BI);
triRadrCompBlkMap2(nCompBlkMap2CI) = nCompBlkMap2C(nCompBlkMap2CI);

% Overlap indices between radar 1 & 2.
eq1_2 = intersect(nCompBlkMap2AI,nCompBlkMap2BI);

% triRadrCompBlkMap2(eq1_2) = -40; % Test area overlapped by radars 1 & 2

small11 = find(nCompBlkMap2A(eq1_2) < nCompBlkMap2B(eq1_2));
small12 = find(nCompBlkMap2A(eq1_2) > nCompBlkMap2B(eq1_2));

triRadrCompBlkMap2(eq1_2(small11)) = nCompBlkMap2A(eq1_2(small11));
triRadrCompBlkMap2(eq1_2(small12)) = nCompBlkMap2B(eq1_2(small12));

% Overlap indices between radar 1 & 3.
eq1_3 = intersect(nCompBlkMap2AI,nCompBlkMap2CI);

% triRadrCompBlkMap2(eq1_3) = -40; % Test area overlapped by radars 1 & 3

small11b = find(nCompBlkMap2A(eq1_3) < nCompBlkMap2C(eq1_3));
small13 = find(nCompBlkMap2A(eq1_3) > nCompBlkMap2C(eq1_3));

```

```

triRadrCompBlkMap2(eq1_3(small11b)) = nCompBlkMap2A(eq1_3(small11b));
triRadrCompBlkMap2(eq1_3(small13)) = nCompBlkMap2C(eq1_3(small13));

% Overlap indices between radar 2 & 3.
eq2_3 = intersect(nCompBlkMap2BI,nCompBlkMap2CI);

% triRadrCompBlkMap2(eq2_3) = -40; % Test area overlapped by radars 2 & 3

small12b = find(nCompBlkMap2B(eq2_3) < nCompBlkMap2C(eq2_3));
small13b = find(nCompBlkMap2B(eq2_3) > nCompBlkMap2C(eq2_3));

triRadrCompBlkMap2(eq2_3(small12b)) = nCompBlkMap2B(eq2_3(small12b));
triRadrCompBlkMap2(eq2_3(small13b)) = nCompBlkMap2C(eq2_3(small13b));

% Overlap indices between radar 1, 2 & 3
eq1_2_3 = intersect(eq1_2,nCompBlkMap2CI);

small11c = find(nCompBlkMap2A(eq1_2_3) < nCompBlkMap2B(eq1_2_3) & nCompBlkMap2A(eq1_2_3) <
nCompBlkMap2C(eq1_2_3));
small12c = find(nCompBlkMap2B(eq1_2_3) < nCompBlkMap2A(eq1_2_3) & nCompBlkMap2B(eq1_2_3) <
nCompBlkMap2C(eq1_2_3));
small13c = find(nCompBlkMap2C(eq1_2_3) < nCompBlkMap2A(eq1_2_3) & nCompBlkMap2C(eq1_2_3) <
nCompBlkMap2B(eq1_2_3));

triRadrCompBlkMap2(eq1_2_3(small11c)) = nCompBlkMap2A(eq1_2_3(small11c));
triRadrCompBlkMap2(eq1_2_3(small12c)) = nCompBlkMap2B(eq1_2_3(small12c));
triRadrCompBlkMap2(eq1_2_3(small13c)) = nCompBlkMap2C(eq1_2_3(small13c));

% triRadrCompBlkMap2(eq1_2_3) = -40; %Test Area Overlapped by 3 radars

%% Plot Blk Map
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plotting triRadrBlkMap
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Creating new directory to store the pics in.
picSavefiledir =
strcat(savefiledir, '/', num2str(hVec(hIndex)), num2str(hVec2(hIndex2)), num2str(hVec3(hIndex3)), ...
        '/', num2str(thetaIndex), num2str(thetaIndex2), num2str(thetaIndex3), '/');

if ~isdir(picSavefiledir)
    mkdir(picSavefiledir);
end

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Beam Height Blockage Map'];
figHndl1 = figure('Name', figStr);
worldmap(latlim, lonlim);
geoshow(triRadrBlkMap, maplegend, 'DisplayType', 'surface')
demcmap(triRadrBlkMap)
colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

% Figure Title
title({'3-Radar Network Coverage Blockage Map: ' ;...
      [radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
      ' ft'];...

```

```

        [radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
        [radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']]
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y--')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y--')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y--')

% Creating file path and name to save map figure.
mapPicFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, ' 40km Coverage Blockage
Map',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
mapPicFile = fullfile(picSavefiledir,mapPicFileName);

saveas(figHndl1,mapPicFile)
close(figHndl1)

%% Plot Complete Blk
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plotting triRadrCompBlkMap
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Plot map
figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Beam Height Blockage Map'];
figHndl2 = figure('Name',figStr);
ax = worldmap(latlim,lonlim);
geoshow(triRadrCompBlkMap,maplegend,'DisplayType','surface')
colormap(jet)
%           colormap(jet)
colorbar
axis off
hold on

tightmap
hold on

%Modifying The Colormap
X = flipud(colormap);
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

% Figure Title
title({'3-Radar Network Coverage Beam Height Blockage Map: ' ;...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
[radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']]
xlabel('Longitude')

```

```

ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y--')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y--')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y--')

% Creating file path and name to save map figure.
BhMapPicFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
BeamHeightBlkMap', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
BhMapPicFile = fullfile(picSavefiledir, BhMapPicFileName);

saveas(figHndl2, BhMapPicFile)
close(figHndl2)

%% Plot Complete Blk 2
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plotting triRadrCompBlkMap2
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Plot map
figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Beam Height Blockage Map'];
figHndl3 = figure('Name', figStr);
ax = worldmap(latlim, lonlim);
geoshow(triRadrCompBlkMap2, maplegend, 'DisplayType', 'surface')
colormap(jet)
%           colormap(jet)
colorbar
axis off
hold on

tightmap
hold on

%Modifying The Colormap
X = flipud(colormap);
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

% Figure Title
title({'3-Radar Network Coverage Beam Height Blockage Map: ' ;...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height : ' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height : '
num2str(hVec2(hIndex2)) ' ft '];...
[radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height : '
num2str(hVec3(hIndex3)) ' ft ']});
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

```

```

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y--')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y--')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y--')

%Creating file path and name to save map figure.
BhMapPicFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
BeamHeightBlkMap2', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
BhMapPicFile = fullfile(picSavefiledir, BhMapPicFileName);

saveas(figHndl3, BhMapPicFile)
close(figHndl3)

%% Hist
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %
% %                               Histogram
% %
% % %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Creating allRange Matrix for new map

% Obtaining the correct starting lat/lon
[lat,lon] = pix2latlon(maplegend,1,1);

%Creating lat vector
latRefVec = lat + (0:length(map(:,1))-1)*maplegend(1,2);

%Creating lon vector
lonRefVec = lon - (0:length(map(1,:))-1)*maplegend(1,2);

%Expand lat/lon vectors to matrices of equal sizes.
sizeVec = size(map);
latMat = repmat(latRefVec',1,sizeVec(2));
lonMat = repmat(lonRefVec,sizeVec(1),1);

%Obtain all ranges and azimuths within map... with respect to CID.
% Radar 1
[allRangeA,allAzA] = distance(radr_lat,radr_lon,latMat,lonMat);
% Radar 2
[allRangeB,allAzB] = distance(radr_lat2,radr_lon2,latMat,lonMat);
% Radar 3
[allRangeC,allAzC] = distance(radr_lat3,radr_lon3,latMat,lonMat);

%Convert ranges from degrees of arc length to km.
allRangeA = deg2km(allRangeA);
allRangeB = deg2km(allRangeB);
allRangeC = deg2km(allRangeC);

%Find indices of all values within radar coverages.
allRangeAI = find(allRangeA <= 40);
allRangeBI = find(allRangeB <= 40);
allRangeCI = find(allRangeC <= 40);

%Merge the blk map data
allRange = allRangeA;
allRange(allRangeBI) = allRangeB(allRangeBI);
allRange(allRangeCI) = allRangeC(allRangeCI);

inRng = find(allRange <= 40);
histVar2 = triRadrCompBlkMap2(inRng);

```

```

figStr = [radrStr ' Beam Height Histogram'];
figHndl4 = figure('Name',figStr);
histVec2 = -40:10:max(histVar2);
hist(histVar2,histVec2)
ylabel('Number of Occurrences')
xlabel('Height of Beam (m)')
title({'3-Radar Network Beam Height Histogram: ' ;...
      [radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
      ' ft '];...
      [radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
      [radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']}))

% Creating file path and name to save map figure.
histFileName = strcat(radRStr, '_', radRStr2, '_', radRStr3, '
Histogram',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
histFile = fullfile(picSavefiledir,histFileName);

saveas(figHndl4,histFile)
close(figHndl4)
pause(1)

%% Surface Area Pie Chart
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Surface Area
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Puerto Rico's Surface Area = 9,104 sq km. It doesn't include Vieques or
% Culebra.

% Determine all of the area covered by the radar.
covSAMap = map(inRng);
covCompSAnumPix = length(covSAMap);
covCompSArea = covCompSAnumPix * 90 * 90;
covCompSArea = covCompSArea * 1e-6; % Now in km^2

% Determine the area of land covered by the radar (m^2).
covLandSAVarIndex = find(covSAMap>=0);
covLandSAnumPix = length(covLandSAVarIndex);
covLandSArea = covLandSAnumPix * 90 * 90;
covLandSArea = covLandSArea*1e-6; % Now in km^2

% Determine the area of land available from block map (m^2).
blkSAMap = triRadrBlkMap(inRng);
noblkLandSAVarIndex = find(blkSAMap>=0);
noblkLandSAnumPix = length(noblkLandSAVarIndex);
noblkLandSArea = noblkLandSAnumPix * 90 * 90;
noblkLandSArea = noblkLandSArea * 1e-6; %Now in km^2

% Determine the area of water covered by the radar (m^2).
covWtrSAVarIndex = find(covSAMap == -10);
covWtrSAnumPix = length(covWtrSAVarIndex);
covWtrSArea = covWtrSAnumPix * 90 * 90;
covWtrSArea = covWtrSArea*1e-6; %Now in km^2

% Determine the area of water covered by the radar (m^2).
noblkWtrSAVarIndex = find(blkSAMap == -10);
noblkWtrSAnumPix = length(noblkWtrSAVarIndex);

noblkWtrSArea = noblkWtrSAnumPix * 90 * 90;
noblkWtrSArea = noblkWtrSArea * 1e-6;

% Land Unblocked Coverage Percentage
landUnBlkd_PoC = noblkLandSArea/covCompSArea*100;

% Land Blocked Coverage Percentage

```

```

landBlkd_PoC = 100 - landUnBlkd_PoC;

% Water Unblocked Coverage Percentage
wtrUnBlkd_PoC = noblkWtrSArea/covCompSArea*100;

% Water Blocked Coverage Percentage
wtrBlkd_PoC = 100 - wtrUnBlkd_PoC;

%%
% Generate Pie Chart

blkLand = covLandSArea - noblkLandSArea;
noBlkLand = covLandSArea - blkLand;

blkWtr = covWtrSArea - noblkWtrSArea;
noBlkWtr = covWtrSArea - blkWtr;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Surface Area Calculation MSG BOX %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SACell = {
    '          Three-Radar Network Coverage: '; ...
    [ '          ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
degs, Height : ' num2str(hVec(hIndex)) ' ft '];...
    [ '          ' radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) '
degs, Height : ' num2str(hVec2(hIndex2)) ' ft '];...
    [ '          ' radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) '
degs, Height : ' num2str(hVec3(hIndex3)) ' ft '];...
    [ ' ' ' '];...
    [ ' ' ' '];...
    [ '          Total Area of Coverage: ' num2str(covCompSArea) ' km^2'];...
    [ ' ' ' '];...
    [ '          Total Area of Land Coverage: ' num2str(noblkLandSArea) ' km^2 --> '
num2str(landUnBlkd_PoC) '%' ];...
    [ ' ' ' '];...
    [ '          Total Area of Water Coverage: ' num2str(noblkWtrSArea) ' km^2 --> '
num2str(wtrUnBlkd_PoC) '%' ];...
    [ ' ' ' '];...
    [ ' ' ' '];};

msghandle1 = msgbox(SACell);
set(msghandle1,'Color',[1 1 1])
msgFileName = strcat(radRstr, '_', radRstr2, '_', radRstr3, '
SAreaCalcs',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
msgFile = fullfile(picSavefiledir,msgFileName);
saveas(msghandle1,msgFile)
close(msghandle1)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radRstr ' ', ' radRstr2 ', & ' radRstr3 ' Coverage Pie Chart'];
figHnd15 = figure('Name',figStr);
pieVar = [noBlkLand blkLand blkWtr noBlkWtr];
explode = [0 1 1 0];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-1)) '% No-Block
Land'], [num2str(roundn(pieVar(2)/sum(pieVar)*100,-1)) '% Blocked Land'],...
    [num2str(roundn(pieVar(3)/sum(pieVar)*100,-1)) '% Blocked
Sea'], [num2str(roundn(pieVar(4)/sum(pieVar)*100,-1)) '% No-Block Sea']];

pie3(pieVar, explode,label)
title({'Three-Radar Network Coverage Pie Chart: ' ;...
    [radRstr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height : ' num2str(hVec(hIndex))
' ft '];...
    [radRstr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height : '
num2str(hVec2(hIndex2)) ' ft '];...
    [radRstr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height : '
num2str(hVec3(hIndex3)) ' ft '];})

```

```

X2 = [051/255 102/255 051/255 ; 102/255 0/255 0/255 ; 153/255 0/255 0/255 ; 051/255 051/255
204/255];
colormap(X2)

% Creating file path and name to save map figure.
pieChartFileName = strcat(radStr, '_', radStr2, '_', radStr3, '
PieChart', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
pieChartFile = fullfile(picSavefiledir, pieChartFileName);

saveas(figHnd15, pieChartFile)
close(figHnd15)
pause(1)

%% Overlap
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Radar Overlap
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Radar Overlap Indices
totRadrCov = inRng;
twoRadrOL1_2I = eq1_2;
twoRadrOL1_3I = eq1_3;
twoRadrOL2_3I = eq2_3;
triRadrOLI = eq1_2_3;

% 3 Radar Overlap surface area calculations.
triRadrOLArea = length(triRadrOLI) * 90 * 90;
triRadrOLArea = triRadrOLArea * 1e-6; %Now in km^2

triWaterI = find(map(triRadrOLI) == -10);
triWater = length(triWaterI) * 90 * 90 * 1e-6;

triLandI = find(map(triRadrOLI) > 0);
triLand = length(triLandI) * 90 * 90 * 1e-6;

triwtrP = triWater/triRadrOLArea * 100;
triLndP = triLand/triRadrOLArea * 100;

% 2 Radar Overlap surface area calculations.
twoRadrOLIndex = setxor(twoRadrOL1_2I, triRadrOLI);
twoRadrOLIndex = vertcat(twoRadrOLIndex, setxor(twoRadrOL1_3I, triRadrOLI));
twoRadrOLIndex = vertcat(twoRadrOLIndex, setxor(twoRadrOL2_3I, triRadrOLI));
twoRadrOLI = length(twoRadrOLIndex);

twoRadrOLArea = twoRadrOLI * 90 * 90;
twoRadrOLArea = twoRadrOLArea * 1e-6; %Now in km^2

twoWaterI = find(map(twoRadrOLIndex) == -10);
twoWater = length(twoWaterI) * 90 * 90 * 1e-6;

twoLandI = find(map(twoRadrOLIndex) > 0);
twoLand = length(twoLandI) * 90 * 90 * 1e-6;

twoWtrP = twoWater/twoRadrOLArea * 100;
twoLndP = twoLand/twoRadrOLArea * 100;

% 1 Radar Coverage Area
oneRadrCovIndex = setxor(totRadrCov, triRadrOLI);
oneRadrCovIndex = setxor(oneRadrCovIndex, twoRadrOLIndex);
oneRadrCovI = length(oneRadrCovIndex);

oneRadrCovArea = oneRadrCovI * 90 * 90;
oneRadrCovArea = oneRadrCovArea * 1e-6; %Now in km^2

```

```

oneWaterI = find(map(oneRadrCovIndex) == -10);
oneWater = length(oneWaterI) * 90 * 90 * 1e-6;

oneLandI = find(map(oneRadrCovIndex) >= 0);
oneLand = length(oneLandI) * 90 * 90 * 1e-6;

onewtrP = oneWater/oneRadrCovArea * 100;
oneLndP = oneLand/oneRadrCovArea * 100;

% Total Radar Coverage Area
totRadrCovArea = length(totRadrCov) * 90 * 90;
totRadrCovArea = totRadrCovArea * 1e-6; %Now in km^2

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Overlap Calculation MSG BOX %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SACell2 = {
    '                               Three-Radar Network Overlap: ' ; ...
    [ '                               ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
degs, Height : ' num2str(hVec(hIndex)) ' ft '];...
    [ '                               ' radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) '
degs, Height : ' num2str(hVec2(hIndex2)) ' ft '];...
    [ '                               ' radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) '
degs, Height : ' num2str(hVec3(hIndex3)) ' ft '];...
    [ ' ' ' '];...
    [ ' ' ' '];...
    [ '                               Total Radar Network Area of Coverage: ' num2str(totRadrCovArea) '
km^2'];...
    [ ' ' ' '];...
    [ '                               Single-Radar Area of Coverage: ' num2str(oneRadrCovArea) ' km^2'];...
    [ '                               Land : ' num2str(oneLand) ' km^2 --> '
num2str(oneLndP) '%'];...
    [ '                               Water : ' num2str(oneWater) ' km^2 --> '
num2str(onewtrP) '%'];...
    [ ' ' ' '];...
    [ '                               Two-Radar Overlap Area of Land Coverage: ' num2str(twoRadrOLArea) '
km^2'];...
    [ ' ' ' '];...
    [ '                               Land : ' num2str(twoLand) ' km^2 --> '
num2str(twoLndP) '%'];...
    [ '                               Water : ' num2str(twoWater) ' km^2 --> '
num2str(twowtrP) '%'];...
    [ ' ' ' '];...
    [ '                               3-Radar Area of Coverage: ' num2str(triRadrOLArea) ' km^2'];...
    [ ' ' ' '];...
    [ '                               Land : ' num2str(triLand) ' km^2 --> '
num2str(triLndP) '%'];...
    [ '                               Water : ' num2str(triWater) ' km^2 --> '
num2str(triwtrP) '%'];...
    [ ' ' ' '];...
    [ ' ' ' '];};

msghandle2 = msgbox(SACell2);
set(msghandle2,'Color',[1 1 1])
msgFileName = strcat(radRstr, '_', radrStr2, '_', radrStr3, '
OverlapCalcs', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
msgFile = fullfile(picSavefiledir, msgFileName);
saveas(msghandle2, msgFile)
close(msghandle2)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Getting Map Overlays %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% For 3 Radar Overlapping Areas
triRadrMap = NaN(size(map));
triRadrMap(triRadrOLI) = 1500;

```

```

% For 2 Radar Overlapping Areas
twoRadrMap = NaN(size(map));
twoRadrMap(twoRadrOLIndex) = 1500;

% For 1 Radar Coverage Area
oneRadrMap = NaN(size(map));
oneRadrMap(oneRadrCovIndex) = 1500;

%% In-Range Overlap
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Radar Overlap "in-Range"
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' ' Overlap Map'];
figHndl6 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(triRadrBlkMap,maplegend,'DisplayType', 'surface')
demcmmap(triRadrBlkMap)
colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

hold on

% Plot Single Radr Coverage
h_OLMap1 = geoshow(oneRadrMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0.8 0.9 0.7])
set(gcf,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot 2 Radar Overlays
h_OLMap2 = geoshow(twoRadrMap,maplegend,'DisplayType','surface') ;
set(h_OLMap2,'FaceColor',[0.6 0.9 0.5])
set(gcf,'Renderer','OpenGL')
set(h_OLMap2,'FaceAlpha',0.8)

hold on

% Plot 3 Radar Overlays
h_OLMap3 = geoshow(triRadrMap,maplegend,'DisplayType','surface');
set(h_OLMap3,'FaceColor',[0.3 0.6 0.3])
set(gcf,'Renderer','OpenGL')
set(h_OLMap3,'FaceAlpha',0.8)

% Figure Title
title([radrFlStr ' ', ' radrFlStr2 ' & ' radrFlStr3 ' ' 40km Coverage Blockage Map'])
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radrlat,radrlon,4000,'y.')
plot3m(radrlat2,radrlon2,4000,'y.')
plot3m(radrlat3,radrlon3,4000,'y.')

```

```

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y--')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y--')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y--')

title({' Three-Radar Network Overlap: '; ...
      [radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
      ' ft '];...
      [radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
      [radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']})

% Creating file path and name to save map figure.
InRngOLFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
InRngOLMap',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
InRngOLFile = fullfile(picSavefiledir,InRngOLFileName);

saveas(figHndl6,InRngOLFile)
close(figHndl6)
pause(1)

%% Plot Overlap
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Radar Overlap
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Overlap Map'];
figHndl7 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(map,maplegend,'DisplayType', 'surface')
demcmap(triRadrBlkMap)
colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

hold on

% Plot Single Radr Coverage
h_OLMap1 = geoshow(oneRadrMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0.8 0.9 0.7])
set(gcf,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot 2 Radar Overlays
h_OLMap2 = geoshow(twoRadrMap,maplegend,'DisplayType','surface') ;
set(h_OLMap2,'FaceColor',[0.6 0.9 0.5])
set(gcf,'Renderer','OpenGL')
set(h_OLMap2,'FaceAlpha',0.8)

```

```

hold on

% Plot 3 Radar Overlays
h_OLMap3 = geoshow(triRadrMap,maplegend,'DisplayType','surface');
set(h_OLMap3,'FaceColor',[0.3 0.6 0.3])
set(gcf,'Renderer','OpenGL')
set(h_OLMap3,'FaceAlpha',0.8)

% Figure Title
title([radrFlStr ' ', ' radrFlStr2 ' & ' radrFlStr3 ' 40km Coverage Blockage Map'])
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y--')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y--')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y--')

title({'Three-Radar Network Overlap: ';...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
[radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']}

% Creating file path and name to save map figure.
OLFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
OLMap',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
OLFile = fullfile(picSavefiledir,OLFileName);

saveas(figHndl7,OLFile)
close(figHndl7)
pause(1)

%% Overlap Pie Chart
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Radar Overlap PieChart
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Overlap Pie Chart'];
figHndl8 = figure('Name',figStr);
pieVar = [oneRadrCovArea twoRadrOLArea triRadrOLArea];
explode = [0 0 1];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-1)) '% Single
Radar'],[num2str(roundn(pieVar(2)/sum(pieVar)*100,-1)) '% 2-Radar Overlap'],...
[num2str(roundn(pieVar(3)/sum(pieVar)*100,-1)) '% 3-Radar Overlap']};

pie3(pieVar, explode,label)

title({'Three-Radar Network Overlap Pie Chart: ';...
[ radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
' ft '];...

```

```

        [ radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
        [ radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft '])

X3 = [ 0.8 0.9 0.7 ; 0.6 0.9 0.5 ; 0.3 0.6 0.3 ];
colormap(X3)

% Creating file path and name to save map figure.
pieChart2FileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
OLPieChart', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
pieChart2File = fullfile(picSavefiledir, pieChart2FileName);

saveas(figHndl8, pieChart2File)
close(figHndl8)
pause(1)

%% Dual Doppler

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Dual Doppler Evalutaion                               %
%                                                                                                                                 %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Defining theta values
theta1 = thetaVec(thetaIndex);
theta2 = thetaVec2(thetaIndex2);
theta3 = thetaVec3(thetaIndex3);

% xbeamDDoppMap = nan(size(map));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radars 1 and 2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Dual Doppler retrieval
xbeamDDopp1_2 = dualDopp(map, maplegend, filedir, radrFlStr, radr_lat, radr_lon, ...
    radrFlStr2, radr_lat2, radr_lon2, theta1, theta2, hVec(hIndex), hVec2(hIndex2));

xbeamDDoppMap = xbeamDDopp1_2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radars 1 and 3 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Dual Doppler retrieval
xbeamDDopp1_3 = dualDopp(map, maplegend, filedir, radrFlStr, radr_lat, radr_lon, ...
    radrFlStr3, radr_lat3, radr_lon3, theta1, theta3, hVec(hIndex), hVec3(hIndex3));

join1_2Ia = find(xbeamDDoppMap(eq1_3) > xbeamDDopp1_3(eq1_3) | isnan(xbeamDDopp1_3(eq1_3)));
join1_2Ib = setxor(eq1_3(join1_2Ia), eq1_3);
xbeamDDoppMap(join1_2Ib) = xbeamDDopp1_3(join1_2Ib);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Radars 2 and 3 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Dual Doppler retrieval
xbeamDDopp2_3 = dualDopp(map, maplegend, filedir, radrFlStr2, radr_lat2, radr_lon2, ...
    radrFlStr3, radr_lat3, radr_lon3, theta2, theta3, hVec2(hIndex2), hVec3(hIndex3));

join2_3Ia = find(xbeamDDoppMap(eq2_3) > xbeamDDopp2_3(eq2_3) | isnan(xbeamDDopp2_3(eq2_3)));
join2_3Ib = setxor(eq2_3(join2_3Ia), eq2_3);
xbeamDDoppMap(join2_3Ib) = xbeamDDopp2_3(join2_3Ib);

% Retrieve all angles higher than 30 degrees (where dual doppler is
% possible)

xbeamDDoppMapB = xbeamDDoppMap;
dDoppI = find(xbeamDDoppMap < 30);
xbeamDDoppMapB(dDoppI) = NaN;

```

```

% Creating another map to overlay over watersheds.
NaNIndex = find(isnan(xbeamDDoppMapB) == 0);

XbeamDDoppWtrshd = nan(size(map));
XbeamDDoppWtrshd(NaNIndex) = 1500;

%% Plot Dual Dopp
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Radar Dual Doppler
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Dual Doppler Capability Map'];
figHndl9 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(xbeamDDoppMap,maplegend,'DisplayType', 'surface')
colormap(jet)
colorbar
hold on

% Figure Title
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y-')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y-')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y-')

title({'Three-Radar Network Dual Doppler Capability: ' ; ...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height : ' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height : '
num2str(hVec2(hIndex2)) ' ft '];...
[radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height : '
num2str(hVec3(hIndex3)) ' ft ']}))

% Creating file path and name to save map figure.
InRngOLFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
DualDopplerI',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
InRngOLFile = fullfile(picSavefiledir,InRngOLFileName);

saveas(figHndl9,InRngOLFile)
close(figHndl9)
pause(1)

%% Plot Dual Dopp II
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Radar Dual Doppler
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Dual Doppler Capability Map'];
figHndl10 = figure('Name',figStr);
worldmap(latlim,lonlim);

```

```

geoshow(xbeamDDoppMapB,maplegend,'DisplayType', 'surface')
colormap(jet)
colorbar
hold on

% Figure Title
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y-')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y-')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y-')

title({'Three-Radar Network Dual Doppler Capability: '; ...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height : ' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height : '
num2str(hVec2(hIndex2)) ' ft '];...
[radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height : '
num2str(hVec3(hIndex3)) ' ft ']])

% Creating file path and name to save map figure.
InRngOLFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
DualDopplerII',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
InRngOLFile = fullfile(picSavefiledir,InRngOLFileName);

saveas(figHndl10,InRngOLFile)
close(figHndl10)
pause(1)

%% Dual Dopp SArea
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot Radar Dual Doppler SA Calcs
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Determine Surface Area where Dual Doppler Retrieval is possible.

dualDoppSAI = find(~isnan(xbeamDDoppMapB));
dualDoppSA = length(dualDoppSAI) * 90 * 90 * 1e-6;

dualDoppWtrI = find(map(dualDoppSAI) == -10);
dualDoppWtr = length(dualDoppWtrI) * 90 * 90 * 1e-6;

dualDoppwtrP = dualDoppWtr/dualDoppSA * 100;

dualDoppLndI = find(map(dualDoppSAI) >= 0);
dualDoppLnd = length(dualDoppLndI) * 90 * 90 * 1e-6;

dualDoppLndP = dualDoppLnd/dualDoppSA * 100;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Surface Area Calculation MSG BOX %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

SACell = { '          Three-Radar Network Multi Doppler Capabilities: '; ...
['          ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
degs, Height : ' num2str(hVec(hIndex)) ' ft '];...
['          ' radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) '
degs, Height : ' num2str(hVec2(hIndex2)) ' ft '];...
['          ' radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) '
degs, Height : ' num2str(hVec3(hIndex3)) ' ft '];...
[' ' ' ' '];...
[' ' ' ' '];...
['          Total Area of Coverage: ' num2str(covCompSArea) ' km^2'];...
[' ' ' ' '];...
['          Multi Doppler Capability Area: ' num2str(dualDoppSA) ' km^2'];...
[' ' ' ' '];...
['          - Over Land Capability: ' num2str(dualDoppLnd) ' km^2 --> '
num2str(dualDoppLndP) '%' ];...
[' ' ' ' '];...
['          - Over Water Capability: ' num2str(dualDoppWtr) ' km^2 --> '
num2str(dualDoppwtrP) '%' ];...
[' ' ' ' '];...
[' ' ' ' '];...

msghandle3 = msgbox(SACell);
set(msghandle3,'Color',[1 1 1])
msgFileName = strcat(radRstr, '_', radRstr2, '_', radRstr3, '
DualDoppCalcs', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
msgFile2 = fullfile(picSavefiledir, msgFileName);
saveas(msghandle3, msgFile2)
close(msghandle3)

%% WtrSheds
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%          Read Watershed Map          %
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[cuencasMap, cuencasMaplegend] = arcgridread('subcuencas_id2.asc');

% Equalling Watershed Map size to that of map
[tempCuencasMap] = eqMapSizev2(map, maplegend, latlim, lonlim, cuencasMap, cuencasMaplegend);

% Create new watersheds map full on NaNs
newCuencasMap = nan(size(tempCuencasMap));
CuencasMap = newCuencasMap;

CuencasI = find(tempCuencasMap >= 0);
newCuencasMap(CuencasI) = tempCuencasMap(CuencasI);

% Complete Watersheds Map
CuencasMap(CuencasI) = 1400;

% Create a map full of NaNs
nanmap = nan(size(newCuencasMap));

% Culebrinas
culebrinasMap = nanmap;
inRngCulebrinasMap = nanmap;
CuleI = find(newCuencasMap == 1);
culebrinasMap(CuleI) = 1400;
inRngCulebrinasMap(inRng) = culebrinasMap(inRng);

% Rio Grande de Anasco
rioGMap = nanmap;
inRngRioGMap = nanmap;
rioGI = find(newCuencasMap == 2);

```

```

rioGMap(rioGI) = 1400;
inRngRioGMap(inRng) = rioGMap(inRng);

% Rio Yaguez
yagMap = nanmap;
inRngYagMap = nanmap;
yagI = find(newCuencasMap == 4);
yagMap(yagI) = 1400;
inRngYagMap(inRng) = yagMap(inRng);

% Guanajibo
guanaMap = nanmap;
inRngGuanaMap = nanmap;
guanaI = find(newCuencasMap == 3);
guanaMap(guanaI) = 1400;
inRngGuanaMap(inRng) = guanaMap(inRng);

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Watershed Multi-Doppler Calculations
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Radar coverage over complete watershed area.

inRngWtrsheds = nanmap;
inRngWtrsheds(inRng) = CuencasMap(inRng);

% Surface Area of Complete Watershed area.
compWtrshedSA = length(CuencasI) * 90 * 90 * 1e-6;

% Surface Area of Watershed Area within radar range.
inRngWtrshedSAI = find(inRngWtrsheds >= 0);
inRngWtrshedSA = length(inRngWtrshedSAI) * 90 * 90 * 1e-6;
inRngWtrshedPoC = roundn(inRngWtrshedSA/compWtrshedSA * 100,-2);

% MultiDoppler Coverage over Watershed Area
DoppWtrShedsI = find(xbeamDDoppMapB(inRngWtrshedSAI) >= 0);

% MultiDoppler Covered Watersheds
DDoppWtrshdSA = length(DoppWtrShedsI) * 90 * 90 * 1e-6;
DDoppWtrshdPoC = DDoppWtrshdSA/inRngWtrshedSA * 100;

% No Multi Doppler Coverage
noDDoppWtrshdSA = inRngWtrshedSA - DDoppWtrshdSA;
noDDoppWtrshdPoC = noDDoppWtrshdSA/inRngWtrshedSA;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Individual DDopp Watersheds Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Culebrinas
compCuleSA = length(CuleI) * 90 * 90 * 1e-6;

inRngCuleI = find(inRngCulebrinasMap >= 0);
inRngCuleSA = length(inRngCuleI) * 90 * 90 * 1e-6;

DDoppCuleI = find(xbeamDDoppMapB(inRngCuleI) >= 0);

DDoppCuleSA = length(DDoppCuleI) * 90 * 90 * 1e-6;
DDoppCulePoC = roundn(DDoppCuleSA/inRngCuleSA * 100,-2);

noDDoppCuleSA = inRngCuleSA - DDoppCuleSA;
noDDoppCulePoC = roundn(noDDoppCuleSA/inRngCuleSA * 100,-2);

% Rio Grande de Anasco
compRioGSA = length(rioGI) * 90 * 90 * 1e-6;

inRngRioGI = find(inRngRioGMap >= 0);

```

```

inRngRioGSA = length(inRngRioGI) * 90 * 90 * 1e-6;
DDoppRioGI = find(xbeamDDoppMapB(inRngRioGI) >= 0);
DDoppRioGSA = length(DDoppRioGI) * 90 * 90 * 1e-6;
DDoppRioGPoC = roundn(DDoppRioGSA/inRngRioGSA * 100,-2);

noDDoppRioGSA = inRngRioGSA - DDoppRioGSA;
noDDoppRioGPoC = roundn(noDDoppRioGSA/inRngRioGSA * 100,-2);

% Yaguez
compYagSA = length(yagI) * 90 * 90 * 1e-6;

inRngYagI = find(inRngYagMap >= 0);
inRngYagSA = length(inRngYagI) * 90 * 90 * 1e-6;

DDoppYagI = find(xbeamDDoppMapB(inRngYagI) >= 0);

DDoppYagSA = length(DDoppYagI) * 90 * 90 * 1e-6;
DDoppYagPoC = roundn(DDoppYagSA/inRngYagSA * 100,-2);

noDDoppYagSA = inRngYagSA - DDoppYagSA;
noDDoppYagPoC = roundn(noDDoppYagSA/inRngYagSA * 100,-2);

% Guanajibo
compGuanaSA = length(guanaI) * 90 * 90 * 1e-6;

inRngGuanaI = find(inRngGuanaMap >= 0);
inRngGuanaSA = length(inRngGuanaI) * 90 * 90 * 1e-6;

DDoppGuanaI = find(xbeamDDoppMapB(inRngGuanaI) >= 0);

DDoppGuanaSA = length(DDoppGuanaI) * 90 * 90 * 1e-6;
DDoppGuanaPoC = roundn(DDoppGuanaSA/inRngGuanaSA * 100,-2);

noDDoppGuanaSA = inRngGuanaSA - DDoppGuanaSA;
noDDoppGuanaPoC = roundn(noDDoppGuanaSA/inRngGuanaSA * 100,-2);

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Watershed Net Retrieval Calculations
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Radar coverage over complete watershed area.

inRngWtrsheds = nanmap;
inRngWtrsheds(inRng) = CuencasMap(inRng);

% Surface Area of Complete Watershed area.
compWtrshedSA = length(CuencasI) * 90 * 90 * 1e-6;

% Surface Area of Watershed Area within radar range.
inRngWtrshedSAI = find(inRngWtrsheds >= 0);
inRngWtrshedSA = length(inRngWtrshedSAI) * 90 * 90 * 1e-6;
inRngWtrshedPoC = roundn(inRngWtrshedSA/compWtrshedSA * 100,-2);

% 1-Radar Coverage over Watershed Area
oneWtrShedsI = find(oneRadRMap(inRngWtrshedSAI) >= 0);
oneWtrshdSA = length(oneWtrShedsI) * 90 * 90 * 1e-6;
oneWtrshdPoC = oneWtrshdSA/inRngWtrshedSA * 100;

% 2-Radar Coverage over Watershed Area
twoWtrShedsI = find(twoRadRMap(inRngWtrshedSAI) >= 0);
twoWtrshdSA = length(twoWtrShedsI) * 90 * 90 * 1e-6;
twoWtrshdPoC = twoWtrshdSA/inRngWtrshedSA * 100;

% 3-Radar Coverage over Watershed Area

```

```

triWtrShedsI = find(triRadrMap(inRngWtrshedSAI) >= 0);
triWtrshdSA = length(triWtrShedsI) * 90 * 90 * 1e-6;
triWtrshdPoC = triWtrshdSA/inRngWtrshedSA * 100;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Individual DDopp Watersheds Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Culebrinas
compCuleSA = length(CuleI) * 90 * 90 * 1e-6;

inRngCuleI = find(inRngCulebrinasMap >= 0);
inRngCuleSA = length(inRngCuleI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneCuleI = find(oneRadrMap(inRngCuleI) >= 0);
oneCuleSA = length(oneCuleI) * 90 * 90 * 1e-6;
oneCulePoC = roundn(oneCuleSA/inRngCuleSA * 100,-2);

% 2-Radar Coverage
twoCuleI = find(twoRadrMap(inRngCuleI) >= 0);
twoCuleSA = length(twoCuleI) * 90 * 90 * 1e-6;
twoCulePoC = roundn(twoCuleSA/inRngCuleSA * 100,-2);

% 3-Radar Coverage
triCuleI = find(triRadrMap(inRngCuleI) >= 0);
triCuleSA = length(triCuleI) * 90 * 90 * 1e-6;
triCulePoC = roundn(triCuleSA/inRngCuleSA * 100,-2);

% Rio Grande de Anasco
compRioGSA = length(rioGI) * 90 * 90 * 1e-6;

inRngRioGI = find(inRngRioGMap >= 0);
inRngRioGSA = length(inRngRioGI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneRioGI = find(oneRadrMap(inRngRioGI) >= 0);
oneRioGSA = length(oneRioGI) * 90 * 90 * 1e-6;
oneRioGPoC = roundn(oneRioGSA/inRngRioGSA * 100,-2);

% 2-Radar Coverage
twoRioGI = find(twoRadrMap(inRngRioGI) >= 0);
twoRioGSA = length(twoRioGI) * 90 * 90 * 1e-6;
twoRioGPoC = roundn(twoRioGSA/inRngRioGSA * 100,-2);

% 3-Radar Coverage
triRioGI = find(triRadrMap(inRngRioGI) >= 0);
triRioGSA = length(triRioGI) * 90 * 90 * 1e-6;
triRioGPoC = roundn(triRioGSA/inRngRioGSA * 100,-2);

% Yaguez
compYagSA = length(yagI) * 90 * 90 * 1e-6;

inRngYagI = find(inRngYagMap >= 0);
inRngYagSA = length(inRngYagI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneYagI = find(oneRadrMap(inRngYagI) >= 0);
oneYagSA = length(oneYagI) * 90 * 90 * 1e-6;
oneYagPoC = roundn(oneYagSA/inRngYagSA * 100,-2);

% 2-Radar Coverage
twoYagI = find(twoRadrMap(inRngYagI) >= 0);
twoYagSA = length(twoYagI) * 90 * 90 * 1e-6;
twoYagPoC = roundn(twoYagSA/inRngYagSA * 100,-2);

% 3-Radar Coverage
triYagI = find(triRadrMap(inRngYagI) >= 0);
triYagSA = length(triYagI) * 90 * 90 * 1e-6;
triYagPoC = roundn(triYagSA/inRngYagSA * 100,-2);

% Guanajibo
compGuanaSA = length(guanaI) * 90 * 90 * 1e-6;

```



```

        ['
num2str(triCulePoC) '% '];...
        [' ' ' '];...
        ['
num2str(triRioGPoC) '% '];...
        [' ' ' '];...
        ['
num2str(triYagPoC) '% '];...
        [' ' ' '];...
        ['
num2str(triGuanaPoC) '% '];...
        [' ' ' '];...
        [' ' ' ']];

Culebrinas: ' num2str(triCuleSA) ' km^2 --> '
Rio Grande de Anasco: ' num2str(triRioGSA) ' km^2 --> '
Yaguez: ' num2str(triYagSA) ' km^2 --> '
Guanajibo: ' num2str(triGuanaSA) ' km^2 --> '

msghandle4 = msgbox(SACell14);
set(msghandle4,'Color',[1 1 1])
msgFileName = strcat(radStr, '_', radStr2, '_', radStr3, '
NetRetrWtrShdCalcs',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
msgFile = fullfile(picSavefiledir,msgFileName);
saveas(msghandle4,msgFile)
close(msghandle4)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           Net Retrieval Watershed Calculations PieChart
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radStr ' Network Retrieval Capability Watersheds Coverage Pie Chart'];
figHndl11 = figure('Name',figStr);
pieVar = [oneWtrshdSA twoWtrshdSA triWtrshdSA];
explode = [0 0 1];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-2)) '% One-Radar Coverage '],...
        [num2str(roundn(pieVar(2)/sum(pieVar)*100,-2)) '% Two-Radar Coverage '],...
        [num2str(roundn(pieVar(3)/sum(pieVar)*100,-2)) '% Three-Radar Coverage ']];

pie3(pieVar, explode,label)
title({'Three-Radar Network Retrieval Watershed Area Capability: '; ...
      [radStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
' ft '];...
      [radStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
      [radStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']]})
X2 = [0/255 153/255 255/255 ; 0/255 51/255 204/255 ; 0/255 51/255 153/255];
colormap(X2)

% Creating file path and name to save map figure.
pieChartFileName2 = strcat(radStr, '_', radStr2, '_', radStr3, '
NetRetrWtrShdPie',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
pieChartFile2 = fullfile(picSavefiledir,pieChartFileName2);

saveas(figHndl11,pieChartFile2)
close(figHndl11)
pause(1)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%
```

```

%                               MultiDopp Watershed Calculations MsgBox                               %
%                                                                           %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SACell15 = {'           ' ' Watershed Multi-Doppler Capability Coverage Area Calculations: ' };...
['           ' ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
degs, Height : ' num2str(hVec(hIndex)) ' ft '];...
['           ' ' radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) '
degs, Height : ' num2str(hVec2(hIndex2)) ' ft '];...
['           ' ' radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) '
degs, Height : ' num2str(hVec3(hIndex3)) ' ft '];...
[' ' ' '];...
[' ' ' '];...
[' MultiDoppler Capability Watershed Area: ' num2str(DDoppWtrshdSA) ' km^2 --> '
num2str(DDoppWtrshdPoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
num2str(DDoppCulePoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) '
num2str(DDoppRioGPoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) '
num2str(DDoppYagPoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
num2str(DDoppGuanaPoC) '%' ];...
[' ' ' '];...
[' No-MultiDoppler Capability Watershed Area: ' num2str(noDDoppWtrshdSA) ' km^2 --> '
num2str(noDDoppWtrshdPoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
num2str(noDDoppCulePoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) '
' num2str(noDDoppRioGPoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) '
num2str(noDDoppYagPoC) '%' ];...
[' ' ' '];...
['           ' ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
num2str(noDDoppGuanaPoC) '%' ];...
[' ' ' '];...
[' ' ' '];...

msghandle5 = msgbox(SACell15);
set(msghandle5,'Color',[1 1 1])
msgFileName = strcat(radStr, '_', radrStr2, '_', radrStr3, '
DDoppWtrShdCalcs',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
msgFile = fullfile(picSavefiledir,msgFileName);
saveas(msghandle5,msgFile)
close(msghandle5)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                               MultiDopp Watershed Calculations PieChart                               %
%                                                                           %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr 'MultiDoppler Capability Watersheds Coverage Pie Chart'];
figHndl2 = figure('Name',figStr);
pieVar = [DDoppWtrshdSA noDDoppWtrshdSA];
explode = [1 0];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-2)) '% MultiDoppler Capability
'],[num2str(roundn(pieVar(2)/sum(pieVar)*100,-2)) '% No-MultiDoppler Capability ']};

```

```

pie3(pieVar, explode,label)
title({'Three-Radar Network MultiDoppler Watershed Area Capability: '; ...
      [radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
      ' ft'];...
      [radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
      num2str(hVec2(hIndex2)) ' ft'];...
      [radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
      num2str(hVec3(hIndex3)) ' ft ']])
X2 = [0/255 153/255 255/255 ; 0/255 51/255 153/255];
colormap(X2)

% Creating file path and name to save map figure.
pieChartFileName2 = strcat(radRStr, '_', radRStr2, '_', radRStr3, '
DDoppWtrShdPie', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
pieChartFile2 = fullfile(picSavefiledir, pieChartFileName2);

saveas(figHndl2, pieChartFile2)
close(figHndl2)
pause(1)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Read Municipios Map                               %
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[muniMap, muniMaplegend] = arcgridread('pr_countries.asc');

% Equalling Municipalities Map size to that of map
[tempMuniMap] = eqMapSize2(map, maplegend, latlim, lonlim, muniMap, muniMaplegend);

% Create new Municipalities Map with NaNs
newMuniMap = nan(size(tempMuniMap));
MuniMap = newMuniMap;

MuniI = find(tempMuniMap >= 0);
newMuniMap(MuniI) = tempMuniMap(MuniI);

% Create a map full of Nans
nanmap = nan(size(newMuniMap));

% Aguadilla
AguadillaMap = nanmap;
inRngAguadillaMap = nanmap;
AguadillaI = find(newMuniMap == 72005);
AguadillaMap(AguadillaI) = 1400;
inRngAguadillaMap(inRng) = AguadillaMap(inRng);

% Aguada
AguadaMap = nanmap;
inRngAguadaMap = nanmap;
AguadaI = find(newMuniMap == 72003);
AguadaMap(AguadaI) = 1400;
inRngAguadaMap(inRng) = AguadaMap(inRng);

% Rincon
RinconMap = nanmap;
inRngRinconMap = nanmap;
RinconI = find(newMuniMap == 72117);
RinconMap(RinconI) = 1400;
inRngRinconMap(inRng) = RinconMap(inRng);

% Anasco
AnascoMap = nanmap;

```

```

inRngAnascoMap = nanmap;
AnascoI = find(newMuniMap == 72011);
AnascoMap(AnascoI) = 1400;
inRngAnascoMap(inRng) = AnascoMap(inRng);

% Mayaguez
MayaMap = nanmap;
inRngMayaMap = nanmap;
MayaI = find(newMuniMap == 72097);
MayaMap(MayaI) = 1400;
inRngMayaMap(inRng) = MayaMap(inRng);

% Cabo Rojo
CaboMap = nanmap;
inRngCaboMap = nanmap;
CaboI = find(newMuniMap == 72023);
CaboMap(CaboI) = 1400;
inRngCaboMap(inRng) = CaboMap(inRng);

% Merge all indices.
compMuniI = vertcat(AguadillaI, AguadaI, RinconI, AnascoI, MayaI, CaboI);

% Complete Municipalities Map
MuniMap(compMuniI) = 1400;

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           MultiDoppler Capability Vulnerability Calculations           %
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Radar coverage over complete municipality area.

inRngMuniMap = nanmap;
inRngMuniMap(inRng) = MuniMap(inRng);

% Surface Area of Complete Municipality areas.
compMuniSA = length(compMuniI) * 90 * 90 * 1e-6;

% Surface Area of Municipality Areas within radar range.
inRngMuniSAI = find(inRngMuniMap >= 0);
inRngMuniSA = length(inRngMuniSAI) * 90 * 90 * 1e-6;
inRngMuniPoC = roundn(inRngMuniSA/compMuniSA * 100,-2);

% Block/No-Block Vulnerability Surface Area
noDDoppMuni = nanmap;

DDoppMuniI = find(xbeamDDoppMapB(inRngMuniSAI) >= 0);

% Surface Area of No-Block Vulnerability Area
DDoppMuniSA = length(DDoppMuniI) * 90 * 90 * 1e-6;
DDoppMuniPoC = roundn(DDoppMuniSA/inRngMuniSA * 100,-2);

% Surface Area of Blocked Vulnerability Area
noDDoppMuniSA = inRngMuniSA - DDoppMuniSA;
noDDoppMuniPoC = roundn(noDDoppMuniSA/inRngMuniSA * 100,-2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Individual Municipality Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Aguadilla
compAguadillaSA = length(AguadillaI) * 90 * 90 * 1e-6;

inRngAguadillaI = find(inRngAguadillaMap >= 0);
inRngAguadillaSA = length(inRngAguadillaI) * 90 * 90 * 1e-6;

DDoppAguadillaI = find(xbeamDDoppMapB(inRngAguadillaI) >= 0);

DDoppAguadillaSA = length(DDoppAguadillaI) * 90 * 90 * 1e-6;

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DDoppAguadillaPoC = roundn(DDoppAguadillaSA/inRngAguadillaSA * 100,-2);

noDDoppAguadillaSA = inRngAguadillaSA - DDoppAguadillaSA;
noDDoppAguadillaPoC = roundn(noDDoppAguadillaSA/inRngAguadillaSA * 100,-2);

% Aguada
compAguadaSA = length(AguadaI) * 90 * 90 * 1e-6;

inRngAguadaI = find(inRngAguadaMap >= 0);
inRngAguadaSA = length(inRngAguadaI) * 90 * 90 * 1e-6;

DDoppAguadaI = find(xbeamDDoppMapB(inRngAguadaI) >= 0);

DDoppAguadaSA = length(DDoppAguadaI) * 90 * 90 * 1e-6;
DDoppAguadaPoC = roundn(DDoppAguadaSA/inRngAguadaSA * 100,-2);

noDDoppAguadaSA = inRngAguadaSA - DDoppAguadaSA;
noDDoppAguadaPoC = roundn(noDDoppAguadaSA/inRngAguadaSA * 100,-2);

% Rincon
compRinconSA = length(RinconI) * 90 * 90 * 1e-6;

inRngRinconI = find(inRngRinconMap >= 0);
inRngRinconSA = length(inRngRinconI) * 90 * 90 * 1e-6;

DDoppRinconI = find(xbeamDDoppMapB(inRngRinconI) >= 0);

DDoppRinconSA = length(DDoppRinconI) * 90 * 90 * 1e-6;
DDoppRinconPoC = roundn(DDoppRinconSA/inRngRinconSA * 100,-2);

noDDoppRinconSA = inRngRinconSA - DDoppRinconSA;
noDDoppRinconPoC = roundn(noDDoppRinconSA/inRngRinconSA * 100,-2);

% Anasco
compAnascoSA = length(AnascoI) * 90 * 90 * 1e-6;

inRngAnascoI = find(inRngAnascoMap >= 0);
inRngAnascoSA = length(inRngAnascoI) * 90 * 90 * 1e-6;

DDoppAnascoI = find(xbeamDDoppMapB(inRngAnascoI) >= 0);

DDoppAnascoSA = length(DDoppAnascoI) * 90 * 90 * 1e-6;
DDoppAnascoPoC = roundn(DDoppAnascoSA/inRngAnascoSA * 100,-2);

noDDoppAnascoSA = inRngAnascoSA - DDoppAnascoSA;
noDDoppAnascoPoC = roundn(noDDoppAnascoSA/inRngAnascoSA * 100,-2);

% Mayaguez
compMayaSA = length(MayaI) * 90 * 90 * 1e-6;

inRngMayaI = find(inRngMayaMap >= 0);
inRngMayaSA = length(inRngMayaI) * 90 * 90 * 1e-6;

DDoppMayaI = find(xbeamDDoppMapB(inRngMayaI) >= 0);

DDoppMayaSA = length(DDoppMayaI) * 90 * 90 * 1e-6;
DDoppMayaPoC = roundn(DDoppMayaSA/inRngMayaSA * 100,-2);

noDDoppMayaSA = inRngMayaSA - DDoppMayaSA;
noDDoppMayaPoC = roundn(noDDoppMayaSA/inRngMayaSA * 100,-2);

% Cabo Rojo
compCaboSA = length(CaboI) * 90 * 90 * 1e-6;

inRngCaboI = find(inRngCaboMap >= 0);
inRngCaboSA = length(inRngCaboI) * 90 * 90 * 1e-6;

```

```

DDoppCaboI = find(xbeamDDoppMapB(inRngCaboI) >= 0);

DDoppCaboSA = length(DDoppCaboI) * 90 * 90 * 1e-6;
DDoppCaboPoC = roundn(DDoppCaboSA/inRngCaboSA * 100,-2);

noDDoppCaboSA = inRngCaboSA - DDoppCaboSA;
noDDoppCaboPoC = roundn(noDDoppCaboSA/inRngCaboSA * 100,-2);

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           Network Retrieval Capability Vulnerability Calculations           %
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Radar coverage over complete municipality area.

inRngMuniMap = nanmap;
inRngMuniMap(inRng) = MuniMap(inRng);

% Surface Area of Complete Municipality areas.
compMuniSA = length(compMuniI) * 90 * 90 * 1e-6;

% Surface Area of Municipality Areas within radar range.
inRngMuniSAI = find(inRngMuniMap >= 0);
inRngMuniSA = length(inRngMuniSAI) * 90 * 90 * 1e-6;
inRngMuniPoC = roundn(inRngMuniSA/compMuniSA * 100,-2);

% 1-Radar Coverage
oneMuniI = find(oneRadrMap(inRngMuniSAI) >= 0);
oneMuniSA = length(oneMuniI) * 90 * 90 * 1e-6;
oneMuniPoC = roundn(oneMuniSA/inRngMuniSA * 100,-2);

% 2-Radar Coverage
twoMuniI = find(twoRadrMap(inRngMuniSAI) >= 0);
twoMuniSA = length(twoMuniI) * 90 * 90 * 1e-6;
twoMuniPoC = roundn(twoMuniSA/inRngMuniSA * 100,-2);

% 3-Radar Coverage
triMuniI = find(triRadrMap(inRngMuniSAI) >= 0);
triMuniSA = length(triMuniI) * 90 * 90 * 1e-6;
triMuniPoC = roundn(triMuniSA/inRngMuniSA * 100,-2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Individual Municipality Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Aguadilla
compAguadillaSA = length(AguadillaI) * 90 * 90 * 1e-6;

inRngAguadillaI = find(inRngAguadillaMap >= 0);
inRngAguadillaSA = length(inRngAguadillaI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneAguadillaI = find(oneRadrMap(inRngAguadillaI) >= 0);
oneAguadillaSA = length(oneAguadillaI) * 90 * 90 * 1e-6;
oneAguadillaPoC = roundn(oneAguadillaSA/inRngAguadillaSA * 100,-2);

% 2-Radar Coverage
twoAguadillaI = find(twoRadrMap(inRngAguadillaI) >= 0);
twoAguadillaSA = length(twoAguadillaI) * 90 * 90 * 1e-6;
twoAguadillaPoC = roundn(twoAguadillaSA/inRngAguadillaSA * 100,-2);

% 3-Radar Coverage
triAguadillaI = find(triRadrMap(inRngAguadillaI) >= 0);
triAguadillaSA = length(triAguadillaI) * 90 * 90 * 1e-6;
triAguadillaPoC = roundn(triAguadillaSA/inRngAguadillaSA * 100,-2);

```

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% Aguada
compAguadaSA = length(AguadaI) * 90 * 90 * 1e-6;

inRngAguadaI = find(inRngAguadaMap >= 0);
inRngAguadaSA = length(inRngAguadaI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneAguadaI = find(oneRadrMap(inRngAguadaI) >= 0);
oneAguadaSA = length(oneAguadaI) * 90 * 90 * 1e-6;
oneAguadaPoC = roundn(oneAguadaSA/inRngAguadaSA * 100,-2);

% 2-Radar Coverage
twoAguadaI = find(twoRadrMap(inRngAguadaI) >= 0);
twoAguadaSA = length(twoAguadaI) * 90 * 90 * 1e-6;
twoAguadaPoC = roundn(twoAguadaSA/inRngAguadaSA * 100,-2);

% 3-Radar Coverage
triAguadaI = find(triRadrMap(inRngAguadaI) >= 0);
triAguadaSA = length(triAguadaI) * 90 * 90 * 1e-6;
triAguadaPoC = roundn(triAguadaSA/inRngAguadaSA * 100,-2);

% Rincon
compRinconSA = length(RinconI) * 90 * 90 * 1e-6;

inRngRinconI = find(inRngRinconMap >= 0);
inRngRinconSA = length(inRngRinconI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneRinconI = find(oneRadrMap(inRngRinconI) >= 0);
oneRinconSA = length(oneRinconI) * 90 * 90 * 1e-6;
oneRinconPoC = roundn(oneRinconSA/inRngRinconSA * 100,-2);

% 2-Radar Coverage
twoRinconI = find(twoRadrMap(inRngRinconI) >= 0);
twoRinconSA = length(twoRinconI) * 90 * 90 * 1e-6;
twoRinconPoC = roundn(twoRinconSA/inRngRinconSA * 100,-2);

% 3-Radar Coverage
triRinconI = find(triRadrMap(inRngRinconI) >= 0);
triRinconSA = length(triRinconI) * 90 * 90 * 1e-6;
triRinconPoC = roundn(triRinconSA/inRngRinconSA * 100,-2);

% Anasco
compAnascoSA = length(AnascoI) * 90 * 90 * 1e-6;

inRngAnascoI = find(inRngAnascoMap >= 0);
inRngAnascoSA = length(inRngAnascoI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneAnascoI = find(oneRadrMap(inRngAnascoI) >= 0);
oneAnascoSA = length(oneAnascoI) * 90 * 90 * 1e-6;
oneAnascoPoC = roundn(oneAnascoSA/inRngAnascoSA * 100,-2);

% 2-Radar Coverage
twoAnascoI = find(twoRadrMap(inRngAnascoI) >= 0);
twoAnascoSA = length(twoAnascoI) * 90 * 90 * 1e-6;
twoAnascoPoC = roundn(twoAnascoSA/inRngAnascoSA * 100,-2);

% 3-Radar Coverage
triAnascoI = find(triRadrMap(inRngAnascoI) >= 0);
triAnascoSA = length(triAnascoI) * 90 * 90 * 1e-6;
triAnascoPoC = roundn(triAnascoSA/inRngAnascoSA * 100,-2);

% Mayaguez
compMayaSA = length(MayaI) * 90 * 90 * 1e-6;

inRngMayaI = find(inRngMayaMap >= 0);
inRngMayaSA = length(inRngMayaI) * 90 * 90 * 1e-6;

```

```

% 1-Radar Coverage
oneMayaI = find(oneRadrMap(inRngMayaI) >= 0);
oneMayaSA = length(oneMayaI) * 90 * 90 * 1e-6;
oneMayaPoC = roundn(oneMayaSA/inRngMayaSA * 100,-2);

% 2-Radar Coverage
twoMayaI = find(twoRadrMap(inRngMayaI) >= 0);
twoMayaSA = length(twoMayaI) * 90 * 90 * 1e-6;
twoMayaPoC = roundn(twoMayaSA/inRngMayaSA * 100,-2);

% 3-Radar Coverage
triMayaI = find(triRadrMap(inRngMayaI) >= 0);
triMayaSA = length(triMayaI) * 90 * 90 * 1e-6;
triMayaPoC = roundn(triMayaSA/inRngMayaSA * 100,-2);

% Cabo Rojo
compCaboSA = length(CaboI) * 90 * 90 * 1e-6;

inRngCaboI = find(inRngCaboMap >= 0);
inRngCaboSA = length(inRngCaboI) * 90 * 90 * 1e-6;

% 1-Radar Coverage
oneCaboI = find(oneRadrMap(inRngCaboI) >= 0);
oneCaboSA = length(oneCaboI) * 90 * 90 * 1e-6;
oneCaboPoC = roundn(oneCaboSA/inRngCaboSA * 100,-2);

% 2-Radar Coverage
twoCaboI = find(twoRadrMap(inRngCaboI) >= 0);
twoCaboSA = length(twoCaboI) * 90 * 90 * 1e-6;
twoCaboPoC = roundn(twoCaboSA/inRngCaboSA * 100,-2);

% 3-Radar Coverage
triCaboI = find(triRadrMap(inRngCaboI) >= 0);
triCaboSA = length(triCaboI) * 90 * 90 * 1e-6;
triCaboPoC = roundn(triCaboSA/inRngCaboSA * 100,-2);

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               MultiDopp Watershed Calculations MsgBox
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SACell16 = {' ' ' MultiDoppler Capability Vulnerability Area Coverage Calculations: ' };...
[' ' ' ' radrStr '- theta: ' num2str(thetaVec(thetaIndex)) '
degs, Height : ' num2str(hVec(hIndex)) ' ft '];...
[' ' ' ' ' radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) '
degs, Height : ' num2str(hVec2(hIndex2)) ' ft '];...
[' ' ' ' ' radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) '
degs, Height : ' num2str(hVec3(hIndex3)) ' ft '];...
[' ' ' ' '];...
[' ' ' ' '];...
[' MultiDoppler Capability Vulnerability Area: ' num2str(DDoppMuniSA) ' km^2 --> '
num2str(DDoppMuniPoC) '%' ];...
[' ' ' ' '];...
[' ' ' ' ' Aguadilla: ' num2str(DDoppAguadillaSA) ' km^2 --> '
num2str(DDoppAguadillaPoC) '%' ];...
[' ' ' ' '];...
[' ' ' ' ' Aguada: ' num2str(DDoppAguadaSA) ' km^2 --> '
num2str(DDoppAguadaPoC) '%' ];...
[' ' ' ' '];...
[' ' ' ' ' Rincon: ' num2str(DDoppRinconSA) ' km^2 --> '
num2str(DDoppRinconPoC) '%' ];...
[' ' ' ' '];...
[' ' ' ' ' Anasco: ' num2str(DDoppAnascoSA) ' km^2 --> '
num2str(DDoppRinconPoC) '%' ];...
[' ' ' ' '];...

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        ['
num2str(DDoppMayaPoC) '%' ];...
        [' ' ' '];...
        ['
num2str(DDoppCaboPoC) '%' ];...
        [' ' ' '];...
        [' NoMultiDoppler Capability Vulnerability Area: ' num2str(noDDoppMuniSA) ' km^2 --> '
num2str(noDDoppMuniPoC) '%' ];...
        [' ' ' '];...
        ['
num2str(noDDoppAguadillaPoC) '%' ];...
        [' ' ' '];...
        ['
num2str(noDDoppAguadaPoC) '%' ];...
        [' ' ' '];...
        ['
num2str(noDDoppRinconPoC) '%' ];...
        [' ' ' '];...
        ['
num2str(noDDoppAnascoPoC) '%' ];...
        [' ' ' '];...
        ['
num2str(noDDoppMayaPoC) '%' ];...
        [' ' ' '];...
        ['
num2str(noDDoppCaboPoC) '%' ];...
        [' ' ' '];...
        [' ' ' '];

Mayaguez: ' num2str(DDoppMayaSA) ' km^2 --> '
Cabo Rojo: ' num2str(DDoppCaboSA) ' km^2 --> '
Aguadilla: ' num2str(noDDoppAguadillaSA) ' km^2 --> '
Aguada: ' num2str(noDDoppAguadaSA) ' km^2 --> '
Rincon: ' num2str(noDDoppRinconSA) ' km^2 --> '
Anasco: ' num2str(noDDoppAnascoSA) ' km^2 --> '
Mayaguez: ' num2str(noDDoppMayaSA) ' km^2 --> '
Cabo Rojo: ' num2str(noDDoppCaboSA) ' km^2 --> '

msghandle6 = msgbox(SACell6);
set(msghandle6,'Color',[1 1 1])
msgFileName = strcat(radRstr, '_', radRstr2, '_', radRstr3, '
DDoppVulnCalcs', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

num2str(hVec2(hIndex2)), num2str(thetaIndex2), '_', num2str(hVec2(hIndex2)), num2str(thetaIndex2), '.j
pg');
msgFile = fullfile(picSavefiledir, msgFileName);
saveas(msghandle6, msgFile)
close(msghandle6)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% MultiDopp Vulnerability Calculations PieChart
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radRstr ' MultiDoppler Capability Vulnerability Coverage Pie Chart'];
figHndl3 = figure('Name', figStr);
pieVar = [DDoppMuniSA noDDoppMuniSA];
explode = [1 0];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-2)) '% MultiDoppler Capability '],...
[num2str(roundn(pieVar(2)/sum(pieVar)*100,-2)) '% No-MultiDoppler Capability ']}];

pie3(pieVar, explode, label)
title({'Three-Radar Network MultiDoppler Vulnerability Area Capability: '; ...
[radRstr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height : ' num2str(hVec(hIndex))
' ft '];...
[radRstr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height : '
num2str(hVec2(hIndex2)) ' ft '];...
[radRstr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height : '
num2str(hVec3(hIndex3)) ' ft ']});
X2 = [153/255 51/255 51/255 100/255 0/255 0/255];
colormap(X2)

% Creating file path and name to save map figure.
pieChartFileName3 = strcat(radRstr, '_', radRstr2, '_', radRstr3, '
DDoppVulnePie', num2str(hVec(hIndex)), num2str(thetaIndex), '_', ...

```



```

        [' ' ' '];...
num2str(triAguadillaPoC) '% '];...
        [' ' ' '];...
        ['
num2str(triAguadaPoC) '% '];...
        [' ' ' '];...
        ['
num2str(triRinconPoC) '% '];...
        [' ' ' '];...
        ['
num2str(triAnascoPoC) '% '];...
        [' ' ' '];...
        ['
num2str(triMayaPoC) '% '];...
        [' ' ' '];...
        ['
num2str(triCaboPoC) '% '];...
        [' ' ' '];...
        [' ' ' '];

msghandle7 = msgbox(SACell7);
set(msghandle7,'Color',[1 1 1])
msgFileName = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
NetRetrVulnCalcs',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
msgFile = fullfile(picSavefiledir,msgFileName);
saveas(msghandle7,msgFile)
close(msghandle7)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           Net Retrieval Vulnerability Calculations PieChart           %
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' Network Retrieval Capability Vulnerability Coverage Pie Chart'];
figHndl3 = figure('Name',figStr);
pieVar = [oneMuniSA twoMuniSA triMuniSA];
explode = [0 0 1];
label = {[num2str(roundn(pieVar(1)/sum(pieVar)*100,-2)) '% One-Radar Coverage '],...
        [num2str(roundn(pieVar(2)/sum(pieVar)*100,-2)) '% Two-Radar Coverage '],...
        [num2str(roundn(pieVar(3)/sum(pieVar)*100,-2)) '% Three-Radar Coverage ']];

pie3(pieVar, explode,label)
title({'Three-Radar Network Retrieval Vulnerability Area Capability: '; ...
        [radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
' ft '];...
        [radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
        [radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']])
X2 = [255/255 100/255 100/255 ; 204/255 51/255 51/255 ; 204/255 10/255 10/255];
colormap(X2)

% Creating file path and name to save map figure.
pieChartFileName3 = strcat(radrStr, '_', radrStr2, '_', radrStr3, '
NetRetrVulnePie',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
pieChartFile3 = fullfile(picSavefiledir,pieChartFileName3);

saveas(figHndl3,pieChartFile3)
close(figHndl3)

```

```

pause(1)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot MultiDopp + Watersheds
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Network MultiDoppler Watersheds Map'];
figHndl4 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(map,maplegend,'DisplayType', 'surface')
demcmap(triRadrBlkMap)
colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

hold on

% Plot Culebrinas Watershed Area
h_OLMap1 = geoshow(inRngCulebrinasMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 102/255 255/255])

hold on

% Plot Rio Grande de Abasco Watershed Area
h_OLMap1 = geoshow(inRngRioGMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 51/255 153/255])

hold on

% Plot Yaguez Watershed Area
h_OLMap1 = geoshow(inRngYagMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 153/255 255/255])

hold on

% Plot Guanajibo Watershed Area
h_OLMap1 = geoshow(inRngGuanaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 51/255 204/255])

hold on

% Plot Dual Dopp Overlay
h_OLMap3 = geoshow(XbeamDDoppWtrshd,maplegend,'DisplayType','surface');
set(h_OLMap3,'FaceColor',[255/255 255/255 255/255])
set(figHndl4,'Renderer','OpenGL')
set(h_OLMap3,'FaceAlpha',0.6)

% Figure Title
title({'Three-Radar Network Watershed MultiDoppler Coverage: '; ...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
[radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']]}
xlabel('Longitude')
ylabel('Latitude')

```

```

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y-')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y-')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y-')

% Creating file path and name to save map figure.
WtrshdFileName2 = strcat(radrStr, '_', radrStr2, '_', radrStr3, ' Watersheds DDopp
Map',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
WtrshdFile2 = fullfile(picSavefiledir,WtrshdFileName2);

saveas(figHndl4,WtrshdFile2)
close(figHndl4)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot NetRetrieval + Watersheds
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Network MultiDoppler Watersheds Map'];
figHndl5 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(map,maplegend,'DisplayType','surface')
demcmap(triRadrBlkMap)
colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

hold on

% Plot Culebrinas Watershed Area
h_OLMap1 = geoshow(inRngCulebrinasMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 102/255 255/255])

hold on

% Plot Rio Grande de Abasco Watershed Area
h_OLMap1 = geoshow(inRngRioGMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 51/255 153/255])

hold on

% Plot Yaguez Watershed Area
h_OLMap1 = geoshow(inRngYagMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 153/255 255/255])

hold on

% Plot Guanajibo Watershed Area

```

```

h_OLMap1 = geoshow(inRngGuanaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0/255 51/255 204/255])

hold on

% Plot Single Radr Coverage
h_OLMap1 = geoshow(oneRadrMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0.8 0.9 0.7])
set(figHndl5,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.6)

hold on

% Plot 2 Radar Overlays
h_OLMap2 = geoshow(twoRadrMap,maplegend,'DisplayType','surface') ;
set(h_OLMap2,'FaceColor',[0.3 0.6 0.5])
set(figHndl5,'Renderer','OpenGL')
set(h_OLMap2,'FaceAlpha',0.6)

hold on

% Plot 3 Radar Overlays
h_OLMap3 = geoshow(triRadrMap,maplegend,'DisplayType','surface');
set(h_OLMap3,'FaceColor',[0.3 0.6 0.3])
set(figHndl5,'Renderer','OpenGL')
set(h_OLMap3,'FaceAlpha',0.6)

% Figure Title
title({'Three-Radar Network Watershed MultiDoppler Coverage: ' ; ...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height : ' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height : '
num2str(hVec2(hIndex2)) ' ft '];...
[radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height : '
num2str(hVec3(hIndex3)) ' ft ']});
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y-')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y-')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y-')

% Creating file path and name to save map figure.
WtrshdFileName2 = strcat(radrStr, '_', radrStr2, '_', radrStr3, ' Watersheds NetRetr
Map',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
WtrshdFile2 = fullfile(picSavefiledir,WtrshdFileName2);

saveas(figHndl5,WtrshdFile2)
close(figHndl5)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot MultiDopp + Vulnerability
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Network MultiDoppler Watersheds Map'];
figHndl6 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(map,maplegend,'DisplayType','surface')
demcmap(triRadrBlkMap)
colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

hold on

% Plot Aguadilla Area
h_OLMap1 = geoshow(inRngAguadillaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[255/255 100/255 100/255])

hold on

% Plot Aguada Area
h_OLMap1 = geoshow(inRngAguadaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 51/255 51/255])

hold on

% Plot Rincon Area
h_OLMap1 = geoshow(inRngRinconMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 10/255 10/255])

hold on

% Plot Anasco Area
h_OLMap1 = geoshow(inRngAnascoMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[255/255 100/255 100/255])

hold on

% Plot Mayaguez Area
h_OLMap1 = geoshow(inRngMayaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 51/255 51/255])

hold on

% Plot Cabo Rojo Area
h_OLMap1 = geoshow(inRngCaboMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 10/255 10/255])

hold on

% Plot Dual Dopp Overlay
h_OLMap3 = geoshow(XbeamDDoppWtrshd,maplegend,'DisplayType','surface');
set(h_OLMap3,'FaceColor',[255/255 255/255 255/255])
set(figHndl6,'Renderer','OpenGL')
set(h_OLMap3,'FaceAlpha',0.6)

% Figure Title
title({'Three-Radar Network Watershed MultiDoppler Coverage: '; ...
[radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height : ' num2str(hVec(hIndex))
' ft '];...
[radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height : '
num2str(hVec2(hIndex2)) ' ft '];...

```

```

        [radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']]
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y-')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y-')
[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y-')

% Creating file path and name to save map figure.
WtrshdFileName2 = strcat(radrStr, '_', radrStr2, '_', radrStr3, ' Vuln DDopp
Map',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
WtrshdFile2 = fullfile(picSavefiledir,WtrshdFileName2);

saveas(figHndl6,WtrshdFile2)
close(figHndl6)

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Plot NetRetrieval + Vulnerability
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figStr = [radrStr ' ', ' radrStr2 ', & ' radrStr3 ' Network MultiDoppler Watersheds Map'];
figHndl7 = figure('Name',figStr);
worldmap(latlim,lonlim);
geoshow(map,maplegend,'DisplayType', 'surface')
demcmmap(triRadrBlkMap)
colorbar
hold on

%Modifies the colormap of the figure in order to produce the ocean's blue
%and the black color for the blocked areas.
X = colormap;
X(2,2) = 0;
X(2,1) = 0.2;
X(1,1) = 0;
X(1,2) = 0;
X(1,3) = 0;
colormap(X);

hold on

% Plot Aguadilla Area
h_OLMap1 = geoshow(inRngAguadillaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[255/255 100/255 100/255])
% set(figHndl7,'Renderer','OpenGL')
% set(h_OLMap1,'FaceAlpha',0.8)

hold on

% Plot Aguada Area
h_OLMap1 = geoshow(inRngAguadaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 51/255 51/255])
% set(figHndl7,'Renderer','OpenGL')
% set(h_OLMap1,'FaceAlpha',0.8)

```

```

hold on

% Plot Rincon Area
h_OLMap1 = geoshow(inRngRinconMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 10/255 10/255])
hold on

% Plot Anasco Area
h_OLMap1 = geoshow(inRngAnascoMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[255/255 100/255 100/255])

hold on

% Plot Mayaguez Area
h_OLMap1 = geoshow(inRngMayaMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 51/255 51/255])

hold on

% Plot Cabo Rojo Area
h_OLMap1 = geoshow(inRngCaboMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[204/255 10/255 10/255])

hold on

% Plot Single Radr Coverage
h_OLMap1 = geoshow(oneRadRMap,maplegend,'DisplayType','surface');
set(h_OLMap1,'FaceColor',[0.8 0.9 0.7])
set(figHndl7,'Renderer','OpenGL')
set(h_OLMap1,'FaceAlpha',0.6)

hold on

% Plot 2 Radar Overlays
h_OLMap2 = geoshow(twoRadRMap,maplegend,'DisplayType','surface') ;
set(h_OLMap2,'FaceColor',[0.6 0.9 0.5])
set(figHndl7,'Renderer','OpenGL')
set(h_OLMap2,'FaceAlpha',0.6)

hold on

% Plot 3 Radar Overlays
h_OLMap3 = geoshow(triRadRMap,maplegend,'DisplayType','surface');
set(h_OLMap3,'FaceColor',[0.3 0.6 0.3])
set(figHndl7,'Renderer','OpenGL')
set(h_OLMap3,'FaceAlpha',0.6)

% Figure Title
title({'Three-Radar Network Watershed MultiDoppler Coverage: '; ...
      [radrStr '- theta: ' num2str(thetaVec(thetaIndex)) ' degs, Height :' num2str(hVec(hIndex))
      ' ft '];...
      [radrStr2 '- theta: ' num2str(thetaVec2(thetaIndex2)) ' degs, Height :'
num2str(hVec2(hIndex2)) ' ft '];...
      [radrStr3 '- theta: ' num2str(thetaVec3(thetaIndex3)) ' degs, Height :'
num2str(hVec3(hIndex3)) ' ft ']});
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radar.
plot3m(radr_lat,radr_lon,4000,'y.')
plot3m(radr_lat2,radr_lon2,4000,'y.')
plot3m(radr_lat3,radr_lon3,4000,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,4000,'y-')
[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,4000,'y-')

```

```

[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,4000,'y-')

% Creating file path and name to save map figure.
WtrshdFileName2 = strcat(radrStr, '_', radrStr2, '_', radrStr3, ' Vuln NetRetr
Map',num2str(hVec(hIndex)),num2str(thetaIndex),'_',...

num2str(hVec2(hIndex2)),num2str(thetaIndex2),'_',num2str(hVec2(hIndex2)),num2str(thetaIndex2),'.j
pg');
WtrshdFile2 = fullfile(picSavefiledir,WtrshdFileName2);

saveas(figHnd17,WtrshdFile2)
close(figHnd17)

%%
end

```

### A1.3.2 Radr3MapRead.m

```

function [map,maplegend,latlim,lonlim] =
radr3MapRead(radrMapFile,radrFlStr,radrStr,radr_lat,radr_lon,...
            radrStr2,radrFlStr2,radr_lat2,radr_lon2,...
            radrStr3,radrFlStr3,radr_lat3,radr_lon3)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           Read 90m Resolution Data and Plot Map
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%           University of Puerto Rico at Mayaguez
%           Department of Electrical and Computer Engineering
%           Created By: Ricardo Rios-Olmo
%
% Purpose:
%   This program creates a map for a network of three radars.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

tic
%Read Elevation Data (ASCII)
[map,maplegend] = arcgridread('srtm_23_09.asc');
toc

% Convert few pixels with negative values to 0 height
map(find(map < 0)) = 0;

% Water surrounding the island is given a negative value
map(isnan(map)) = -10;

% Determining coordinates for points in space given by rng and az for radar 1.
[lat0a, lon0a] = reckon(radr_lat, radr_lon, km2deg(40),0);
[lat90a, lon90a] = reckon(radr_lat, radr_lon, km2deg(40),90);
[lat180a, lon180a] = reckon(radr_lat, radr_lon, km2deg(40),180);
[lat270a, lon270a] = reckon(radr_lat, radr_lon, km2deg(40),270);

% Determining coordinates for points in space given by rng and az for radar 2.
[lat0b, lon0b] = reckon(radr_lat2, radr_lon2, km2deg(40),0);
[lat90b, lon90b] = reckon(radr_lat2, radr_lon2, km2deg(40),90);
[lat180b, lon180b] = reckon(radr_lat2, radr_lon2, km2deg(40),180);
[lat270b, lon270b] = reckon(radr_lat2, radr_lon2, km2deg(40),270);

% Determining coordinates for points in space given by rng and az for radar 3.
[lat0c, lon0c] = reckon(radr_lat3, radr_lon3, km2deg(40),0);

```

```

[lat90c, lon90c] = reckon(radr_lat3, radr_lon3, km2deg(40),90);
[lat180c, lon180c] = reckon(radr_lat3, radr_lon3, km2deg(40),180);
[lat270c, lon270c] = reckon(radr_lat3, radr_lon3, km2deg(40),270);

% Determine smaller and larger lat between radars 1 & 2.
if lat180a < lat180b
    lat180 = lat180a;
else
    lat180 = lat180b;
end

if lat0a > lat0b
    lat0 = lat0a;
else
    lat0 = lat0b;
end

% Determine smaller and larger lon between radars 1 & 2.
if lon270a < lon270b
    lon270 = lon270a;
else
    lon270 = lon270b;
end

if lon90a > lon90b
    lon90 = lon90a;
else
    lon90 = lon90b;
end

% Determine smaller and larger lat between previous result and radar 3.
if lat180c < lat180
    lat180 = lat180c;
end

if lat0c > lat0
    lat0 = lat0c;
end

% Determine smaller and larger lon between previous result and radar 3.
if lon270c < lon270
    lon270 = lon270c;
end

if lon90c > lon90
    lon90 = lon90c;
end

% Establish lat/lon limits
latlim = [lat180-0.3 lat0+0.3];
lonlim = [lon270-0.3 lon90+0.3];

% Clip map matrix... too large!
[x1,y1] = latlon2pix(maplegend, latlim(2), lonlim(1));
[x2,y2] = latlon2pix(maplegend, latlim(1), lonlim(2));

newmap = map(round(x1):round(x2), round(y1):round(y2));

[lat, lon] = pix2latlon(maplegend, round(x1), round(y1));

maplegend(3,1) = lon;
maplegend(3,2) = lat;

map = newmap;

% Just in case
map(isnan(map)) = -10;

```

```

tic
%Plot map
figStr = [radrStr ' ', ' radrStr2 ' & ' radrStr3 ' Network Map'];
figHndl = figure('Name',figStr);
ax = worldmap(latlim,lonlim);
geoshow(map,maplegend,'DisplayType','surface')
demcmap(map)
colorbar
axis off
hold on

tightmap
hold on

X = colormap;
X(1,2) = 0;
X(1,1) = 0.2;
colormap(X);
toc

% Figure Title
title([radrStr ' ', ' radrStr2 ' & ' radrStr3 ' Network 40km Coverage Map'])
xlabel('Longitude')
ylabel('Latitude')

%Marks the location of the radars.
plot3m(radr_lat,radr_lon,1400,'y.')
plot3m(radr_lat2,radr_lon2,1400,'y.')
plot3m(radr_lat3,radr_lon3,1400,'y.')

%Plot radar coverage.
[Cirlat,Cirlon] = scircle1(radr_lat,radr_lon,km2deg(40));
plot3m(Cirlat,Cirlon,1400,'y')

[Cirlat2,Cirlon2] = scircle1(radr_lat2,radr_lon2,km2deg(40));
plot3m(Cirlat2,Cirlon2,1400,'y')

[Cirlat3,Cirlon3] = scircle1(radr_lat3,radr_lon3,km2deg(40));
plot3m(Cirlat3,Cirlon3,1400,'y')

% Creating file path and name to save map figure.
[path, name, ext] = fileparts(radrMapFile);
filename = fullfile(path,'/', ['medMap' radrFlStr radrFlStr2 radrFlStr3 '.jpg']);

saveas(gcf,filename)
close(figHndl)

save (radrMapFile,'map', 'maplegend', 'latlim', 'lonlim')

```

### A1.3.3 eqMapSize.m

```

function [newMap] = eqMapSize(BigMap,BigMaplegend,bigLatlim,bigLonlim,...
                             smallMap,openfiledir,radrFlStr,radr_lat,radr_lon)

% =====
%
%                               Equal Map Sizes
%
% =====
%
%                               University of Puerto Rico at Mayaguez
%                               Department of Electrical and Computer Engineering
%                               Created By: Ricardo Rios-Olmo
%

```

```

% Purpose:
% This program makes the size of two different maps the same. The
% smaller map will be change to match the larger map.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Define big map size
bigMapSizeVec = size(BigMap)

% Define small map size
smallMapSizeVec = size(smallMap);

% Load single radar map info
filename = strcat('medMapData',radrFlStr, '.mat');
radrMapFile = fullfile(openfiledir,filename);
load(radRMapFile)

% Determine on which pixels lies the small map
[lat,lon] = pix2latlon(maplegend,0,0);
[row, col] = latlon2pix(BigMaplegend,lat,lon);

if row == 0
    row = 1;
end

if row > bigMapSizeVec(1)
    row = 1;
end

if col == 0
    col = 1;
end

if col > bigMapSizeVec(2)
    col = 1;
end

row = round(row);
col = round(col);

%Define new map with all blocking values
newMap = -40*(ones(bigMapSizeVec));

rowIndex = row + smallMapSizeVec(1) - 1;
colIndex = col + smallMapSizeVec(2) - 1;

% Insert small map on new map
newMap(rowIndex:rowIndex,col:colIndex) = smallMap(:,:);

size(newMap)

```

### A1.3.4 dualDopp.m

```

function [xbeam1_2] = dualDopp(map,maplegend,savefiledir,radrFlStr1,radrlat1,radrlon1,...
                             radrFlStr2,radrlat2,radrlon2,theta1,theta2,h1,h2)

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %
% % Multi-Dopper Capability Evaluation %
% %
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% University of Puerto Rico at Mayaguez

```

```

%           Department of Electrical and Computer Engineering
%           Created By: Ricardo Rios-Olmo
%
% [xbeam1_2] = dualDopp(map,maplegend,savefiledir,radrlat1,radrlon1,...
%                   radrlat2,radrlon2,theta1,theta2,h1,h2)
%
%
% Description:  This program returns the crossbeam angles between the radars
%              were dual doppler maybe retrieved at specified height in the
%              atmosphere.
%
% Input arguments:  map           Current map being used.
%                  maplegend     Current maplegend.
%                  radrlat1      Radar 1 latitude coordinate in degrees.
%                  radrlon1      Radar 1 Longitude coordinate in degrees.
%                  radrlat2      Radar 2 latitude coordinate in degrees.
%                  radrlon2      Radar 2 longitude coordinate in degrees.
%                  theta1        Radar 1 minimum elevation angle.
%                  theta2        Radar 2 minimum elevation angle.
%                  h1            Radar 1 tower height in ft.
%                  h2            Radar 2 tower height in ft.
%
%
% Outout arguments:  xbeam1_2    Returns the value for crossbeam angles
%                               enabling dualdoppler retrieval at
%                               determined height in the atmosphere.
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%                               Create Azimuth Matrices
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Obtaining the correct starting lat/lon
[lat,lon] = pix2latlon(maplegend,1,1);

%Creating lat vector
latRefVec = lat + (0:length(map(:,1))-1)*maplegend(1,2);

%Creating lon vector
lonRefVec = lon - (0:length(map(1,:))-1)*maplegend(1,2);

%Expand lat/lon vectors to matrices of equal sizes.
sizeVec = size(map);
latMat = repmat(latRefVec',1,sizeVec(2));
lonMat = repmat(lonRefVec,sizeVec(1),1);

%Obtain all ranges and azimuths within map... with respect to ...
% Radar 1
[allRangeA,allAzA] = distance(radrlat1,radrlon1,latMat,lonMat);
% Radar 2
[allRangeB,allAzB] = distance(radrlat2,radrlon2,latMat,lonMat);

%Convert ranges from degrees of arc length to km.
allRangeA = deg2km(allRangeA);
allRangeB = deg2km(allRangeB);

xbeam = abs(allAzA - allAzB);

% Keep angles between 0 --> 180
xbeamIa = find(xbeam > 180);
xbeam(xbeamIa) = abs(xbeam(xbeamIa) - 360);

% Keep angles between 0 --> 90
xbeamIb = find(xbeam > 90);
xbeam(xbeamIb) = abs(xbeam(xbeamIb) - 180);

```



```

%         thetaStr1 = strcat(num2str(thetaRadr1),'_');
%
%     end
%
%     if mod(thetaRadr2,round(thetaRadr2)) ~= 0
%
%         thetaStr2 = strcat(num2str(thetaRadr2),'_5');
%
%     else
%
%         thetaStr2 = strcat(num2str(thetaRadr2),'_');
%
%     end
%
%     bhfilename1 = strcat(radrFlStr1,thetaStr1,'bhMat.mat');
%     bhfilename2 = strcat(radrFlStr2,thetaStr2,'bhMat.mat');
%     bhfile1 = fullfile(bhfiledir,bhfilename1);
%     bhfile2 = fullfile(bhfiledir,bhfilename2);
%
%     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% BH Matrix %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%     if ~exist(bhfile1,'file')
%
%         tic
%
%         bhMat1 = bhCalc(allRangeA,h_radr1,bw,thetaRadr1);
%         bhMat = bhMat1;
%         save(bhfile1, 'bhMat')
%
%         toc
%
%     else
%
%         load(bhfile1)
%         bhMat1 = bhMat;
%
%     end
%
%     if ~exist(bhfile2,'file')
%
%         tic
%
%         bhMat2 = bhCalc(allRangeB,h_radr2,bw,thetaRadr2);
%         bhMat = bhMat2;
%         save(bhfile2, 'bhMat')
%
%         toc
%
%     else
%
%         load(bhfile2)
%         bhMat2 = bhMat;
%
%     end
%
%     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Interest Area %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%     AreaWant1 = find(bhMat1(OLAreaI) >= 1000 & bhMat1(OLAreaI) <= 2500);
%     AreaWant2 = find(bhMat2(OLAreaI) >= 1000 & bhMat2(OLAreaI) <= 2500);
%
%     interArea = intersect(AreaWant1,AreaWant2);
%
%     xbeam1_2(OLAreaI(interArea)) = xbeam(OLAreaI(interArea));
%
%     cwaitbar([2 thetaRadr2/length(thetaVec2)])
% end
%
%     cwaitbar([1 thetaRadr1/length(thetaVec1)])
% end
%
% close(wait)

```