Project Description

Introduction

Improving today's weather monitoring and forecasting requires an increase in both the resolution and volume coverage of observations in the lowest kilometers of the troposphere. This is especially true in Puerto Rico, where complex orography limits the use of traditional long-range radar systems making the deployment of a network of short range radars an attractive alternative to observe the weather. While current technology has been successfully used for many years to provide weather forecast, coverage and resolution of the lower atmosphere needs to be improved to help the scientist to understand today's rapidly changing weather phenomena that is undetected under the long-range radar beam. Figure-1 shows an illustration of the coverage from the long-range radar. To achieve this goal, a network consisting of three X-band radars that will have the ability to monitor the earth's lower troposphere is proposed here. The radars will be strategically located in the west coast of Puerto Rico positioned in a configuration that optimizes the overall performance of the system. The radar network will be operated by a Managing System Control and Decision Center (MSCDC) which is an integral part of the system. The network will provide precise weather forecast to a region in Puerto Rico that has traditionally been plagued by intense rain and flash floods but lack of precise data and the complex orography of the Island has lead to poor prediction of these events.

Different research activities will arise from the development of the X-band radar network. Hydrologists, atmospheric scientists, electrical engineers, computer engineers, and others will join efforts to establish an unprecedented weather monitoring and forecast system in Puerto Rico based in the radar network proposed. The data generated will also be used by state and federal agencies to provide precise weather forecast to the population, potentially saving life and property. A number of scientist around the World have also shown interest in studying and understanding complicated weather phenomena in a tropical and mountainous environment such as in Puerto Rico, and this system will provide the necessary volume coverage and resolution for research opportunities in this direction.

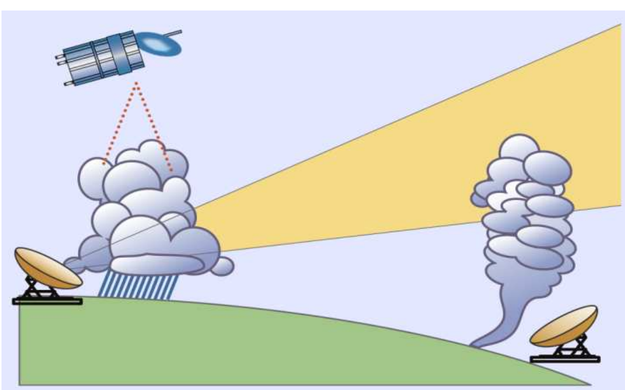

Figure 1– Due to Earth's curvature, 72% of the atmosphere is not observed, i.e., undetected weather.

We propose, for the Puerto Rico's west coast, the development of a network of three short range dual polarized X-band Doppler radars, this weather sensing network will achieve breakthrough improvements in sensitivity and resolution for sampling storms, thermodynamic state, and other critical variables throughout the entire troposphere.

The radars will be highly reliable, and will operate in collaborative networks that are capable of targeting an event from multiple angles, to accurately estimate rainfall levels near the ground, and to detect precursors of future storms—all in response to changing end-user needs.

a. Research Activities

Results from Prior NSF Support **-** Dr. Jose G. Colom is Associate Director of the Collaborative Adaptive Sensing of the Atmosphere (CASA - NSF Award Number 0313747) at the University of Puerto Rico Mayaguez (UPRM), while Dr. Sandra Cruz Pol is the current PI at UPRM and Dr. Rafael Rodríguez Solís is an active researcher of the center. Under the auspices of CASA, several researchers from the University of Massachusetts, Colorado State University, University of Oklahoma, and UPRM collaborated to develop a Distributed Collaborative Adaptive Sensing (DCAS*)* testbed in Oklahoma [McLaughlin et al. 2005]. The testbed consists of four dual polarized X-band Doppler radars separated by approximately 25 km. The radars are situated in southern Oklahoma, midway between two WSR-88D (NEXRAD) radars. Figure-2 shows the four Oklahoma radars in the final phase of their construction.

Figure 2 - Oklahoma testbed radars

The Oklahoma testbed was deployed in 2006 and has been fully functional since August 2006. A case study of a nearly stationary east-to-west warm frontal boundary in August 16, 2006 provided storm formations across the testbed location. The DCAS data obtained from that day was then compared to NEXRAD and it revealed much greater storm structure in time and space [Brotzge et al. 2006]. Also, during the spring of 2007, data from the four Oklahoma radars and NEXRAD were combined in a high resolution data assimilation experiment [Brewster, et al. 2006]. In this study, data from the DCAS radars was merged with NEXRAD, filling the domain below 1.2 km, previously undetected by NEXRAD.

While primary efforts were directed to prove DCAS technology at the Oklahoma testbed, CASA also supported research to be performed at UPRM. During the last year the first X-band weather radar developed at UPRM was deployed in Mayaguez (See Figure 3), a second commercially available X-band radar was also deployed at Aguadilla (northwest) donated by EWR at Saint Louis, MO. These two instruments are non-Doppler single polarized radars, but they have provided rain reflectivity measurements that have been compared to data generated by the Puerto Rico NEXRAD (TJUA), located about 150 km east from the west coast [Vega, 2007]. UPRM is also involved in the development of future CASA radars using solid state technology. Prototypes for an X-band phase shifter, microstrip antenna arrays, and power feeding networks were also completed at UPRM. Most of the circuit's fabrication

Figure 3 - X-band radar on UPRM's ECE Building

and testing was performed at UPRM thanks to the acquisition of microwave instrumentation through the NSF MRI: Acquisition of Microwave Instrumentation for the UPRM Radiation Laboratory (#9977178) granted in 1999 to Rafael Rodríguez Solís and José G. Colom, Co-PI, and PI of this proposal. The instrumentation and facilities provided by UPRM (anechoic chamber) are still fully operational and are an important part of any microwave frequency research performed at UPRM, around 26 MSEE and over 60 undergraduate students have completed or are currently working on their research with this instrumentation.

Background **-** Puerto Rico is a tropical Island located in the northeastern Caribbean Sea. Precipitation in this tropical environment is extremely irregular making precise weather forecast a major challenge. Precipitation in the Island is primarily affected by regions of relatively low atmospheric pressure imbedded in easterly waves during summer months and cold fronts during winter months. Mayagüez region is characterized by a wet bi-modal season during the summer and fall with severe rain and thunderstorms from low altitude weather systems that might cause significant damage depending on the intensity, and a relatively dry season during the spring semester that can be interrupted by an off-season tropical wave or a cold front from the north.

It is well known that there are some limitations associated with long-range radar rainfall estimation [Hunter 1996; Fulton et al. 1998; and Westrick et al. 1999], plus high and low radar reflectivity caused by mountainous region lead to underestimation or overestimation of rainfall [Klazura et al. 1999]. In the case of Puerto Rico, most of the forecast relies from data generated by TJUA. Due to the complexity of the terrain, this radar is placed at high altitudes, and in the case of Puerto Rico the antenna can be positioned in an elevation angle up to 0.5 degrees. The combination of these factors prevents the radar beam from sampling the lower portion of the atmosphere at far ranges. Using Mayagüez as reference, simple calculations that take into account the earth curvature shows that the first 1.5 km of the lower atmosphere are not sampled by TJUA, which causes significant under and over estimation of rain from the low altitude weather systems.

A range of mountains along the center of the Island (Cordillera Central) extends all the way to the west coast partially surrounding Mayaguez from the north, east, and part of the southeast. In addition there are three rivers (Guanajibo, Yagüez, and Añasco) in the area that flows into the Mayagüez Bay. Overflow of these rivers in the past has caused considerably property and human damage. Lower atmosphere and real time data that feeds hydrological basin models can then be used to predict river flows or flash flooding and create a warning alarm system that can potentially save life and property.

Weather Forecasting Alternatives for the Caribbean **-** Precise weather forecast of the tropics remains as one of the most challenging research topics in the scientific community. In addition, a combination with complex orography can make the problem extremely difficult if proper data is not available. The complex terrain with high intensity rain adds for high probabilities of flash flooding, mud slides, and river overflows in vulnerable zones. In densely populated areas people are exposed to all types of atmospheric related unwanted phenomena and an advanced alarm warning system that can save life and property is desirable. It is well known in the scientific community that in order to establish such a system, space and time high resolution data needs to be provided in real time. Since long-range radars present certain limitations that will not provide the desired data, a network of shorter range and higher resolution small radars is proposed for this type of environment. The network can be accommodated taking into consideration the terrain complexity and will provide high resolution data of the lower atmosphere. Radar data such as reflectivity and differential propagation phase is used to create desired products such as rain rate and wind speeds that are used for forecast and serve as input for hydrological models. Initial goals for the research activities to be provided by the proposed radar network are:

1. Optimization for deployment of the 3 radar units. While there are more than 3 possible locations for the deployment of the radars it is important to know which configuration will reduce rainfall rate estimation errors and other radar products due to the footprint overlapping of the weather scenario.

2. The rain rate, wind speed, and other products generated from the radar measurement needs development and continuous validation to comply with the conditions of the new environment. This could take a few years to fine tune.

3. Development of hydrological model that will take into account the slope inclinations, and soil type and will accept "real time" data from the radars to implement a warning alarm system. The low atmosphere and high resolution data should provide the proper input for the model. "Real time" intervals to update the radar products should also be examined.

4. The study of hurricane-generated micro-tornadoes and water spouts is another topic that can be developed as part of this research. Such systems have been observed in the west coast area, but have remained undetected by NEXRAD.

Radar Network in the West Coast of Puerto Rico **-** The terrain complexity and variability of the weather makes Mayagüez an ideal location for the three radar network that is proposed here. There are many dense populated cities in the World with similar orography and climate characteristics as those found in Mayagüez. For example, cities in Central and South America with similar conditions lack of even the benefit of having long-range weather radar monitoring their region. The successful deployment and operation of the Puerto Rico west coast radar network will present a realistic alternative to monitor the weather in these regions. The proposed radar network will consist of three dual polarized X-band Doppler radars. There are currently four locations that are under consideration to install the radars. Three of the locations are UPRM properties and two of them are ready for radar installation. Figure 4 shows a satellite picture of the west coast of Puerto Rico with "A", "B","C" and "D" identified on the map as the four potential radar locations, the distance between point "B" and "C" is approximately 35 km. The design of the system makes possible the integration of additional radars in the future. It is also evident that a radar range of approximately 20 km will provide the desired overlapping between footprints. Location "A" is in the top of the Electrical Engineering Building and is currently holding an X-band radar recently developed at UPRM (See Figure 3). Location "C" is UPRM property and it consists of a 50 ft tower holding a portable commercial X-band radar shown in Figure 5. Node "B" is also a location belonging to UPRM, this one is located in Cerro Las Mesas at an altitude of 1260 ft. This location provides an unobstructed view of Mayagüez town and beyond. This location is an old secluded building with a communication tower that once renovated could be used to install one of the radars.

Figure 4 - Locations for radar deployment in Puerto Rico's west coast

The last point ("D") is located in Mount Atalaya at an altitude of 900 ft. This mount basically blocks Mayagüez from the rest of the towns to the north, many TV and radio towers are located on the top of this mountain. A local TV station already offered space in a current unused tower to install one of the UPRM radars. It is evident from Figure 4 that by selecting points "B", "C", and "D" as the location of the radars, a larger portion of the west coast will be covered. Coverage overlap between adjacent radars will offer the best resolution in those particular areas. Areas without overlaping are more sensitive to signal extinction due to extreme rain and do not provide multiple radar data products. A second configuration could be achieved selecting locations "A", "B", and "D" in this particular configuration the three radars will overlap coverage over the Mayagüez region. This increases the resolution and increases the robustness and capabilities of the system. This configuration will also provide multiple radar products over the region where the three Mayagüez rivers been under consideration for the hydrological basin model are located. It is expected that the location in Cerro Las Mesas and Mount Atalaya will be selected since the high altitude minimizes radar blockage. The

Figure 5 - EWR in Aguadilla tower

Figure 6 - Cerro Las Mesas location in Mayaguez

selection of the third point will depend on simulation results expected to be completed before the construction of the radars begin.
This radar network will be based in the DCAS technology developed by the CASA ERC. The first testbed associated with the CASA project consisted of four radars similar to the ones proposed here. Preliminary results have shown a significant increase in data resolution and robustness of the system. The mountainous terrain and the need of lower atmosphere data makes this approach ideal for the Puerto Rico's west coast.

Research and Student Training Activities **-** This project will provide opportunities in a new area of research and research training through increase interaction between students and faculty from UPRM, CSU, UMass and the National Weather Service. It is of particular importance the hands-on training that faculty, graduate and undergraduate students from UPRM will have in the construction, operation, calibration, and eventually research activities derived from the data analysis of this network. The construction will include integration of areas in radar systems, meteorology, atmospheric science, hydrology, control systems, computer science (data management and software), and social sciences.

Participation of graduate and undergraduate students will be coordinated by the PI, José G. Colom and Dr. Sandra Cruz Pol. UPRM graduate students will be trained to develop the network by experts in the area at CSU, this activity will be coordinated by Dr. Chandrasekar from CSU. An attractive alternative for the graduate students is also that they will be able to spend a semester or two at CSU as regular graduate students and return to UPRM to continue their research. This is possible thanks to an MOU between CSU and UPRM where graduate students can complete a collaborative PhD while research can be performed at UPRM. Once the students are back in Puerto Rico to continue their research they will be supervised by Drs. José G. Colom and Rafael Rodríguez Solís. Weekly meeting will be scheduled with CSU with the video conference facilities available at both institutions. A similar MOU exist with UMass as well, and students will be trained in the development of the MSCDC of the radar network, this activity will be coordinated by Eric Knapp, collaborator from UMass. Other alternatives are Summer Internships for graduate and undergraduate students from UPRM at CSU and/or UMass. We anticipate that during the initial phase of the project up to 3 engineering graduate students will participate in the development of the network and five undergraduate students will also be involved in other aspects or the radar construction and deployment. Initial involvement of students will be coordinated via CASA administration at UPRM. The students participating will be involved in the development of the radar network, including the construction of the radars, calibration, operation, and data analysis. CASA is currently supporting 10 graduate students and is providing research opportunities to 5 undergraduate students during the semester. Since CASA is funded until 2013, they will partially support student participation in the project. Eventually graduate students will also participate in research activities including analysis of the data, development of hydrological models, and radar product fine tuning. It is expected that once the radars are operational, faculty and graduate students involved in weather related project around UPRM and other institutions will join research activities initiated by the radar network. Other sources of funding for undergraduate students exist from REU CASA and REU in Atmospheric Sciences from the Physics Department.

The proposed radar network will support activities that will bring research to the classroom through undergraduate research projects, seminars, and demonstrations. Introduction to Radar Systems, Microwave Engineering, and Antenna Engineering are courses where the radar system or a part of the system can be discussed. Other courses such as Microwave Remote Sensing and Active Remote Sensing: Weather Radars will benefit from demonstrations and data sets developed to retrieve radar products. Data sets from different case studies will also be developed for meteorological courses currently offered in the Physics Department. A module to be integrated to a current CASA course will also be developed. This course was offered last year as part of the CASA educational program and covers several topics related to the project including radar systems, antennas, remote sensing, data storage and management, and social sciences. We also expect the development and construction of the radar network will lead to a case study appropriate for the capstone design course in the area of Applied Electromagnetics. Dissemination of the result of this work will be done by ASEE and IEEE Education Society conferences and journals.

These institutions have successfully coordinated in the past, video courses to be taken by students from the different campuses. Courses in Meteorology from OU and Weather Doppler Radar Systems from CSU have been offered to UPRM students by experts in the area. The proposed network presents an excellent opportunity to develop similar courses in the area of Radar Network Technology in collaboration with CSU and UMass to make it available to all students via video conference.

Since over 95% of UPRM's students belong to underrepresented groups, the involvement of minority students, including women, in the development and operation of the network will be substantial. In particular, the percent of women in Electrical Engineering is one of the highest in the US. We expect a significant participation from women undergraduate and graduate students.

b. Description of Research Instrumentation and Needs

We are proposing to build a network of three dual polarized X-band Doppler radars that will work in a collaborative and adaptive fashion to optimize radar products such as rain rate and wind speed. A Managing System Control and Decision Center (MSCDC) serves as the heart of the network to provide monitoring, warning, and control of the system. The radars will be developed by UPRM students under the supervision of CSU and UPRM personnel. The MSCDC will be developed in collaboration with UMass. Proper configuration of the network is critical to minimize any error estimation from the products. This network of radars is the best alternative to sample the lower atmosphere in regions with complex terrain and irregular weather characteristics such as Mayaguez. This type of adaptive system has been successfully developed and tested in Oklahoma, but results of similar systems in tropical regions have not been reported in the literature. While there are several weather X-band radars commercially available in US and Europe, they are not appropriate to work in a network configuration such as the one proposed here.

Commercially Available Radars **-** Weather X-band radars are commercially available from companies such as: EWR in Missouri and Enterprise Electronic Corporation in Alabama. They are usually based in marine radar technology and are modified for atmospheric applications. The original purpose of the radar was not atmospheric, and modifications might not provide the desired capabilities for a weather system. Most X-band weather radars that are commercially available are sold as stand-alone units. Usually the antenna spins at a constant speed and does not have means to control elevation and/or azimuth angle which is essential to achieve adaptability in a multi-radar network. To keep the cost low, commercially available radars often lack either dual-polarization and/or Doppler features. Most of these units are integrated to an image-processing software, and access to the raw data is often restricted, limiting academic research. More sophisticated units including dual polarization and Doppler are also available, but are designed for long-range applications and operation is usually at lower frequencies to minimize atmospheric attenuation.

Rationale to Develop the Dual Polarized X-Band Doppler Radar Network **-** In addition of proven success of this technology in the CASA Oklahoma testbed, we decided to base the design of the network in a similar technology for the following reasons:

1. Due to availability of X-band components, X-band radars can be lower in cost and complexity when compared to higher frequency systems. Their size is also small compared to current NWS/FAA S-band radars.

2. High frequency radars such as X-band have smaller size, including the antenna, which makes it easier to control mechanically and allows faster antenna speeds.

3. Polarimetric radars make signal attenuation correction and rain rate estimation possible [Bringi and Chandrasekar, 2001], and also provide information from raindrop shape. This is specially important in highly-humid tropical weather.

4. Doppler features are required to measure wind speed and movement of rain bands. It is also used for filtering of undesired clutter.

5. Short range operation (such as the case of radar network) maintains high temporal and space resolution which is essential to measure variations of rain in tropical weather.

6. Measurements from lower atmosphere are possible providing information of rain rate closer to the ground which benefits the hydrological models.

It is important to address that while a single radar will measure reflectivity, Doppler velocity, spectrum width, differential reflectivity, and differential phase among other parameters, a single unit will not provide any overlapping, losing the advantage of multiple radar products. Probability of signal extinction from extreme rain events is higher with a single radar operation. A system of three radar units properly configured provides the following advantages:

1. Can be configured according to the complexity of the terrain to monitor the lower atmosphere.

2. High time and space resolution can be optimized by adaptively positioning the radar beams towards relevant meteorological events.

3. Rain rate measurements from different radars can be processed to increase or improve a parameters such as signal to noise ratio or high resolution.

4. Multiple radar looks from different angles provides improvement of the system by proving the consistency of measurement such as rain rate.

5. Multiple Doppler wind velocity provides mechanism to map the velocity vector within a storm, providing precise information of precipitation motion.

6. The system vulnerability for signal extinction due to attenuation is minimized.

7. Robustness of the system is increased. In extreme severe conditions, such as a hurricane, operation of the system might continue in the event that one of the units stops running.

Radar System Specifications **-** Key parameters for each radar are listed in Table 1 [Junyent et al. 2005]. The network is comprised of three X-band magnetron-based radars. The radar network will be configured in such a way as to maximize dual-Doppler coverage. Each radar is dual-polarized, with single and dual-PRF capability, and will be remotely configurable and controllable. They will have a parabolic antenna mounted on a pedestal capable of high speed acceleration to approximate the agility of a phase-array antenna. Each radar samples the received digital radar signals, and the Doppler moment data such as reflectivity and velocity are generated in real-time. The base variables include reflectivity, velocity, spectrum width, and the dual-polarization radar products.

Key System Parameters	
Operating Frequency	9.3 GHz
Wavelength	0.03 m 3.22cm
Antenna Diameter	1.2 m
Antenna Beamwidth	1.8 deg
Antenna Gain	38 dB
Maximum Radar Scanning Speed	35 deg/sec
Maximum Radar Acceleration	50 deg/sec^2
Maximum Range	36 km
Range Resolution	26 m
Effective Transmitted Power	12.5 kW
Average Transmitted Power	25 W
Dual Pulse Repetition Frequency	1.6 kHz, 2.4 kHz
Noise Figure	5.5 dB
System Losses	-20 dB
Mean Sensitivity	2.8 dBZ

Table 1 – Key Radar Parameters

Preliminary Results from Existing Equipment **-** Two X band stand-alone radars are located at Mayaguez (ECE Building) and Aguadilla and they are both FCC licensed for operation. The Mayaguez radar (called PR-1) was developed by UPRM students supervised by PI Dr. Jose G. Colom. A Raytheon MK-2 X-Band marine radar was modified by UPRM students to be used as an atmospheric sensor. The modifications were mainly to the antenna/spinner section and the data acquisition system, an internal calibration loop was also integrated to the radar hardware.

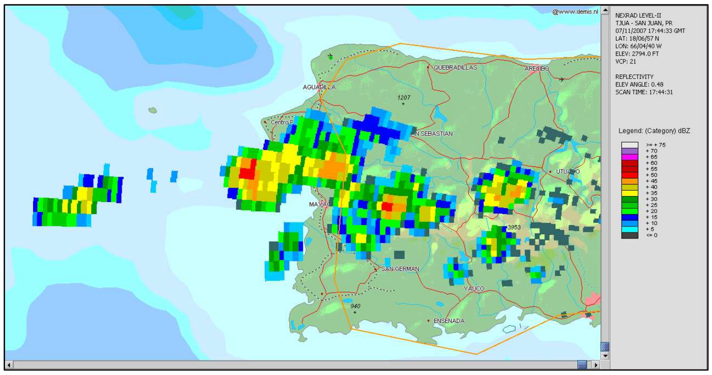

Figure 7 - NEXRAD data from 7/11/06 13:43:33

In July 11, 2006 data from a weather system moving from east to west across the Mayaguez area was sampled with the PR-1. The results were later compared to NEXRAD. Figures 7 and 8 are showing data from NEXRAD and PR-1 at about the same time. It is evident that the images show common areas where both radar systems had some similarities. These similarities confirm that there was weather activity at the same locations during the time span chosen [Vega, 2006]. Furthermore, it is noticed that PR-1's images show a higher level of detail regarding the features of the weather detected due to the better resolution, but lack of polarization and Doppler allows only reflectivity measurements to be possible.

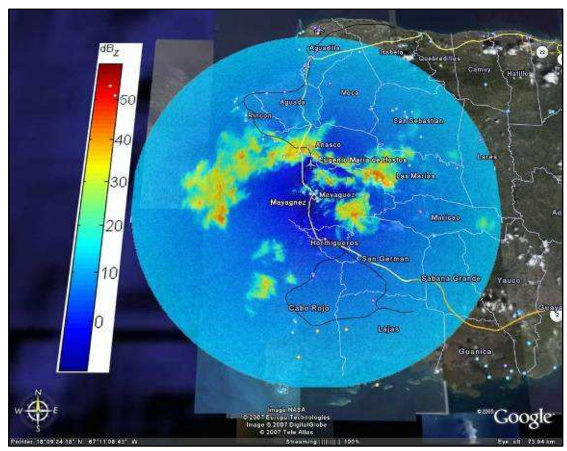

Figure 8 - PR-1 data from 7/11/06 13:43:58

The second radar was acquired through a donation of EWR, a radar company located at St. Louis, MO. Last summer, two graduate students had Internships at EWR and they were able to participate in field experiments and learn about the design and programming of this particular unit. One of the students is currently assigned to continue research activities with the PR-1, while the other one is assigned to the EWR radar. They are both supervised by the PI. The EWR radar is very user friendly and it can provide weather images, but access to the raw data is restricted. This radar is also a single polarization system and does not have Doppler capabilities. It is expected that access to the software will be granted promptly and access to the raw data will be possible, this will increase opportunities in research activities. Figure 9 shows a typical display view from this system. Besides

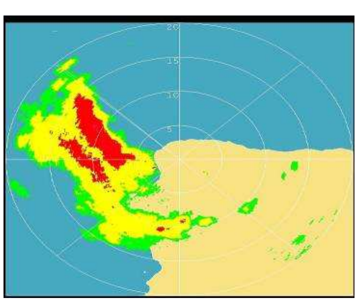

Figure 9 - EWR Radar display from a rain storm in the Aguadilla region.

preliminary data from both X-band radars located in Puerto Rico, data from the Oklahoma testbed is also available and discussed below. This data is a strong proof that the proposed network for Puerto Rico is the proper choice to monitor weather in a tropical environment. Figure 10 shows a fraction of the results from an early case study in August 16, 2006. The plots are a close-up from images covering larger regions. In [Brotzge et al. 2006] examination of the data from the radar network reveals much greater storm structure in time and space than can be seen from the NEXRAD imagery. Animated versions of the plots (not shown here) show rapid intensification and decay of storm cells, which NEXRAD cannot provide due to lower resolution and update times of 4-5 minutes. Brotzge also indicates that single cell development can be seen clearly with the radar network data and that NEXRAD data indicates some increase in reflectivity, but much less intense.

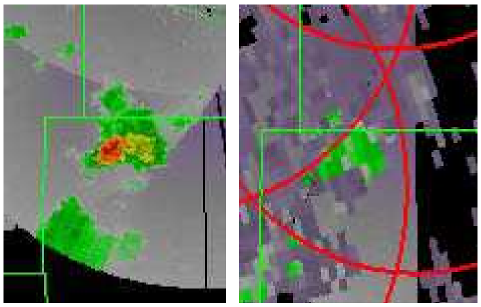

Figure 10 - Data from radar network (left) at 22:12:59 and NEXRAD (right) at 22:12:47

The good preliminary results obtained from the Oklahoma testbed and the advancements in radar technology at UPRM during the last few years (as reported here) will make possible the deployment of a similar system at Puerto Rico. Researchers from UPRM will work closely with experts in the area from CSU and UMass.

A licensed technician with experience in radar systems and trained and certified on tower installations will be hired strictly for the fabrication and deployment of the radar network. In addition, a Project Consultant strictly to help in the radar system development will be hired.

c. Impact of Infrastructure Project

In areas such as meteorology, atmospheric sciences, and radar engineering minorities are underrepresented compared to the US population. It is only a few years ago that a certificate in meteorology/atmospheric sciences under the Physics Department was established. Radar engineering courses were also recently added to the ECE MSEE curriculum and only one MSEE in radar engineering has been recently awarded (Fall 2006). While ECE does not have a PhD. Program, the PI and Co-PIs from this proposal are proud to inform that from about 26 students graduated with a MSEE in the last 8 years, at least nine are currently working in their PhDs in U.S. Institutions (4 in UMass, 2 in CSU, 1 in U Colorado, and 2 in MSU). With the CASA project, and other grants received by NASA and NOAA, research opportunities in this area have significantly increased. With the development of the radar network proposed here, it is expected that the number of underrepresented minorities in this area, especially Hispanics, will significantly increase. Through the UMass and CSU MOU in place, graduate students from UPRM will have the opportunity to pursue a Ph.D. working in research derived from the proposed work. The students will be exposed to state of the art technology and will need the radar network to accomplish all the research goals previously stated. The research activities derived from the radars will build upon the ongoing research infrastructure developed by CASA at UPRM. In support of CASA research, this project will help to establish an adaptive and collaborative network of radars in Puerto Rico that will be used to monitor the weather from the lower atmosphere. It will also support hydrological models currently under development by hydrologists associated to CASA and other NOAA projects.

Besides CASA, funding for the research initiatives will come from other ongoing or pending research support. The PI is pending as collaborator in a NASA proposal recently submitted and titled "Estimation of Internal Rainfall, Soil Moisture and Evaporation Variability within a Remotely Sensed Pixel", the Co-PI Dr. Sandra Cruz-Pol is also pending in a project to train Colombian engineers to establish a network of weather sensor. We also anticipate that once the network of radars is deployed and operational, such an asset will facilitate obtaining funding by state and federal agencies interested in protecting life and property from severe weather events. In summary, our team of scientists has access to experts in the area (CSU and UMass) through several years of collaboration previous to the CASA project. They also have developed experience in weather radar technology, microwave remote sensing, and related areas due in part to CASA and other NASA and NOAA collaborations. The network will give UPRM researchers a unique regional capability of densely sampling tropical weather that will contribute to assess their state. Also the proposed educational modules will give opportunity to student within and outside CASA to learn from a unique meteorological problem. Since 95% of the students at UPRM belong to an underrepresented minority group and about 30% of ECE students are female we expect a significant number of women participating in research activities at graduate and undergraduate level.

From preliminary results reported from similar systems, it is expected that accurate meteorological and hydrological models will be developed for tropical weather and will help to establish efficient management strategies to protect life and property. Similar programs can be developed for areas with the same tropical characteristics inside and outside Puerto Rico, serving as an alternative for other countries to deploy an efficient weather system.

d. Management Plan

The development and deployment of the radar network, and consequently is continuous operation requires a rigid management plan. The plan requires: experience in properly specify, ordering, and work with vendors from specialized parts to ensure a timely delivery of the components; expertise in radar technology, especially in such a new technology that includes adaptability and collaboration of radar units; and finally contribution from dedicated scientists and staff to conduct science once the system is in place.

The scientists involved in this proposal have collaborated for many years in different projects and they are experts in different areas encompassing the proposed work. Their dedication in developing this new technology will increase motivation of users exposed to the new technology.

The PI is a leader in microwave engineering and during the last few years has been working in the development of X-band radars. The PI Sandra Cruz Pol has extensive research experience in microwave remote sensing of clouds and rain, she is also a leader in outreach and education (K-12 and teachers) and she is currently involved in global warming outreach activities. Dr. Rafael Rodriguez Solis is an expert in microwave antennas and he is currently involved research concerning solid state radars. Dr. Chandrasekar is a World's expert in Polarimetric Weather

Radars and related areas, and is one of the only people with knowledge in radar network adaptability and collaboration. Eric Knapp is a research scientist from UMass and he has been extensively involved in the design, fabrication and testing of microwave radars.

Dr. Jose Colom will be the person responsible of the deployment of the network in Puerto Rico and will supervise the radar construction in UPRM. He will work closely with Dr. Chandrasekar who will provide training to UPRM students and faculty to build the radars. Dr. Rafael Rodriguez Solis will also supervise radar construction in Puerto Rico and will work closely with CSU collaborators to calibrate the radars. Dr. Sandra Cruz Pol will work closely with Dr. Chandrasekar to select the optimum deployment configuration she also will be responsible for preparation of radar sites. Eric Knapp will coordinate MSCDC development with Jose G. Colom. Eventually radar testing and validation will be performed by all the PI's. They will also choose an interdisciplinary team of students that will be trained to participate in the different phases of development. It is expected that undergraduate, MS, and PhD level students will be part of the team.

Timeline

Time (from start of project)	*Task*	*Responsible PI*
3 months	*Complete and verify Radar specifications*	*Colom, Chandrasekar, Rodriguez*
6 months	*Deployment Configuration*	*Cruz-Pol, Chandrasekar*
9 months	*Delivery of all parts*	*Colom, Rodriguez Solis*
9 months	*Training of UPRM faculty and students at CSU*	*Chandrasekar*
12 months	*Construction of first radar start*	*Colom, Rodriguez-Solis, Chandrasekar*
18 months	*Radar site preparation done*	*Cruz-Pol*
24 months	*Deployment of radar#1 in site #1*	*Colom*
27 months	*Testing and validation*	*Colom, Chandrasekar*
30 months	*Calibration*	*Rodriguez-Solis, Chandrasekar*
36 months	*Deployment of radar#2 in site #2*	*Colom*
36 months	*Deployment of radar#3 in site #3*	*Colom*
36 months	*MSCDC Development*	*Colom and Knapp*
42 months	*Testing and validation of 3 radar network*	*Colom, Chandrasekar*
48 months	*Calibration of 3 radar network*	*Chandrasekar, Rodriguez-Solis*
54 months	*Fine Tuning*	*Colom, Chandrasekar,*
60 months	*Fully functional and available for interested users*	*Colom*

Table 2 – Timeline

The timeline indicates that radar parts should be starting arriving 9 to 10 months after placing the order. By that time students and faculty have been trained at CSU and should be ready to start working in the construction of the first radar. It is expected that after testing and tuning, the radar should be ready for deployment in 24 months. The validation, testing, and calibration of the first radar will take several months, but it is expected that the next two radars will be deployed in a quickly manner. Enough time has been given to test, validate, and calibrate the 3 radar network, but with the experience of CSU and UMass personnel the system might be fully functional before the 60 month goal. An estimated cost for one radar is shown in the table below. The cost does not include the integration as a network. See budget justification for details.

Antenna	1	**15,000.00**	**15,000.00**
Magnetron	1	**625.00**	**625.00**
HV Modulator and Power Supply	1	**15,000.00**	**15,000.00**
Circulator	4	**156.25**	**625.00**
Crossguide Directional Coupler	2	**500.00**	**1,000.00**
TR Limiter	2	**406.25**	**812.50**
SPDT Switch	2	**2,375.00**	**4,750.00**
Low Noise Amplifier	2	**1,500.00**	**3,000.00**
100 MHz Master Oscillator	1	**2,456.25**	**2,456.25**
Phase Locked Oscillator	1	**1,562.50**	**1,562.50**
RF filter	2	**625.00**	**1,250.00**
Mixer	2	**437.50**	**875.00**
Coax X-band Power divider	2	**375.00**	**750.00**
Noise source	1	**1,500.00**	**1,500.00**
Coax X-band Direction Coupler	2	**625.00**	**1,250.00**
Assorted Waveguide Components	1	**7,500.00**	**7,500.00**
Connectors, cables, assorted electronics	1	**10,000.00**	**10,000.00**
IF down conversion board	1	**3,750.00**	**3,750.00**
Radar Subtotal			**71,706.25**
Azimuth Pedestal	1	**150,000.00**	**150,000.00**
Elevation positioner	1	**12,500.00**	**12,500.00**
Radar enclosure	1	**8,750.00**	**8,750.00**
Radar mounting frame	1	**6,250.00**	**6,250.00**
Power Supply	1	**2,500.00**	**2,500.00**
Radome Base and mounting frame	1	**8,750.00**	**8,750.00**
Radome	1	**28,625.00**	**28,625.00**
Mechanical Subtotal			**217,375.00**
FPGA board	1	**25,000.00**	**25,000.00**
Radar-PC	1	**2,500.00**	**2,500.00**
Control PC	1	**3,750.00**	**3,750.00**
SNS-PC	1	**8,750.00**	**8,750.00**
Ethernet hardware	1	**3,125.00**	**3,125.00**

Table 3 – Estimated cost for parts of one radar unit

Once the network is completed, we believe it will be a unique regional facility. We will make it readily available to users in the research community. The system will also be available for NWS to help for local weather forecast. Local, private and federal agencies will also have access to the data. A fee structure, to be determined, will be charged to outside users to cover the cost of equipment deployment and having a team of UPRM personnel (tehcnician and graduate student) operating the equipment. It is expected that a system like this could be used as a kick-off to establish an Atmospheric Research Center for Western Puerto Rico funded by UPR (similar to Red Sismica of Puerto Rico).

We already have a strong demonstrated and funded need for such an asset within our immediate group of PIs but we believe that dissemination of our results in local engineering and technical publications, conference and journal papers will attract new users and raise interest from companies and universities in the continental U.S. and the Caribbean to engage in collaborations involving weather, meteorology and applied electromagnetics fields.