
AWRA 2010 SUMMER SPECIALTY CONFERENCE
San Juan, Puerto Rico

August 30– September 1, 2010

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CALIBRATION AND VALIDATION OF CASA RADAR RAINFALL ESTIMATION

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ABSTRACT: Reliable and consistent weather data is needed to evaluate potential climate change and be able to take informed decisions in order to lessen the negative effects of natural disasters. Events like flash floods can be predicted by using models, however these require current and consistent rainfall information. The Collaborative Adaptive Sensing of the Atmosphere (CASA) program at the University of Puerto Rico-Mayaguez is currently working with compact and low cost radars to estimate rainfall in western Puerto Rico. These radars provide very high-resolution rainfall information; however, this method requires validation and calibration to be useful for monitoring weather events. For this purpose, a 28 rain gauge network in a 16-km² area near the radar location was used as ground truth measurements. Preliminary results indicate that the CASA radar is over-estimating total storm rainfall. Various rain events were compared to the radar rainfall estimates and a mean bias correction factor of 0.8 was developed for total storm rainfall.

KEY TERMS: radar rainfall estimation; rain gauge; remote sensing; weather radar; Puerto Rico.

INTRODUCTION

Radar has been used extensively for weather applications in recent years (Bringi and Chandrasekar, 2001); therefore, validation of these radars has always been an important aspect of their implementation (Taffe and Kucera, 2005). Although radar validation is a recurring topic, the radar that has been validated in this study is not the standard weather radar normally used. The objective of this study is to validate the use of compact Off-The-Grid radar (OTG) in western Puerto Rico. The use of the radar will be important in future research where on-demand weather data is needed. Also, it will provide more accurate data than the National Weather Service's NEXRAD located in Cayey, PR, since this OTG radar is located in the Mayaguez area, and consequently, errors related to Earth curvature and the topographic blockage are eliminated. To this purpose, commercial X-band marine radars were modified for weather applications and adapted to work as OTG (Pablos et al. 2010). The radar was calibrated at the CSU-CHILL National Weather Radar Facility in Fort Collins, CO. Afterwards, this radar was installed at the University of Puerto Rico – Mayaguez Campus (UPRM), and named OTG1. Data was compared with ground truth measurements from selected rain gauges associated with a dense network of 28 rain gauges in a 4 km x 4 km area located about 2 km east of the UPRM campus. These rain gauges are tipping bucket type and set to record data every ten minutes for up to 48 days.

TECHNICAL APPROACH

In this study three months of rainfall data collected from the rain gauge network has been used to validate data obtained from the OTG1 radar. The three months chosen for comparison were April, May and June 2010. Figure 1 shows the dense network of rain gauges in the Miradero area of Mayaguez, PR, which provides nearly continuous spatial sampling of rainfall from 2-6 km from the radar location.

Rain Gauges

The rain gauges used in this study are manufactured by Spectrum Technologies Inc. in Plainfield, Illinois. These are self-emptying tipping bucket rain gauges with a data logger. The data logger records each tip of the bucket as 0.3 mm of rainfall. Rainfall is recorded as the total accumulated rainfall during a set interval of time. The interval may be set to 1, 5, 10, 15, 30, 60, or 120 minutes. The set interval will determine how long the logger can operate. The logger has a red LED, which flashes every 2 seconds to indicate that the logger is operational. A CR2032 3.0V battery supplies power to the logger and according to the manufacturer should be replaced every year.

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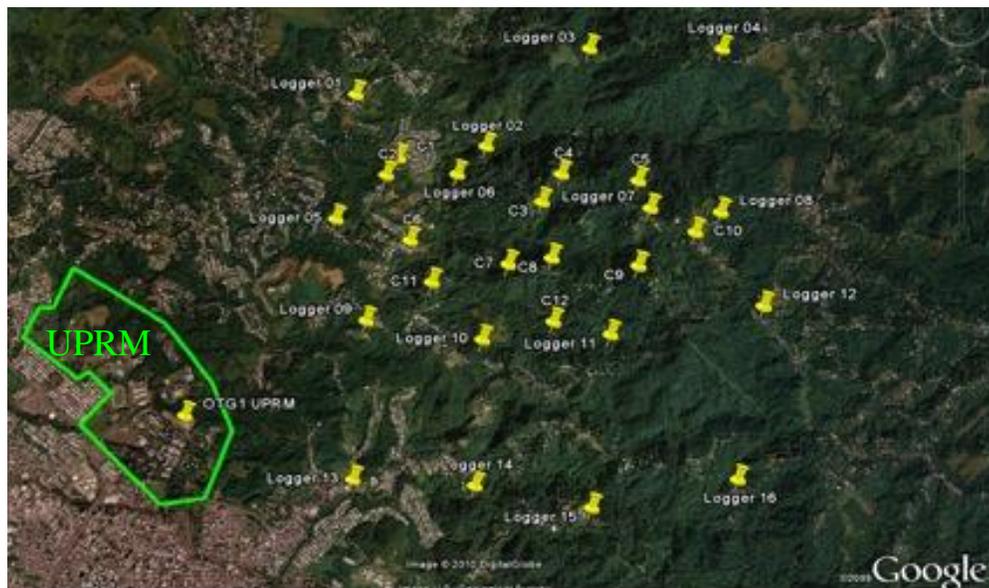


Figure 1: Rain Gauge Locations near the University of Puerto Rico –Mayagüez Campus (UPRM).

During the summer of 2006, 16 rain gauges were installed in the Miradero area of the Municipality of Mayagüez, Puerto Rico about 2 km east of the Mayagüez Campus of UPRM (UPRM NOAA CREST, 2009). The locations for the rain gauges were chosen by looking at a 4 km x 4 km GOES (Geostationary Operational Environmental Satellite) pixel to determine rainfall variability within one satellite pixel (Harmsen et al., 2008). The chosen pixel was subdivided into 16 sub pixels of 1 km x 1 km resolution and rain gauges were installed as close as possible to the center of each pixel. Most of the rain gauges were installed on private properties; therefore permission had to be obtained from the owner for the installation as well as for future monthly visits. These groups of rain gauges were named Loggers 01 through 16 in order from west to east and north to south (left to right and up to down).

A group of 12 additional rain gauges were installed during the summer of 2007 in the central area of the GOES pixel. These were named C1 through C12. These data will also be used to better understand the local sub watershed present in the area, for a flood forecast alarm system currently being developed at UPRM.

At present, 25 of the 28 total rain gauges are operational. Two of the non-operational rain gauges are currently missing. The other rain gauges have been non-operational due to lack of access to the area where the rain gauge is installed. The time interval of the data loggers is set at 10 minutes for a total capacity of 48 days of rainfall data. The batteries run out rather quickly in many rain gauges. According to the manufacturer the battery should last one year, yet currently they are lasting at most 4 months. For this reason the rain gauges are visited once a month for data download and equipment maintenance.

OTG1 Radar

A Furuno model 1934C-BB marine radar was modified for weather applications and adapted to work with off-the-grid power. The radar operates at 9.41 GHz and has a peak power of 4 kW. The fan beam antenna provided by the manufacturer was switched out for a parabolic dish reflector to reduce clutter. The parabolic dish has a 3.8° beam width and a 32.4dB gain. It also has an external adjustment mechanism, which is used to vary the elevation angle (see figure 2). The radar antenna motor rotates at 26 rpm, however, data is averaged every ten scans and outputted every 3 minutes. A digitizer is used to acquire the heading pulse, bearing pulse, trigger pulse and video signal. Afterwards, the data is processed and organized to obtain reflectivity measurements in dBZ and generate the PPI plot (see figure 3).

The OTG radar was outfitted with a solar power system designed to provide power for eight hours of operation on a full charge. Two 12V gel batteries rated at 97.6Ah provide power for the radar, which are in turn powered by two 12V solar panels delivering up to 85W, all controlled by a charge controller. An inverter is used to provide power for the radar's Windows XP platform computer, which uses a low power consumption Intel Atom motherboard.



Figure 2: OTG1 Radar

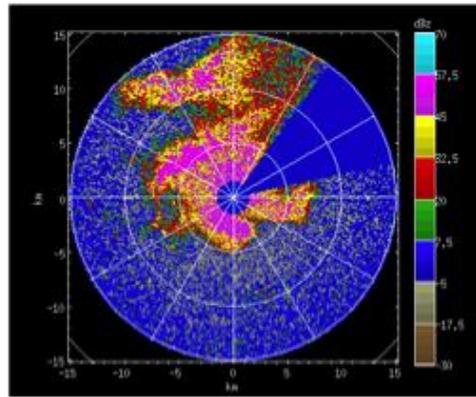


Figure 3: PPI plot OTG1 (15 m resolution)

Currently, the OTG1 radar is set to record data every three minutes. The radar covers a radius of 15.36 km, which equals a total coverage area of 741.1947 km². For each spin, the radar takes measurements every 0.087891° for a total of 4096 steps (4096 x 0.087891° = 360°), and for each of these steps, 1024 samples are taken every 15m (1024 x 15m = 15,360m = 15.36 km). The data obtained is of high resolution and generates a 1024x4096 matrix.

Comparison Procedure

To compare the rain gauge data with the radar, the rain gauge locations were located within the radar plot and output matrix. This was done by using Geographical Information System (GIS) software. The coordinates of the radar location and the rain gauges were input into the program to determine each rain gauge’s distance from the radar and also the bearing of its location relative to the radar. Each of these bearings were converted to a number usable in the output matrix by the following formula:

$$\text{Bearing (in degrees)} \times (4096/360^\circ) = \text{step in which the rain gauge is located} \tag{1}$$

The distance from the radar to each of the rain gauges was also converted to a number useable in the matrix, in this case:

$$[\text{Distance from radar (in km)} \times (1000\text{m} / 1 \text{ km})] \div 15 = \text{sample in which the rain gauge is located} \tag{2}$$

In order to make a successful comparison we must look for the result at the following coordinates in the matrix:

$$(\text{Step where rain gauge is located, sample where rain gauge is located}) = \text{dBZ for gauge location} \tag{3}$$

Further processing requires that the radar data be converted to the same units as the rain gauge data (rainfall in mm/hr or rain rate) by the Rosenfeld Tropical formula (Baquero et al., 2006) relating reflectivity (Z) and rain rate (R):

$$Z = 250 R^{1.2} \tag{4}$$

Comparison Automation

To make the task of comparing rain gauge data with radar data more automated, a MatLab program (www.mathsoft.com) was developed. The MatLab program (rain_rate.m) converts the raw radar data into dBZ and afterwards into rain rate (mm/hr). After converting the data, the program takes the date of the radar file and creates a matrix that displays the date in each column and the rain gauge location readings for that date under that column. It takes all available files, and compares each data set of each rain gauge with the radar data pixel corresponding to its location. The program does this for all available radar data files. Plots are generated in which the rain rate can be seen along the range of the radar, and then compares the values of the radar data pixel corresponding to the rain gauge and the value collected with the rain gauge.

Storm Identification

Storms were identified for the three chosen comparison months by creating a 3-month daily report from each rain gauge data file. For the purpose of this study, a storm is a medium to high intensity rainfall event lasting close to an hour or more. Each report was manually inspected and days of high rainfall were identified. After identifying the day of the rainfall event, the rainfall measured in each rain gauge was inspected and storms were identified.

RESULTS AND CONCLUSIONS

Through this study we have obtained our best datasets during the months from April 2010 to June 2010. The OTG1 was working during these months for specific rainfall events and the rain gauge network was operational for the full duration of the three-month period. Comparisons of four storms were performed and the results are plotted for selected rain gauge locations. Figure 4 presents a comparison for the four storms. Figure 5 presents a 1:1 plot of measured and estimated rainfall for individual storms. The measured and estimated (radar) data reveal the least agreement for storm 4, and the greatest agreement for storm 3. Figure 6 presents the 1:1 plot for measured and estimated rainfall for all storms combined. The coefficient of determination for the uncalibrated data is quite low ($r^2 = 0.3036$). Figure 7 presents a table showing measured and estimated total storm rainfall (average per gauge), radar minus measured total storm rainfall, and a mean bias correction factor for each storm (rain gauge rainfall divided by radar rainfall). The overall mean bias correction factor is 0.8 (standard deviation = 0.07). Figure 8 shows a Plan Position Indicator (PPI) plot image from the radar on June 28th at 3:30pm during a storm.

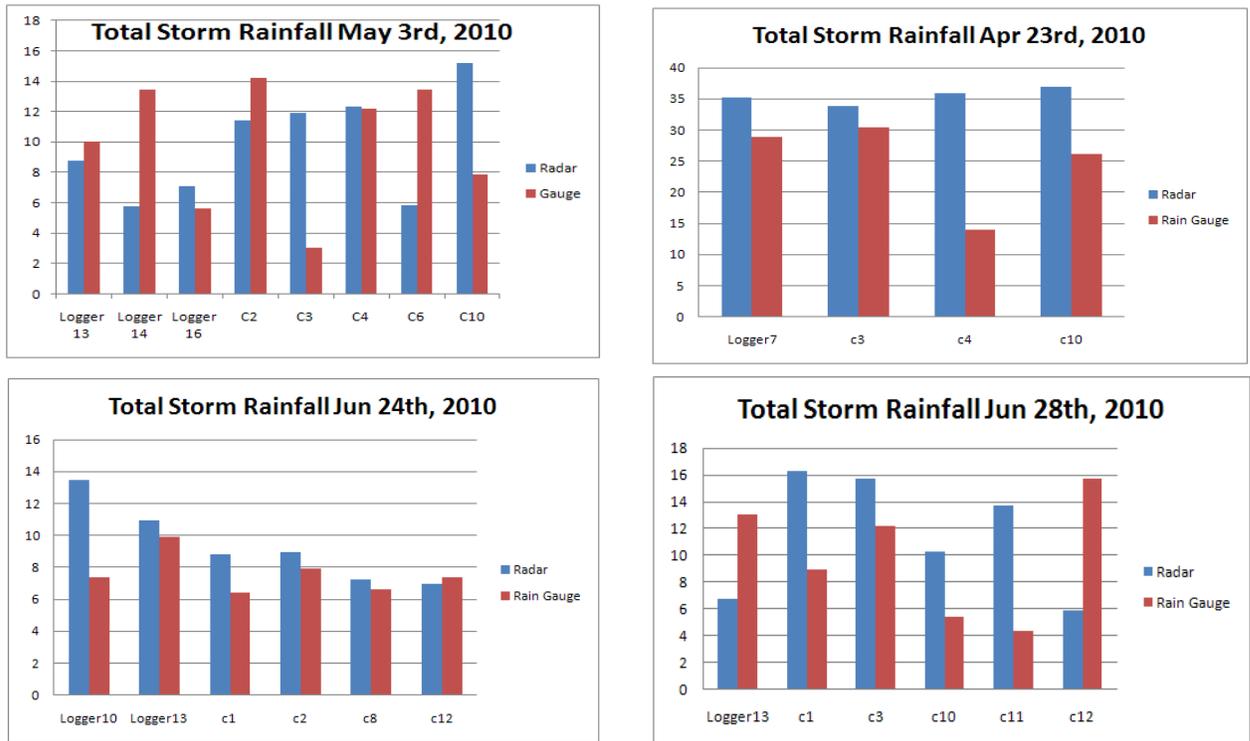


Figure 4: Comparison for each storm showing Radar (blue) vs. Rain Gauge (red).

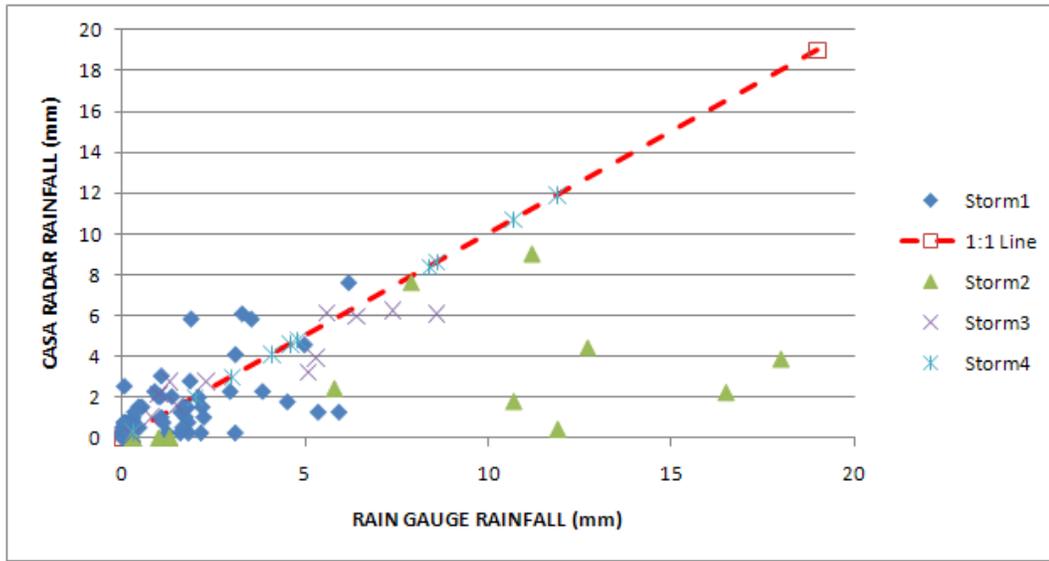


Figure 5: 1:1 plot of measured and estimated rainfall for each storm

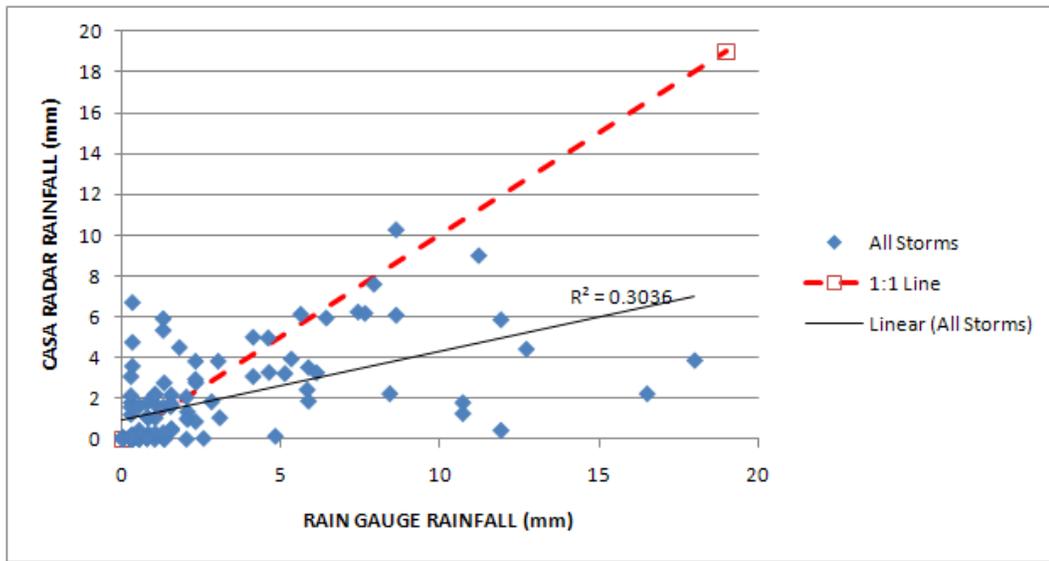


Figure 6: 1:1 plot of measured and estimated rainfall for all storms

| STORM NO. | DATE | NUMBER OF GAUGES USED | GAUGES (mm) | RADAR (mm) | RADAR - GAUGES (mm) | BIAS CORRECTION FACTOR |
|-----------|-----------|-----------------------|-------------|------------|---------------------|------------------------|
| 1 | 3-May-10 | 9 | 10.29 | 12.39 | 2.1 | 0.83 |
| 2 | 23-Apr-10 | 4 | 99.5 | 141.96 | 42.46 | 0.70 |
| 3 | 24-Jun-10 | 6 | 45.6 | 56.41 | 10.81 | 0.81 |
| 4 | 28-Jun-10 | 6 | 59.6 | 68.63 | 9.03 | 0.87 |

Figure 7: Table comparison for all storms

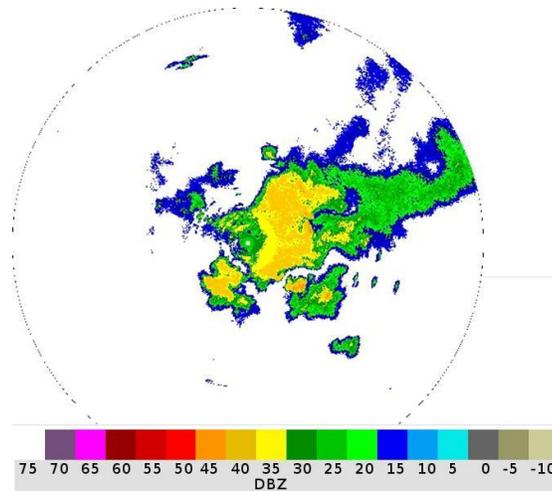


Figure 8: PPI plot of radar reading during a storm on June 28th, 2010.

Some differences between rain gauge and radar estimates may be due to various factors including overhead obstruction of the rain gauge and the rain gauge not being positioned completely level. The rain gauges were tested during June and are currently in the process of being retested to ensure that they are correctly calibrated. An influential factor on radar readings is that the radar is currently showing clutter in its surrounding area out to approximately 2 km, where some rain gauges are located. The CASA program is working on positioning the OTG1 radar in a new platform, which will provide it with a higher elevation and less clutter.

FUTURE WORK

Retesting the rain gauge network will lead to further radar and rain gauge data comparisons. After further validation of the OTG1 radar it will be useful for validating the GOES Multi-Spectral Cloud-Patch-Based Rainfall Algorithm over western PR, currently being developed by UPRM NOAA-CREST. This in turn achieves the NOAA-CREST Hydro-Climature Research goals of:

- Developing satellite multi-sensor rainfall retrieval algorithms and merging model estimates with ground truth measurements to improve quantitative precipitation estimation (QPE).
- Validating remotely sensed rainfall products for improving their retrieval algorithms.

ACKNOWLEDGMENTS

This work is supported by NSF (grant 0313747) and NOAA-CREST (grant NA06OAR4810162). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect those of NOAA and NSF.

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