FLOOD ALERT SYSTEM USING RAINFALL FORECAST DATA IN WESTERN PUERTO RICO

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ABSTRACT

The Western Puerto Rico area is subject to flooding due to sudden, extreme rainfall events, some of which fail to be detected by NOAA's NEXRAD radar. The use of new radars with higher spatial resolution and covering the low atmosphere are vital for flood forecasting efforts, and for studying and predicting atmospheric phenomena. Recently the University of Puerto Rico in Mayagüez initiated investigations using two (2) types of these radars, Off-the Grid (OTG) and TropiNet (RXM-25), respectively, in the Mayagüez Bay Drainage Basin area. This is the first time that such radar technology will be used for hydrologic analyses and specifically for rainfall forecasting in Puerto Rico. The forecast analysis will be made using time series with autoregressive methods and selecting the stochastic model parameters most appropriate for an optimal prediction; with the radar results, a distributed hydrologic model (*Vflo*™) is used to obtain the spatial distribution of flooding depth.

Index Terms— Hydrological models, meteorological radar, radar rainfall measurements.

1. INTRODUCTION

The use of the short-range X-band radars (OTG and TropiNet) in western Puerto Rico provide higher spatial/temporal resolution and better atmospheric information in the lower atmosphere than the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) radar NEXRAD (Next-generation Radar), which is subject to land curvature effects, blockage by mountains due to its location and has a lower spatial resolution (*Trabal* et al. 2011, *Cruz-Pol* et al., 2011) (Figure 1). The NEXRAD radars can provide information that can help mitigate disasters caused by flash floods. Errors can occur with the methodology for observations far from the radar, where the earth's curvature limits the observation of the lower atmosphere, below 10,000 feet or 3 kilometers (called the gap) above sea level for Mayagüez area and nearby towns (*McLaughlin* et al., 2008). At these locations, NEXRAD cannot "see" if raindrops are forming within the gap, resulting in a different rain rate than other radars which can measure the lower portion of the cloud (e.g., OTG and TropiNet).

In the TropiNet radar, the rain rate equations can be selected and changed and its characteristics like azimuth and elevation angles can be manipulated as well. In Puerto Rico the rain rate equation used for the Tropinet radar is the tropical equation with a threshold reflectivity (Z) of 53dBZ; Z values above 53 dBZ are assumed to be hail and are not considered for this region.

Another difference between NEXRAD and TropiNet radar is that NEXRAD has Doppler capabilities, providing information on cloud motion, and TropiNet has Polarimetric capabilities, which gives information on precipitation type and rate. Polarimetric radars refer to dual polarization radars which transmit waves that have horizontal and vertical orientations. The horizontal wave provides a measure of horizontal dimension of the cloud and rainfall and the vertical wave provides a measure of particles size, shape and density, characteristics which make it possible to obtain rain rate values more successfully than those without double polarization.

Using the TropiNet radar data and a hydrologic model, it is possible to determine the precipitation and runoff from specific watersheds and define zones with higher probabilities of flooding. It is also possible to develop short-term rainfall forecast models, which can be integrated within the hydrologic model prediction. The goal of this research is to develop a prototype real-time flood forecast alarm system for the Mayagüez Bay Drainage Basin (MBDB) using a temporal stochastic (auto-regressive) model, capable of forecasting rainfall and flooding one-hour in advance.

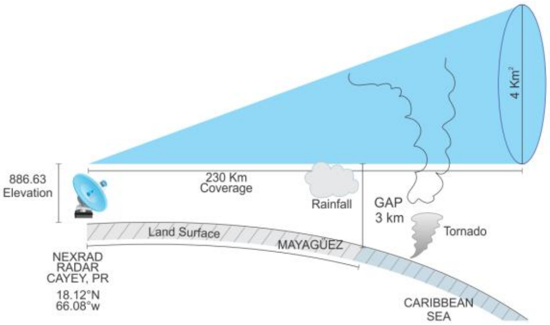

Figure 1. Long range problem with NEXRAD. The figure does not include topography of the land surface.

2. RADAR RAINFALL ESTIMATION AND PRODUCT

The National Weather Service is in charge of providing weather, hydrology, and climate forecasts and warnings for the United States, including Puerto Rico and the U.S Virgin Islands, working with a network of 159 high resolutions Doppler weather radars, commonly referred to as NEXRAD (Next-Generation Radar). This radar, located in Cayey, Puerto Rico, measures reflectivity to 1km by 1 degree resolution to a distance of 460 km and detects precipitation and atmospheric movement or wind. The technical name for NEXRAD is WSR-88D, which stands for Weather Surveillance Radar, 1988, Doppler (*National Climatic Data Center*, 2012).

In March 2012 the first of three TropiNet radars was successfully installed in Cornelia, Cabo Rojo. The others will be installed in Lajas and Isabela. Its name is RMX-25 radar, but is also referred to as TropiNet. The radar is designed to cover a range between 30 and 50 km at very high sampling resolution (60 x 60 meters) and offer state-of-the-art radar data products allow the radar beam to measure reflectivity close to the ground, overcoming the shadow effect of the Earth's curvature, while maintaining high range and azimuth. The RXM-25 is prepared to operate as a single radar unit or as radar network, allowing both manual and automated control and the radar allows a motion over the whole hemisphere, working with the X-band frequency which is higher than the traditional radar frequencies at S-band, making the measurements of rainfall more accurate (see Figure 2).

It also uses a low operating cost magnetron transmitter, capable of delivering up to 12 W of average power per polarization channel. The RXM-25 is designed for easy access and maintenance, all of its signal processing and radar control software runs on a single server.

Figure 2. RXM-25 -(TropiNet Project).

3. STUDY AREA

The study area, which encompasses the MBDB, is 819.1 km^2 in area (*Rojas González*, 2012) and is located in western Puerto Rico (Figure 3). The watershed also has three (3) important water bodies: Rio Grande de Añasco, Río Guanajibo and Río Yagüez. The area includes twelve (12) municipalities: Mayagüez, Añasco, Las Marías, San Sebastián, Lares, Maricao, Yauco, Adjuntas, Sabana Grande, San Germán, Hormigueros and a part of Cabo Rojo.

The climate of the study area is considered humid tropical. The average annual rainfall at the Mayagüez Airport is 2,166 mm. The amount of rainfall varies considerably throughout the study area. Most of the rainfall occurs during the months of May through November with 1,809 mm on average. The months of January through April are considered the dry season with 357 mm rainfall on average. Along the west coast of Puerto Rico, the sea breeze effect carries wet air from the Mona Channel eastward, converging with the Trade Wind and resulting in intense convective rainstorms almost every afternoon within the MBDB during the wet season (*Jury* et al., 2009).

Figure 3. Puerto Rico Island and Drainage Basin**.**

4. HYDROLOGIC/INUNDATION MODELING

The most common numerical methods used for this type of model are the finite difference or finite element methods. An example of a numerically distributed model and the one that will be used in this research is *Vflo*, developed by *Vieux and Vieux* (2002). Several hydrologic studies in Puerto Rico have utilized the Vflo model, including *Rojas González* et al. (2010) and *Rojas González* (2012). *Vflo* uses radar rainfall data as hydrological input to simulate distributed runoff and is based on Geographic Information (GIS) data.

Vflo provides high-resolution, physics-based distributed hydrologic modeling for managing water from catchment to river basin scale. The prediction of flow rate and stage can be made in every grid cell in a catchment, river or region, and the output is integrated with the *Vflo*-Inundation-Analyst module. The Vflo-Inundation-Analyst module along with Digital Elevation Model (DEM) data is used to show the extent of flooding superimposed onto a land map. An example of the inundation map is presented in Figure 4 using data from a storm that occurred within the study area on October 12, 2005.

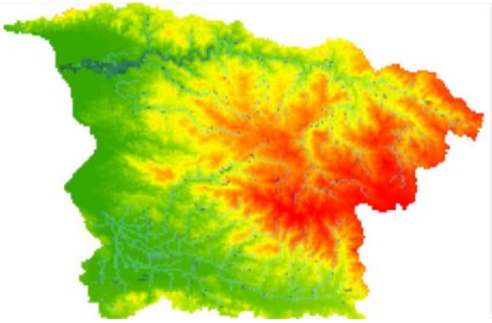

Figure 4 . Inundation Analyst results for the MBDB for a storm on October 12, 2005 (50 m resolution). Topographic variation is shown in the map. Flood inundation can be observed along several of the rivers. The width of the rivers (blue) represents the degree of inundation.

5. STOCHASTIC MODEL FORECAST OF RAINFALL

In places where the flooding for precipitation is sudden, the study of the mathematical modeling of precipitation is needed; this being one of the most significant themes in hydrology.

The possibility of modeling frequent events, with the purpose of determining values of precipitation in advance, is referred to as “now casting”. Now casting facilitates warning and evacuation of flooded areas in advance, however, now casting is subject to problems related to the short-term prediction of rainfall. In Puerto Rico the most common type of rainfall is convection rainfall, occurring in regions where the ground is subject to radiation heating. This is why areas such as the Tropics experience heavy rainfalls with short duration most afternoons *(Jury* et al., 2009). Under such circumstances, it is necessary to have efficient simulation models, which produce reliable short-term forecasts of rainfall.

Some forecasting models used for precipitation, such as *Burlando* et al. (1993) and *Salas* et al. (1980), have used stochastic models for prediction. *Burlando* et al. (1993), assumed that hourly rainfall follows an autoregressive moving average (ARMA) process. According to *Salas and Obeysekera* (1992), forecasting hydrologic variables is an important step in the planning and operational analysis of water resources systems. The process is generally composed of six main stages, (1) Identification of model composition, (2) Identification of model type, (3) Identification of model form, (4) estimation of model parameters, (5) testing goodness of fit of the model, and (6) evaluation of uncertainties. Numerous stochastic models are proposed in the literature and include models of temporal and space-time prediction.

The model of temporal prediction is the type of model being studied in this investigation, Given a set points in space, the rainfall is analyzed at the specific points with time as the independent variable. The random process is characterized by a domain whose elements constitute a set of a priori known points regularly spaced along the time axis; in this case it is possible to speak of a stochastic process autoregression (AR).

In this study, the time series of precipitation depth in every pixel selected within the drainage area are well suited to be interpreted through stochastic models (Figure 5). The stochastic process has two (2) variables, the current depth H(t) and the previous depth H(t-n) that are functions of the time (t). The function time is discrete with cumulative rainfall selected each ten minutes for input into the hydrologic model *Vflo* using TropiNet data. At least fifteen storms (15) have been analyzed since 2012.

With the cumulative rainfall depth data, it was possible to derive a linear relationship between cumulative depth from prior measurements and the current depth, expressed as H(t-i) and H(t), respectively. The general relationship between them can by modeled by the simple linear equation:

$$Y = a_0 + a_1 X$$

$$R^2 = 0.4844$$

where Y is H(t) and X is H(t-i). After evaluating numerous storms, it was possible to determine that between t-2 and t-3 time steps is the minimum number necessary to predict the next hour of precipitation in each pixel. The coefficient of determination was obtained from the data for the storm of the October 1, 2012.

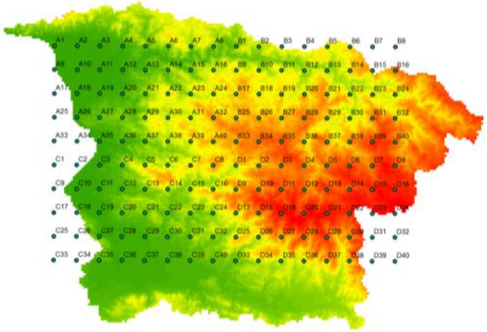

Figure 5. Mayagüez Bay Drainage Basin Location of every pixel Analyzed. Colors represent variations in topographic and the points are the pixels

Recently work has focused on the mathematical background associated with the two steps for forecasting rainfall: the first is analyzing available data to develop a probabilistic distribution, referred to as the variable height, and the second step is to apply an autoregressive model plus a nonstationary component to the available data.

6. CONCLUSION

This paper describes work in progress on a flood alert system using rainfall forecast data in western Puerto Rico. The system relies on estimates of rainfall from the RMX-25 radar, also referred to as TropiNet. The radar system has several advantages over NOAA's NEXRAD radar, including, very high spatial resolution and its ability to sense rainfall in the lower atmosphere, where much of the convective precipitation develops within the study area. Short-term estimates (e.g., 1-hr) of rainfall depth serve as input to a hydrologic/inundation model. Rainfall forecast analyses are made using time series with autoregressive methods and selecting the stochastic model parameters most appropriate for an optimal prediction. The hydrologic model *Vflo*™ and the associated Inundation Analyst™ are used for runoff and flood analyses. An example of flood prediction for a storm near Mayaguez, Puerto Rico, on October 12, 2005, was presented. This work is significant because it represents the first attempt to implement now casting in western Puerto Rico using meteorological data from high resolution radars.

7. ACKNOWLEDGEMENTS

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