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DEVELOPMENT OF A TROPICAL CYCLONE RAINFALL CLIMATOLOGY AND PERSISTENCE (R-CLIPER) MODEL

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1. INTRODUCTION

A tropical cyclone (TC) drops copious amounts of precipitation daily. The rainfall over the oceans is not a serious concern to society, but once a TC makes landfall, and even several hundred miles inland after the hurricane force winds have ceased, it can produce a serious threat to society from urban and inland flooding. Indeed, in the last 30 years the majority of deaths related to TCs have been attributed to flooding (Rappaport 2000).

Improved quantitative precipitation forecasts (QPF) in TCs are one of the primary goals of the U. S. Weather Research Program (USWRP) effort on TC landfall (Marks and Shay, 1999). The varied nature of precipitation makes the QPF topic very complex. Although much of the significant precipitation occurs in conjunction with convective clouds, stratiform clouds also account for significant precipitation accumulations over extended intervals. While all of these mechanisms are active in TCs, the vortex structure acts to dynamically constrain the smaller scale circulations that often confound QPF.

Estimates of rainfall based on radar and other remote sensors offer promising avenues for improvement. At the same time numerical models, both operational and research, have been improved, running on faster computers at higher resolution, and with improved model physics. However, there is little previous work validating the model QPF performance in TCs. Partly it is because of the lack of accurate observations of the rain distribution and evolution in TCs.

A major obstacle to improving QPF in TCs is a lack of a comprehensive climatology of TC precipitation, i.e., a description of the distribution of rain in space and time. Few precipitation climatologies exist for TCs in the United States, and other TC basins have similarly limited climatologies. However, remote sensors such as those on the NASA Tropical Rain Measurement Mission (TRMM) satellite; in particular the microwave imager (TMI) and the active precipitation radar (PR), are providing a first cut at a credible TC rain climatology (Lonfat et al 2000). This climatology is precisely what is needed to develop a simple rainfall climatology and persistence (R-CLIPER) model, which can be used to validate numerical models and other QPF methods.

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2. DATA AND METHOD OF ANALYSIS

2.1 Rain Gauge Data

A TC R-CLIPER was developed originally based upon 53 years of U.S. rain gauge data (DeMaria and Tuleya, 2001). The gauge data set includes 125 U.S. landfalling storms from 1948-2000. There were about 10^6 hourly rain gauge reports within 500 km of the storm center. Only storms that were hurricanes at landfall are included (46 storms). There were about $5.6X10^5$ hourly gauge reports within 500 km of the storm center for these cases. The gauge data was stratified into 50 10-km wide annuli surrounding the storm center and mean rainfall rates were computed for each annuli (Fig. 1). In order to handle storms after they made landfall an inland-decay model was developed using the rain gauge data set by stratifying the results by time after landfall. The rainfall climatology was reduced to a linear fit of the mean rainfall rates (R) by radius (r) and time (t) after landfall defined as:

$$R(r,t) = (ae^{-\square t}+b)e^{-(r-rm)/re} \quad (1)$$

where parameters a and □ are defined from the fit to the gauge data in time, and b by the fit to the gauge data by radius, where r_m is the radius of maximum rainfall (=0) and r_e=500 km. This approach results in a circularly symmetric rain distribution that can be combined with the forecast track to produce a swath of rain along the forecast track before and after landfall. The climatology was combined with the operational track forecasts through the automated

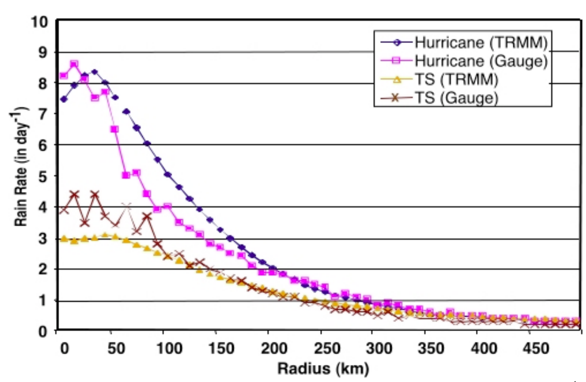

Fig. 1. Gauge-based TC rainfall climatology (in day^{-1}) from 1948-2000 and TRMM TMI-based TC rain climatology (in day^{-1}) from December 1997-2000. Comparisons are made for tropical storms and hurricanes.

tropical cyclone forecast (ATCF) system used at TPC/NHC to compute an integrated rain distribution for each forecast interval to produce the R-CLIPER.

The gauge-based R-CLIPER model was implemented at NHC in September 2001. However, because the hourly gage data is sparse, particularly within 100 km of the storm center, it is difficult to obtain a large enough sample to stratify the data by storm intensity.

2.2 TRMM Data

To overcome this limitation the R-CLIPER was expanded to include a global satellite-based TC rainfall climatology based on rain estimates from the NASA Tropical Rain Measurement Mission (TRMM) satellite; in particular the microwave imager (TMI) (Lonfat et al 2000). To date, this climatology includes global TMI rain estimates in 245 storms from December 1997 to December 2000, yielding 2121 events, where 64% of the events were tropical storms, 26% were category 1-2 hurricanes, and 10% were category 3 or higher.

The climatology provides a mean rain rate and the rain rate probability distribution in a storm-centered coordinate system composed of 50 10-km wide annuli in four quadrants. The results are stratified as a function of storm intensity (Fig. 2). The results show that the mean rain rate increases by a factor of four (3 in day^{-1} for tropical storms versus 12 in day^{-1} for category 3 and higher TCs) within 50 km of the storm center with increasing intensity. Figure 2 also indicates that the radius of maximum rainfall (r_m) also decreased with increasing intensity (i.e., from 55 km for tropical storms, to 45 km for category 1-2 hurricanes, and to 28 km for category 3-5 hurricanes).

A comparison of the satellite-based to the gauge-based climatology for all hurricanes and tropical storms depicted in Fig. 1 denotes a surprising similarity between the two mean rainfall rate curves with radius and intensity. The major difference is the high variability of the mean rainfall rate at radii<100 km in the gauge climatology, particularly for tropical storms, which is caused by the low number of points in those annuli. There is also a lack of a minimum in the mean rainfall rate at small radii for the gauge-based climatology. Despite these slight differences, this comparison gives a good indication of the veracity of both climatologies.

The satellite-based R-CLIPER uses the TMI rain climatology partitioned by storm intensity developed by Lonfat et al (2000) to provide the storm-centered mean rain rate distribution out to 500 km radius (r_e) from the storm center as a function of radius:

$$R(r) = (R_0) + (R_m - R_0)(r/r_m) \qquad r<r_m$$

$$= R_m \exp(-(r-r_m)/r_e) \qquad r>r_m \qquad (2)$$

where parameters R_0, and R_m, are the mean rainfall rates at r_e and r_m, respectively. The climatology was

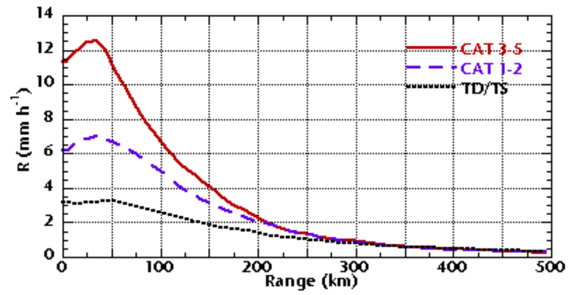

Fig. 2. TMI-based rainfall climatology (in day^{-1}) for tropical storms, Category 1-2, and Category 3-5 hurricanes.

combined with the operational track forecasts through the ATCF in the same manner as the gauge-based climatology to compute an integrated rain distribution for each forecast interval to produce the R-CLIPER.

3. SUMMARY

An important use of the R-CLIPER is to provide a benchmark for the evaluation of other more-general QPF techniques. To evaluate the R-CLIPER forecasts it will be run on a number of past storms to provide some statistics on model performance and to develop different data products useful to the hurricane specialists. With the help of representatives of the NWS Hydrometeorological Prediction Center (HPC) and TPC/NHC we selected five cases to test R-CLIPER: Andrew (1992), Fran (1996), Danny (1997), Floyd (1999), and Allison (2001). The R-CLIPER forecasts will be compared with 6-h areal average rainfall amounts on a 1°X1° grid, used by HPC. This type of information is available back 10-12 years. Comparisons with storm total rain gauge data will also be performed.

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