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The Effect of Shear and Topography on Rainfall Forecasting with R-CLIPER

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1. Introduction

In recent decades, fresh water flooding has become the main threat to human life when a tropical cyclone (TC) makes landfall (Rappaport, 2000). Fresh water flooding from TCs also has major economic impacts. In 2001, for example, flooding in the Houston area from Tropical Storm Allison generated more than $6 billion in total damage. While significant improvements have been made in forecasting tropical cyclone track (Franklin et al 2003, Aberson 2001) and, to a lesser extent, intensity (DeMaria and Gross 2003; DeMaria et al. 2004), much less attention has been focused on forecasting rainfall. Only recently efforts have been made to develop standardized techniques for evaluating tropical cyclone quantitative precipitation forecasts (Marchok et al. 2004; Rogers et al. 2005).

Until recently, methods used to estimate rainfall were based on simple geometric considerations, using forward speed and the storm size to predict the rainfall accumulation (Rule of Thumb). In 2001, Marks and DeMaria developed a method using climatology and persistence information (R-CLIPER) that takes into account the storm intensity, size and mean radial distribution of rainfall. R-CLIPER is a statistical model, using radial distributions of azimuthally averaged rainfall described in Lonfat et al. (2004), to construct an instantaneous rainfall footprint that depends on the storm intensity. The footprint along the forecast track is interpolated over an Atlantic-wide grid with 25-km and 10 minute resolution to provide accumulation maps of rainfall. In its current operational form, the model assumes that storms are symmetric.

Recent studies have shown, however, that both the instantaneous and accumulated rainfall in TCs can have significant spatial variability. Wind shear and interaction of a TC with topography are two of the main drivers of asymmetries in TC rainfall. The model presented here builds on R-CLIPER to provide a simple implementation of the effect of shear and topography on the accumulated rainfall in TCs. R-CLIPER and the shear/topography models are applied to the 2004 hurricane season and results are compared to Stage IV observations.

2. Model Description

The model implementation uses a philosophy similar to that applied in R-CLIPER. The calculation of the total rain at a given location is provided by the following equation:

$$R_{tot} = R_{R\text{-}CLIPER} + R_{shear\ mod} + R_{topography} \qquad (1)$$

where R_{tot} is the total rainfall field, $R_{R\text{-}CLIPER}$ is the rain field produced by the standard version of R-CLIPER, $R_{shear\ mod}$ is the rain field associated with the vertical shear-generated asymmetry, and $R_{topography}$ is the rain field generated by topography. The formulation of $R_{shear\ mod}$ and $R_{topography}$ is described below.

The shear is parameterized through the use of wavenumber 1 and 2 Fourier coefficients following the methodology described in Lonfat et al. (2004). The effects of topography are modeled as perturbations to the instantaneous rainfall footprint described above. Many processes would ideally need to be modeled to fully capture the interaction of a TC with topography. However, given the strong dependence of topographically-induced rainfall on the surface wind and its interaction with terrain gradients, the effect of topography is modeled by building a correction factor to the rainfall footprint that is exclusively proportional to the low-level flow-dependant gradient of ground elevation (or elevation advection by the flow in storm-relative terms). The surface wind footprint is generated at every time step (15 minutes) where the rainfall footprint is calculated and a simplified version of topographic lifting term χ is computed for each grid point, where:

$$R_{topography} = \vec{V}.\nabla h_s \qquad (2)$$

with $\vec{V}$ representing the surface (10-meter) wind field and h_s the ground elevation. Besides increasing rainfall on the upslope sides, this simple approach also captures the lack of rain on the leeward sides (i.e., the shadow effect), since in those regions the flow-relative analysis yields a negative elevation gradient, resulting in a negative correction factor.

3. Results and Discussion

As an example of the performance of the various models, Figure 1 shows total rainfall over a 6-day time period (12 UTC 4 to 12 UTC 10 September) over the region impacted by the second landfall of Hurricane Frances (2004). All three models capture the width of Frances' rainfall swath, but amplitudes are generally too small in R-CLIPER and the shear model. The effect of shear is significant near landfall and when the storm recurves over northern Florida. When the storm recurves, an asymmetry in the rainfall develops even in the symmetric model. Accounting for topography has a significant effect on the rainfall that is predicted in the Appalachians. In Fig. 1d, the maximum rainfall observed in the Appalachians is similar to that observed in Fig. 1a. In all three models, rainfall is significantly under predicted in Northeast Florida. Analysis of hourly Stage IV observations showed several rain bands with training echoes over the area south and west of Jacksonville, Florida. The current model is not able to capture such training echoes that affect a given region for a long period of time.

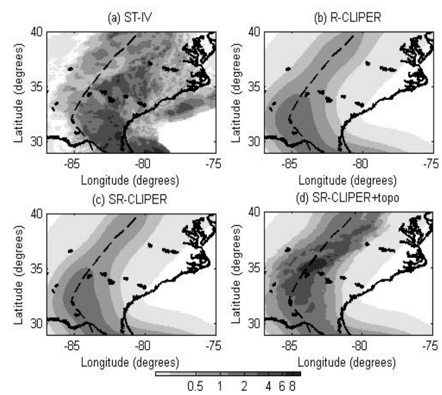

Fig. 1: Rainfall accumulation in Hurricane Frances (2004): a) ST4 –radar derived observations, b) R-CLIPER, c) R-CLIPER with the addition of shear, d) R-CLIPER with shear and topography

4. Summary and concluding remarks

This paper explores a simple technique to improve rainfall prediction from the operational R-CLIPER model. It is the first explicit attempt at accounting for shear and topography in a statistical forecasting model.

The model is easy to run and although it is very simple, it provides quick forecast estimates of the peak expected rainfall and its spatial distribution. This information can for example be helpful towards the assessment of fresh water flooding risk.

References are available upon request.