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An Examination of Hurricane Debby (2000) with the 2000 and 2003 Versions of the GFDL Hurricane Prediction System

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1. INTRODUCTION

The ability of operational dynamical models to simulate tropical cyclone (TC) intensity change is gradually improving. However, only very minimal overall forecast skill has been realized, primarily by regional models such as the evolving Geophysical Fluid Dynamics Laboratory (GFDL) hurricane prediction system. Statistical-dynamical models remain the most skillful objective guidance for TC intensity change, but even these models show little or no skill in forecasting rapid intensity changes. While rapid intensification is a high-priority forecast concern, significant challenges are also presented by cases of rapid weakening such as Hurricane Debby (2000). Debby unexpectedly and rapidly weakened on 23 August while moving along the northern coast of the island of Hispaniola, and later dissipated on 24 August over the northwestern Caribbean Sea. While Debby never directly impacted the United States, most of the operational National Hurricane Center guidance, including the GFDL hurricane prediction system, indicated that Debby would remain intact and follow a track that would threaten the southeastern coast of Florida. Since the GFDL model offers great potential for providing improved operational guidance in such cases in the future, its performance during Debby has been closely examined to help identify areas for improvement.

Rhome et al. (2001) and Rhome (2002) presented a diagnosis of operational GFDL runs during Debby using *in situ* observations, satellite data, and NCEP global analyses. It was shown that the observed GFDL high intensity and northward track biases during this event were coincident with a weak initial vertical shear bias, insensitivity of the model vortex to vertical shear, and an overall cyclogenetic tendency. These studies further proposed that a complex interaction existed within the model between the storm and the environment. Specifically, excessive cyclogenesis modified the surrounding environment through enhanced convection, vertical redistribution of latent heat, and eastward advection of low potential vorticity (PV) outflow by the mean environmental flow. This advection produced excessive upper-level ridge development and reduced vertical shear, favoring additional intensification and establishing a self-developmental tendency. The excessive ridging also produced a more southerly steering component that contributed to the northward track bias.

This paper expands upon these earlier results by comparing the original operational 2000 GFDL simulations with select reruns from an upgraded 2003 version of the model. Comparisons between the 2000 and 2003 versions are used in an attempt to isolate possible causes of model tendencies and to assess the impact of the upgrades on the GFDL forecast performance for Debby.

2. DATA AND METHODOLOGY

Numerous upgrades have been made to the operational GFDL model since 2000 (Bender et al. this volume). During 2002, the three-nest grid configuration was changed to a two-nest configuration. The middle and innermost grids with $1/3^0$ and $1/6^0$ horizontal resolution, respectively, were replaced with a single grid with $1/6^0$ resolution while the horizontal resolution of the outer grid was enhanced from one degree to $1/2^0$. Additional changes included increasing the vertical resolution from 18 to 42 sigma levels, replacing the "soft" convective adjustment scheme with a simplified version of the Arakawa-Schubert scheme, replacing the Mellor-Yamada boundary layer closure scheme with NCEP's Global Forecast System (GFS) scheme, modifying the pressure gradient computation, and improving the model initialization.

In the current study, the 2003 version of the GFDL (hereafter GFDL2003) was rerun at four selected initial times during the Debby case, and the output was then compared with results of operational runs of the 2000 GFDL model (hereafter GFDL2000) initialized at the same times, as well as with observed data. Maintaining consistent post-processing of the gridded data between model versions was problematic due to the changes in 2003 to the grid resolution (both vertical and horizontal) and grid configuration. Therefore, this analysis focused more on comparisons between the 2000 and 2003 versions of GFDL track and intensity forecasts for Debby.

3. RESULTS

Overall, track and intensity biases observed within the GFDL2000 operational simulations of Debby were reduced but not completely removed in the GFDL2003 reruns. Specifically, two of the four GFDL2003 reruns resulted in a significant improvement over GFDL2000 for both track and intensity (group 1), while the two remaining cases produced some improvement in track but little or no improvement in intensity (group 2). Examples from both group 1 and group 2 are displayed in Figure 1. This graphic shows a comparison of the track (panel A) and intensity (panel B) guidance between the GFDL2000 and GFDL2003 simulations initialized at 1200 UTC 22 August (hereafter 082212) and at 1200 UTC 23 August (hereafter

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082312). In both cases, the northward track bias is reduced in the GFDL2003 rerun. However, the high intensity bias was reduced only in the simulation initialized at 082312. The improvement in both track and intensity for the 082312 case was associated with a significant reduction in the excessive downstream ridge development (not shown). Conversely, for the 082212 GFDL2003 simulation that produced some improvement in track but little improvement in intensity, the model retained the tendency to excessively develop the downstream ridge, albeit a weaker one. These results strongly suggest that excessive ridge development was one of the main contributors to the forecast biases, but they still do not reveal the underlying causes for the model errors.

Analysis of the GFDL initial conditions offers at least a partial explanation for the model errors. For example, a weak vertical shear bias was observed at the initial time within the GFDL2000 for the 082312 simulation when compared with the NCEP analysis shear. This weak initial shear bias was coincident with, and thought to be related to, excessive cyclogenesis and subsequent ridge modification in that model run. Although the exact same initial shear calculation was not possible from the GFDL2003 due to the changes in the grid configuration, the lesser track and intensity biases in the GFDL2003 run at 082312 strongly suggest that the 2003 model upgrades mitigated the effects of the weak initial shear bias in the original GFDL2000 run. Conversely, the original GFDL2000 run initialized at 082212 contained a much more accurate initialization of vertical shear, and the corresponding GFDL2003 rerun initialized at the same time showed little or no intensity forecast improvement.

Considering the 082212 and 082312 cases together, it is hypothesized that the positive impacts generated by the GFDL2003 upgrades are more apparent but still limited in cases when a weak initial shear bias, created by the axisymmetric spinup procedure, is retained during strong shear events. While the GFDL2003 appeared to be less cyclogenetic for Debby than the GFDL2000, the inaccurate initial shear still seemed to create a favorable environment for cyclogenesis which set up the self-developmental cycle outlined in Rhome et al. (2001).

4. DISCUSSION AND CONCLUSIONS

Comparisons between the 2000 and 2003 versions of selected GFDL simulations for Hurricane Debby (2000) indicate positive impacts of the 2003 upgrades. Northward track and high intensity biases in GFDL2000 were both significantly reduced in two of the four GFDL2003 reruns examined. For these two cases, excessive downstream ridge development was lessened, leading to a more realistic environment in the model that fed back to produce more realistic track and intensity forecasts. These results strongly suggest that the storm-environment interaction proposed by Rhome et al. (2001) was a significant factor in the performance of the GFDL model during Debby. GFDL2003 reruns that did not show significant track and intensity forecast improvement over the operational GFDL2000 simulations retained the excessive development of a downstream ridge. According to the third author, these results are consistent with overall improvements achieved at GFDL based upon reruns of several cases from 2001 and 2002.

The cyclogenetic tendency and weak initial vertical shear bias often seen in the GFDL model (although not always simultaneously) during Debby appeared to be due to limitations in the axisymmetric spinup (bogusing) technique. This procedure often produced an unrealistically strong initial vortex that was vertically coupled in the GFDL2000 Debby simulations, regardless of the magnitude of the environmental shear. This problem was exacerbated, and led to even greater track and intensity forecast biases, when the weak initial vertical shear bias was present in the model environment, since this produced conditions that were even more favorable for intensification in the model. The improved model resolution and physics available within the GFDL2003 Debby reruns likely contributed to the improvements over the original operational GFDL2000 simulations. However, the tendencies for a weak initial vertical shear bias and an unrealistically strong initial vortex likely remained largely unchanged in GFDL2003, since the axisymmetric spinup procedure was retained in that version. Therefore, at least in the Debby cases examined in this study, the 2003 resolution and physics upgrades appeared to partially compensate for the cyclogenetic tendencies arising from the spinup procedure. This effect appears to have produced just a partial reduction in the high intensity and northward track biases using GFDL2003 during Debby. Given further refinement of the spinup procedure, the full benefits of the recent upgrades may be realized in later GFDL reruns of Hurricane Debby.

5. REFERENCES

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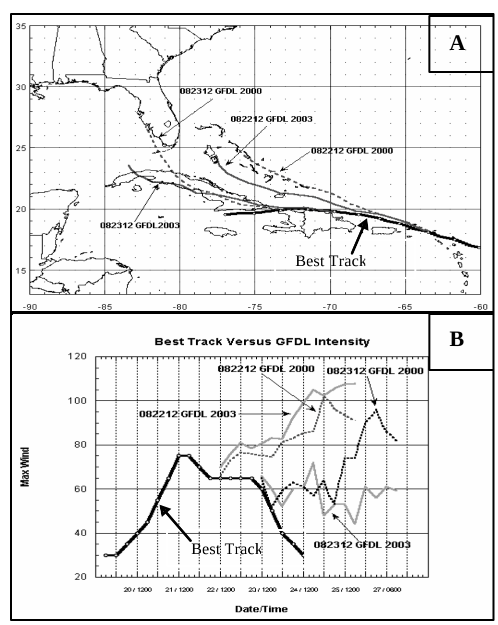

Figure 1. Comparison of selected GFDL2000 and GFDL2003 (A) track and (B) intensity forecasts for Debby (2000).