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HIGH-RESOLUTION WRF SIMULATIONS OF TWO RECENT ATLANTIC HURRICANE SEASONS

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1. INTRODUCTION

Current mesoscale numerical models, such as the Weather Research and Forecasting (WRF) model, are capable of simulating intense tropical cyclones (TC) with realistic structures. However, the ability of WRF to capture the full intensity of a TC is dependent upon the horizontal resolution used. In order to accurately represent both the primary and secondary TC circulations, model simulations must be configured with sufficient resolution to explicitly represent convection and not rely upon a convective parameterization (e.g., Gentry 2007).

Gentry (2007) studied how TC intensity and structure are affected by changes in horizontal grid spacing from 12 to 1 km when convection is simulated explicitly, and found that significant sensitivity to horizontal resolution is still present even with sub 4-km grid spacing. However, grid spacings between 8 and 4 km did adequately resolve the primary and secondary circulations, with the strongest changes in TC intensity not occuring until grid spacing dropped below 4-km.

Current computational limitations prevent global circulation models (GCMs) from operating at sufficiently small grid spacing to simulate convection explicitly. With our experimental design, the goal is to produce high-resolution, explicit convection WRF simulations of an Atlantic hurricane season with initial and boundary conditions adjusted to resemble future climate regimes, as portrayed by a GCM forecast. However, it must first be established that WRF can simulate recent hurricane activity, adequately capturing trends in activity seen between seasons. Therefore, in this study, a proof of concept simulation is presented in order to investigate the extent to which the WRF model can simulate the intense 2005 and relatively inactive 2006 hurricane seasons.

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2. METHODS

The Weather Research and Forecasting (WRF) model (Version 2.2; Skamarock et al. 2005) is used for two different simulations with the same model domain and physics configuration. The Lin microphysical parameterization and the Yonsei University boundary layer scheme (Lin et al 1983; Hong et al. 2006) are used. No CP scheme is employed. The model is run from 1 to 30 September of 2005 and 2006 (hereby referred to as S05 and S06, respectively) using the 1° National Centers for Environmental Prediction (NCEP) Final Analysis from the Global Forecast System (GFS) for initial and boundary conditions. Boundary conditions are updated every 24 hours, and a fixed sea-surface temperature (SST) field is used. Output is produced for every 12 hours of model time. A 6-km grid is used to simulation the main development region (MDR), being 1850 by 600 points with 28 vertical modified half-σ levels (Fig. 1).

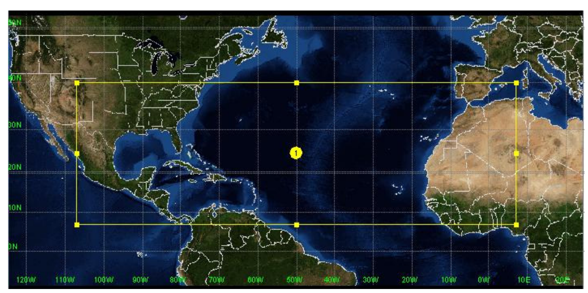

Fig. 1. WRF model domain.

In order to objectively locate and track TCs in the model output, a detection algorithm is developed after the methodology of Knutson et al (2007), with an additional criterion that the TC center must be within 200 km of a grid cell 10-m wind of at least 33 ms^{-1}. Therefore, this methodology excludes TCs of tropical storm and depression strength.

3. VERIFICATION

The seasons of 2005 and 2006 are chosen because of the contrast in Atlantic TC activity between these years. 2005 was a record-breaking Atlantic season, with the most hurricanes (15) and the highest accumulated cyclone energy index. Also, this was the first season with four hurricanes reaching category 5 strength on the Saffir-Simpson scale, for a total of 7 major (category 3 or above) hurricanes (Beven et al 2008, Simpson 1974). In contrast, 2006 was less active, with only 4 hurricanes and 2 major TCs. The month of September is selected because it represents the climatologically peak for the Atlantic season (NHC 2008). The observed TCs present during September 2005 and 2006 are listed in table 1.

Despite overall seasonal differences, there was less contrast between the two seasons during this peak month with each having 5 hurricanes and 2 major TCs. However, 2005 was still more active, with a category 5 storm (Rita) and a category 3 (Maria), as opposed to the two category 3 hurricanes (Gordon and Helene) in 2006.

Summary of TCs Present in Sept. 2005 Verification		
Designation	**Category**	**Dates**
Lee	TS	28 Aug – 3 Sept
Maria	Cat 3	1- 13 Sept
Nate	Cat 1	5 – 12 Sept
Ophelia	Cat 1	6 – 23 Sept
Philippe	Cat 1	17 – 24 Sept
Rita	Cat 5	18 - 26 Sept
Summary of TCs Present in Sept. 2006 Verification		
Designation	**Category**	**Dates**
Florence	Cat 1	3 – 12 Sept
Gordon	Cat 3	10 – 20 Sept
Helene	Cat 3	12 – 24 Sept
Isaac	Cat 1	27 Sept – 2 Oct

Table 1. TCs present during September 2005 and 2006, listed with their peak intensity on the Saffir-Simpson scale, and the dates during which they were present.

4. MODEL RESULTS

Using the detection algorithm discussed above, hurricanes of category 1 intensity and above are found and listed in table 2. The simulations correctly characterize the activity of the two seasons, with 2005 being the more active simulation. Similar to the verification, S05 produces 6 hurricanes with 3 major hurricanes. S06 is less similar to its verification, with only 2 hurricanes and 1 major. However, WRF is able to reproduce the trend between the two seasons.

Summary of TCs Present in S05 Model Run		
Designation	**Category**	**Dates**
Alpha	Cat 4	3-11
Beta	Cat 2	6-7
Gamma	Cat 4	18-28
Delta	Cat 4	23-
Epsilon	Cat 2	28-
Summary of TCs Present in S06 Model Run		
Designation	**Category**	**Dates**
Alpha	Cat 4	4-25
Beta	Cat 2	29-

Table 1. TCs present during the simulations of September 2005 and 2006, listed with their peak intensity on the Saffir-Simpson scale, and the dates during which they were present. Where no ending date is specified, the TC is still present at the end of the model run. Note that the designation of the TCs is done for convenience and does *not* reflect the names of actual hurricanes during the later part of the 2005 season.

In the S05 WRF simulation, all 3 major TCs make landfall on the U.S. coast, with Alpha making landfall in the Gulf, Delta impacting the east coast, and Gamma affecting both coasts (Fig. 2). Alpha tracks through the gap between the Yucatan Peninsula and Cuba at category 3 strength before making landfall on the Mississippi coast.

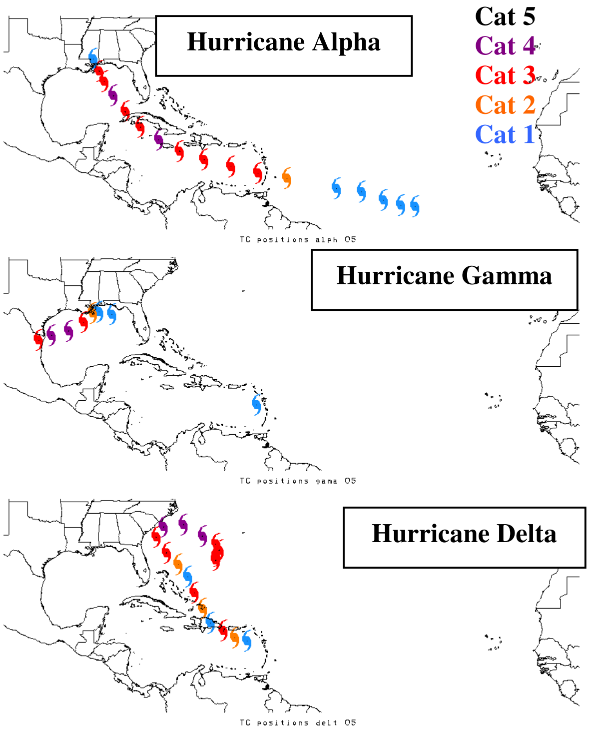

Fig. 2. 12-hourly TC positions during the storms Alpha (top), Gamma (middle), and Delta (bottom) in the S05 simulation, plotted according to intensity on the Saffir-Simpson scale.

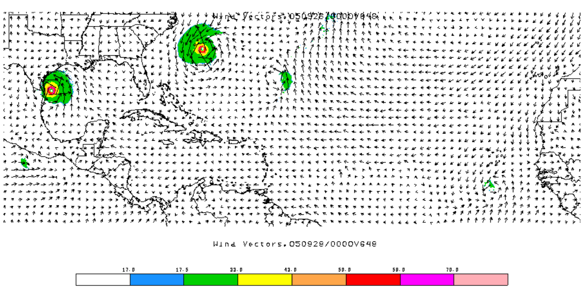

Fig. 3. 10-m winds, contoured and with vectors, at 00 UTC 28 September 2005, according to strength on the Saffir-Simpson scale where blue indicates tropical depression, green tropical storm, yellow category 1, orange category 2, red category 3, pink category 4, and light pink category 5.

Subsequently, Delta and Gamma move together across the Atlantic toward the Florida coast with Gamma to the northwest of Delta. Gamma arrives at the Florida coast first and makes landfall on the northern coast, then moves across the state, and emerges over the Gulf at category 1 strength. It re-strengthens as it tracks close to the coastline before making a second landfall near the Mississippi-Louisiana border as a category 2 hurricane. It then tracks to the southwest and makes a third landfall on the Texas, Mexico border as a category 4 storm (Fig. 3). Meanwhile, Delta veers poleward as it approaches Florida, staying just off the coast of North and South Carolina at category 4 strength. It eventually jogs back out into the Atlantic without making landfall and remains at category 3 strength until the end of the simulation.

The tracks of the long-lived major TCs also reveal the limitations imposed by the horizontal extent of the model domain. In S06, Alpha is present for nearly the entire simulation because of its inability to move out of the model domain. After westward across the Atlantic, Alpha veers poleward, until it encounters the northern terminus of the domain (Fig. 4). It then takes a looping pattern east, until it is intercepted and swept along by a mid-latitude trough. This is similar to the path of Delta in S05, which moves up the east coast, then turns away from the domain edge and heads southeastward.

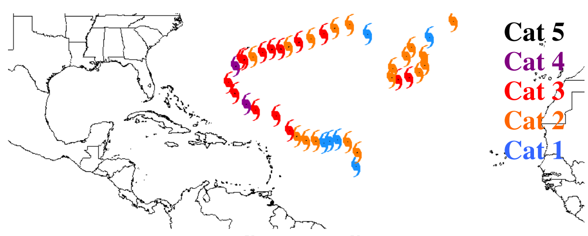

Fig. 4. Positions of Hurricane Alpha in S06 shown every 12 hours.

The inability of TCs to cross the domain boundary could be due in part to the GFS boundary conditions, which may not reflect the presence of a strong TC leaving the boundary. After turning away from the boundary, both Delta in S05 and Alpha in S06 remain major hurricanes and head back toward the interior of the model domain. This could affect the formation other TCs because of the upper-tropospheric warming and drying effect, or shear from the outflow of the deep TC still within the domain.

5. FINDINGS AND FUTURE WORK

In this study, the ability of WRF to reproduce the level of TC activity in recent hurricane seasons has been examined using month-long, proof of concept simulations of September 2005 and 2006. WRF demonstrates the ability to simulate TCs of varying intensities. The simulation develops both weak hurricanes and major TCs from weak initial disturbances. Also, WRF does reproduce the trend in TC activity, producing more total hurricanes and major TCs in 2005 than in 2006. The model appears to have "overshot" the trend in this case, simulated more hurricanes and major TCs in 2005 than seen in the verification and producing less TC activity in the 2006 simulation than was present in reality. Overall, WRF appears to be capable of simulating TCs of varying intensity on a seasonal timescale, and reproducing levels of TC activity seen in individual seasons, but additional simulations will be needed before we can make a more definitive statement.

Future work will concentrate on exploring sensitivity to domain configuration. Changes to the eastern extent of the model domain may affect the number of initial disturbances entering the domain from the east. If the eastern boundary lies further west, the model must depend more upon the boundary condition to provide initial disturbances to develop into TCs. This could result in a simulated season that better reproduces verification, as the timing of when initial disturbances are introduced into the domain would be controlled by the analysis, rather than the simulation. Also, nudging of the model solution toward the analysis may be explored as a means to produce a simulated season that better resembles reality. Changes to the northern boundary of the domain must also be considered, as TCs in these simulations have already shown a preference for moving away from the boundary after veering poleward. A different lateral boundary condition could allow strong TCs to move poleward and leave the domain in a manner better resembling real TC tracks. Additional simulations will also be run using a time-varying SST field, as the use of a static for such a long simulation is unrealistic and is an additional source of sensitivity for these results.

6. ACKNOWLEDGEMENTS

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