P1.2 **2004 Hurricane Danielle Tropical Cyclogenesis Forecasting Study Using the NCAR Advanced Research WRF Model**

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## 1. INTRODUCTION

Presently, the tropical cyclone formation is an outstanding issue by forecasters that still need to be resolved. The importance in the study of the genesis process lie in that most of the hurricanes in the Atlantic Ocean develop from cyclones that build up off the west coast of Africa. A study made by Thorncroft and Hodges (2000) shows that a notable positive correlation exist between the African easterly waves (AEW) activity and Atlantic tropical cyclone activity. The 2004 Atlantic hurricane season showed proof of this correlation with eleven of sixteen tropical systems being developed from AEWs. Currently, due to their relevance, a better understanding of the nature of AEWs is desired, including the initiation of these systems, their growth, and their interaction with covective systems.

The 2004 hurricane season characterized for being one of the most intense and active seasons since 1950, having 15 named storms, and 9 hurricanes from which 6 were categorized as major hurricanes. Nine of these systems made landfall along the United States coastline, with the state of Florida enduring one tropical storm and four hurricanes; from which three of these were characterized as major hurricanes. The first eight strikes, including all five Florida strikes, occurred during the months of August and September which coincide to the AEWs most active period. Hurricane Danielle was one of the eleven systems that evolved from AEWs, reaching a category 2 as its maximum intensity in the Saffir-Simpson Scale. Even though this system remained on the open waters of the eastern Atlantic Ocean and there were no damages associated to it, its characteristics linked with tropical cyclones while inland makes it suitable for this study which aims to examine the skill of the Weather Research and Forecasting (WRF) model in the tropical cyclone genesis process.

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The ability of WRF model to anticipate the tropical cyclone formation is analyzed for 2.5 days and 4.5 days forecast periods prior to development into a tropical depression (TD). Results of the two simulations forecast periods are compared and evaluated in terms of the WRF integration length, domain size, and cumulus parameterizations used. Results obtained by the 2.5 day forecast period ahead of the TD stage shows the WRF model ability capturing the genesis process.

## 2. METHODOLOGY

The WRF Model was integrated using a grid spacing of 20 km and 18 vertical levels for four simulations. The first two simulations for Hurricane Danielle are started at 0Z 9 August 2004, 4.5 days prior to the formation of the tropical depression (TD), and run for 6 days (denoted as WRF R1 and WRF R2). WRF R1 and R2 have a domain of 46º W to 16º E longitude and 0ºN to 26ºN latitude. The last two simulations of Danielle are started at 0Z 11 August 2004, 2.5 days before the TD formation, and run for 3.5 days (denoted as WRF R3 and WRF R4). WRF R3 and R4 have a domain covering from 34º W to 4º E longitude and from 3º N to 24º N latitude.

The physics options used for the WRF runs include Lin et al. microphysics, rrtm longwave radiation, Dudhia shortwave radiation scheme, Monin-Obukhov (Janjic Eta) surface-layer scheme, Noah land-surface model for the land-surface option, Mellor-Yamada-Janjic Eta boundary layer, Kain-Fritsch (new Eta) cumulus for WRF R1 and R3, and Grell-Devenyi for WRF R2 and R4. Initial and boundary conditions are obtained from NCEP final GFS analysis. Forecasted fields of sea-level pressure (SLP) and 10 meter wind field are examined for Hurricane Danielle since the AEW came off the African coast until further intensification into a tropical storm (TS). AEWs inland location is tracked for each simulation using the 700 hPa wind intensity and streamlines. The GFS analysis timing together with the Meteosat IR satellite images are used as the parameters to determine the WRF model forecast accuracy in determining when the AEW emerged off the coast.

The model forecasts are verified against the data from the National Hurricane Center (NHC) archive when the system evolves to the TD and TS stages.

## 3. RESULTS

Preliminary results in terms of the tropical system forecasted location show a difference of about 3 degrees longitude (Figures 5 and 6) for all the runs that involved the Kain-Fritsch cumulus scheme (runs denoted as R1 and R3). In the time when the EW came off Africa on August 12 12Z (Figures 5a and 5b) until August 13 06Z, WRF R1 and WRF R2 sea level pressure forecasts were equivalent (Figure 1). During the intensification period, corresponding to the TD (Figures 5c and 5d) and TS stages (Figures 5e and 5f); the WRF R2 forecasted SLP compares well to NHC estimate (Figure 1). The R2 showed the best results for simulated maximum sustained winds (Figure 2). However, in relation to WRF R3 and R4, both simulations showed good skill in the forecast of SLP through all the intensification period compared to GFS and NHC (Figure 3). Consistently, the two latter simulations forecasted a more intense storm during the TD and TS stages. A maximum difference of 11 hPa compared to NHC SLP intensity was forecasted by WRF R3. Associated with the maximum sustained winds, both WRF R3 and WRF R4 forecasts showed excellent skill throughout all the times (Figure 4). A more intense storm is also suggested by a maximum difference of 5 knots in the maximum sustained winds for the last time of the forecast which is consistent with the strengthening of the system using SLP.

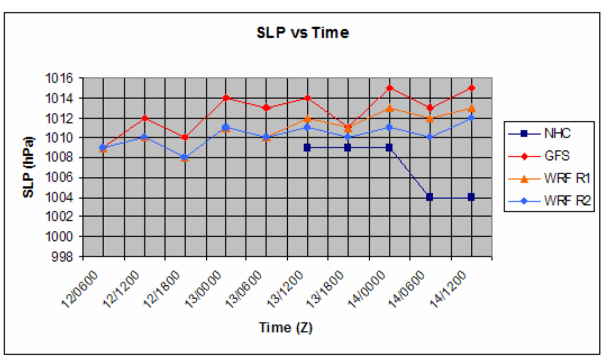


**Figure 1.** WRF R1 and R2 forecasted SLP

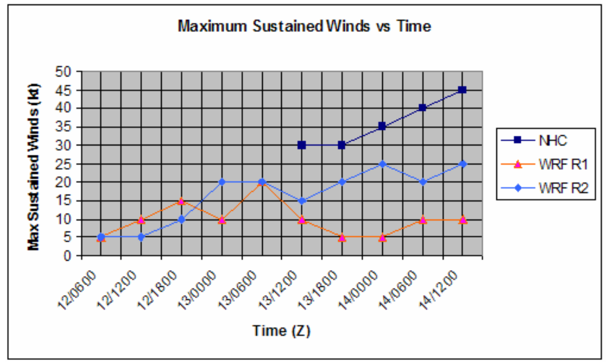


**Figure 2.** WRF R1 and R2 forecasted 10m winds

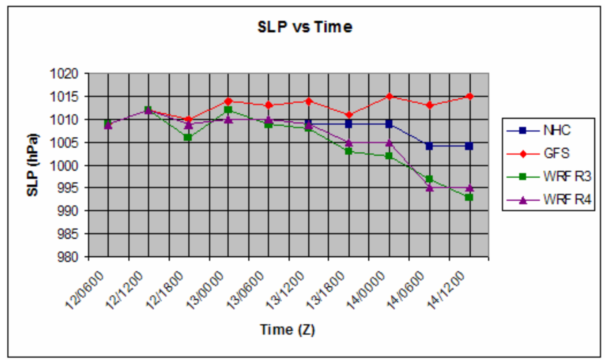


**Figure 3.** WRF R3 and R4 forecasted SLP

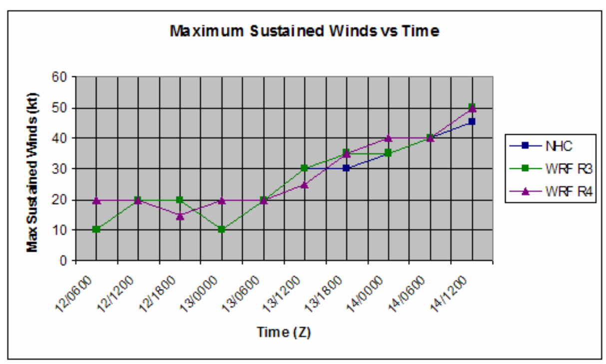


**Figure 4.** WRF R3 and R4 forecasted 10m winds

## 4. CONCLUSIONS

Compared to NHC data, WRF R1 and R2 improved the forecast of SLP when compared against the GFS. Similarly, WRF R3 and WRF R4 demonstrated superior skill relative to the Global Forecasting System in simulating the SLP, specifically during the tropical depression and tropical storm stages.

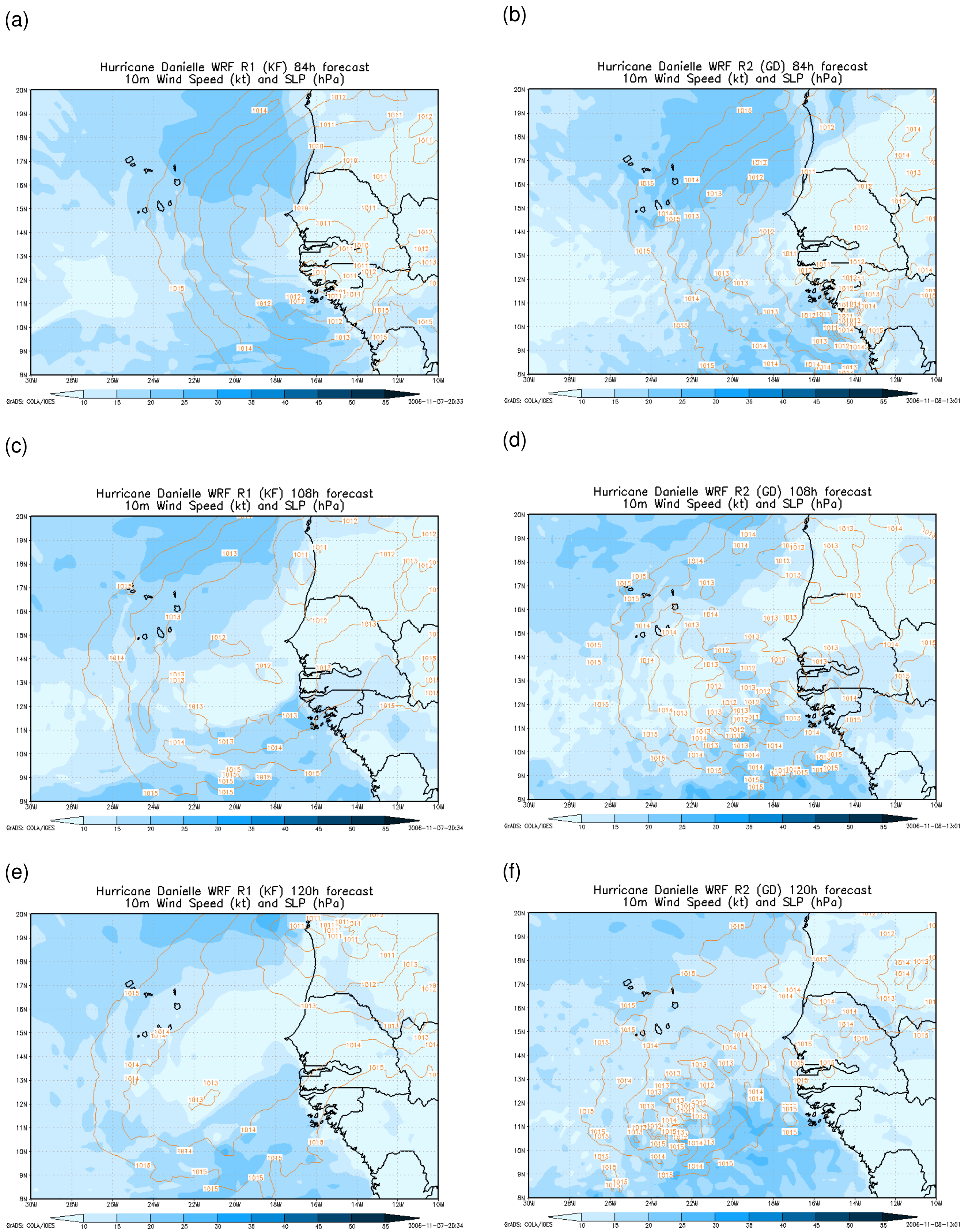


**Figure 5.** 10 meters wind speed and sea level pressure for WRF (a) R1 84h forecast August 12 12Z (b) R2 84h forecast August 12 12Z (c) R1 108h forecast August 13 12Z (d) R2 108h forecast August 13 12Z (e) R1 120h forecast August 14 00Z (f) R2 120h forecast August 14 00Z

(a) (b) (c) (d) (e) (f)

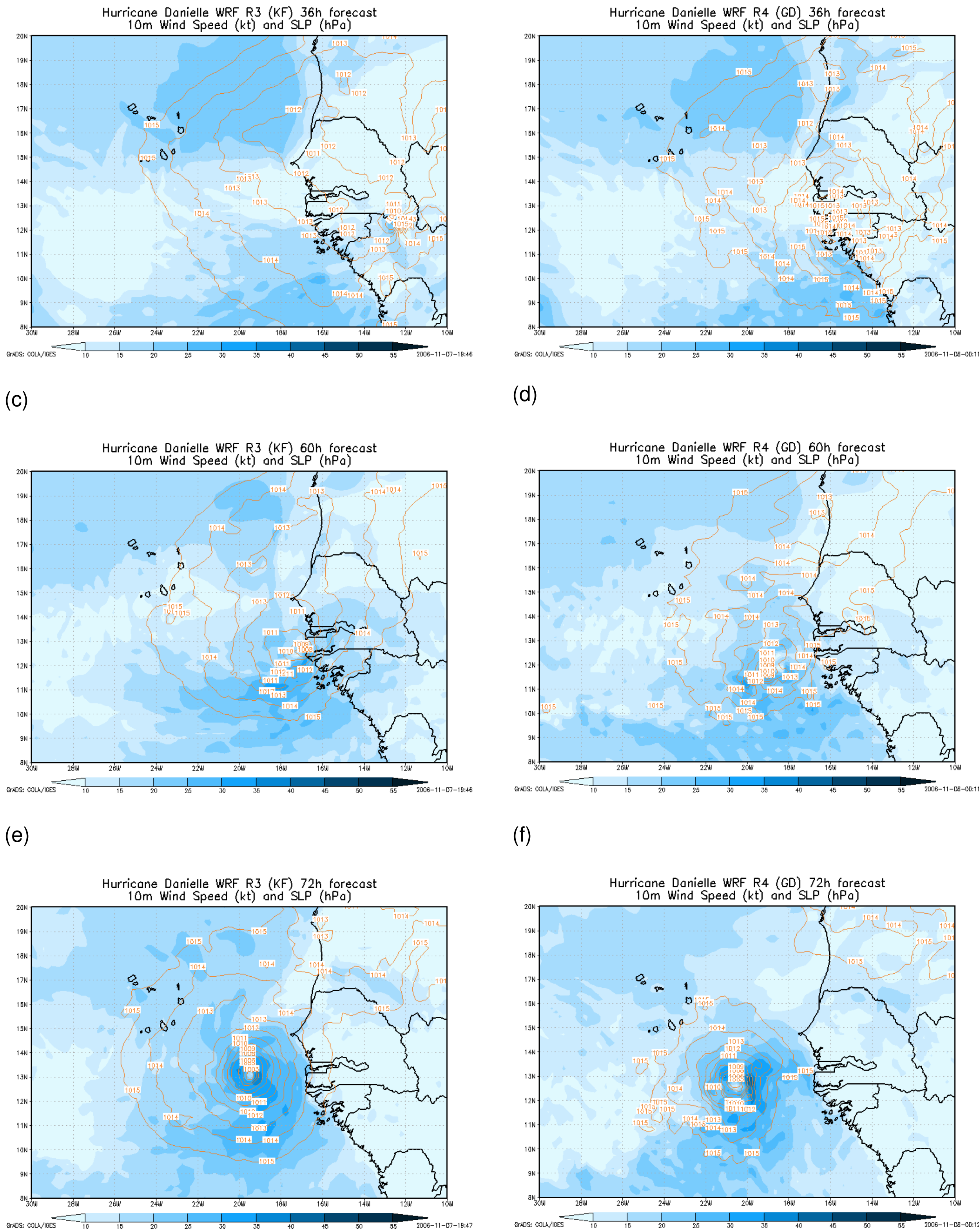


**Figure 6.** 10 meters wind speed and sea level pressure for WRF (a) R3 36h forecast August 12 12Z (b) R4 36h forecast August 12 12Z (c) R3 60h forecast August 13 12Z (d) R4 60h forecast August 13 12Z (e) R3 72h forecast August 14 00Z (f) R4 72h forecast August 14 00Z

WRF R2 which was simulated using the Grell-Devenyi cumulus scheme showed better forecasted results in terms of SLP and winds than WRF R1 which was simulated using the Kain-Fritsch cumulus parameterization. In general, WRF R3 and R4 demonstrated the best skill forecasting the intensification stages of Hurricane Danielle after leaving the African continent as showed in Figure 7. As expected, maximum sustained winds increase with a decrease in sea level pressure which R3 and R4 demonstrate. The opposite is demonstrated by WRF R1 and R2 which forecasted rise in SLP with increasing winds. In summary, we find that the longer integration of the model, the size of the domain and the cumulus parameterizations used influenced the results.

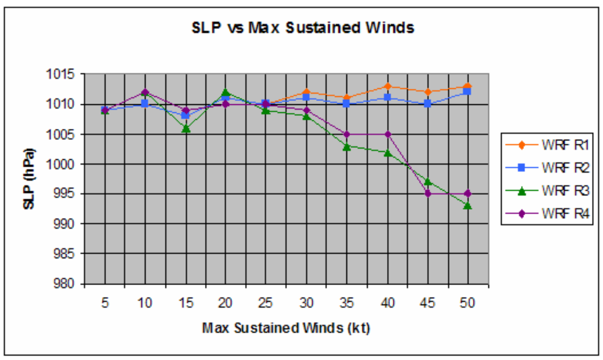


**Figure 7.** WRF runs SLP and wind speed comparison

## 5. FUTURE WORK

Since Meteosat-7 IR satellite images (not shown) give an insight into the precursor of Hurricane Danielle which was associated with a convective system, the interaction of the AEW and MCS will be further analyzed to determine its role in facilitating intensification to a hurricane. Additionally, the WRF model forecast skill in examining the AEW while inland will be studied.

## 6. ACKNOWLEDGEMENTS


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## 7. REFERENCES


Berry, G., Thorncroft, C., and T. Hewson, 2006: African Easterly Waves during 2004 - Analysis using objective techniques. *Mon. Wea. Rev.,* 1-50

Burpee, R. W., (1974): Characteristics of the North African easterly waves during the summers of 1968 and 1969. *J. Atmos. Sci.*, 31, 1556-1570

Burpee, R. W., 1972: The origin and structure of easterly waves in the lower troposphere of North Africa. *J. Atmos. Sci.*, 29, 77–90

Gray, WM., 1968: Global view of the origin of tropical disturbances and storms. *Mon.Weather Rev.,* 96, 669–700

Goerss, J.S. and R.A. Jeffries, 1994: Assimilation of synthetic tropical cyclone observations into the Navy Operational Global Atmospheric Prediction System. *Wea. Forecasting,* 9, 557-576

Jenkins, G., S., 1997: The 1988 and 1990 Summer Season Simulations for West Africa using a regional climate model. *J. Climate*, Vol. 10, No. 6, 1255–1272.

Montgomery, M. T., Farrell, B. F., 1993: Tropical Cyclone Formation. *J. Atmos. Sci.* Vol. 50, No. 2, 285-310

Ooyama, K. V., 1982: Conceptual evolution of the theory and modeling of the tropical cyclone. *J. Met. Soc. Japan*, 60, 369-380

Ritchie, E.A, Simpson, J., Liu, W.T, Velden, C., Brueske, K., Halverson, J., Pierce, H., 2003: A Closer Look at Hurricane Formation and Intensification Using New Satellite Technology, 1-32

Schumacher, C, Houze RA, 2004: Mesoscale Convective Systems over Sub-Saharan Africa and the Tropical East Atlantic. *26$^{th}$ Conf. on Hurricanes and Trop. Meteorol.,* 1-2.

Thorncroft, C., and Hodges, K., 2000: African Easterly Wave Variability and its Relationship to Atlantic Tropical Cyclone Activity, *J. Climate*, 14, 1166-1179