4B.7 AN EVALUATION OF THE MICROPHYSICS FIELDS OF HURRICANE DENNIS (2005) AT DIFFERENT STAGES OF ITS LIFECYCLE

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1. INTRODUCTION

Much work has been done in recent years to collect microphysical data to better understand the processes determining the creation, conversion, and fallout of precipitation particles and its feedback on tropical cyclones. This work is important because these microphysical processes can play an important role in governing the magnitude and distribution of latent heating, which ultimately determines tropical cyclone intensity and rainfall. With the advent of high-resolution numerical models (grid length ≈ 1-2 km), simulations of tropical cyclones can be performed that do not require the parameterization of deep convection, which is a traditional source of uncertainty in determining latent heating distributions. However, the need to parameterize microphysical processes, boundary layer fluxes, and turbulence remains a source of uncertainty in numerical models.

Recent work has involved developing techniques for comparing the statistics of microphysics fields (e.g., vertical motion, hydrometeor concentrations, radar reflectivity) from observations and simulations of tropical cyclones (McFarquhar et al. 2006; Rogers et al. 2006). While such comparisons have revealed consistent differences between the simulations and the observations, they have only been performed on mature hurricanes. There are many differences in the structure and dynamics of weak vs. mature hurricanes which may be reflected in the microphysics fields (e.g., updraft magnitudes, graupel concentrations, convective and stratiform partitioning). Such differences in will lead to differences in the magnitude and distribution of latent heating, which will in turn impact the subsequent development of incipient tropical cyclones. It is thus important to determine these differences and whether numerical models are capable of reproducing them.

2. METHODOLOGY

During July 2005, NOAA and NASA participated in a joint field campaign supporting NOAA's Intensity Forecasting Experiment (IFEX, Rogers et al. 2006) and NASA's Tropical Cloud Systems and Processes experiment (TCSP, Halverson et al. 2006). The joint objectives of these experiments were to improve the understanding of tropical cyclone genesis and intensity change and the role of microphysics in those processes. Two NOAA P-3 aircraft and the NASA ER 2 aircraft were based in San Jose, Costa Rica during July and targeted incipient and developing cyclones in the Caribbean Sea, Gulf of Mexico, and East Pacific. A variety of fields were measured from the aircraft involved, such as particle size spectra from CIP and PIP probes on the P-3's, Doppler velocity and reflectivity from the P-3's and ER-2; temperature and humidity profiles from the ER-2; and flight-level temperature, humidity, and wind fields from the P-3's and the ER-2.

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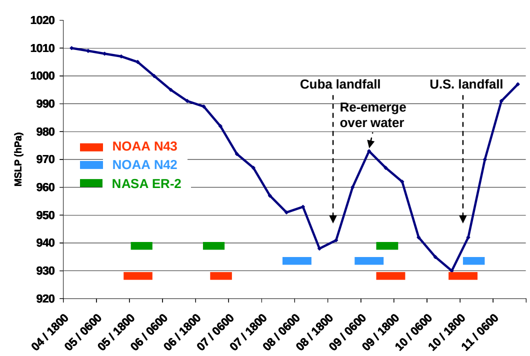
3. HURRICANE DENNIS

One of the tropical cyclones that was sampled during the IFEX/TCSP field campaign was Dennis. Dennis formed in the southeastern Caribbean and tracked through the Caribbean and into the eastern Gulf of Mexico (Fig. 1a),

(a)

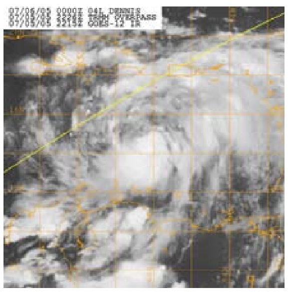


(b)

Figure 1. (a) Track plot of Hurricane Dennis (2005). (Courtesy UW/CIMSS). (b) Plot of time series of best track central pressure for Hurricane Dennis from 18 UTC 04 July to 06 UTC 11 July. Times that storm was sampled by NOAA P-3's and NASA ER-2 are denoted by colored bars.

where its final landfall occurred in the Florida panhandle as a Category 3 hurricane. Dennis was monitored by either the P-3 or the P-3 and ER-2 jointly for almost all of its lifecycle, from the point it was first named a tropical storm until after landfall (Fig. 1b).

Joint P-3/ER-2 flights during the first two days of Dennis' lifecycle, while Dennis was a tropical storm, were targeted for the microphysics experiment. During these two days Dennis was becoming better organized, with areas of cold cloud tops surrounding the developing center of the system (Fig. 2).



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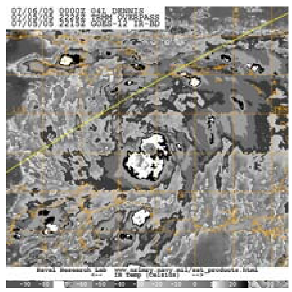

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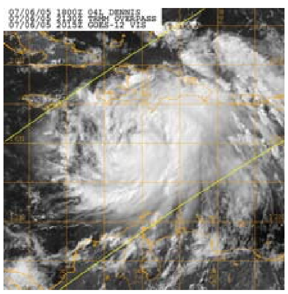

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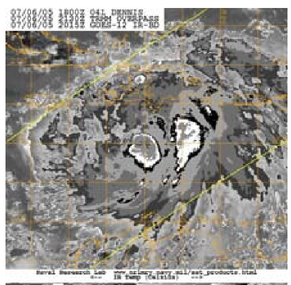
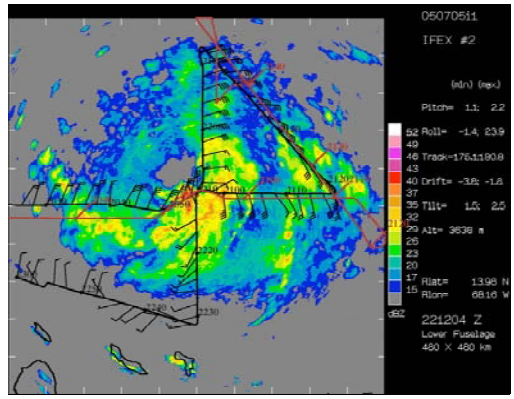


(d)

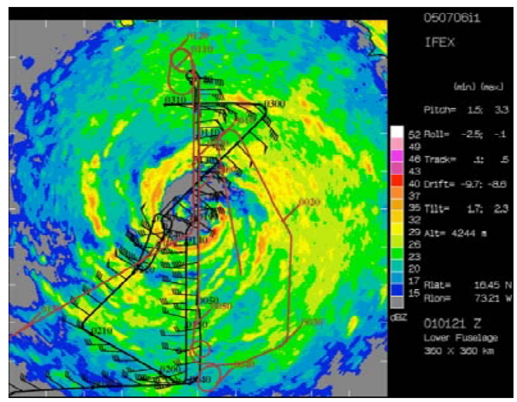
Figure 2. (a) GOES-12 infrared image of Tropical Storm Dennis at 2215 UTC 5 July 2005; (b) As in (a) but for infrared image with BD enhancement curve; (c) GOES-12 visible image of Tropical Storm Dennis at 2015 UTC 6 July 2005; (d) As in (c), but for infrared image with BD enhancement curve. (Courtesy NRL-Monterey).

4. PRELIMINARY RESULTS

Good coordination between the NOAA P-3 and NASA ER-2 aircraft was achieved during the first two days of Dennis' lifecycle (Fig. 3). On 5 July the two aircraft were displaced by about 10 km in the horizontal for much of the pattern and were vertically stacked during the downwind leg of the figure-4 pattern flown by the P-3 (Fig. 3a). An area of convection was located on the east and southeast side of the storm, but there was little organization in the reflectivity pattern. By 01 UTC 7 July (Fig. 3b), the storm was much better organized, and the reflectivity pattern indicated an eyewall had developed on the south side of the center with a principal rainband spiralling out from that point. The P-3 flew a pattern that began at 4.2 km (about +6 deg. C) altitude and ascended to 5.8 km (about -4 deg. C) while maintaining vertical alignment with the ER-2, then repeated the pattern by descending back to 4.5 km. This maneuver was repeated two more times during the



(a)



(b)

Figure 3. Plot of P-3 lower-fuselage reflectivity (shaded, dBZ) from 2212 UTC 05 July for Tropical Storm Dennis. Flight track and times and flight-level winds (m s-1; full barb is 5 m s-1) for P-3 (black) and ER-2 (brown) are overlain. (b) As in (a), but for 0101 UTC 07 July.

pattern. Both the eyewall and principal rainband, with areas of convective and stratiform rain, were sampled by both aircraft during this part of the pattern.

Flight-level data from one portion of the pattern flown on 7 July (Fig. 4) shows various flight-level parameters. Flight-level temperatures were below freezing during the three ascent-descent maneuvers. Wind speeds approached 40 m s^{-1} at flight-level, though surface winds (not shown) remained below hurricane strength. Peak flight-level updrafts were 6 m s^{-1}, while liquid (ice) concentrations exceeded 6 g kg^{-1} (4 g kg^{-1}) in the vicinity of these updrafts. Particle images from the CIP probe (Fig. 5) when the aircraft was at 5500 m (-4 C) indicate a mixture of ice crystals and rimed particles, some with diameters exceeding 1.6 mm.

A plot of P-3 lower-fuselage reflectivity (Fig. 6) at 0131 UTC 7 July shows the eyewall and principal rainband structure that was sampled by the P-3 and ER-2. Reflectivity and Doppler velocity from a portion of the P-3 and ER-2 track centered around 0131 UTC is shown in Fig. 7. Both aircraft sampled the eyewall and rainband feature, though notable differences in resolution are evident. The reflectivity field shows the two cores of precipitation associated with the eyewall and rainband. Ice crystals

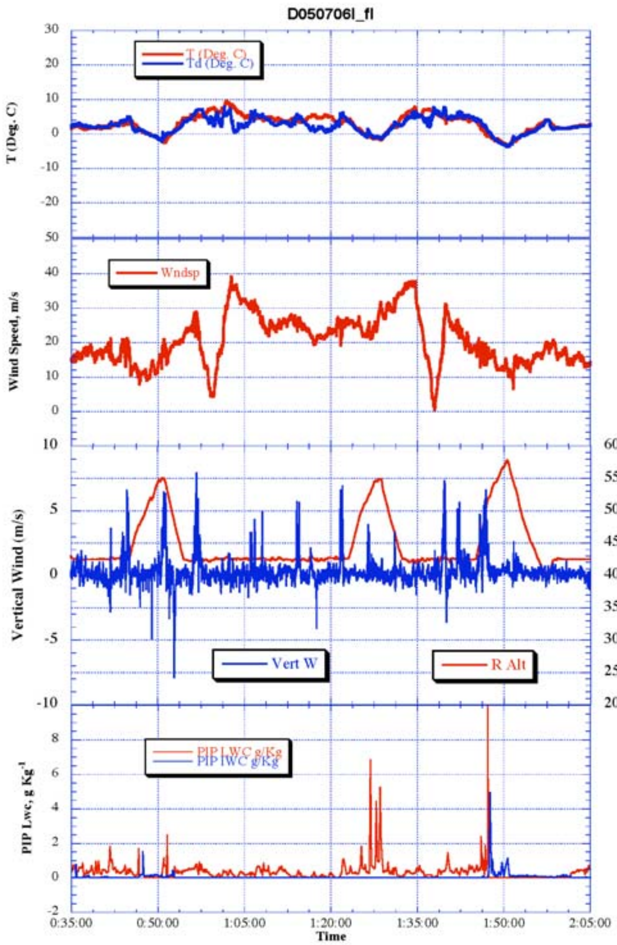


Figure 4. Flight-level values of temperature (deg C), dewpoint (deg C) wind speed (m s^{-1}), vertical velocity (m s^{-1}), radar altitude (m), and PIP liquid and ice water contents (g kg^{-1}) from the NOAA P-3 from 0035 to 0205 UTC 7 July.

within the eyewall extend above 16 km, while the rainband only extends up to 13 km. The Doppler velocities show a pronounced couplet of positive and negative values that slopes outward with height in the eyewall. No coherent vertical motion structure is seen in the rainband from either aircraft.

5. FUTURE WORK

The first task that will be accomplished is to perform a high-resolution (1.67 km) simulation of Dennis using the MM5 model. A standard set of physical parameterizations will be used, including the Tao-Simpson (1993) single-moment 5-class bulk microphysical parameterization scheme and the Blackadar (1982) planetary boundary layer parameterization (other schemes can be tested as well, but this configuration will comprise the control simulation). With a control simulation performed, comparisons will be made between the simulated fields and the observed fields. Some comparisons will be attempted between specific features (e.g., eyewall and rainband structure) in the model and the observations, especially for different periods of Dennis' lifecycle.

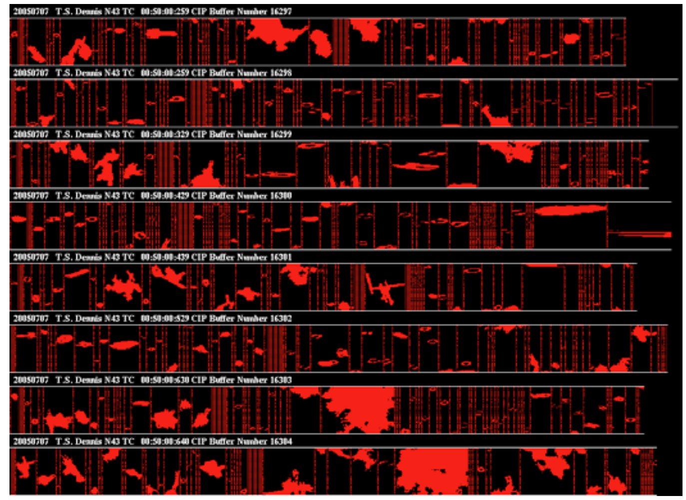


Figure 5. CIP Particle images at 0050 UTC 7 July. Width of each strip is 1.6 mm.

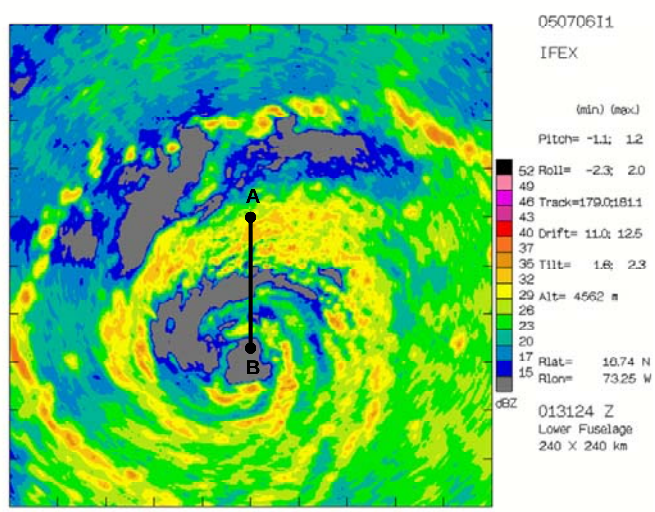


Figure 6. P-3 lower-fuselage reflectivity valid at 0131 UTC 7 July. Line A-B denotes location of P-3 cross section in Fig. 7.

A more robust comparison will arise from comparing the statistics of the microphysics fields from the observations and the simulations. The evaluation methodology described in Rogers et al. (2006) will be performed, which includes comparing the means and distributions of vertical velocity, hydrometeor concentration, and reflectivity, and correlations of vertical velocity and reflectivity. Particular attention will be paid to how well the model reproduces these statistics for the early stages of the lifecycle of Dennis (i.e., 5-7 July) and the late stages of Dennis' lifecycle (i.e., 9-10 July). For the times where the P-3 and ER-2 were vertically stacked, comparisons between the Doppler velocities measured from each aircraft can be made to refine estimates of particle fall speeds, especially around the melting level where graupel is more likely to be present. The limited amount of probe measurements above the melting level can be used to compare the distributions of frozen particles from the observations with the simulated distributions. They can also be used to compare correlations between flight-level vertical velocity and ice concentrations in the observations and the simulations.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

McFarquhar, G.M., H. Zhang, G. Heymsfield, R. Hood, J. Dudhia, J. Halverson, and F. Marks, Jr., 2005: Factors affecting the evolution of Hurricane Erin 2001 and the distributions of hydrometeors: Role of microphysical processes. J. Atmos. Sci., In press.

Halverson, J., M. Black, S. Braun, D. Cecil, M. Goodman, G. Heymsfield, R. Hood, J. Molinari, R. Rogers, C. Velden, E. Zipser, R. Kakar, 2006: NASA's Tropical Cloud Systems and Processes (TCSP) Experiment: Investigating the Genesis and Intensification of Hurricanes, Bulletin of the American Meteorological Society. (submitted).

Rogers, R.F., M.L. Black, S.S. Chen, and R.A. Black, 2006: An Evaluation of Microphysics Fields from Mesoscale Model Simulations of Tropical Cyclones. Part I: Comparisons with Observations. J. Atmos. Sci., submitted.

Rogers, R.F., S.D. Aberson, M.L. Black, P. Black, J. Cione, P. Dodge, J. Dunion, J. Gamache, J. Kaplan, M. Powell, N. Surgi, N. Shay, and E. Uhlhorn, 2006: The Intensity Forecasting Experiment (IFEX): A NOAA Multi-year Field Program for Improving Tropical Cyclone Intensity Forecasts. Bulletin of the American Meteorological Society. (submitted).

Tao, W.-K., and J. Simpson, 1993: The Goddard cumulus ensemble model. Part I: Model description. Terr. Atmos. Oceanic Sci., 4, 35-72.

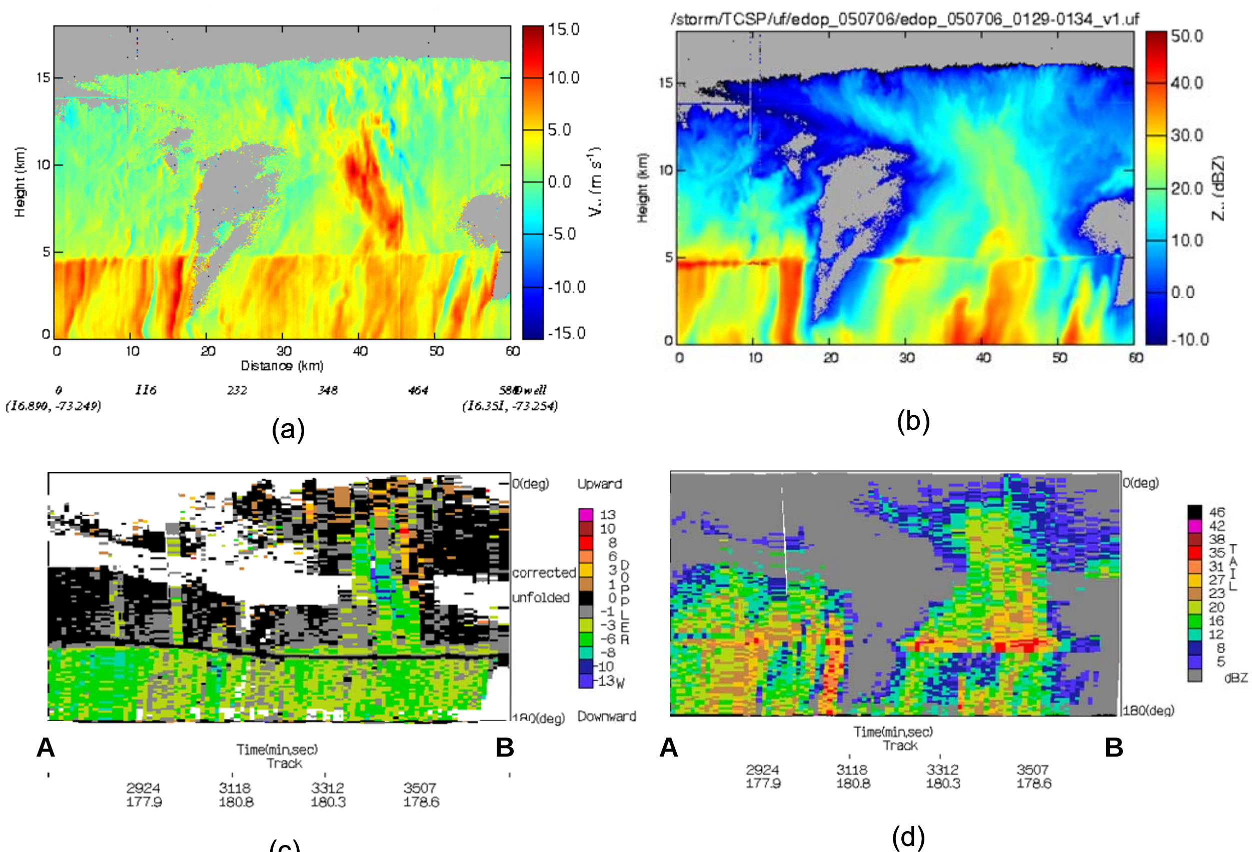

Figure 7. Cross sections of Doppler velocity (shaded, m/s, a and c) and reflectivity (shaded, dBZ, b and d) from 7 July from the EDOP (a and b) and P-3 tail radar (c and d).