The Properties of Convective Clouds Over the Western Pacific and Their Relationship to the Environment of Tropical Cyclones

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LONG-TERM GOALS

The long-term goal of the proposed work is to advance our understanding of the relationship between large-scale and mesoscale environmental conditions and small but powerful convective events during tropical cyclone development and intensity changes. Our ultimate goal is to identify the necessary conditions that determine the formation and evolution of a tropical cyclone.

OBJECTIVES

With the data obtained during ONR's field program of " Tropical Cyclone Structure 2008 (TCS-08)" over the western Pacific region, the objective of this proposed study is to investigate large-scale environmental conditions, mesoscale phenomena and small scale convective bursts as well as their interactions that are responsible for tropical cyclone formation and intensity changes. Specific areas include 1) Characterize the intensity of convection over the western Pacific oceans from radar, aircraft and satellite data; 2) Derive an accurate mesoscale environment of convective systems through the assimilation of satellite, radar, lidar and in-situ data; 3) Evaluate the quality of the global forecast system (e.g. NOGAPS) for accurate tropical cyclone analyses and forecasts; 4) Understand the environmental factors that determine tropical cyclone formation and rapid intensification.

APPROACH

In order to achieve the research objectives of this proposal, our approach integrates observational data analysis, mesoscale data assimilation and forecast evaluations. This includes 1) analyzing TCS-08 field data in conjunction with the available satellite data products from Aqua and TRMM, 2) developing mesoscale data assimilation techniques to assimilate satellite, radar, lidar and in-situ data into WRF/COAMPS mesoscale model(s), and 3) evaluating the performance of global ensemble forecasting to understand the quality of global forecasts and also study the predictability of tropical cyclone formation and evolution. People involved in this project include PI (Dr. Zhaoxia Pu) and her graduate student (Andrew Snyder) as well as NRL collaborators: Drs. Carolyn Reynolds and Allen Zhao.

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14. ABSTRACT
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WORK COMPLETED

Works completed in FY08 include:

(1) Participated in the TCS-08 field program

PI (Dr. Pu), a graduate research assistant (Andrew Snyder) and collaborators all participated the TCS-08 field experiment at the Monterey operation centers during August and September 2008. The purpose of this involvement in the field program is not only to help on the field program missions but also to identify the interesting cases and data for follow-up research.

(2) Airborne Doppler radar data assimilation

Research activities have been conducted to get ready to use the TCS-08 data for proposed study. Specific development has been achieved to examine the impact of the mesoscale assimilation of airborne Doppler radar reflectivity and radial velocities on the forecast of tropical cyclone intensity change.

(3) Track the tropical cyclogenesis and evolution in global forecasts

A software package has been developed to trace the genesis and evolution of the tropical cyclones genesis and evolution in global ensemble forecasts. A preliminary test and study have been conducted to evaluate the performance of the NCEP global ensemble in predicting tropical cyclogenesis. This effort makes the PI and students ready to move on to evaluating the NOGAPS global analysis and ensemble forecasts for the forecast of tropical cyclone genesis and evolution.

RESULTS

(1) *Impact of cloud microphysical processes on the intensity forecast of tropical cyclones: High resolution numerical simulations and Doppler radar data assimilation*

A study by the PI and her graduate student investigated the sensitivity of high-resolution numerical simulations of hurricane rapid intensification to the cloud microphysical processes in the Weather Research and Forecasting (WRF) model. Results indicated that the numerical simulations of hurricane intensity are very sensitive to the choice of the microphysical schemes in the model (Li and Pu 2008). The results also imply that the accurate specification of the microphysical properties in the storm inner core area is very important for hurricane forecasts.

In a follow-up study, airborne Doppler radar reflectivity and radial velocity data, collected from NOAA P-3 aircraft, were assimilated into WRF model to improve the initial specification of cloud microphysics properties and dynamic conditions in the inner core of Hurricane Dennis (2005). Based on the high-resolution numerical simulations, the intensity and inner-core dynamics and thermodynamics are impacted by assimilating the radar data. Specifically, the assimilation of both radar reflectivity and radial velocity data improves the forecasts of Hurricane Dennis's intensity changes, rainfall structures and track (Pu et al. 2008). Figure 1 illustrates the impact of the assimilation of the airborne Doppler radar reflectivity and radial velocity on the forecast of hurricane Dennis' intensity change and precipitation.

With ample experience with the WRF model and its data assimilation system, our recent research effort is moving towards the use of COAMPS model and its data assimilation for studying tropical cyclones.

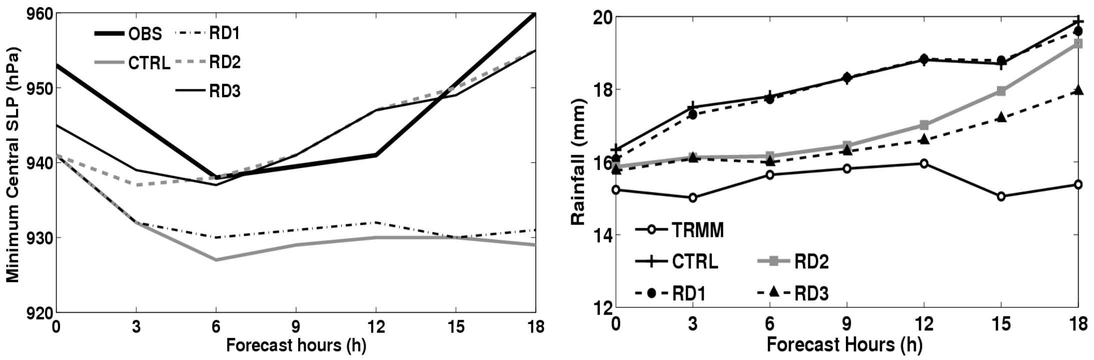

Figure 1: Impact of assimilation of Airborne Doppler radar data on the numerical simulation of the intensity changes of Hurricane Dennis (2005). Time series of observed and simulated minimum Sea Level Pressure (left) and hourly precipitation rate (right) between 0600 UTC 8 and 0000 UTC 9 July 2005. National Hurricane Center best track data (OBS) and rainfall rate from NASA TRMM satellite (TRMM) compared with the experimental forecast results with the assimilation of radar reflectivity (RD1), radial velocity (RD2) and both radar reflectivity and radial velocity (RD3).

(2) Developed a tracking method to trace tropical cyclogeneses in global forecasts

Tracking methods have been developed and tested to trace the formation and evolution of tropical cyclones in global ensemble forecasts. With the GrADS program and NCEP global ensemble forecasting products, we developed a software package to trace the tropical storm genesis and evolution over the ocean. Specifically, we compared various methods to track the storms using different variables (geopotential heights, vorticity maxima and circulation winds) at different pressure levels (925mb, 850mb, 700mb, 500mb). The most efficient method to track the storm genesis and evolution has been identified. Specifically, results indicate that it is easy to trace the strong storms (in terms of tropical cyclone intensity). With any of the aforementioned variables and pressure levels, the results tend to be in agreement. However, with the weak storm (in genesis and tropical depression stages), track results from different variables and levels tend to be diverse, therefore, it is necessary to use combined variables and levels to accurately trace the storm.

(3) Evaluated the predictability of tropical cyclone formation in global ensemble systems.

With the track method developed, work has been conducted to evaluate the ability of the NCEP global ensemble in predicting tropical cyclogenesis over the east Atlantic from cases during August-September 2006. With 7 developing and non-developing wave cases, synoptic and statistical analyses have been performed to investigate the accuracy of tropical cyclogenesis forecast from the NCEP global ensemble. Results indicated that NCEP ensemble forecasting has good skill in predicting the matured storms in terms of their track owing to the implementation of the storm relocation method in ensemble forecasts. However, forecasts of tropical cyclogenesis are very uncertain in the NCEP ensemble based on the case studies. In addition, based on the evaluation, strong waves tend to have a higher probability of genesis. Further investigation also indicates that NCEP ensemble forecasts can be helpful in understanding the factors that influence cyclogenesis. Ensemble spread may well indicate the most uncertain conditions that influence the predictability of tropical cyclogenesis.

Based on the evaluation that has been done with the NCEP ensemble, our effort has moved to evaluate the performance of NOGAPS ensemble forecast in predicting tropical cyclone formation and evolution. NOGAPS ensemble fields from the TCS-08 time period are currently being archived for this purpose.

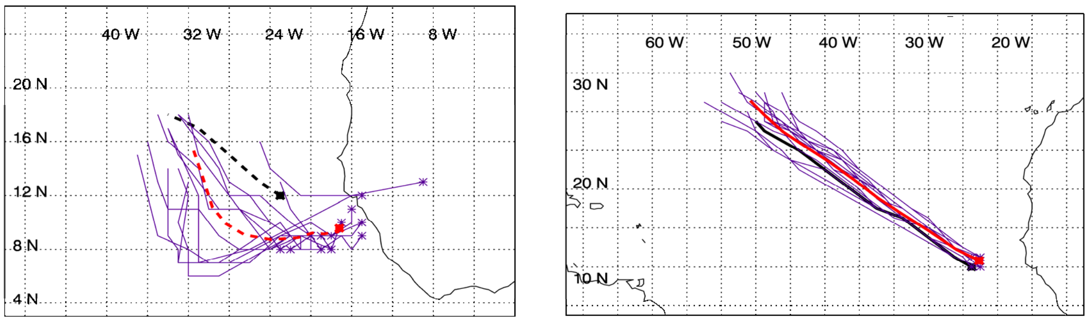

Figure 2: Sample results of storm tracking with NCEP ensemble forecasts. The left panel shows 5-day ensemble forecast from 00UTC 19 August 2006, 66 hours before Tropical Storm Debby's formation. The right panel shows the 5-day ensemble forecast from 0000UTC 22 August 2006, 6 hours after the Tropical Storm Debby's genesis. (Purple: forecasted tracks from 14 ensemble members. Red: ensemble mean track; Black: Actual track)

(4) Field data quality control

We have documented the synoptic background of each field mission during the TCS-08 field program. Quality controls for data assimilation are going to be conducted once the data become available to us.

IMPACT/APPLICATIONS

The development of storm track methods and the study of the impact of radar data assimilation provides significant opportunities to study the environmental conditions of tropical cyclone genesis, evolution and intensification. Evaluation of the performance of ensemble forecasts of tropical cyclone will also be helpful for the future development and improvement of ensemble forecast systems.

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