Development of an HWRF Diagnostics Module to Evaluate Intensity and Structure Using Synthetic Flight Paths Through Tropical Cyclones

Project Description for Visitor Program Opportunity
Development Testbed Center
National Center for Atmospheric Research

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FIG. 1. A satellite image of Hurricane Rita near peak intensity, taken at 1920 UTC on 21 September 2005. Image credit: NASA.

1. Introduction

Much effort has been invested to improve the track and intensity forecasts of the WRF for Hurricanes Model (HWRF). While these efforts have resulted in significant progress, substantial deficiencies remain. Like many other regional hurricane models, many of the modeled storms in HWRF suffer from an overprediction of size. This size overprediction, as well as other variances between the structure of the modeled storm and the real storm, often cause degradation in HWRF's forecasts of track and intensity (which are of primary importance to forecasters). To assess and identify the deficiencies that lead to structural errors, it is necessary to develop alternative verification approaches that go beyond the computation of errors and biases in track and intensity. A plethora of routine aircraft reconnaissance flights are taken each year, as well as targeted research missions. These data provide a wealth of observations of kinematic and thermodynamic quantities in the very storms that HWRF is endeavoring to simulate. To date, such observations have been underutilized in verification efforts, due mainly to the substantial work that must be accomplished in order to compare these observations within a framework that is consistent with HWRF's resolution and its modeled storm location.

This proposal outlines the development of a module to evaluate the intensity and structure of simulated tropical cyclones (TCs) in operational and retro HWRF runs. This will be accomplished by sampling the modeled storms along synthetic flight paths that correspond to the actual aircraft flights that were flown in the real storm. The proposed work supports one of the DTC's main objectives to develop and maintain a community statistical verification system for use by the broad NWP community.

2. Viability of synthetic flight paths for verification

Before developing the proposal idea further, it is important to first consider the value of flight level data for diagnosing symmetric and asymmetric storm structure in TCs. Rogers and Uhlhorn (2008) compared flight level data with surface wind measurements from the Stepped Frequency Microwave Radiometer (SFMR, Uhlhorn et al. 2007) instrument in Hurricane Rita (2005) and found that the amplitude and azimuthal location (phase) of the wavenumber-1 asymmetry of the storm-relative winds varied in time over the course of several days. Powell et al. (2009) have used these data extensively to determine the relationship between the surface radius of maximum winds (RMW) and the flight level RMW in a number of storms. These studies (and many others) show that the aircraft flight level and SFMR data are of sufficiently high quality to quantitatively capture both the details of the primary circulation as well some nuances of the finer-scale structures.

A very recent study (Uhlhorn and Nolan 2011) has demonstrated the viability of using synthetic flight paths in a simulated storm. Their fig. 6, shown here as Fig. 2, shows a standard figure-four (or *alpha*) flight pattern superimposed on a snapshot of the model's wind field. Their fig. 6, shown here as Fig. 3 shows the resulting surface and flight-level wind "observations" that were obtained by temporally and spatially sampling the model storm along the indicated flight path.

While Uhlhorn and Nolan (2011) used the synthetic flight path approach to investigate the representativeness of aircraft-based intensity estimates to the theoretical maximum intensity in a storm, their approach offers some helpful guidance that is relevant to the proposed work. For instance, since the planned implementation of the high-resolution HWRF has an inner mesh spacing of 3 km, it will be necessary to filter the aircraft data from the real storm to match the temporal and spatial characteristics of the synthetic flight paths. Their work

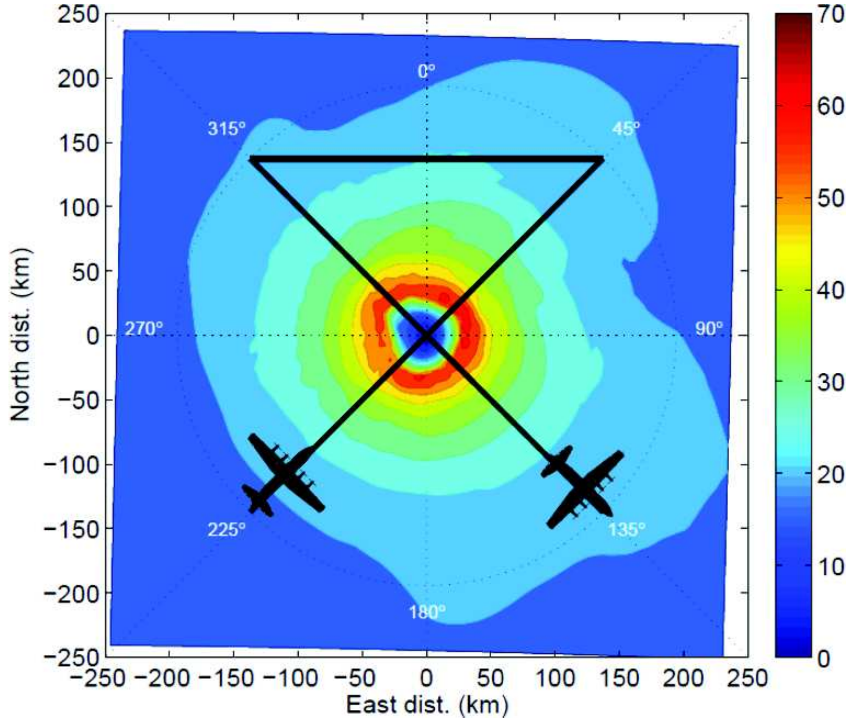

FIG. 2. A standard figure-4 (or alpha) flight pattern superimposed on a snapshot of the model's surface wind field. Reproduced from Fig. 6 of Uhlhorn and Nolan (2011).

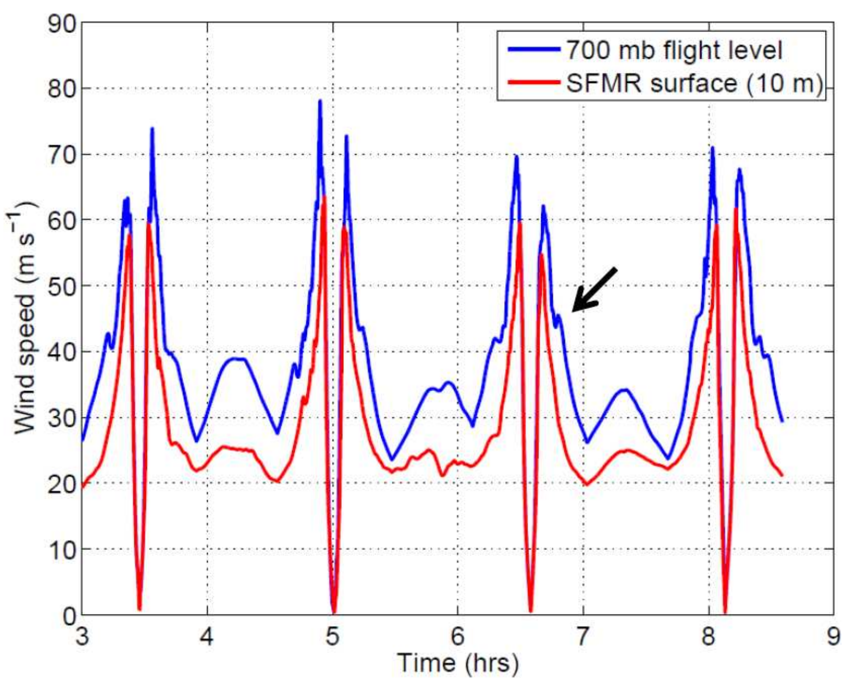

FIG. 3. The resulting traces of surface and flight level wind speed in time, obtained by sampling the modeled storm along the paths shown in Fig. 2. Reproduced from Fig. 8 of Uhlhorn and Nolan (2011).

was conducted in the context of a high resolution idealized simulation, but some of the same filtering methods can likely be employed in the proposed work.

3. Status of aircraft data required to accomplish the proposed work

Due to the variety of aircraft data formats and processing requirements, it is not a trivial task to use the NOAA and Air Force Reconnaissance Reserve (AFRES) aircraft data. To be used effectively in the proposed project, these data will need to be translated from earth-relative coordinates into a reference frame centered on the moving storm. Back in 2008, I spent a couple months developing a prototype code system to read and process the aircraft data. The code I developed can read three of the five main data formats and is able to translate the data into storm-relative coordinates using the wind centers provided by the Hurricane Research Division (HRD; the wind centers are obtained using the method of Willoughby and Chelmow 1982). I also developed an algorithm to automatically parse the full flight level data into radial legs; having the data processed into radial legs greatly simplifies the task of comparison with model data. Fig. 4 shows a summary of all available aircraft data for Hurricane Dennis (2005), processed into radial legs by this prototype code system. Of course, an actual verification comparison would probably just compare one aircraft leg to one model leg at a time.

The development of the data-processing code has been on hold for the past few years as I worked on other projects, but during the first half of 2012, I plan to develop the readers for the other two data formats and finalize the last steps needed to process the aircraft data into a structured data set. I must do this work to lay the groundwork for another proposal I plan to submit next summer, so I am confident that these tasks will be completed prior to the commencement of work for this proposed DTC work.

4. Expected outcomes

The expected outcome of this work is a prototype verification module that will conduct an extensive comparison between any given HWRF model run and the aircraft data that were taken in the actual storm. Given a specific real-time or retro model run, the module will determine the range of dates spanned by the HWRF simulation and then query a library of previously processed aircraft flight data. If matches are found, the module will then sample the model forecast fields along the actual flight paths that were flown in the real storm, but translated relative to the moving center of the model storm. The most challenging technical aspect of this work will probably be the development of the code that samples the fields of the model storm across the multiple nests.

The module will generate a comprehensive suite of plots that summarize the similarities and differences between the model storm and the actual storm. Variables to be compared at flight level include the tangential and radial wind components, the thermodynamic quantities of temperature, dew point temperature, and relative humidity, and possibly some microphysical quantities. The simulated surface wind speed will also be compared against SFMR measurements. Computations will also be made of the model's azimuthally-averaged storm structure to explore the possibility of using other more robust metrics than the standard 1-min maximum wind speed. If time permits, more advanced diagnostics will be computed, such as vorticity and inertial stability.

I expect that completion of the above tasks will require the full two months of PI-salary support offered

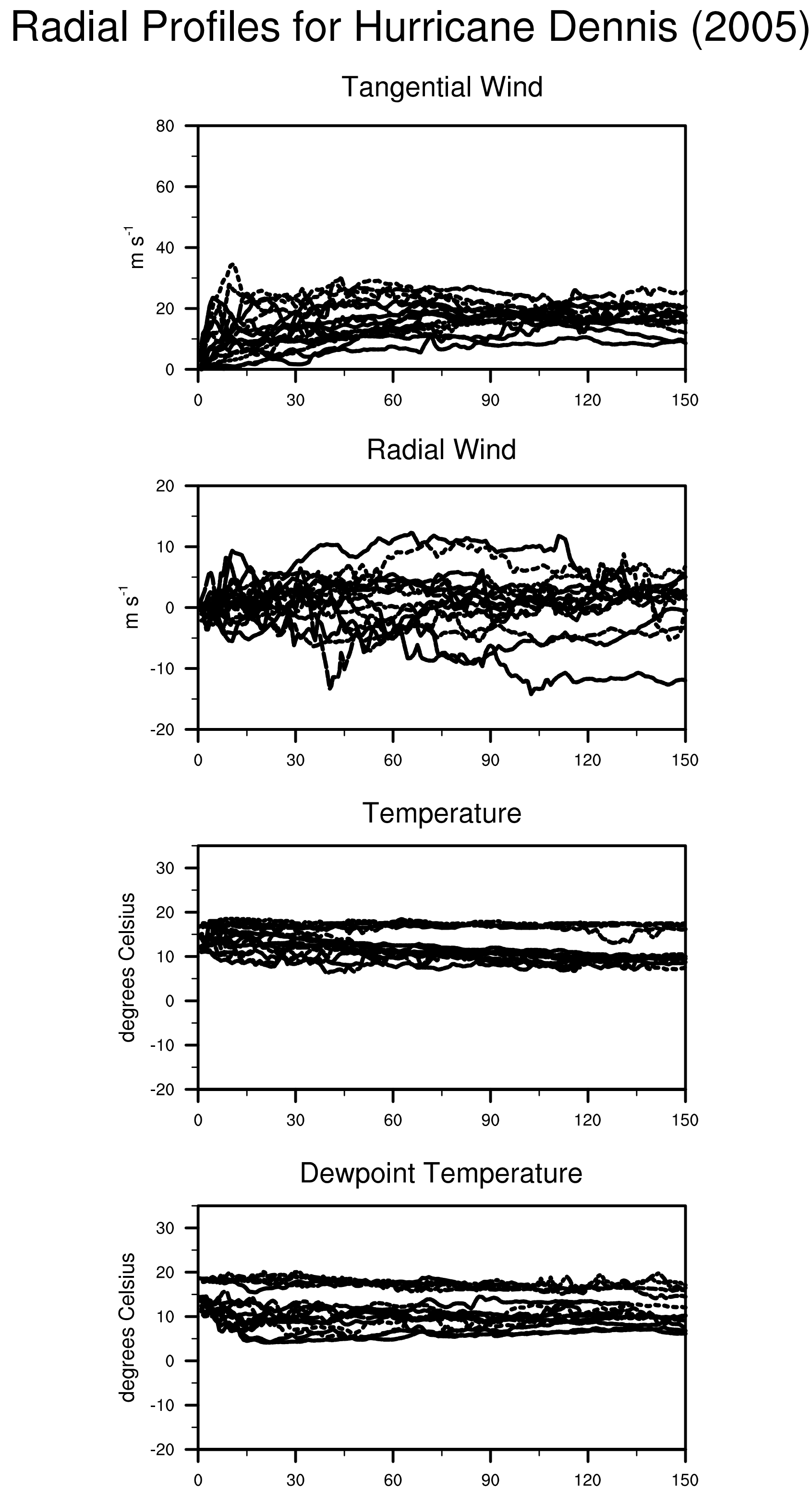

FIG. 4. Example of radial profiles various quantities at flight level for all available aircraft data from Hurricane Dennis (2005). From top to bottom, panels show the tangential wind, the radial wind, the temperature, and the dew point temperature.

through this opportunity, however, I believe it will be a relatively straightforward task to work with DTC personnel to turn this prototype module into a complete stand-alone module that could be offered as part of DTC's wider community verification efforts.

5. Computational Resource Requirements

a. Processing

The processing required to accomplish this project can be served by a robust multi-core workstation. The computer I am already using here at NCAR is suitable for this purpose. I do not expect anticipate any need for time on the supercomputer.

b. Disk Space and Storage

The aircraft data sets and comparable synthetic observations obtained from the model may eventually require several hundred gigabytes of data storage, but I do not expect the need for mass storage space (other than for backup purposes). I would request that the workstation computer that is set up for this purpose have two 1 TB hard drives.

6. Summary

The completion of this work should greatly enhance our ability to diagnose deficiencies in the HWRF model. By moving beyond track and intensity to compare the kinematic and thermodynamic characteristics of simulated storms to actual storms, model developers should gain new insights into the paths they can take to address these deficiences, resulting in more accurate HWRF simulations, and ultimately leading to improved hurricane forecasts.

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