Impacts of Turbulence on Hurricane Intensity

Yongsheng Chen
Department of Earth and Space Science and Engineering
York University, 4700 Keele Street, Toronto, Ontario, M3J 1P3
Phone: (416) 736-2100 ext.40124 FAX: (416) 736-5817 E-mail: yochen@yorku.ca

Richard Rotunno, and George H. Bryan
NCAR, P.O. Box 3000, Boulder, CO 80301-3000, USA
Phone: (303) 497-8904 FAX: (303) 497-8181 E-mail: rotunno@ucar.edu

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LONG-TERM GOALS

Our recent studies have found that hurricane boundary layer turbulences, which can only be parameterized in the current weather-prediction models, play significant roles in controlling the hurricane intensity. The long-term goal of this project is thus to improve the hurricane intensity forecast by developing a more physically based turbulence parameterization scheme.

OBJECTIVES

The turbulence effect on the hurricane intensity can be quantified only if the turbulences can be resolved in the numerical models. One objective of the current project is to perform a set of large-eddy simulations with increasing resolution until the statistics are converged. These simulations will then be analyzed to estimate eddy-diffusion coefficients for use in weather-prediction models.

APPROACH AND WORK PLAN

Because of the multi-scale nature of hurricanes, the proposed large-eddy simulation work is also a challenging computational problem. A three-dimensional research cloud model (CM1) with horizontal grid stretching capability is used to conduct convergence test. The Weather Research and Forecasting (WRF) model is used as a weather-prediction model to examine the eddy-diffusion coefficients obtained from CM1 simulation in both idealized and real-data hurricane cases.

The PI, Dr. Yongsheng Chen, will analyze the existing high-resolution WRF simulations, implement the findings from WRF and CM1 simulations in new real-data WRF retrospective forecasts, and supervise a graduate student as part of this project.

Dr. George Bryan, the developer of CM1 model, will conduct numerical simulation and analysis of idealized hurricanes using the CM1 model.

Dr. Richard Rotunno will synthesize WRF and CM1 simulations and design a new radial-turbulence parameterization scheme of weather-prediction models with typical resolution of O(1km).

Due to delays in funding availability in the PI's institute and in recruiting graduate student, the Year-1 work plan was revised: estimating turbulence length scales (l_h) from ARW and CM1 models at eddy-resolving resolution was postponed; effects of turbulence parameters at typical model resolutions were conducted (original Year-2 plan); variations of environmental factors such as temperature and humidity profiles, and sea-surface temperature (SST) associated with the hurricane rapid intensity change were investigated (original Year-3 plan).

In the coming year, convergence test using CM1 will be performed. Large-eddy simulations using ARW and CM1 models will be analyzed to determine the turbulence length scale, which will then be used in WRF model simulations of idealized hurricanes. Typical environmental temperature and humidity profiles and SST obtained in Year-1 will be used to initialize the idealized simulations.

WORK COMPLETED

Computing time was acquired at a supercomputing center in Ontario, Canada (SHARCNET: www.sharcnet.ca). The WRF and CM1 models being used for the idealized simulations were tested and optimized for their computer hardware. Several diagnostic calculations were added into the distributed-memory code of CM1 so that the most important analyses for this study are now done during model integration, which will prevent time-consuming analysis of large data files after the simulations are completed. A large number of simulations were conducted using CM1 with 1-km horizontal grid spacing to test the effects of horizontal turbulence length scale (l_h) and surface drag coefficient (C_D) at typical model resolution; these simulations are being used to configure the high-resolution statistical convergence tests that will begin soon. A conference paper (Bryan et al. 2010) was written using these preliminary results, and a formal journal article is being drafted.

About one million temperature and humidity profiles retrieved from Global Position System (GPS) observations during 4 hurricane seasons (2006-2009) were acquired and processed. These profiles along with the gridded sea-surface temperature data were analyzed for every Atlantic storm in the 4-year period.

RESULTS

The 3D simulations conducted so far have confirmed the overall results obtained with a much simpler (2D) model published previously by Bryan and Rotunno (2009). Specifically, we find that *maximum* hurricane intensity is very sensitive to parameterized turbulence in the horizontal direction; maximum intensity varies by a factor of 2 when using previously used formulations of turbulence. Furthermore, hurricane intensity in the 3D model can easily exceed that of the strongest storm ever observed, consistent with the 2D model, but only when the turbulence model is made ineffective.

We also find new results that are challenging existing theories on hurricane intensity. Compared to the 2D model, the 3D model produces weaker hurricanes (by ~20% in terms of wind speed) and the 3D model usually takes longer to obtain peak intensity. These results are contrary to conclusions reached recently by other investigators (e.g., Montgomery et al. 2009, 2010). Given our carefully constructed methodology (which uses the same equations and numerical techniques in the 2D and 3D versions of the model), we think the slower overall development and weaker maximum intensity is physically realistic, and is mostly attributable to mixing between the eye and eyewall. Specifically, we find that the 3D model resolves mesoscale vortices (that cannot be produced in 2D models) that mix momentum between the eye and the eyewall, ultimately "spinning up" the eye at the expense of momentum in the eyewall (where maximum winds are located). Previous studies have focused more on the thermodynamics of the eye-eyewall exchange process, but we suspect that the exchange of momentum results in a net weakening of hurricanes that exceeds any potential strengthening from thermodynamic turbulent exchange. A conference paper was submitted with these results and conclusions (Bryan et al. 2010) and another set of idealized runs are being constructed to further evaluate these conclusions.

From the large scale perspective, the analyses of GPS soundings show that hurricane ambient temperature profiles averaged over the hurricane seasons are close to moist neutral. But they differ by 2-3 degrees among different categories. Preliminary results also show that rapid intensity change tends to occur at a preferred SST range.

IMPACT AND APPLICATIONS

Quality of Life

The ultimate goal of this study is to improve hurricane prediction. Accurate hurricane track and intensity forecasts are crucial to effective protection of people and property.

Specifically, our current results are significant because they have a direct impact on how real-time hurricane forecasting models are designed. The horizontal turbulence parameterization in real-time models is usually configured based on trial-and-error or from theoretical studies that may not apply to hurricanes (e.g., Smagorinsky 1963). Our work is leading towards a physically justifiable turbulence parameterization for real-time models, such as the WRF model that is being used by researchers and forecast centers world-wide.

TRANSITIONS (For the 4 NOPP evaluation factors below, please describe how the results (hardware, software, knowledge) are being utilized by others. Transition is taken to mean, "products which are being incorporated into more developmental (or operational) programs or have already been incorporated in other's plans.")

RELATED PROJECTS

REFERENCES

Please list references associated with this effort.

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PUBLICATIONS

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