THE IMPACT OF LIGHTNING ON INTENSITY FORECASTS USING THE HWRF MODEL: IDEALIZED TROPICAL CYCLONE

293554

Keren Rosado*
Howard University NOAA/EPP/GRTS Fellow, Washington, DC/Collage Park, Maryland
Vijay Tallapragada
NOAA/NWS/EMC/GCWMB, Collage Park, Maryland
GregoryJenkins
The Pennsylvania State University, University Park, Pennsylvania
Lin Zhu
NOAA/NCEP/EMC, Collage Park, Maryland

1. INTRODUCTION

Due to the low confidence when forecasting intensity and trajectory of tropical cyclones The National Oceanic and Atmospheric Administration (NOAA) created the Hurricane Forecast Improvement Project (HFIP) in 2010 with the ten-year goal of improving tropical cyclone intensity and track forecasts by 50% for days one through five. Part of this goal is to improve forecast of the tropical cyclone rapid intensification. In order to contribute to this goal, we have investigated the role of lightning during the life cycle of a tropical cyclone using the Hurricane Weather Research and Forecast (HWRF) hurricane model.

Previous research done by Price at al. (2009), Pan et al. (2010; 2014) Thomas et al. (2010); DeMaria et al. (2012), and Fierro et al. (2015) show that there is a correlation between lightning and intensity changes in tropical cyclones. The association between lightning and intensity changes allows us to use lightning as a proxy to calculate tropical cyclone intensity changes. Some of the microphysics associated with lightning and tropical cyclones are graupel and hail located in the "charging zone". When the amount of these two microphysics variables increases in a tropical cyclone, refractivity values increase indicating strong updrafts. It is in the areas of high refractivity where we have more probability of lightning MacGorman et al. (1989); MacGorman and Rust (1998).

This study will evaluate the implementation of a lightning parameterization into Hurricane Weather Research and Forecast (HWRF) operational.

**Corresponding author address:* Keren Rosado, PhD student. Dept of Atm Science Howard University, NOAA/EPP/GRTS Fellow /NOAA/NWS/NCEP/EMC University Research CT Cubicle 2783 College Park, MD 20740; e-mail: keren.rosado@noaa.gov

The case study that will be analyzed and evaluated is an HWRF Idealized Tropical Cyclone. The hypothesis is that an improvement in the forecast of lightning may lead to corresponding reductions in the HWRF hurricane model intensity bias.

This research is designed to address the following two questions: "How well does the HWRF model forecast lightning spatial distributions before, during, or after tropical cyclone intensification?" and "What is the functional relationship between atmospheric moisture content, lightning, and intensity in the HWRF model?" In order to address these questions a lightning parameterization called
the Lightning Potential Index (LPI) was implemented into the HWRF model.

2. METHODOLOGY

2.1 Hurricane WRF

HWRF operational computer model is atmospheric – ocean model non-hydrostatic fully compressible with 61 atmospheric vertical levels and model top 2hPa Tallapragada et al. (2014;2015). The HWRF model provides high-resolution real time tropical cyclone forecasts for the Atlantic, Eastern Pacific and West Pacific Oceans. This model was designed based on the Weather Research and Forecast system (WRF) Tallapragada et al. (2014;2015) and the Geophysical Fluids Dynamics Laboratory (GFDL) hurricane model. HWRF is composed of one outer domain 80° x 80° (18km) with grid spacing of 0.135° with two-way movable nested grids that follow tropical cyclones i.e. intermediate domain 12° x 12° (6km) with a grid spacing of 0.045° and cloud resolving domain 7.1° x 7.1° (2km) with a grid spacing of 0.015°.

2.2 Lightning Parameterization

The LPI is the measurement of the potential for charge generation and separation that leads to lightning flashes in a convective thunderstorm between 0°C and -

20°C, where the charge separation is driven by collisions of ice and graupel particles in the presence of supercooled water that is most effective Saunders (2008); Yair et al.(2010). The LPI is calculated by using simulated grid-scale vertical velocity and simulated hydrometeor mass mixing ratios of liquid water, cloud ice, snow, and graupel.

2.2.1 Lightning Parameterization: The Implementation

The LPI code was implemented into the Thompson Microphysics into the HWRF model. The LPI is a 2D variable calculated by using mixing ratios of: liquid, ice, snow, and groupel. All this mixing ratio (kg/kg) values are coming or calculated in Thompson Microphysics. Other variables used in LPI calculation are: vertical velocity, temperature, height, t_base, and t_top. Variables added to the Thompson microphysics in order to be able to calculate the LPI were: liquid mixing ratio, z-full, t_base=273.15, t_top=253.15.
After the variables that were needed were added to the Thompson Microphysics the LPI variable was added to the following HWRF codes: Registry, module_michrophysics_driver.F, module_PHYSICS_CALLS.F, and solve_nmm.F.

3. CASE STUDY

3.1 Idealized Tropical Cyclone

The idealized tropical cyclone in the HWRF model is set up as the operational HWRF i.e. with three domains: 18, 6 and 2 km but with the exception that there is no ocean coupling and the sea surface temperature is constant (302 K). Initial conditions are generated from a vortex superposed on a base state inactive sounding and from GFS (WPS). Initial intensity is set up as 20 m/s and radius of maximum winds are at 90 km. The initialization of the idealized vortex is done by the calculation of a nonlinear balance equation in pressure based sigma coordinates. This equation is solved into a in a rotated latitude longitude in an E grid Lateral boundary conditions are the same as the ones used for a real case Tallapragada et al. (2015. In this particular case study the microphysics were changed from Ferrier-Aligo to Thompson microphysics.

3.2 Experimental Design

A 120 hour simulation of two Idealized tropical cyclones e.g. Idealized tropical cyclone and Idealized tropical cyclone with lightning parameterization has been conducted to evaluate the evolution of the spatial distribution of lightning location and density.

4. RESULTS AND CONCLUSIONS

Output from the Idealized HWRF tropical cyclone has been analyzed and compared to an Idealized HWRF tropical cyclone with lightning parameterization. Preliminary results from this investigation show: the implementation of the LPI did not affect the model forecast as expected Fig 1: Top. i.e. the LPI is a diagnostic tool; a correlation between lightning and intensity changes exist; the potential for lightning increases to its maximum peak hours prior to the idealized tropical cyclone reaching it maximum speed Fig 1: Bottom. Future work following this implementation includes the analysis of the following real cases in the Atlantic: Hurricane Earl 2010, Tropical Storm Fiona 2010, Hurricane Igor 2010, and Hurricane Joaquin 2015. In the West Pacific Hurricane Patricia 2015 will be analyzed as well. Results from this investigation will improve our knowledge of the mechanism behind lightning as a proxy for tropical cyclone steady state intensification and tropical cyclone rapid intensification forecast, consequently, moving a step closer to achieving NOAA's goal of reducing the intensity error by 50% for days one through five.

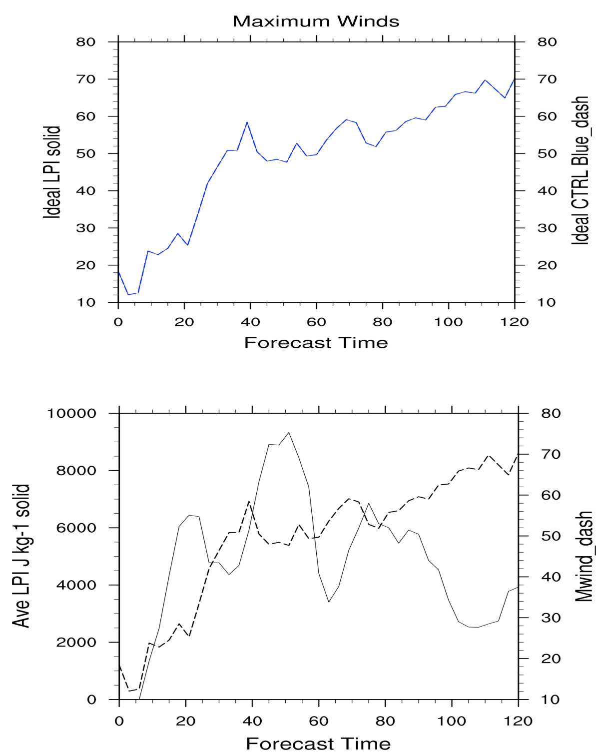

Figure 1. One hundred and twenty hours simulation of an idealized tropical cyclone using HWRF. Top: Time series comparison of the maximum winds calculated in the Ideal_CTRL and Ideal_CTRL experiments. Bottom: LPI values versus (solid line) the maximum winds calculated in the Ideal_LPI experiment (dash line).

5. REFERENCE

DeMaria, M., R.T. DeMaria., J.A. Knaff., D. Molenar, 2012: Tropical Cyclone Lightning and Rapid Intensity Change. *Mon. Wea. Rev*., 140, 1828-1842.

Fierro, A.O., E.R. Mansell, C. L. Ziegler, D. R. MacGorman, 2015: Explicitly Simulated Electrification and Lightning within a Tropical Cyclone Based on the Environment of Hurricane Isaac (2012). *J . Atmos. Sci.,* 72*,* 4167–4193*.*

MacGorman, D. R., and W. D. Rust, 1998: The Electrical Nature of Storms. Oxford University Press, 422 pp.

MacGorman, D. R., D. W. Burgess, V. Mazur, W. D. Rust, W. L. Taylor, and B. C. Johnson, 1989: Lightning rates relative to tornadic storm evolution on 22 May 1981. *J. Atmos. Sci*., 46, 221–251.

Price, C., M. Asfur, and Y. Yair, 2009: Maximum hurricane intensity preceded by increase in lightning frequency. *Nature Geoscience.,* 2, 329-332.

Pan, L., X. Qie, D. Liu, D. Wang, and J. Yang, 2010: The lightning activities in super typhoons over the Northwest Pacific. *Sci. China Earth Sci*., 53, 1241–1248.

Pan, L., X. Qie, and D. Wang, 2014: Lightning activity and its relation to the intensity of typhoons over the Northwest Pacific Ocean. *Adv. Atmos. Sci*., 31, 581–592.

Tallapragada, V., L. Bernardet, M. K. Biswas, I. Ginis, Y. Kwon, Q. Liu, T. Marchok, D. Sheinin, B. Thomas, M. Tong, S. Trahan, W. Wang, R. Yablonsky, X. Zhang, 2015: Hurricane Weather Research and Forecasting (HWRF) Model: 2015 Scientific Documentation, 113 pp.

Tallapragada, V., C. Q. Kieu, Y.C. Kwon, S.G. Trahan, Q. Liu, Z. Zhang, and I.-H. Kwon, 2014: Evaluation of Storm Structure from the Operational HWRF Model during 2012 Implementation. *Mon. Wea. Rev.,* 142, 4308–4325.

Thomas, J. N., N. N. Solorzano, S. A. Cummer, and R. H. Holzworth, 2010: Polarity and energetics of inner core lightning in three intense North Atlantic hurricanes. *J. Geophys. Res*., 115, A00E15.