10C.4 The Role of the WISHE Mechanism in Rapid Intensification of Tropical Cyclones

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1. Introduction

The rapid intensification (RI) of tropical cyclones (TCs) is one of the important processes affecting the TC intensity evolution and remains a big challenge in TC intensity prediction. RI was defined when a TC intensifies by more than 30 kt (15.4 m s^{-1}) during 24 hours (Kaplan and DeMaria 2003) or the minimum sea level pressure in the storm center falls more than 42 hPa in one day (Holliday and Thompson 1979). In addition, the swirling wind fields of TC usually expand or intensify during RI since in this period TC intensifies significantly. The role of the wind-induced surface heat exchange (WISHE) mechanism are worth of close examination since the mechanism describes the positive feedback between the surface wind speed and the surface energy flux.

The idea of WISHE mechanism in TC was proposed by Rotunno and Emanuel (1987) and Emanuel (1989). First, a finite-amplitude tropical disturbance is essential, and the accompanied sufficient strong heat fluxes (which are proportional to surface wind speed) can effectively support the development of the disturbance. Then the surface wind speed can intensify, followed by the strengthening of the surface heat fluxes. Further amplification of the vortex will proceed through this positive feedback. In this study, how the increasing surface wind and heat fluxes at the air-sea interface affects RI is investigated.

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2. Methodology

The Advanced Research Weather Research and Forecasting (WRF, version 3.6.1) model is used in this study to conduct simulations associated with Typhoon Megi (2010). The sizes of the three domains are 334×250 (d1), 181×181 (d2), and 301×301 (d3), with a grid spacing of 12, 4, and 1.33 km, respectively. A 96-hour simulation is carried out from the initial time at 0000 UTC 15 October 2010 (0 h) to the final time at 0000 UTC 19 October 2010 (96 h). The topography of Philippines is removed to reduce the effect from the terrain. There are 35 eta levels with more condensed levels in the boundary layer. The physics parameterization schemes used in this study include the WSM6 microphysics scheme, the Rapid Radiative Transfer Model scheme for long wave radiation, the Dudhia scheme for short wave radiation, the YSU planetary boundary layer scheme, and the Kain-Fritsch scheme in d1.

To examine the sensitivity of RI to surface heat fluxes (hereafter referred to as the WISHE mechanism), in sensitivity experiments, the surface wind is capped at several designated values in the calculation of total surface heat fluxes in the whole domain to suppress the WISHE feedback. The values of the designated value are set at 20, 15, and 10 m s^{-1}. Each sensitivity experiment also starts to be simulated at 0000 UTC 15 October 2010. The method to suppress WISHE mechanism in this work is the same as in the related works (e.g., Montgomery et al. 2009; Zhang and Emanuel 2016). With only one variable revised to suppress the WISHE mechanism, this method provides a simple way to examine the role of the WISHE mechanism in SEF. In total, a control experiment (CTL) with an identified RI period and three sensitivity experiments (CAP-20, CAP-15, and CAP-15, the number indicates the value of the capped wind speed) with suppressed surface heat fluxes are conducted in this work.

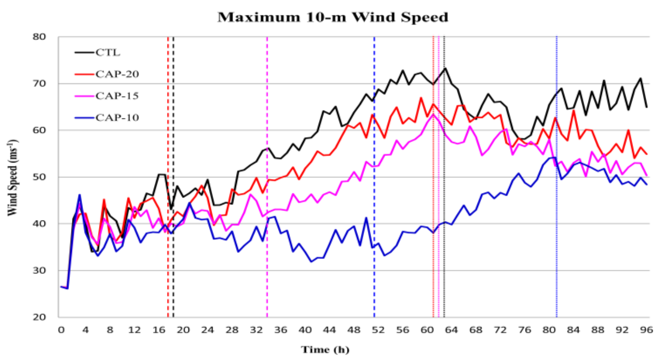

Figure 1. The evolution of the maximum 10-m wind speed in all the experiments. Different color correspond to different experiments. The dash lines indicate the start time of RI, and the dot lines indicate the ended time of RI.

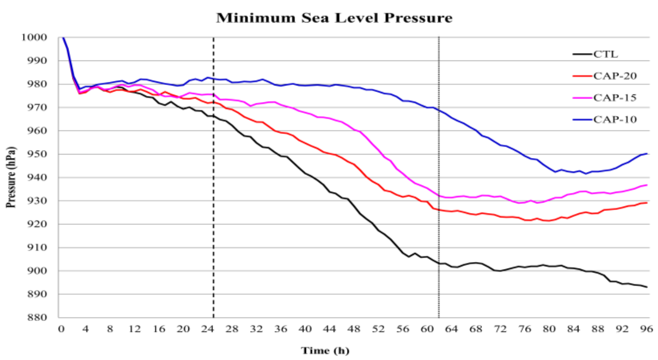

Figure 2. Same as Figure 1 but for the minimum sea level pressure.

3. Results

Figures 1 and 2 show the intensity evolution of all experiments. In Figure 1, the definition of RI follows the criteria of the increase of the maximum 10-m wind speed, while in Figure 2 the criteria of the minimum sea level pressure is adopted to identify the RI period. Interestingly, storms from the wind-capped experiments reach the criteria of RI with the increase of the maximum surface wind speed by more than $15 ms^{-1}day^{-1}$, but fail to achieve the criteria in terms of the deepening of the minimum sea level pressure by more than 42 hPa during one day. Analyses show that the warm core in the TC center in sensitivity experiment is weaker and shallower than that in CTL, as the establishment of the warm core is important to the deepening of the sea level pressure during RI period (e.g., Chen and Zhang 2013). The strength of the vertical velocity is also weaker in the sensitivity experiment than that in CTL, especially the downward vertical motion. From the potential temperature budget in this work, it is found that downward vertical motion dominates the increase of the potential temperature in the TC center, while regions of increasing potential temperature extend from 3 to 16 km height (not shown).

In addition, analyses show that suppressing the WISHE mechanism in the sensitivity experiments can affect the thermodynamic environment and the convective-scale processes: for instance, lower convective available potential energy, less active convective convection (including convective bursts and weak-to-moderate convection), weaker warm core, and shallower inflow in the boundary layer. However, characteristics related to RI (e.g., active weak-to-moderate convection, diabatic heating in high inertial stability area around the inner core region) can be found in all experiments.

4. Summary

In this study, the role of the WISHE mechanism in RI is evaluated. Suppression on the WISHE feedback leads to delayed RI and shorter RI period. Moreover, the peak intensity (both minimum sea level pressure and maximum 10-m wind speed) is also reduced in the WISHE-capped experiments. Although several RI-related features (e.g., strong vertical motion in the inner core region prior to RI) are found in all experiments, capping the WISHE mechanism causes weaker and shallower warm core in the core region in the sensitivity experiments. The above results have pointed out the crucial role of the WISHE feedback in RI. Further in-depth examinations remain to be carried out.

5. References

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