A Modeling Study of the Effects of Vertical Wind Shear on the Raindrop Size Distribution in Typhoon Nida(2016)

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Introduction

The effects of vertical wind shear (VWS) on the raindrop size distribution in tropical cyclone (TC) are investigated based on the theoretical analyses (Fig.1a) that intense VWS, which commonly appears in the lower layers of TCs, can enhance the collisional breakup of raindrops.

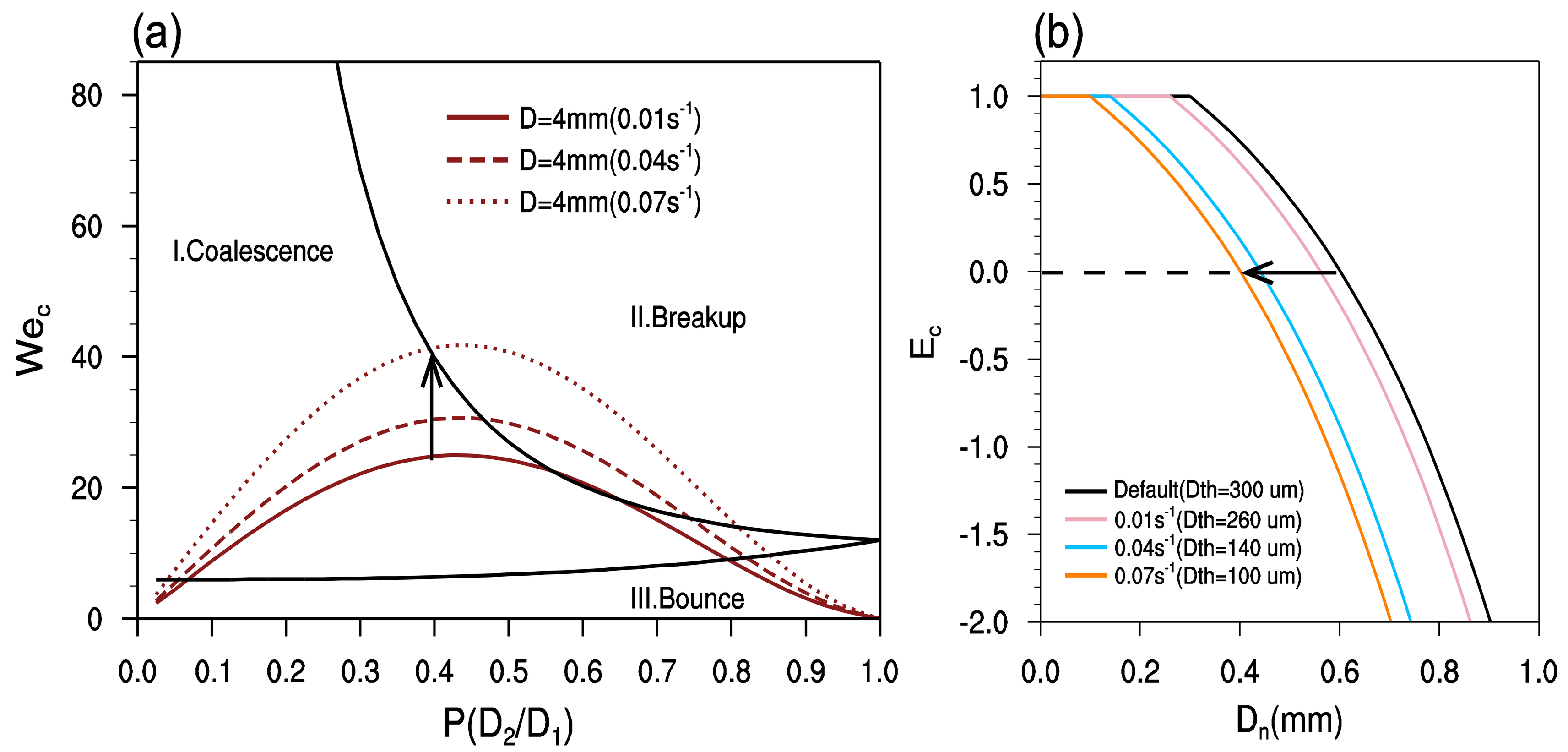

Fig. 1 (a) Regime diagram for the binary raindrop collision outcomes adopted from Testik (2009). The solid, long and short dashed brown lines denote the collisional Weber number determined by the horizontal speed difference between a 4-mm (D1) raindrop and a raindrop ranging from 0.1 to 4-mm (D2) under low (0.01 s^{-1}), moderate (0.04 s^{-1}), and high (0.07 s^{-1}) shears, respectively. The black vertical arrow indicates the shift of collision outcome from coalescence regime to breakup regime due to the increasing vertical wind shear. (b) Raindrop collection/breakup efficiency E_c as a function of number-weighted mean raindrop diameter for the default and modified breakup parameterization in Morrison microphysics.

Method

The raindrop collection/breakup efficiency (E_c) is modified based on the above theoretical analyses. A simple linear function as Eq.1 is proposed to represent the effect of VWS on the threshold of raindrop breakup (D_{th}, at which the breakup begins to occur). Its value is a constant of 300 μm in the original Morrison microphysics (Fig. 1b).

$$E_c = 1, D_n < D_{th}$$

$$E_c = 2 - \exp[2.3 \times 10^{-3}(D_n - D_{th})], D_n \geq D_{th}$$

$$where\ D_{th} = max(300 - 4000 * VWS, 100) \quad \text{Eq. (1)}$$

Results

- Unrealistic large raindrops are produced using the default Morrison microphysics (**CTRL**). A clear decrease in percentage occurrence of excessively high values of radar reflectivity (Z_H) and differential reflectivity (Z_{DR}) is shown when reducing the constant cloud droplet number concentration (**NC30**) and a further considering the effect of VWS on the raindrop breakup process (**NC30_WS**) (Figs. 2 and 3).

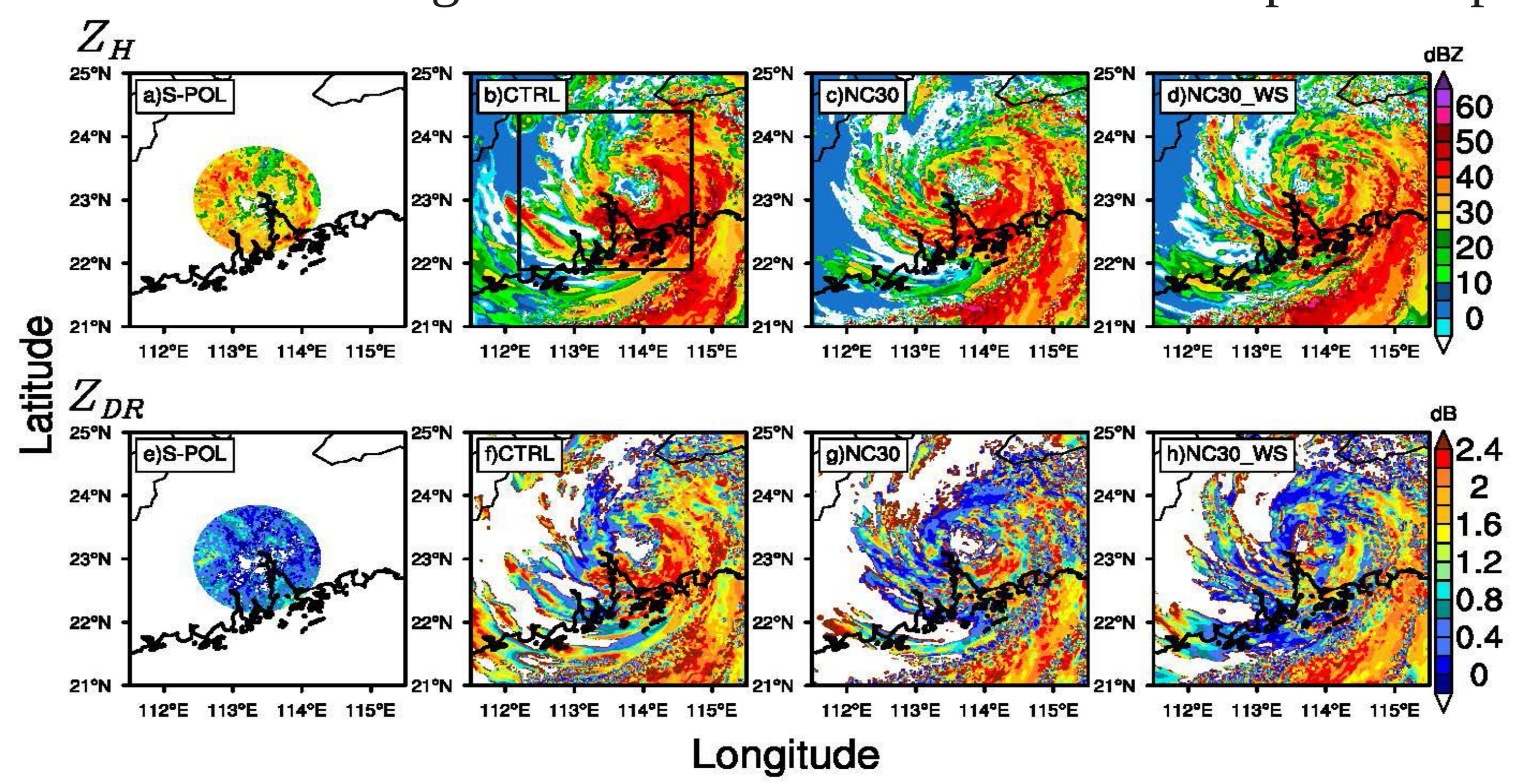

Fig. 2 Observed and simulated horizontal radar reflectivity (dBZ) and differential reflectivity (dB) at 1.5-km altitude from (a) (e) Guangzhou S-POL radar; (b) (f) CTRL; (c) (g) NC30 and (d) (h) NC30_WS runs at 0100 UTC 02 August.

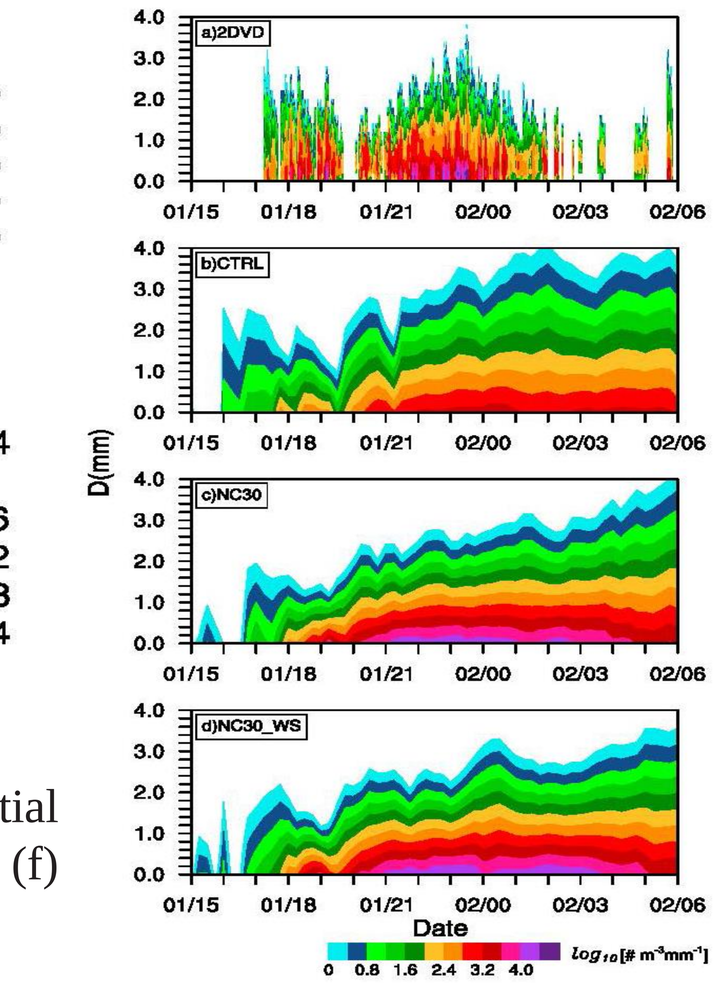

Fig. 3 Time series of observed and simulated raindrop size distribution. Color shading presents the number concentration in logarithmic.

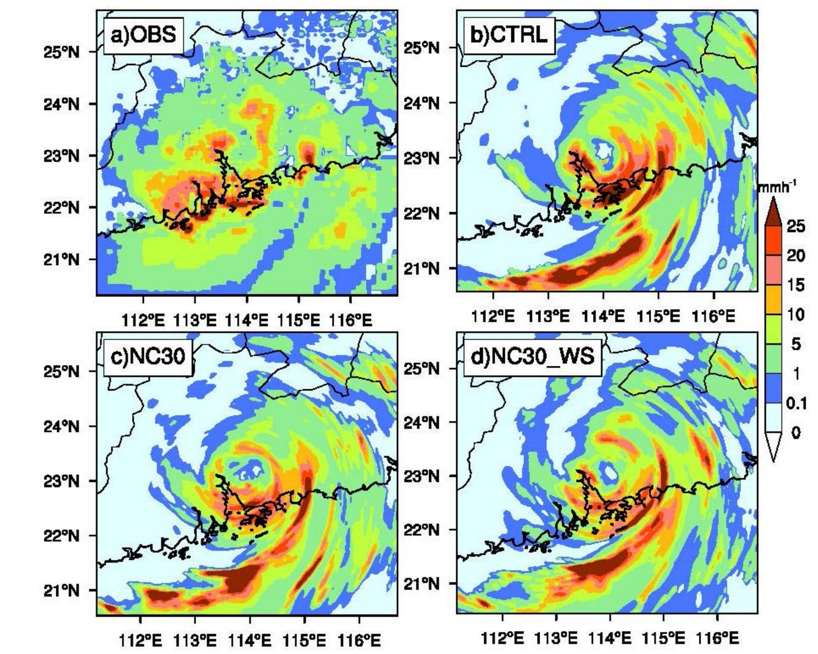

Fig. 4 Spatial distributions of observed and simulated rainfall rates at 0100 UTC 02 August.

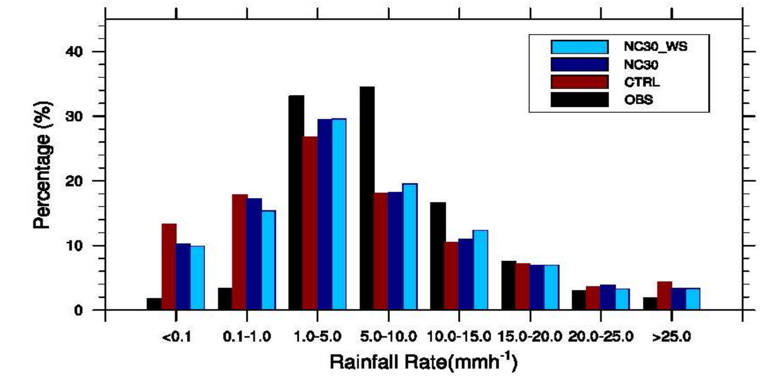

Fig. 5 Probability density functions of observed and simulated rainfall rates

- As the raindrop sizes in the CTRL run are too large, the heavy rain rate (25 mm/h) in the inner core region spreads more widely while the area of moderate rain rate (1-25 mm/h) is relatively smaller than that in the observations. The two sensitivity experiments reproduce a smaller area of extreme precipitation, owing to the reduced existence of large-sized raindrops in them (Figs. 4 and 5).

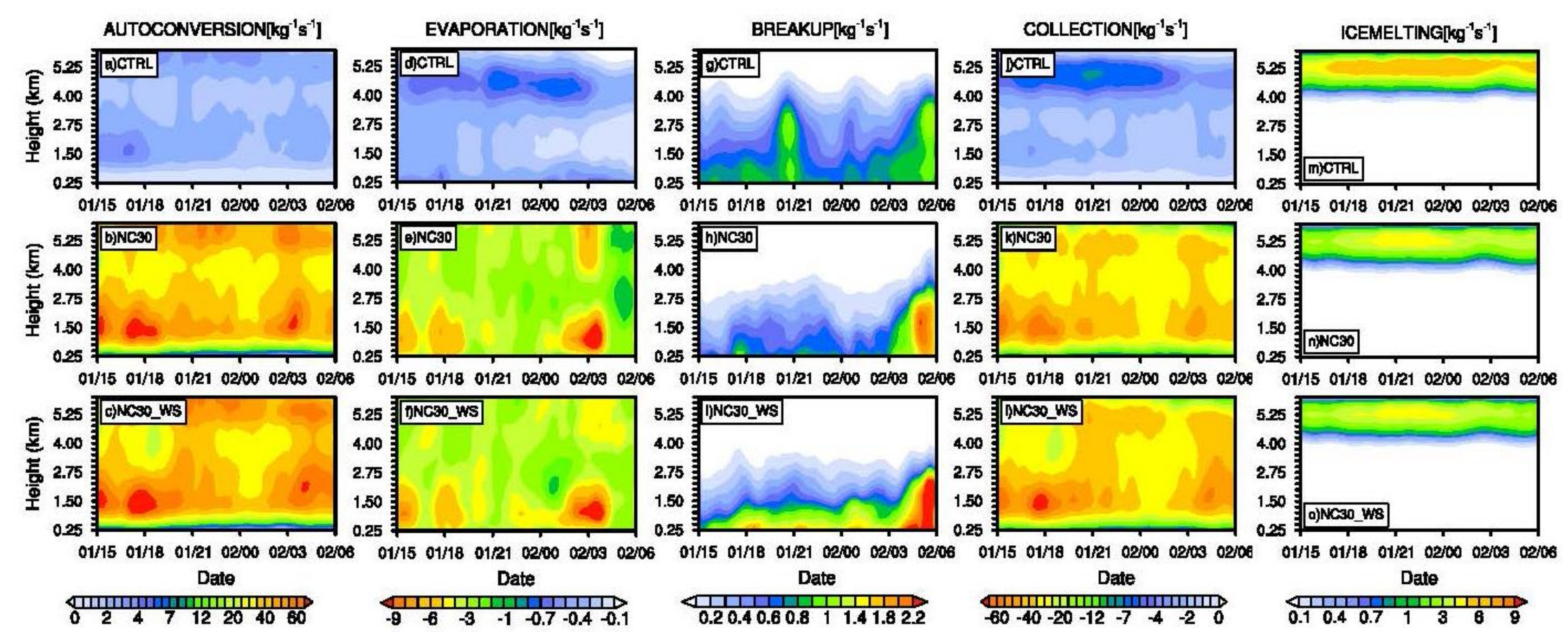

Fig. 6 Source and sink terms of raindrop number concentration (a-c) auto-conversion of cloud droplets to raindrops, (d-f) evaporation of raindrops, (g-i) breakup of raindrops, (j-l) self-collection of raindrops and (m-o) melting of snow/graupel.

- The auto-conversion of cloud droplets to raindrops clearly enhances, leading to more smaller-sized raindrops in the two sensitivity runs. The smaller size of raindrops will induce the larger rate of evaporation (Figs. 6d-f) owing to the increased total surface area. Focusing on the effects of VWS on the microphysical processes in vortex, the NC30_WS run demonstrates an obviously higher breakup efficiency of raindrops, a little stronger evaporation and self-collection rates below 2-km height compared with these in the NC30 run, since the threshold (D_{th}) drops with the strong vertical wind shears.

Conclusions

The numerical simulation of typhoon Nida(2016) with the default Morrison microphysics contains unrealistic large raindrops due to improper setting of cloud droplet number concentration and raindrop breakup parameterization. Reducing the cloud droplet number concentration as well as modifying the threshold diameter of raindrops at which breakup occurs as a function of VWS will lead to a comparable raindrop size distribution and precipitation with the observations.

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