Response to Reviewer 1's comments

[General Comments] *In the study, the authors explore the idea of improving numerical simulation by improving the representation of the autoconversion from cloud to rain (ACT) with a "weighted ensemble (EN)" ATC parameterization. To construct the EN scheme, four widely used ATC parameterizations are employed, and then the EN scheme is coupled into the Thompson microphysics scheme in WRF. With the EN scheme, the authors run nested (to ~1 km) simulations of an extreme precipitation event over southern China and then examine the results by comparison of accumulated precipitation and radar reflectivity to observations. Besides, a detailed analysis is given in vertical motion and hydrometeor mass mixing ratios. The results show that the WRF model with EN run matches the observations better, compared to the BR scheme which is used originally in the Thompson microphysics scheme.*

The premise of trying to improve cloud microphysical parameterization through such a kind of ensemble approach is interesting and potentially useful. One unique feature of the ensemble approach is that the weighted mean is calculated within a microphysics scheme with a negligible increase in computation cost. In my opinion, the ensemble approach could easily be extended to other cloud microphysical processes. Besides, the ensemble scheme appears to be a useful tool that can be used to effectively switch between a single scheme alone as desired or to take the average result of chosen ensemble members. This paper is generally in a good shape, well organized, and conclusions well supported. However, there are a few items of concern that the authors should address before being accepted for publication

Response: Thank you very much for your thorough review and constructive comments that have helped improve the quality of our manuscript.

(1) Several grammar errors and typos throughout the text, please check carefully.

Response: We apologize for the language problems. We have revised the English writing of the manuscript carefully. The errors of word choice, verb tense, sentence structure as well as grammatical and bibliographical errors have been systematically dealt with and the relevant mistakes have been corrected in the revised manuscript.

(a) Line 43 "articales" —>"articles"

Corrected.

(b) Line 51 "riandrops" —>"raindrops"

Corrected.

(c) Line 291 "were" —>"was"

Corrected.

(d) Line 512 suggest changing “more heavy” to “heavier”
Modified.

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(2) In Section 2, four widely used autoconversion schemes are employed in the present study. Please elaborate on the advantages and disadvantages of these schemes, which might tell readers more information.
Response: Thanks for your kind suggestion. Detailed descriptions about the selected schemes have been added in the revised manuscript. For your convenience, the revised portions are also given as follows.

For the Kessler (KE) scheme:
Kessler (1969) initially proposed a simple parameterization scheme that related the autoconversion rate to cloud water content. Owing to the simple and linear expression, the KE scheme is computationally straightforward to implement in numerical models. However, the major limitation of the KE scheme results in its inability to identify different conditions such as maritime and continental clouds (Ghosh and Jonas, 1999). More specifically, the KE scheme only took cloud water content (CWC) into account, while cloud number concentration was not incorporated. This may partially explain the KE scheme yielded the large errors at low CWC proposed by Cotton (1972). Besides, it is impossible to obtain the thresholds directly used in the scheme from observations at present. However, cloud microphysical processes are sensitive to the threshold (Plsselt et al., 2019). In order to get reasonable results, different values of q_0 were chosen by various studies. For instance, a value of 0.5 g m^{-3} is given in Kessler’s (1969), Reisner (1998), and Schultz (1995). Thompson (2004) reduced to a small value of 0.35 g m^{-3}. Kong and Yau (1997) and Tao and Simpson (1993) gave a value of 2 g kg^{-1}, while a small value of 0.7 g kg^{-1} was assigned in Chen and Sun (2002).

For the Berry-Reinhardt (BR) scheme
The BR scheme was developed theoretically in which not only CWC but also cloud number concentration was incorporated. An important characteristic is that maritime and continental clouds can be differentiated by the BR scheme using different parameters (Simpson and Wiggert, 1969; Pawlowska and Brenguier, 1996). Cotton (1972) argued that the BR scheme seems to underestimate rain formation in their simulations.

For the Khairoutdinov-Kogan (KK) scheme
The KK scheme was established based on a series of large-eddy simulations. The KK scheme uses a simple power-law expression based on bin microphysical

calculations. Generally, speaking, the autoconversion rate increases with increasing CWC and/or decreasing cloud number concentration. The simple expression is a key advantage of the KK scheme, which makes it possible to analytically integrate the microphysical process rates over a probability density function (Griffin and Larson, 2013). In view of Fig. 1c, the KK scheme has a strong dependency on N_c. Increasing N_c from 100 to 500, ATC rates decrease dramatically, especially at the CWCs over 1.0 g m^{-3}. Unlike other schemes, ATC is allowable in the KK scheme even with very low CWCs, which might lead to overestimations under such conditions.

For the Liu-Daum-McGraw-Wood (LD) scheme

The LD scheme assumes that autoconversion rate is determined by CWC, cloud number concentration, and relative dispersion of cloud droplets. Xie and Liu (2015) suggested that the LD scheme considering spectral dispersion was more reliable for improving the understanding of the aerosol indirect effects, compared to the KE and BR schemes.

References:

Chen, S.-H. and Sun, W.-Y.: A One-dimensional Time Dependent Cloud Model, J. Meteor. Soc. Japan, 80, 99-118, https://doi.org/10.2151/jmsj.80.99, 2002.

Cotton, W. R.: Numerical Simulation of Precipitation Development in Supercooled Cumuli—Part I, Mon. Wea. Rev., 100, 757-763, https://doi.org/10.1175/1520-0493(1972)100<0757:NSOPDI>2.3.CO;2, 1972.

Ghosh, S. and Jonas, P. R.: On the application of the classic Kessler and Berry schemes in Large Eddy Simulation models with a particular emphasis on cloud autoconversion, the onset time of precipitation and droplet evaporation, Ann. Geophys., 16, 628-637, https://doi.org/10.1007/s00585-998-0628-2, 1999.

Griffin, B. M. and Larson, V. E.: Analytic upscaling of a local microphysics scheme. Part II: Simulations, Quart. J. Royal Meteor. Soc., 139, 58-69, https://doi.org/10.1002/qj.1966, 2013.

Kessler, E.: On the Distribution and Continuity of Water Substance in Atmospheric Circulations, Circulations. Meteor. Monogr., 10. American Meteorological Society, Boston, 1969.

Kong, F. and Yau, M. K.: An explicit approach to microphysics in MC2, Atmos.-Ocean, 35, 257-291, https://doi.org/10.1080/07055900.1997.9649594, 1997.

Pawlowska, H., and J. L. Brenguier, A study of the microphysical structure of stratocumulus clouds. Proc. 12th Int. Conf. Clouds and precipitation, Zurich, Ed. P. R. Jones, Published by Page Bros., Norwich, U.K., 123-126, 1996.

Posselt, D. J., He, F., Bukowski, J., and Reid, J. S.: On the Relative Sensitivity of a Tropical Deep Convective Storm to Changes in Environment and Cloud Microphysical Parameters, J. Atmos. Sci., 76, 1163-1185, https://doi.org/10.1175/JAS-D-18-0181.1, 2019.

Reisner, J., Rasmussen, R. M., and Bruintjes, R. T.: Explicit forecasting of supercooled liquid water in winter storms using the MM5 mesoscale model, Quart. J. Roy. Meteor. Soc., 124, 1071-1107, https://doi.org/10.1002/qj.49712454804 1998.

Schultz, P.: An Explicit Cloud Physics Parameterization for Operational Numerical Weather Prediction, Mon. Wea. Rev., 123, 3331-3343, https://doi.org/10.1175/1520-0493(1995)123<3331:AECPPF>2.0.CO;2, 1995.

Simpson, j. and Wiggert, v.: Models of precipitating cumulus towers, Mon. Wea. Rev., 97, 471-489, https://doi.org/10.1175/1520-0493(1969)097<0471:MOPCT>2.3.CO;2, 1969.

Tao, W.-K. and Simpson, J.: Goddard Cumulus Ensemble Model. Part I: Model Description, Terr. Atmos. Oceanic Sci., 4, 35-72, https://doi.org/10.3319/TAO.1993.4.1.35(A), 1993.

Thompson, G., Rasmussen, R. M., and Manning, K.: Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part I: Description and Sensitivity Analysis, Mon. Wea. Rev., 132, 519-542, https://doi.org/10.1175/1520-0493(2004)132<0519:EFOWPU>2.0.CO;2, 2004.

Xie, X. and Liu, X.: Aerosol-cloud-precipitation interactions in WRF model: Sensitivity to autoconversion parameterization, Journal of Meteorological Research, 29, 72-81, 10.1007/s13351-014-4065-8, 2015.

(3) Line 377 "the EN scheme generated larger rainfall area and stronger rainfall rate than those of the BR scheme". The result is interesting. I would suggest adding more explanation to make it easily understood.

Response: Given the spatial distribution of hourly rainfall during the period (i.e., 0600 BST to 0700 BST 7) when maximum hourly rainfall occurred, the EN scheme generated larger rainfall area and stronger rainfall than those of the BR scheme, although both schemes produced similar spatial distribution patterns in rainfall area, and temporal-averaged surface temperature and horizontal wind filed. For a given CWC, the EN scheme has a larger ATC rate, compared to the BR scheme, and the difference becomes obvious with the increase of CWC. Consequently, the EN scheme produced more rain water of small- to middle size, compared to the BR scheme. The larger rain water was favorable for the coalescence of large precipitation particles from the upper levels, which made the larger contribution to the extreme rainfall rate. This is why the EN scheme produced larger rainfall than the BR scheme.

(4) Line 397-398 Evaporation does produce decreasing reflectivity field near the surface. However, large particle (raindrop) breakup is another microphysical process that can lead reflectivity values to decrease toward the surface.

Response: Yes. Except for the evaporation, large particle (raindrop) breakup can lead reflectivity values to decrease toward the surface because reflectivity is much sensitive to raindrop size. In the present case, the evaporation of raindrops was remarkable. However, a slight difference was found in differential reflectivity Zdr in the lower levels (Fig. R1), indicating that large particle (raindrop) breakup was weak.

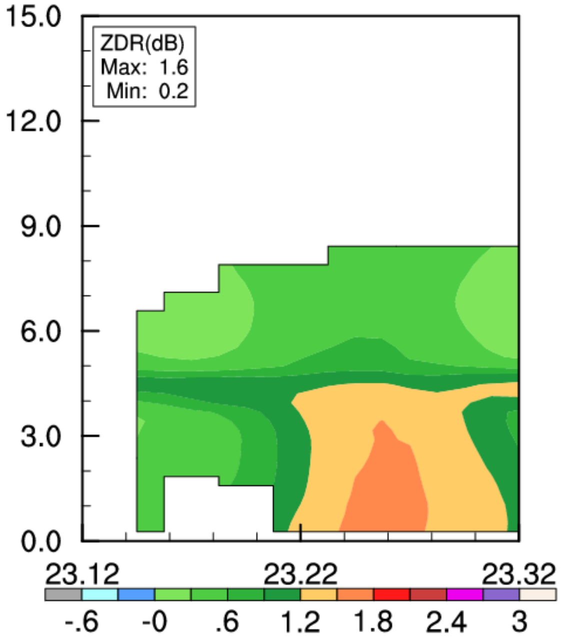

Fig. R1 Temporal-averaged vertical cross-section along C-D in Fig. 6 of the simulated differential reflectivity (dB, shadings) during the period from 0600 BST to 0700 BST 7 May, 2017.

(5) Line 402, The authors need to reword this sentence. It is hard to determine the raindrop number concentration.

Response: Thank you very much for the reminder. We have removed the sentence.

(6) Although the ensemble approach is coupled in the WRF model, it might be beneficial for a global modeling system with distinctly cloud microphysical processes over the world. Some discussions in the last part may expand the application scope of the ensemble approach.

Response: Thanks for your suggestion. We have extended this part with a detailed discussion of the potential applications of the EN scheme.

We appreciate you very much for your positive and constructive comments and suggestions on our manuscript, which are valuable in improving the quality of our manuscript.