A Case Study of the Effects of Aerosols on South China Convective Precipitation Forecast

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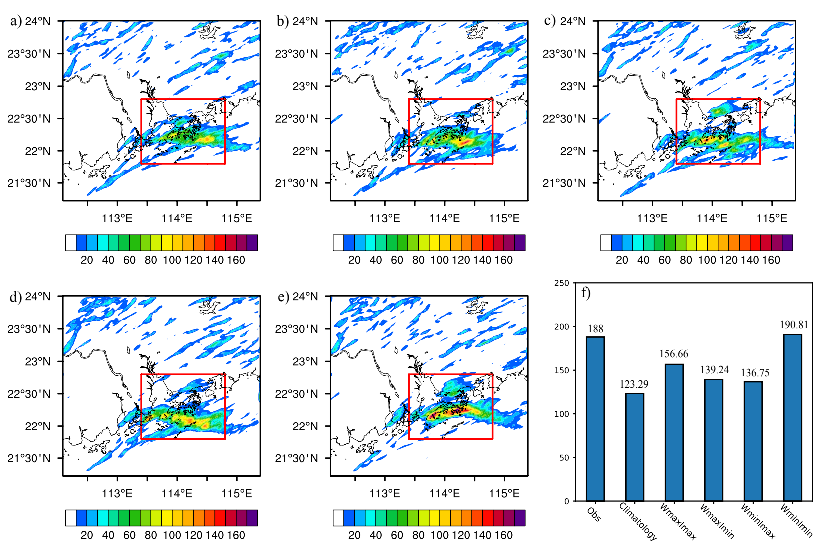
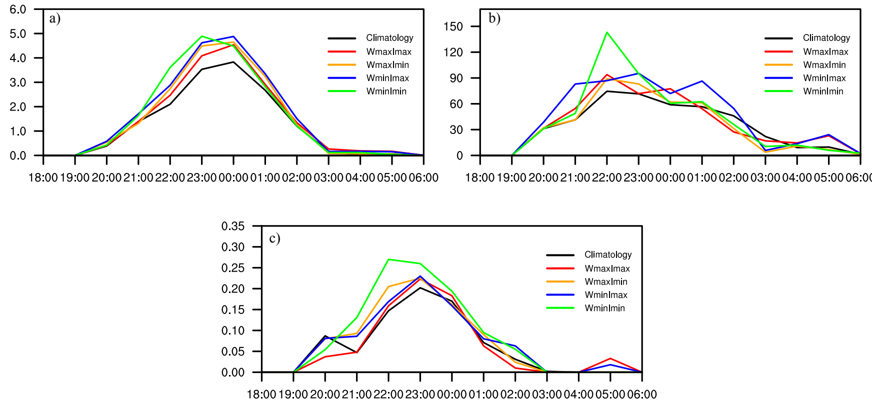
Abstract

Previous studies on South China's convective precipitation forecast focused on the effects of multi-scale dynamics and microphysics parameterizations. However, how the uncertainty in aerosol data might cause errors in quantitative precipitation forecast (QPF) has yet to be investigated. In this case study, we estimate the impact of aerosol uncertainties on the QPF for South China's severe convection using convection-permitting simulations. The variability range of aerosol concentrations is estimated with past observation for the pre-summer months. Simulation results suggest that the rainfall pattern and intensity change notably when aerosol concentrations are varied. The simulation with low aerosol concentrations produces the most intense precipitation, approximately 50\% stronger than the high-concentration simulation. Decreasing aerosol hygroscopicity also increases precipitation intensity, especially in pristine clouds. The aerosol uncertainty changes alter the number of cloud condensation and ice nuclei, which modifies the altitude and amount of latent heating and thereby modulates convection.

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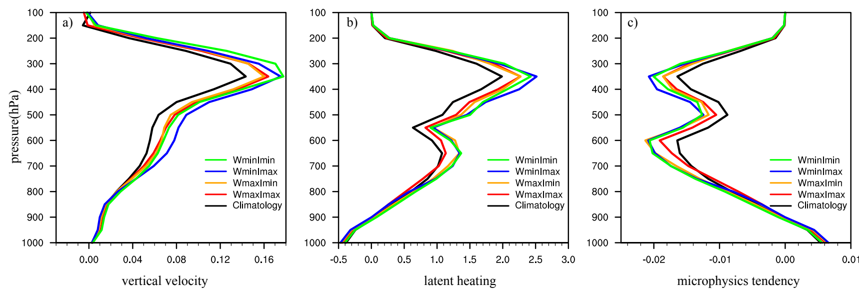
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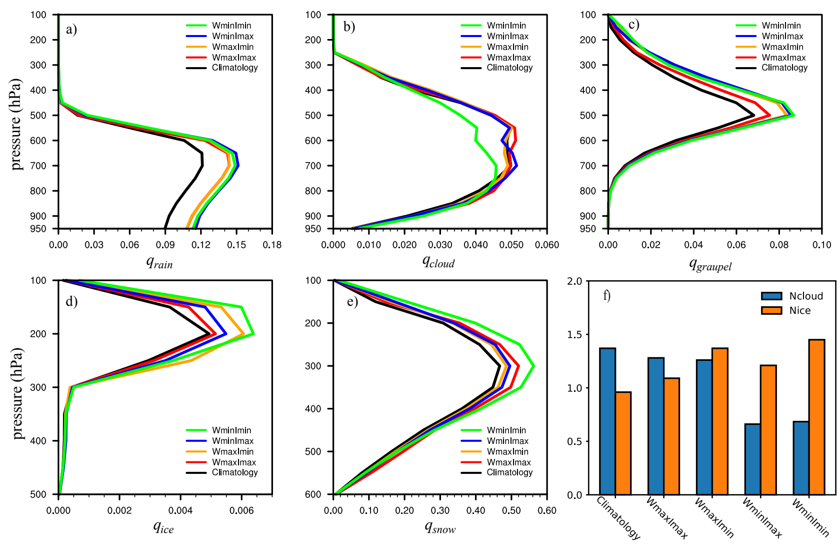
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A Case Study of the Effects of Aerosols on South China Convective Precipitation Forecast

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Key Points:

- The pre-summer rainfall in South China is often caused by convection with low predictability.
- Convection-permitting simulations of a severe storm case were conducted with possible aerosol concentrations and properties scenarios.
- For this case study, lower concentrations of water- and ice-friendly aerosols lead to notably more vigorous convection and precipitation.

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Abstract

Previous studies on South China's convective precipitation forecast focused on the effects of multi-scale dynamics and microphysics parameterizations. However, how the uncertainty in aerosol data might cause errors in quantitative precipitation forecast (QPF) has yet to be investigated. In this case study, we estimate the impact of aerosol uncertainties on the QPF for South China's severe convection using convection-permitting simulations. The variability range of aerosol concentrations is estimated with past observation for the pre-summer months. Simulation results suggest that the rainfall pattern and intensity change notably when aerosol concentrations are varied. The simulation with low aerosol concentrations produces the most intense precipitation, approximately 50% stronger than the high-concentration simulation. Decreasing aerosol hygroscopicity also increases precipitation intensity, especially in pristine clouds. The aerosol uncertainty changes alter the number of cloud condensation and ice nuclei, which modifies the altitude and amount of latent heating and thereby modulates convection.

Plain Language Summary

Convective weather frequently happens in South China during the pre-summer season with limited forecast skills. Previous studies have investigated the impact of large-scale circulation, water vapor conditions, and complex topography in forming convective precipitation systems. However, how chemistry interacts with weather dynamics has yet to be investigated in the context of South China's convective weather. Aerosols can serve as cloud condensation nuclei (CCN) and ice nuclei (IN), and their concentration or property variation can affect various processes in cloud and precipitation formation. To estimate the impact of aerosol uncertainty on South China's pre-summer rainfall, we conducted simulations of a severe convection case with different aerosol concentrations and properties. We found that the typical aerosol concentration and property variability changed the convective system notably, which further influenced the rainfall pattern and intensity. The aerosols invigorate convection when they cause more latent heating or shift the vertical heating distribution upward. This work contributes to understanding the aerosol effects on convection and suggests the potential benefits of increasing aerosol observations in the future to improve the operational numerical forecast.

1 Introduction

Intense convection frequently occurs during the April-June (pre-summer) rainy season in South China and produces almost half the amount of local annual rainfall, and severe flooding resulting from extreme precipitation in this season often endangers the safety of lives and causes substantial economic losses (Luo et al., 2017). Previous studies examined the modulation of the pre-summer rainfall in South China from the perspectives of large-scale circulation, macro- and micro-scale cloud processes, and local dynamics (e.g., Luo et al., 2017; G. Chen et al., 2018; M. Li et al., 2022). It is found that a large fraction of the pre-summer rainfall is produced by convection in the warm sector region hundreds of kilometers ahead of a cold or quasi-stationary front. However, the convection initiation (CI), which depends on the multiscale interaction of atmospheric dynamics, is notoriously known for its relatively low predictability in the warm sector regions (Luo et al., 2017; Bai et al., 2021; Zhang et al., 2022). Therefore, the warm-sector CI is a major contributor to the errors in quantitative precipitation forecast (QPF) for the region. Recent studies revealed that a few factors, including low-level jets, small-scale variability of moisture pooling, and local orography together regulate the CI, rendering its accurate prediction very challenging (Du & Chen, 2018, 2019b; Bai et al., 2021).

Besides the complexity of dynamics, uncertainties in microphysics parameterizations can also strongly affect the prediction of the convective rainfall in the South China region. Qian et al. (2018) found that although using different microphysics schemes did not strongly affect CI, the movement and organization of simulated squall lines are sensitive to the variation of microphysics parameterizations. Yin et al. (2018) suggest that latent heating is an important factor in governing the intensity of convection, while rain evaporation is also suggested as a critical process due to its effect on regulating cold pool intensity (Qian et al., 2018; Zhao et al., 2021; Zhou et al., 2022). Zhao et al. (2021) additionally highlighted the impact of the accurate and flexible representation of ice particle properties on simulating the transition zone between convective and stratiform precipitation in a squall line.

However, how atmospheric chemistry, namely aerosols, may play a role in affecting the QPF in South China through interacting with cloud microphysics has not been quantitatively evaluated. A recent study based on radar and distrometer observations for South China suggests that raindrops in this region have sizes larger than the typical "maritime" regime but number concentrations higher than the typical "continental" regime (Yu et al., 2022). Such unique characteristics of hydrometers may reflect the complexity of the aerosol source and composition in this region due to its coastal location and the development of industries in South China (Wong et al., 2022). Aerosols play the roles of cloud condensation nuclei (CCN) and ice nuclei (IN), and therefore the variability of aerosol composition and concentration can directly change cloud characteristics and indirectly influence the radiation budget of the atmosphere, the accuracy of which is critical for successful climate modeling. Idealized numerical simulations have helped to make important progress on the interaction between aerosols and convective systems, but it is still unclear how relevant the uncertainties in aerosol information are to the QPF in a particular region. This issue is partially a result of the complexity of aerosol-dynamics interaction depending on detailed characteristics of deep convection over different regions (Fan et al., 2016). The other factor is the idealized approach adopted by some previous studies, which often compare arbitrarily defined 'pristine' and 'polluted' conditions with the concentration of aerosols differing from a factor of ten to a few orders of magnitude (e.g., Q. Chen et al., 2019; Chang et al., 2021; Miyamoto, 2021). Researchers had to design their experiments in such an idealized way because of the lack of long-term concurrent observation of aerosol properties that can address the covariability of aerosols, dynamics, and thermodynamics (Fan et al., 2016). Here, we use available observations of aerosols properties in Hong Kong to estimate the range of their variability and employ the Weather Research and Forecast (WRF) model with the aerosol-aware Thompson microphysics scheme (Thompson & Eidhammer, 2014) to semi-quantitatively assess the impact of the uncertainties of aerosol information on the QPF of South China coastal region convection.

2 Methods and Experiments

2.1 Case Description

We conduct our experiments with the severe convective rainstorm case on June 27 and 28, 2021, in Hong Kong. It is categorized as a "black rainstorm" (hourly rainfall exceeding 70mm) according to Hong Kong Observatory's (HKO) rainstorm warning system. The heavy rainfall appears to be caused by a boundary layer jet (Supporting Fig. S1), which is often associated with warm sector convection (Du & Chen, 2019a). However, this case is not typical in that the cold front to the west of Hong Kong is weak, if not none (Supporting Fig. S1b). Although, the active southwesterly airstream does bring warm moist flow from the South China Sea to the coast of Guangdong. The precipitation was intense and persistent on the morning of June 28, and a black rainstorm warning was issued. Over 150 millimeters of rainfall were recorded at many observation stations. Numerical forecast underestimated the precipitation and led to a late issuing of the black rainstorm warning on the morning of June 28 (HKO, 2021).

2.2 Experiment Design

The simulation was configured with three nested domains with horizontal grid resolutions of 9km, 3km, and 1km, respectively, using the WRF model version 4.3.1 (Supporting Figure S1). The vertical direction has 51 levels up to the model top at 50hPa. Each simulation was run for 24 hours, starting from 06 UTC on June 27, 2021. The Thompson aerosol-aware microphysics scheme (Thompson & Eidhammer, 2014) was employed in the simulations. The aerosols in the scheme are divided into water-friendly aerosols for cloud condensation nuclei (CCN) and ice-friendly aerosols for ice nuclei (IN). The CCN activation is based on a look-up table which is derived from the Köhler activation theory with a parcel model, and the IN-number concentration follows the parameterization of DeMott et al. (2010). The water-friendly aerosol is comprised of sulfates, nitrate, sea salts, and organic carbon, and the ice-friendly aerosol is primarily considered to be dust. The aerosol emissions are simplified and represented based on the starting near-surface aerosol concentrations. The scheme is a bulk microphysics scheme and has double moment ice and rain. Other model configuration details are shown in Supporting Table S1.

A set of simulations were run to test the impact of different aerosol states with varying water- and ice-friendly aerosol concentrations on the cloud and precipitation development. The default option for the aerosol-aware scheme is to use the climatological mean aerosol concentration derived from the seven years (2001-2007) simulation of the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model (Colarco et al., 2010; Thompson & Eidhammer, 2014). Our simulation using this default option is denoted as the "Climatology" experiment as a reference.

For sensitivity tests, we adjust the aerosol concentration based on the observed variability of aerosols in Hong Kong. Observational aerosol data are available for April to June 2020 at the Tuen Mun Air Quality Monitoring Station in Hong Kong (22°23'28.4" N, 113°58'37.1" E, 30 m above ground level) (Wong et al., 2022). Since the observatory data is near the surface, the scale factor is calculated with respect to the lowest level of the GOCART climatology data. The mass concentration of chemical species, including SO_4^{2-}, NO_3^-, Na^+, organic carbon (OC) and Al were obtained every three days. The number concentration of the water-friendly aerosol (including sulfates, nitrate, sea salts, and organic carbon) and ice-friendly aerosol (i.e. dust) was calculated from the observation of related ion mass concentration by assuming that the aerosol size distribution follows a lognormal distribution. The characteristic diameter and geometric standard deviation from the analysis results of Bian et al. (2014) were used, and we assumed the aerosols were externally mixed.

The three-month time series of the number concentration of those aerosols in the observation period are shown in Supporting Figure S2. In that period, the maximum values of the water- and ice-friendly aerosol number concentrations are 0.818 and 0.795 times, respectively, of the GOCART climatological monthly mean value for the precipitation event; the minima are 0.045 and 0.080 times, respectively, of the GOCART value. We scale the aerosol data for entire simulation domains with those factors to roughly represent the range of aerosol concentration variability in the pre-summer season. By combing the maximum and the minimum of the aerosol number concentrations, we obtain four different experiments denoted as "WmaxImax", "WmaxImin", "WminImax", and "WminImin", where "W" and "I" indicate water-friendly and ice-friendly aerosols, respectively, and "max" or "min" following "W" or "I" indicates the scaling factor corresponding to the maximum or minimum bounds of the associated aerosol group.

In our analysis, it is found that OC dominates the number concentration of water-friendly aerosols. Observation data (Bian et al., 2014) suggests the OC aerosol has a relatively large fraction of mass in the smaller condensation mode, leading to the higher number concentration in the calculation assuming aerosols are externally mixed. The relatively flat size distribution of the OC is beneficial to CCN activation in that size is suggested to be more important than composition in determining CCN activity (Dusek et al., 2006; Moore et al., 2012). Additionally, even though most fresh organic species are insoluble, the aged organic species coated by soluble species such as sulfuric acid vapor are more hygroscopic and can be activated as CCN; some observational studies have found that the carbonaceous species coupled with sulfate, nitrite, and ammonium account for a larger fraction in the condensation mode aerosols with evenly size distribution (Furutani et al., 2008; Novakov & Penner, 1993). To further evaluate the potential bias in our estimation with assumed external mixing, we estimated the actual number concentration of aerosols in the condensation mode based on the measurement by a Scanning Mobility Particle Sizer (SMPS) at HKUST. The SMPS data is for April 2021 and for the diameter range of 10 nm to 763 nm. Assuming the local size distribution of aerosols is time-invariant, we can establish a relation between the condensation mode number concentration and $PM_{2.5}$ mass concentration. Applying this relationship to the $PM_{2.5}$ data for April to June 2020 yields an estimation of condensation model number concentration for the period, which ranges between 231 cm^{-3} and 4281 cm^{-3}. This range is roughly consistent with our estimation, including all sizes and assuming external mixing, which ranges from 620 cm^{-3} to 5458 cm^{-3}. Therefore, while the external mixing state assumption used in our estimation is not the reality (Riemer et al., 2019), it is

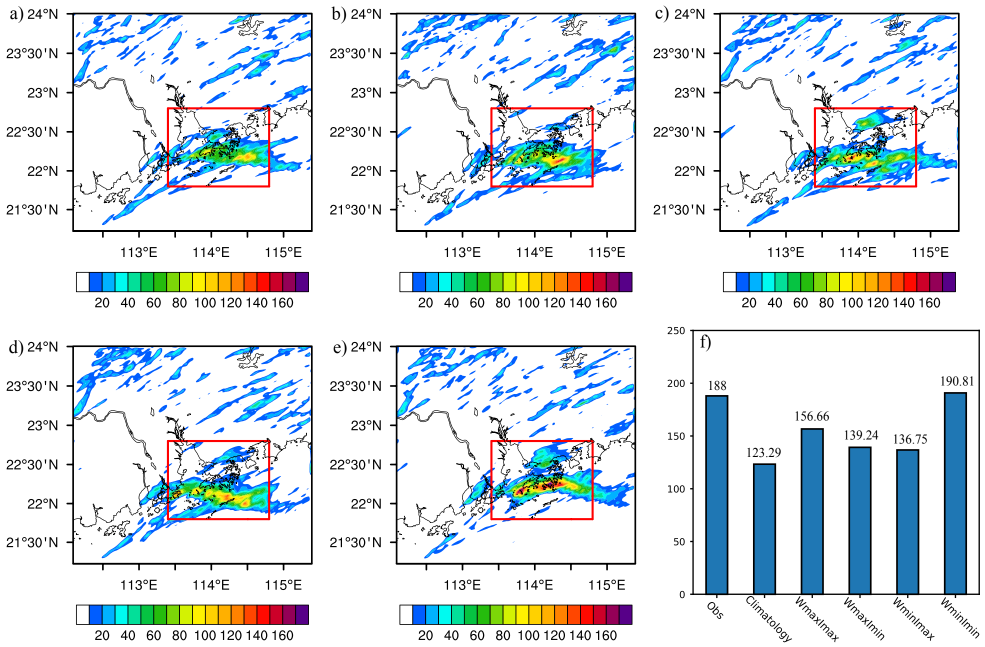

Figure 1. Accumulated precipitation from 12 UTC, 27 June to 06 UTC, 28 June of different experiments: (a) Climatology, (b) WmaxImax, (c) WmaxImin, (d) WminImax, (e) WminImin. The red box is marked as the core precipitation area in the domain. (f) is the maximal accumulated precipitation (mm) of the observation and the simulations over the core area.

reasonable to use those estimation results to approximate the variability of the number concentration of water-friendly aerosols in this study.

3 Results

The accumulated precipitation in the simulations from 12 UTC, 27 June, to 06 UTC, 28 June, is shown in Figure 1. We first compare the precipitation intensity and spatial pattern for all experiments. From Figure 1a-e, it can be found that the precipitation patterns and intensity are different by changing the aerosol concentrations. All the simulations with reduced aerosol concentrations in the four comparison experiments show more intense convection than the climatology simulation. The convection of simulations with lower aerosol concentrations is stronger than those with higher aerosol concentrations. For example, the precipitation of the WminImin (Figure 1e) is stronger than the WmaxImax (Figure 1b). In addition, reducing the water-friendly and reducing ice-friendly aerosol, the precipitation center of the WminImin simulation is located near Hong Kong, and the strongest precipitation happened around Hong Kong Island, which matches the observation very well. Thus, varying the aerosol conditions can change the CI, in this case, subtly. Furthermore, the intense convention centers of the two Wmin simulations have larger cores than those in other experiments.

The maximum accumulated precipitation for all the experiments is shown in Figure 1f. The four altered aerosol state simulations produce stronger precipitation maxima than the climatology simulation, which underestimates precipitation compared with the observation. Furthermore, the WminImin simulation with the minimal aerosol concentration predicted a maximum of approximately 190 mm, comparable with the observed rainfall of 180 mm. We noticed that when reducing the water-friendly aerosols, the tendency of the maximum precipitation variation is different in the Wmin and Wmax groups or the Imax and Imin groups. However, the comparison in Figure 1f is only

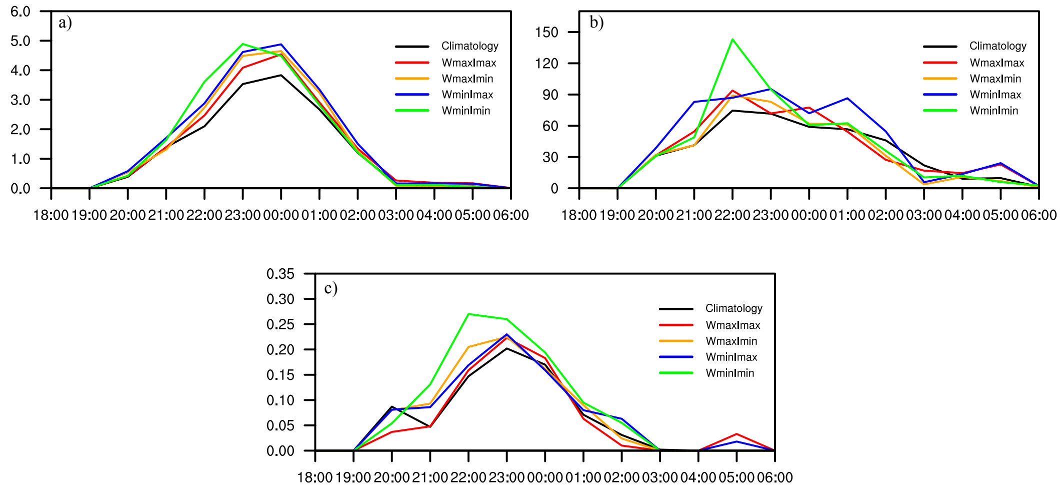

Figure 2. The hourly area average precipitation of the main region (red box in Figure 1), (b) the maximum hourly precipitation in the core area, and (c) the ratio of the area with hourly rainfall larger than 20mm to the total area of the core area.

based on the rainfall maximum point and misses the information over the whole precipitating area, so below, we further analyze the precipitation over the main precipitation area (red box in Figure 1f).

The simulation results are evaluated based on the average (Figure 2a) and maximum precipitation (Figure 2b) over the main impact area marked by the red box in Figure 1 from 19:00 UTC to 05:00UTC. The area average (Figure 2a) and the maximum (Figure 2b) precipitation intensity in the two simulations with minimum water-friendly aerosol (Wmin) simulations are higher than in other groups. The WminImax simulation has 30% more area-averaged precipitation than the Climatology simulation, of which the precipitation intensity is the weakest during the entire process. The WminImin simulation shows more extensive area-averaged precipitation at the early stage. Decreasing the water (ice) aerosol concentration would lead to stronger precipitation in the core area under the high ice-friendly (water-friendly) aerosol concentration condition. However, in the groups with minimum water- or ice-friendly aerosol, the effect of reducing the other kind of aerosol is less significant. In addition, the hourly precipitation maxima in the WminImin simulation are 140 mm, which is twice larger than that of the Climatology simulation at 22:00 UTC. The maximum precipitation of WminImax is also relatively higher. Figure 2c shows the percentage of the area where the rainfall is larger than 20 mm in the main region. The heavy precipitation covered a larger area in the two simulations with minimum ice-friendly aerosol concentration. The area covered by heavy rainfall in the WminImin simulation is almost twice as large as the Climatology run for some short periods.

Therefore, the precipitation prediction differs notably for the varying aerosol states. Changing aerosol states influenced the temporal and spatial evolution of convective systems and thereby affected the rainfall locations as well in the simulations. Higher rainfall intensity is found in the minimal aerosol concentration simulation, which is more consistent with the observed intense rainfall. Lower water-friendly aerosol concentration expands the precipitation to a larger zone, and the area average precipitation is relatively enhanced; reducing the ice-friendly aerosol can induce more intense precipitation and maximum precipitation intensity.

We further examined the dynamic and microphysical conditions of different aerosol states to understand the effects of aerosols. Figure 3 shows the vertical profiles of the averaged vertical velocity from 21:00UTC to 02:00UTC over the main precipitation area. In the Wmin simulations, the updraft velocity, latent heating, and microphysics tendency are more stronger. Likewise, the simula-

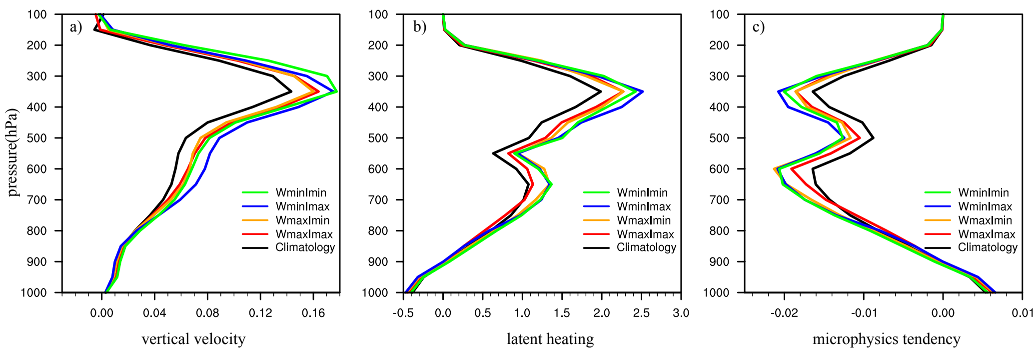

Figure 3. The vertical profiles of (a) vertical velocity ($m \cdot s^{-1}$), (b) latent heating ($K \cdot d^{-1}$) and (c) microphysics tendency for water vapor (10^{-3} s^{-1} from 21:00 UTC to 02:00 UTC, averaged over the main precipitation area marked by the red box in Figure 1 for the five simulations.

tions in Imin groups also produce larger latent heating and more microphysics tendency than other groups, despite the different water-friendly aerosol conditions. The updraft velocity of the WminImax simulation is 60% (30%) larger than that in the Climatology simulation at 600hPa (300 hPa). In addition, the latent heating and microphysics-induced tendency of the WminImin experiment is also higher, which is 30% and 20% more than the Climatology simulation, respectively, both at low and high-pressure levels. As a result, the precipitation intensity of the simulation with minimum ice-friendly aerosols is higher than the other simulations in Figure 3. The difference in the profiles reveals that, in this case, the environmental conditions are influenced by the aerosol concentration, and reducing both kinds of aerosols can enhance the precipitation with higher updraft velocity, more microphysical conversion and more latent heating. However, different mechanisms are involved here. While the WminImin simulation exhibits stronger ascent in the upper troposphere, the WminImax exhibits stronger ascent in the middle and lower troposphere and more latent heat release at the upper levels.

We also compare the hydrometeor contents to evaluate the impact of the aerosol concentration directly. Figure 4 shows the main precipitation region mean vertical profiles of the mass mixing ratios (a-e) and vertically integrated number concentration (f) of the hydrometeors. The rainwater (Figure 4a) is directly related to the precipitation. Figure 4a shows that the area-averaged rain mass mixing ratio in the groups with reduced water-friendly aerosol concentration is higher than the climatology group. We can see that the mass mixing ratio and number concentration of liquid cloud water in Figure 4b and Figure 4f are significantly increased in the simulations with larger water-friendly aerosol concentrations. The droplet size in those simulations then would be reduced, which can expand the cloud lifetime and decrease rainwater. Somewhat surprisingly, the graupel, snow, and ice mass mixing ratio increased significantly in the experiments with minimum ice-friendly aerosols, contributing to the precipitation increase. It appears that firstly the concentration of liquid cloud droplets has an important impact on convection intensity by enhancing precipitation efficiency, thus, the Wmin simulations have higher cloud ice number concentrations than Wmax simulations. Secondly, the decreased ice-friendly aerosol leads to higher cloud ice number concentration and further precipitation particles due to the enhanced homogeneous process and more latent heat released at upper levels, both of which can invigorate deep convection (Deng et al., 2018; Min et al., 2008). Previous studies also confirmed that pristine convective clouds tend to develop a colder (higher) top (R. Li et al., 2017). These factors lead to the result that the WminImin simulation produces the largest maximum precipitation rate in Figure 2.

The hygroscopicity of the aerosols is also essential to the CCN activation, which further impacts the convection evolution. These results are all based on the same default hygroscopicity parameter, 0.4, in the aerosol-aware Thompson scheme. However, the mixing state and chemical composi-

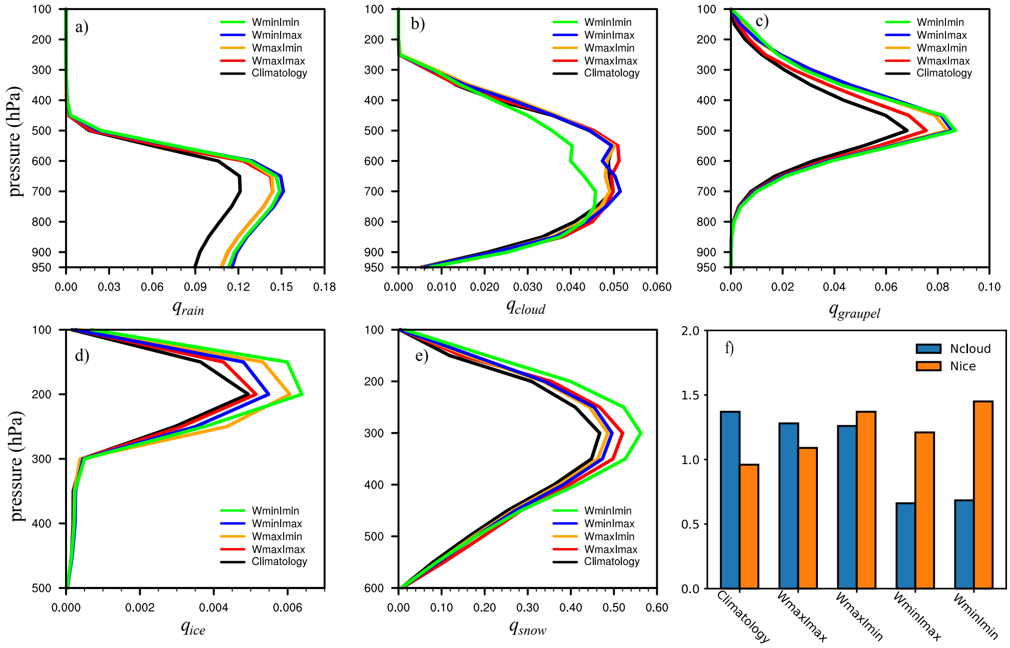

Figure 4. The vertical profiles of the mass mixing ratio (g kg^{-1}) of the (a) q_{rain}, (b) q_{cloud}, (c) $q_{graupel}$, (d) q_{ice}, (e) q_{snow} averaged from 21:00UTC to 02:00UTC over the core area marked as the red box in Fig. 1 for the five simulations. (f) The core area mean of vertically integrated number concentration of liquid cloud (10^7 m^{-2}, blue bar), ice cloud (10^5 m^{-2}, red bar).

tion will change the aerosol hygroscopicity. Therefore, we further conducted another two simulations under maximal and minimal aerosol conditions (WmaxImax and WminImin) following Yeung et al. (2014) in which they suggested that the hygroscopicity of aerosol in Hong Kong is around 0.3. The analyzed hygroscopicity is based on the observation of the Hong Kong supersite. The precipitation simulation results are shown in Supporting Figure S3. We can see that the precipitation pattern and location are similar under different aerosol concentration conditions. However, the precipitation intensity is changed and is more sensitive to the hygroscopicity when the aerosol concentration is minimal. Compared to the default hygroscopicity simulations, the maximal precipitation decreased by 20% for WminImin and only 5% WmaxImax.

4 Conclusion

Aerosols serving as the cloud condensation nuclei and the ice nuclei are critical factors in cloud formation. Aerosol concentration and composition variation can change the hydrometer size and number concentration, cloud evolution, and furthermore, the dynamics and thermodynamics of convection. In this study, we investigate the impact of aerosol concentration and property uncertainty on the forecast of convective rainfall in South China with a case study. The aerosol-aware Thompson microphysics scheme was used to evaluate the aerosol effect in convection-permitting WRF simulations. We defined four aerosol concentration scenarios based on the observed variability of aerosols in Hong Kong and included another reference run using the GOCART climatology data. All the simulations based on observation aerosol concentrations, which are lower than GOCART climatology, exhibited more intense convection and precipitation than the reference simulation. Decreasing the hygroscopicity from the model default to a smaller value suggested by observation also increases the predicted precipitation, but the change is more notable when aerosol concentrations are low.

The simulation with minimum water- and ice-friendly aerosol concentration conditions produced the most intense rainfall, which is close to the observed maximum value of the accumulated rainfall and is approximately 50% higher than the prediction based on GOCART climatology. Thus, the QPF of pre-summer is indeed sensitive to aerosol conditions for, at least, some intense convective systems. For the case we studied, the reduction in CCN appears to enhance precipitation by increasing droplet size and decreasing number concentration, which thereby reduces mid-level evaporation and strengthens convection. The amount of IN appears to affect convection intensity by altering the fraction of homogeneous and heterogeneous processes, the form of which becomes more dominant in pristine clouds and deepens convection through the delayed release of latent heat at upper levels.

Our assessment is, admittedly, semi-quantitative, because, besides approximations used in our aerosol data analysis, the microphysics scheme also has its own limitations (Morrison et al., 2020). Additional complexity arises due to the dependency of aerosol effects on cloud systems and the environment, which may lead to different signs of precipitation changes in different cases when aerosol conditions are varied (Fan et al., 2016). However, this preliminary evaluation suggests that accurate aerosol measurement is essential for improving the numerical prediction of South China's pre-summer convection. Fan et al. (2016) suggested that long-term concurrent measurements of aerosol properties and meteorological fields are important for advancing our understanding and modeling capability of aerosol-cloud interaction. Such observations, if available, are beneficial not only to research efforts but also to operational weather forecasts.

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Open Research Section

The Weather Research and Forecast model is publicly available at https://github.com/wrf-model/WRF. We archived the namelist for our simulations and ion data at https://doi.org/10.5281/zenodo.7401445.

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Supporting Information for "A Case Study of the Effects of Aerosols on South China Convective Precipitation Forecast"

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1. Tables S1
2. Figures S1 to S4

Table S1. WRF configuration for the simulations.

Parameterization	**Scheme**
Initial and boundary condition	ECMWF Reanalysis V5 (ERA5)
Microphysics	Thomspon aerosol-aware
Long-wave radiation	RRTM
Short-wave radiation	RRTM
Surface	Noah Land Surface Model
PBL	ACM2

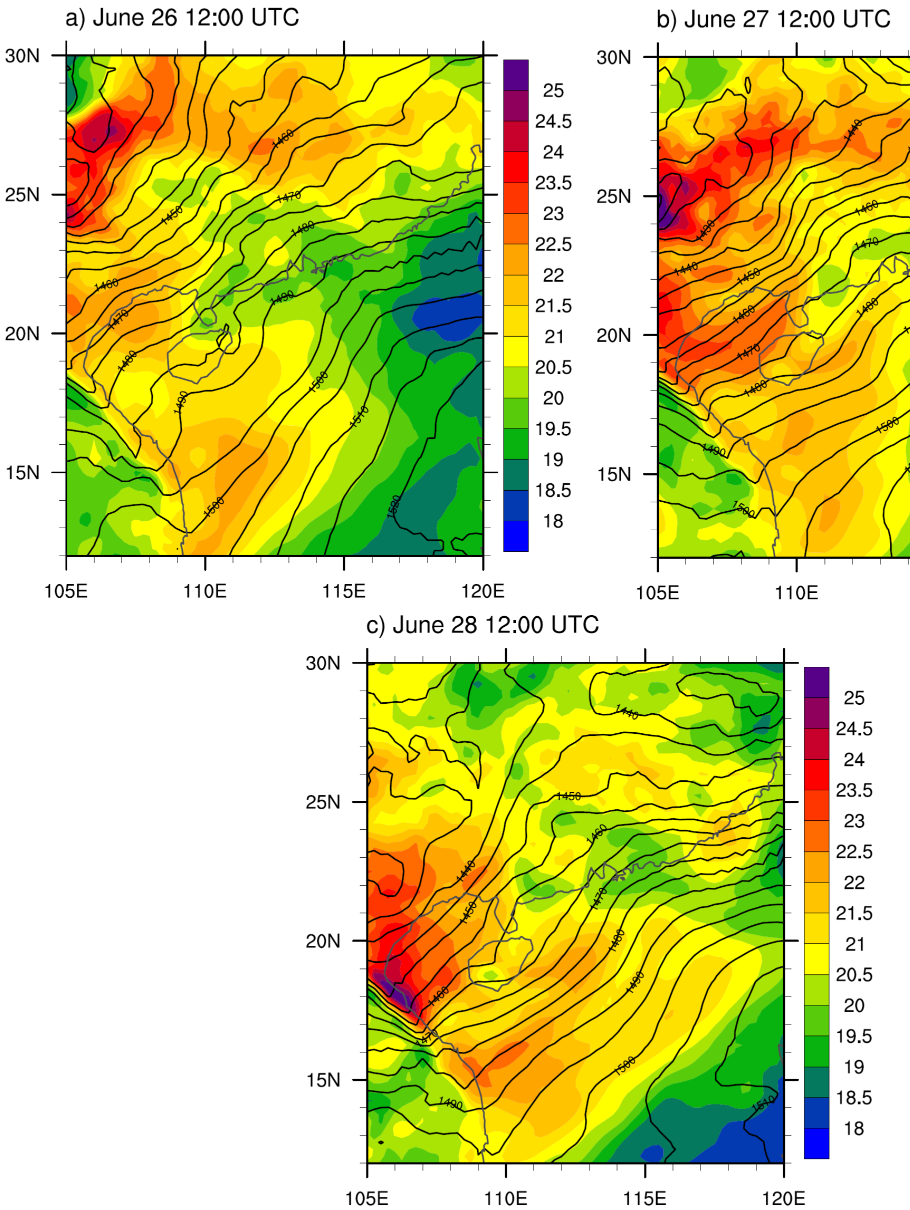

Figure S1. The 850 hPa level geopotential height (contours) (m) and temperature (color shading) °C for 12:00 UTC, June 26 to 28, 20221.

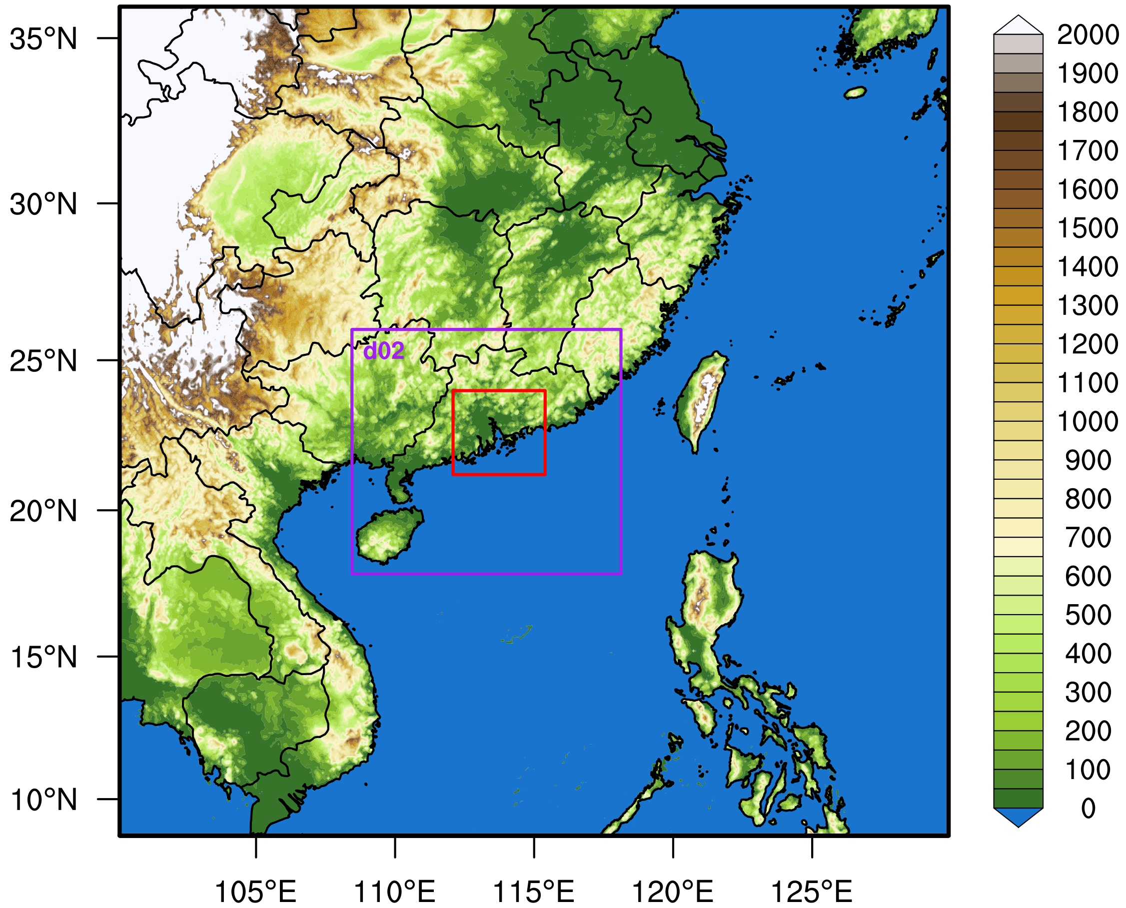

Figure S2. The three nested domains with horizontal grid resolutions of 9km, 3km and 1km.

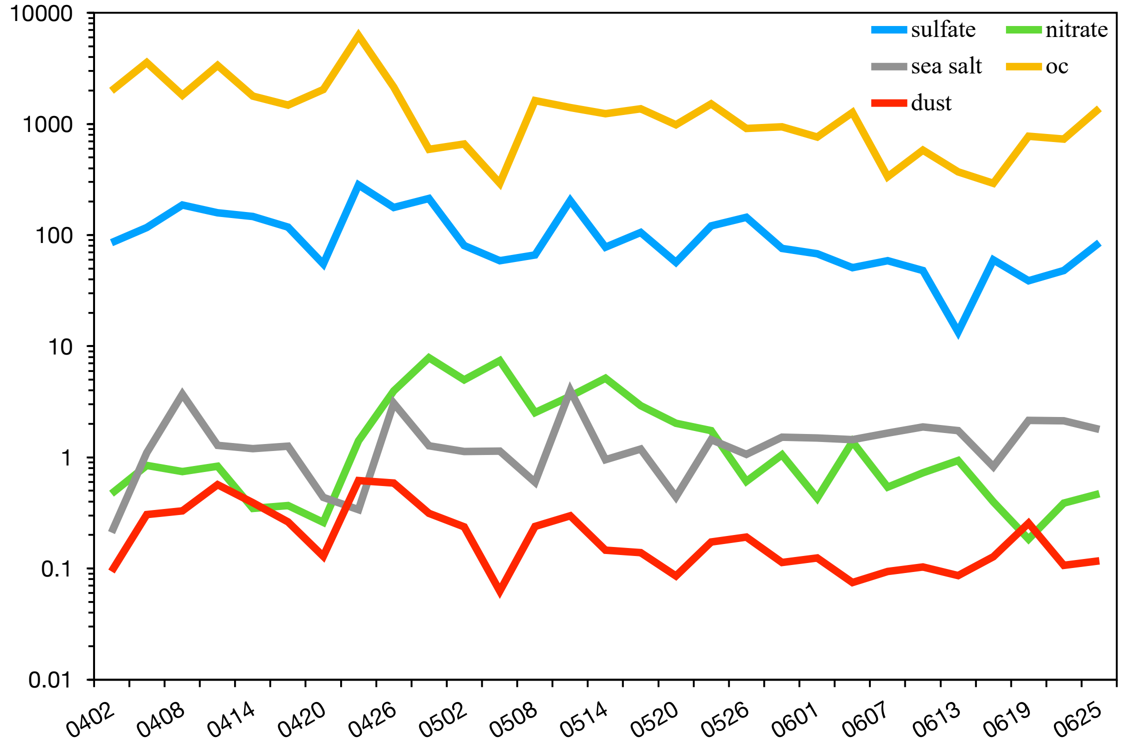

Figure S3. The number concentration (cm^{-3}) of the water-friendly aerosols: sulfate (blue), nitrate (green), sea salt (grey), organic carbon (OC) (yellow) and ice-friendly aerosols: dust (red) from 2 April 2020 to 25 June for every three days.

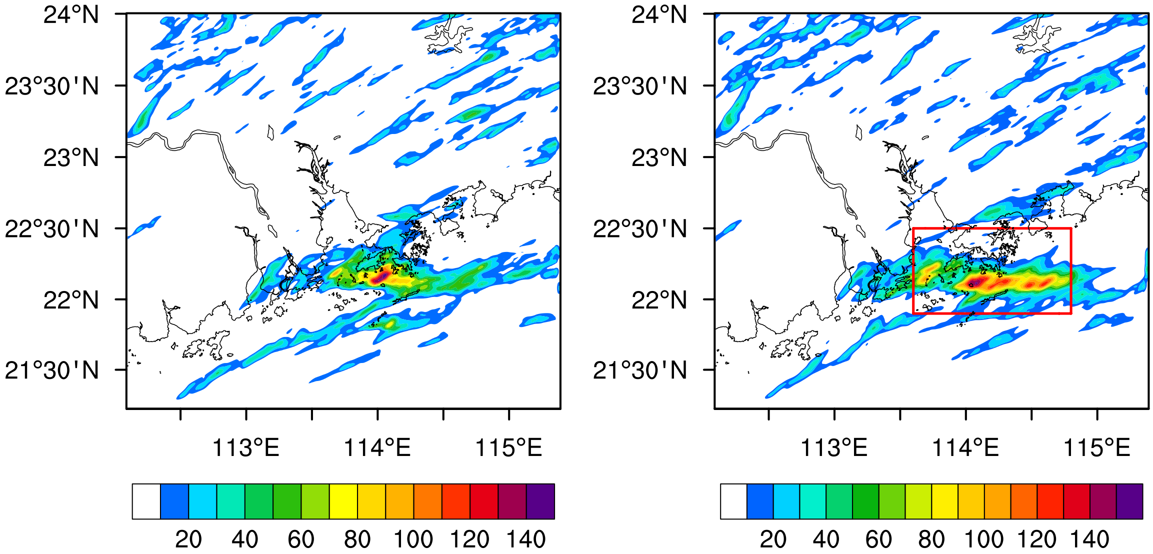

Figure S4. Accumulated precipitation from 12 UTC, 27 June to 06 UTC, 28 June: (a) WmaxImax, (b) WminImin. The red box denotes the main precipitation area in the domain.