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Investigating the influence of aerosol effects on extreme rainfall simulations over the UK using WRF and WRF-chem model

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In recent decades, WRF has been widely used in regional rainfall simulations, and many studies have shown it has good performance in reproducing rainfall distribution. However, the WRF simulated rainfall amounts are often significantly underestimated which might be due to insufficient consideration of aerosol-cloud-precipitation-meteorology interaction in its mdoelling. WRF-chem as a meteorology-chemistry coupling model is expected to improve such a shortcoming. In this study, we carry out a series of WRF and WRF-chem simulations of a large-scale extreme rainfall event (occurred from October 11th to 15th, 2018) over the UK to explore whether different aerosol effects could help improve the rainfall simulation performance.

To compare and evaluate the influences of different aerosol effects, four types of simulations using WRF and WRF-chem were conducted. The baseline simulation (called WF_B) was simulated by WRF without any emission data and chemical boundary conditions. The sensitivity simulation (WC_NE) was simulated by WRF-chem with emission data and chemical boundary conditions as well as used a chemical mechanism. But it turned off aerosol direct and indirect effects. The other two sensitivity simulations WC_DE and WC_DAIE were conducted by turning on the direct aerosol effect and turning on all (direct and indirect) aerosol effects, respectively. All simulations used the same domain configurations, physical schemes, and meteorological boundary conditions. Through comparing the difference between the four simulated rainfall distributions and amounts, the impact of aerosol direct effect, indirect effect, and net (direct + indirect) effect on extreme rainfall simulation were estimated.

The simulation results were compared with UK radar observations. The sensitivity study shows that the rainfall intensity performance greatly improved with the inclusion of the aerosol-cloud interaction in the modelling (indirect effect). However, aerosol-radiation feedback (direct effect) does not have a significant impact on rainfall intensity estimations. One of the reasons was because the aerosol indirect effect has a great influence on droplet/particle concentration, precipitation efficiency and cloud life in nature. Statistics show that there are 115 grids in radar

observation with rainfall greater than 100 mm, while WF_B, WC_NE, WC_DE and WC_DAIE simulations have respectively 44, 44, 44 and 117 grids with rainfall greater than 100 mm. In addition, the Root Mean Square Error of WF_B, WC_NE, WC_DE and WC_DAIE accumulated rainfall is 2.501, 2.501, 2.484 and 0.779 respectively. On the other hand, the rainfall spatial performances of the four simulations are relatively close, which were not improved obviously with the inclusion of aerosol effects. Their probability of detection (POD), frequency bias index (FBI), critical success index (CSI), and false alarm ratio (FAR) performances were averaged at 0.941, 0.946, 0.936, and 0.006, respectively. Finally, using the chemical mechanism and chemical data but turning off aerosol effects resulted in similar rainfall estimations of WRF-chem and original WRF. In summary, it is highly recommended to turn on WRF aerosol effects, especially the indirect aerosol effects in extreme rainfall simulations.