Supplemental Information for

Impacts of black carbon on the formation of advection-radiation fog during a haze pollution episode in eastern China

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S1 Evaluation of DSR and SHF

The simulated downward shortwave radiation (DSR) and surface heat flux (SHF) are compared with observations at SORPES station in Nanjing. Figure S1a shows that, in EXP_NORAD and EXP_NOAER, the model produces overestimated DSR with a MB of about 166 W m^{-2}, while in EXP_CTL the MB of DSR is only 69 W m^{-2}. The difference of about 97 W m^{-2} indicates that the presence of high aerosol loading leads to a significant decrease of DSR. The difference between EXP_NOAER and EXP_NORAD is negligible for the DSR, implying that the impact of ACI on DSR is rather insignificant in this event. In EXP_NOBC which removes the radiative effect of BC, the results show that the mean bias (MB) of DSR is about 115 W m^{-2}. These results show that the contribution of BC on the decrease of DSR is about 46 W m^{-2} while the contribution of non-BC aerosols is about 41 W m^{-2}, suggesting that BC and non-BC aerosols have comparable contributions to the decrease of incoming solar radiation at the surface. This impact can also lead to a decrease of surface heat flux (SHF) in the daytime. As shown in Fig. S1b, the EXP_CTL has a MB of only 1.78 W m^{-2}, the EXP_NOBC has a relatively larger MB of 22.89 W·m^{-2}, while EXP_NORAD and EXP_NOAER produce almost the same impact on SHF with a MB of about 43 W m^{-2}. The results in Fig. S1b are consistent with those in Fig. S1a. The EXP_CTL can reproduce the DSR and SHF very well in Nanjing with relatively small bias and high correlation coefficient. However, the

EXP_NORAD produces significant overestimations of DSW and SHF. The almost same results of DSR and SHF between EXP_NOAER and EXP_NOBC also suggest an insignificant impact from ACI in this event.

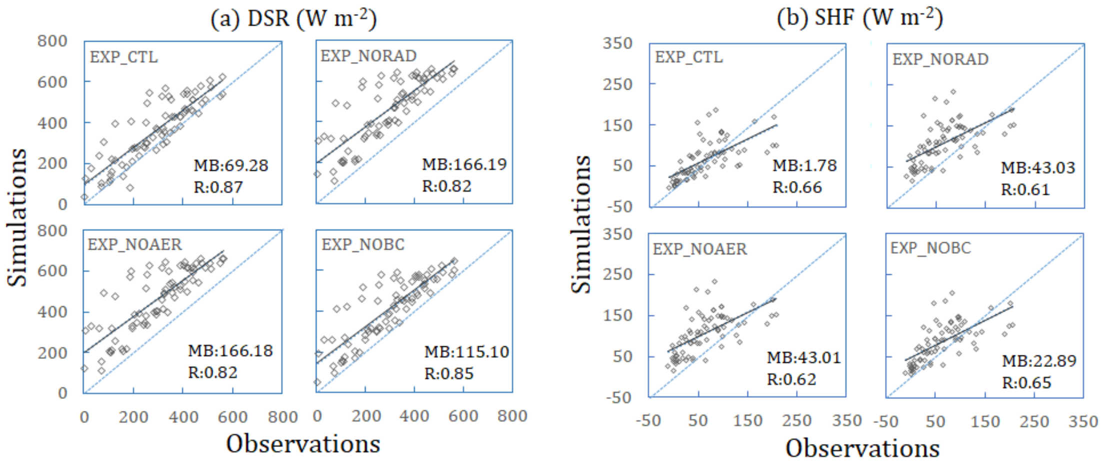

Figure S1. Comparison of DSR **(a)** and SHF **(b)** between simulation results in the four experiments and observations at SORPES station in Xianlin campus of Nanjing University. The four experiments are EXP_CTL, EXP_NORAD, EXP_NOAER and EXP_NOBC. The black line represents the fitting result of linear regression, and the Mean Bias (MB) and Correlation Coefficient (R) are denoted in each plot. The data in the daytime (08:00 - 17:00 LST) ware used and the data in the fog day (on 7 December) were removed.

S2 Evaluation of simulation results during fog episode

The simulated results of RH2 and T2 in EXP_CTL and EXP_NOAER are compared with the observations at Lukou meteorological station from 09:00 LST on 6 December to 16:00 LST on 7 December, during which the fog occurred. Figures S2a and S2b show that the simulated RH2 and T2 in EXP_CTL agree well with the observational data at this site. However, EXP_NOAER systematically underestimates RH2 during this period when compared with the observational data. The simulated RH2 in EXP_NOAER cannot reach 100%. Thus EXP_NOAER cannot reproduce the fog episode in this site. EXP_NOAER overestimates T2 before the fog episode, since in this experiment the shadowing effect of aerosols is removed, which results in a higher surface air temperature by a larger magnitude of surface heating in the daytime. T2 in EXP_NOAER decreases in the whole night, because there is no fog. After sunrise, T2 in EXP_NOAER increases quickly, also because there is no fog, and the solar radiation heats the surface directly, then the warm surface heats the atmosphere. The simulated vertical profiles of RH and Q in EXP_CTL and EXP_NOAER are compared with the observations at Nanjing meteorological station at 08:00 LST on 7 December, and the data are illustrated in Figs. S2c and S2d. The difference in the results between the two case is mainly in the near surface layer below 300 m. The simulated profiles of RH and Q in EXP_CTL agree well with the observational data, while EXP_NOAER significantly underestimates RH and T in this layer.

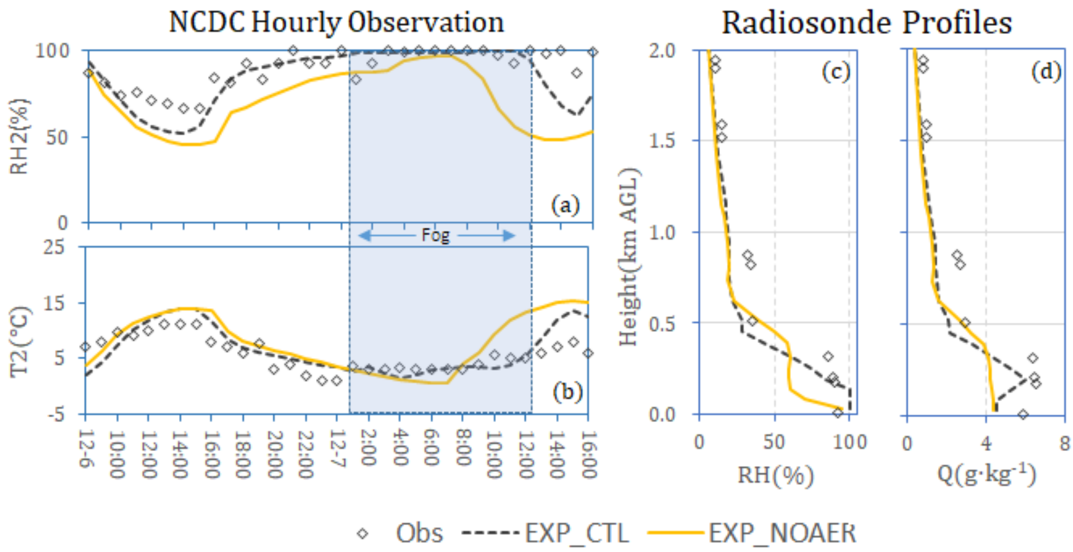

Figure S2. Comparison of the evolution of RH2 **(a)** and T2 **(b)** between simulation results and observations at Lukou station (which locates at 36 km south of Nanjing city) from 09:00 LST on 6 December to 16:00 LST on 7 December (the left panel), and comparison between simulated and observed vertical profile of RH **(c)** and Q **(d)** at 08:00 LST on 7 December at Nanjing meteorological station (which locates in the middle between Nanjing city and Lukou station) (the right panel). The blue shaded area denotes the duration of observed fog episode at this site.

S3 Contributions of BC and non-BC to spatial distribution of fog

To further know the contributions of BC and non-BC aerosols to the spatial distribution of fog, we calculated horizontal distribution of liquid water content (LWC) in the surface layer induced by all aerosols, as well as BC and non-BC aerosols respectively, from the different experiments. The results are illustrated in Fig. S3. The total contribution of both BC and Non-BC to this fog event is mainly caused by the ARI processes (Fig. S3a), while the effect of ACI is negligibly small (Fig. S3b). The fog spreads widely in the YRD region and the nearby north-western area. In can be seen clearly in Figs S3c and S3d that the contribution of BC to distribution area of fog is larger than that of non BC aerosols. When the effect of BC is removed, the area of fog (shown in Fig. S3c) becomes much smaller than that with the effects of both BC and non-BC aerosols are included (shown in Fig. S3a), and the area of fog distributes in a patchy pattern.

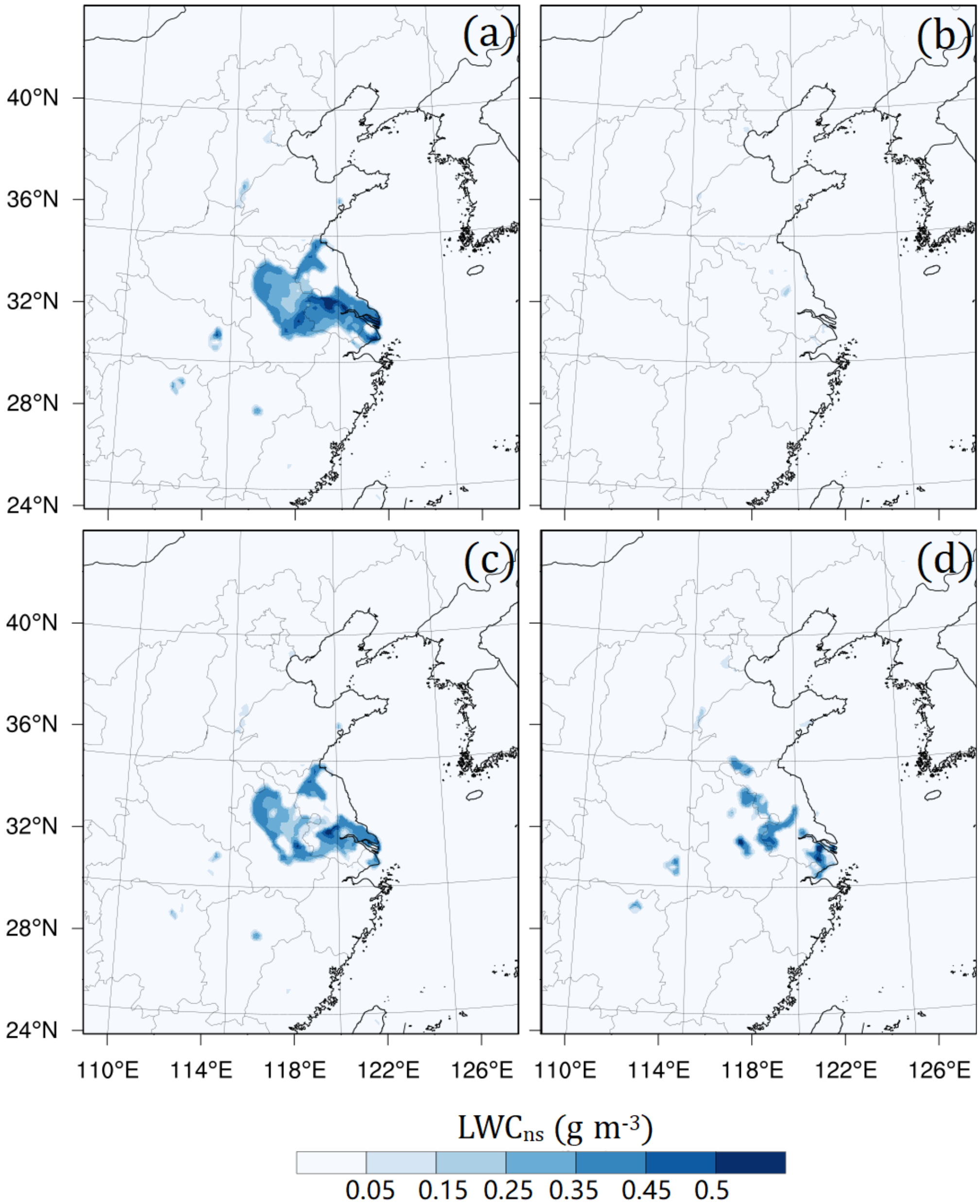

Figure S3. Contribution of aerosols to LWC in the surface layer from EF_ARI **(a)**, EF_ACI **(b)**, EF_BC **(c)** and EF_NBC **(d)** at 08:00 LST on 7 December.

S4 Cartoon of the enhanced moisture advection by BC

In order to visualize the process of enhanced moisture advection by BC, we worked out a cartoon. The cartoon begins with the state at 10:00 LST, including the distribution of BC concentration, the low-pressure perturbation and cyclonic anomaly in wind field induced by BC, the enhanced moisture advection by BC, and the intensified fog (represented by the increase of LWC) in the surface layer, as shown in Fig. S4. Only the BC-induced increase of RH (represented by isolines) can be seen in this figure, since the fog does not appear at this time. The fog can be seen in the cartoon, which is linked to the key-press in the figure caption.

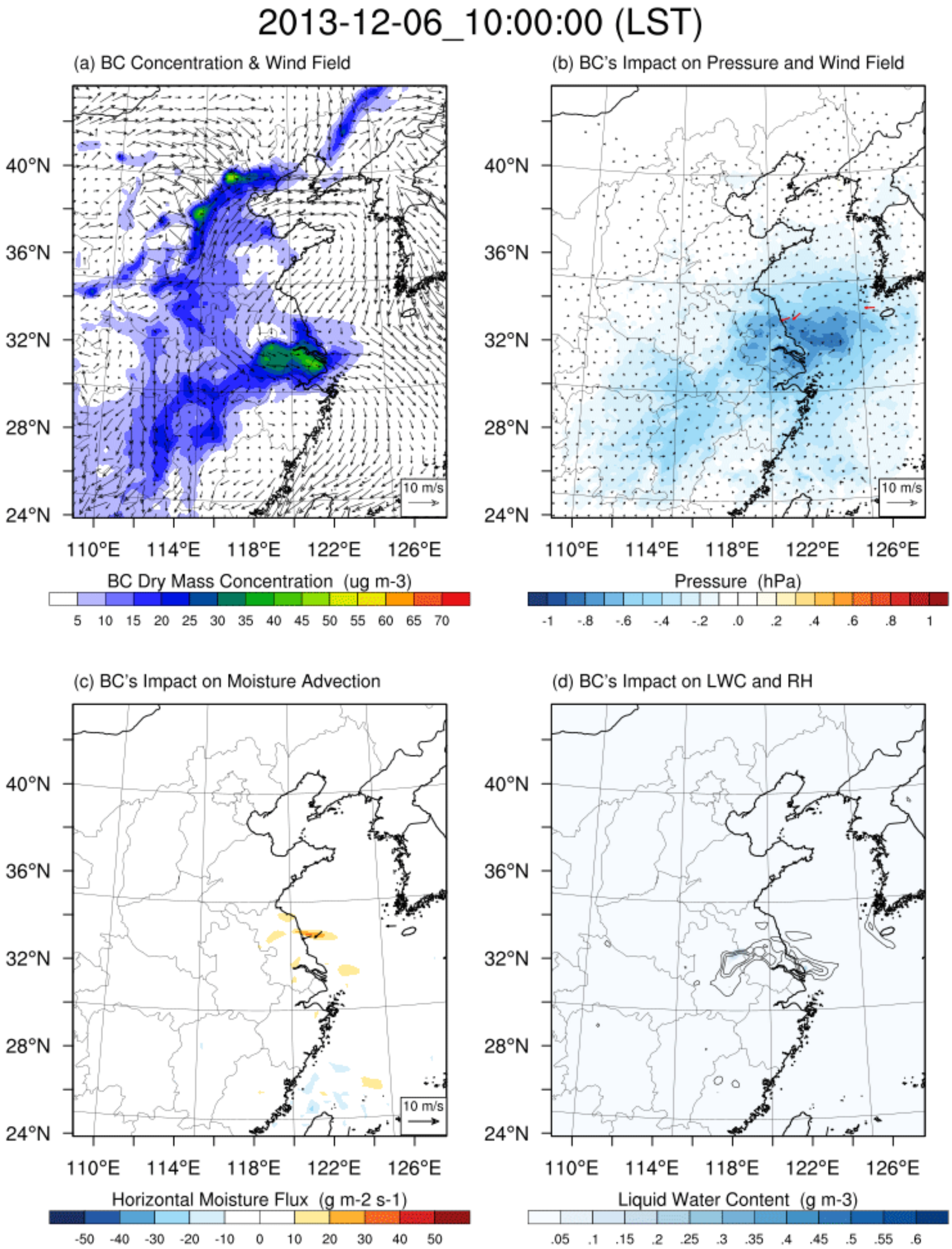

Figure S4. Distributions of BC surface concentration and wind field in the surface layer from EXP_CTL **(a)**, BC-induced low-pressure perturbation and cyclonic anomaly in wind field **(b)**, the enhanced moisture advection by BC **(c)**, and the BC-induced increase of RH (represented by isolines with the interval of 5%) or BC-induced increase of LWC (represented by blue shadow) **(d)** at 10:00 LST on 6 December. The red arrows in (b) and the black arrows in (c) denote the change of wind speed caused by BC with the magnitude larger than 3 m s^{-1} (Actually they are the same but with different colors). You can see the cartoon by pressing the Link at [here].

S4 The dome effect of BC on increasing moisture in the lower part of PBL

The dome effect of BC is to stabilize the PBL due to the heating of BC in the upper part of PBL in the daytime, which can suppress the PBL development and reduce PBLH. Figure S5 shows that over the land, where BC concentration is relatively high, the dome effect makes the PBLH significantly reduced. The lower PBL height helps to restrict the moist air advected here from other place in a shallow layer, which is favorable for the moist air to maintain its high moisture level (if the PBLH is higher, the moist air will be mixed in a thicker layer, which can decrease the moisture level in the lower part of PBL). Meanwhile, the stabilized PBL weakens the vertical mixing of turbulence, which can help to accumulate the moisture in the surface layer. As shown in Fig. S5, the moisture around Nanjing decreases with height, and the highest moisture is in the surface layer in the daytime.

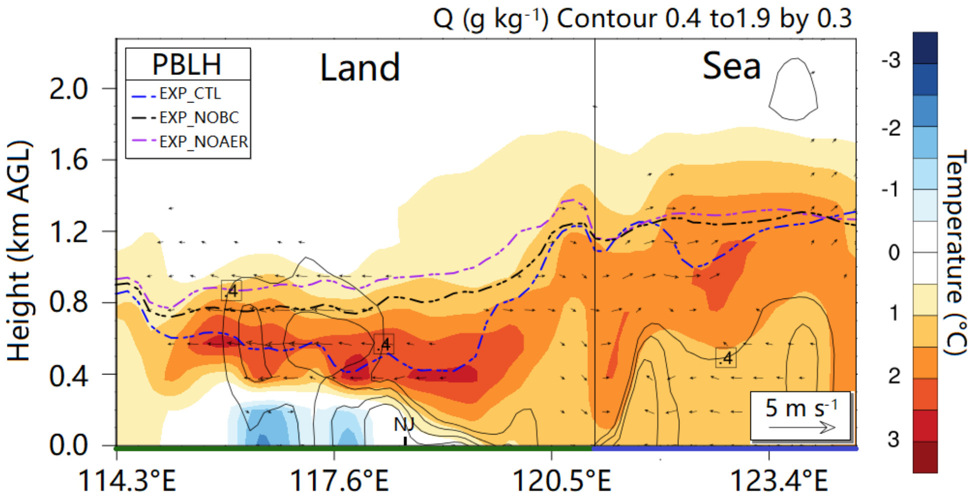

Figure S5. Cross-section of BC-induced changes of temperature (colors) and water vapor mixing ratio (isolines) at 14:00 LST on 6 December at the location denoted in Fig. 10d. The PBLHs in EXP_CTL, EXP_NOBC and EXP_NOAER are denoted as the blue, black and purple dashed lines. The vertical line denotes the boundary between land (the green part of *x* axis) and sea (the blue part of *x* axis). NJ at bottom represents the location of Nanjing.

The dome effect of BC also exists over the sea where the BC concentration is not negligibly small. Figure S5 also shows that the moisture over the offshore area is increased in EXP_CTL. However, the PBLH in this case is not reduced significantly, maybe due to the relatively low BC concentration and the relatively weak dome effect (another reason is concerned with the uncertainty of PBL scheme in diagnosing PBLH, but this problem is beyond the scope of this study and is not discussed further). The distribution of increase of temperature and moisture is horizontally heterogeneous. We calculated the average profiles of potential temperature and water vapor mixing ratio in the offshore area denoted in Fig. 10d at 14:00 LST on 6 December in EXP_CTL and EXP_NOBC, and plotted the results in Fig. S6. In EXP_NOBC, the potential temperature is almost constant with height below 800 m, indicating that this layer is well mixed and the PBLH should be about 800–1000 m. However, in EXP_CTL, the potential temperature between 400–800 m turns out to increase with height, suggesting a lower PBLH (Fig. S6a). Meanwhile, the water vapor mixing ratio in EXP_NOBC decreases slowly with height while it decreases faster with height in EXP_CTL, suggesting that the dome effect of BC weakens the vertical mixing and helps to accumulate moisture in the lower part of PBL over the sea. This can, at least partially, explain why the moisture in the surface layer over the offshore area is increased by BC.

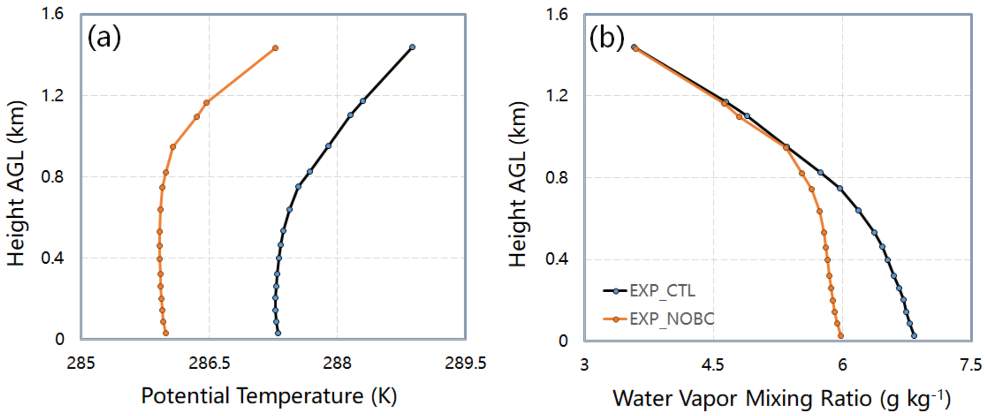

Figure S6. The average profiles of potential temperature **(a)** and water vapor mixing ratio **(b)** in the offshore area denoted in Fig. 10d at 14:00 LST on 6 December in EXP_CTL and EXP_NOBC.