

## Supplementary information

### Physical processes influencing the Asian climate due to black carbon emission over East and South Asia

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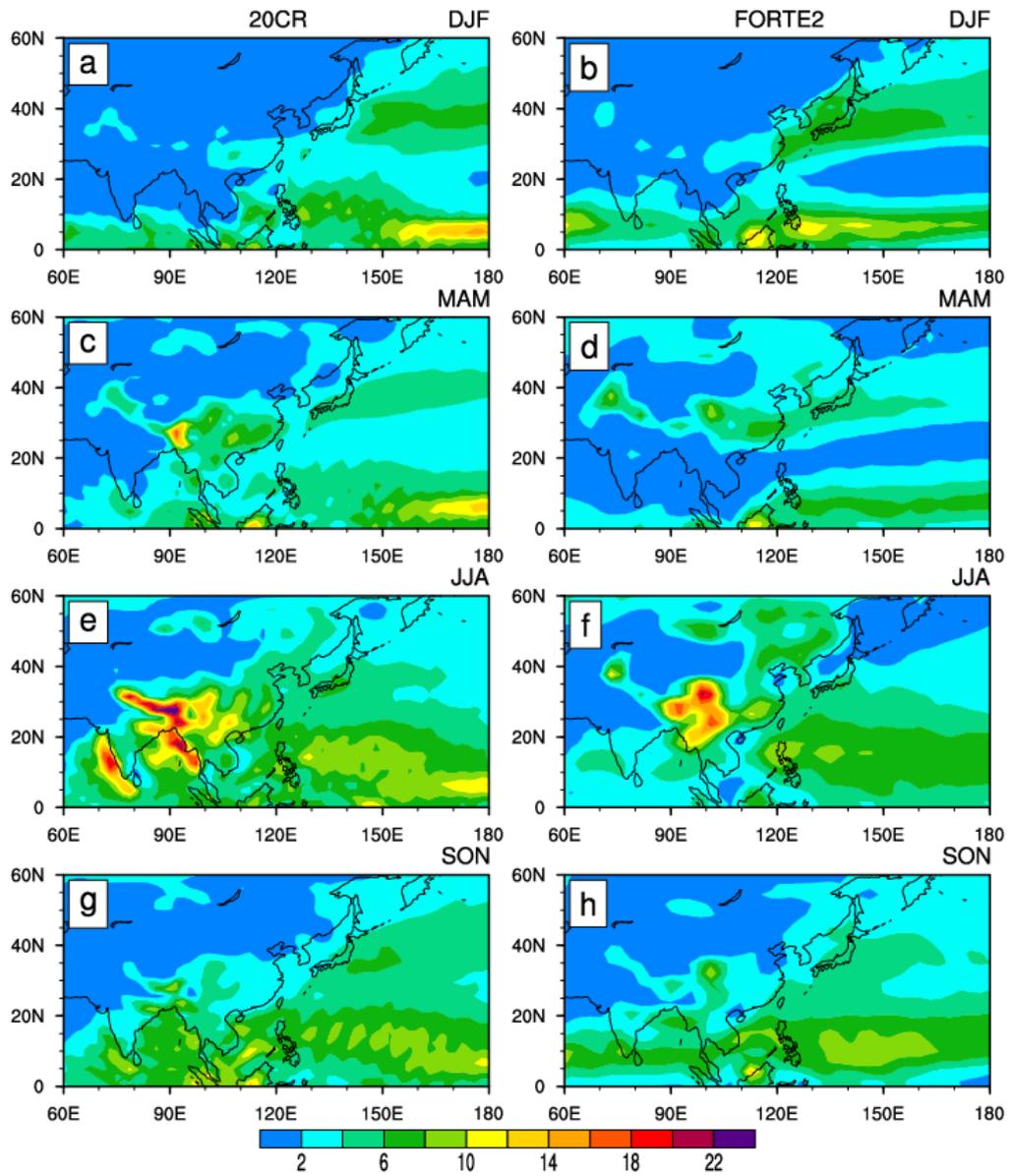
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**Table S1.** Details of the five models in the PDRMIP project

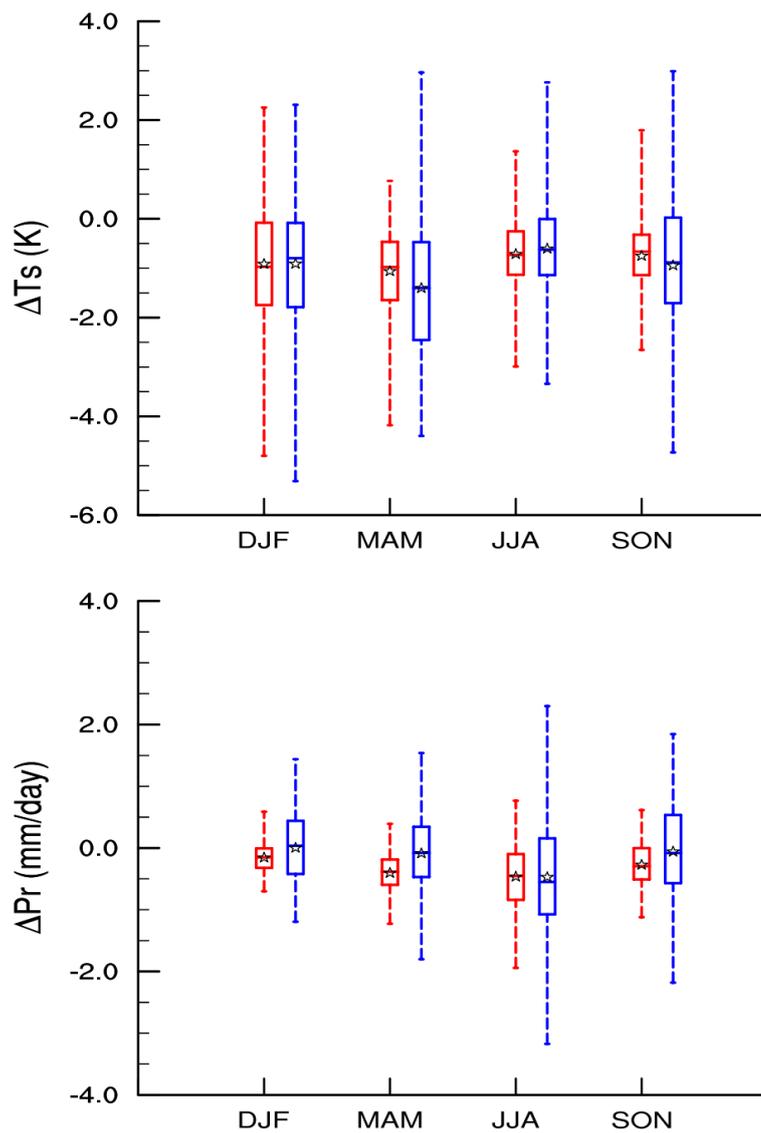
Model	Resolution (lonxlat)	Aerosol setup	Indirect effects included
CESM1-CAM5	2.5°x1.9° 30 levels	CMIP5 Emissions (year 2005)	All indirect effects
GISS-E2-R	2.5°x2° 40 levels	AeroCom Phase II concentrations	no indirect effects
HadGEM3	1.875°x1.25° 85 levels	AeroCom Phase II concentrations	no indirect effects
MIROC- SPRINTARS	1.4°x1.4° 40 levels	HTAP2 emissions (year 2010)	All indirect effects
NorESM1	2.5°x1.9° 26 levels	AeroCom Phase II concentrations	All indirect effects

**Table S2.** Area-averaged responses for net TOA and surface energy over East China in BC\_CHI and BC\_CHI\_IND, and over India in BC\_IND and BC\_CHI\_IND. Positive values mean downward for radiation and flux changes. Responses significant above the 95% level are shown in bold. Unit: W/m<sup>2</sup>

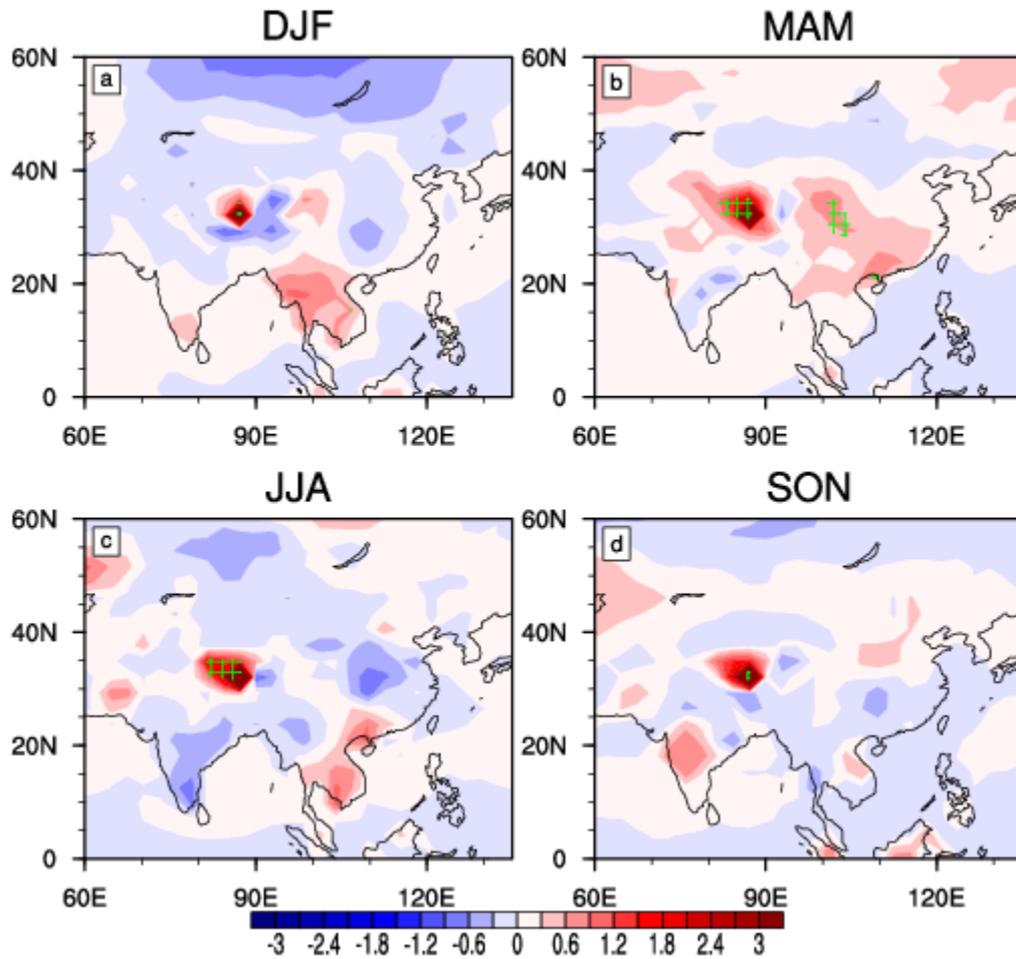
	BC_CHI			BC_IND			BC_CHI+IND		
	(20°N-53°N,95°E-133°E)			(5°N-35°N,65°E-95°E)			(20°N-53°N,95°E-133°E)/(5°N-35°N,65°E-95°E)		
	DJF	MAM	SON	DJF	MAM	SON	DJF	MAM	SON
TOA SW	<b>4.21</b>	<b>8.91</b>	<b>4.52</b>	<b>4.08</b>	<b>6.96</b>	4.39	<b>4.59/4.57</b>	<b>8.75/7.51</b>	4.24/ <b>5.63</b>
SW	<b>-16.2</b>	<b>-30.03</b>	<b>-17.49</b>	<b>-23.57</b>	<b>-27.80</b>	<b>-23.35</b>	<b>-15.80/-23.26</b>	<b>-31.0/-28.13</b>	<b>-17.98/-23.26</b>
LW	-4.16	<b>-6.87</b>	<b>-4.76</b>	-1.21	-0.98	-3.26	-4.18/-1.11	-5.6/0.19	<b>-5.0/-2.55</b>
SH	<b>6.14</b>	<b>9.26</b>	<b>5.36</b>	<b>6.55</b>	<b>10.86</b>	<b>6.78</b>	<b>6.73/6.66</b>	<b>9.48/10.37</b>	<b>6.09/7.16</b>
LH	<b>8.29</b>	13.45	11.75	12.42	5.62	<b>11.12</b>	<b>9.36/12.94</b>	<b>14.02/4.88</b>	11.35/9.89



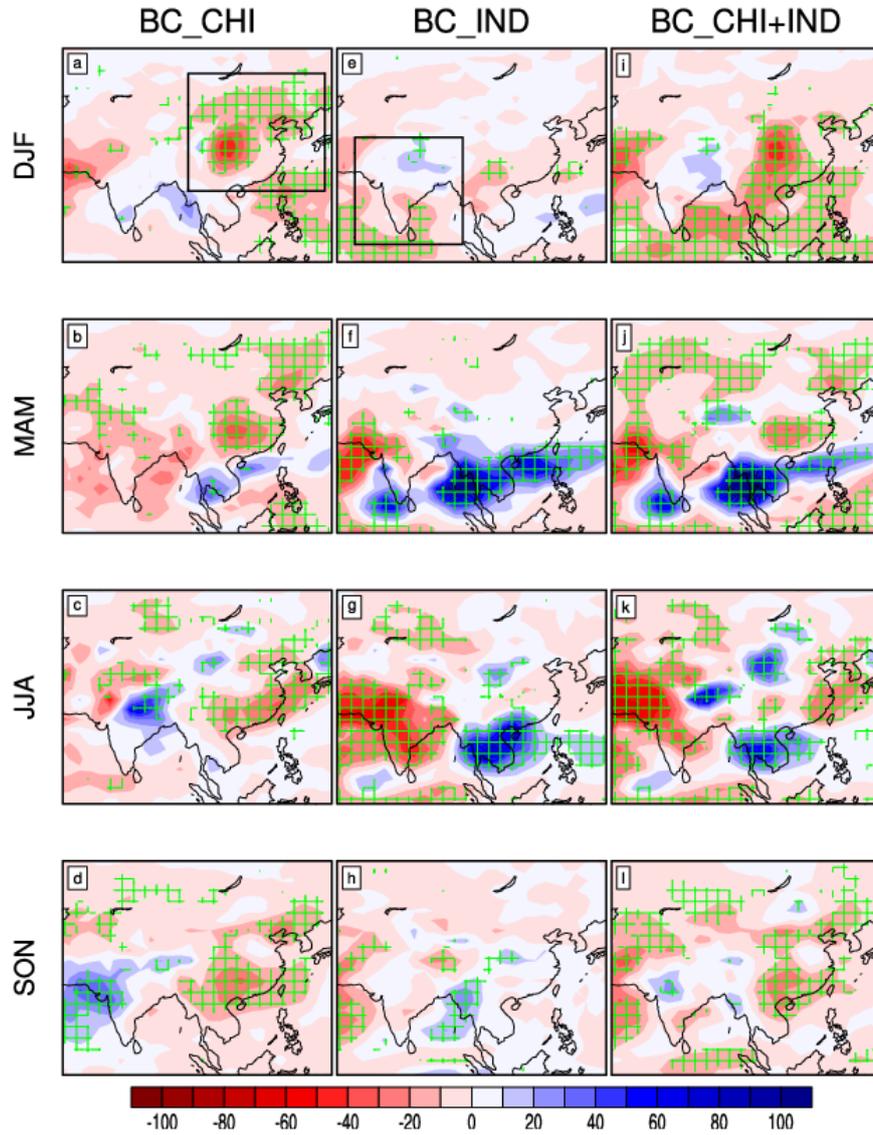
**Figure S1.** Climate state of precipitation in (left) 20CR and (right) the baseline simulation of FORTE2 in (a-b) DJF, (c-d) MAM, (e-f) JJA and (g-h) SON. Unit: mm/day



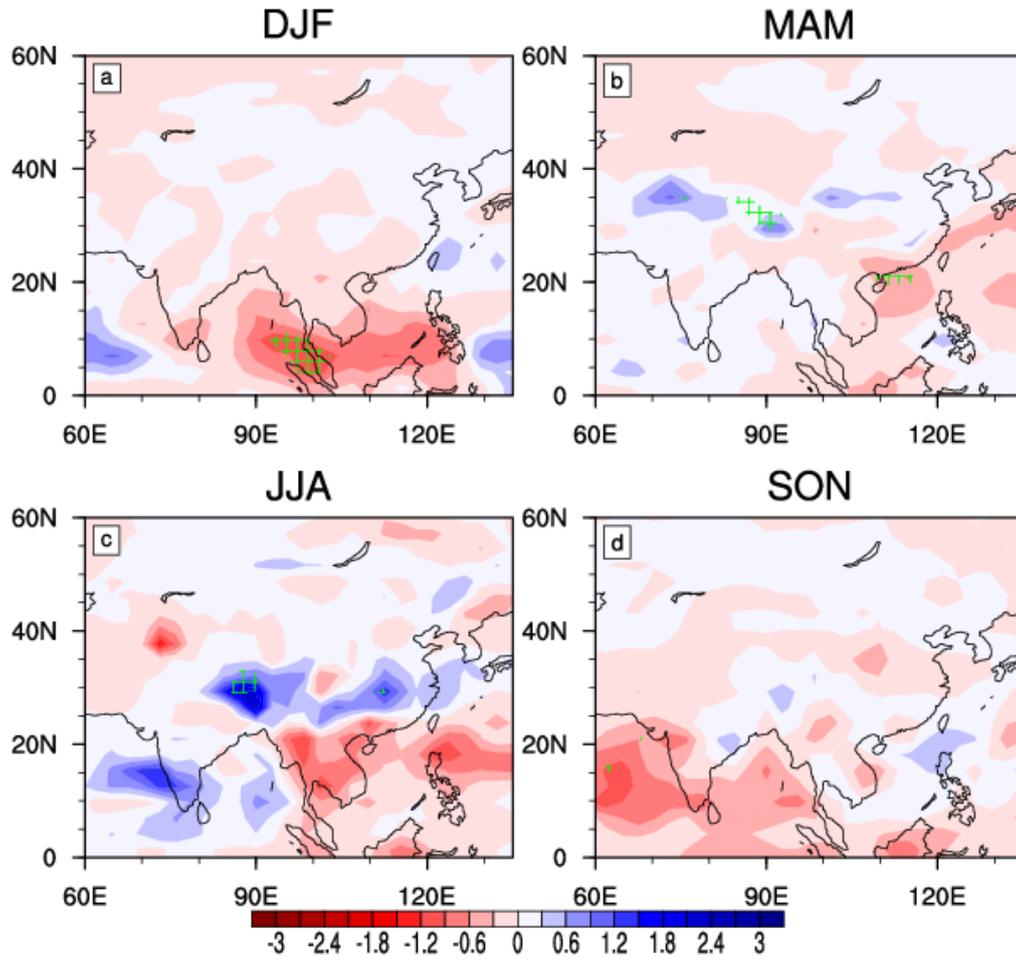
**Figure S2.** Box and Whisker plots showing the distributions of (upper) Ts and (lower) Pr differences between the perturbation simulations and baseline simulation. Boxes mean the interquartile range of differences; lines within the boxes mean the median; whiskers mean the minimum and maximum values, respectively; Stars show the average value. Red box and whisker plots represent area-averaged differences between BC\_CHI and piC over East China. Blue box and whisker plots represent area-averaged differences between BC\_IND and piC over India.



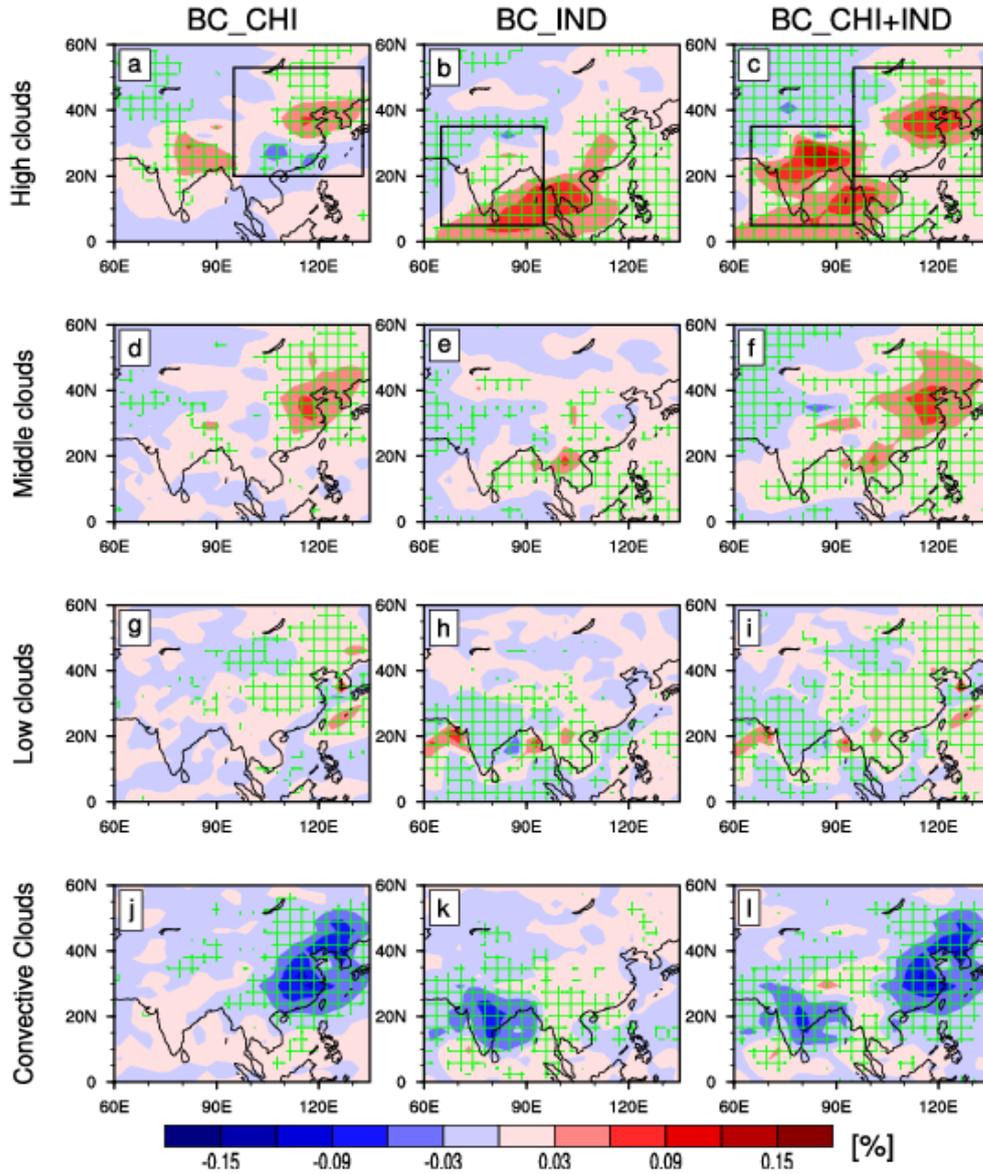
**Figure S3.** The linearity of Ts responses to Asian BC aerosol in four seasons [BC\_CHI+IND-(BC\_CHI+BC\_IND)]. The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. Unit: K



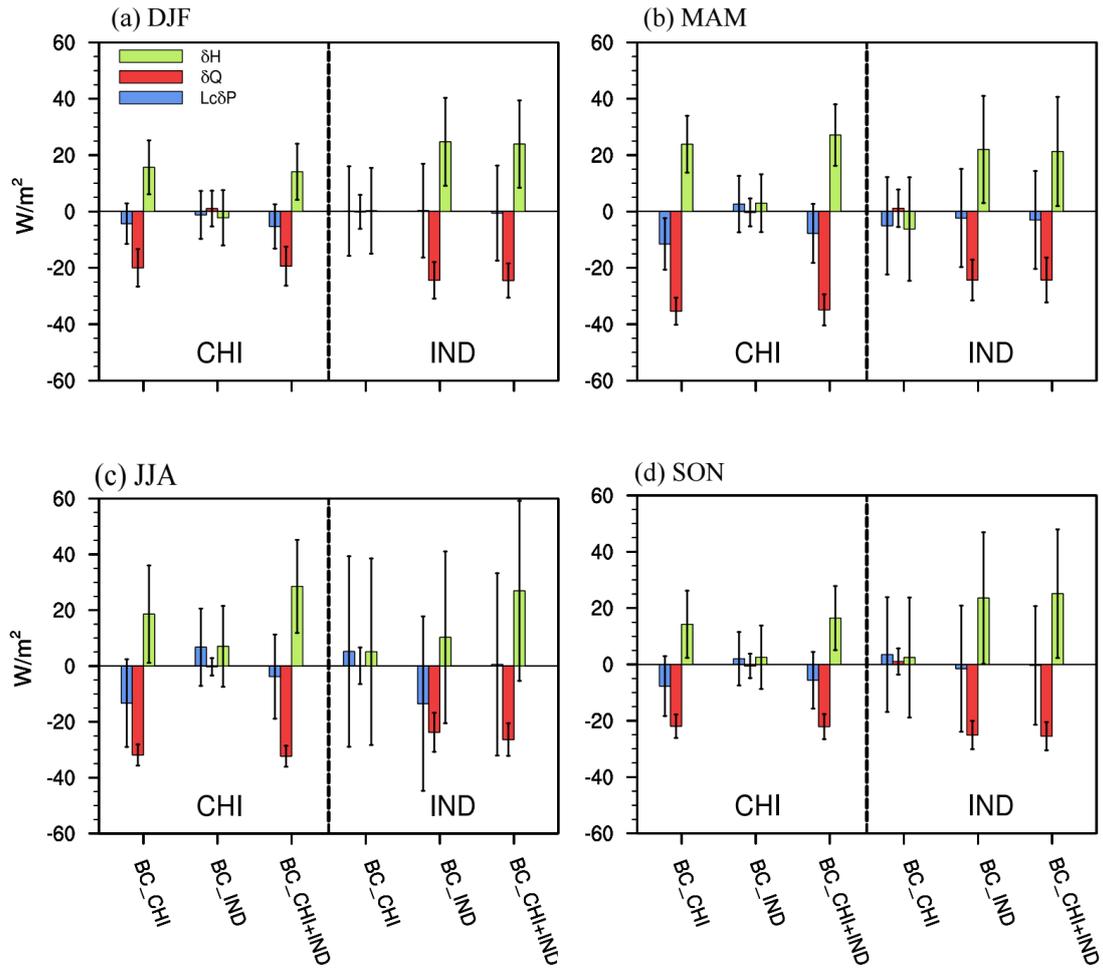
**Figure S4.** Spatial patterns of precipitation rate responses in (a-d) BC\_CHI, (e-h) BC\_IND, and (i-l) BC\_CHI+IND for four seasons. The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. The black squares highlight the separate region where BC aerosols are perturbed. Unit: %



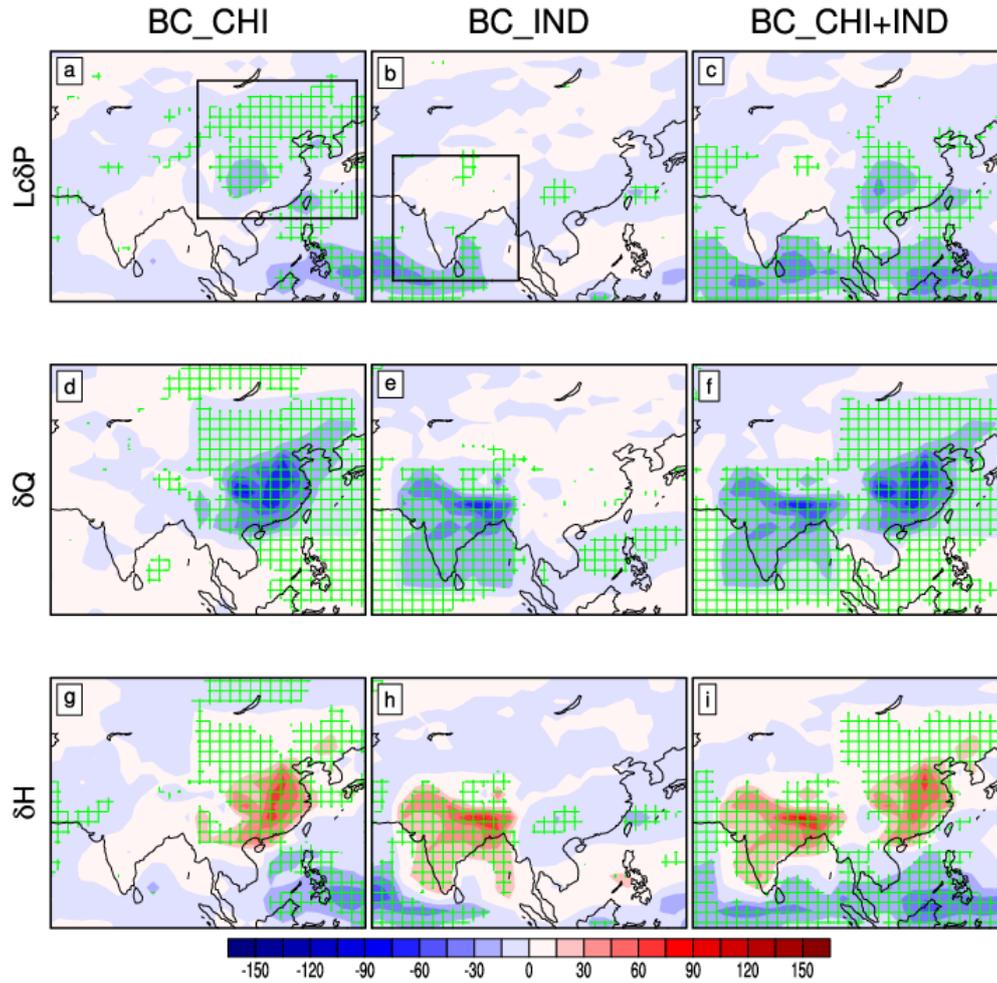
**Figure S5.** As Figure S3 but for precipitation. Unit: mm/day



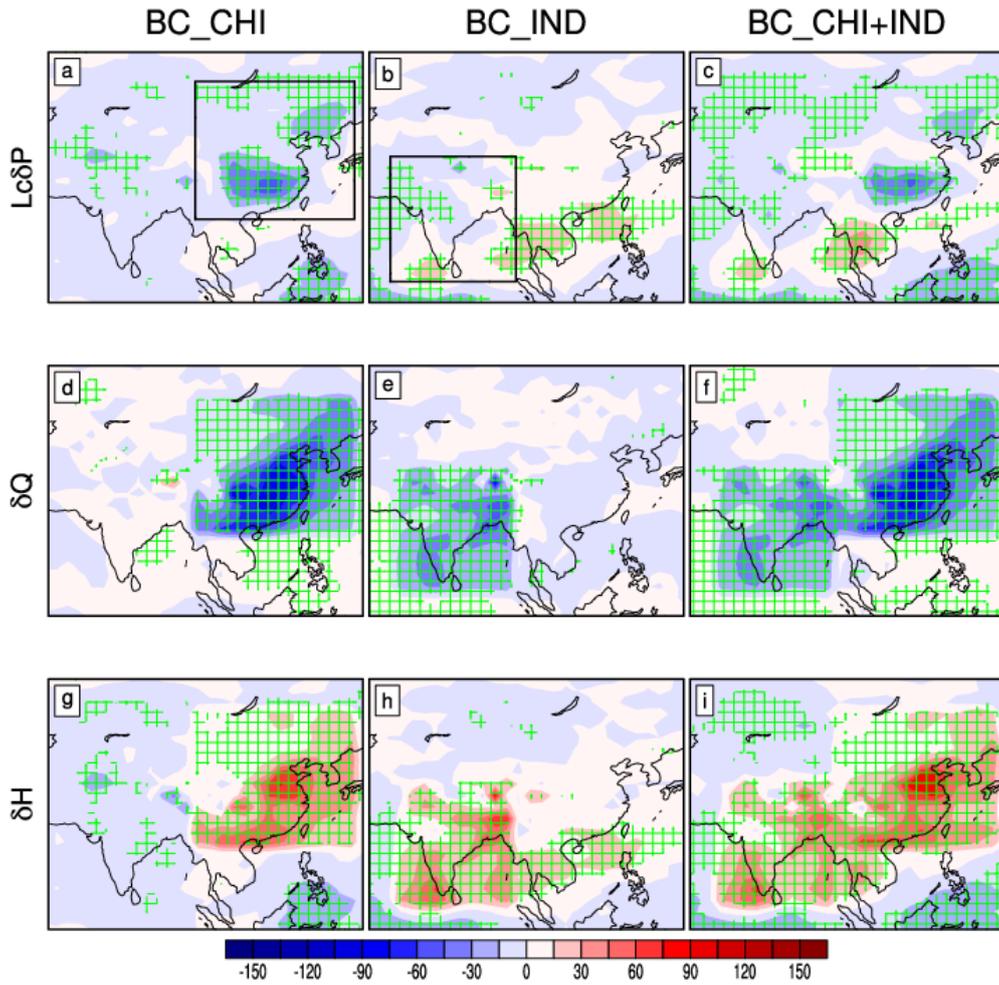
**Figure S6.** Summer spatial patterns of responses in (a-c) high clouds, (d-f) middle clouds, (g-i) low clouds and (j-l) convective clouds in BC\_CHI, BC\_IND and BC\_CHI+IND. The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. The black squares highlight the regions where BC are perturbed. Unit: %



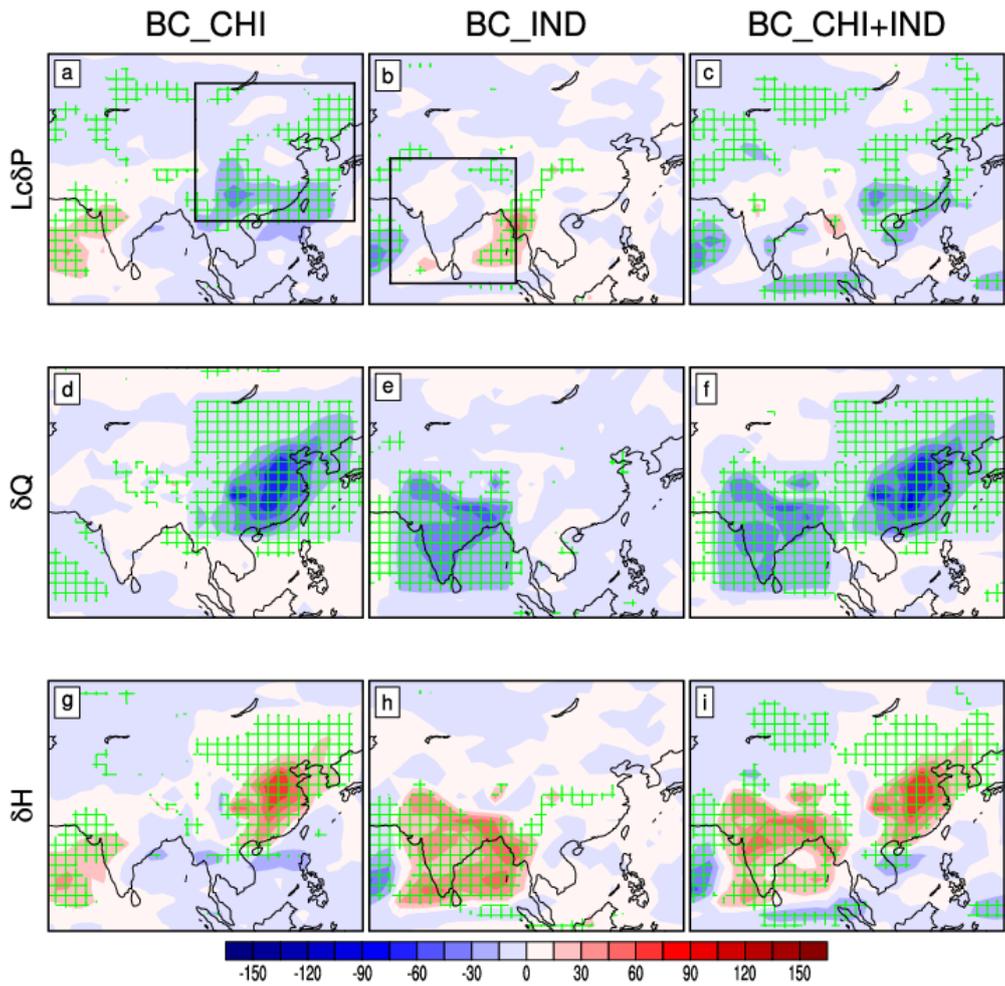
**Figure S7.** Area-averaged responses of the atmospheric energy budget terms over East China (CHI: 95°E-133°E, 20°N-53°N) and India (IND: 65°E-95°E, 5°N-35°N) in BC\_CHI, BC\_IND, and BC\_CHI+IND. (a) winter, (b) spring, (c) summer and (d) autumn. Error bars represent  $\pm 1$  standard deviations of the response. Unit:  $W/m^2$



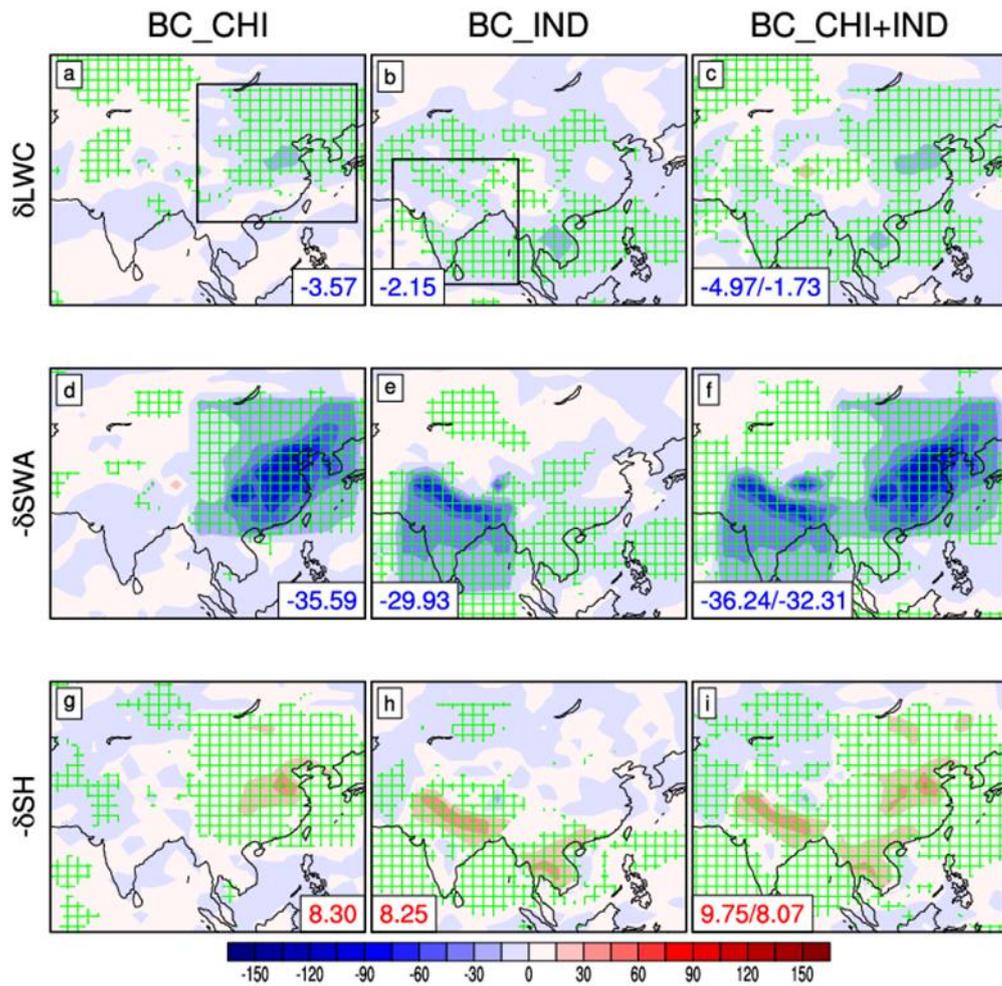
**Figure S8.** Winter spatial patterns of responses of the atmospheric energy budget terms in BC\_CHI, BC\_IND, and BC\_CHI+IND. (a-c)  $L_c\delta P$ , (d-f)  $\delta Q$  and (g-i)  $\delta H$ . The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. The black squares highlight the regions where BC are perturbed. Unit:  $W/m^2$



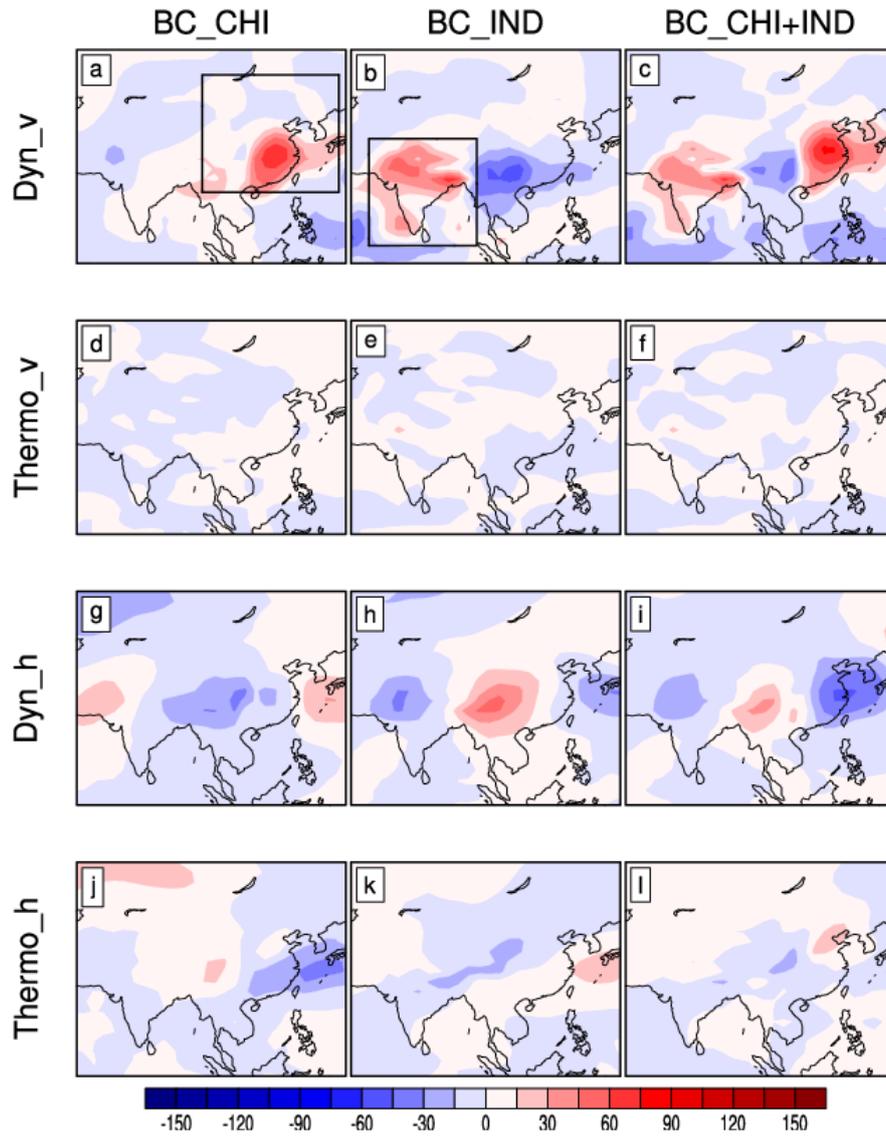
**Figure S9.** As Figure S8 but for spring.



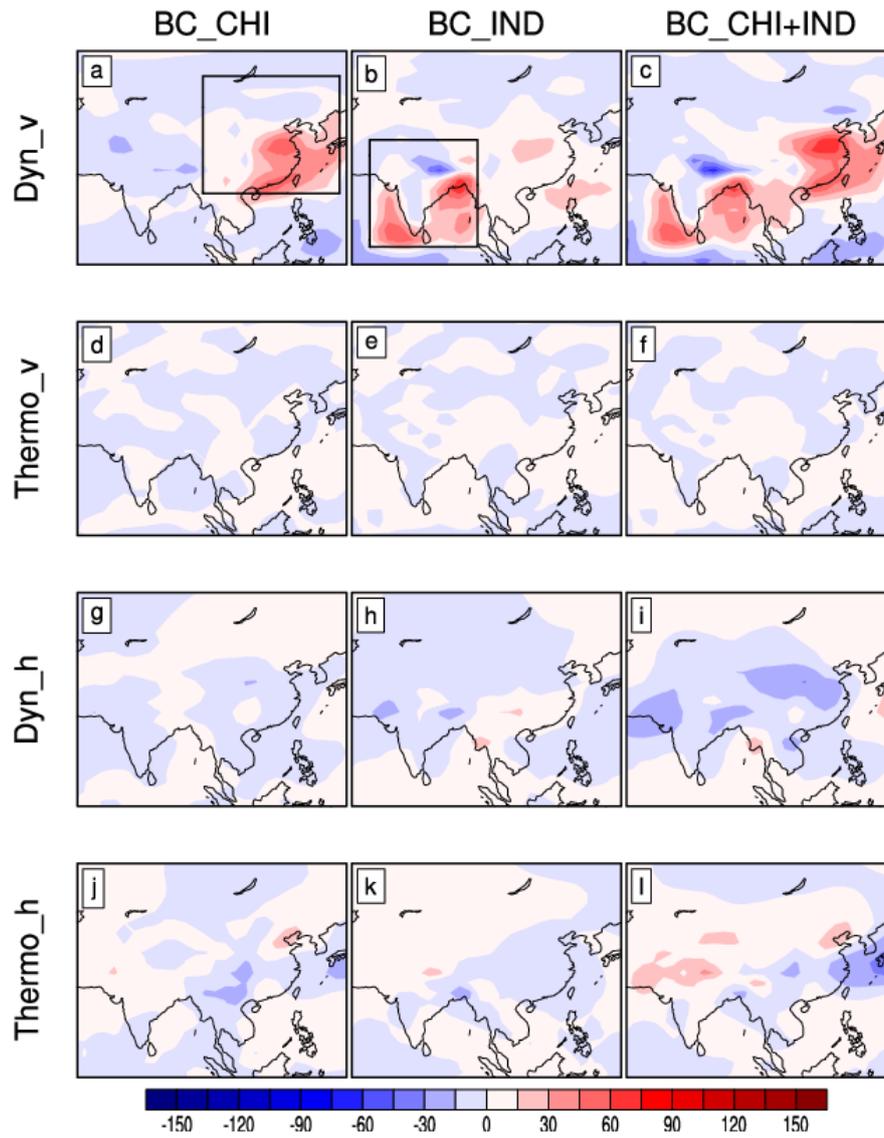
**Figure S10.** As Figure S8 but for autumn.



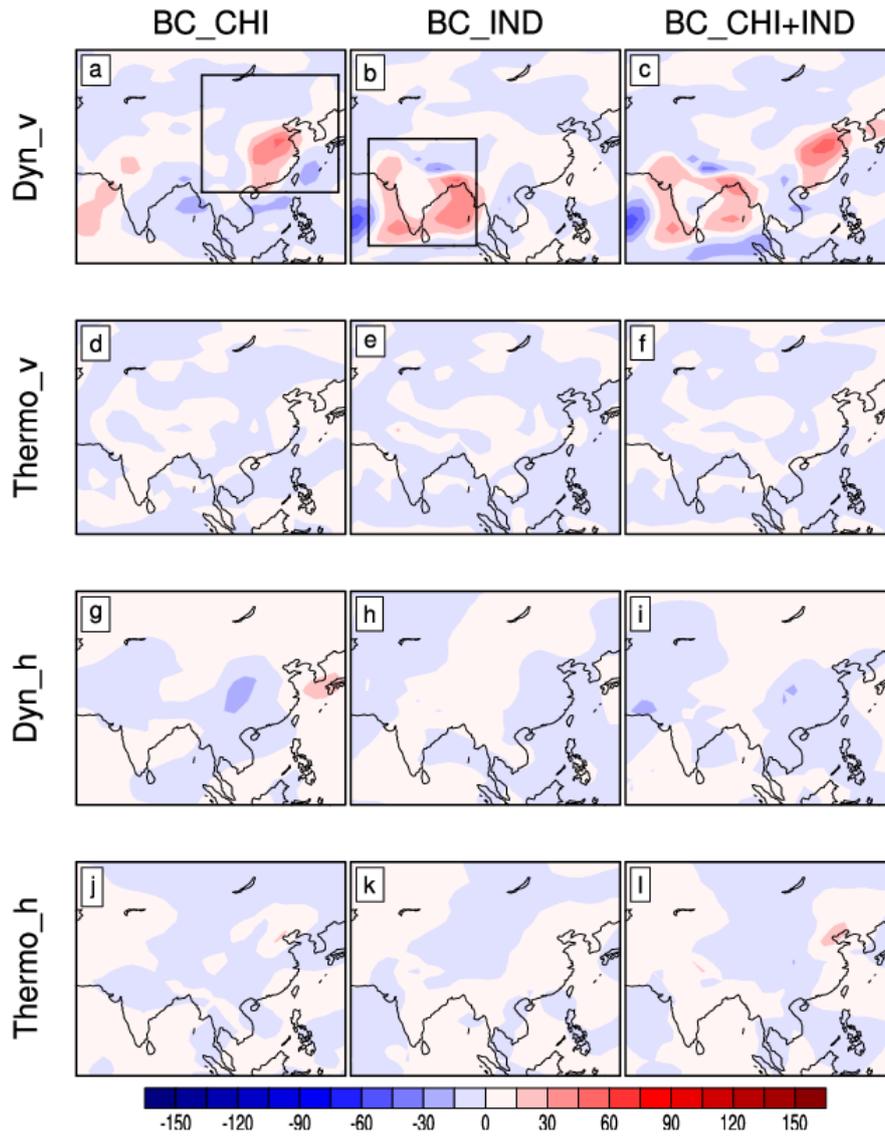
**Figure S11.** Summer spatial patterns of responses of (a-c) net longwave cooling (LWC), (d-f) net shortwave absorption (SWA), and (g-i) sensible heat flux from the surface (SH) in BC\_CHI, BC\_IND, and BC\_CHI+IND. Area-averaged values over East China and India are given in the lower right corners and lower left corners, respectively. The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. The black squares highlight the regions where BC are perturbed. Unit:  $W/m^2$



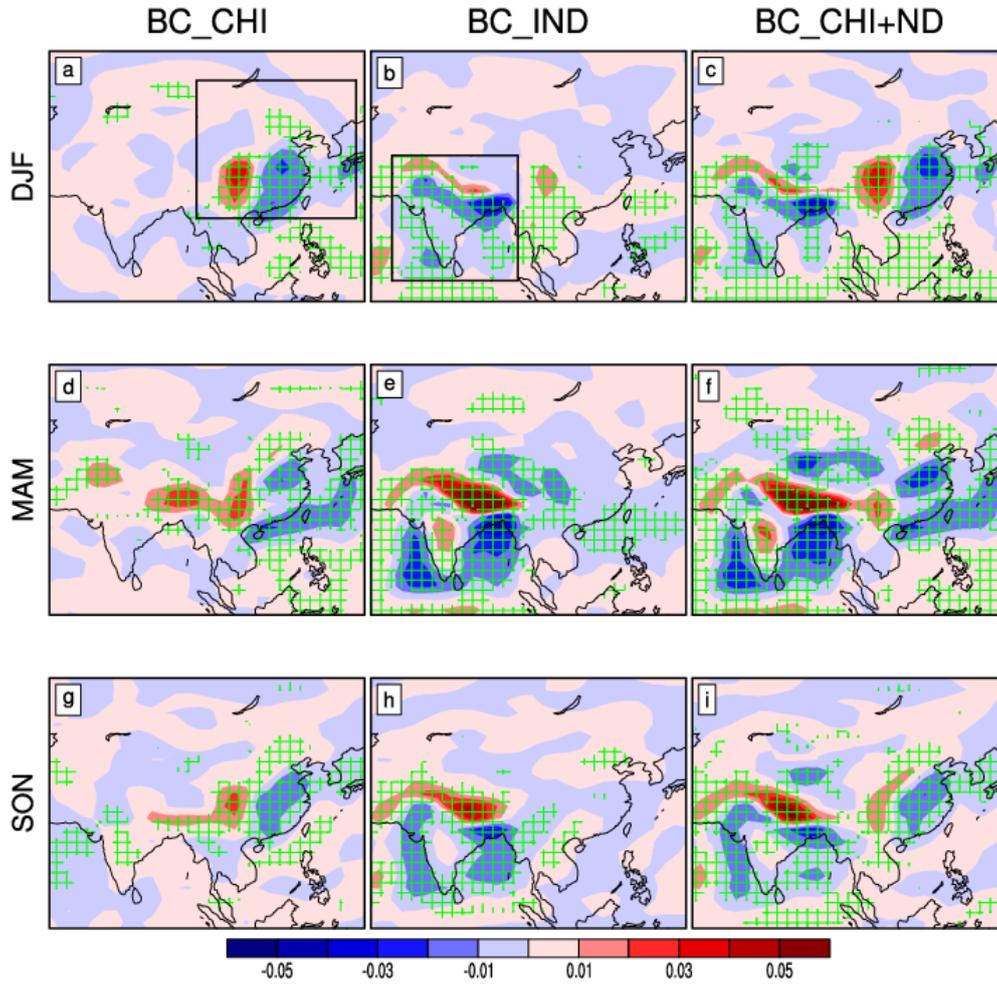
**Figure S12.** Winter spatial patterns of responses in the four terms decomposed by  $\delta H$  in BC\_CHI, BC\_IND, and BC\_CHI+IND. (a-c) the dynamic components with changes in vertical atmospheric circulations ( $\delta H_{\text{Dyn}_v}$ ), (d-f) the thermodynamic components with changes in vertical atmospheric circulations ( $\delta H_{\text{Thermo}_v}$ ), (g-i) dynamic components with changes in horizontal DSE gradients ( $\delta H_{\text{Dyn}_h}$ ), and (j-l) thermodynamic components with changes in horizontal DSE gradients ( $\delta H_{\text{Thermo}_h}$ ). The black squares highlight the regions where BC are perturbed. Unit:  $W/m^2$



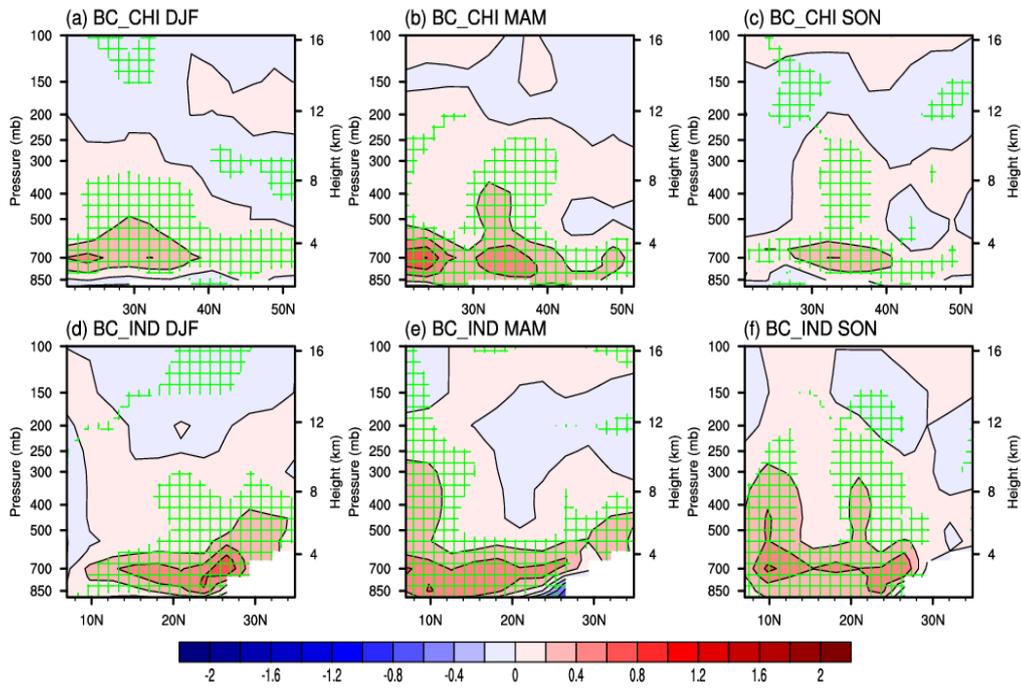
**Figure S13.** As Figure S12 but for spring.



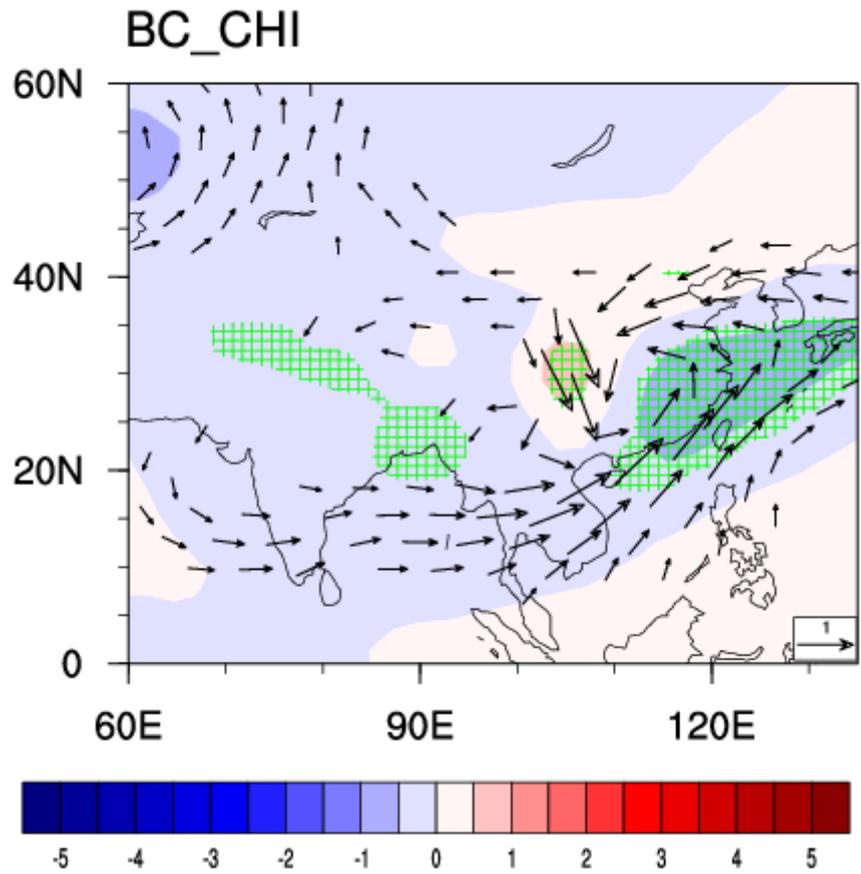
**Figure S14.** As Figure S12 but for autumn.



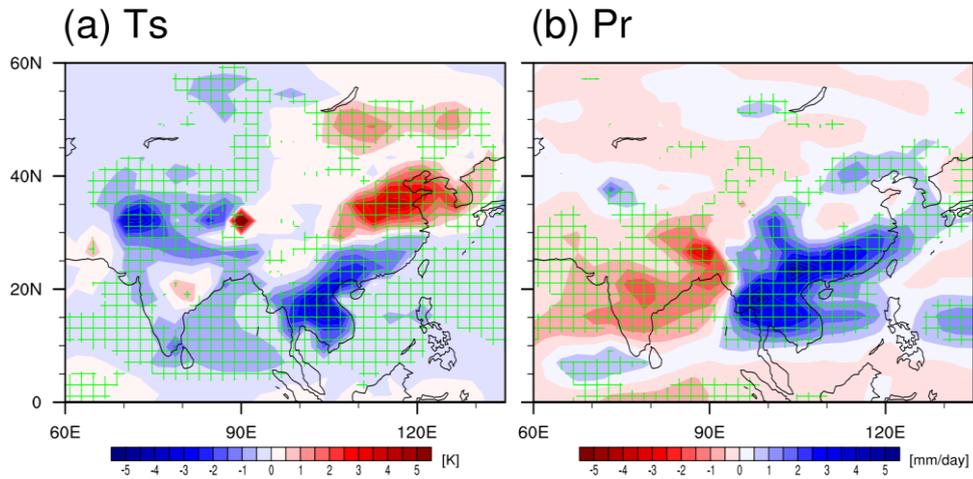
**Figure S15.** Spatial patterns of responses in Omega at 850 hPa in BC\_CHI, BC\_IND and BC\_CHI+IND. (a-c) DJF, (d-f) MAM, and (g-i) SON. The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. The black squares highlight the regions where BC are perturbed. Unit: Pa/s



**Figure S16.** Zonal mean of diabatic heating responses averaged over (a-c) East China (95°E-133°E) for BC\_CHI, and over (d-f) India (65°E-95°E) for BC\_IND, in DJF, MAM, and SON. The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. Unit: K/day



**Figure S17.** Winter spatial pattern of responses in SLP (Unit: hPa) and horizontal wind at 850 hPa (Unit: m/s) for BC\_CHI. The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test. Only regions with at least one component of the wind significant above the 95% level are shown.



**Figure S18.** Summer (a) Ts (Unit: K) and (b) precipitation (Unit: mm/day) responses to the dipole pattern measured by a sum of  $-(BC\_CHI-piC)$  and  $(BC2-piC)$ . The green gridlines indicate the regions where the responses are statistically significant above 95% level based on a two-tailed Student's t-test.