Table S1 Model performance statistics for T2, WS10, and RH2 (from the M-G case) in the six megacities over NCP during the study period from 1 February to 18 February 2020 (units: K, m s^{-1}, %).

City	Long Name	Location	T2					WS10					RH2				
			Obs	Sim	R	MB	NMB	Obs	Sim	R	MB	NMB	Obs	Sim	R	MB	NMB
BJ	Beijing	116.5°E, 39.8°N	272.6	273.9	0.89	1.3	0.5%	2.8	2.6	0.72	-0.19	-6.8%	61.8	68.9	0.76	7.1	11.4%
TJ	Tianjin	117.1°E, 39.1°N	273.4	275.0	0.92	1.6	0.6%	3.1	2.9	0.80	-0.15	-4.9%	65.1	70.8	0.77	5.6	8.7%
SJZ	Shijiazhuang	114.4°E, 38.1°N	273.7	275.4	0.88	1.7	0.6%	2.8	2.7	0.52	-0.11	-3.9%	51.6	68.3	0.57	16.7	32.4%
ZZ	Zhengzhou	113.7°E, 34.7°N	278.5	278.6	0.88	0.2	0.1%	2.8	2.7	0.62	-0.03	-1.1%	62.5	75.5	0.84	13.0	20.8%
TY	Taiyuan	112.6°E, 37.8°N	272.9	272.3	0.86	-0.6	-0.2%	2.7	3.3	0.57	0.63	23.8%	48.3	62.0	0.55	13.6	28.2%
JN	Jinan	117.1°E, 36.6°N	275.5	276.8	0.93	1.2	0.4%	2.7	3.7	0.54	0.98	35.7%	65.3	76.7	0.62	11.4	17.4%
ALL			274.4	275.3	0.89	0.9	0.3%	2.8	3.0	0.63	0.19	7.1%	59.1	70.4	0.69	11.2	19.8%

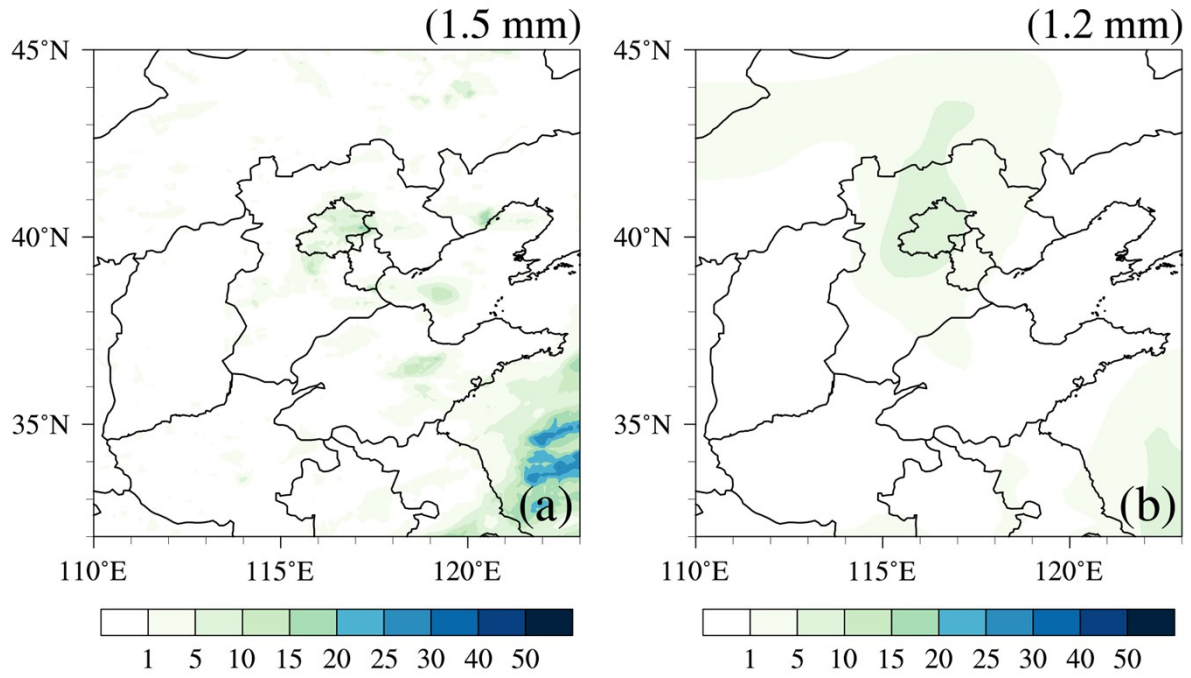

Figure S1 (a) The GPM retrieved, (b) model simulated (from the M-G case) accumulated precipitation during the haze episode on 8-13 February 2020 (unit: mm). The numbers in the upper-right corner of each panel represent domain average values.

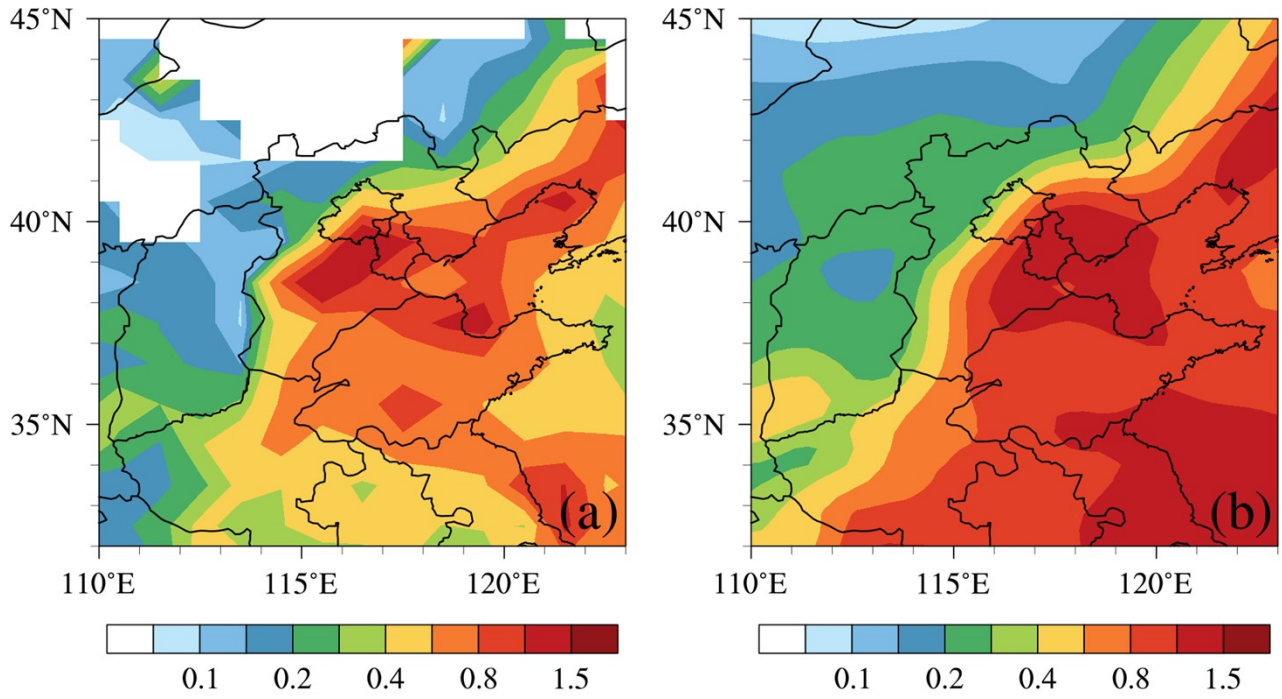

Figure S2 AOD at 550 nm at 10:30 LST from (a) MODIS retrieval and (b) model simulation (from the M-G case), averaged over the haze episode on 8-13 February 2020.

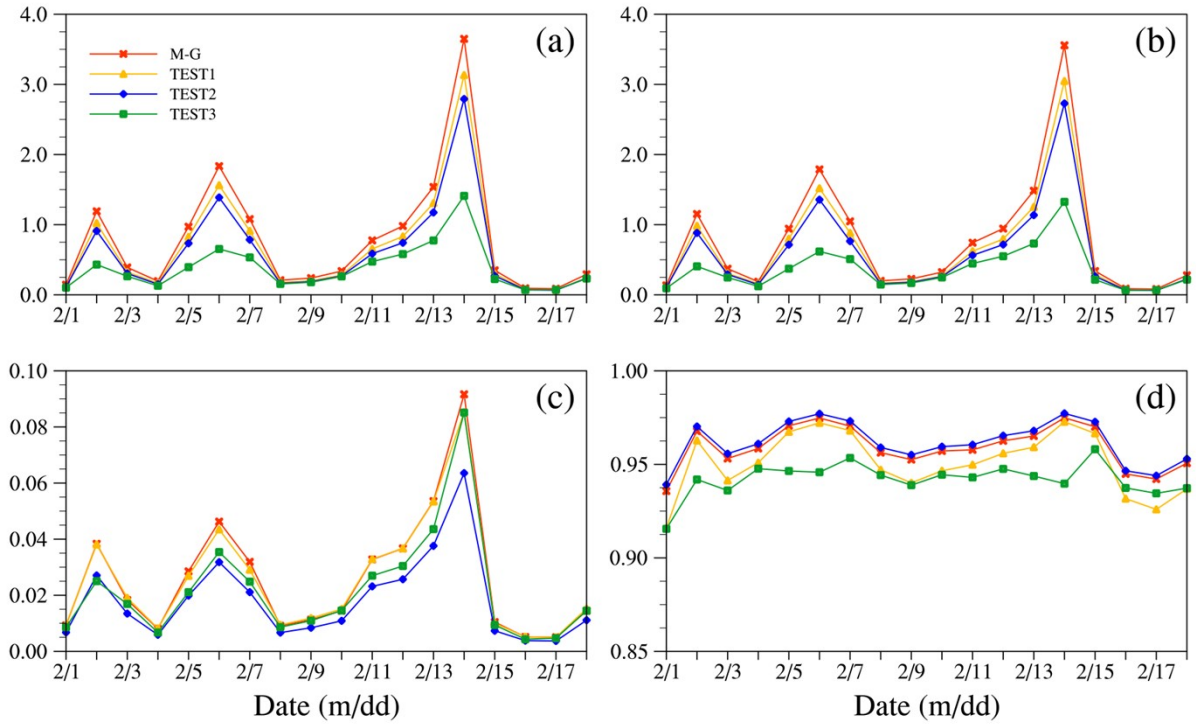

Figure S3 Model simulated daily mean (a) AOD, (b) scattering AOD, (c) absorption AOD, (d) SSA in Beijing on 1-18 February, 2020. Model results from the M-G and the three test cases are presented.

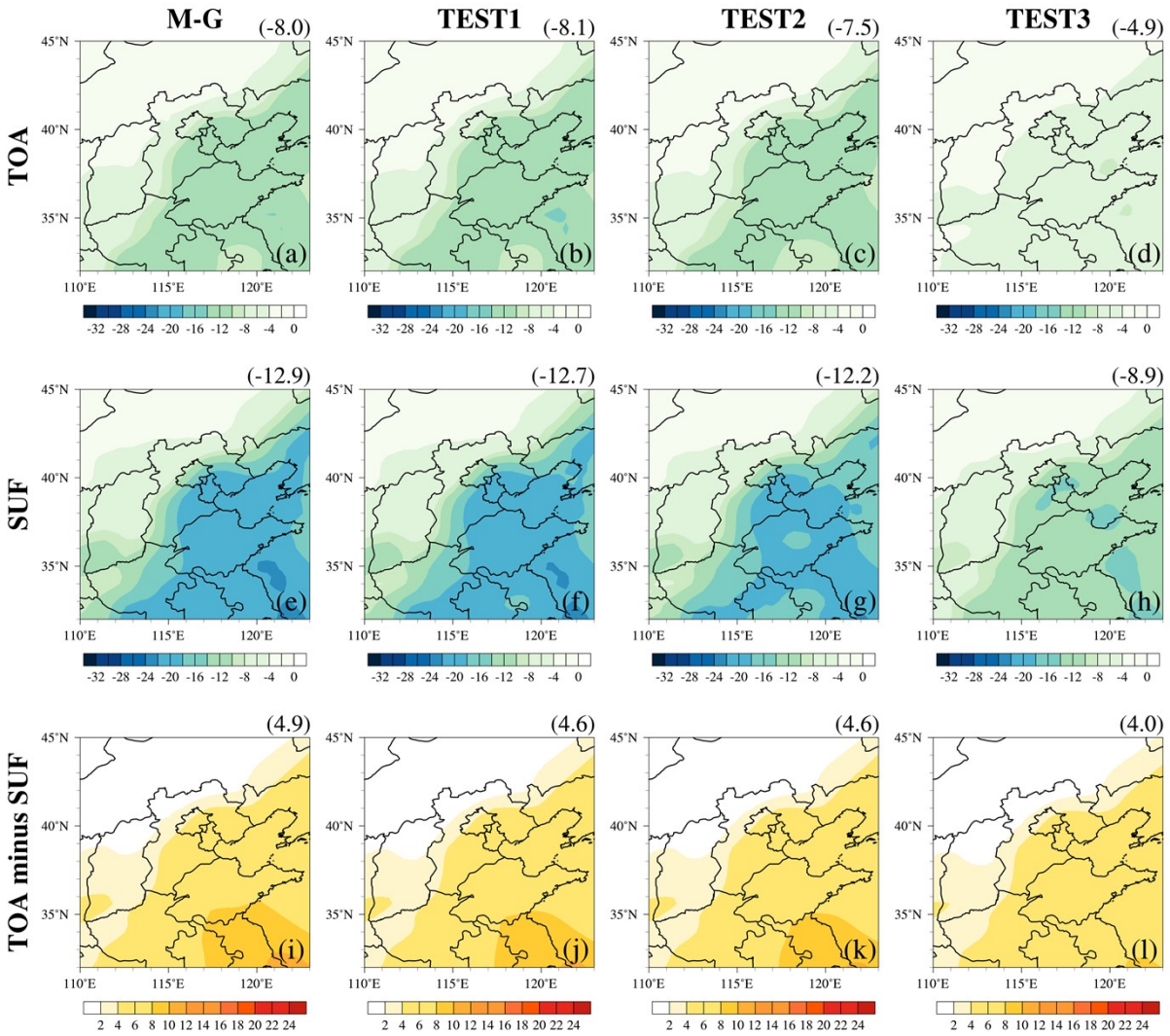

Figure S4 Model simulated period-mean DREs at TOA (a-d), at the surface (e-h), and in the atmosphere (i-l) during the haze episode on 8-13 February 2020, from the M-G and the three test cases regarding affecting factors of size distribution, coating fraction and hygroscopic growth. The numbers in the upper-right corner of each panel represent domain average values (unit: W m-2).

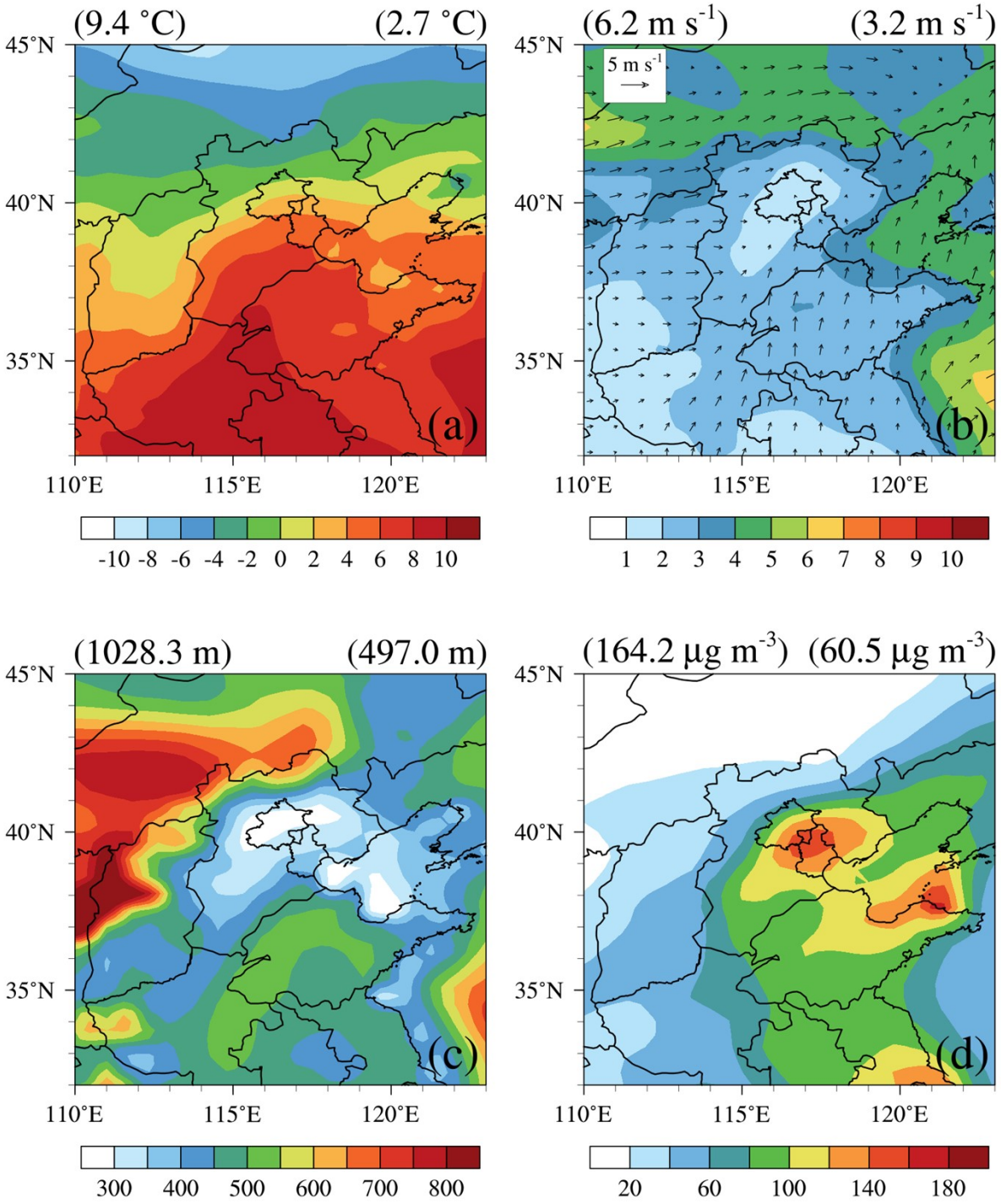

Figure S5 Model simulated period-mean (a) 2m temperature (T2, ℃), (b) 10m wind (WS10, m s^{-1}), (c) planetary boundary layer height (PBLH, m), (d) $PM_{2.5}$ concentration ($PM_{2.5}$, µg m^{-3}) from CASE0 during the haze episode on 8-13 February 2020. The numbers in the upper-left and upper-right corners of each panel represent the maximum and average values in the domain, respectively.

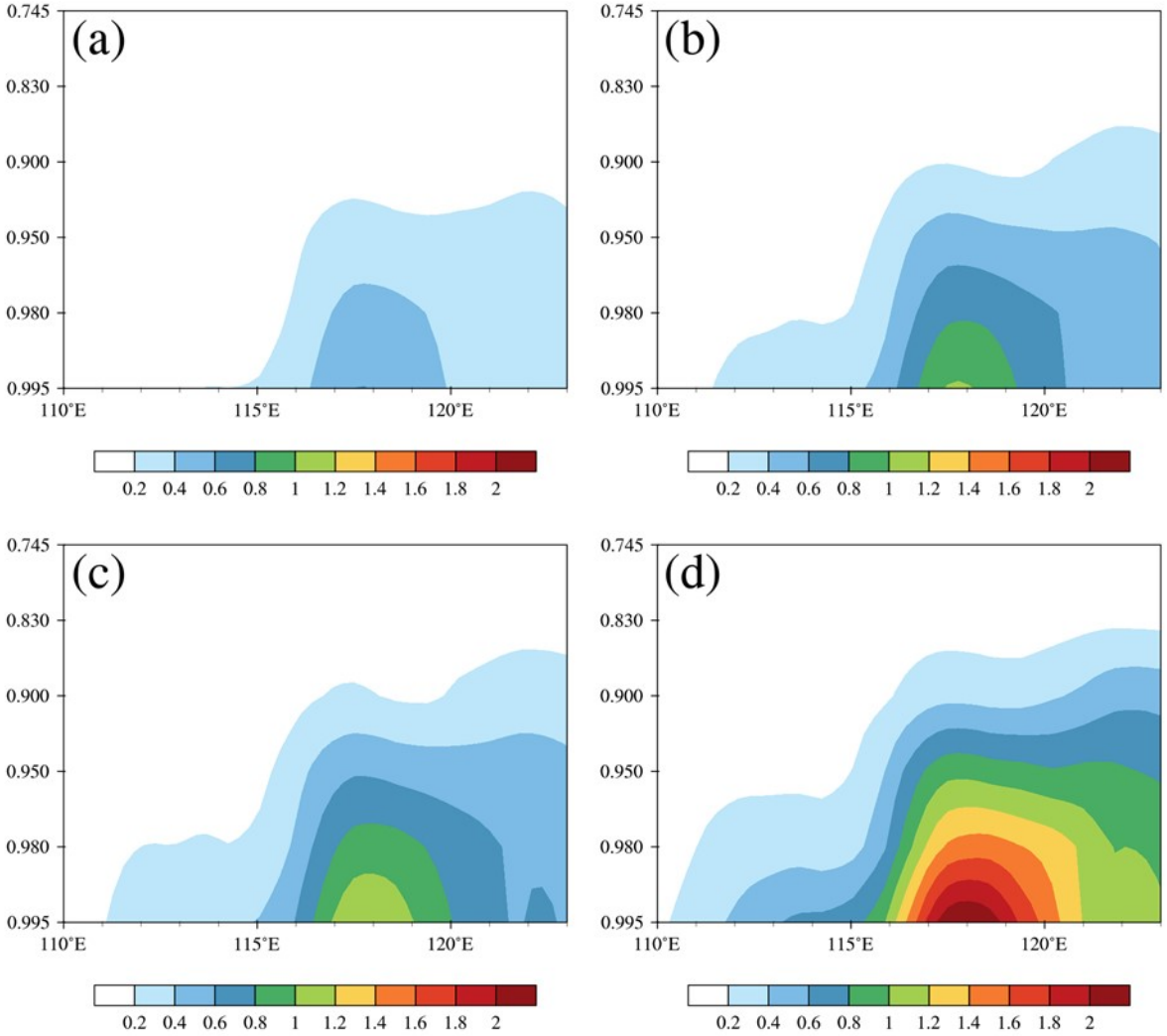

Figure S6 Model simulated period-mean vertical distributions of AHR induced by aerosols at 40°N from (a) EXT, (b) M-G, (c) C-S, and (d) HOM cases during the haze episode on 8-13, February 2020 (unit: K/day). The y-axis uses sigma coordinate.