Supplementary Material

Text S1: Evaluation of meteorological simulation

Performance of meteorological simulation is important for the inversion estimation since the meteorological parameters determine the transport process from the sources to the observation and influence the estimation of flow-dependent background error covariance. The air temperature, relative humidity and precipitation also affect the atmospheric chemistry and the removal of air pollutants. The meteorology simulation was evaluated against the daily observations from China Meteorological Administration (CMA) with spatial distribution of meteorological observation sites shown in Fig. S10. Figure S11–16 present the comparisons of simulated and observed regional mean daily meteorological parameters (i.e., u-wind, v-wind, temperature, relatively humidity and precipitation) over six regions of China from January to February 2020, with calculated evaluation statistics summarised in Table S4. In general, the simulation can well capture the main feathers of the observed meteorological conditions in all regions for our simulation period. All variables exhibited small RMSE values in all regions, that are around 1 m/s for wind speed, 1℃ for T, 10% for RH and 0.08–2.38mm for precipitation. Therefore, the WRF can generally well reproduce the meteorological conditions for all regions of China, which is adequate for our inversion estimates.

Figures

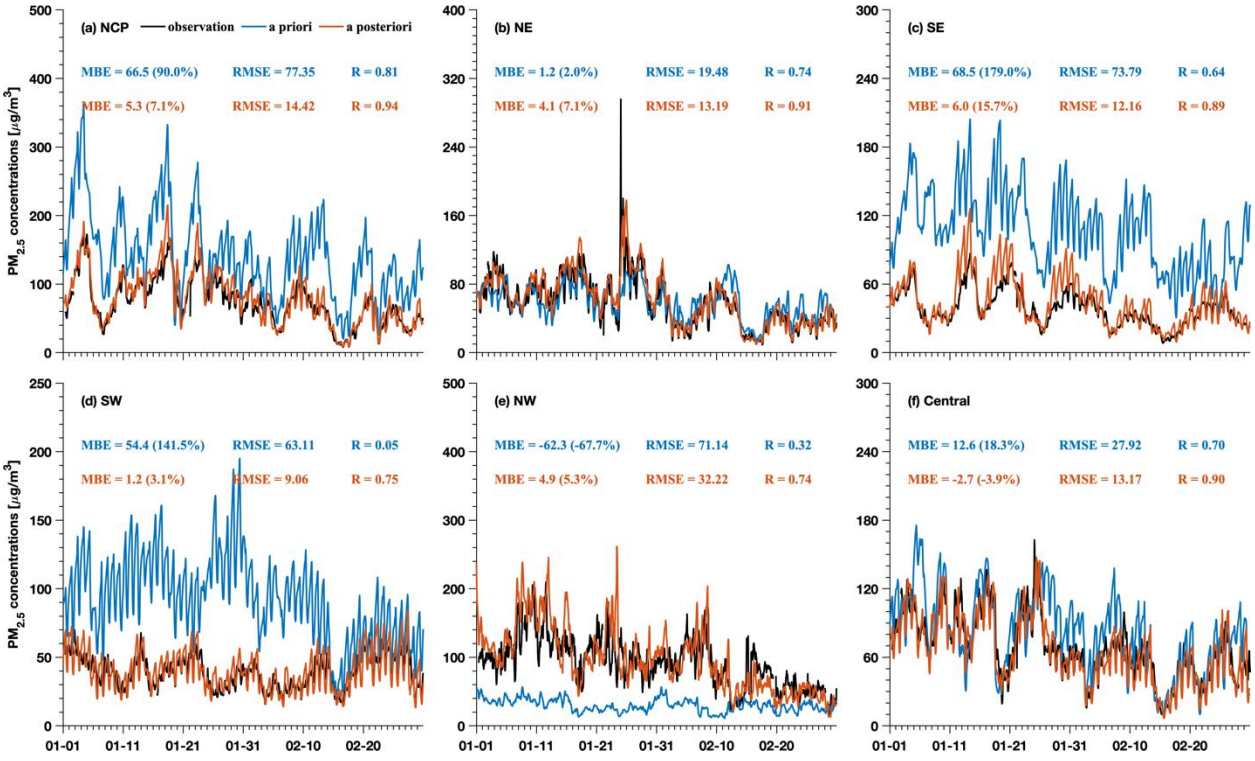


Figure S1: Time series of $PM_{2.5}$ concentrations over (a) NCP, (b) NE, (c) SE, (d) SW, (e) NW and (f) Central regions from 1st Jan to 29th Feb 2020 obtained from observation (black line) and simulation using a priori (blue line) and a posteriori (orange line) emissions.

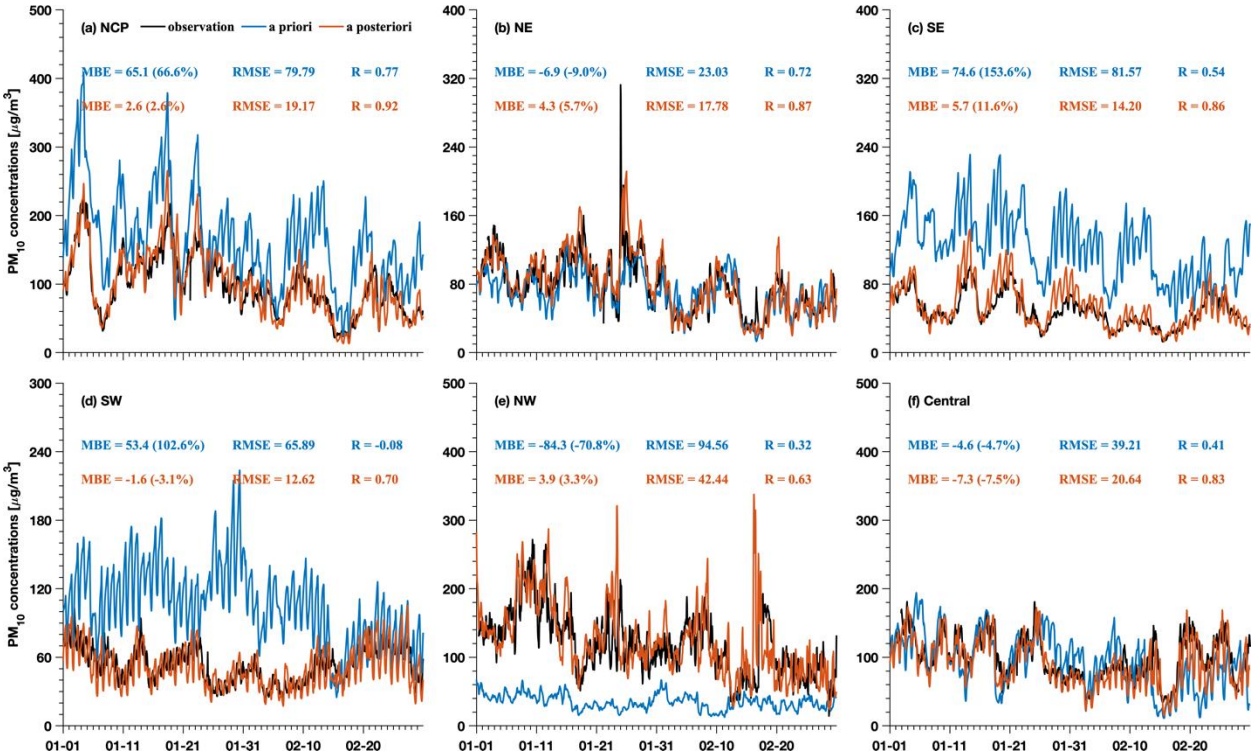


Figure S2: Same as in Fig. S1 but for PM_{10} concentrations.

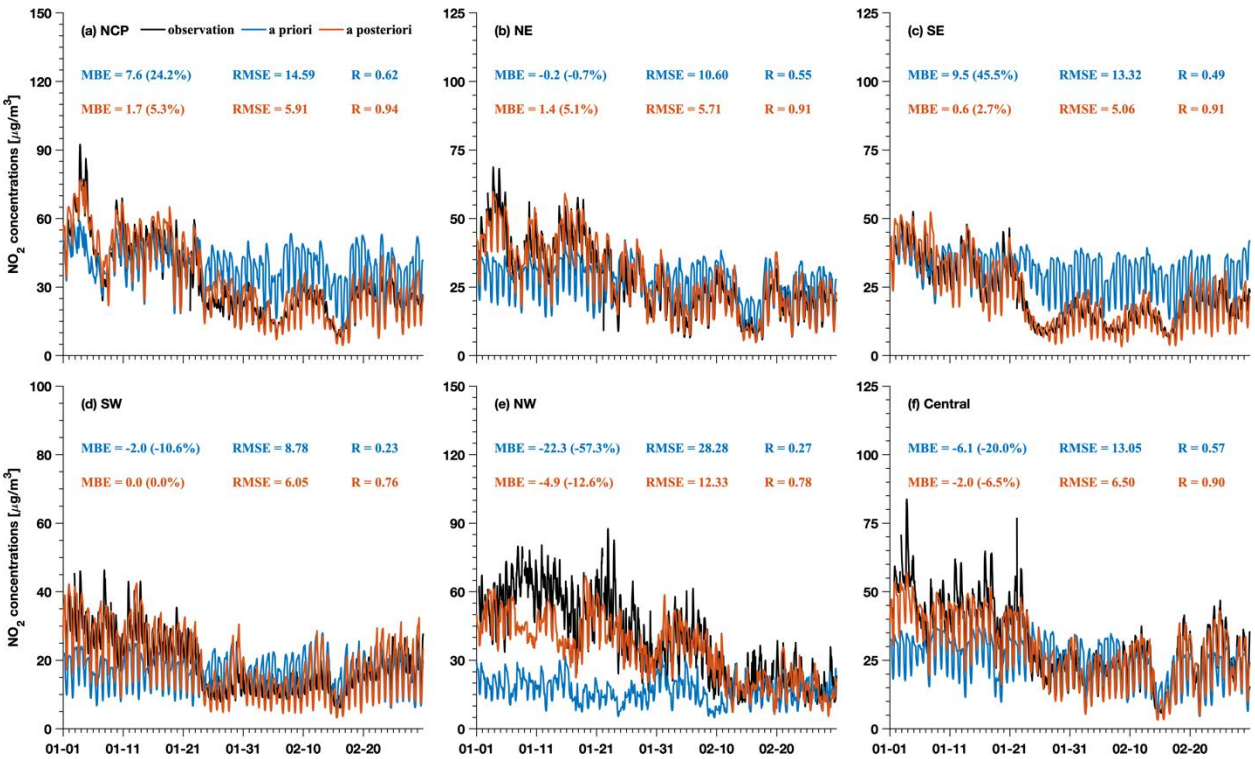
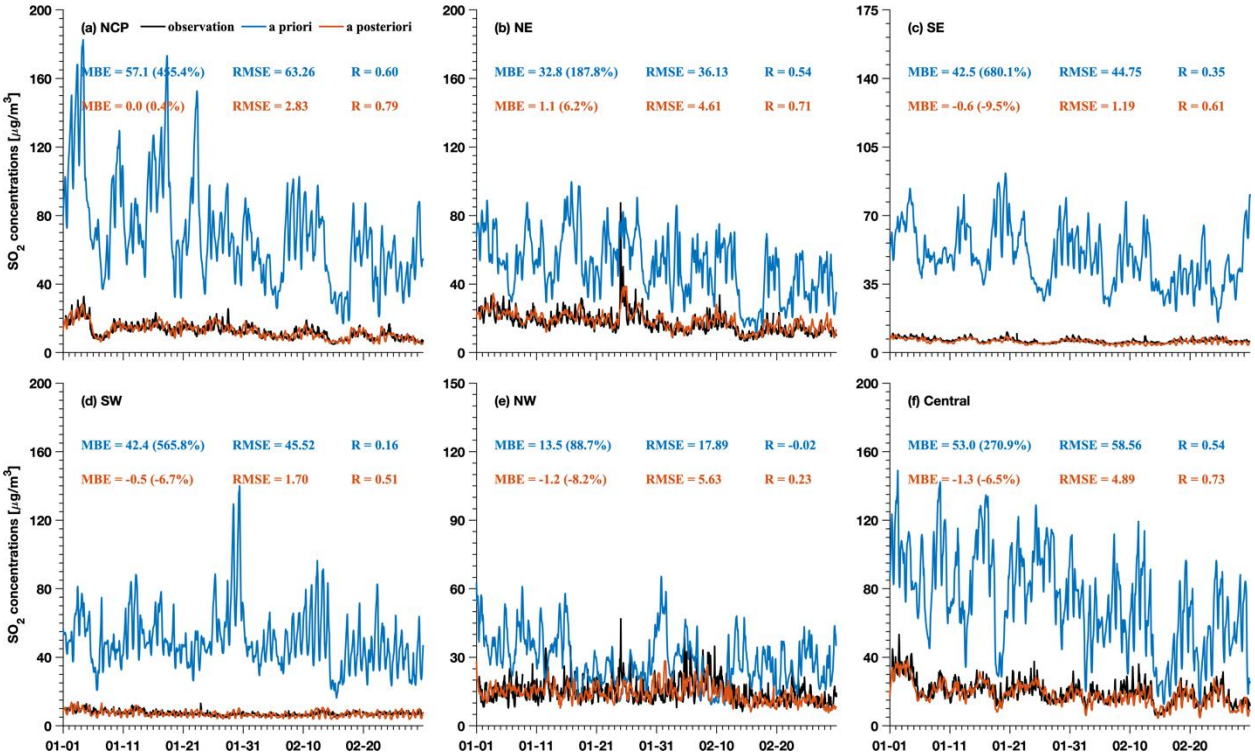


Figure S3: Same as in Fig. S1 but for NO_2 concentrations.



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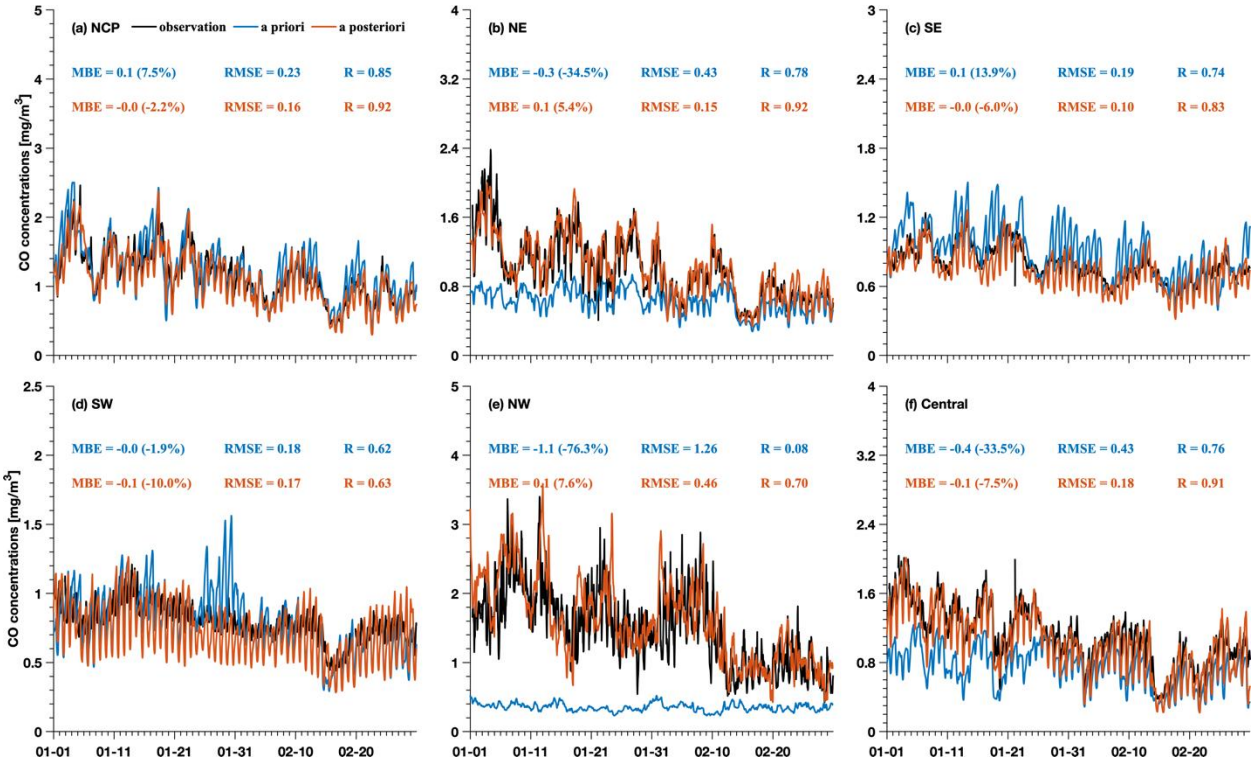
23 **Figure S4: Same as in Fig. S1 but for SO_2 concentrations.**



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25 **Figure S5: Same as in Fig. S1 but for CO concentrations.**

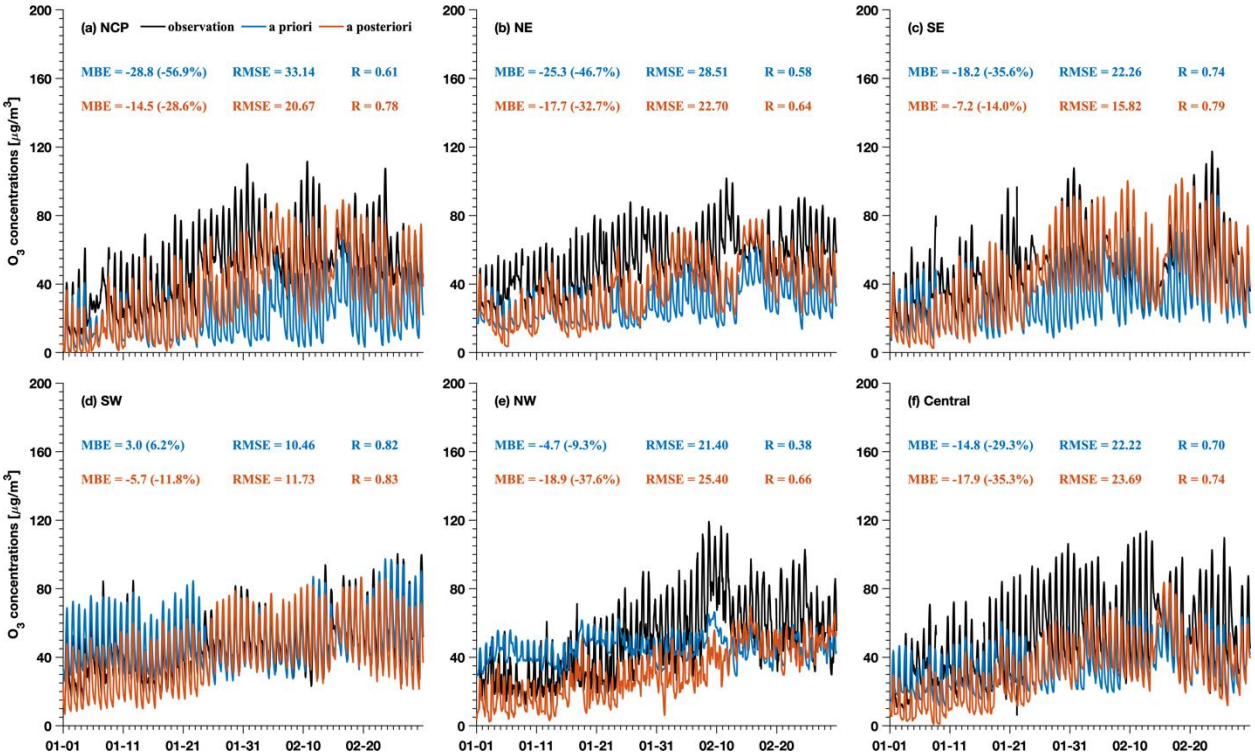


Figure S6: Same as in Fig. S1 but for O_3 concentrations.

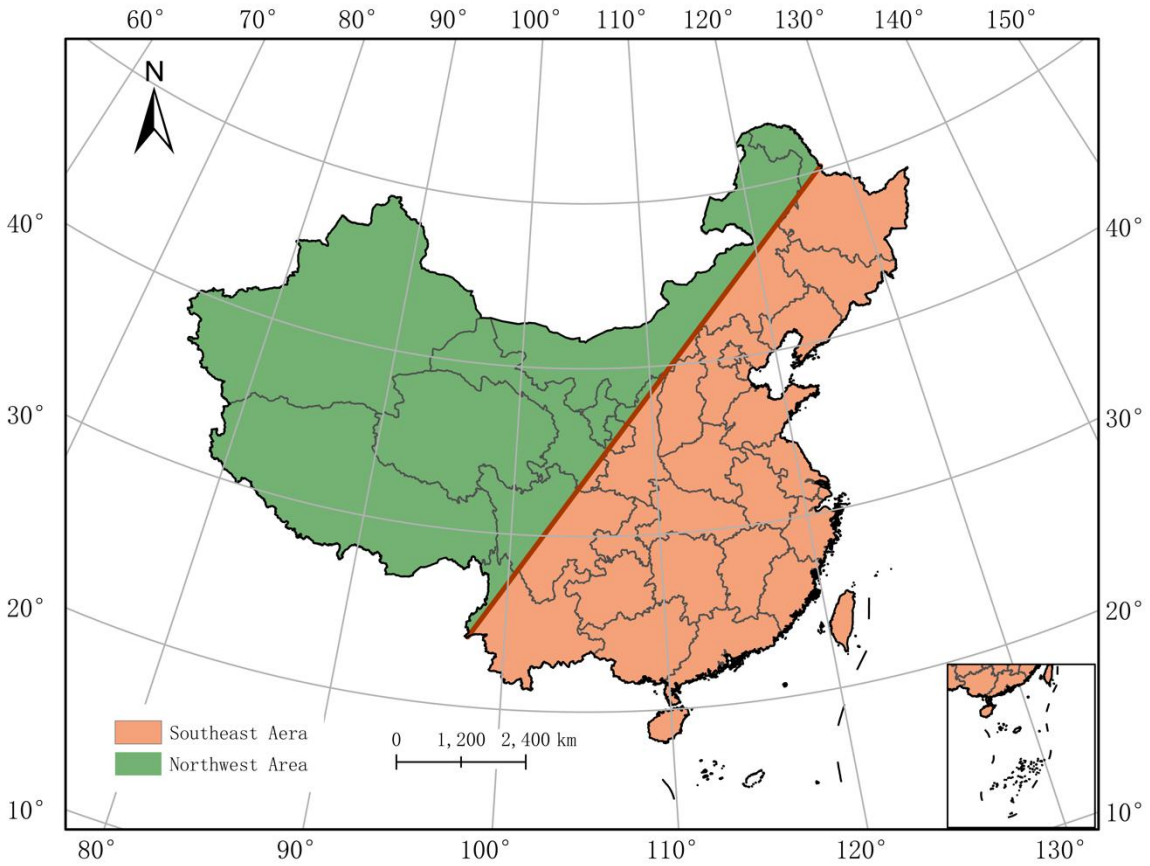


Figure S7: Geographical definition of southeast China (orange part) and northwest (green part) based on the Hu Huanyong Line. This line divides the China based on the population with population in east of this line (southeast China) accounts for 86.72% of the total population in China.

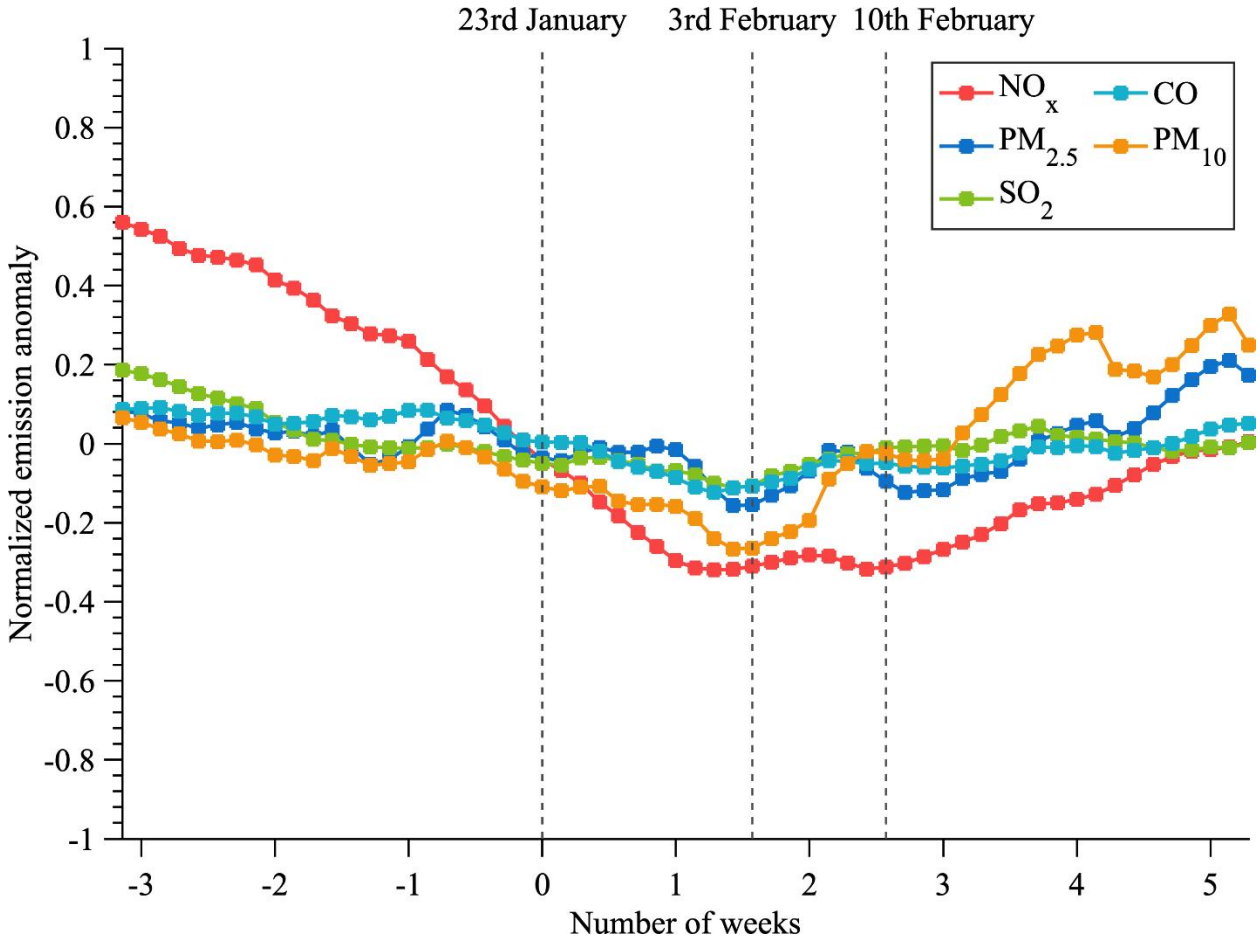


Figure S8: Time series of normalized emission anomaly estimated by inversion results for different species in southeast China (defined in Figure S4) from 1st January to 29th February 2020. The normalized emission anomaly is calculated by the emission anomaly divided by the averaged emission during the whole period.

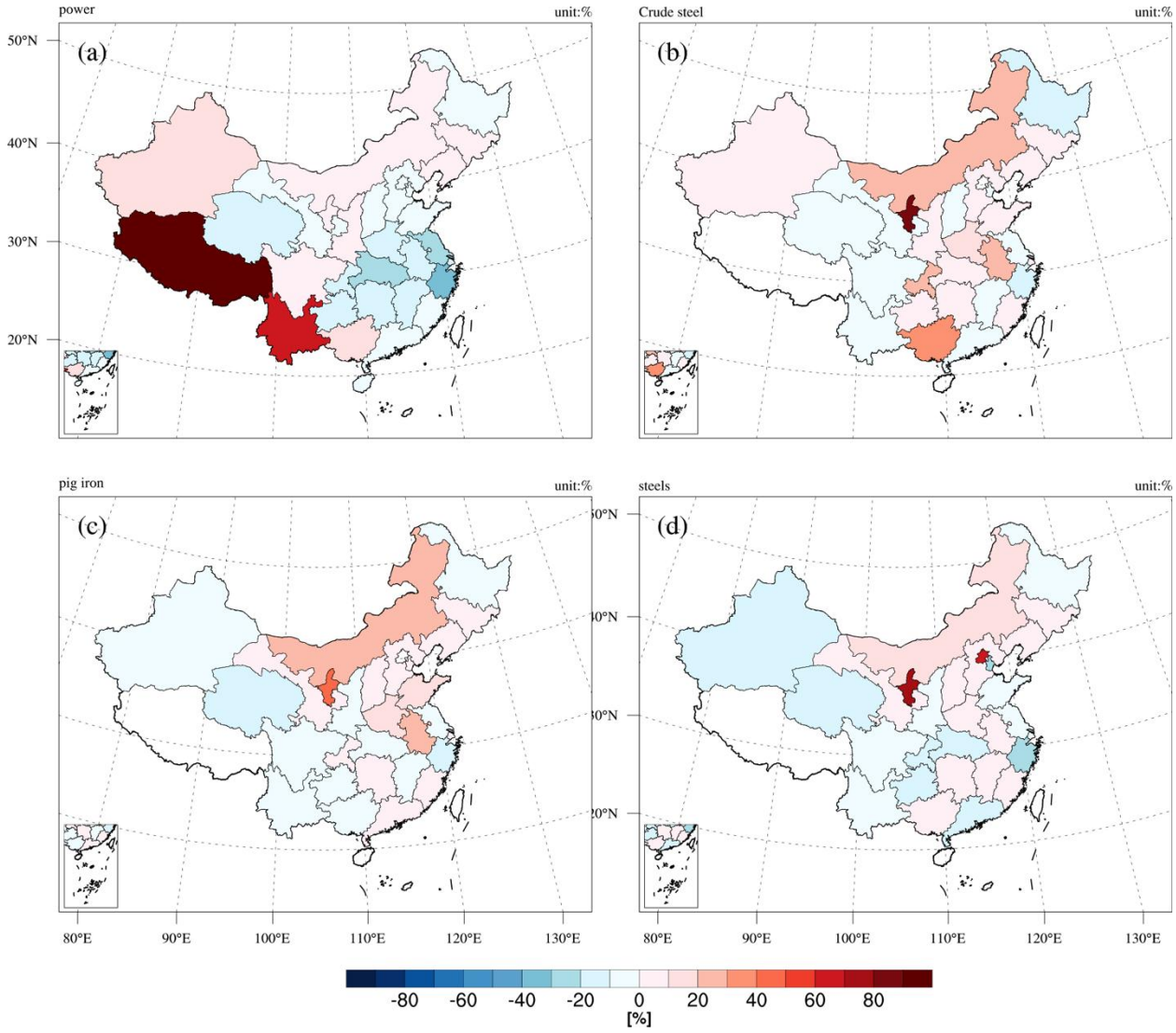


Figure S9: Changes in (a) thermal power generation, productions of (b) crude steel, (c) pig iron, and (d) steels in China in the first two months of 2020 compared to those in 2019.

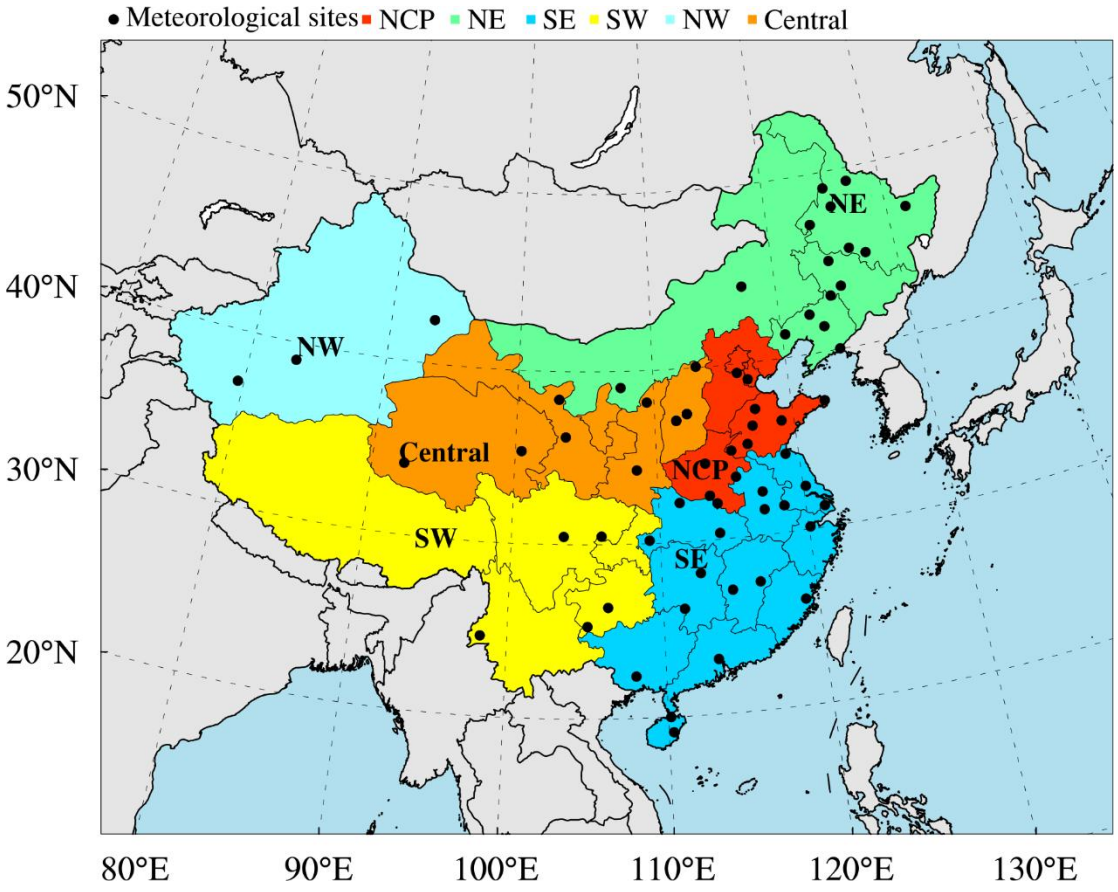


Figure S10: Spatial distribution of meteorological observation sites used in the evaluation of meteorology simulations over different regions of mainland China.

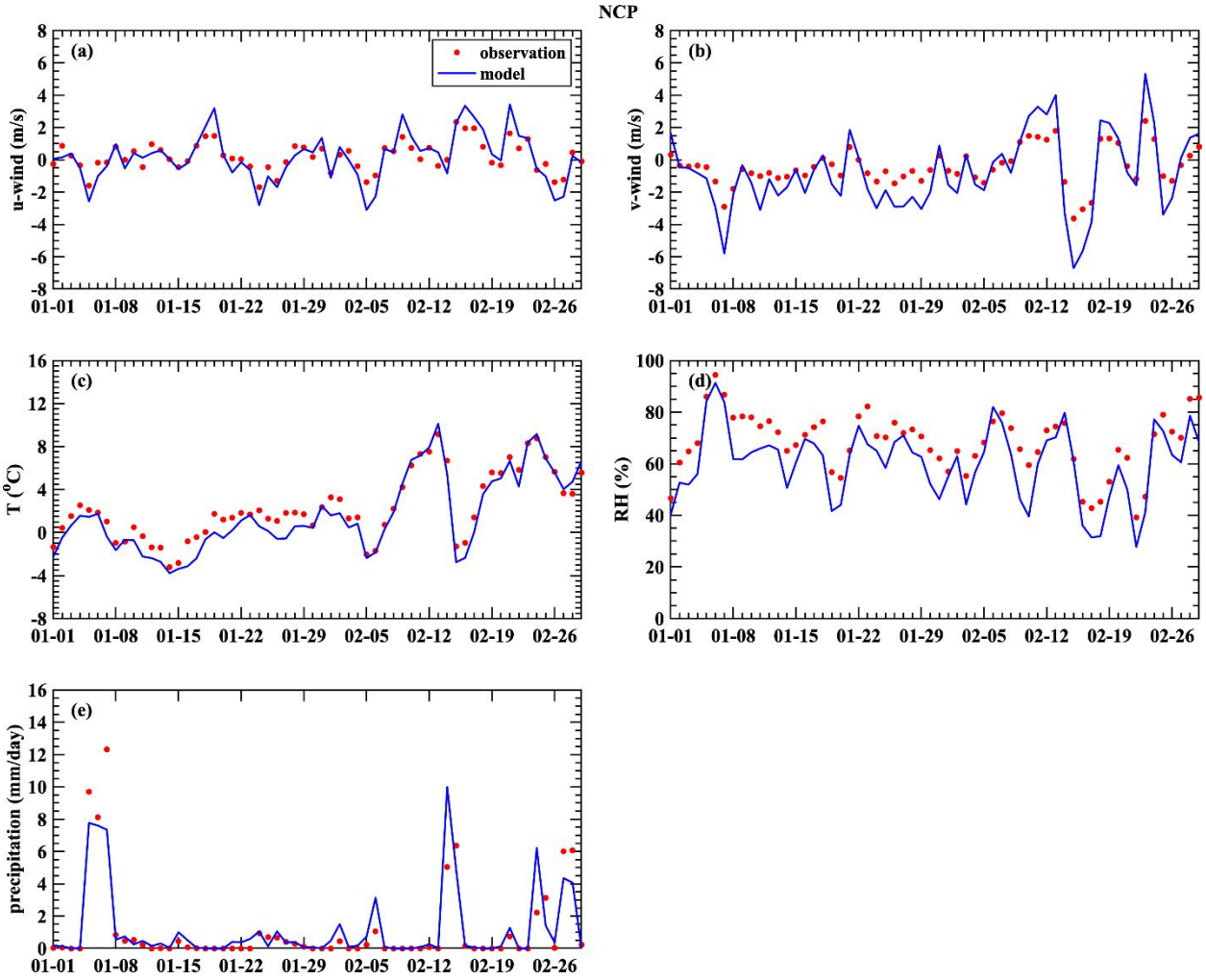
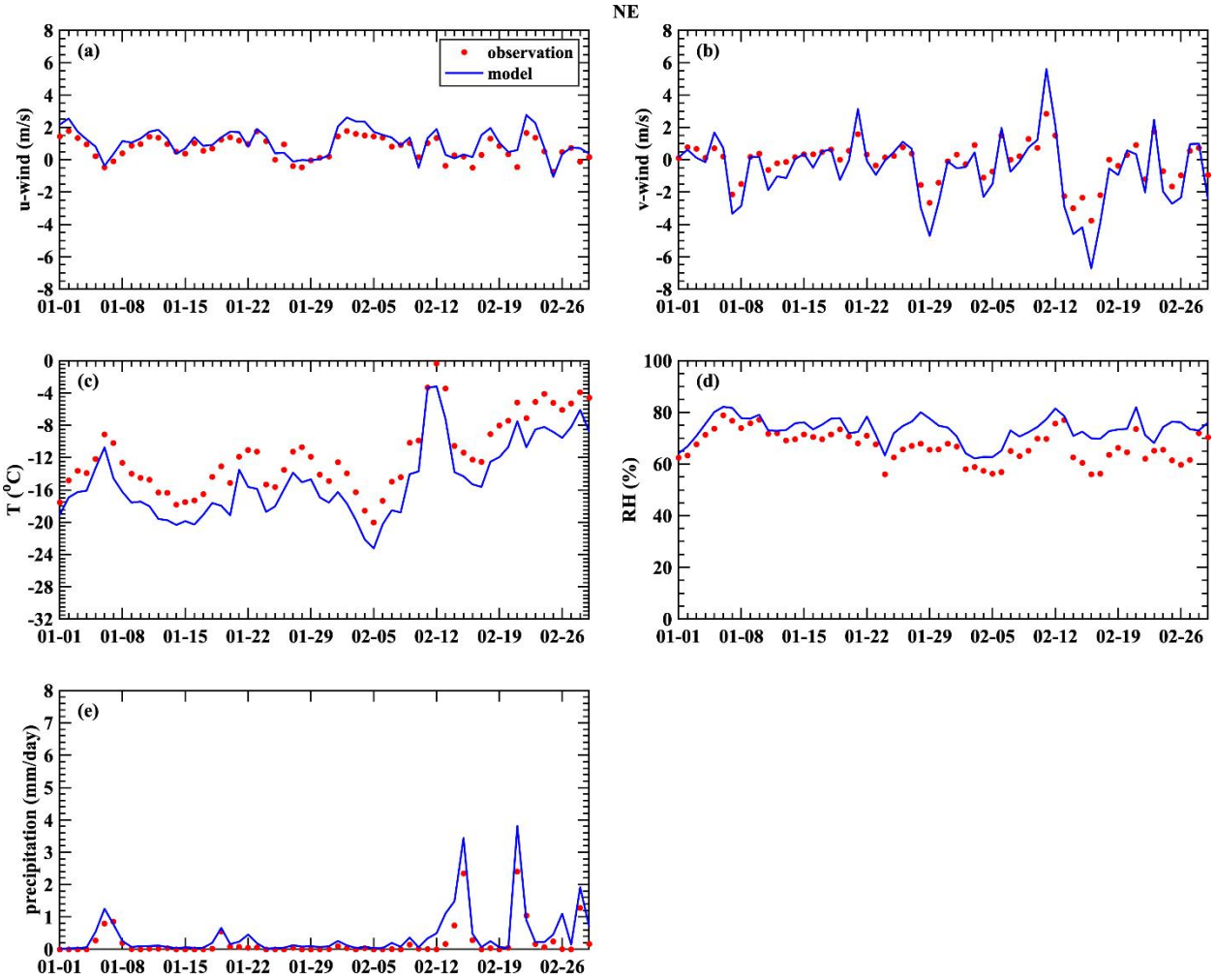


Figure S11: Timeseries of observed (red dots) and simulated (blue line) values of (a) u-wind, (b) v-wind, (c) temperature, (d) relative humidity and (e) precipitation over NCP region from 1st Jan 2020 to 29th Feb 2020.



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58 **Figure S12: Same as in Figure S11 but over the NE region.**

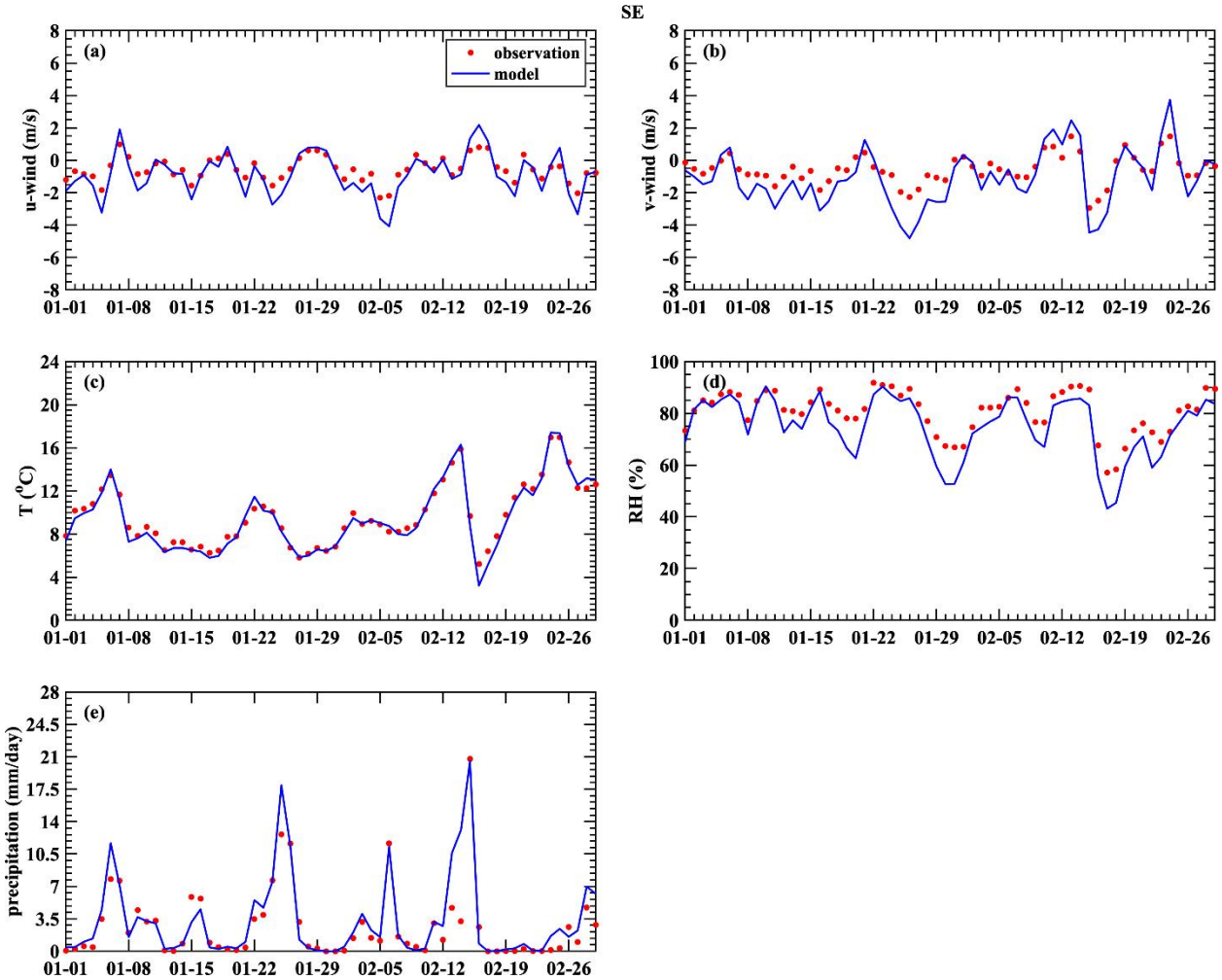
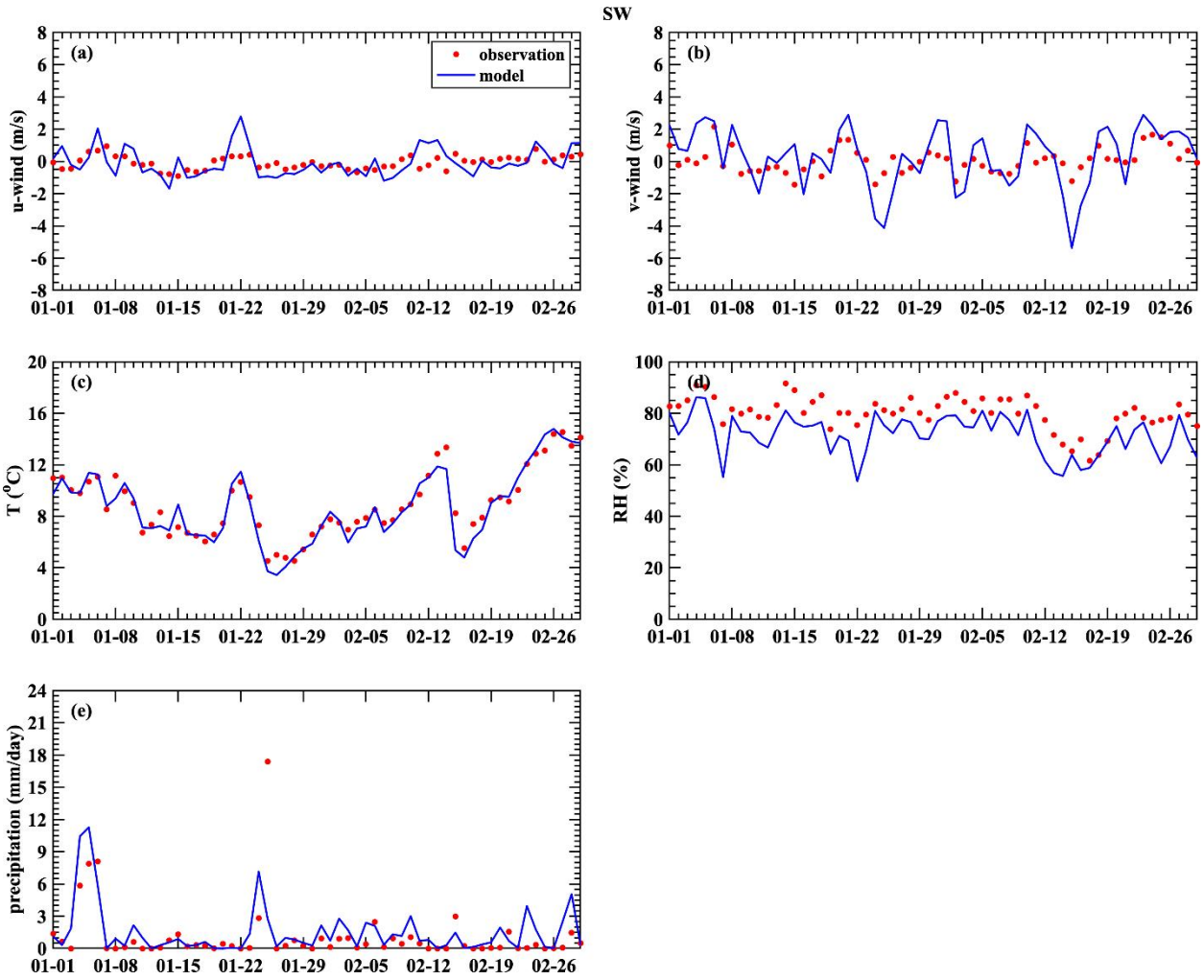


Figure S13: Same as in Figure S11 but over the SE region.



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62 **Figure S14: Same as in Figure S11 but over the SW region.**

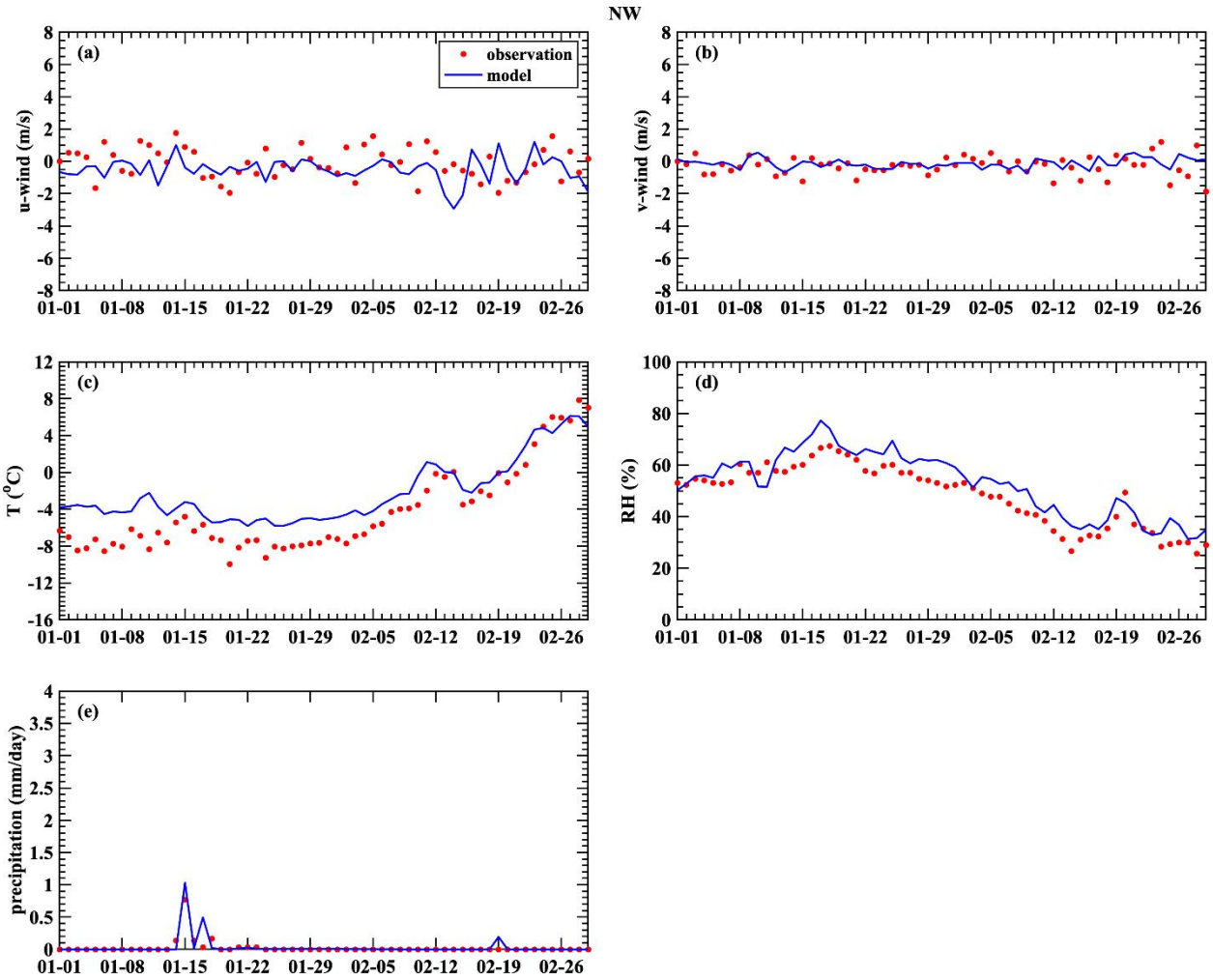

Figure S15: Same as in Figure S11 but over the NW region.

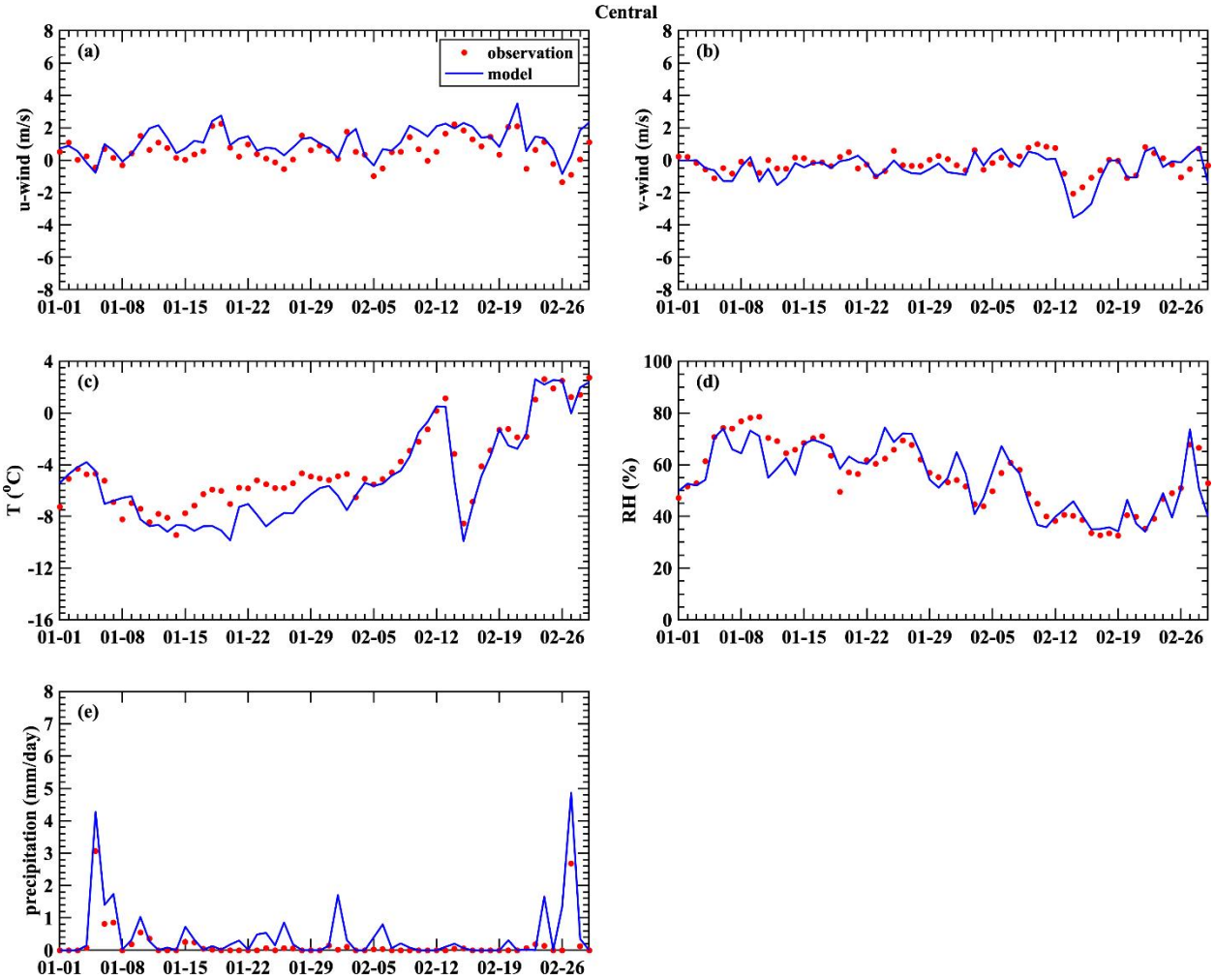

Figure S16: Same as in Figure S11 but over the Central region.

Tables

Table S1: Evaluation statistics of cross-validation run (outside of bracket) and a priori simulation (inside bracket)

	$PM_{2.5}$ ($\mu g/m^3$)				PM_{10} ($\mu g/m^3$)			
	R	MBE	NMB(%)	RMSE	R	MBE	NMB (%)	RMSE
NCP	0.94 (0.81)	5.3 (66.5)	7.1 (90.0)	14.4 (77.4)	0.92 (0.77)	2.6 (65.1)	2.6 (66.6)	19.2 (79.8)
NE	0.91 (0.74)	4.1 (1.2)	7.1 (2.0)	13.2 (19.5)	0.87 (0.72)	4.3 (-6.9)	5.7 (-9.0)	17.8 (23.0)
SE	0.89 (0.64)	6.0 (68.5)	15.7 (179.0)	12.2 (73.8)	0.86 (0.54)	5.7 (74.6)	11.6 (153.6)	14.2 (81.6)
SW	0.75 (0.05)	1.2 (54.4)	3.1 (141.5)	9.1 (63.1)	0.70 (-0.08)	-1.6 (53.4)	-3.1 (102.6)	12.6 (65.9)
NW	0.74 (0.32)	4.9 (-62.3)	5.3 (-67.7)	32.2 (71.1)	0.63 (0.32)	3.9 (-84.3)	3.3 (-70.8)	42.4 (94.6)
Central	0.90 (0.70)	-2.7 (12.6)	-3.9 (18.3)	13.2 (27.9)	0.83 (0.41)	-7.3 (-4.6)	-7.5 (-4.7)	20.6 (39.2)
	NO_2 ($\mu g/m^3$)				SO_2 ($\mu g/m^3$)			
	R	MBE	NMB(%)	RMSE	R	MBE	NMB (%)	RMSE
NCP	0.94 (0.62)	1.7 (7.6)	5.3 (24.2)	5.9 (14.6)	0.79 (0.60)	0.0 (57.1)	0.4 (455.4)	2.8 (63.3)
NE	0.91 (0.55)	1.4 (-0.2)	5.1 (-0.7)	5.7 (10.6)	0.71 (0.54)	1.1 (32.8)	6.2 (187.8)	4.6 (36.1)
SE	0.91 (0.49)	0.6 (9.5)	2.7 (45.5)	5.1 (13.3)	0.61 (0.35)	-0.6 (42.5)	-9.5 (680.1)	1.2 (44.7)
SW	0.76 (0.23)	0.0 (-2.0)	0.0 (-10.6)	6.1 (8.8)	0.51 (0.16)	-0.5 (42.4)	-6.7 (565.8)	1.7 (45.5)
NW	0.78 (0.27)	-4.9 (-22.3)	-12.6 (-57.3)	12.3 (28.3)	0.23 (-0.02)	-1.2 (13.5)	-8.2 (88.7)	5.6 (17.9)
Central	0.90 (0.57)	-2.0 (-6.1)	-6.5 (-20.0)	6.5 (13.1)	0.73 (0.54)	-1.3 (53.0)	-6.5 (270.9)	4.9 (58.6)
	CO (mg/m^3)				O_3 ($\mu g/m^3$)			
	R	MBE	NMB(%)	RMSE	R	MBE	NMB (%)	RMSE
NCP	0.92 (0.85)	-0.03 (0.08)	-2.2 (7.5)	0.16 (0.23)	0.78 (0.61)	-14.5 (-28.8)	-28.6 (-56.9)	20.7 (33.1)
NE	0.92 (0.78)	0.05 (-0.33)	5.4 (-34.5)	0.15 (0.43)	0.64 (0.58)	-17.7 (-25.3)	-32.7 (-46.7)	22.7 (28.5)
SE	0.83 (0.74)	-0.05 (0.11)	-6.0 (13.9)	0.10 (0.19)	0.79 (0.74)	-7.2 (-18.2)	-14.0 (-35.6)	15.8 (22.3)
SW	0.63 (0.62)	-0.08 (-0.02)	-10.0 (-1.9)	0.17 (0.18)	0.83 (0.82)	-5.7 (3.0)	-11.8 (6.2)	11.7 (10.5)
NW	0.70 (0.08)	0.11 (-1.13)	7.6 (-76.3)	0.46 (1.26)	0.66 (0.38)	-18.9 (-4.7)	-37.6 (-9.3)	25.4 (21.4)
Central	0.91 (0.76)	-0.08 (-0.37)	-7.5 (-33.5)	0.18 (0.43)	0.74 (0.70)	-17.9 (-14.8)	-35.3 (-29.3)	23.7 (22.2)

Table S2. The time of degrading responses level to COVID-19 virus in each province of mainland China.

Province	Region	date	Measurement
Beijing	NCP	30th Apr 2020	Degrade first level of response to second level
Tianjin	NCP	30th Apr 2020	Degrade first level of response to second level
Hebei	NCP	30th Apr 2020	Degrade first level of response to second level
Henan	NCP	19th Mar 2020	Degrade first level of response to second level
Shandong	NCP	7th Mar 2020	Degrade first level of response to second level
Inner Mongolia	NE	25th Feb 2020	Degrade first level of response to third level
Jilin	NE	26th Feb 2020	Degrade first level of response to second level
Liaoning	NE	4th Mar 2020	Degrade first level of response to second level
Shanghai	SE	24th Mar 2020	Degrade first level of response to second level
Anhui	SE	25th Feb 2020	Degrade first level of response to second level
Guangdong	SE	24th Feb 2020	Degrade first level of response to second level
Guangxi	SE	24th Feb 2020	Degrade first level of response to third level
Jiangsu	SE	25th Feb 2020	Degrade first level of response to second level
Jiangxi	SE	12th Mar 2020	Degrade first level of response to second level
Zhejiang	SE	2nd Mar 2020	Degrade first level of response to second level
Hainan	SE	26th Feb 2020	Degrade first level of response to third level
Hubei	SE	2nd May 2020	Degrade first level of response to second level
Hunan	SE	10th Mar 2020	Degrade first level of response to second level
Fujian	SE	27th Feb 2020	Degrade first level of response to second level
Yunnan	SW	24th Feb 2020	Degrade first level of response to third level
Sichuan	SW	26th Feb 2020	Degrade first level of response to second level
Guizhou	SW	24th Feb 2020	Degrade first level of response to third level
Chongqing	SW	10th Mar 2020	Degrade first level of response to second level
Xizang	SW	7th Mar 2020	Degrade first level of response to third level
Ningxia	Central	28th Feb 2020	Degrade first level of response to second level
Shanxi	Central	24th Feb 2020	Degrade first level of response to second level
Gansu	Central	21st Feb 2020	Degrade first level of response to third level
Shanaxi	Central	28th Feb 2020	Degrade first level of response to third level
Qinghai	Central	26th Feb 2020	Degrade first level of response to third level
Xinjiang	NW	26th Feb 2020	Degrade first level of response to second level

Table S3. Inversion estimated emissions of different air pollutants in southeast China as well as their changes between different periods in COVID-19 time

	NO_x	$PM_{2.5}$	PM_{10}	SO_2	CO
P1 (Gg/day)	57.1	34.8	60.9	17.9	876.3
P2 (Gg/day)	32.9	31.8	52.1	16.0	774.7
P3 (Gg/day)	35.9	34.3	71.0	17.0	805.2
(P2-P1)/P1	-42.4%	-8.6%	-14.3%	-10.9%	-11.6%
(P3-P2)/P1	5.2%	7.2%	31.0%	5.7%	3.5%
(P3-P1)/P1	-37.2%	-1.4%	16.6%	-5.2%	-8.1%

Table S4: Evaluation statistics for the meteorology simulation

Region	U (m/s)			V (m/s)			T (℃)			RH (%)			Precipitation (mm/day)		
	R	MBE	RMSE	R	MBE	RMSE	R	MBE	RMSE	R	MBE	RMSE	R	MBE	RMSE
NCP	0.92	-0.04	0.72	0.96	-0.38	1.31	0.98	-0.71	1.07	0.91	-7.95	9.76	0.88	0.06	1.22
NE	0.90	0.35	0.51	0.97	-0.45	1.01	0.98	-3.13	3.25	0.79	6.53	7.47	0.95	0.20	0.36
SE	0.95	-0.32	0.69	0.96	-0.55	1.07	0.99	-0.21	0.58	0.96	-5.44	6.80	0.91	0.59	1.96
SW	0.46	0.00	0.78	0.65	0.24	1.48	0.96	-0.19	0.81	0.81	-8.53	9.66	0.56	0.42	2.38
NW	-0.01	-0.39	1.27	0.16	0.16	0.64	0.96	2.07	2.60	0.94	4.71	6.23	0.86	0.01	0.08
CENTRAL	0.92	-0.04	0.72	0.78	-0.26	0.60	0.94	-0.73	1.42	0.88	-0.40	6.14	0.91	0.26	0.53