Opposite variations of peak and low ozone concentrations in eastern China: Positive effects of NO_x control on ozone pollution

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Figures:

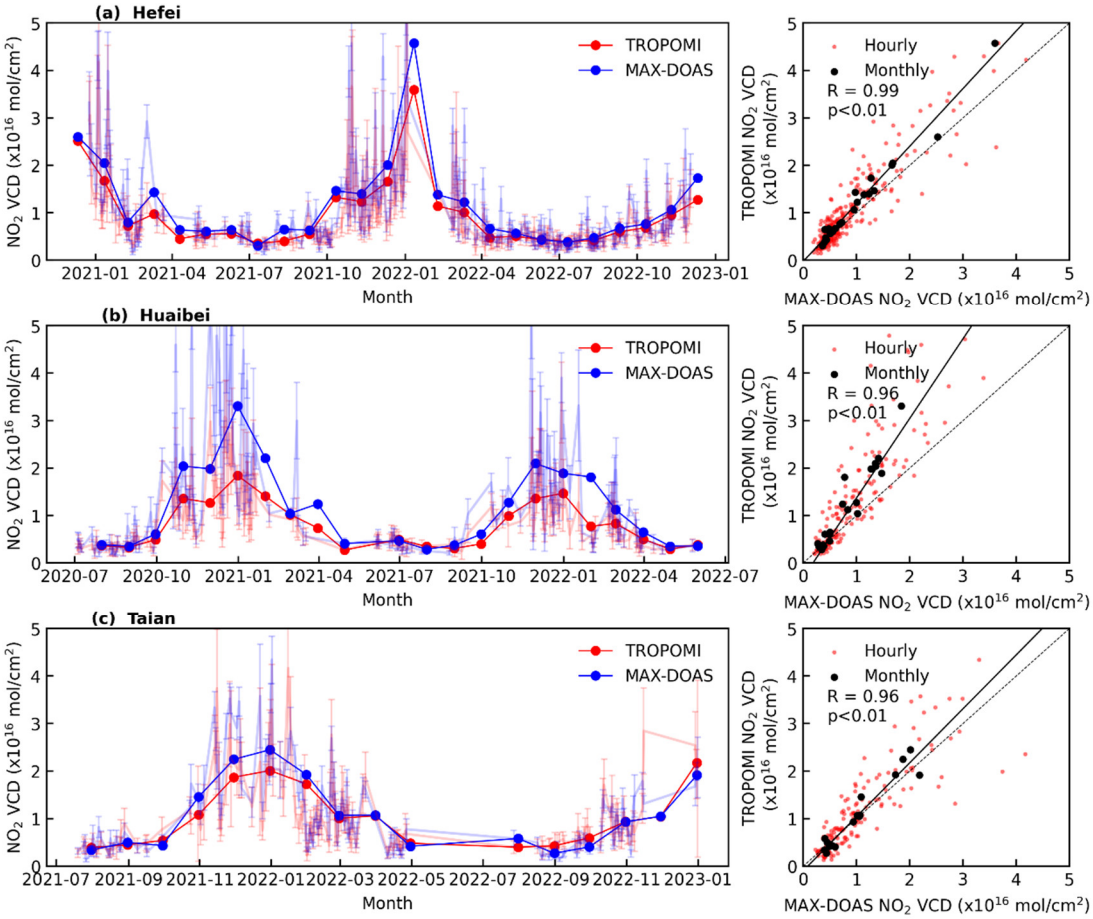

Fig.S1. Time series comparison (left panel) and scatter plot comparison (right panel) of monthly mean TROPOMI and MAX–DOAS NO_2 VCD during the whole observation period in (a) Hefei, (b) Huaibei, and (c) Tai'an, respectively. The light red and light blue dots in left panel represent the TROPOMI and MAX–DOAS observed hourly values, respectively, and the solid red and solid blue dots represent the TROPOMI and MAX–DOAS observed monthly mean values, respectively. The vertical bar in hourly values represents errors.

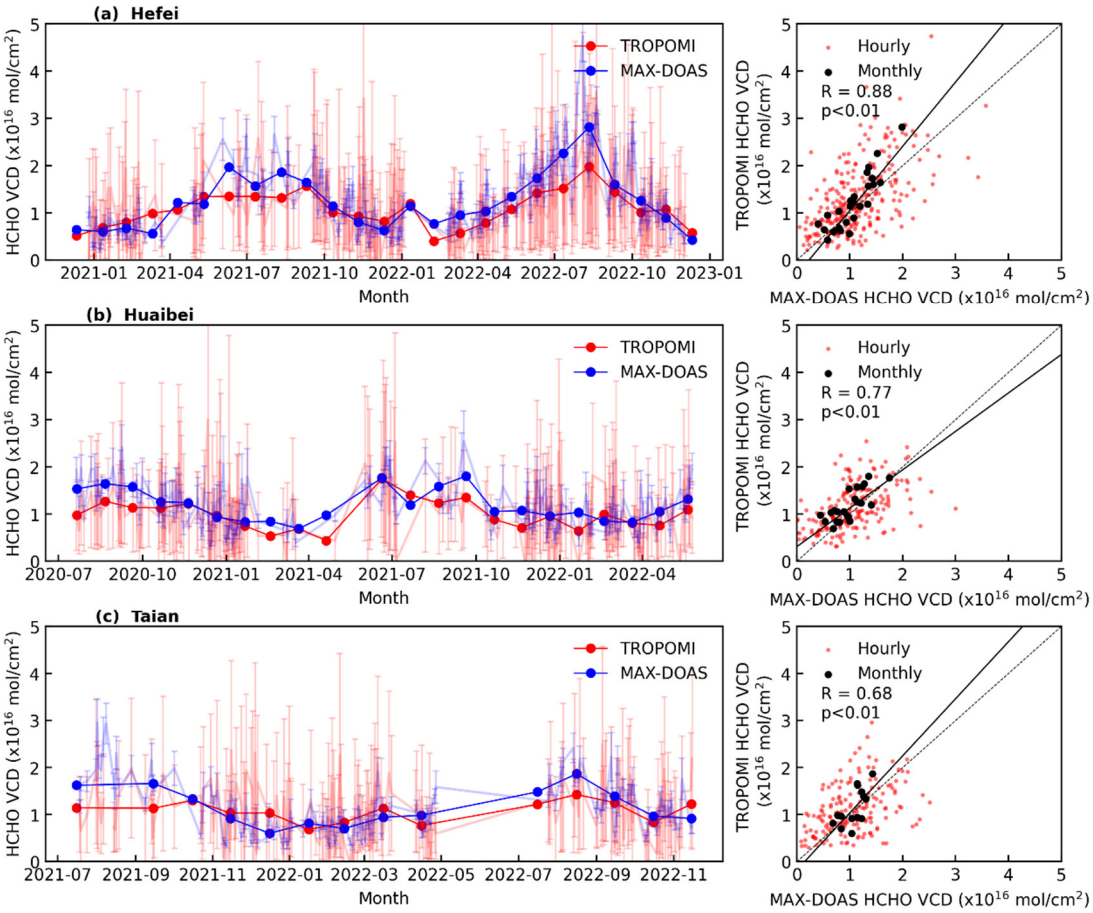

Fig.S2. The same as Fig.S1 but for HCHO VCD comparison.

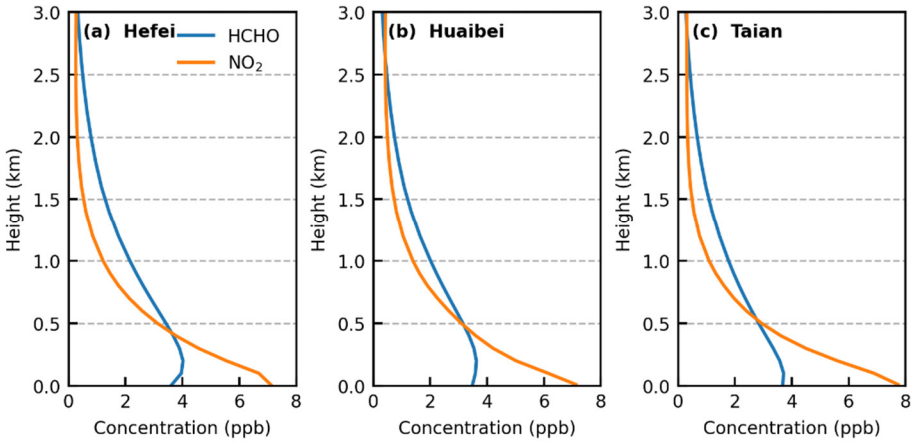

Fig.S3. Mean profiles of NO_2 and HCHO concentrations in (a) Hefei, (b) Huaibei, and (c) Tai'an during the whole observation period from May to September.

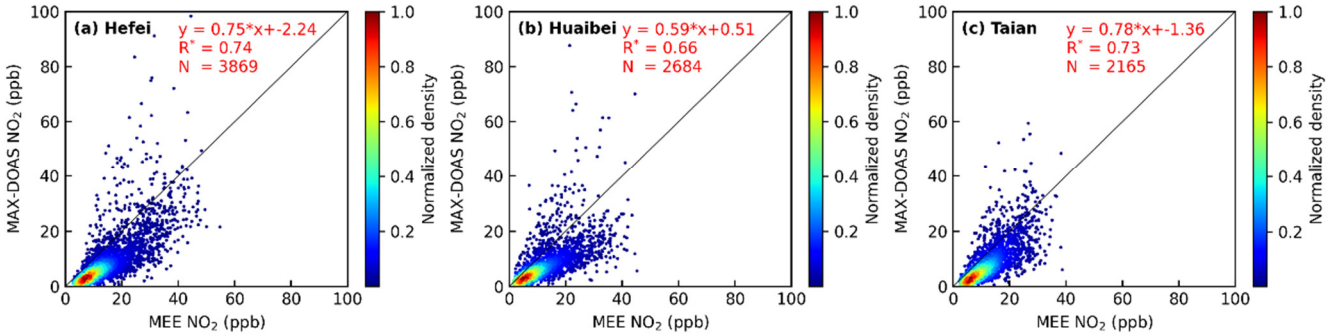

Fig.S4. Scatter plots show the correlation between the surface hourly NO_2 concentrations observed by Ministry of Ecology and Environment of China (MEE) and ground–based MAX–DOAS in (a) Hefei, (b) Huaibei, and (c) Tai'an during the whole observation period. The linear fitting function and correlation coefficient are show at the top of each panel, N=number of samples, and the superscript asterisk indicates P<0.01. Here, the color bar indicates the density.

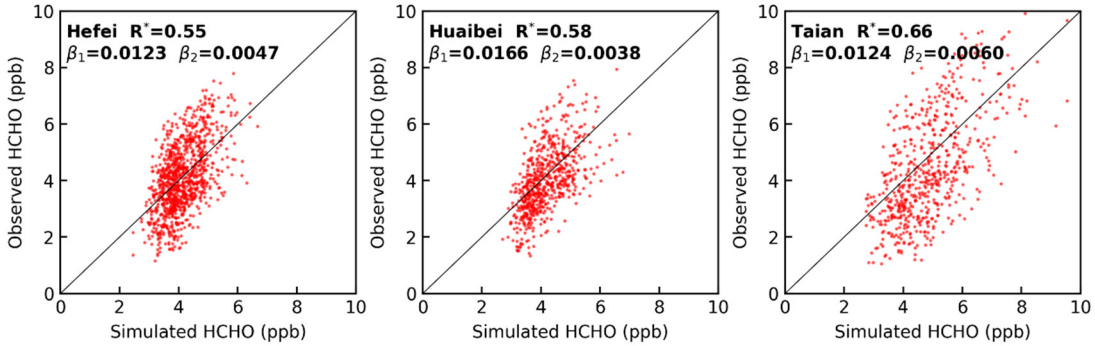

Fig.S5. Correlation analysis result of the simulated HCHO from the multi–linear regression model and measured HCHO, and the superscript asterisk indicates P<0.01.

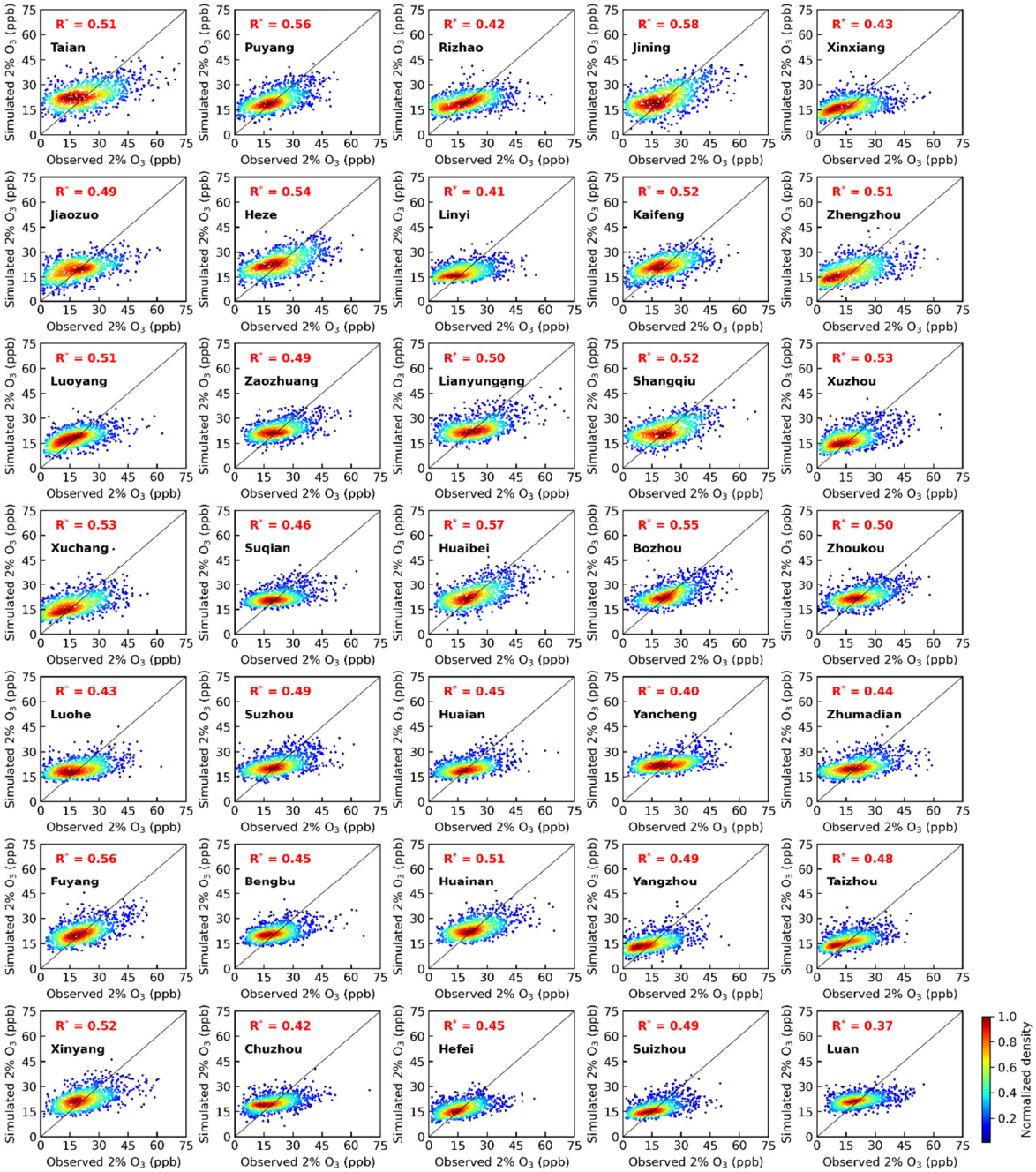

Fig.S6. Scatter plots between daily observed 2nd O_3 percentile concentrations and daily 2nd O_3 percentile concentrations simulated by a stepwise multiple linear regression model driven by three key meteorological factors. The Pearson correlation coefficient is shown at the top of each panel, and the superscript asterisk indicates P<0.01. Here, the color bar indicates the density.

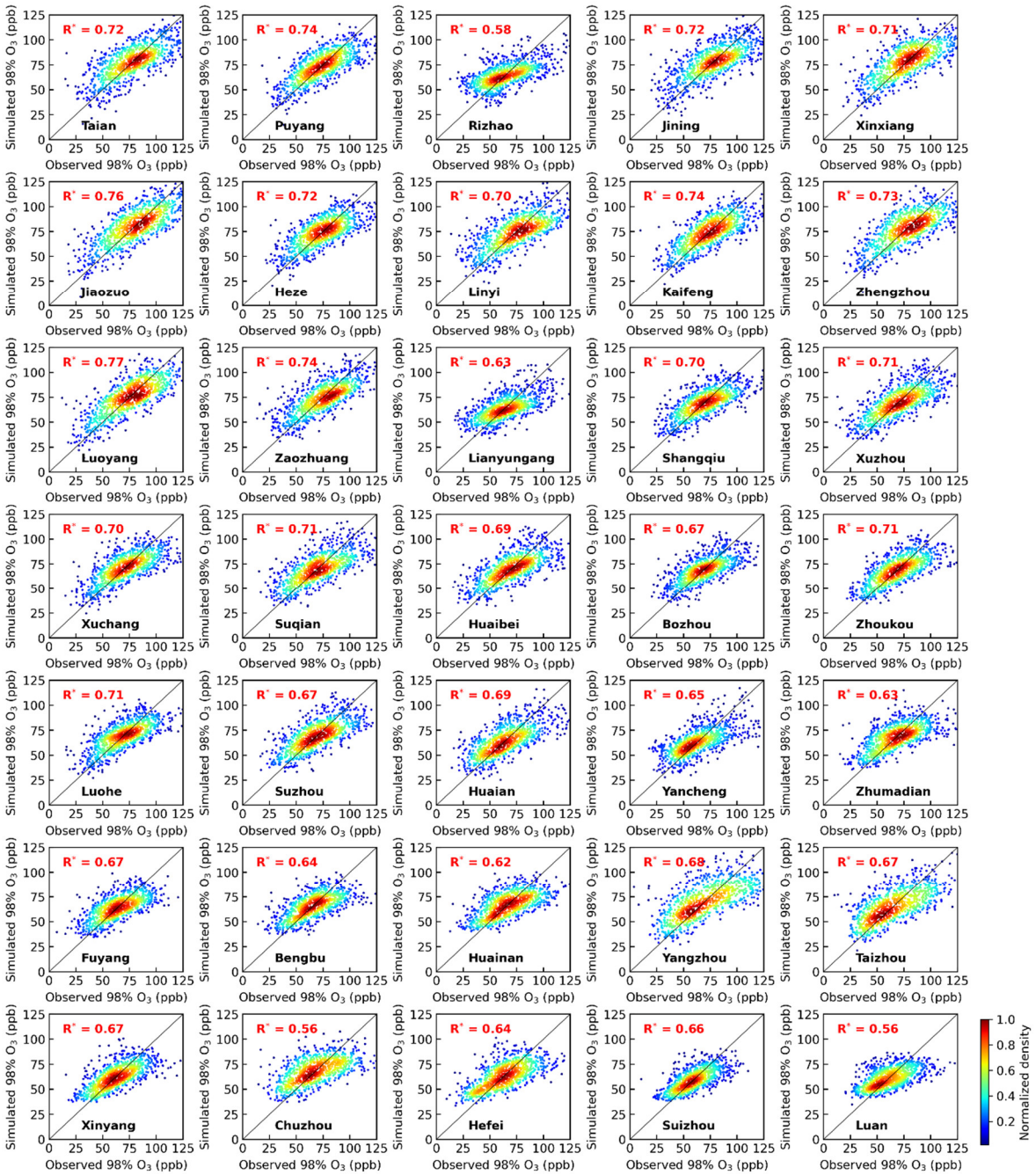

Fig.S7. The same as Fig.S6 but for 98th O_3 percentiles.

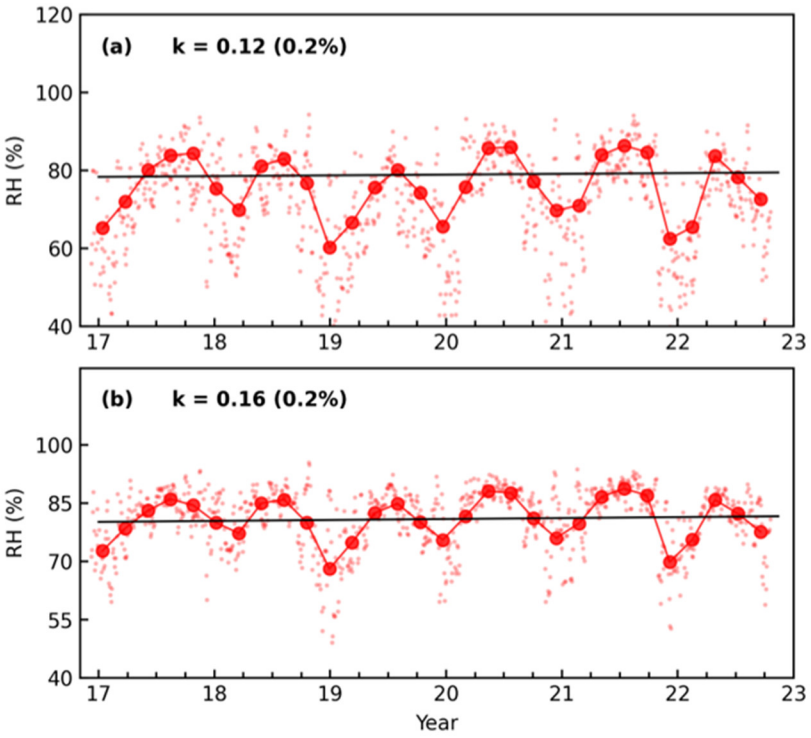

Fig.S8 Trend of RH in ERA5 reanalysis data over (a) HRB and (b) eastern China during May–September 2017–2022.

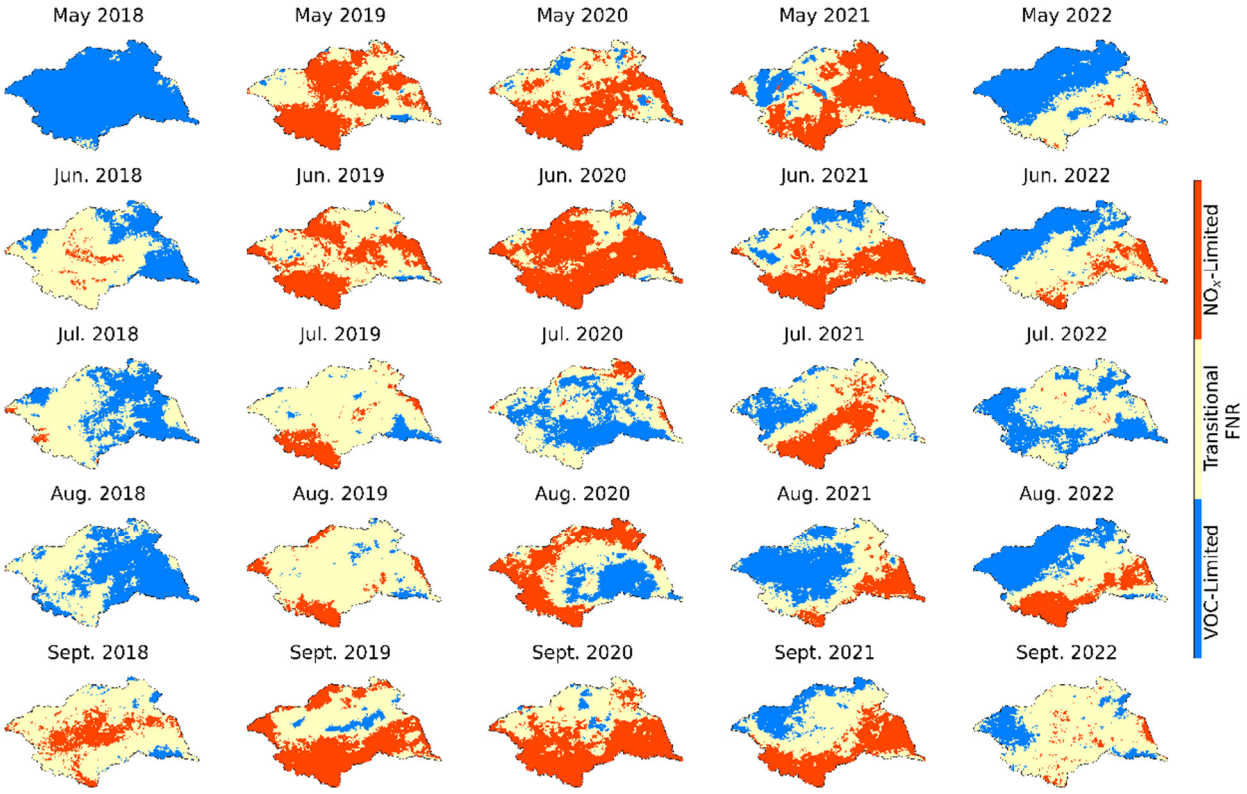

Fig.S9. Spatial and temporal variations of monthly mean FNR from May–September 2018–2022. The date is shown at the top of each panel.

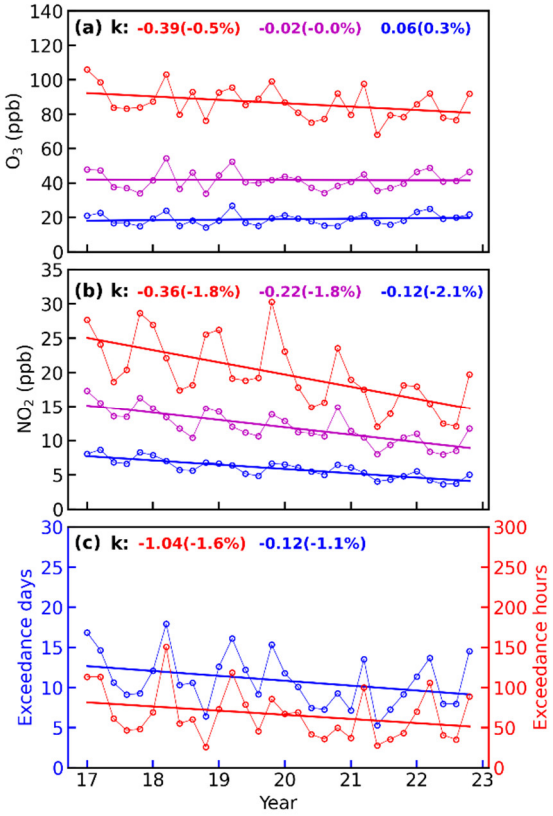

Fig.S10 Trends of surface (a) O_3, (b) NO_2, (c) O_3 exceedance days and O_3 exceedance hours in eastern China during May–September 2017–2022. The red, magenta, and blue solid lines in (a) and (b) indicate the trends for the 98th, 50th, and 2nd percentiles, respectively. The labels on (a) and (b) represent the trends in O_3 and NO_2 for May–September 2017–2022, units: ppb/year. The labels on (c) represent the trends in O_3 exceedance days and O_3 exceedance hours for May–September 2017–2022. The percentage change is indicated in brackets.

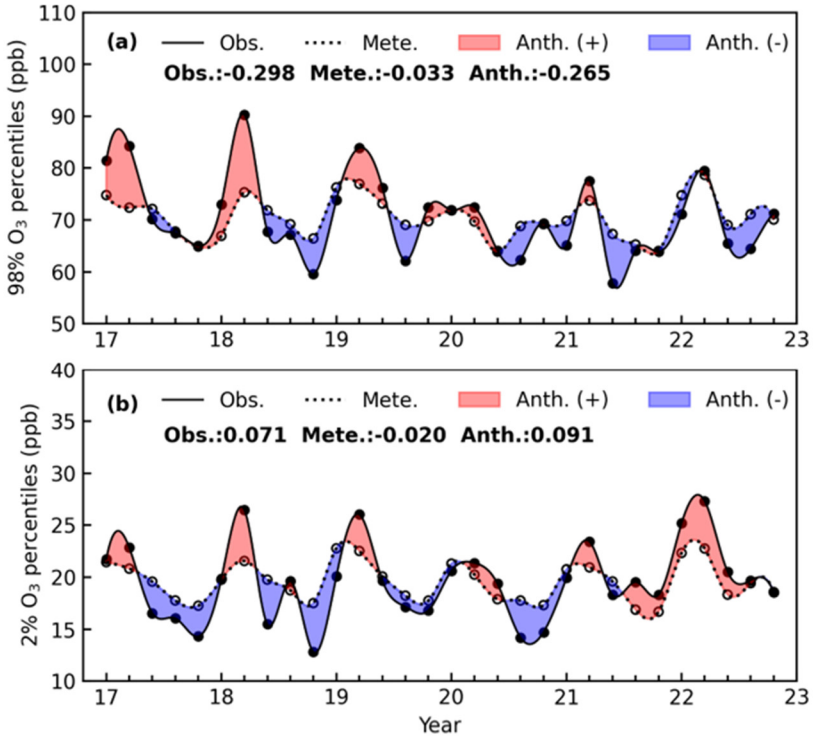

Fig.S11 Variations in observed (a) 98th and (b) 2nd O_3 percentiles (solid lines connected by solid black dots), meteorological (a) 98th and (b) 2nd O_3 percentiles component (dotted lines connect black hollow points) in MLR simulations, and the anthropogenic (a) 98th and (b) 2nd O_3 percentiles component (red and blue shading) in eastern China during May–September 2017–2022. The labels at the top of each panel represent the trend in observed, meteorological, and anthropogenic components.

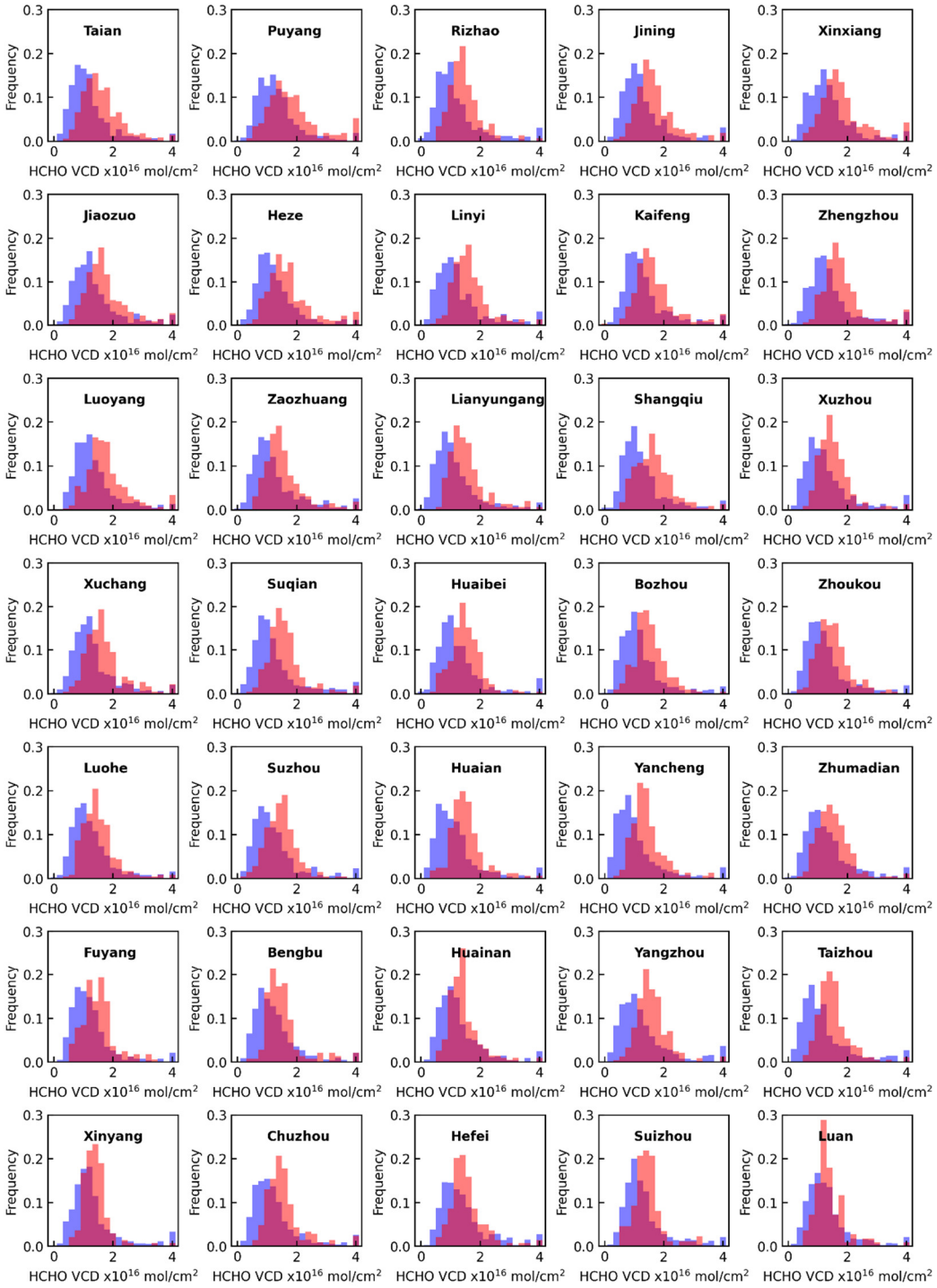

Fig.S12 Histograms of HCHO VCD for O_3 exceedance days (red) and O_3 normal days (blue) in each city of HRB during May–September 2018–2022. The city name is shown at the top of each panel.

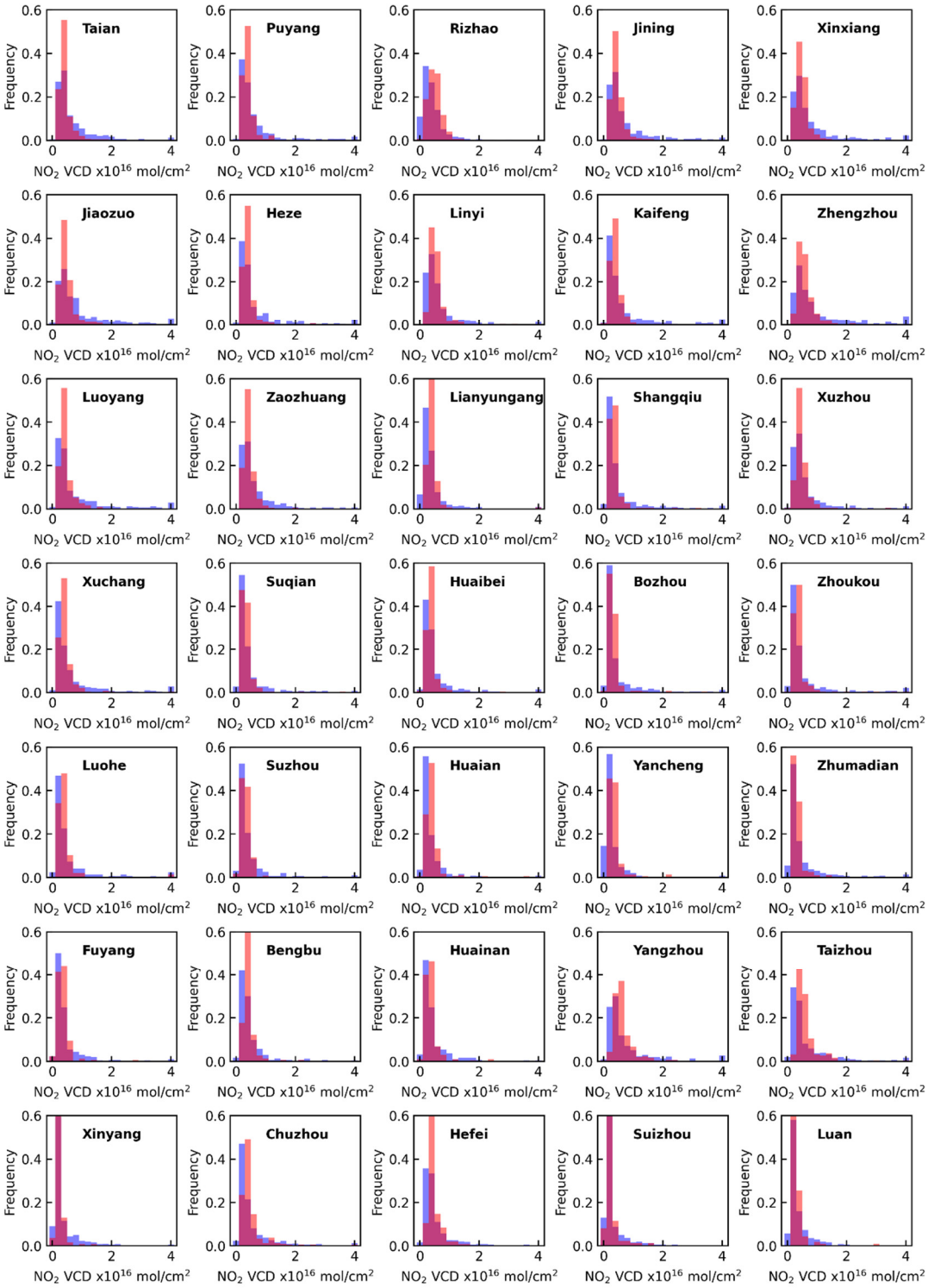

Fig.S13 The same as Fig.S12 but for NO_2 VCD.

Tables:

Table S1. Meteorological fields considered as possible 98% O_3 and 2% O_3 covariates

	Variables	Symbol	Average time (LT)	Units
98%	2–m temperature	T2	Maximum	K
	Surface relative humidity	RH	24 h	%
	Total cloud cover	TCC	08–18 h	0-1
	UV radiation at the surface	UVB	08–18 h	J/m^2
	Total precipitation	TP	24 h	mm
	Mean sea level pressure	MSLP	24 h	Pa
	Wind speed	U, V	24 h	m/s
	Boundary layer height	BLH	08–18 h	m
	Vertical velocity at 850 hPa	V850	24 h	m/s
2%	2–m temperature	T2	Minimum	K
	Surface relative humidity	RH	19–07 h	%
	Total precipitation	TP	24 h	mm
	Mean sea level pressure	MSLP	24 h	Pa
	Wind speed	U, V	24 h	m/s
	Boundary layer height	BLH	19–07 h	m
	Vertical velocity at 850 hPa	V850	24 h	m/s

Table S2. Trends of 98th, 50th and 2nd O_3 percentiles, O_3 exceedance hours, and mean NO_2 concentrations in each city of HRB during May–September 2017–2022

	O_3 (ppb/year)				**NO_2 (ppb/year)**
	98th	50th	2nd	Exceedance hours	mean
Taian	-0.74(-0.6%)	-0.24(-0.5%)	0.16(1.2%)	-2.8(-2.2%)	-0.20(-1.7%)
Puyang	-0.72(-0.7%)	-0.15(-0.3%)	0.00(0.0%)	-2.2(-2.3%)	-0.21(-1.8%)
Rizhao	-0.17(-0.2%)	-0.12(-0.3%)	0.23(2.7%)	-0.4(-0.9%)	-0.21(-1.7%)
Jining	-0.62(-0.5%)	-0.21(-0.4%)	0.21(1.8%)	-2.1(-1.7%)	-0.27(-2.3%)
Xinxiang	-0.91(-0.8%)	-0.10(-0.2%)	0.14(1.7%)	-2.2(-2.0%)	-0.41(-2.6%)
Jiaozuo	-0.87(-0.7%)	0.05(0.1%)	0.19(1.9%)	-1.4(-1.1%)	-0.39(-2.9%)
Heze	-0.39(-0.4%)	0.02(0.0%)	0.25(1.9%)	-1.0(-1.0%)	-0.3.0(-2.4%)
Linyi	-0.71(-0.6%)	-0.09(-0.2%)	0.05(0.6%)	-1.6(-1.6%)	-0.26(-1.9%)
Kaifeng	-0.50(-0.5%)	-0.06(-0.1%)	0.21(1.7%)	-1.3(-1.3%)	-0.18(-1.7%)
Zhengzhou	-0.67(-0.6%)	0.04(0.1%)	0.29(3.5%)	-1.6(-1.4%)	-0.52(-3.0%)
Luoyang	-0.68(-0.6%)	-0.17(-0.4%)	0.14(1.4%)	-2.4(-2.3%)	-0.32(-2.4%)
Zaozhuang	-0.20(-0.2%)	0.04(0.1%)	0.08(0.6%)	-0.5(-0.4%)	-0.02(-0.2%)
Lianyungang	0.14(0.2%)	0.05(0.1%)	0.10(0.7%)	0.0(0.0%)	-0.13(-1.3%)
Shangqiu	-0.45(-0.4%)	0.10(0.2%)	0.22(1.9%)	-1.3(-1.7%)	-0.19(-1.9%)
Xuzhou	-0.60(-0.6%)	-0.06(-0.1%)	0.12(1.2%)	-2.0(-2.3%)	-0.24(-1.8%)
Xuchang	-0.84(-0.8%)	0.02(0.1%)	0.32(3.8%)	-2(-2.5%)	-0.36(-2.8%)
Suqian	-0.52(-0.5%)	-0.15(-0.3%)	0.07(0.5%)	-2.2(-2.7%)	-0.13(-1.4%)
Huaibei	-0.64(-0.6%)	-0.14(-0.3%)	0.14(1.0%)	-2.5(-2.9%)	-0.26(-2.8%)
Bozhou	-0.46(-0.5%)	-0.08(-0.2%)	0.09(0.6%)	-1.6(-2.1%)	-0.21(-2.7%)
Zhoukou	-0.70(-0.7%)	-0.07(-0.2%)	0.08(0.6%)	-1.8(-2.4%)	-0.24(-2.5%)
Luohe	-0.30(-0.3%)	0.13(0.3%)	0.24(2.2%)	-0.5(-0.7%)	-0.24(-2.3%)
Suzhou	-0.91(-0.9%)	-0.22(-0.5%)	0.12(0.9%)	-3.0(-3.7%)	-0.39(-3.8%)
Huaian	-0.56(-0.6%)	-0.03(-0.1%)	0.19(1.5%)	-1.7(-2.9%)	-0.17(-1.7%)
Yancheng	-0.13(-0.1%)	0.11(0.3%)	0.20(1.4%)	0.1(0.2%)	-0.15(-1.8%)
Zhumadian	-0.95(-0.9%)	-0.03(-0.1%)	0.33(3.0%)	-2.5(-3.7%)	-0.29(-2.9%)
Fuyang	-0.09(-0.1%)	0.21(0.5%)	0.26(2.0%)	-0.3(-0.6%)	-0.24(-2.3%)
Bengbu	-0.33(-0.3%)	-0.02(-0.1%)	-0.07(-0.5%)	-1.4(-2.5%)	-0.30(-2.5%)
Huainan	-0.59(-0.6%)	-0.13(-0.3%)	0.04(0.2%)	-2.3(-3.4%)	-0.17(-1.9%)
Yangzhou	-0.48(-0.4%)	-0.05(-0.1%)	0.08(1.4%)	-1.5(-1.8%)	-0.27(-2.0%)
Taizhou	-0.52(-0.5%)	-0.06(-0.1%)	0.03(0.3%)	-1.2(-1.9%)	-0.22(-2.1%)
Xinyang	-0.52(-0.6%)	0.03(0.1%)	0.15(1.1%)	-1.0(-2.1%)	-0.14(-1.9%)
Chuzhou	-0.38(-0.4%)	-0.11(-0.2%)	-0.01(-0.1%)	-1.8(-2.5%)	-0.31(-2.5%)
Hefei	-0.71(-0.7%)	-0.05(-0.1%)	-0.07(-0.8%)	-1.9(-3.8%)	-0.31(-2.0%)
Suizhou	-0.21(-0.2%)	0.05(0.1%)	0.09(1.0%)	-0.6(-2.2%)	-0.15(-2.0%)
Luan	-0.24(-0.3%)	0.00(0.0%)	-0.10(-0.7%)	-0.8(-2.0%)	-0.35(-3.2%)

Table S3. Meteorological drivers of 98% O_3 percentile concentrations in each city of HRB during May–September 2017–2022

	Meteorological variable				Meteorological variable		
	1st	2st	3st		1st	2st	3st
Taian	T	RH	V	Bozhou	RH	T	V850
Puyang	T	RH	TCC	Zhoukou	RH	T	V850
Rizhao	RH	T	BLH	Luohe	RH	T	V850
Jining	RH	T	TP	Suzhou	RH	T	TCC
Xinxiang	T	RH	TCC	Huaian	RH	T	V850
Jiaozuo	T	RH	U	Yancheng	RH	T	U
Heze	T	RH	MSLP	Zhumadian	RH	T	V850
Linyi	T	RH	TCC	Fuyang	RH	TCC	U
Kaifeng	T	RH	TCC	Bengbu	RH	T	TCC
Zhengzhou	T	RH	TCC	Huainan	RH	T	V
Luoyang	T	U	RH	Yangzhou	RH	T	V
Zaozhuang	RH	T	TCC	Taizhou	RH	V	V
Lianyungang	RH	T	U	Xinyang	RH	TCC	V850
Shangqiu	RH	T	V850	Chuzhou	RH	T	U
Xuzhou	RH	T	TCC	Hefei	RH	TCC	U
Xuchang	T	RH	V850	Suizhou	RH	TCC	U
Suqian	RH	T	TCC	Luan	RH	TCC	U
Huaibei	RH	T	TCC	-	-	-	-

Table S4. Meteorological drivers of 2% O_3 percentile concentrations in each city of HRB during May–September 2017–2022

	Meteorological variable				Meteorological variable		
	1st	2st	3st		1st	2st	3st
Taian	V850	RH	MSLP	Bozhou	RH	MSLP	V850
Puyang	BLH	RH	T	Zhoukou	RH	MSLP	U
Rizhao	U	BLH	T	Luohe	RH	BLH	U
Jining	RH	T	V	Suzhou	RH	U	MSLP
Xinxiang	BLH	T	RH	Huaian	RH	U	MSLP
Jiaozuo	U	RH	T	Yancheng	RH	U	MSLP
Heze	RH	MSLP	V850	Zhumadian	RH	BLH	MSLP
Linyi	RH	BLH	U	Fuyang	RH	MSLP	BLH
Kaifeng	RH	U	MSLP	Bengbu	RH	MSLP	U
Zhengzhou	BLH	RH	T	Huainan	RH	MSLP	BLH
Luoyang	BLH	MSLP	RH	Yangzhou	V	RH	BLH
Zaozhuang	RH	T	U	Taizhou	T	V	RH
Lianyungang	RH	V850	U	Xinyang	RH	MSLP	BLH
Shangqiu	RH	T	V	Chuzhou	RH	V850	U
Xuzhou	RH	BLH	T	Hefei	RH	BLH	MSLP
Xuchang	BLH	RH	U	Suizhou	BLH	RH	U
Suqian	RH	MSLP	U	Luan	RH	MSLP	T
Huaibei	RH	U	V	-	-	-	-