

Supporting information

Diverse mixing states and atmospheric processes of urban amine-containing particles in the North China Plain

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Table S1. The relative aerosol acidity (R_{ra}) and relative peak area of sulfate during three time periods in summer.

Periods	R_{ra}	Sulfate
7:00 – 9:00	71.6 ± 9.0	0.29 ± 0.03
12:00 – 14:00	72.8 ± 3.4	0.42 ± 0.04
18:00 – 20:00	100.9 ± 39.0	0.33 ± 0.06

Table S2. The correlations (r^2) of TMA and DEA particles with secondary organic ions during winter and summer in Liaocheng.

Marker ions	Winter		Summer	
	TMA	DEA	TMA	DEA
$^{42}\text{CNO}^-$	0.22	0.71	0.28	0.62
$^{59}\text{C}_2\text{H}_3\text{O}_2^-$	0.17	0.60	0.00	0.61
$^{89}\text{HC}_2\text{O}_4^-$	0.05	0.82	0.00	0.61

Table S3. Number fractions (%) of sulfate, nitrate, and ammonium in TMA-, DEA-, and total amine-containing particles.

Marker ions	Winter			Summer		
	TMA	DEA	Amines	TMA	DEA	Amines
$^{97}\text{HSO}_4^-$	92.6	99.0	98.6	56.4	95.1	93.0
$^{62}\text{NO}_3^-$	91.6	96.6	96.4	79.3	84.0	83.4
$^{18}\text{NH}_4^+$	43.1	36.2	36.4	15.7	22.8	22.4

Table S4. Linear correlations (r^2) of peak areas of TMA-, DEA-containing particles with sulfate and nitrate during winter and summer.

Marker ions	Winter			Summer		
	TMA	DEA	Amines	TMA	DEA	Amines
$^{97}\text{HSO}_4^-$	0.68	0.87	0.81	0.04	0.76	0.75
$^{62}\text{NO}_3^-$	0.45	0.69	0.68	0.04	0.38	0.37

Table S5. Differences in meteorological factors, number count and number fraction of amines in total particles, PM_{2.5} mass, aerosol liquid water content (ALWC) concentration, and relative aerosol acidity (R_{ra}) between haze and clean periods in Liaocheng.

Species	Haze	Clean
I. Meteorological parameters		
Temperature (°C)	1.6 ± 1.6	2.2 ± 2.6
Relative humidity (%)	59.4 ± 13.5	48.0 ± 14.3
II. Number count and number fraction of amine in total particles		
Amines	29755	11881
Total single particles	95675	42737
Amine/total particles ratio	31.1%	27.8%
III. Others		
PM _{2.5} (µg m ⁻³)	83.8 ± 23.1	47.9 ± 27.0
ALWC (µg m ⁻³)	37.7 ± 24.8	14.0 ± 12.6
R_{ra}	46.0 ± 20.1	28.6 ± 8.6

Table S6. The correlation coefficients (r) of number count of amine particles with temperature, relative humidity, ALWC, and R_{ra} during haze and clean periods.

	Haze	Clean
Temperature (°C)	-0.76**	-0.20
Relative humidity (%)	0.51**	-0.01
ALWC (µg m ⁻³)	0.03	0.51**
R_{ra}	0.90**	0.73**

** The correlation is significant at the 0.01 level (two-tailed).

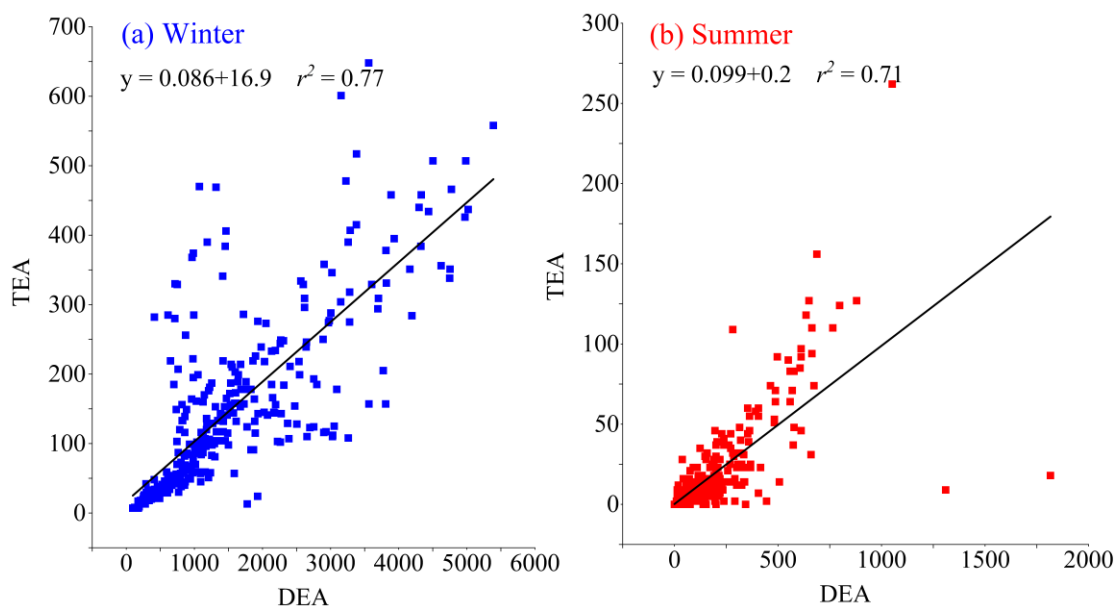


Fig. S1. Linear regression analysis (r^2) between the number count of DEA- and TEA-containing particles during (a) winter and (b) summer.

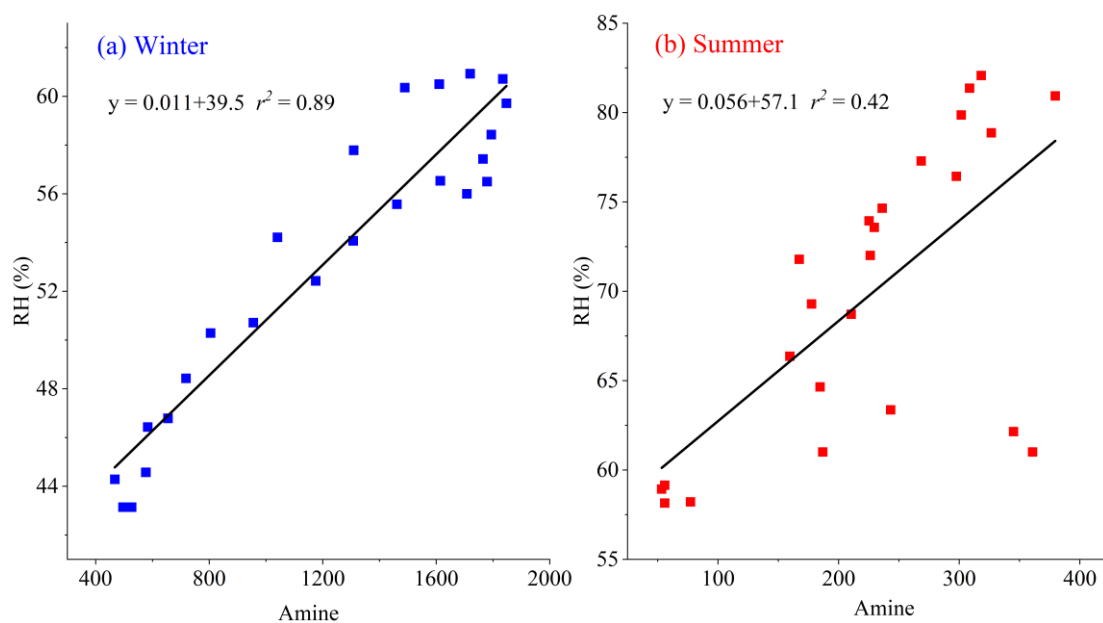


Fig. S2. The linear regressions (r^2) between diurnal counts of amine-containing particles and relative humidity (RH) in (a) winter and (b) summer. The diurnal counts of amine-containing particles were averaged from hourly counts during the sampling periods.

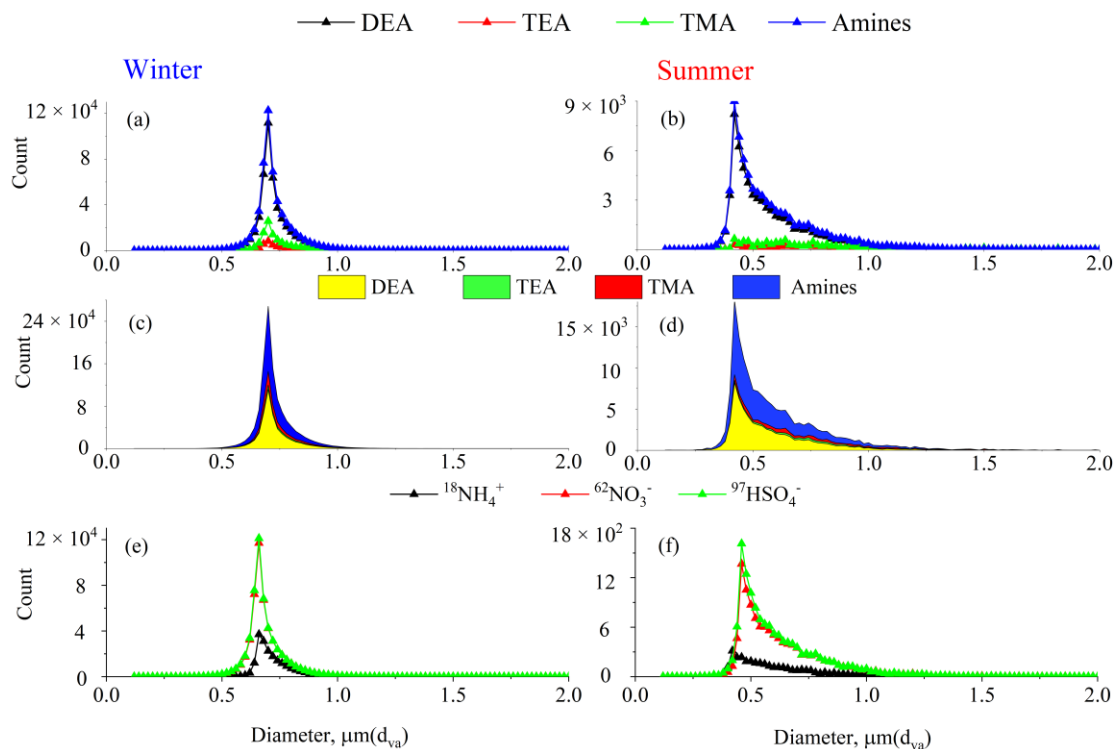


Fig. S3. Unscaled size distributions of DEA-, TEA-, TMA-, and amine-containing particles, along with ammonium, nitrate, and sulfate in amine-containing particles during winter and summer.

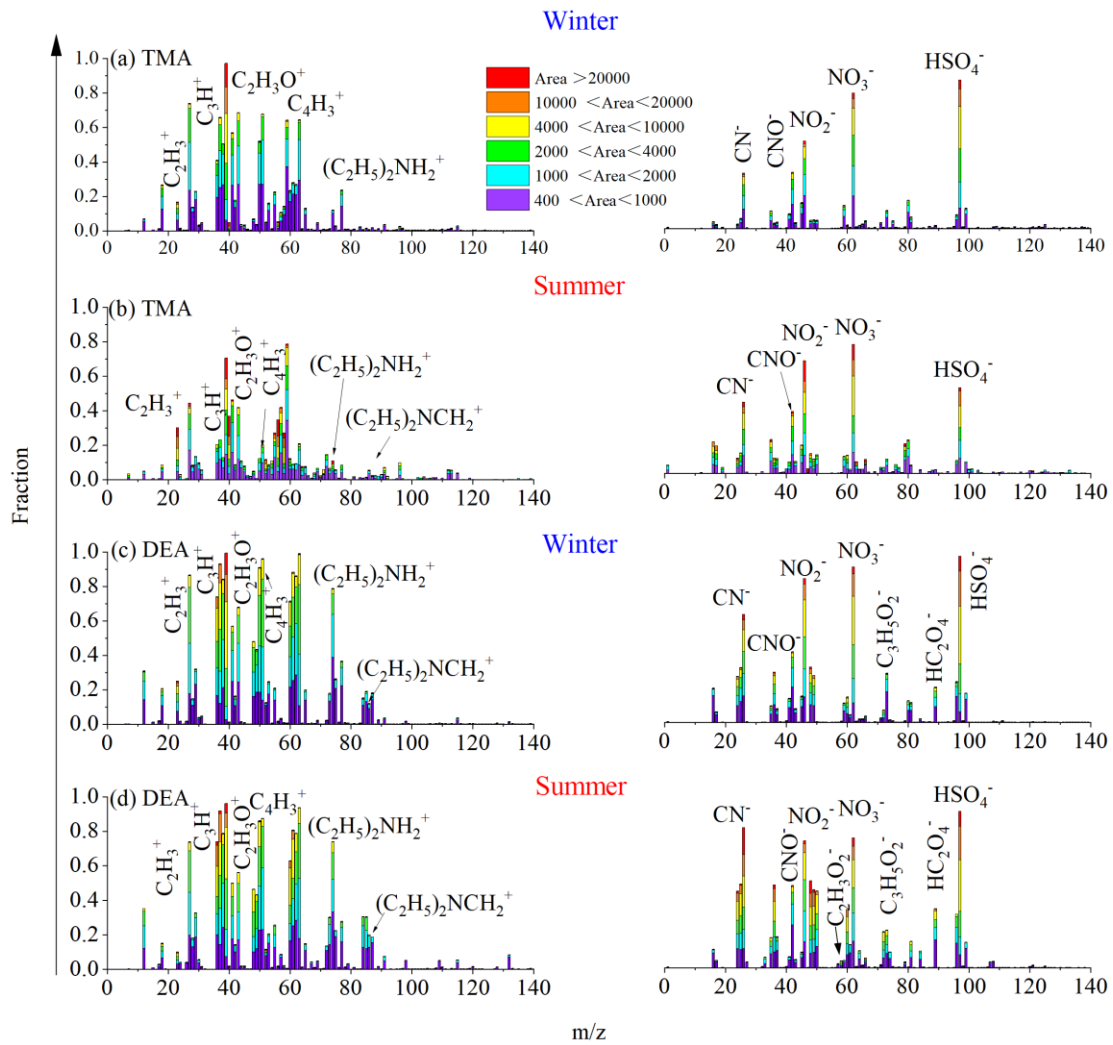


Fig. S4. The mass spectra of TMA- and DEA-containing particles in winter and summer.

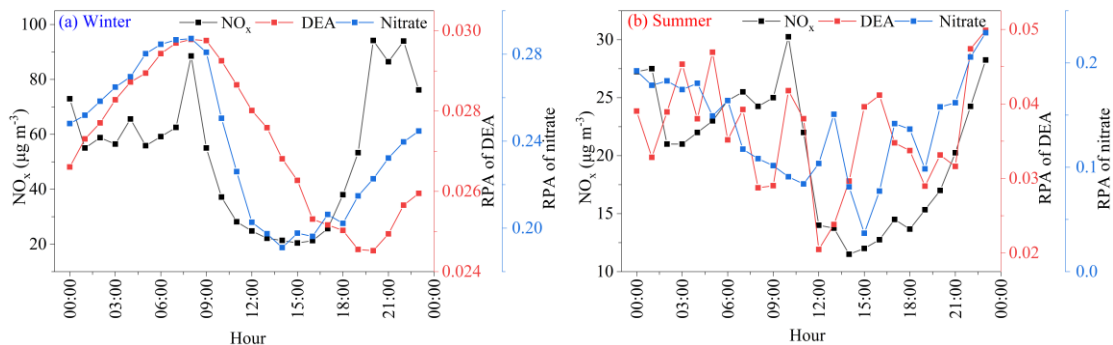


Fig. S5. The diurnal variations of NO_x and the relative peak areas (RPAs) of DEA-containing particles and nitrate in (a) winter and (b) summer.

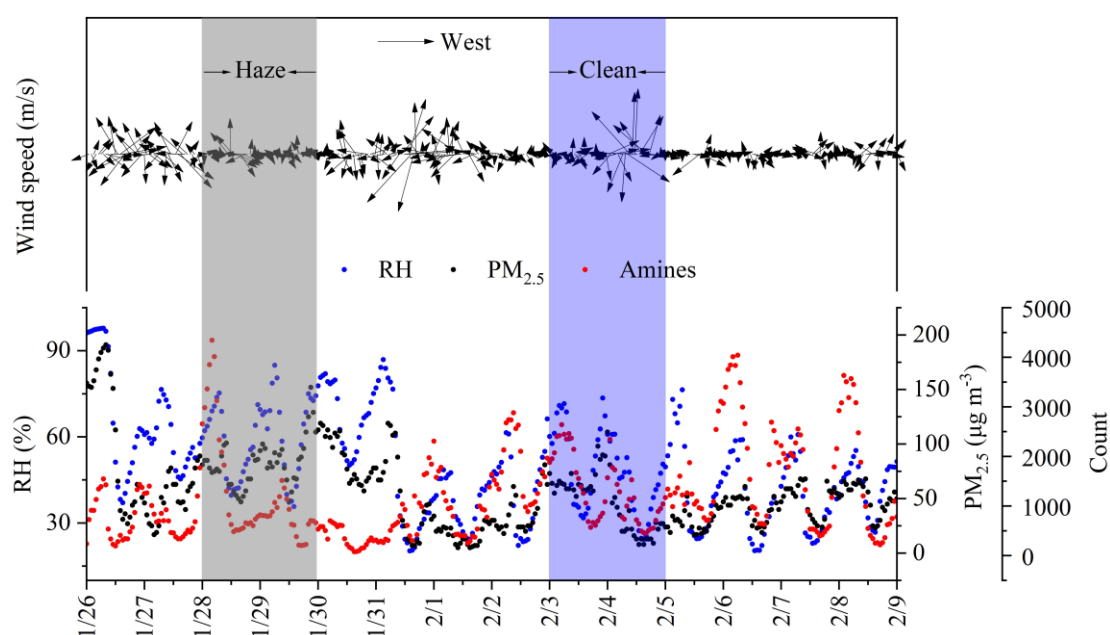


Fig. S6. Temporal variations of meteorological factors, $\text{PM}_{2.5}$ mass concentrations, and counts of amine-containing particles on haze days (gray-shaded areas) and clean days (blue-shaded areas) in winter (Note: While only one $\text{PM}_{2.5}$ concentration exceeding $100 \mu\text{g m}^{-3}$ was recorded during the cleaning period, this represents a single isolated data point within the entire dataset of 48 measurements (constituting $\sim 2.1\%$ of observations, Fig. S6). From a statistical perspective, a single outlier in a dataset of this size ($n = 48$) has negligible influence on the overall conclusions. The period was selected based on pre-defined criteria for "clean" conditions (e.g., absence of anthropogenic events, stable meteorology). The transient spike ($111 \mu\text{g m}^{-3}$) likely resulted from an ephemeral, non-representative event (e.g., localized dust resuspension and other factors). When $\text{PM}_{2.5}$ peaked at $111 \mu\text{g m}^{-3}$, the total concentration of amine-containing particles did not reach its maximum. Given the outlier's minimal statistical weight and the consistency of the remaining 97.9% of data, we maintain that the period reliably represents a clean-air state for our analysis, as supported by the significant differences in mixing state and influencing factors between haze and clean days described in Section 3.4. Therefore, this high-value period was retained.).

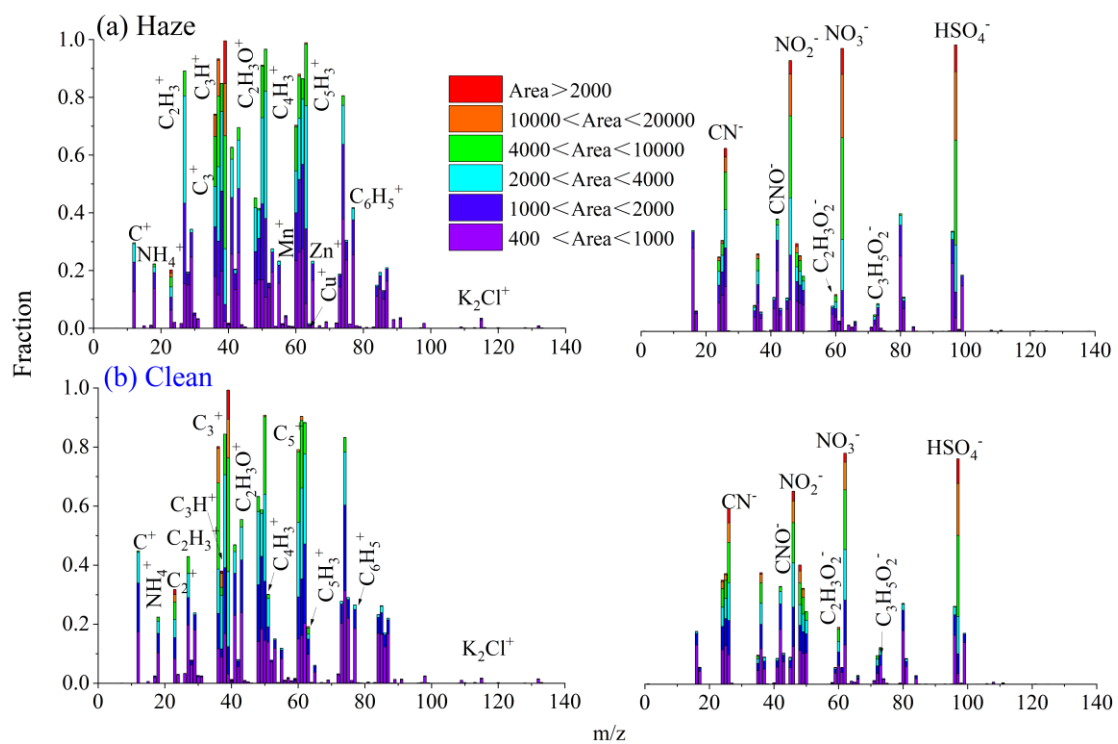


Fig. S7. The mass spectra of amine-containing particles (a) on haze days and (b) clean days during winter.

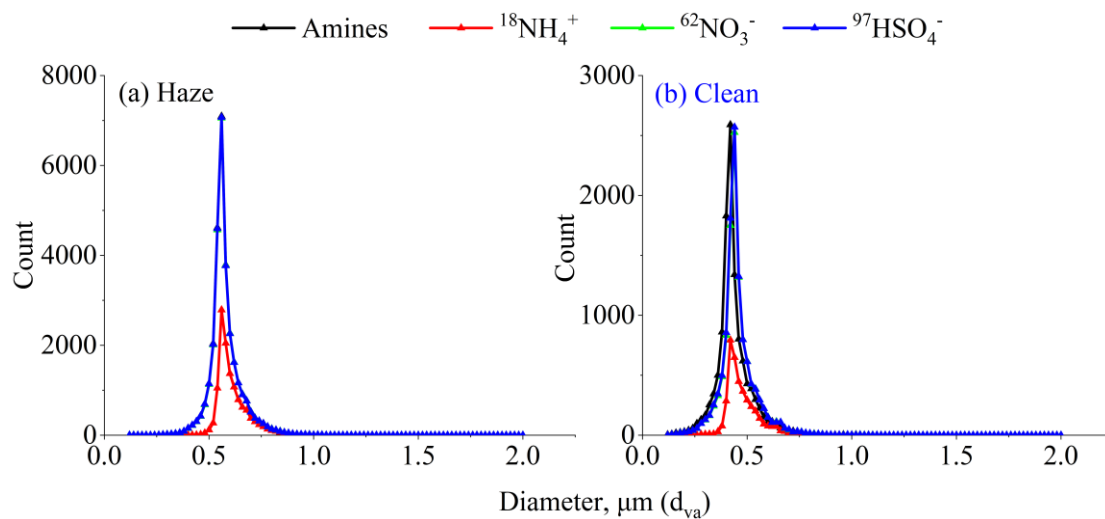


Fig. S8. The unscaled size distributions of amine-containing particles and secondary inorganic ions (a) on haze days and (b) clean days during winter.

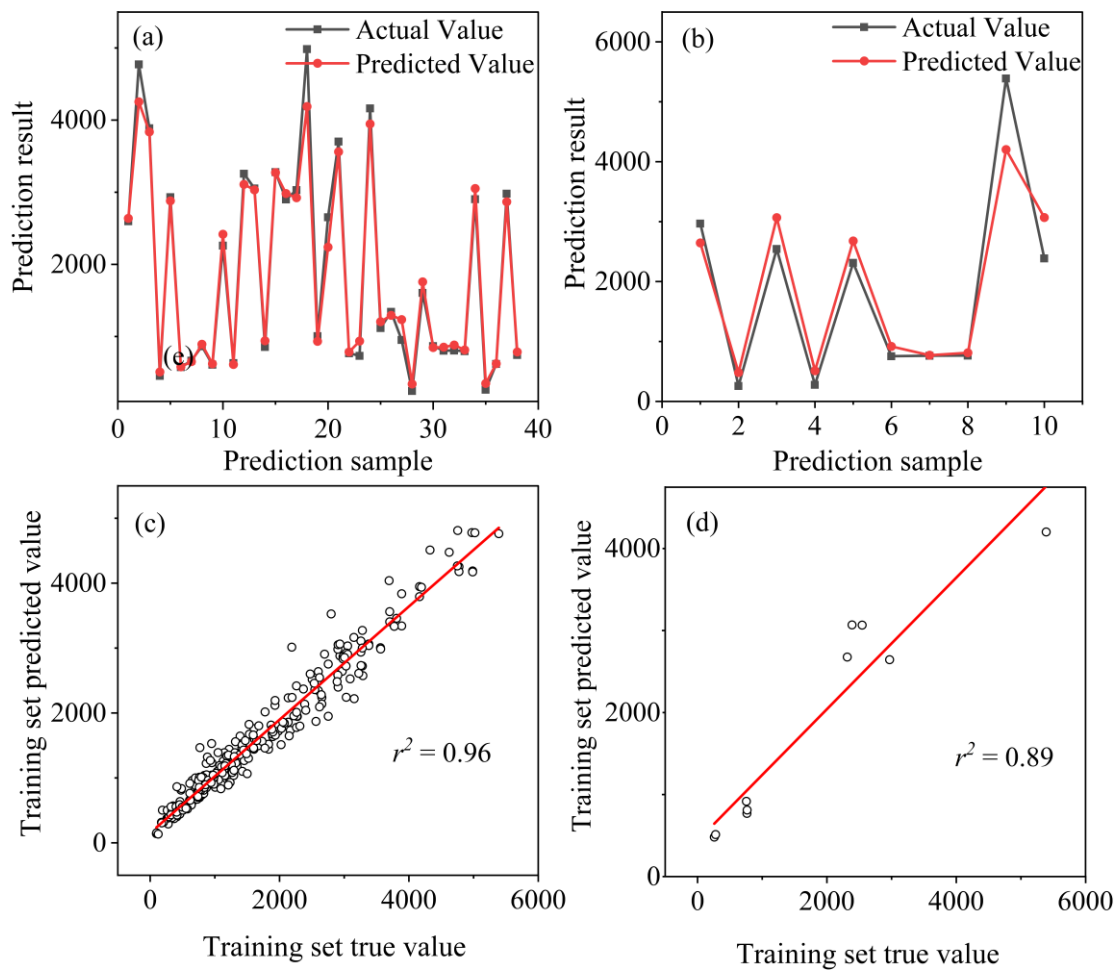


Fig. S9. (a, c) Comparison of predicted and actual amine-containing particles between the training and test sets, (b, d) comparison of the predicted value and the actual value in the training set in predicting amine-containing particles determined by random forest analysis on haze days during winter.

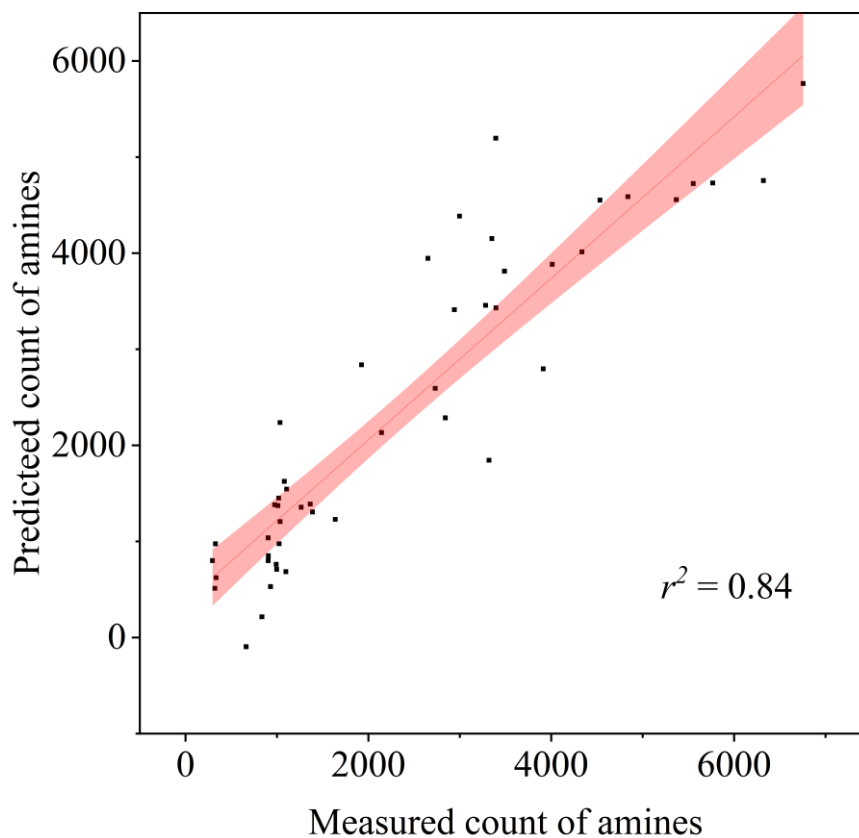


Fig. S10. Relationship between measured and predicted counts of amine-containing particles determined by multiple linear regression analysis on haze days during winter.