Analysis of long-term aerosol optical properties combining AERONET sunphotometer and satellite-based observations in Hong Kong

Xinyu Yu [1], Janet Nichol [2], Kwon Ho Lee [3], Jing Li [1], Man Sing Wong [1,4*]

[1] *Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hong Kong, China*
[2] *Department of Geography, University of Sussex, Brighton, BN19RH, UK*
[3] *Department of Atmospheric & Environmental Sciences, Gangneung-Wonju National University, Gangneung, 26403, South Korea*
[4] *Research Institute for Land and Space, The Hong Kong Polytechnic University, Hong Kong, China*
** Corresponding author. E-mail address: Ls.charles@polyu.edu.hk (M.S. Wong)*

2.4 Extreme-point symmetric mode decomposition (ESMD)

ESMD was developed based on ensemble empirical mode decomposition (EEMD, Wang & Li, 2013), which can be used to detect the time-dependent non-linear tendency without antecedent assumption. After using ESMD, original signals can be decomposed into several intrinsic mode functions (IMFs) and a residual curve (R). The specific decomposition process of ESMD is as follows:

(1) Input time series $Y(m)$, set the maximum number of filters$K$ and the number of remaining poles l, and find all of the local extreme points (maximum points and minimum points). Label them as E_m $(1 \le m \le n), E_m = (z_m,\ x_m)$.
(2) Connect the adjacent poles E_m with lines, and record the midpoints of the lines as F_m $(1 \le m \le n-1)$, then add boundary midpoints F_0 and F_n.
(3) Construct p interpolation curves L_1, …, L_P (p > 1) with $n+1$ midpoints, and calculate the mean value by $L^* = (L_1 + \cdots + L_p)/p$.
(4) Repeat the above steps for $Y(m) - L^*$ until $|L^*| \le \varepsilon$ (ε is the allowable error) or the filters times get the preset maximum K, then we get the first IMF component M_1.
(5) Repeat the above 4 steps for the remaining sequence $Y(m) - M_1$ until the remaining trend residual R(m) is a single signal or is no longer larger than a given extreme point, then we can obtain the IMF component M_2, M_3, …, M_n, separately.
(6) Change the value of K within the limited interval $[K_{min},\ K_{max}]$ and calculate the variance ratio G, record the sequence as $Y(m) = \{y_m\}_{m=1}^N$, the trend residual as $R(m) = \{r_m\}_{m=1}^N$. σ and σ_0 are the relative standard deviation of $Y(m) - R(m)$ and the standard deviation of $Y(m)$, respectively. When $G = \sigma/\sigma_0$ gets the minimum value, it means that the sequence

with the trend residual $R(m)$ removed is the closest to the original sequence $Y(m)$, that is, the decomposition effect is the best.

(7) Plot the graph of the variance ratio with K, and select the maximum number of filters times K_0 according to the minimum variance ratio. Repeat (1) ~ (6) to obtain the optimal decomposition result (IMF1, IMF2, ..., IMFn and R).

3. Results and discussion

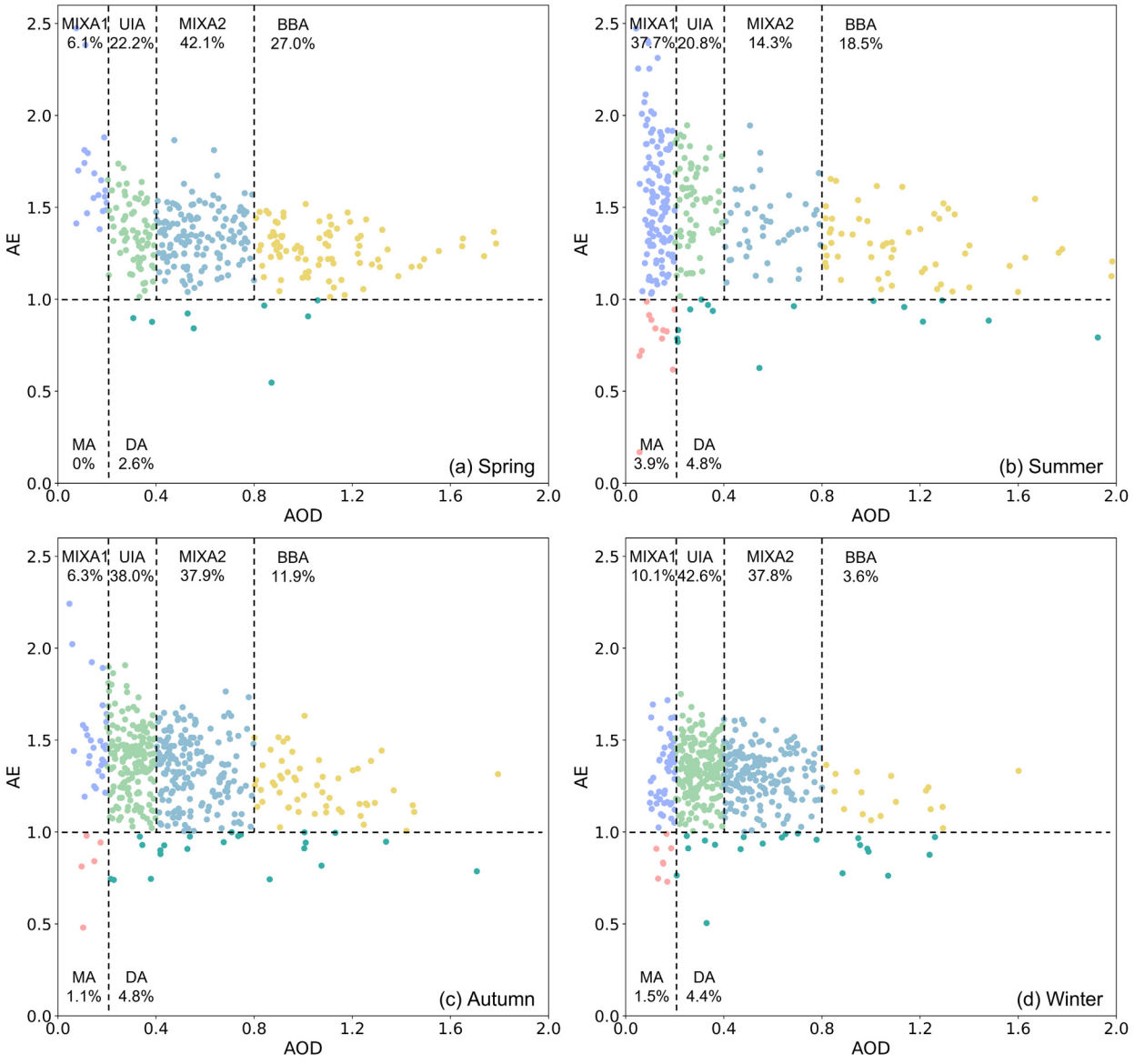


Figure S1. Seasonal aerosol types based on daily measurements of the PolyU AERONET station. (a) spring; (b) summer; (c) autumn and (d) winter.

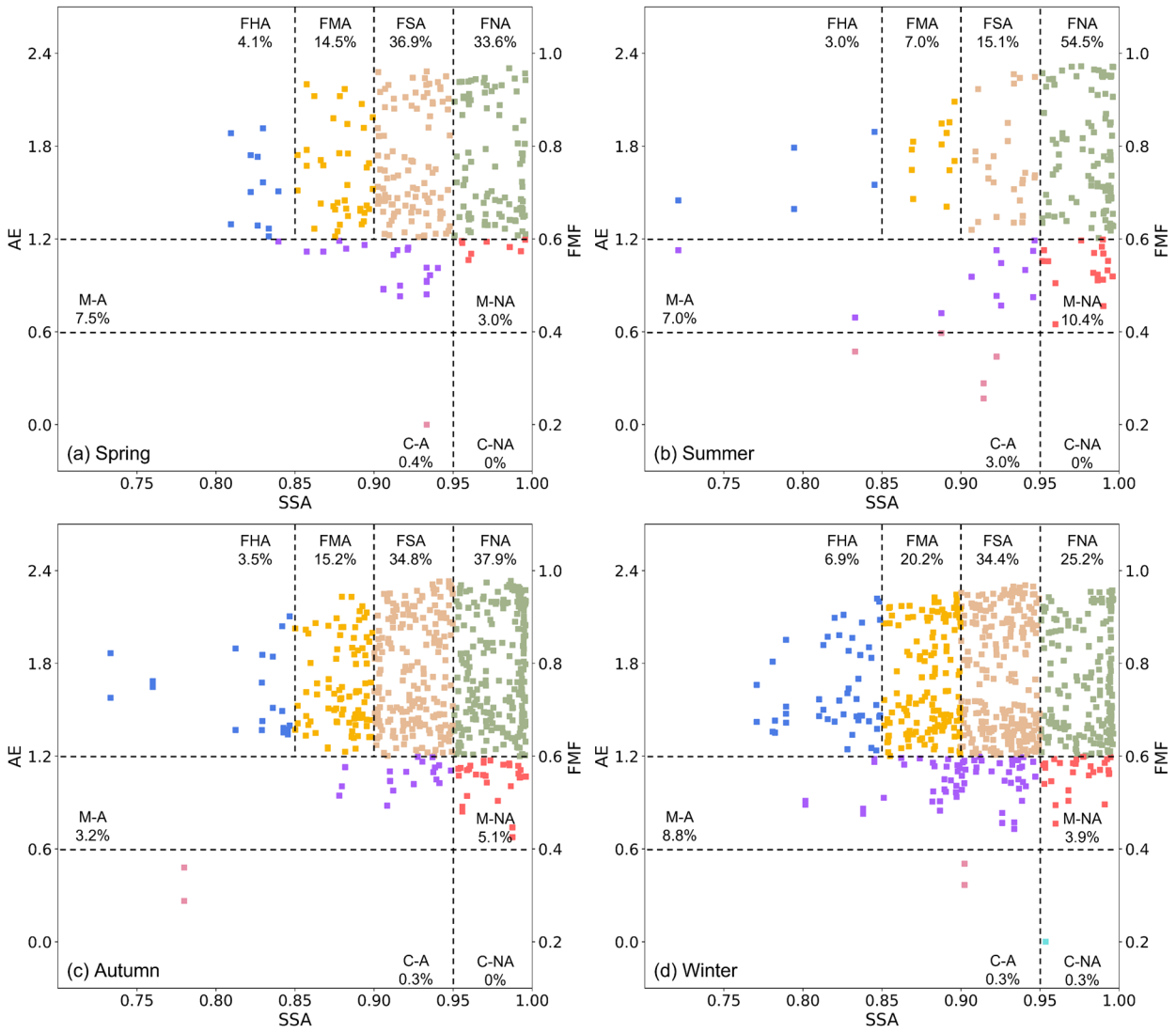


Figure S2. Seasonal absorbing aerosol types based on daily measurements of the PolyU AERONET station. (a) spring; (b) summer; (c) autumn and (d) winter.

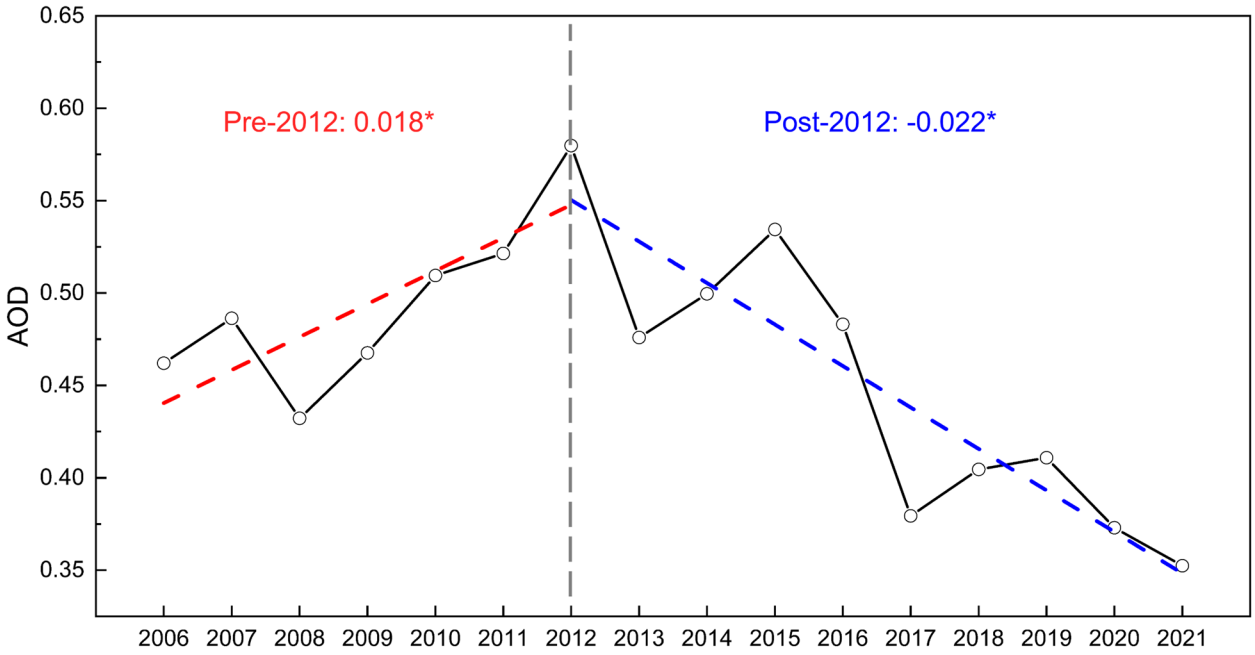
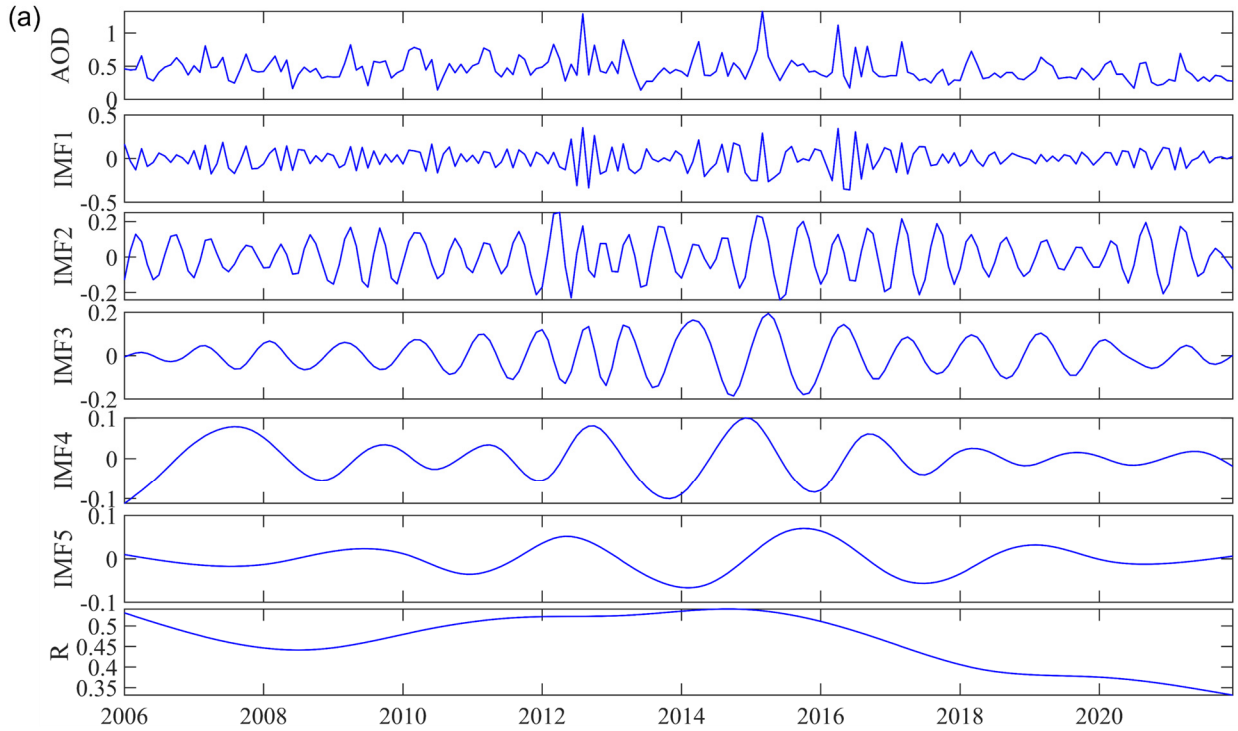


Figure S3. Variations of annual mean AOD with the linear trend (yr^{-1}) in two different periods, namely pre-2012 (red) and post-2012 (blue). * represents the trends passing the 95% confidence level.



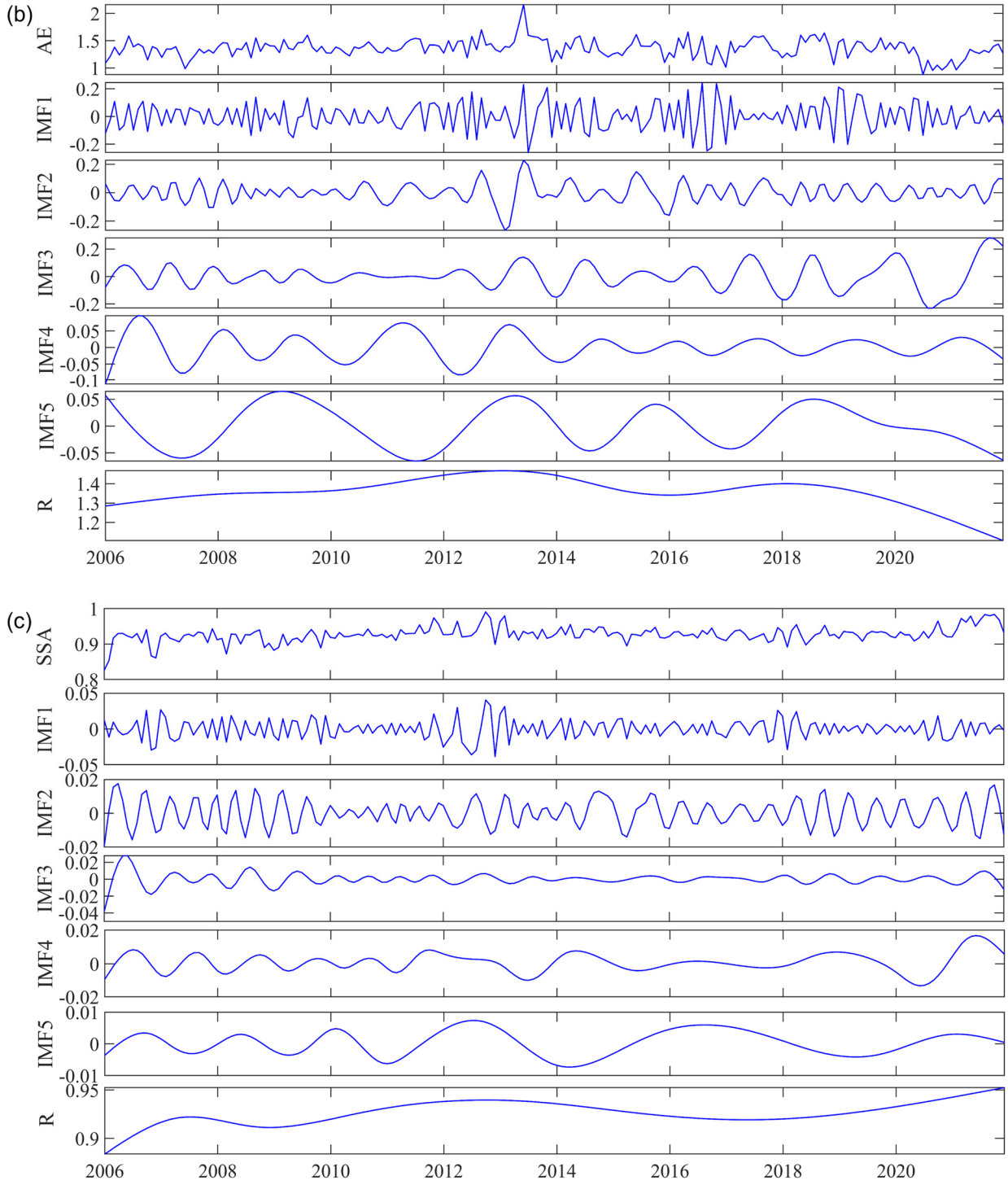


Figure S4. The decomposed results of aerosol optical parameters based on ESMD. (a) AOD, (b) AE and (c) SSA.

Table S1. Variance contribution rate (VCR, %) and correlation coefficient (CC) of the IMFs.

		Spring		Summer			Autumn		Winter		
		IMF1	IMF2	IMF1	IMF2	IMF3	IMF1	IMF2	IMF1	IMF2	IMF3
AOD	VCR	82.31	4.66	59.47	27.27	7.41	47.03	17.51	54.36	16.04	-
	CC	0.86*	0.09	0.76*	0.42*	0.19	0.51*	0.38*	0.60*	0.36*	-
AE	VCR	50.66	18.25	29.05	34.06	-	35.35	39.64	46.62	38.61	-
	CC	0.67*	0.34*	0.51*	0.47*	-	0.57*	0.58*	0.69*	0.62*	-
SSA	VCR	39.11	23.02	37.92	11.10	-	54.03	17.59	22.76	14.58	14.06
	CC	0.17	0.41*	0.69*	0.38*	-	0.75*	0.44*	0.52*	0.33*	0.38*

* represents the significance test at the 95% confidence level

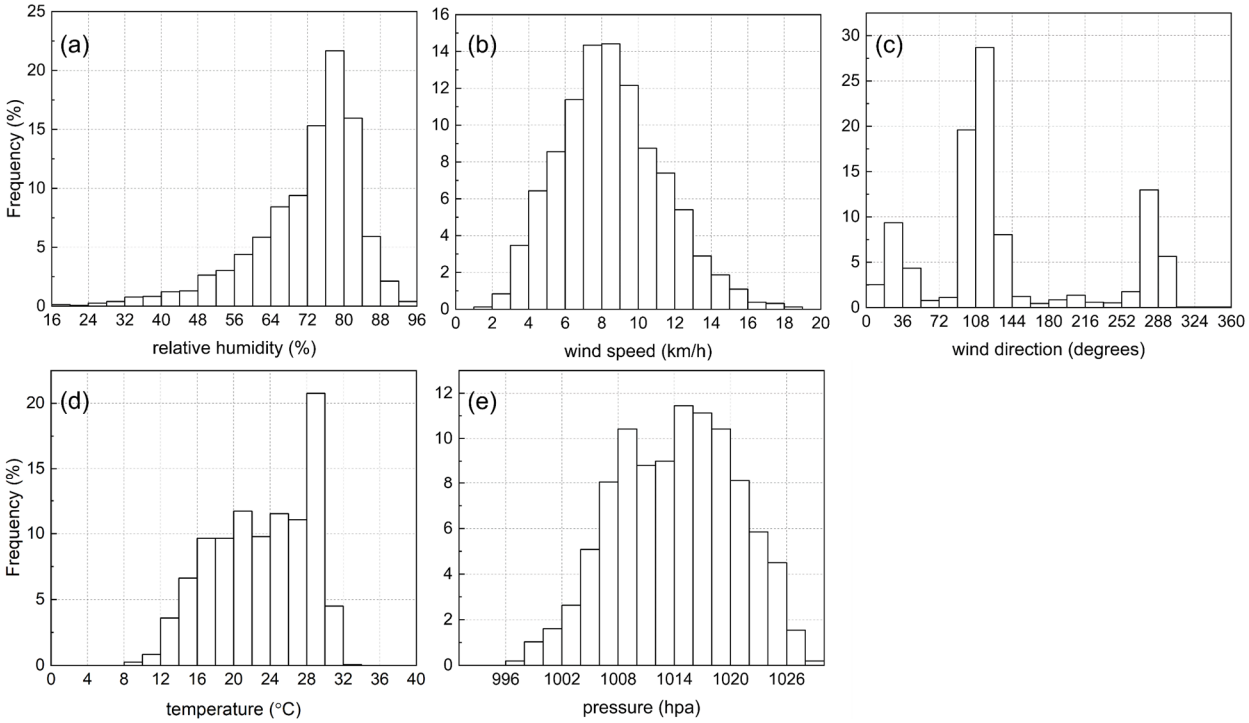


Figure S5. Distribution frequency of meteorological factors.

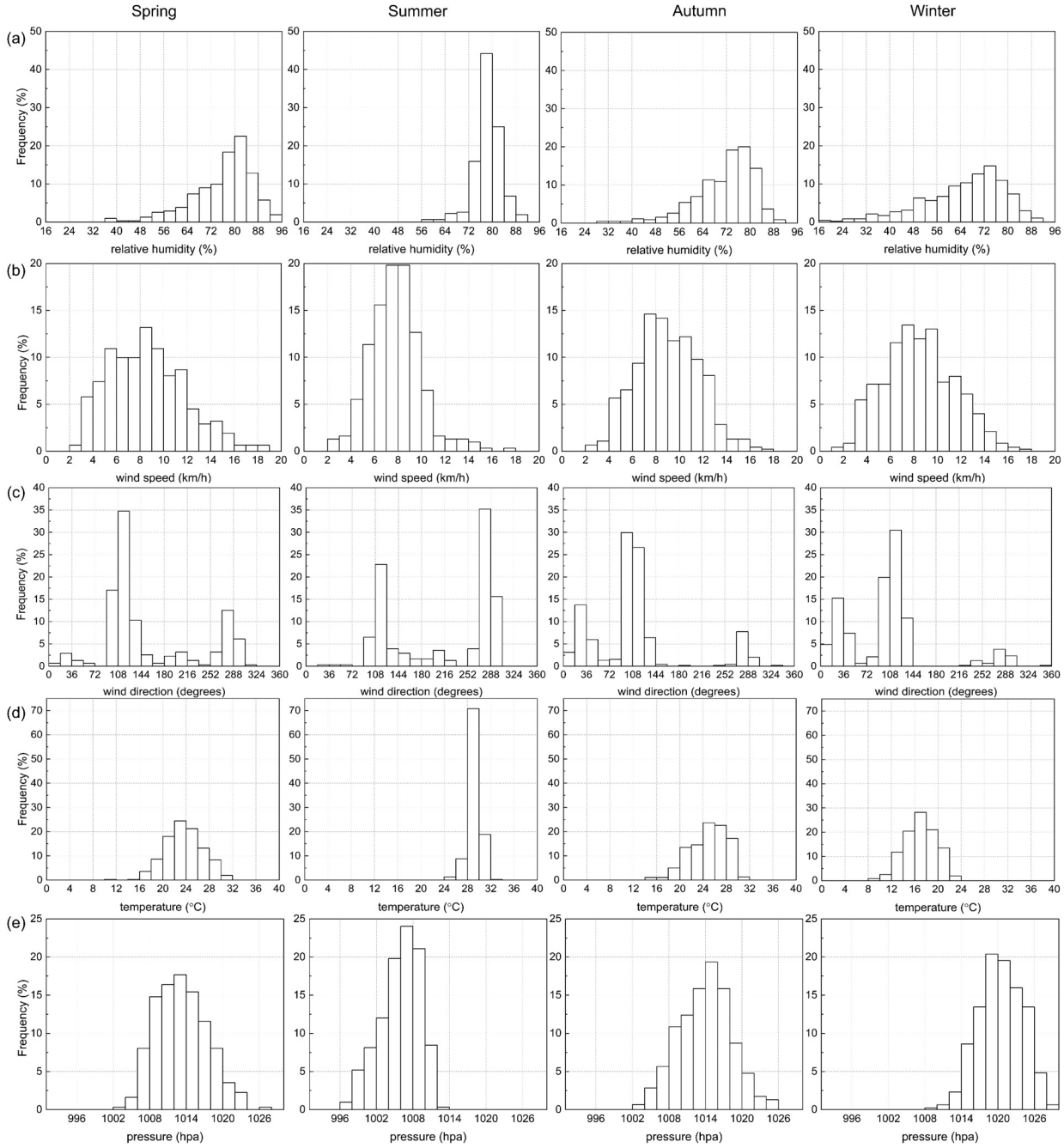


Figure S6. Distribution frequency of multi-seasonal meteorological factors.