

Supporting information:

Secondary Organic Aerosol Formation in Coastal Air Modulated by Continental Outflow and High Humidity

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There are 29 pages of the SI, including 3 text sections, 17 figures, and 5 tables:

SI-1 In-situ OFR Experiments

The OFR reaction chamber is cylindrical with an internal volume of 13.3 L. During the OFR experiments, the sample flow rate was maintained at 12.5 L min⁻¹, corresponding to a residence time of approximately 64 s. The OFR was operated in OFR185 mode using two low-pressure mercury lamps (GPH436T5VH/4P, Light Sources Inc.). OH radicals were generated via photolysis of H₂O at $\lambda = 185$ nm and photolysis of O₃ at $\lambda = 254$ nm. The OH concentration inside the OFR was varied by adjusting the voltage applied to the lamps. A typical experimental sequence included six lamp-voltage settings ranging from 1.5 to 6 V, with each condition maintained for 20 min.

The photochemical age in the OFR chamber is characterized by OH exposure (OH_{exp}), which was estimated based on the following empirical equation (1), as detailed in our previous study (Liu et al., 2025).

$$\log OH_{exp} = a + (b + c \times OHR_{ext}^d + e \times \log(O_{3,out} \times \frac{180}{t}) \times OHR_{ext}^f) \times \log(O_{3,out} \times \frac{180}{t}) + \log H_2O + \log(\frac{t}{180}) \dots\dots\dots (1)$$

where the $O_{3,out}$ (molecules cm⁻³) represents the ozone concentrations measured at the exit of the OFR, H_2O (%) represents the water vapor mixing ratio in the OFR, OHR_{ext} (s⁻¹), is the external OH reactivity, t (s) is the mean residence time, $a-f$ are the fitting parameters derived from the OH_{exp} calibration experiments.

A schematic of the experimental setup is provided in **Figure S2**. Ambient air containing both gaseous organics and particles was introduced directly into the OFR through a Swagelok PFA Teflon tube. PFA was selected because of its chemical inertness and low adsorption of gaseous organics (Deming et al., 2019). Previous studies using the same type of OFR (i.e., PAM) reported negligible wall losses of gaseous organics and SO₂, with SO₂ serving as a surrogate for wall-adhering species (Lambe et al., 2011; Hu et al., 2022). Because the residence time in this study (~64 s) was shorter than those used in the previous studies (105-170 s) (Lambe et al., 2011; Hu et al., 2022), wall losses of gaseous

species in our study are anticipated to be even lower than those in the cited studies, and no separate correction was applied.

Particle losses through the PFA inlet and OFR chamber were experimentally quantified by comparing aerosol component concentrations measured downstream of the OFR under dark conditions with the corresponding ambient concentrations measured through the ambient sampling line (i.e., the bypass line). To minimize particle losses during bypass measurements, ambient particles were delivered directly to the ACSM through stainless-steel tubing. The measured loss for OA, sulfate, nitrate and ammonium was approximately 15%, 8%, 20% and 14%, representing the combined particle losses through the PFA inlet and OFR chamber. All OFR-derived aerosol concentrations reported in this study were corrected using this experimentally determined loss factor.

The wall loss correction for low volatile organic compounds (LVOCs), which are oxidized products from organic precursors, was also performed according to the estimation method in Palm et al. (2016). The approximate lifetimes of low-volatile organic compounds (LVOCs) condensation onto aerosols (τ_{aer}) and loss to the walls of the OFR (τ_{wall}) were estimated using the following equations (2-6). The τ_{aer} was ~12 s, which was much shorter than τ_{wall} (395 s), suggesting that the LVOCs wall was negligible.

$$K_{wall} = \frac{1}{\tau_{wall}} = \frac{A}{V} \times \frac{2}{\pi} \times \sqrt{k_e \times D} \dots\dots\dots (2)$$

where k_e represents the coefficient of eddy diffusivity (0.0036 s^{-1}), D is the diffusion coefficient ($7 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$) (Palm et al., 2016), and the ratio of OFR surface area to volume (A/V) is 25 m^{-1} . Hence, the k_{wall} is about 0.0025 s^{-1} , and the corresponding τ_{wall} is about 395 s.

$$\tau_{aer} = \frac{1}{4\pi \times CS \times D} \dots\dots\dots (3)$$

$$CS = \int_0^{\infty} r \beta_{(r)} N_{(r)} dr \dots\dots\dots (4)$$

$$\beta(r) = \frac{K_n + 1}{0.377 \times K_n + 1 + \frac{4}{3} \times \alpha^{-1} \times K_n^2 + \frac{4}{3} \times \alpha^{-1} \times K_n} \dots\dots\dots (5)$$

where the CS is the condensational sink, r is the particle radius, $N(r)$ is the particle number size distribution measured during the OFR experiments, $\beta(r)$ is the Fuchs-Sutugin correction, and K_n is the Knudsen number and estimated using equation (6). The mass accommodation coefficient α is 1 (Liang et al., 2024).

$$K_n = \frac{2 \times \lambda}{D_p} \dots\dots\dots (6)$$

where λ (nm) is the mean free path, set to 100 nm (Liang et al., 2024), and D_p (nm) is the aerosol particle diameter.

The potential influences of photolysis and heat effects induced by UV lamps on the pre-existing OA were also evaluated. During our OFR experiments, two 185 UV lamps were operated at relatively low voltages of 1.5-6 V, and the maximum SOA enhancement was observed at lamp voltages of only 1.5-2 V. Meanwhile, the sample flow rate was maintained at 12.5 L min⁻¹, resulting in a residence time of approximately 64 s. Also, nitrogen was continuously supplied at 0.2-0.3 L min⁻¹ between the lamps and their protective sleeves to dissipate heat. These measures can effectively limit OA loss from photolysis and heating within the OFR. Moreover, previous studies have suggested that OA photolysis induced by 185 and 254 nm radiation is negligible over short OFR residence times (<5 min) (Malecha et al., 2018; Peng et al., 2016). The average temperature inside the OFR was 26.7 ± 2.5 °C, and the average temperature difference between the OFR and ambient air was only 1.0 ± 3.6 °C. After excluding experiments conducted at OFR temperatures above 30 °C, the maximum SOA enhancement decreased only slightly from 1.19 to 1.13 µg m⁻³ and occurred at the same equivalent photochemical age of approximately 3.2 days. Similarly, excluding experiments with an OFR-ambient temperature difference greater than 2 °C changed the maximum SOA enhancement only slightly, from 1.19 to 1.21 µg m⁻³. These analyses indicate that lamp-induced photolysis and heating had only a minor influence on OA

measurements.

SI-2 Measurements

(1) Gaseous components

Formaldehyde (HCHO) was measured using a G2307 gas concentration analyzer (Picarro Inc., USA). Other VOCs were measured using an online gas chromatography-mass spectrometry/flame ionization detector (GC-MS/FID, TH-300, Wuhan Tianhong Instrument Co., Ltd., China) and a proton transfer reaction time-of-flight mass spectrometer (PTR-ToF-MS, ToFwerk AG, Switzerland). VOCs can be ionized via proton-transfer reactions with the hydronium ion (H_3O^+) and were detected as $\text{VOC}\cdot\text{H}^+$ via PTR-ToF-MS. GC-MS/FID and PTR-ToF-MS were calibrated daily using gas standards (Linde Gas Inc., USA). When specific VOCs were measured simultaneously by GC-MS/FID and PTR-ToF-MS, GC-MS/FID results were used preferentially due to its better isomer-resolving capability (Gao et al., 2023). Detailed VOC identification and quantification followed the data processing protocol described by Gao et al. (2023).

(2) Particulate components

A time-of-flight aerosol chemical speciation monitor (ToF-ACSM-X, Aerodyne Research, Inc., USA) coupled with a capture vaporizer was used to measure non-refractory aerosols. The ionization efficiency of ToF-ACSM-X was calibrated using the size-selected ammonium nitrate particles generated via an aerosol generator (3076, TSI, Inc., US). The relative ionization efficiency for organics, nitrate, sulfate, ammonium, and chloride was set to 1.4, 1.1, 1.9, 3.6, and 1.3, respectively. A collection efficiency of 1.0 was applied for the ACSM (Hu et al., 2017). After taking into account the ionization efficiency and relative ionization efficiency, as well as the particle wall loss within the OFR chamber, the mass concentration of aerosol components was finally determined.

Positive matrix factorization (PMF) analysis was further applied to the organic mass spectra to estimate the approximate proportion of POA and SOA in total OA during field measurements, following

the procedures described by Ulbrich et al. (2009) and Zeng et al. (2026). The analysis was based on ambient measurements from April 29 to June 3 to avoid potential effects of OFR-bypass switching during the OFR experiments. Ions with signal-to-noise ratios below 0.2 (“bad” variables) were removed, while the errors of ions with signal-to-noise ratios between 0.2 and 2 (“weak” variables) were doubled. Because O^+ , HO^+ , H_2O^+ , and CO^+ are constrained proportionally to CO_2^+ in the fragmentation table, their uncertainties were multiplied by $\sqrt{5}$ to prevent these dependent ions from being overweighted. PMF was run in exploration mode with one to four factors and fPeak values from -1 to 1 in increments of 0.2. The two-, three-, and four-factor solutions are presented in **Figures S3-S6**. Factors were classified as POA- or SOA-related based on their mass spectra, elemental ratios, and temporal correlations with black carbon (BC), a tracer of primary emissions. Factors with lower O/C ratios (0.5-0.8), higher H/C ratios (1.9-2.3), and temporal variations correlated with BC were classified as POA-related, whereas those with higher O/C ratios (1.3-1.7) and lower H/C ratios (1.1-1.4) were classified as SOA-related. Although the three- and four-factor solutions further subdivided the POA- and SOA-related components, the combined SOA fraction remained relatively stable at 75%, 69%, and 75% of OA in the two-, three-, and four-factor solutions, respectively. Because PMF was used primarily to estimate the approximate proportion of POA and SOA in total OA rather than to resolve detailed OA sources, the two-factor solution was selected as the most parsimonious and physically interpretable solution for this purpose.

(3) Auxiliary measurements

Other atmospheric measurements were also available, including inorganic gases (SO_2 , NO_x , O_3 , CO) measured with standard gas analyzers (Thermo Fisher Scientific Inc.), and meteorological parameters (RH, temperature, wind speed, wind direction). To characterize air-mass origins, 24 h backward trajectories arriving at Tanxu Island were calculated using the TrajStat model at a 1 h temporal resolution and an arrival height of 100 m above ground level (a.g.l.). This configuration has also been

used to distinguish continental and marine air masses in previous coastal studies (Liu et al., 2020a; Li et al., 2025). Trajectories showing no evident passage over land were classified as marine, whereas those showing clear transport from continental regions before reaching Tanxu Island were classified as continental (**Figure S15a**). Trajectories influenced by both marine and continental regions, with neither influence clearly dominant, were classified as mixed and excluded from the comparison. In addition, a weighted potential source contribution function analysis was conducted for SOA in urban Shanghai during the summer to identify major transport pathways and potential source regions.

SI-3 Data analysis

(1) Estimation of SOA production

Estimated SOA production from the gas-phase OH oxidation of detected VOCs was calculated based on their OH-oxidation losses in the OFR chamber and their corresponding SOA yields, as described by Equations (7) and (8) (Gao et al., 2025; Huang et al., 2024). In this study, a total of 117 potential SOA precursors were considered. Their classifications, OH reaction rate constants, and SOA yield parameters are presented in **Tables S1-S3**. For compounds lacking experimentally determined OH rate constants, the rates were estimated using the empirical Equation (9) proposed by Donahue et al. (2013).

$$SOA = \Delta Precursor_i \times [Y_i] \quad (7)$$

$$\Delta Precursor_i = [Precursor_i] \times (1 - e^{-k_{OH,i} \times OH_{exp}}) \quad (8)$$

where SOA ($\mu\text{g m}^{-3}$) is the mass concentration of SOA produced, $[Y_i]$ is the SOA yield of precursor i at the corresponding OA loading in the OFR, $\Delta Precursor_i$ ($\mu\text{g m}^{-3}$) and $[Precursor_i]$ ($\mu\text{g m}^{-3}$) is the reacted mass concentration and the initial concentration of the SOA precursor i, $k_{OH,i}$ ($\text{molecules cm}^{-3} \text{s}^{-1}$) is the OH reaction rate constant for precursor i, and OH_{exp} ($\text{molecules cm}^{-3} \text{s}$) is the OH exposure inside the OFR chamber.

$$k_{OH,i} = -1.2 \times 10^{-12} \times (n_c + 9 \times n_o - 10 \times (\frac{n_o}{n_c})^2) \dots \dots \dots (9)$$

where n_c and n_o are the carbon and oxygen numbers.

SOA yields were determined using established parameterization approaches, including the Secondary Organic Aerosol Potential (SOAP) method, the two-product model, and the five-product Volatility Basis Set (VBS) model, detailed in Equations (10-12). All yield parameterizations used here were derived from laboratory chamber experiments. The average NOx concentration during the campaign was 9.7 ppb, and therefore, laboratory SOA yield parameters determined in the presence of NOx were applied. In addition, some compounds without reported SOA yield are assigned to surrogate compounds. Specifically, SRAs with carbon numbers greater than eight were represented by m/p-xylene (Akherati et al., 2020); PAHs by naphthalene (Akherati et al., 2020); oxygenated aromatic compounds by benzyl alcohol (Sasidharan et al., 2023); furans by furan and methyl furan (Akherati et al., 2020).

$$Y_i = \frac{SOAP_i \times \Delta Precursor_i \times SOA_{toluene}}{\Delta toluene} \div 100 \dots \dots \dots (10)$$

where $SOAP_i$ is the propensity of species i to form SOA on an equal mass emitted basis relative to toluene. $SOA_{toluene}$ ($\mu\text{g m}^{-3}$) and $\Delta toluene$ ($\mu\text{g m}^{-3}$) are the SOA mass formed from toluene and the mass of toluene consumed, respectively.

For the two-product model method:

$$Y_i = M_{org} \times \left(\frac{\alpha_1 \times K_{p,1}}{1 + K_{p,1} \times M_{org}} + \frac{\alpha_2 \times K_{p,2}}{1 + K_{p,2} \times M_{org}} \right) \dots \dots \dots (11)$$

where M_{org} ($\mu\text{g m}^{-3}$) is the mass concentration of organic aerosol in the experiments measured downstream of OFR. α_1 , α_2 , and $K_{p,1}$, $K_{p,2}$ are mass-based stoichiometric coefficients and absorption equilibrium partitioning coefficients of product i , respectively.

For the four-product VBS model method:

$$Y_i = a_1 \times \frac{1}{1 + \frac{1}{M_{org}}} + a_{10} \times \frac{1}{1 + \frac{10}{M_{org}}} + a_{100} \times \frac{1}{1 + \frac{100}{M_{org}}} + a_{1000} \times \frac{1}{1 + \frac{1000}{M_{org}}} \dots\dots\dots (12)$$

where M_{org} ($\mu\text{g m}^{-3}$) is the mass concentration of organic aerosol in the experiments measured downstream of OFR. α_1 , α_{10} , α_{100} , and α_{1000} denote the mass yield coefficients for products in the volatility bins with effective saturation concentrations (C^*) of 1, 10, 100, and 1000 $\mu\text{g m}^{-3}$, respectively.

(2) Estimation of volatility

The effective saturation concentration (C^* , $\mu\text{g m}^{-3}$) of gaseous organics was estimated using molecular corridors described by Li et al. (2016).

$$\log_{10} C^* = (n_C^0 - n_C^i) b_C - n_O^i b_O - 2 \frac{n_C^i n_O^i}{n_C^i + n_O^i} b_{CO} - n_N^i b_N - n_S^i b_S \dots\dots\dots (13)$$

where n_C^0 is the reference carbon number; n_C^i , n_O^i , n_N^i and n_S^i represent the numbers of carbon, oxygen, nitrogen and sulfur atoms, respectively; b_C , b_O , b_N and b_S denote the contribution of each atom to $\log_{10} C^*$, respectively, and b_{CO} is the carbon-oxygen nonideality. The parameters for CH, CHO, CHN, CHON, and CHONS compounds are the same as those reported by Li et al. (2016). Due to the lack of specific parameters for CHS and CHNS compounds (i.e., CS_2 , CH_4S , $\text{C}_2\text{H}_6\text{S}$, and $\text{C}_7\text{H}_5\text{NS}$ in this study), their parameters were assumed by analogy to be the same as those for CHONS compounds. Products were divided into five volatility bins according to the value of C^* , including VOCs ($C^* > 3 \times 10^6 \mu\text{g m}^{-3}$), intermediate organic compounds (IVOCs, $300 < C^* < 3 \times 10^6 \mu\text{g m}^{-3}$) and semi-volatile organic compound (SVOCs, $0.3 < C^* < 300 \mu\text{g m}^{-3}$).

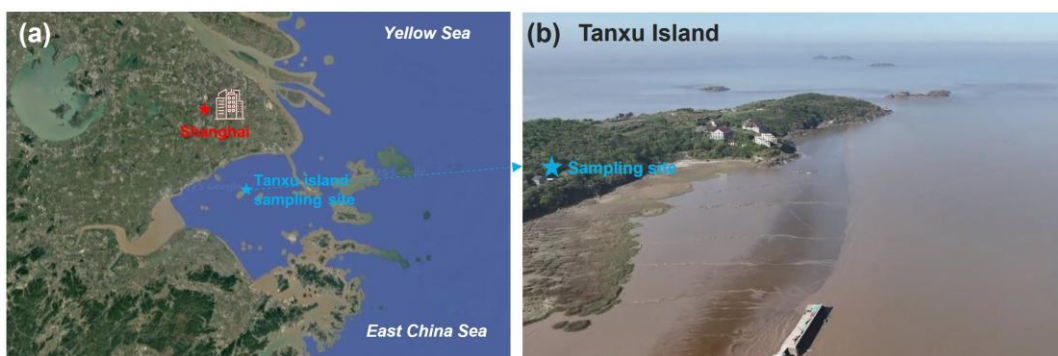


Figure S1. (a) Location of the Tanxu Island, and (b) the surrounding environments of the sampling site.

Map in (a): Imagery © 2024 NASA, Map data © 2024 Google.

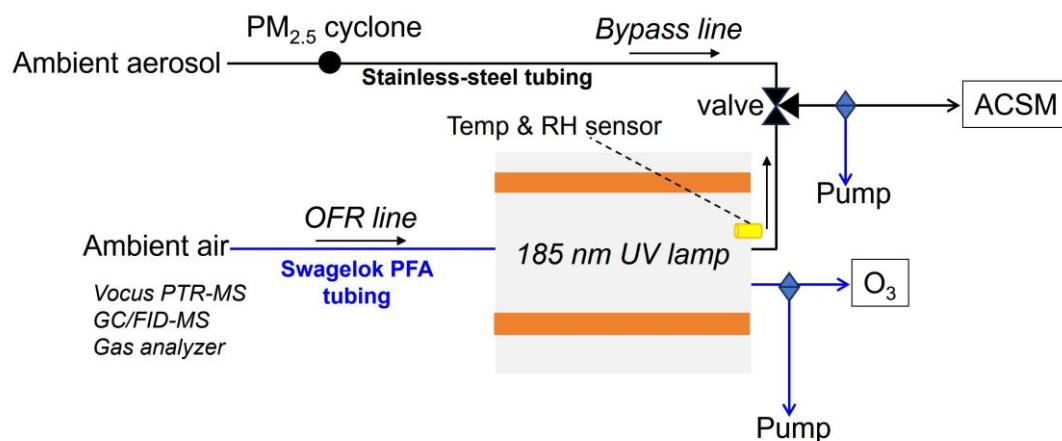


Figure S2. Schematic of the OFR sampling system. Ambient air was introduced into the OFR through PFA tubing (blue lines), while ambient aerosol was delivered to the ACSM through a stainless-steel bypass line (black lines).

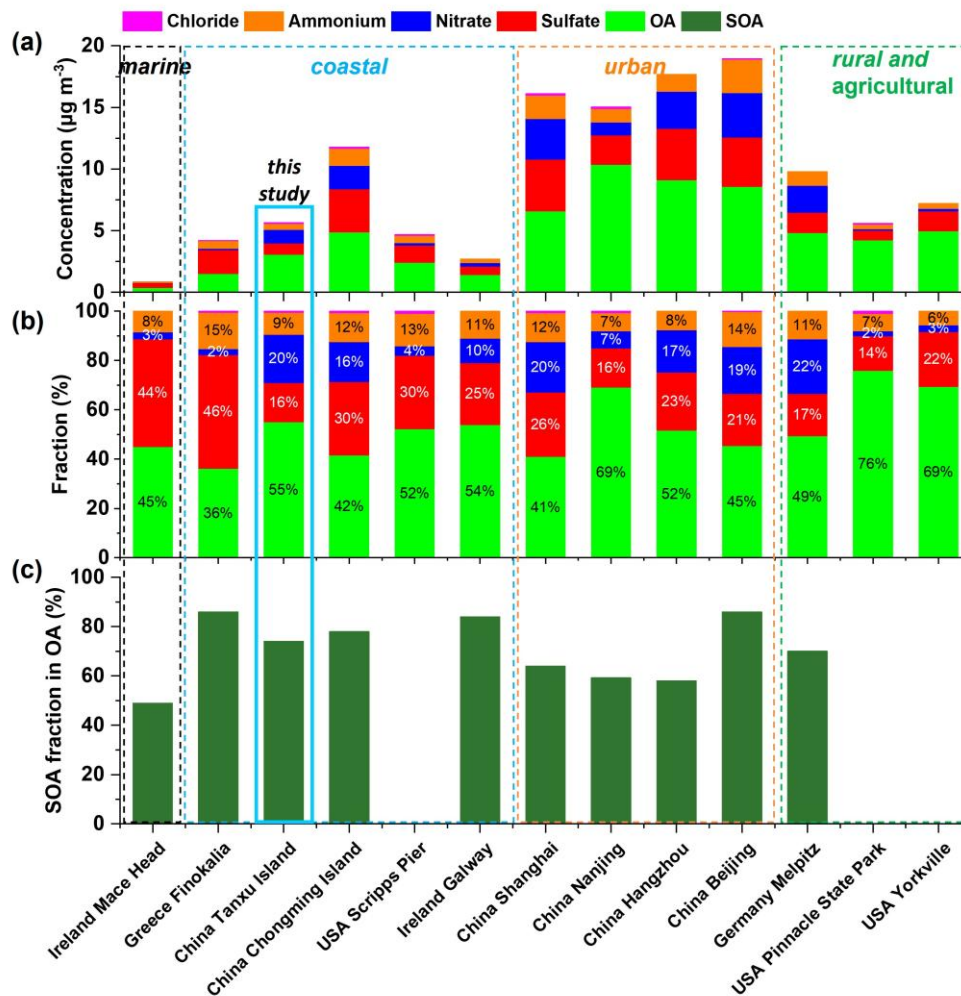


Figure S3. (a) Concentration, (b) fraction of aerosol components, and (c) the SOA fraction in OA among different sites during the warm season (Chevassus et al., 2025; Florou et al., 2024; Han et al., 2025; Tian et al., 2025; Lin et al., 2019; Shan et al., 2026; Zhang et al., 2025; Li et al., 2023; Atabakhsh et al., 2023; Zhang et al., 2020; Nah et al., 2018; Yin et al., 2023). Values not explicitly reported in the original studies are left blank. Detailed information can be found in **Table S4**.

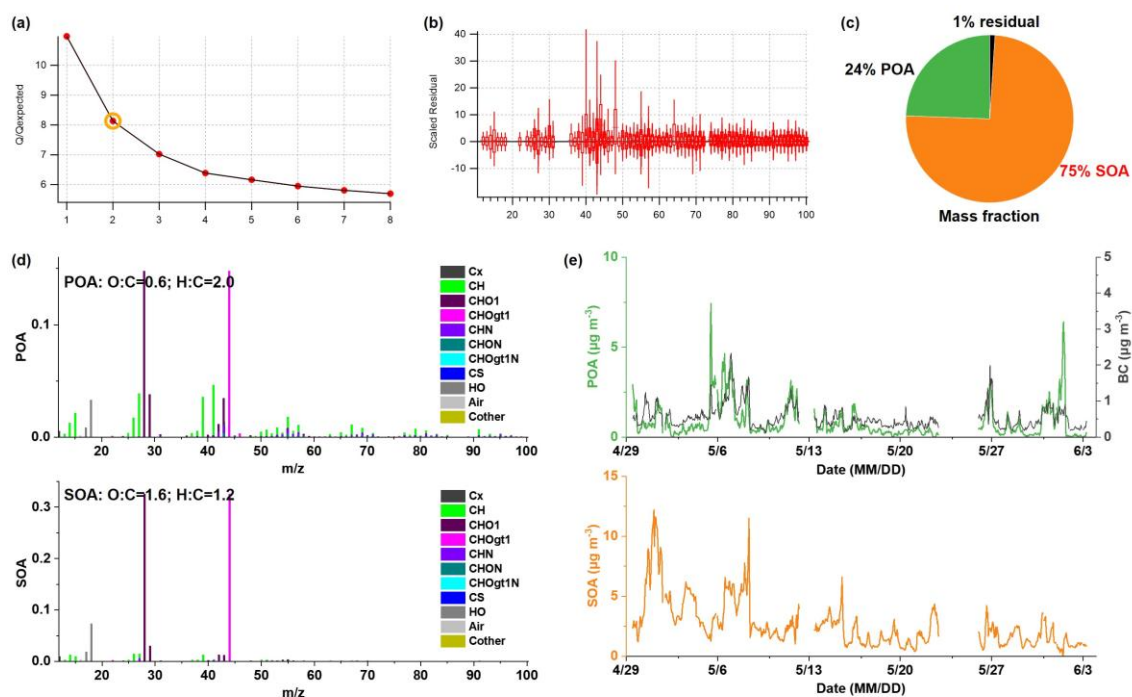


Figure S4. Diagnostic plot for the PMF analysis of a two-factor solution. (a) Q/Q_{expected} vs. the number of factors, (b) residuals for the two-factor solution, (c) mass fraction, (d) mass spectral profiles, and (e) time series of the two resolved factors. The time series of black carbon (BC) is also shown for comparison with the POA factors.

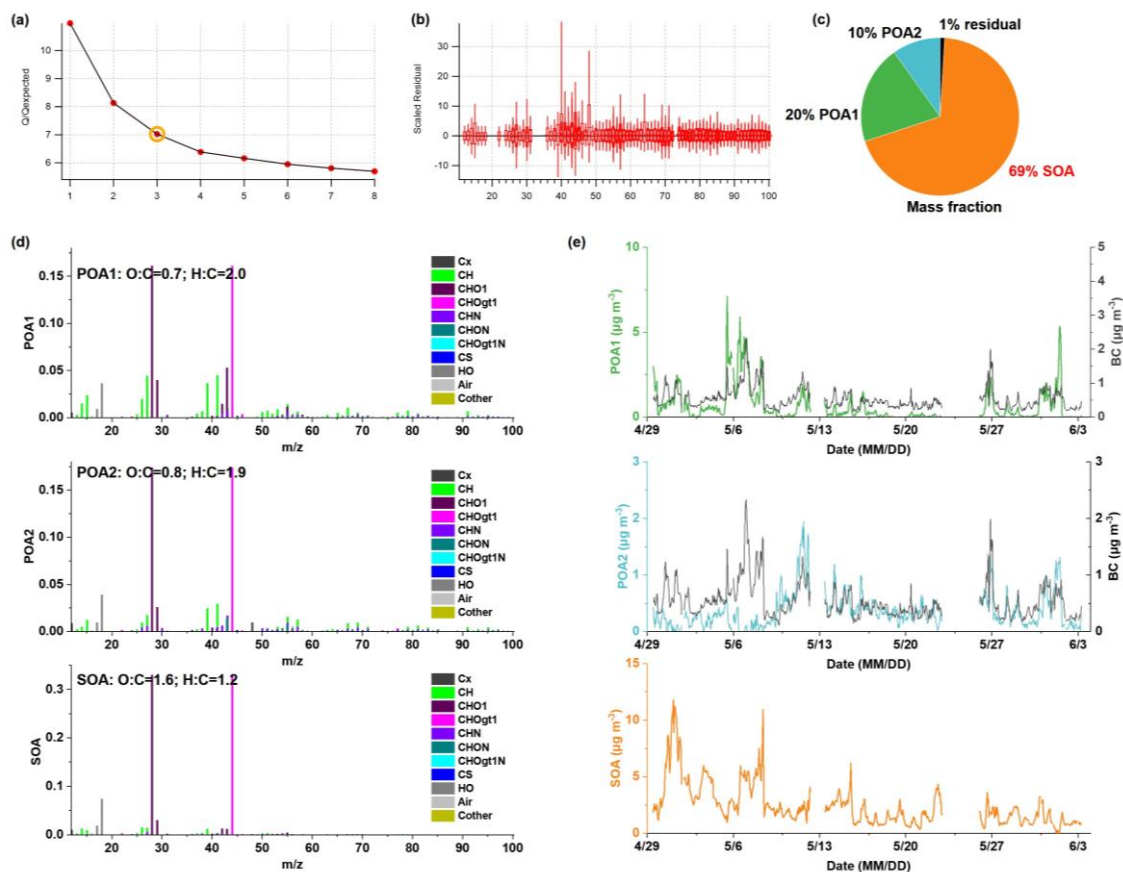


Figure S5. Diagnostic plot for the PMF analysis three-factor solution. (a) Q/Qexpected vs. the number of factors, (b) residuals for the three-factor solution, (c) mass fraction, (d) mass spectral profiles, and (e) time series of the three resolved factors. The time series of black carbon (BC) is also shown for comparison with the POA factors.

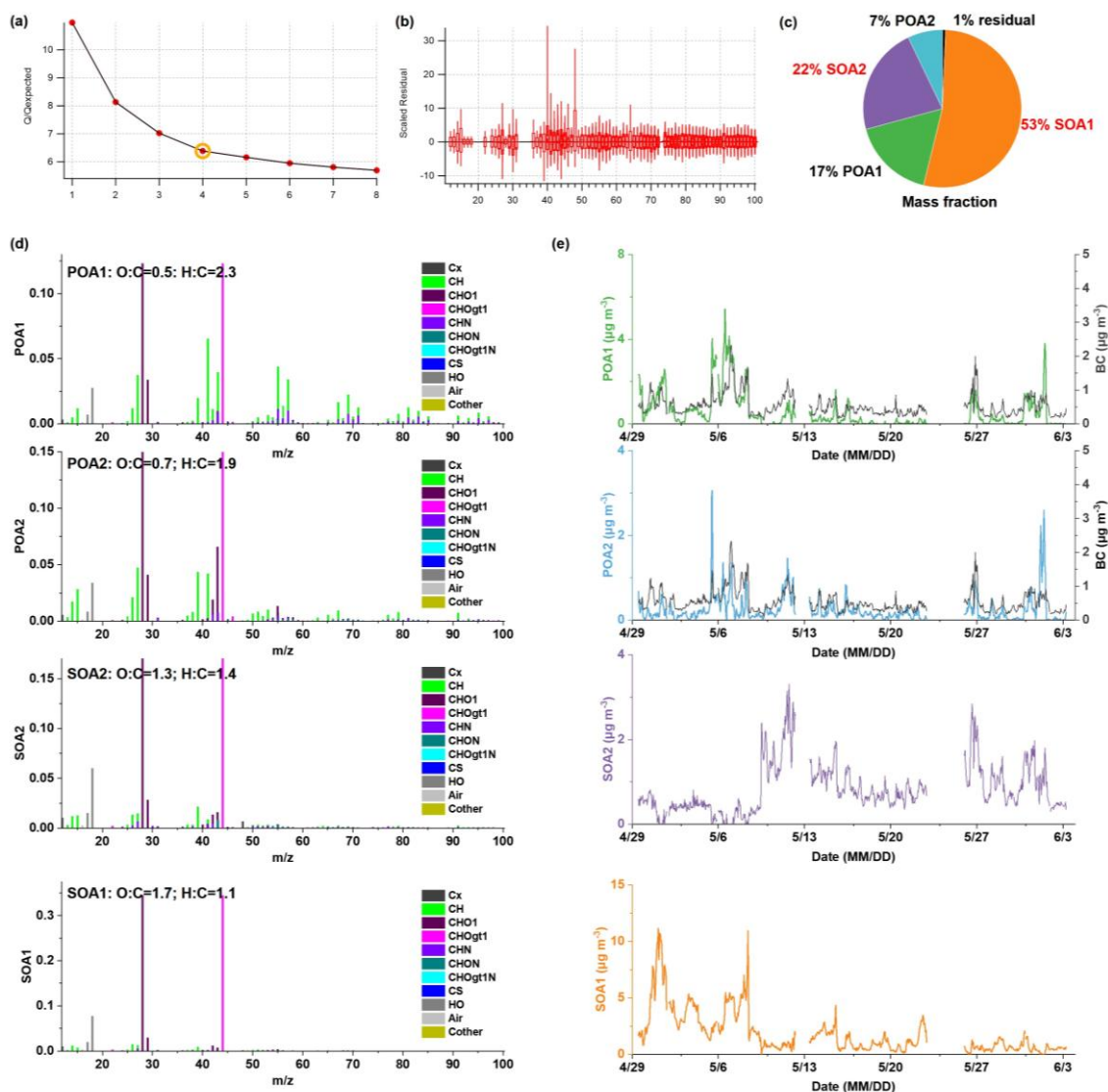


Figure S6. Diagnostic plot for the PMF analysis of a four-factor solution. (a) Q/Q_{expected} vs. the number of factors, (b) residuals for the four-factor solution, (c) mass fraction, (d) mass spectral profiles, and (e) time series of the four resolved factors. The time series of BC is also shown for comparison with the POA factors.

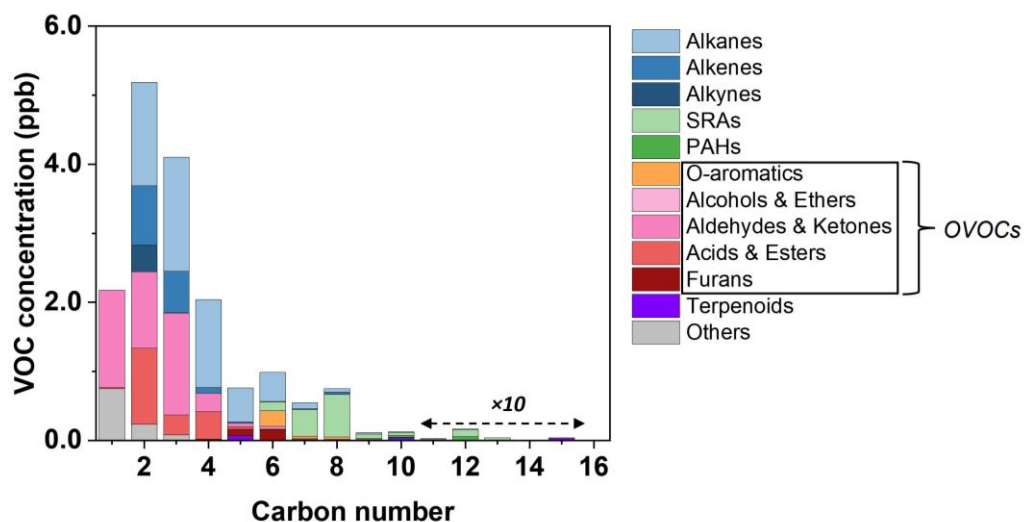


Figure S7. Concentration distribution binned by carbon number of identified compound categories

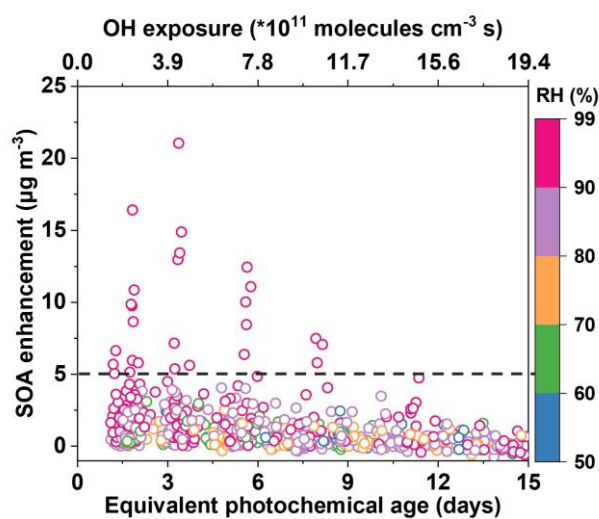


Figure S8. Distribution of SOA enhancement under different equivalent photochemical age. The symbol color denotes relative humidity (RH).

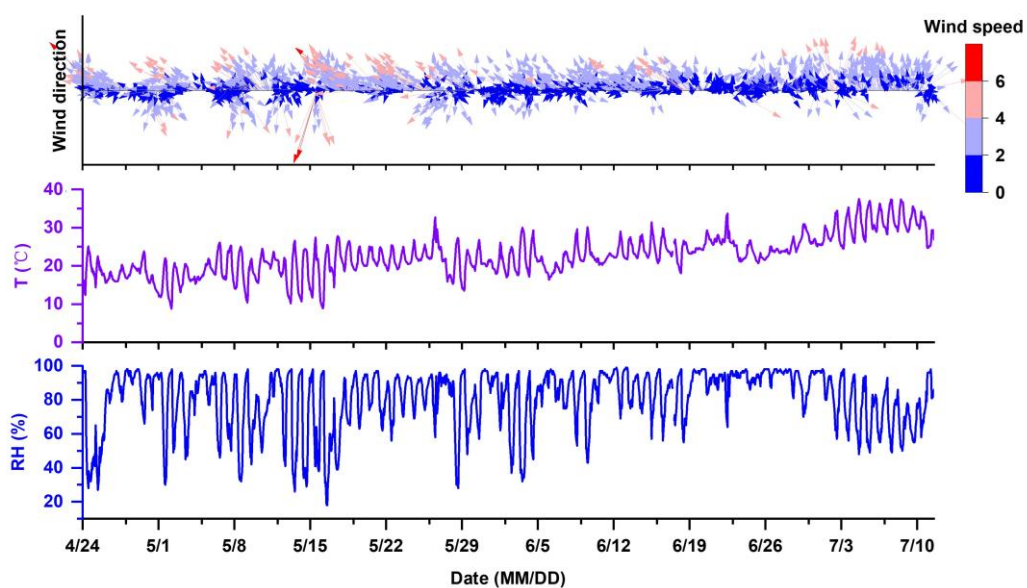


Figure S9. Meteorological parameters, including wind speed, wind direction, temperature (T), and relative humidity (RH) during the campaign

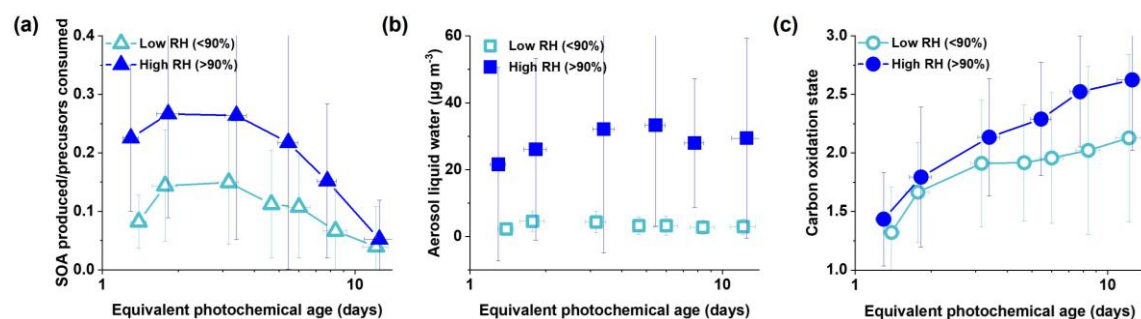


Figure S10. (a) SOA enhancement normalized by precursor consumption, (b) aerosol liquid water content, and (c) carbon oxidation state of SOA at different equivalent photochemical ages. Precursor consumption accounted for SRAs, PAHs, O-aromatics, furans, and terpenes.

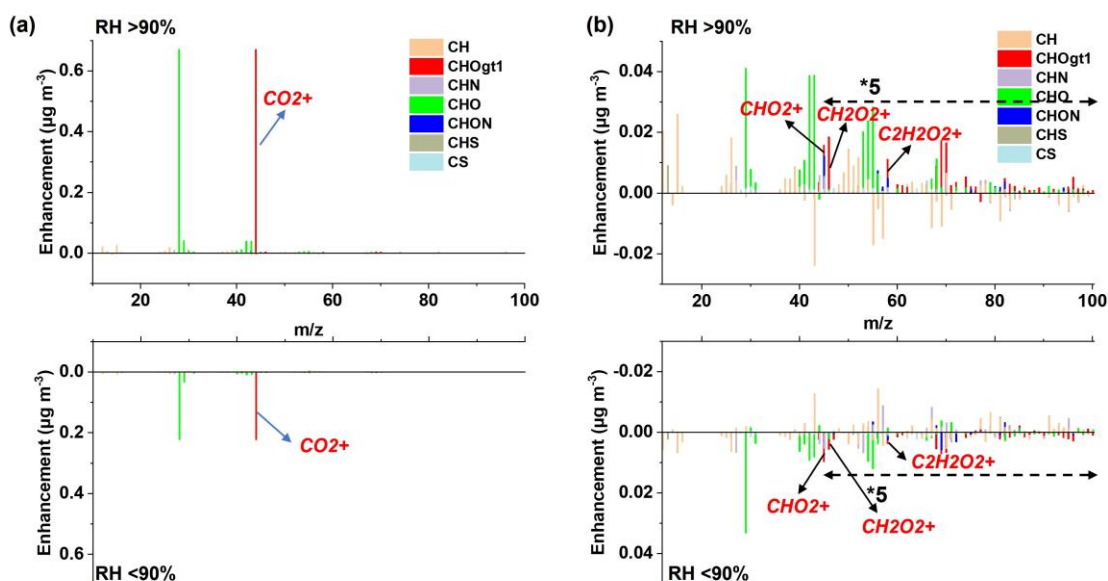


Figure S11. Mass spectra of SOA enhancement detected by ACSM at an equivalent photochemical age of approximately 2.4 days at RH < 90% and RH > 90%. (a) Complete mass spectra and (b) expanded view after excluding the CO^+ and CO_2^+ fragments for clarity.

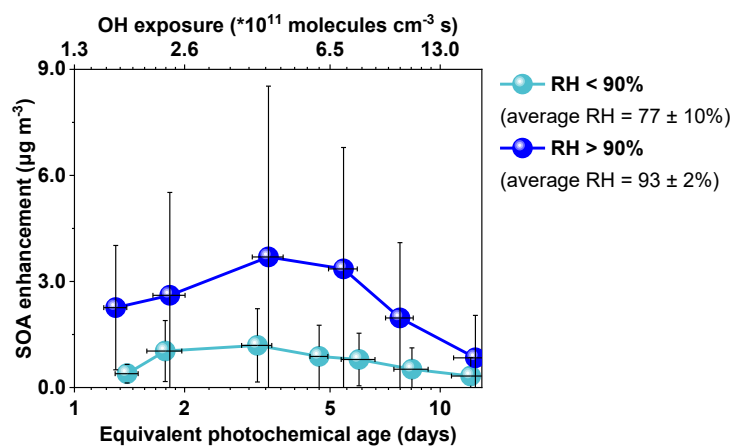


Figure S12. SOA enhancement from OH oxidation of coastal air at Tanxu Island under RH < 90% and RH > 90%

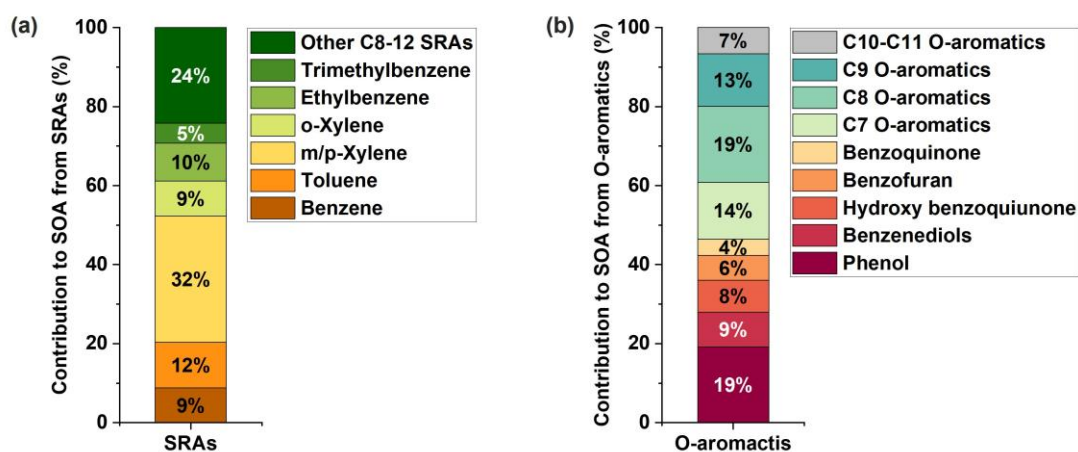


Figure S13. (a) Fractional contribution of specific aromatic hydrocarbons to the total SOA formed from SRAs, (b) fractional contribution of specific oxygenated aromatic compounds to the total SOA formed from O-aromatics

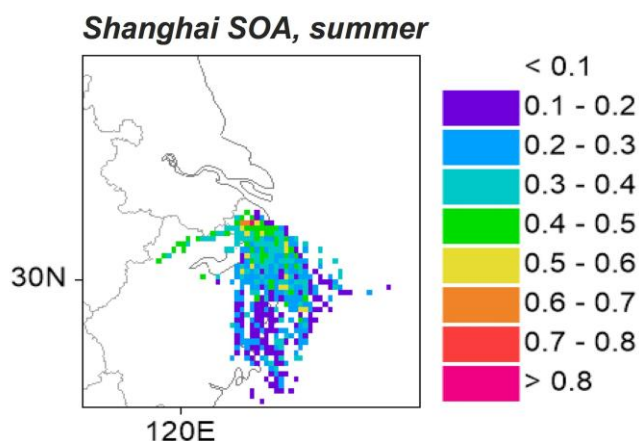


Figure S14. Weighted potential source contribution function analysis of SOA in summer urban Shanghai

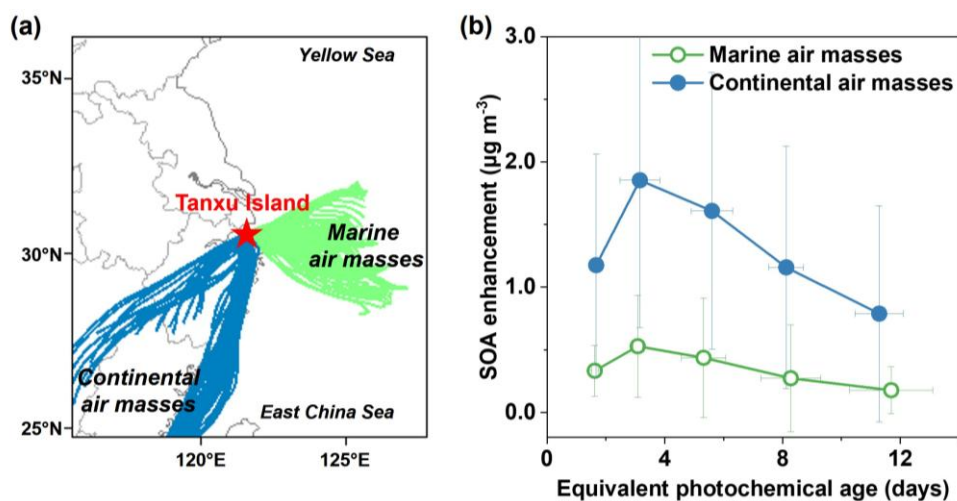


Figure S15. (a) Marine and continental air masses, and (b) comparison of SOA enhancement between marine and continental air masses. Only OFR experiments at $\text{RH} < 90\%$ were included.

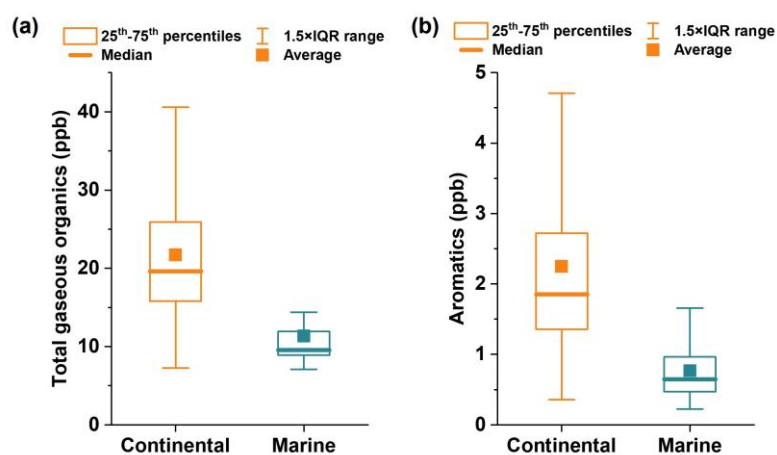


Figure S16. Comparison of (a) total gaseous organics and (b) aromatics (including SRAs, PAHs, and O-aromatics) between continental and marine air masses. Boxes represent the 25th-75th percentiles, horizontal lines indicate medians, squares indicate means, and whiskers represent the $1.5 \times$ interquartile range.

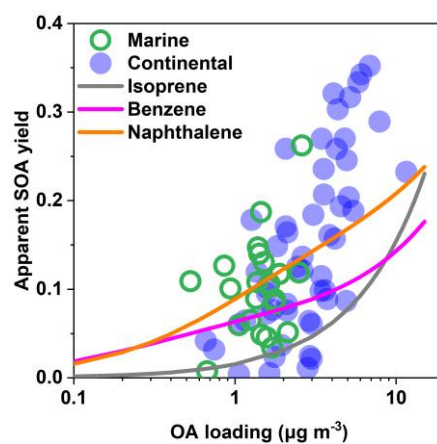


Figure S17. Apparent SOA yield of marine and continental air masses. Apparent SOA yields were defined as the ratio of SOA enhancement upon OFR oxidation to consumed concentrations of major precursors, including SRAs, PAHs, O-aromatics, furans, and terpenes. Only OFR experiments at $\text{RH} < 90\%$ were included.

301 **Table S1.** Yield parameterization for precursors estimated using the SOAP method (Derwent et al., 2010)

Species (proposed)	Molecule weight	Formula	Compound (proposed)	OH reaction rate constant ($10^{-12} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$)	SOAP
Alkenes	54.09	C ₄ H ₆	1,3-Butadiene	65.89	1.8000
Alkenes	56.11	C ₄ H ₈	1-Butene	31.07	1.2000
Alkanes	100.20	C ₇ H ₁₆	2,3-Dimethylpentane	3.00	0.4000
Alkanes	86.18	C ₆ H ₁₄	3-Methylpentane	5.20	0.2000
Alkenes	42.08	C ₃ H ₆	Propylene	26.02	1.6000
Alkenes	56.11	C ₄ H ₈	Trans-2-butene	63.17	4.0000
Alkenes	70.13	C ₅ H ₁₀	Trans-2-pentene	67.00	3.1000
Alkenes	56.11	C ₄ H ₈	Cis-2-butene	55.77	3.6000
Alkenes	70.13	C ₅ H ₁₀	Cis-2-pentene	65.00	3.1000
Alkynes	26.04	C ₂ H ₂	Acetylene	0.76	0.1000
Alkanes	30.07	C ₂ H ₆	Ethane	0.25	0.1000
Alkenes	28.05	C ₂ H ₄	Ethylene	8.15	1.3000
Alkanes	72.15	C ₅ H ₁₂	Isopentane	3.60	0.2000
Alkanes	58.12	C ₄ H ₁₀	n-Butane	2.38	0.3000
Alkanes	100.20	C ₇ H ₁₆	n-Heptane	6.81	0.1000
Alkanes	86.18	C ₆ H ₁₄	n-Hexane	5.25	0.1000
Alkanes	72.15	C ₅ H ₁₂	n-Pentane	3.84	0.3000
Aldehydes & Ketones	86.13	C ₅ H ₁₀ O	2-Pentanone	4.40	0.6000
Aldehydes & Ketones	58.08	C ₃ H ₆ O	Propanal	19.67	0.5000
Aldehydes & Ketones	58.08	C ₃ H ₆ O	Acetone	0.19	0.3000
Aldehydes & Ketones	72.11	C ₄ H ₈ O	Methyl ethyl ketone	1.20	0.6000
Aldehydes & Ketones	100.16	C ₆ H ₁₂ O	Methyl isobutyl ketone	12.73	0.6000
Aldehydes & Ketones	30.03	CH ₂ O	Formaldehyde	8.47	0.7000
Acids & Esters	46.01	CH ₂ O ₂	Formic acid	0.43	0.1000
Aldehydes & Ketones	44.03	C ₂ H ₄ O	Acetaldehyde	15.00	0.6000
Acids & Esters	60.03	C ₂ H ₄ O ₂	Acetic acid	3.68	0.1000
Acids & Esters	102.13	C ₅ H ₁₀ O ₂	propyl acetate	3.40	0.2000
Acids & Esters	74.08	C ₃ H ₆ O ₂	Methyl acetate	0.35	0.1000
Alcohols & Ethers	60.10	C ₃ H ₈ O	Isopropyl alcohol	5.09	0.4000

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Table S2. Yield parameterization for precursors estimated using two product model (Ng et al., 2007b; Eddingsaas et al., 2012; Han et al., 2016; Ng et al., 2007a; Xu et al., 2015; Song et al., 2007; Liu et al., 2016; Wyche et al., 2009)

Species (proposed)	Molecule weight	Formula	Compound (proposed)	OH reaction rate constant ($10^{-12} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$)	α_1	$K_{p,1}$	α_2	$K_{p,2}$
Terpenes	68.12	C ₅ H ₈	Isoprene	99.63	19.7110	0.0008	0.0000	0.0000
Terpenes	136.13	C ₁₀ H ₁₆	Monoterpenes	73.52	0.2619	0.0368	0.2614	0.0346
Terpenes	204.20	C ₁₅ H ₂₄	Sesquiterpenes	300.00	0.2619	0.0368	0.2614	0.0346
SRAs	120.19	C ₉ H ₁₂	1,2,3-Trimethylbenzene	32.70	0.1600	0.2500	0.0200	0.0100
SRAs	120.19	C ₉ H ₁₂	1,2,4-Trimethylbenzene	32.50	0.1600	0.2500	0.0200	0.0100
SRAs	120.19	C ₉ H ₁₂	1,3,5-Trimethylbenzene	56.70	0.1600	0.2500	0.0200	0.0100
SRAs	106.17	C ₈ H ₁₀	o-Xylene	13.60	0.1300	0.1300	0.0000	0.0300
SRAs	106.17	C ₈ H ₁₀	Ethylbenzene	7.00	0.1300	0.1300	0.0000	0.0300
SRAs	106.17	C ₈ H ₁₀	m/p-Xylene	18.70	0.1300	0.1300	0.0000	0.0300
SRAs	104.15	C ₈ H ₈	Styrene	58.00	0.1300	0.1300	0.0000	0.0300
SRAs	120.19	C ₉ H ₁₂	o-Ethyltoluene	11.90	0.1600	0.2500	0.0200	0.0100
SRAs	120.19	C ₉ H ₁₂	p-Ethyltoluene	11.80	0.1600	0.2500	0.0200	0.0100
SRAs	120.19	C ₉ H ₁₂	m-Ethyltoluene	18.60	0.1600	0.2500	0.0200	0.0100
SRAs	120.19	C ₉ H ₁₂	iso-Propylbenzene	6.30	0.1600	0.2500	0.0200	0.0100
SRAs	120.19	C ₉ H ₁₂	n-Propylbenzene	5.80	0.1600	0.2500	0.0200	0.0100
SRAs	78.11	C ₆ H ₆	Benzene	1.22	0.0720	3.3150	0.8880	0.0090
SRAs	92.14	C ₇ H ₈	Toluene	5.58	0.0580	0.4300	0.1130	0.0470
SRAs	118.18	C ₉ H ₁₀	C ₉ H ₁₀ aromatic compounds	10.80	0.1300	0.1300	0.0000	0.0300
SRAs	134.22	C ₁₀ H ₁₄	C ₁₀ H ₁₄ aromatic compounds	12.00	0.1300	0.1300	0.0000	0.0300
SRAs	132.20	C ₁₀ H ₁₂	C ₁₀ H ₁₂ aromatic compounds	12.00	0.1300	0.1300	0.0000	0.0300
SRAs	148.25	C ₁₁ H ₁₆	C ₁₁ H ₁₆ aromatic compounds	13.20	0.1300	0.1300	0.0000	0.0300
SRAs	146.23	C ₁₁ H ₁₄	C ₁₁ H ₁₄ aromatic compounds	13.20	0.1300	0.1300	0.0000	0.0300
SRAs	162.27	C ₁₂ H ₁₈	C ₁₂ H ₁₈ aromatic compounds	14.40	0.1300	0.1300	0.0000	0.0300
SRAs	160.26	C ₁₂ H ₁₆	C ₁₂ H ₁₆ aromatic compounds	14.40	0.1300	0.1300	0.0000	0.0300
SRAs	102.14	C ₈ H ₆	Phenylacetylene	9.60	0.1300	0.1300	0.0000	0.0300

Table S3. Yield parameterization for precursors estimated using the VBS model (Sasidharan et al., 2023; Stefenelli et al., 2019; Ma et al., 2017)

Species (proposed)	Molecule weight	Formula	Compound (proposed)	OH reaction rate constant ($10^{-12} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$)	α_1	α_{10}	α_{100}	α_{1000}
Alkanes	114.23	C8H18	2,2,4-Trimethylpentane	3.38	0.0000	0.1500	0.0000	0.0000
Alkanes	114.23	C8H18	2,3,4-Trimethylpentane	6.60	0.0000	0.1500	0.0000	0.0000
Alkanes	114.23	C8H18	2-Methylheptane	8.31	0.0000	0.1500	0.0000	0.0000
Alkanes	114.23	C8H18	3-Methylheptane	8.59	0.0000	0.1500	0.0000	0.0000
Alkanes	114.23	C8H18	C8Alkanes	8.16	0.0000	0.1500	0.0000	0.0000
Alkanes	128.26	C9H20	C9Alkanes	9.75	0.0000	0.1500	0.0000	0.0000
Alkanes	142.28	C10H22	n-decane	11.03	0.0000	0.1500	0.0000	0.0000
PAHs	156.10	C12H12	diMetNap	60.00	0.1650	0.0050	0.5160	0.8810
PAHs	142.09	C11H10	Methylnaphthalene	50.00	0.1650	0.0050	0.5160	0.8810
PAHs	128.07	C10H8	naphthalene	23.00	0.1650	0.0050	0.5160	0.8810
PAHs	144.21	C11H12	4-Methyl-1,2-dihydronaphthalene	13.20	0.1650	0.0050	0.5160	0.8810
PAHs	202.09	C16H10	Pyrene, Fluoranthene	39.61	0.1650	0.0050	0.5160	0.8810
PAHs	154.09	C12H10	Acenaphthene	66.86	0.1650	0.0050	0.5160	0.8810
PAHs	152.07	C12H8	Acenaphthalene	15.05	0.1650	0.0050	0.5160	0.8810
PAHs	130.09	C10H10	DihydroNaphth	28.50	0.1650	0.0050	0.5160	0.8810
PAHs	178.09	C14H10	Phenanthrene, anthracene (PA_Ant)	26.50	0.1650	0.0050	0.5160	0.8810
PAHs	166.09	C13H10	Fluorene	8.85	0.1650	0.0050	0.5160	0.8810
PAHs	116.16	C9H8	Indene	10.80	0.1650	0.0050	0.5160	0.8810
O-aromatics	122.08	C8H10O	C2 phenols	46.64	0.1513	0.1592	0.0001	0.0000
O-aromatics	150.08	C9H10O2	C9aroAcid	100.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	110.04	C6H6O2	Benzenediols	80.08	0.1513	0.1592	0.0001	0.0000
O-aromatics	94.05	C6H6O	Phenol	28.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	106.05	C7H6O	Benzaldehyde	12.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	122.04	C7H6O2	benzoic acid	38.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	108.03	C6H4O2	Benzoquinone	4.60	0.1513	0.1592	0.0001	0.0000
O-aromatics	138.08	C8H10O2	Tyrosol	100.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	152.09	C9H12O2	Propylbendiol	201.80	0.1513	0.1592	0.0001	0.0000
O-aromatics	164.09	C10H12O2	Eugenol	100.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	134.08	C9H10O	Dimetbenzaldehyde	4.50	0.1513	0.1592	0.0001	0.0000
O-aromatics	154.07	C8H10O3	Syringol	100.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	136.06	C8H8O2	ToluicAcid	12.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	108.06	C7H8O	Cresols	26.20	0.1513	0.1592	0.0001	0.0000
O-aromatics	148.06	C9H8O2	MetBendialdehyde	35.20	0.1513	0.1592	0.0001	0.0000
O-aromatics	148.10	C10H12O	Methyl chavicol	50.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	162.04	C9H6O3	MetphthalicAnhydride	2.09	0.1513	0.1592	0.0001	0.0000
O-aromatics	160.06	C10H8O2	formylcinnamaldehyde	200.28	0.1513	0.1592	0.0001	0.0000
O-aromatics	174.08	C11H10O2	Methoxynaphthol	200.97	0.1513	0.1592	0.0001	0.0000
O-aromatics	120.15	C8H8O	Tolualdehyde	16.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	166.13	C8H6O4	PhthalicAcid	9.60	0.1513	0.1592	0.0001	0.0000
O-aromatics	148.12	C8H4O3	Phthalic anhydride	0.75	0.1513	0.1592	0.0001	0.0000
O-aromatics	158.16	C10H6O2	Naphthoquinone	3.01	0.1513	0.1592	0.0001	0.0000
O-aromatics	144.06	C10H8O	Naphthalenol	37.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	124.02	C6H4O3	Hydroxy benzoquinone	4.60	0.1513	0.1592	0.0001	0.0000
O-aromatics	132.06	C9H8O	Cinnamaldehyde	37.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	136.10	C9H12O	Trimethylphenol	131.29	0.1513	0.1592	0.0001	0.0000
O-aromatics	140.05	C7H8O3	Trihydroxytoluene	200.56	0.1513	0.1592	0.0001	0.0000
O-aromatics	152.05	C8H8O3	Vanillin; hydrophenylAA	85.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	180.00	C9H8O4	C9Acid ester	51.63	0.1513	0.1592	0.0001	0.0000
O-aromatics	118.05	C8H6O	BenzoFuran	37.00	0.1513	0.1592	0.0001	0.0000
O-aromatics	146.08	C10H10O	diMetbenzofuran	37.00	0.1513	0.1592	0.0001	0.0000
Furans	72.11	C4H8O	Tetrahydrofuran	16.10	0.0350	0.0050	0.2760	0.0000
Furans	112.08	C5H4O3	Hydroxyfurfural, Metfuranedione	34.08	0.0350	0.0050	0.2760	0.0000
Furans	124.10	C8H12O	Butylfuran	104.51	0.0350	0.0050	0.2760	0.0000
Furans	96.06	C6H8O	Dimethylfuran	132.00	0.0350	0.0050	0.2760	0.0000
Furans	112.06	C6H8O2	DiMetfuranone	57.00	0.0350	0.0050	0.2760	0.0000
Furans	84.06	C5H8O	Dihydromethylfuran; cyclopentanone	11.49	0.0350	0.0050	0.2760	0.0000
Furans	68.03	C4H4O	Furan	40.00	0.0350	0.0050	0.2760	0.0000
Furans	98.04	C5H6O2	Furfuryl alcohol, PentynoicAcid	13.60	0.0350	0.0050	0.2760	0.0000
Furans	96.03	C5H4O2	Furfural	35.55	0.0350	0.0050	0.2760	0.0000
Furans	82.05	C5H6O	Methyl furan	37.09	0.0350	0.0050	0.2760	0.0000
Furans	128.05	C6H8O3	Furaneol	132.00	0.0350	0.0050	0.2760	0.0000
Furans	126.04	C6H6O3	5-Hydroxymethylfurfural	100.00	0.0350	0.0050	0.2760	0.0000
Furans	110.08	C7H10O	TriMetfuran	23.26	0.0350	0.0050	0.2760	0.0000

Table S4. Sampling periods, instruments, concentrations of non-refractory aerosol components, and SOA fraction in OA at different sites during the warm season (Chevassus et al., 2025; Florou et al., 2024; Han et al., 2025; Tian et al., 2025; Lin et al., 2019; Shan et al., 2026; Zhang et al., 2025; Li et al., 2023; Atabakhsh et al., 2023; Zhang et al., 2020; Nah et al., 2018; Yin et al., 2023). Values not explicitly reported in the original studies are left blank.

Sampling site	Site type	Sampling period	Instrument	OA ($\mu\text{g m}^{-3}$)	Sulfate ($\mu\text{g m}^{-3}$)	Nitrate ($\mu\text{g m}^{-3}$)	Ammonium ($\mu\text{g m}^{-3}$)	Chloride ($\mu\text{g m}^{-3}$)	SOA fraction (%)
Mace Head, Ireland	Marine	August 2015	AMS	0.38	0.37	0.02	0.07	0.00	49
Finokalia, Greece	Coastal	May-June 2016	AMS	1.52	1.94	0.10	0.62	0.02	86
Tanxu Island, China	Coastal	April-July 2024	ACSM	3.10	0.90	1.10	0.50	0.03	75
Chongming Island, China	Coastal	June-August 2020	ACSM	4.90	3.50	1.90	1.40	0.07	78
Scripps Pier, USA	Coastal	July-September 2023	ACSM	2.44	1.39	0.18	0.62	0.04	
Galway, Ireland	Coastal	June 2016	ACSM	1.46	0.68	0.27	0.30	0.00	84
Shanghai, China	Urban	May-June 2017	AMS	6.60	4.20	3.30	1.90	0.10	64
Nanjing, China	Urban	July-September 2022	AMS	10.39	2.38	1.04	1.12	0.09	59.2
Hangzhou, China	Urban	August-October 2023	ACSM	9.14	4.15	3.03	1.36	0.00	58
Beijing, China	Urban	June-August 2022	AMS	8.60	4.00	3.60	2.70	0.04	86
Melpitz, Germany	Rural/agricultural	June-August 2017	ACSM	4.84	1.67	2.16	1.11	0.00	70
Pinnacle State Park, USA	Rural/agricultural	September 2017	AMS	4.26	0.78	0.11	0.39	0.06	
Yorkville, USA	Rural/agricultural	August 2016	AMS	5.00	1.60	0.20	0.40	0.00	

Table S5. Sampling periods, instruments, and concentrations of gaseous organic components among different sites during the warm season (Tian et al., 2025; Liu et al., 2019; Liu et al., 2020b; Zhang et al., 2021; Sun et al., 2024; Qian et al., 2025). Values not explicitly reported in the original studies are left blank.

Sampling site	Site type	Sampling period	Instrument	Alkanes (ppb)	Alkenes (ppb)	Alkynes (ppb)	Aromatic hydrocarbo	OVOCs (ppb)	Others (ppb)
China Tanxu Island	Coastal	April-July 2024	GC-MS/FID and PTR-ToF MS	5.5	1.7	0.4	1.3	6.8	1.1
China Chongming Island	Coastal	June-August 2020	GC-MS/FID	4.8	2.5	0.3	1.5		
China Haiyan	Coastal	October 2020	GC-MS/FID	8.2	3.3	0.8	2.0	6.6	0.5
China Shanghai	Urban	May 2017	GC-MS/FID	15.1	2.4	1.2	5.1	13.5	
China Hangzhou	Urban	June to October 2023	GC-MS/FID and PTR-ToF MS	14.4	1.7		6.0		2.2
China Beijing	Urban	July 2016	GC-MS/FID	12.7	2.8	1.8	2.4	7.5	0.3
China Guangzhou	Urban	July to August 2016	GC-MS/FID	21.8	4.2	1.7	7.0		
China Hong Kong Coastal Water	Over coastal water	August 2020 to July 2021	GC-MSD/ECD/FID	8.9	1.2	1.1	1.9		0.1

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