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Effects of SO_2 on optical properties of secondary organic aerosol generated from photooxidation of toluene under different relative humidity

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S1. Calculation of mass absorption cross section

Mass absorption cross section (MAC, square meters per gram), is a convenient proxy for the relationship between radiative transfer and mass (Bond and Bergstrom, 2006). For small particles (e.g., particles smaller than 200nm), MAC is defined as

$$\mathrm{MAC} = \frac{6\pi}{\rho\lambda}\mathrm{Im}[\frac{m^2-1}{m^2+2}] \quad (1)$$

where ρ is the density of the particles, and m is complex refractive index (Bohren and Huffman, 1983).

S2. Calculation of simple forcing efficiency

Simple forcing efficiency (SFE) parameterization proposed by Bond and Bergstrom are used for investigating the direct radiative forcing at the Earth's surface (Chýlek et al., 1995;Bond and Bergstrom, 2006)

$$\mathrm{SFE} = \frac{S_0}{4}\tau_{atm}^2(1-F_c)[2(1-a_s)^2\frac{Q_{bs}\cdot C}{M} - 4a_s\frac{Q_a\cdot C}{M}] \quad (2)$$

where SFE is in units of watts per gram, S_0 is the solar irradiance (1370W/m^2), τ_{atm} is the atmospheric albedo (0.79), Fc is the cloud fraction (approximately 0.6), a_s is the surface albedo (average 0.19), M is aerosol mass, C is the cross section, Q_{bs} and Q_a are the aerosol backscattering efficiency and the absorption efficiency, respectively. On the basis that SOA are spherical, the SFE could simplified to equation (6):

$$\begin{aligned}\mathrm{SFE} &= \frac{S_0}{4}\tau_{atm}^2(1-F_c)\left[2(1-a_s)^2\frac{Q_{bs}\cdot\frac{1}{4}\pi D^2}{\rho\cdot\frac{1}{6}\pi D^3} - 4a_s\frac{Q_a\cdot\frac{1}{4}\pi D^2}{\rho\cdot\frac{1}{6}\pi D^3}\right] \\ &= \frac{S_0}{4}\tau_{atm}^2(1-F_c)\frac{3}{2\rho D}[2(1-a_s)^2Q_{bs} - 4a_sQ_a]\end{aligned} \quad (3)$$

At 532 nm, the SOA generated by toluene in all conditions showed no absorption, so Q_a could be set to zero and the ratio of SFE could be simplified to equation (7)

$$\mathrm{SFE} = \frac{3S_0}{4}\tau_{atm}^2(1-F_c)\frac{1}{\rho D}(1-a_s)^2Q_{bs} \quad (4)$$

Table S1. Identified MS peaks, molecular weight, formula and calculated RIs of main products of toluene-derived SOA in positive mode.

Molecular formula	M + H	M + Na	D	DS	W	WS	Calculated RI
$C_3H_9NO_3$	107.97	130.16		√			1.3727
$C_4H_{10}O_6$		113.10		√			1.3595
$C_4H_9NO_2$		126.05	√	√		√	1.4013
$C_4H_8O_5$	137.06		√				1.4073
$C_4H_8O_4$		142.94	√				1.4070
$C_5H_8O_5$	149.02	170.96	√	√	√	√	1.4413
$C_4H_6O_5$		157.08	√	√		√	1.4238
$C_7H_{15}NO_3$	162.04		√				1.4072
$C_5H_8O_6$	164.92		√	√	√	√	1.4451
$C_7H_9NO_4$	172.09				√	√	1.5110
$C_7H_{17}NO_6$		174.95		√		√	1.3787
$C_7H_{14}O_6$	195.12		√	√	√	√	1.4091
$C_6H_{15}NO_6$	198.11			√			1.3776
$C_9H_{14}O_5$	203.05					√	1.4793
$C_{11}H_{24}O_3$	205.07			√		√	1.3874
$C_9H_{14}O_5$	206.97					√	1.4715
$C_7H_{15}NO_6$	210.11		√	√	√		1.4112
$C_7H_{16}O_7$	212.15			√			1.3800
$C_{11}H_{22}O_4$	218.92		√				1.4173
$C_7H_{15}NO_7$	226.14		√				1.4124
$C_{11}H_{23}NO_4$	234.20	256.56	√	√	√	√	1.4190
$C_{14}H_{28}O_4$	261.23		√				1.4265
$C_{13}H_{27}NO_4$	262.23		√	√	√	√	1.4275
$C_9H_{20}O_9$	273.16		√	√			1.3894
$C_{13}H_{27}NO_5$	278.24		√	√	√	√	1.4268
$C_{13}H_{26}O_6$	279.16		√	√		√	1.4247
$C_{13}H_{29}NO_5$	280.26		√	√			1.3945
$C_{12}H_{27}NO_6$	282.27		√	√	√	√	1.3950
$C_{15}H_{31}NO_7$	290.27		√	√	√	√	1.4268
$C_{10}H_{20}O_{10}$	301.14		√	√	√	√	1.4204
$C_9H_{19}NO_{10}$	302.24		√	√	√		1.4231
$C_8H_{17}NO_{11}$	304.26		√	√	√	√	1.4293
$C_9H_{20}O_{11}$	305.25			√			1.3893
$C_{10}H_{18}O_{11}$	315.16					√	1.4529
$C_{14}H_{27}NO_7$	318.24				√		1.5227
$C_9H_{21}NO_{11}$	320.25		√	√	√	√	1.3934
$C_{16}H_{27}NO_7$	346.33				√		1.5258
$C_{11}H_{22}O_{12}$	347.22		√	√	√	√	1.4266
$C_{16}H_{33}NO_7$	352.24		√				1.4303

$C_{12}H_{25}NO_{11}$	360.31		√				1.4268
$C_{16}H_{28}O_9$	365.11					√	1.4947
$C_{14}H_{31}NO_{10}$	374.36		√	√	√		1.3991
$C_{18}H_{32}O_{10}$	409.29					√	1.4974
$C_{15}H_{30}O_{13}$	419.31	441.30	√				1.4330
$C_{22}H_{46}O_9$	455.31			√			1.4085
$C_{17}H_{35}NO_{13}$	462.14		√	√		√	1.4366
$C_{15}H_{30}O_{16}$	467.10		√	√	√	√	1.4335
$C_{20}H_{42}O_{12}$	475.38			√			1.4066
$C_{23}H_{40}O_{12}$	509.25				√		1.5374
$C_{25}H_{47}NO_{10}$	522.60					√	1.5081
$C_{20}H_{41}NO_{15}$	536.16		√	√	√	√	1.4405
$C_{18}H_{36}O_{18}$	541.12		√	√	√		1.4380
$C_{27}H_{51}NO_{10}$	550.70					√	1.5109
$C_{22}H_{38}O_{16}$	559.50				√		1.5382
$C_{24}H_{50}O_{14}$	563.53		√	√	√		1.4127
$C_{26}H_{46}O_{14}$	583.51				√		1.5423
$C_{21}H_{44}O_{18}$	585.53		√	√	√		1.4110
$C_{24}H_{51}NO_{16}$	610.18		√	√	√		1.4147
$C_{26}H_{46}O_{16}$	615.15				√		1.5432
$C_{29}H_{52}O_{15}$	641.60				√		1.5465
$C_{28}H_{51}NO_{15}$	642.60				√		1.5461

Table S2. Identified MS peaks, molecular weight, formula and calculated RIs of main products of toluene-derived SOA in negative mode.

Molecular formula	M - H	D	DS	W	WS	Calculated RI
$C_9H_{14}O_6$	217.04				√	1.4762
$C_{12}H_{16}O_4$	223.02			√		1.5459
$C_6H_{12}O_9$	227.21	√		√		1.4100
$C_{12}H_{26}O_4$	233.14		√			1.3918
$C_{10}H_{23}NO_5$	236.10		√		√	1.3908
$C_9H_{20}O_7$	238.88	√	√			1.3872
$C_7H_{14}O_9$	241.23	√				1.4173
$C_7H_{16}O_9$	243.13	√		√		1.3884
$C_{11}H_{25}NO_5$	250.13		√		√	1.3888
$C_9H_{18}O_8$	253.23	√				1.4166
$C_9H_{21}NO_7$	254.24		√			1.3911
$C_8H_{16}O_9$	255.22	√	√	√	√	1.4152
$C_{12}H_{22}O_6$	260.88	√		√	√	1.4523
$C_{11}H_{22}O_7$	265.13	√	√	√	√	1.4245
$C_9H_{18}O_9$	269.26	√				1.4175
$C_{14}H_{24}O_5$	271.09				√	1.4904
$C_{15}H_{30}O_4$	273.04	√				1.4264
$C_{13}H_{29}NO_5$	278.26	√	√	√	√	1.3945
$C_{10}H_{16}O_9$	279.04				√	1.4875
$C_{12}H_{27}NO_6$	280.25		√		√	1.3950
$C_{10}H_{20}O_9$	283.25	√	√	√	√	1.4196
$C_7H_{17}NO_{11}$	290.12		√		√	1.3925
$C_{15}H_{32}O_5$	291.14		√			1.3950
$C_{13}H_{26}O_7$	293.16	√	√	√	√	1.4267
$C_{11}H_{22}O_9$	297.14	√	√		√	1.4261
$C_{15}H_{26}O_6$	301.04				√	1.4918
$C_{13}H_{26}O_8$	309.18	√	√	√	√	1.4274
$C_{12}H_{24}O_9$	311.15	√	√	√	√	1.4235
$C_{15}H_{26}O_7$	317.06				√	1.4926
$C_{11}H_{16}O_{11}$	323.23			√		1.5230
$C_{13}H_{27}NO_8$	324.24	√	√	√	√	1.4256
$C_{13}H_{26}O_9$	325.17	√	√	√		1.4282
$C_{16}H_{28}O_7$	331.06				√	1.4941
$C_{15}H_{31}NO_7$	336.31	√	√	√		1.4287
$C_{16}H_{34}O_7$	337.19		√			1.3997
$C_{15}H_{32}O_8$	339.18	√	√	√	√	1.3984
$C_{11}H_{18}O_{12}$	341.09				√	1.4878
$C_{11}H_{22}O_{12}$	345.12	√		√		1.4266
$C_{11}H_{25}NO_{11}$	346.02		√			1.3972

$C_{16}H_{34}O_8$	353.18		√			1.4004
$C_{16}H_{32}O_9$	367.37	√				1.4318
$C_{17}H_{30}O_9$	377.06				√	1.4961
$C_{16}H_{28}O_{10}$	379.06				√	1.4954
$C_{18}H_{38}O_8$	381.21		√			1.4032
$C_{19}H_{32}O_8$	387.10			√	√	1.5313
$C_{18}H_{38}O_9$	397.20		√			1.4042
$C_{15}H_{31}NO_{11}$	400.20	√		√		1.4327
$C_{14}H_{28}O_{13}$	402.82	√		√	√	1.4295
$C_{17}H_{30}O_{11}$	409.08				√	1.4974
$C_{19}H_{41}NO_8$	410.16		√		√	1.4049
$C_{14}H_{24}O_{14}$	415.02				√	1.4945
$C_{17}H_{29}NO_{11}$	422.18			√		1.5313
$C_{15}H_{26}O_{14}$	429.03				√	1.4965
$C_{21}H_{44}O_9$	439.06				√	1.4072
$C_{23}H_{40}O_9$	459.28			√		1.5364
$C_{23}H_{42}O_9$	461.04				√	1.5036
$C_{19}H_{32}O_{13}$	467.04			√		1.5334
$C_{23}H_{46}O_{10}$	481.30	√	√	√	√	1.4422
$C_{20}H_{36}O_{13}$	483.04				√	1.5032
$C_{23}H_{49}NO_{11}$	514.36		√			1.4122
$C_{23}H_{40}O_{13}$	523.22			√		1.5380
$C_{24}H_{46}O_{12}$	525.24	√		√		1.4748
$C_{24}H_{50}O_{12}$	529.30		√		√	1.4120
$C_{22}H_{38}O_{15}$	541.05			√		1.5366
$C_{30}H_{59}NO_7$	544.71	√	√	√	√	1.4815
$C_{27}H_{50}O_{13}$	580.98				√	1.5126
$C_{27}H_{50}O_{14}$	597.21				√	1.5125

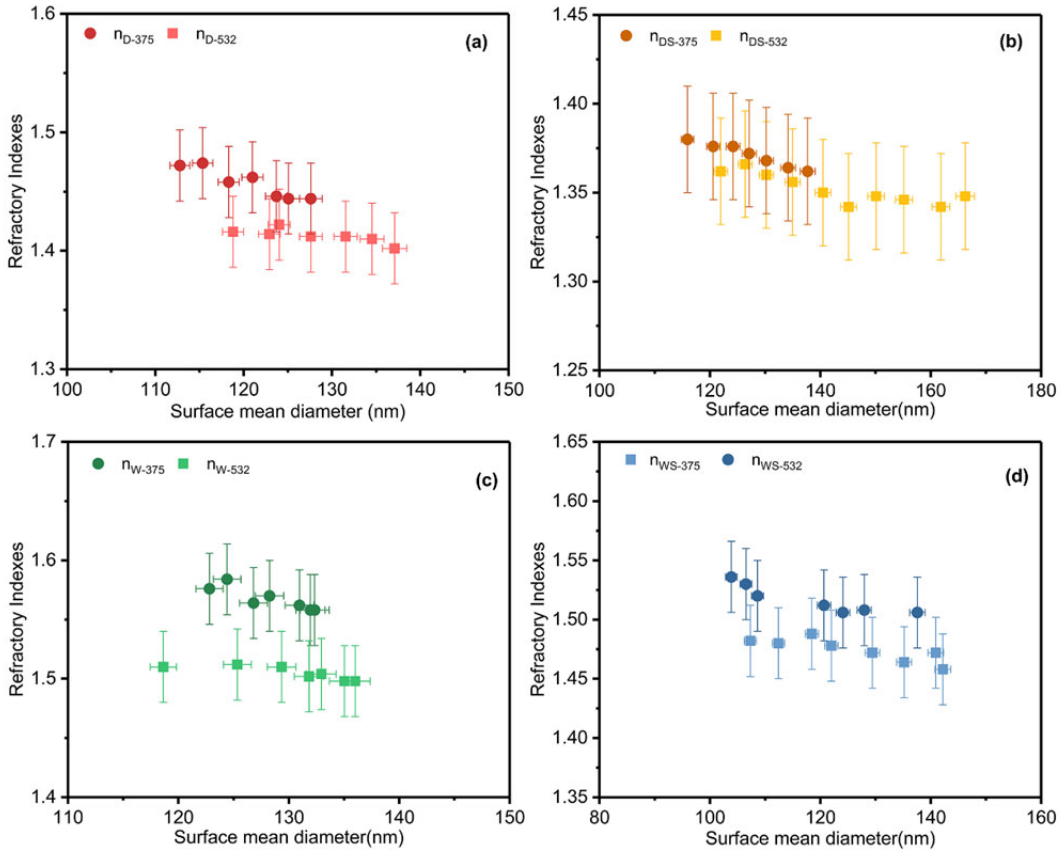

Figure S1. Variation tendency of the values of RI of SOAs with surface mean diameter increasing by four different conditions at (a) D1, (b) DS1, (c) W1, (d) WS1

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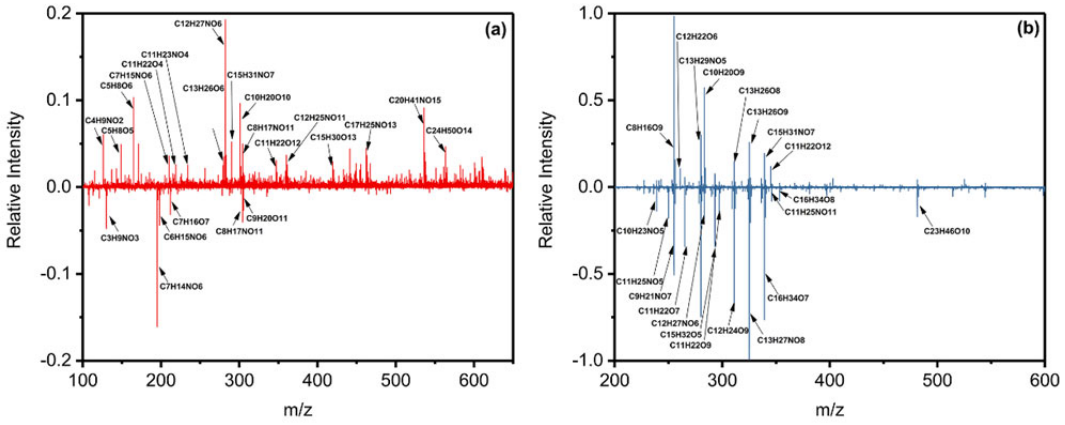

Figure S2. MS difference between condition D and DS in (a) positive, (b) negative mode. The Y axis is the subtraction of relative intensity (indicated by the peak intensity relative to the strongest peak intensity) between condition D and DS. Products whose relative intensities above zero are in a higher concentration under condition D while those below zero are on the contrary.

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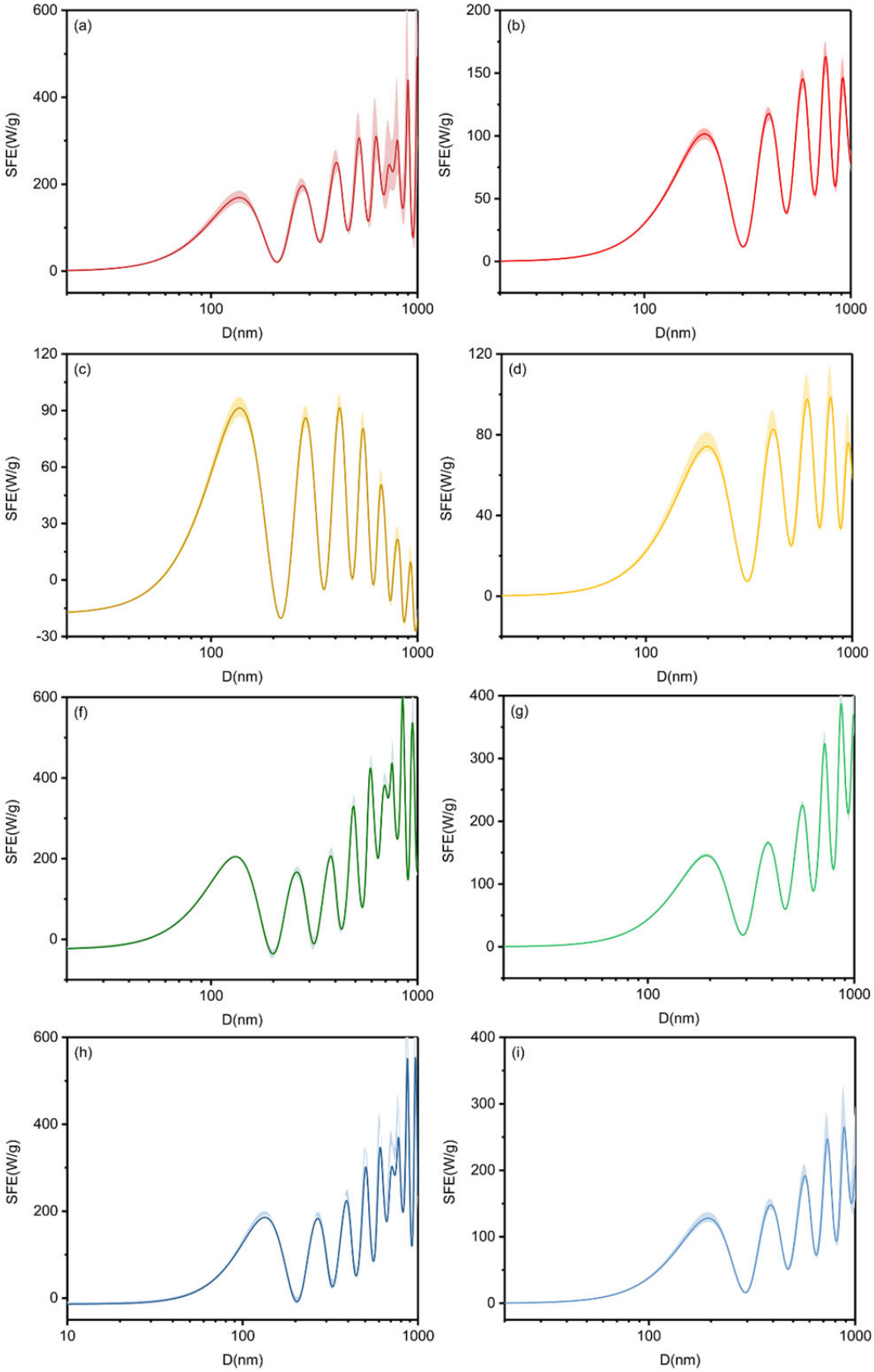

Figure S3. The simple forcing efficiency (SFE) of toluene secondary organic aerosol derived under conditions (a) D at 375 nm (b) D at 532 nm, (c) DS at 375 nm, (d) DS at 532 nm, (e) W at 375 nm, (f) W at 532 nm, (g) WS at 375 nm, (h) WS at 532 nm. The lines are the average values, the shaded areas are uncertainties.