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Can semi-volatile organic aerosols lead to fewer cloud particles?

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Introduction

Atmospheric aerosols influence climate mainly via two pathways:

①aerosol–radiation interactions， which affect the Earth’s radiative energy balance by absorbing and scattering terrestrial and solar radiation.

②aerosol–cloud interactions， which affect cloud microphysics by activating and serving as seeds for cloud formation.

Introduction

- •MATRIX : Multiconfiguration Aerosol TRacker of mixing state
- •VBS : volatility basis set
- •MATRIX-VBX:The impact of condensing organic aerosols on activated cloud number concentration is examined in a new aerosol microphysics box model

MATRIX-VBS (Gao et al., 2017) is an aerosol microphysics model that includes organic aerosol volatility in its calculations.It was developed by implementing VBS (volatilitybasis set; Donahue et al., 2006) in the aerosol microphysicsmodel MATRIX (Bauer et al., 2008), which is a box model that is also used in the NASA GISS ModelE Earth system

Model.

Introduction

Semi-volatile organic aerosols contribute significantly to the growth of particles to CCN sizes (Yu, 2011). More notably, as aerosol size increases, the range of organic volatilities involved in aerosol growth increases.

As was the case for the original aerosol microphysics model MATRIX, our further-developed box model MATRIX-VBS (Gao et al., 2017) follows the same multimodal aerosol activation approach by Abdul-Razzak and Ghan (2000). The activation parameterization accounts for aerosol size distribution, composition, mixing state, and in-cloud updraft velocity.

Methods

1、Representation of the aerosol number and the chemical composition distribution with respect to size and calculation of the CNN spectrum.
2、Determination of the maximum supersaturation by a numerical solution of an algebraic equation and calculation of droplet number concentration from the supersaturation spectrum.

Model description

Sectional representation of size distribution

$$n^d(D_p) = \frac{dN}{dD_P} = \frac{N_m}{D_{p,m} - D_{p,m-1}}$$

$$F^d(D_p) = \int_0^{D_p} n^d(D_p) dD_p = \sum_{j=1}^{m-1} N_j + N_m(\frac{D_p - D_{p,m-1}}{D_{p,m} - D_{p,m-1}})$$

CCN spectrum

$$n^s(s) = \frac{dN}{ds} = \frac{N_i}{s_{c,j} - s_{c,j-1}}, s_{c,j-1} \leq s \leq s_{c,j}$$

$$F'(s) = \int_0^{D_p} n^s(s) ds = \sum_{j=1}^{i=1} N_j + N_i(\frac{s - s_{c,i-1}}{s_{c,i} - s_{c.i-1}})$$

Model description

Droplet number concentration estimation

Once the maximum parcel supersaturation, Smax , is know, the number of CCN that will active into drops, Nd, is given by

$$N_d = F^s(s_{max})$$

Simulations

Monte Carlo analysis

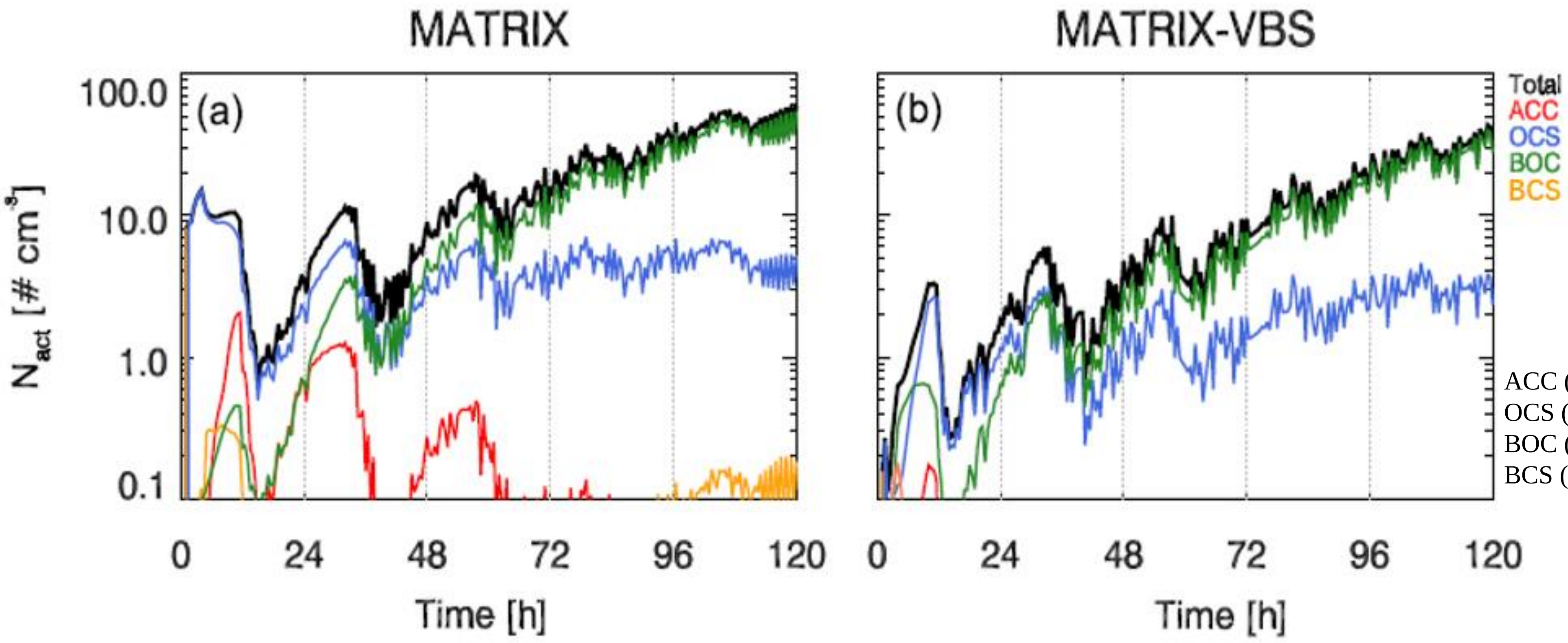
Table 2. Parameters used in the Monte Carlo simulations.

Parameter			Range
T (K)			270, 280, 290, 300, 310
RH (%)			0.1, 20, 40, 60, 80, 100
Latitude			0, 30° N/S, 60° N/S, 90° N/S
Updraft velocity ($m\,s^{-1}$)			0.5, 1, 2
Emissions of aerosols ($\mu g\,m^{-3}\,s^{-1}$)	Sulfate (SO_2 in molecules cm^{-3})		10^5, 10^6, 5×10^6
	Primary organics		5×10^{-6}, 5×10^{-5}, 5×10^{-4}
	Nonvolatile biogenic organics from terpene source		1×10^{-8}, 5×10^{-6}, 1×10^{-5}
	Black carbon		10^{-6}, 10^{-5}, 10^{-4}
Emissions of gases (molecules cm^{-3})	Volatile organic compounds (in sets)	Alkenes	5×10^2, 5×10^3, 5×10^4
		Paraffin	5×10^3, 10^4, 5×10^4
		Terpenes	10^4, 10^5, 10^6
		Isoprene	10^4, 10^5, 50^6
	NO_x		10^5, 10^6, 10^7

Simulations

- temperature,
- RH
- latitude
- emissions levels — clean / moderate / polluted
- updraft velocity

Results and discussion



ACC (SO4, NO3, NH4)
OCS (organic carbon, SO4,NO3, NH4)
BOC (black carbon, organic carbon, SO4, NO3,NH4)
BCS (black carbon, SO4, NO3, NH4)

Figure 1. Activated number concentration of aerosol populations (see main text for details) for MATRIX (a) and MATRIX-VBS (b) for 290K and 40% RH at 30°N latitude with medium emission levels and 0.5ms-1 updraft velocity.

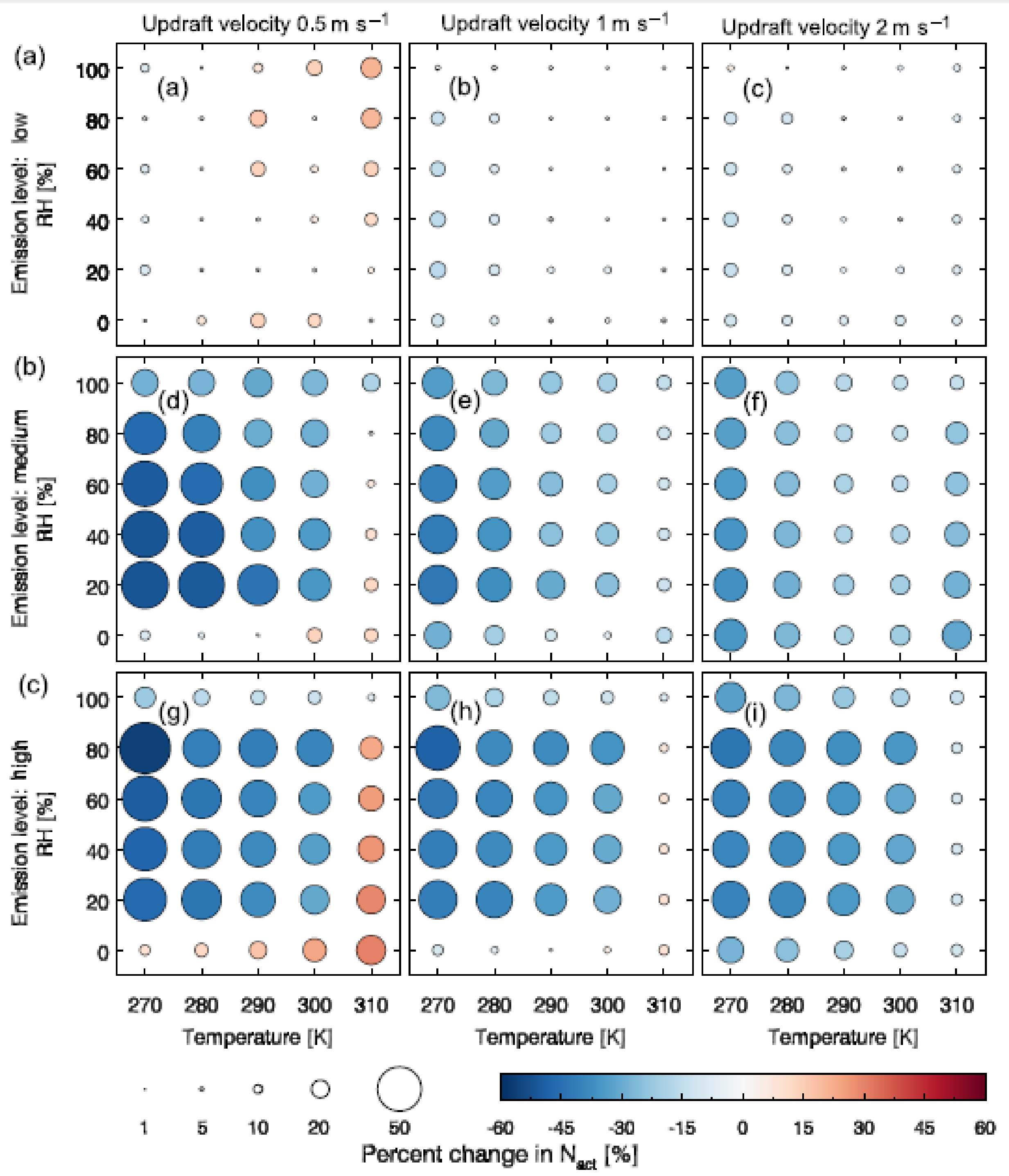


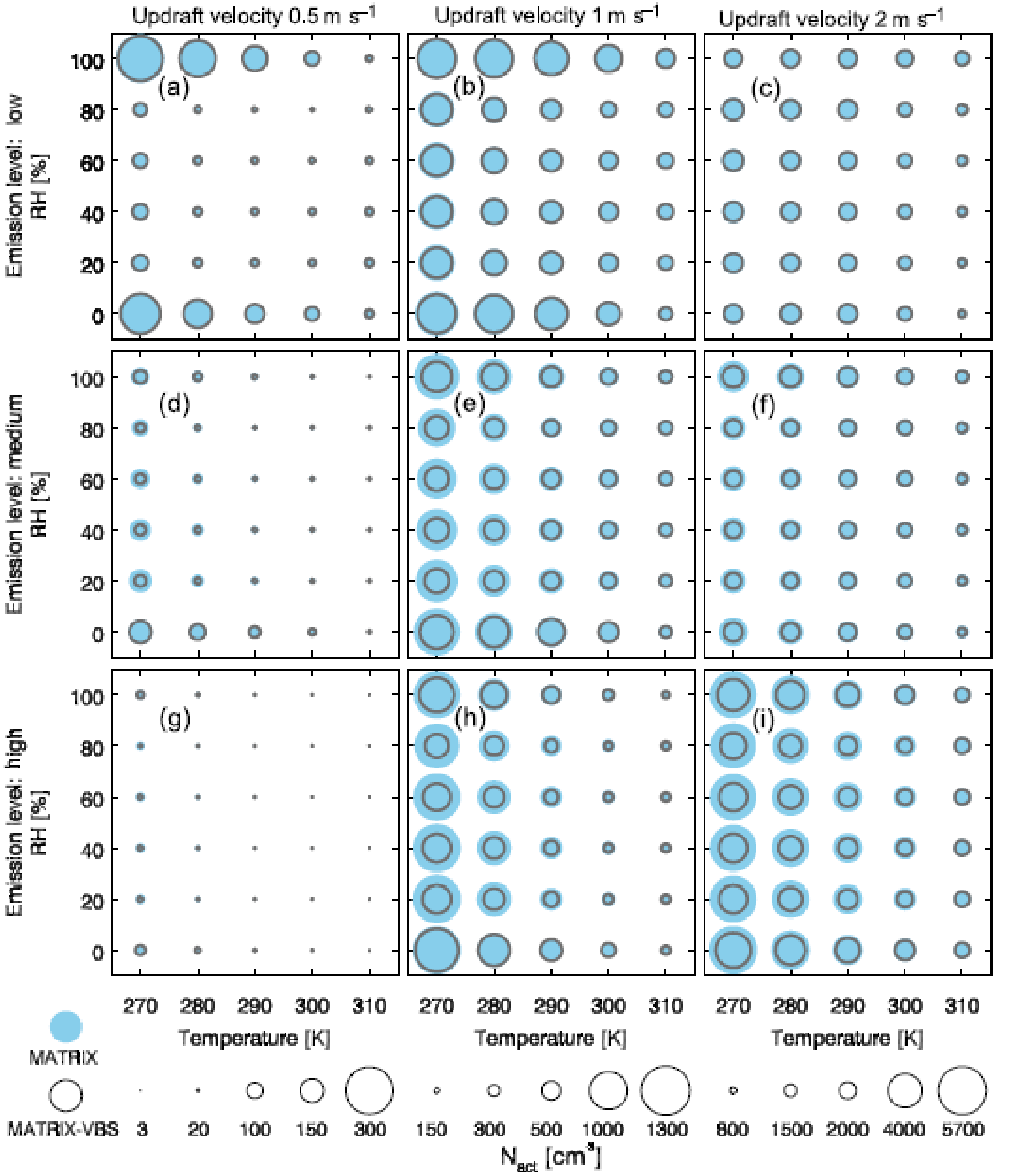
Figure 2 shows a more comprehensive look across all temperature and RH scenarios studied. The results show that for most scenarios, MATRIX-VBS has lower (blue circles) activated number concentration compared to MATRIX. However, some rare cases show the opposite behavior.

Results and discussion

Table 3. Minimum and maximum of fractional change in average activated number concentration over the last 24 h between the two models with low-, medium-, and high-level emissions at updraft velocities of 0.5, 1, and 2 $m s^{-1}$.

	Fractional change in activated number concentration					
Updraft velocity ($m s^{-1}$)	0.5		1		2	
	Min	Max	Min	Max	Min	Max
Low emission level	−9 %	+21 %	−16 %	+2 %	−14 %	+5 %
Medium emission level	−51 %	+14 %	−42 %	−5 %	−36 %	−13 %
High emission level	−56 %	+31 %	−48 %	+9 %	−43 %	−9 %

Across all scenarios, the changes in activated number concentration between MATRIX-VBS and MATRIX range from 56% to C31%



Also within most emission level–updraft velocity scenarios (Fig. 3, Table 4), as temperature increases, there are fewer activated particles in MATRIX.We also observed the same behavior in MATRIXVBS, higher temperature and fewer activated particles.

Results and discussion

Table 4. Minimum and maximum of average activated number concentration over the last 24 h of MATRIX and MATRIX-VBS with low-, medium-, and high-level emissions at updraft velocities of 0.5, 1, and 2 $m\,s^{-1}$.

		Activated number concentration					
Updraft velocity ($m\,s^{-1}$)		0.5		1		2	
		Min	Max	Min	Max	Min	Max
Low emission level	MATRIX	23	305	351	1160	963	2799
	MATRIX-VBS	24	283	338	1026	887	2473
Medium emission level	MATRIX	19	152	359	1233	1476	3711
	MATRIX-VBS	16	139	304	884	1021	2498
High emission level	MATRIX	3	60	199	1280	1925	5703
	MATRIX-VBS	3	63	185	1150	1677	4142

Results and discussion

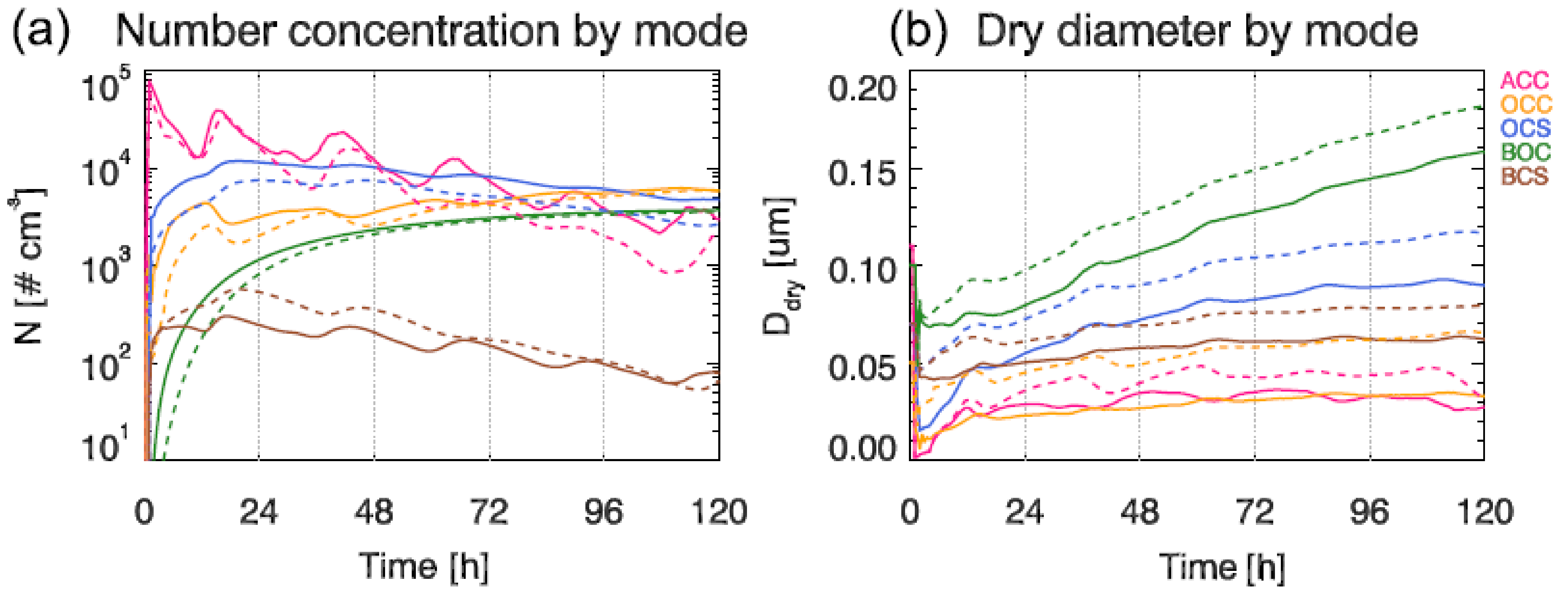


Figure 4. Number concentration (a) and dry particle diameter (b) by mode (color lines) for MATRIX (dashed lines) and MATRIX-VBS (solid lines) for the experiments with the same conditions as Fig. 1.

Conclusions

- Results show that by considering semi-volatile organics in MATRIX-VBS, there is a lower activated particle number concentration, except in cases with low cloud updrafts, in clean environments at above-freezing temperatures, and in polluted environments at high temperatures (310 K) and extremely low-humidity conditions.

- The MATRIX-VBS model considering semi-volatile organic compounds has a higher amount of aerosol, a smaller dry particle diameter, and a lower concentration of activated particles.

Conclusions

- our study is performed in a box model that does not resolve cloud droplet growth as the air mass rises and cools, which leads to additional condensation of organic vapors and water due to the temperature decline and contributes to cloud droplet growth due to additional water uptake.

Thanks for your attention!