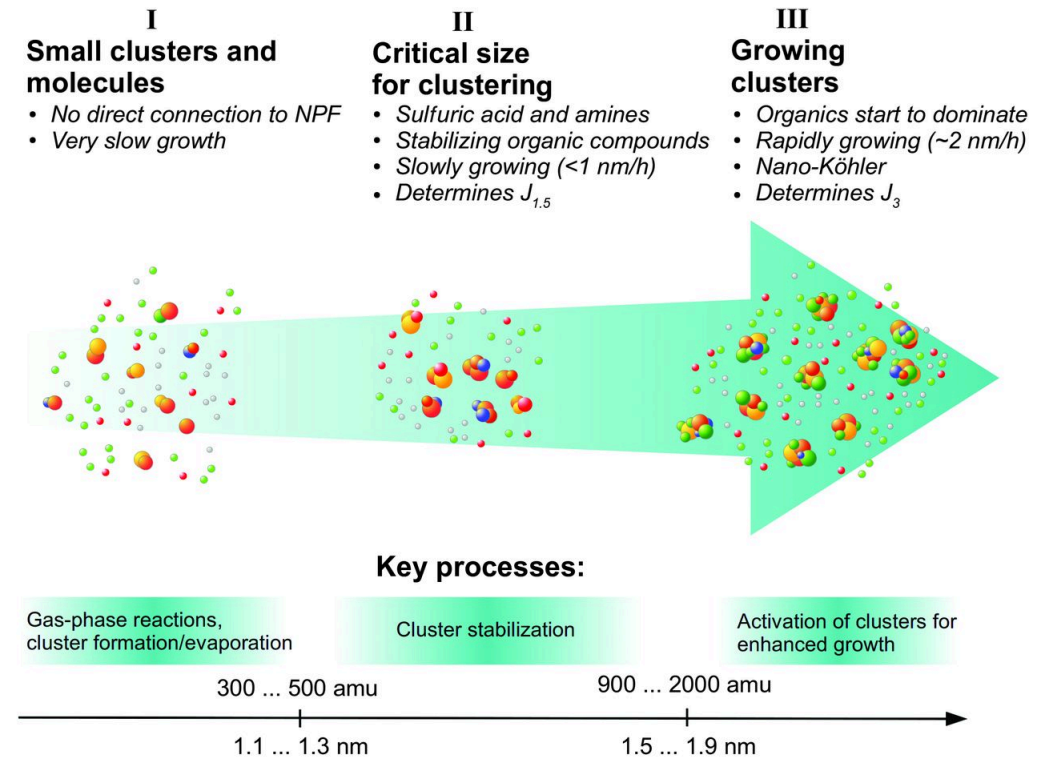# Improving the Representation of Ultra-fine Aerosols in the E3SM Atmosphere Model

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New particle formation (aerosol nucleation)

► New particle formation through gas-to-particle conversion

► Increases both aerosol mass and number

► Newly formed particles are hydrophilic, but not effectively scavenged

► Can grow into larger sizes and act as CCN - an important process for aerosol forcing

► More important at cloud-permitting scales (with much stronger updraft)

I
Small clusters and molecules
- *No direct connection to NPF*
- *Very slow growth*

II
Critical size for clustering
- *Sulfuric acid and amines*
- *Stabilizing organic compounds*
- *Slowly growing (<1 nm/h)*
- *Determines $J_{1.5}$*

III
Growing clusters
- *Organics start to dominate*
- *Rapidly growing (~2 nm/h)*
- *Nano-Köhler*
- *Determines J_3*

Key processes:

Gas-phase reactions, cluster formation/evaporation

Cluster stabilization

Activation of clusters for enhanced growth

300 ... 500 amu   900 ... 2000 amu

1.1 ... 1.3 nm   1.5 ... 1.9 nm

Kulmala et al (2013)

► Current MAM doesn't have a nucleation mode

► Nucleation is considered but newly-formed particles will immediately grow into Aitken mode particles.

► Nucleation processes in free troposphere and in near surface layer are considered separately.
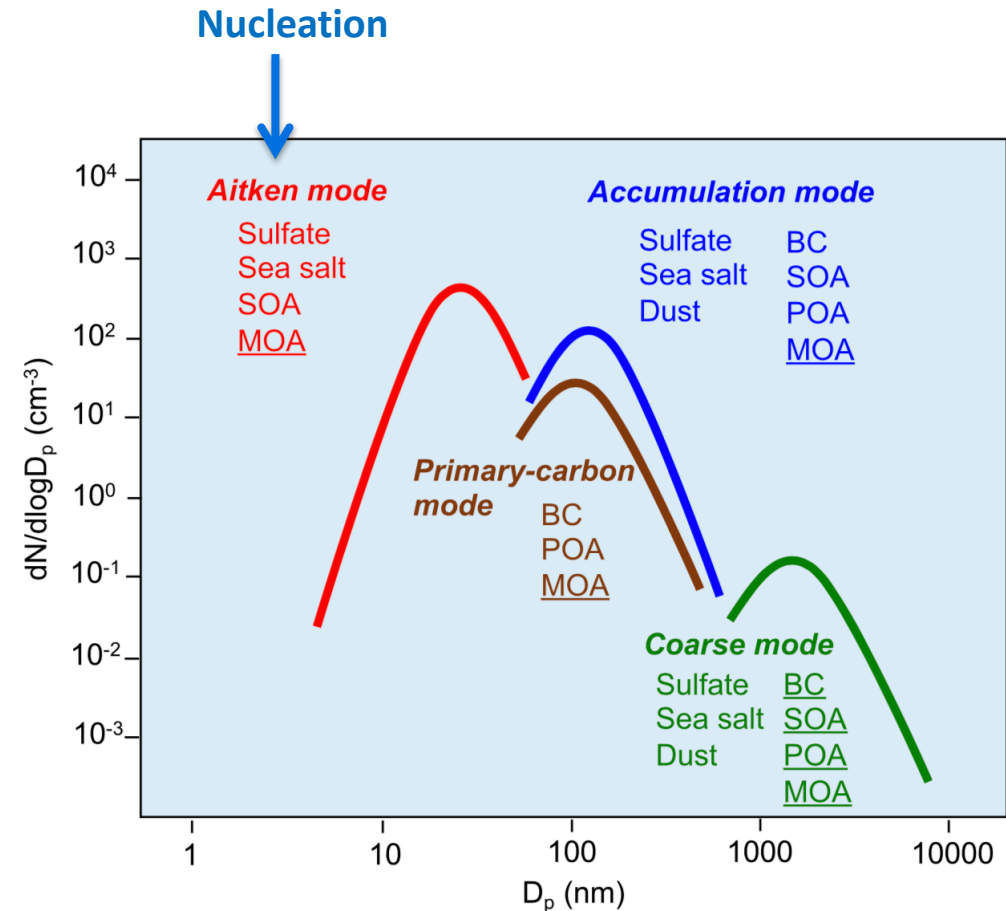
Adapted from Wang et al (2020)

New nucleation mode / MAM5

Mode	Mode width	Diameter range (um)
Nucleation	**1.6**	**<0.0087**
Aitken	1.6	0.0087–0.052
Accumulation	1.8	0.0535–0.44
Coarse	1.8	1.0–4.0
Primary Carbon	1.6	0.01-0.1

► Three additional tracers (number and mass): resolved and resolved transport

► Interaction between aerosol microphysics processes (including the impact of SOA condensation in nucleation mode)

► Possible wet removal (only for impaction scavenging)

► Currently no dry removal (deposition/sedimentation)

► No impact on radiation
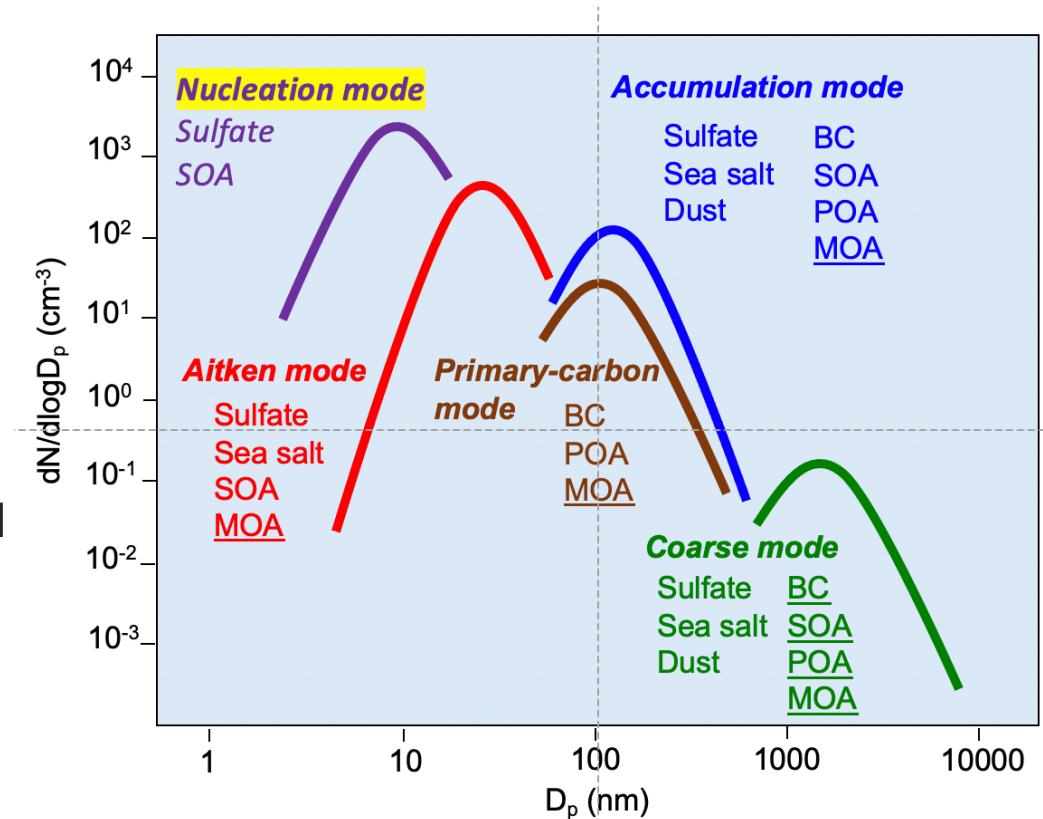
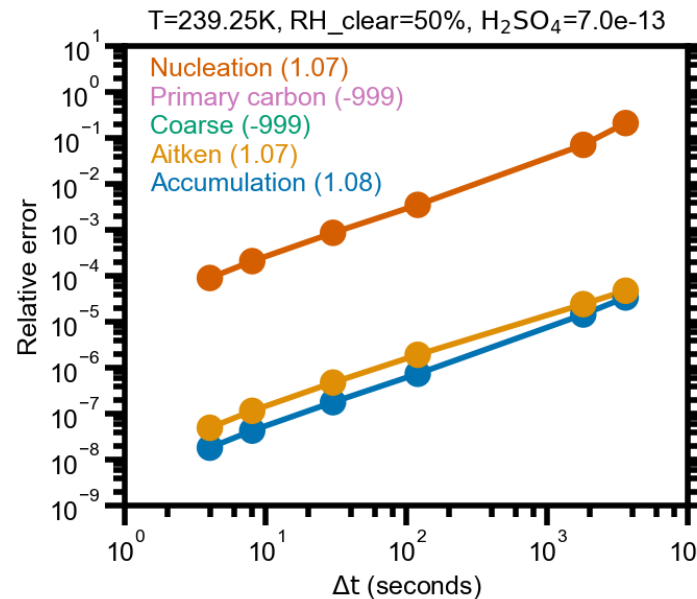*Adapted from Wang et al (2020)*

Code verified with the MAM box model

Governing equations

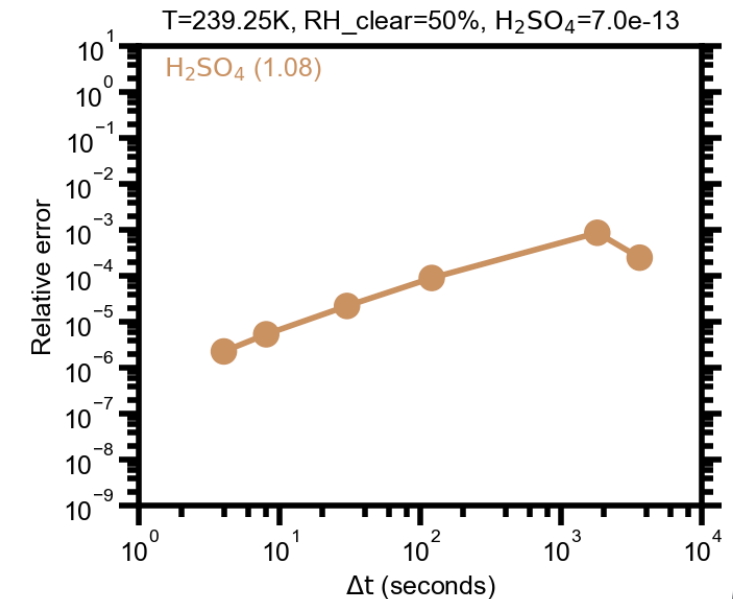$$\frac{dq_a}{dt} = F_{nucleation} + F_{condensation} + F_{coagulation} + F_{rename}$$

$$\frac{dq_g}{dt} = -F_{nucleation} - F_{condensation}$$

- ▶ 1-hour simulation
- ▶ Δt varies from 1s to 3600s.
- ▶ Reference solution: $\Delta t = 1s$
- ▶ Linear convergence is expected if no clipping or other artificial fixer is applied

Sulfate aerosol mass

T=239.25K, RH_clear=50%, H_2SO_4=7.0e-13

Nucleation (1.07)
Primary carbon (-999)
Coarse (-999)
Aitken (1.07)
Accumulation (1.08)

H_2SO_4 gas

T=239.25K, RH_clear=50%, H_2SO_4=7.0e-13

H_2SO_4 (1.08)

Global model results

► Nudged simulation for the year 2016-2018

► Annual mean vertical distribution ultrafine aerosol number is shown

► Near surface, there are less Aitken mode particles in MAM5 compared to MAM4.

► While in the upper troposphere, more Aitken mode particles are formed due to strong condensation.

MAM4 ultrafine aerosol number
Aitken mode

MAM5 ultrafine aerosol number

Nucleation mode

Aitken mode
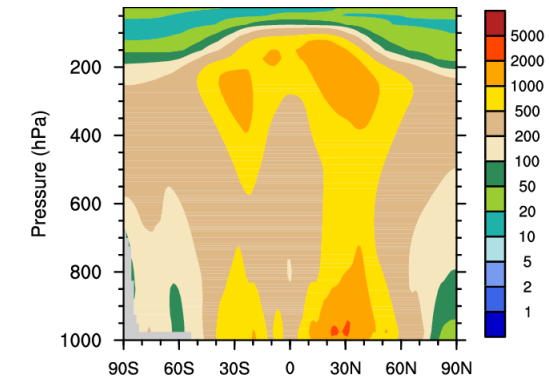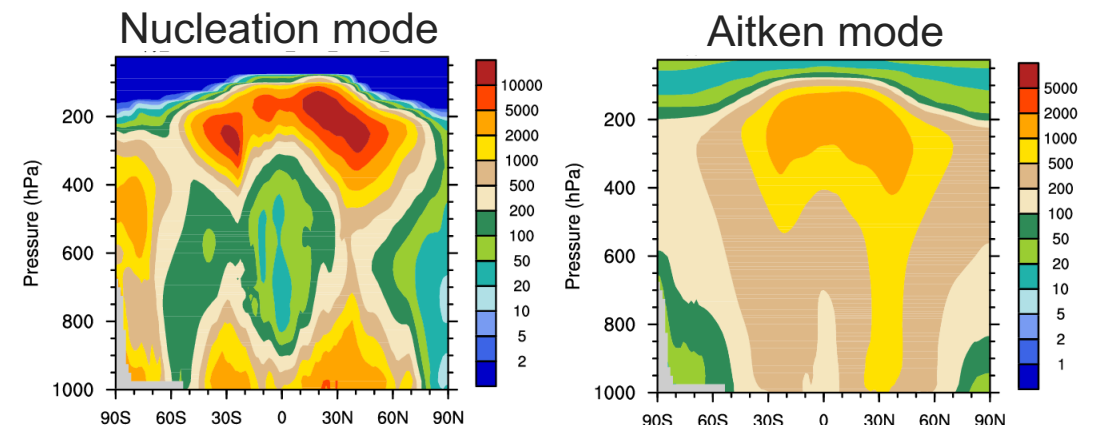
Summary

► Nucleation mode is added in MAM to better represent ultrafine aerosol particles and their interactions with cloud and precipitation at cloud-permitting scales

► The nucleation mode includes both sulfate and SOA, and the impact of SOA condensation on newly-formed sulfate particles is considered

► MAM5 (MAM4 + nucleation mode) reasonably simulates the global distribution of nucleation mode particles

► See Poster (Tang S. et al.) for model evaluation against ARM observations