Intercomparison of Aerosol Microphysics Parameterizations in the MAM Aerosol Box Model

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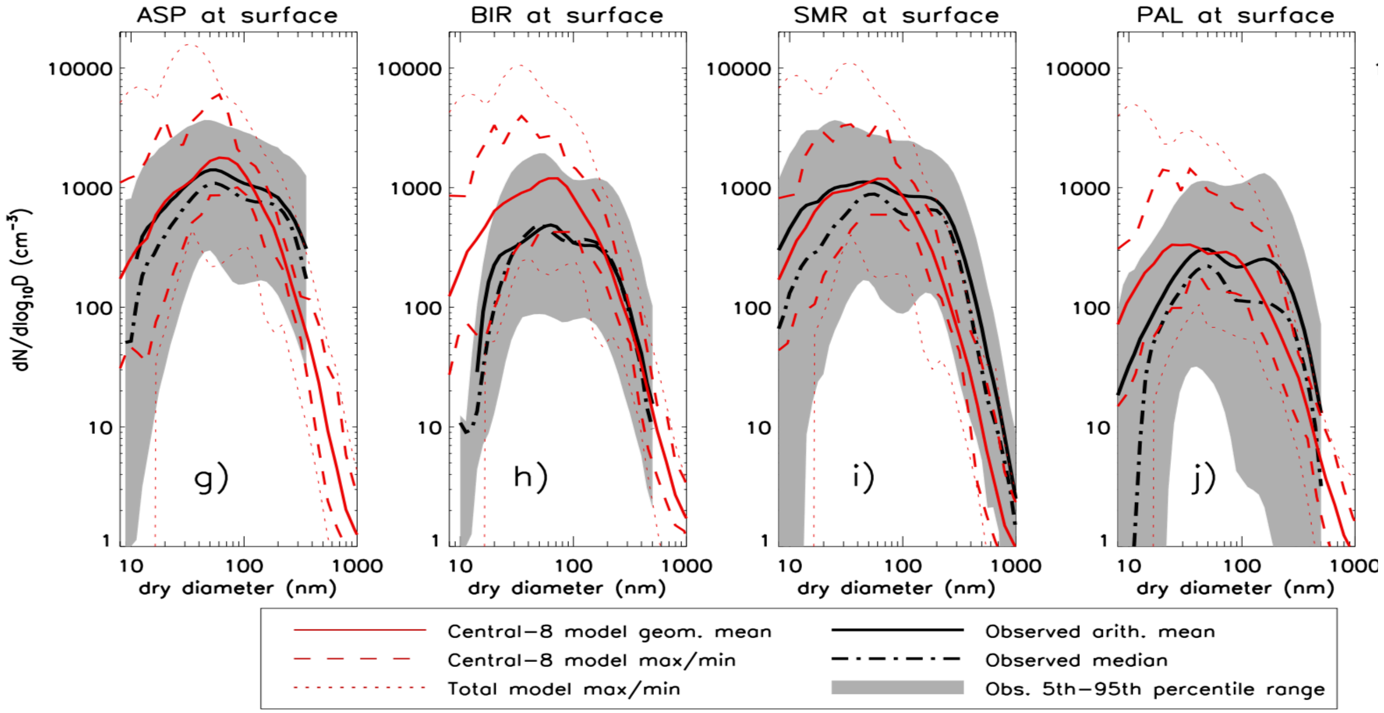
Motivation

- Can isolate a certain process(es) from other processes/interactions
- Easy to implement and test new parameterizations
- Cheap and can be tested at very short time steps
- Easy to maintain and use it for collaborations

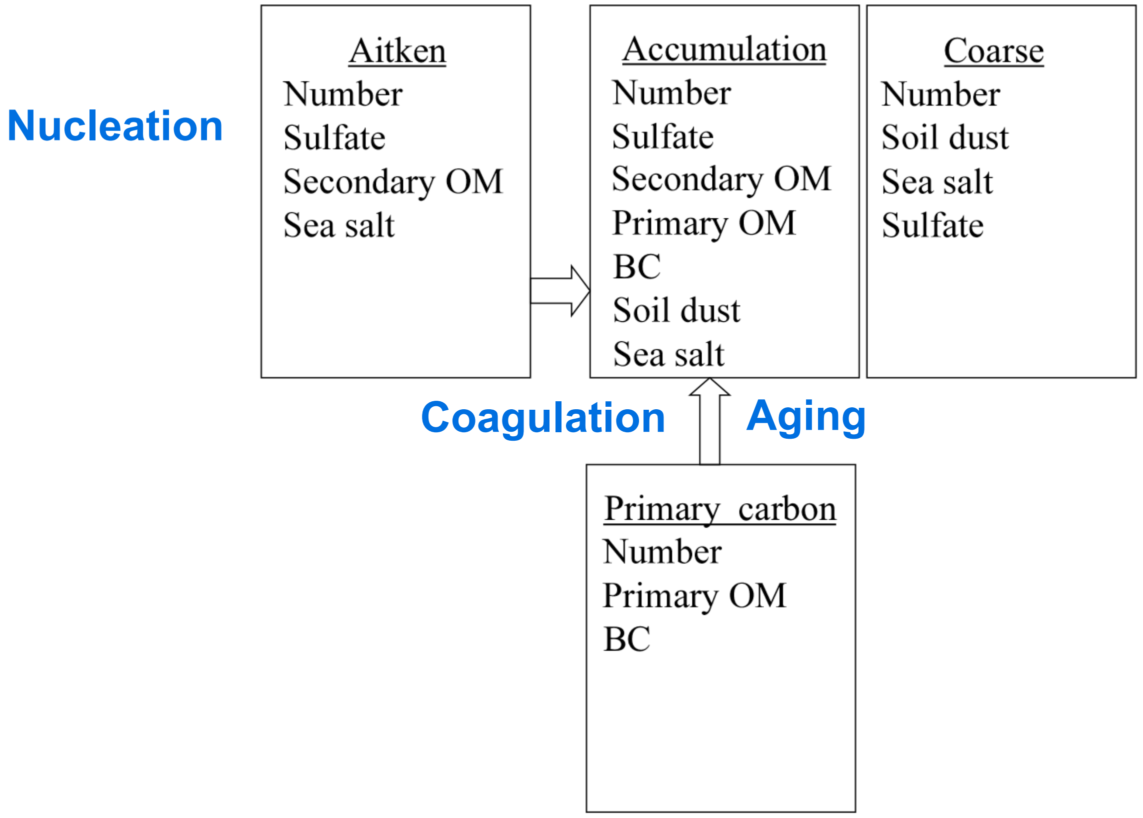


Mann et al. (2014)

Many questions were left unanswered in previous global modeling intercomparison studies.

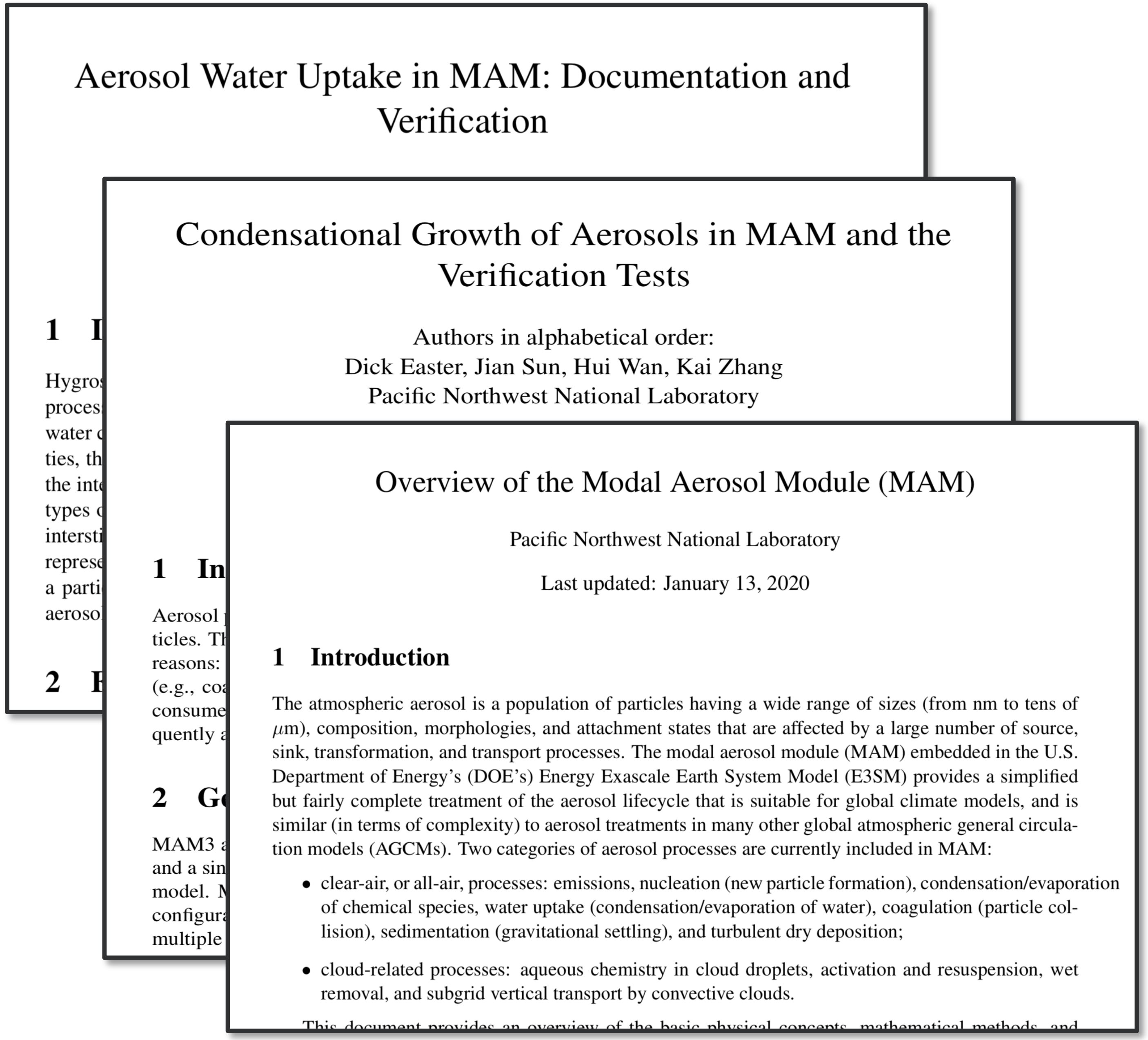
MAM Aerosol Box Model

- First version developed by Dick Easter
- Initially to facilitate code development (e.g. major revision to process parameterizations, new species and modes)
- Can be configured as a single-box or multi-box model using data structure used in E3SM and CESM
- Various drivers now available for testing individual processes in isolation or in combination
- Improved I/O and post-processing workflow



Adapted from Liu et al. (2016)

And Better Documented (for both physics and numerics)



Aerosol Water Uptake in MAM: Documentation and Verification

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Condensational Growth of Aerosols in MAM and the Verification Tests

Authors in alphabetical order:
Dick Easter, Jian Sun, Hui Wan, Kai Zhang
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Overview of the Modal Aerosol Module (MAM)

Pacific Northwest National Laboratory

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1 Introduction

The atmospheric aerosol is a population of particles having a wide range of sizes (from nm to tens of μm), composition, morphologies, and attachment states that are affected by a large number of source, sink, transformation, and transport processes. The modal aerosol module (MAM) embedded in the U.S. Department of Energy's (DOE's) Energy Exascale Earth System Model (E3SM) provides a simplified but fairly complete treatment of the aerosol lifecycle that is suitable for global climate models, and is similar (in terms of complexity) to aerosol treatments in many other global atmospheric general circulation models (AGCMs). Two categories of aerosol processes are currently included in MAM:

- clear-air, or all-air, processes: emissions, nucleation (new particle formation), condensation/evaporation of chemical species, water uptake (condensation/evaporation of water), coagulation (particle collision), sedimentation (gravitational settling), and turbulent dry deposition;
- cloud-related processes: aqueous chemistry in cloud droplets, activation and resuspension, wet removal, and subgrid vertical transport by convective clouds.

This document provides an overview of the basic physical concepts, mathematical methods, and

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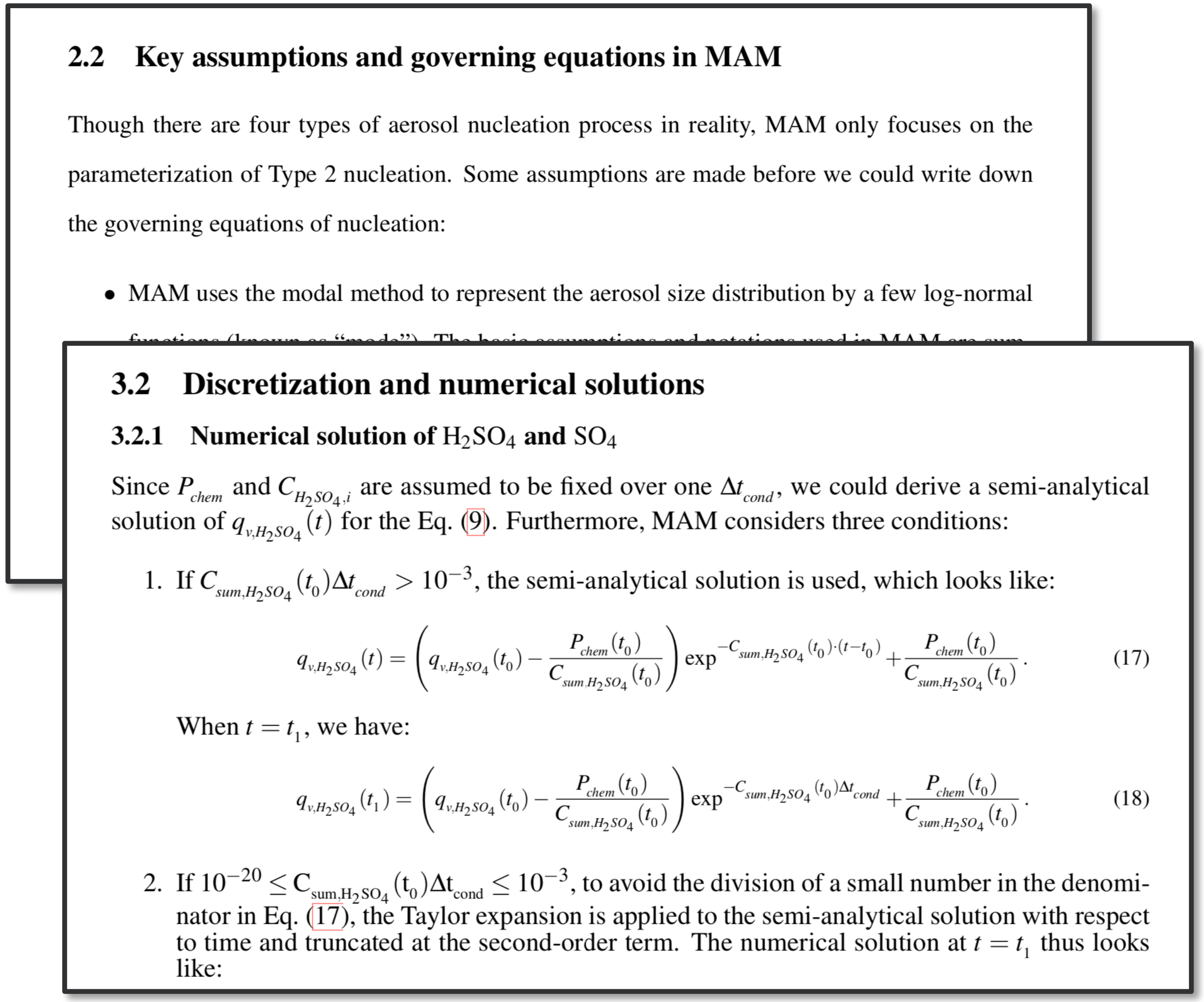

2.2 Key assumptions and governing equations in MAM

Though there are four types of aerosol nucleation process in reality, MAM only focuses on the parameterization of Type 2 nucleation. Some assumptions are made before we could write down the governing equations of nucleation:

- MAM uses the modal method to represent the aerosol size distribution by a few log-normal

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3.2 Discretization and numerical solutions

3.2.1 Numerical solution of H_2SO_4 and SO_4

Since P_{chem} and $C_{H_2SO_4,i}$ are assumed to be fixed over one Δt_{cond}, we could derive a semi-analytical solution of $q_{v,H_2SO_4}(t)$ for the Eq. (9). Furthermore, MAM considers three conditions:

1. If $C_{sum,H_2SO_4}(t_0)\Delta t_{cond} > 10^{-3}$, the semi-analytical solution is used, which looks like:

$$q_{v,H_2SO_4}(t) = \left(q_{v,H_2SO_4}(t_0) - \frac{P_{chem}(t_0)}{C_{sum,H_2SO_4}(t_0)}\right)\exp^{-C_{sum,H_2SO_4}(t_0)\cdot(t-t_0)} + \frac{P_{chem}(t_0)}{C_{sum,H_2SO_4}(t_0)}. \tag{17}$$

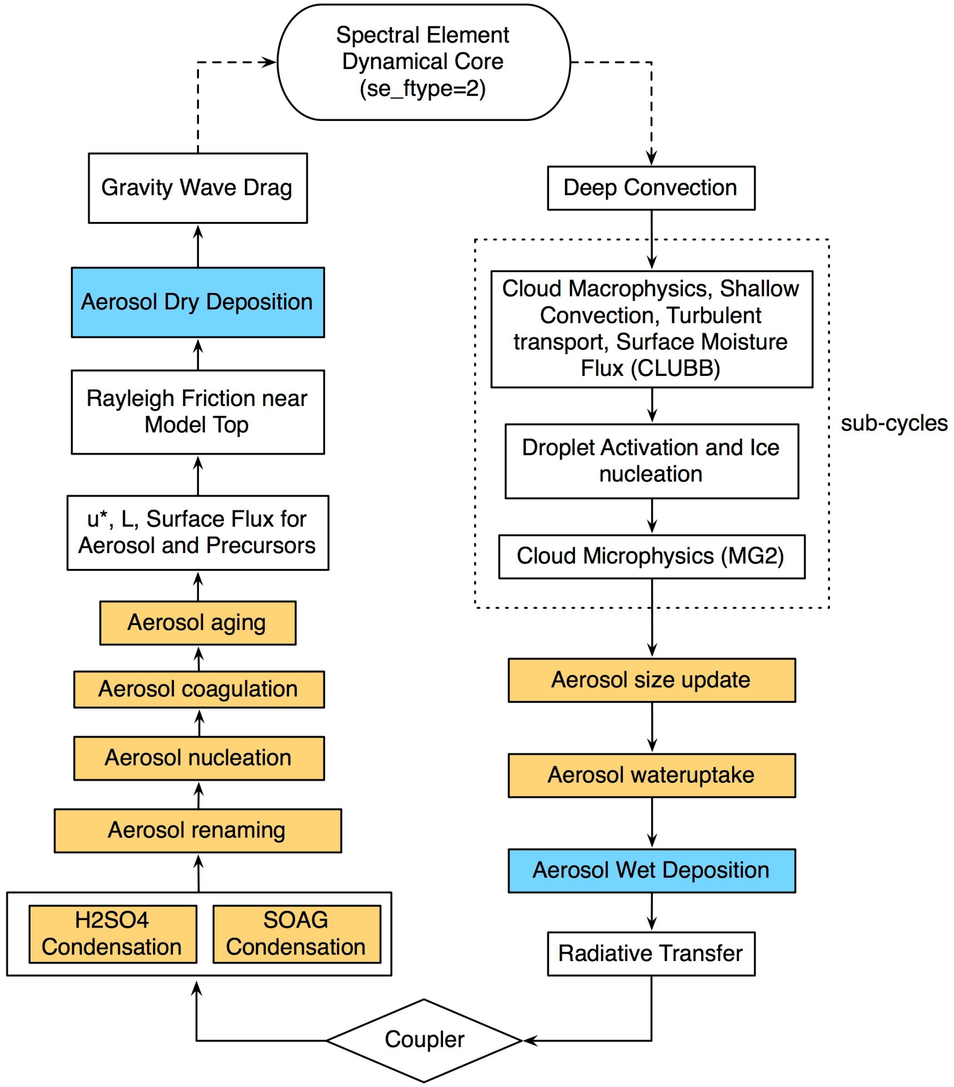
   When $t = t_1$, we have:

$$q_{v,H_2SO_4}(t_1) = \left(q_{v,H_2SO_4}(t_0) - \frac{P_{chem}(t_0)}{C_{sum,H_2SO_4}(t_0)}\right)\exp^{-C_{sum,H_2SO_4}(t_0)\Delta t_{cond}} + \frac{P_{chem}(t_0)}{C_{sum,H_2SO_4}(t_0)}. \tag{18}$$

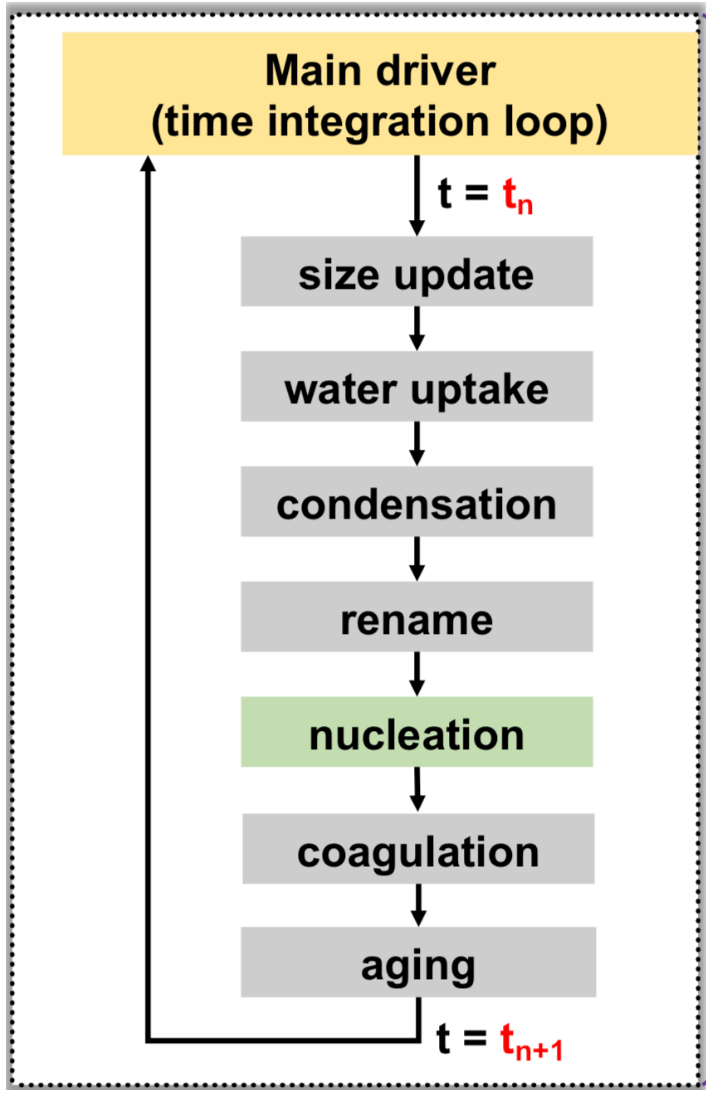
2. If $10^{-20} \leq \mathrm{C}_{\mathrm{sum,H_2SO_4}}(\mathrm{t}_0)\Delta\mathrm{t}_{\mathrm{cond}} \leq 10^{-3}$, to avoid the division of a small number in the denominator in Eq. (17), the Taylor expansion is applied to the semi-analytical solution with respect to time and truncated at the second-order term. The numerical solution at $t = t_1$ thus looks like:

Processes Considered and Their Coupling

MAM in the E3SM atmosphere model



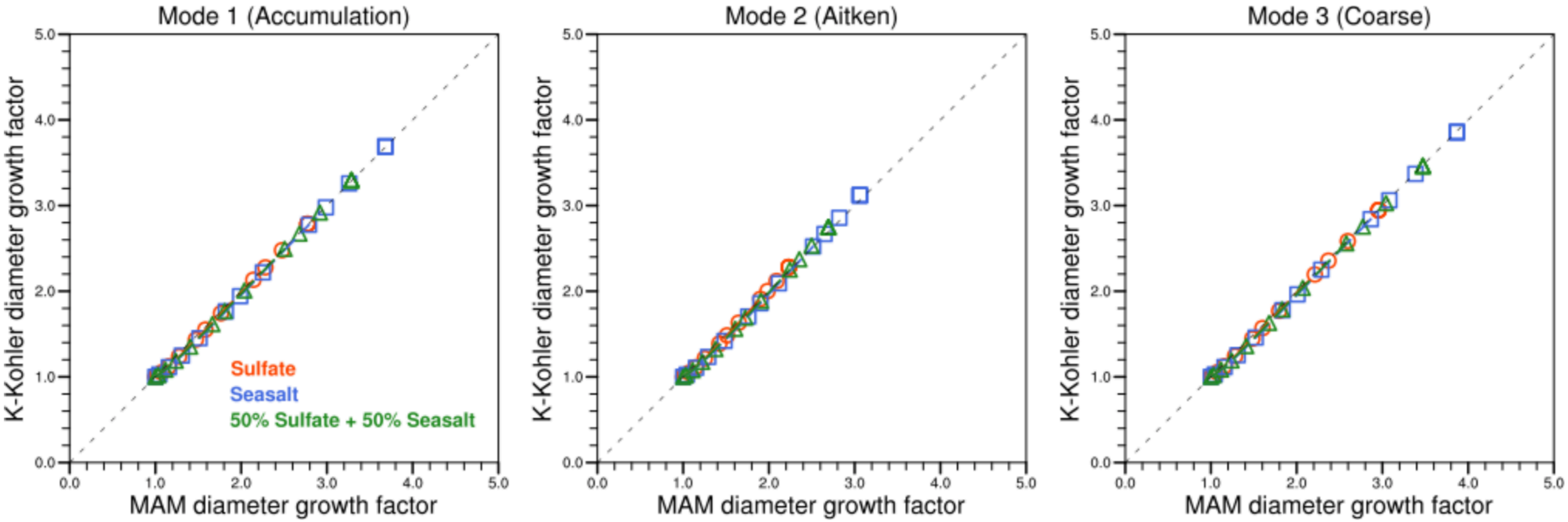
MAM box model



Example 1a: Comparing Waterupake Schemes

***Calculated with the same hygroscopicity values** (sulfate=0.53, sea salt=1.12)*

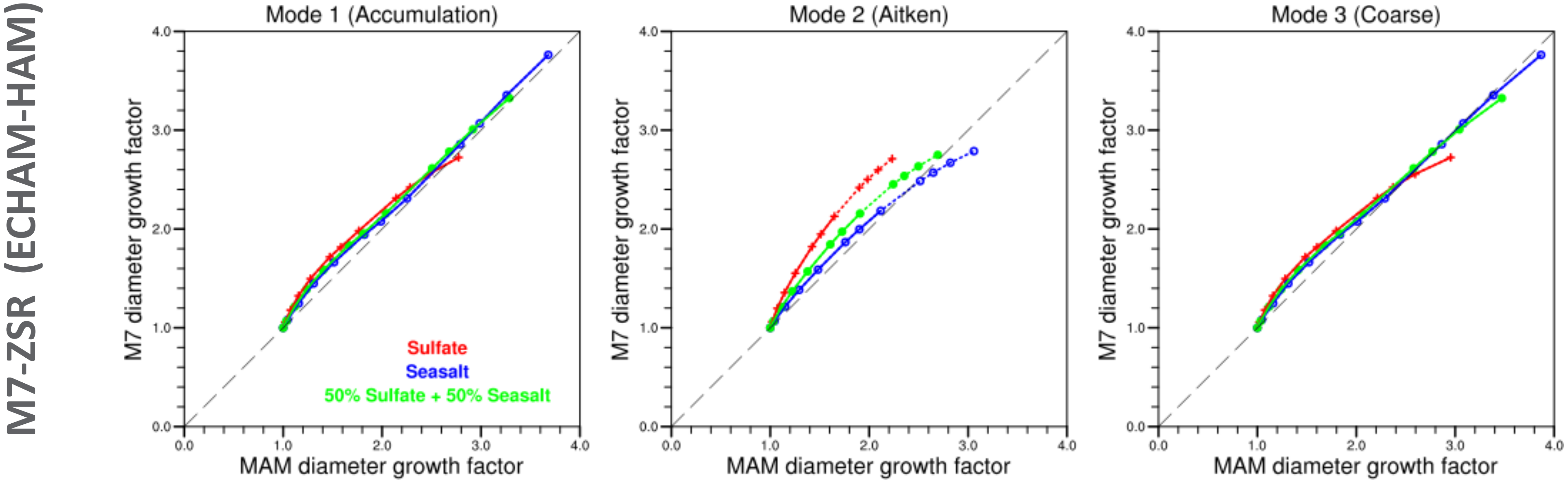
κ-Köhler theory



Köhler theory

Petters and Kreidenweis (2007)
Ghan et al. (2001)

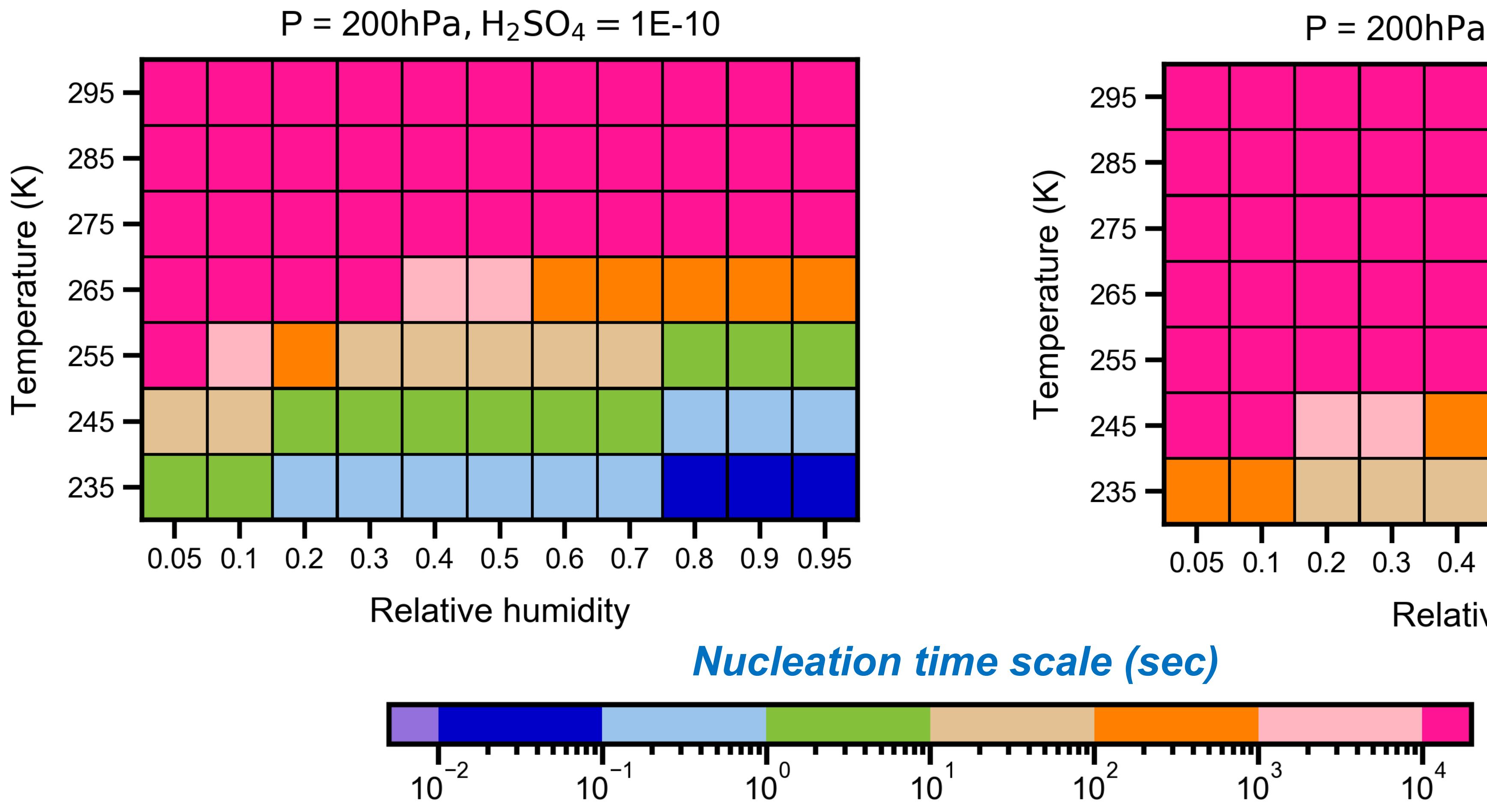
Example 1b: Comparing Waterupake Schemes



MAM Köhler (E3SM/CESM)

Example 2: Nucleation time scale analysis

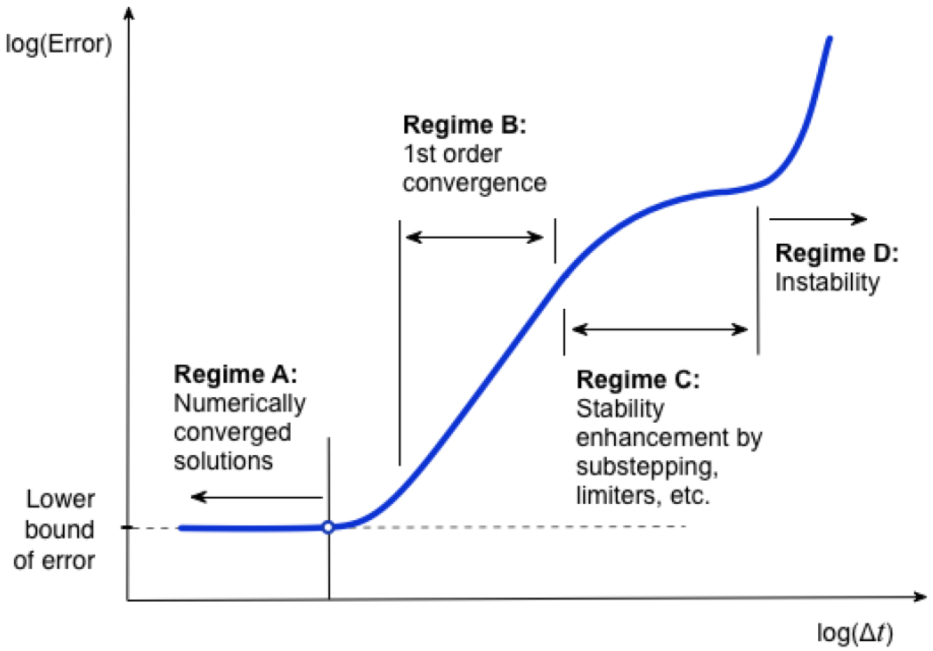
Binary nucleation in upper troposphere



dt = 30min in $E3SM_{atm}$

Example 3: Time Step Convergence

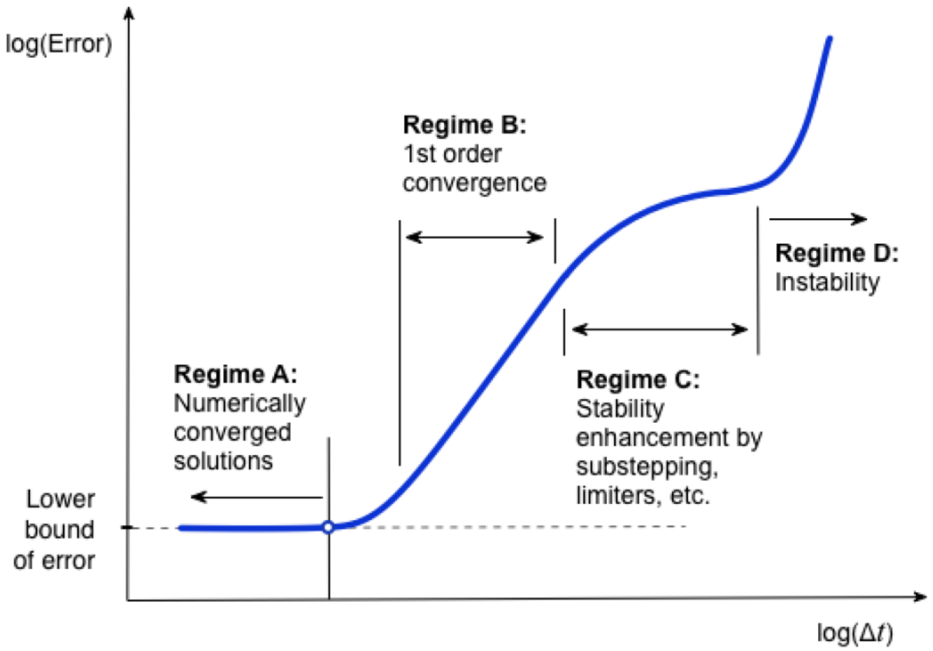
Convergence regimes



Wan et al. (2020)

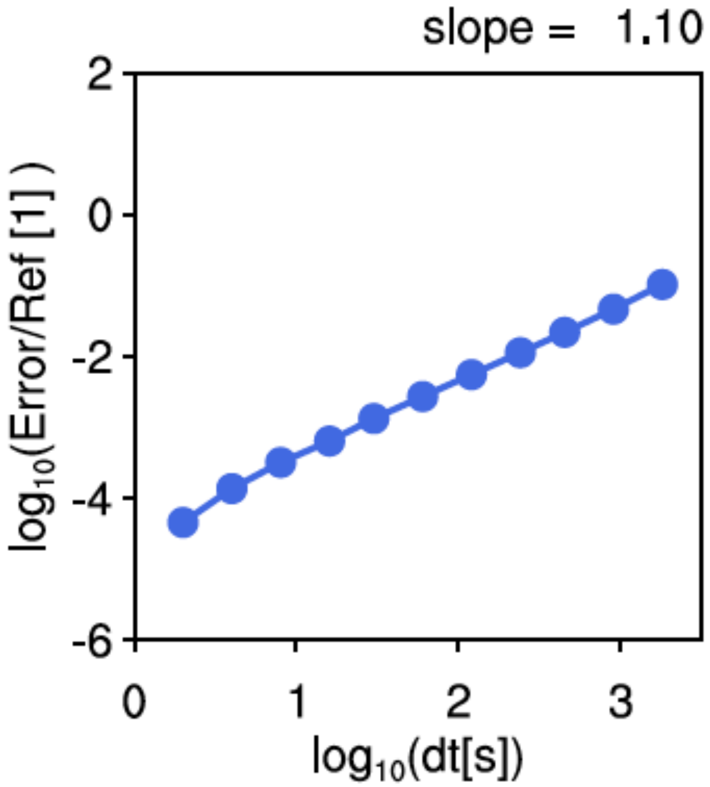
Example 3: Time Step Convergence

Convergence regimes



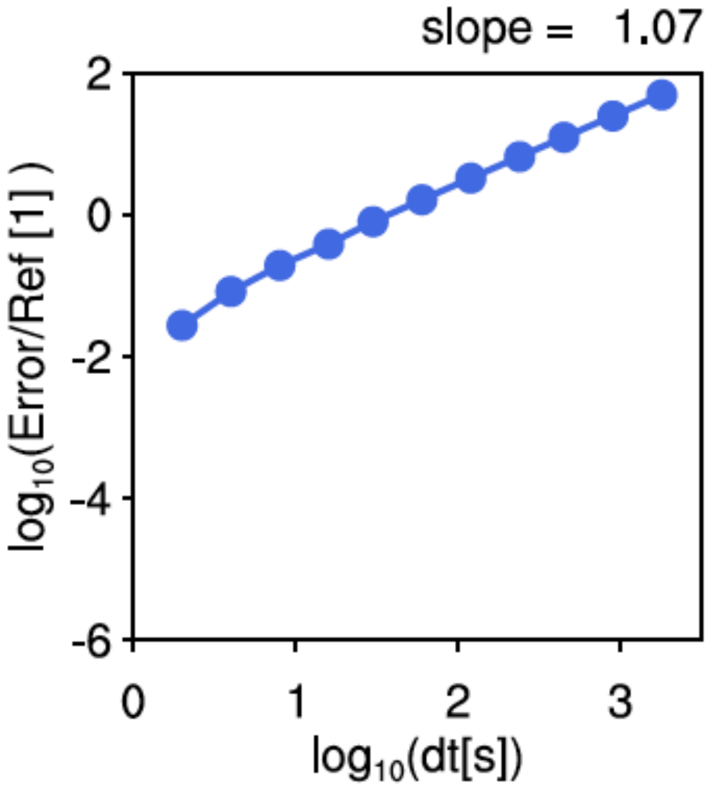
Wan et al. (2020)

Small condensation rate



~1st older convergence
Relatively large error
with dt = 30min.

Large condensation rate



~1st older convergence
Very large error, even
with dt = 100s.

Summary

- The MAM aerosol box model is improved to better accommodate the needs for model development and testing
- Modeler can use it to implement and test new parameterizations more easily
- Ideal tool for parameterization intercomparison
- Will be publicly released to the community soon.

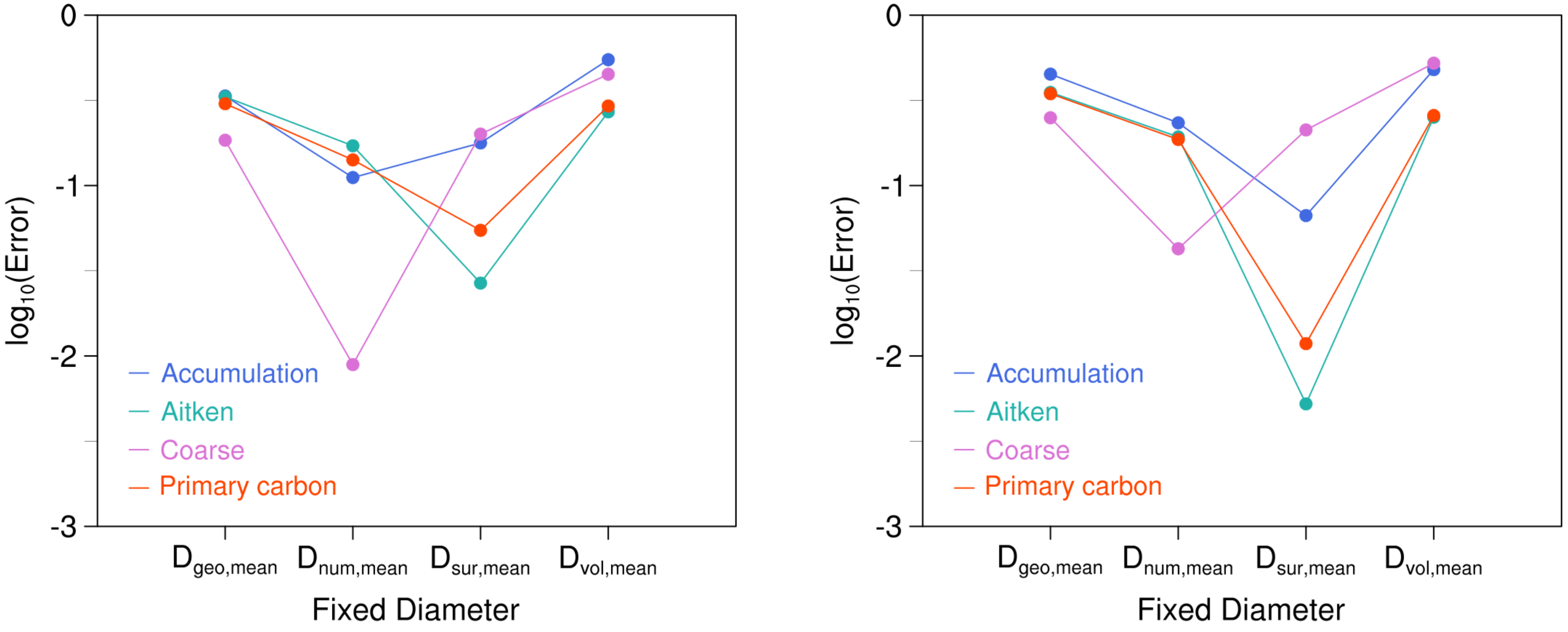
BACKUP

Error in Condensation (mass transfer coefficient)

Geometric mean diameter: **$D_{geo,mean}$** used in M7 (Vignati et al., 2004)

The diameter of average surface area: **$D_{sur,mean}$** used in M3 (Wilson et al., 1996)

Near Surface (273K, 1000hPa) **Upper troposphere (230K, 200hPa)**



Some methods have much larger error (~50% for $D_{geo,mean}$)