Aerosol Model Development for the Future-Generation E3SM at Convection-Permitting Scales

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Acknowledgement: Dick Easter, Susannah Burrows, Manish Shrivastava

Proposed improvements

Goal: Improving the representation of aerosol properties and lifecycle

Adaptation (for running global convection-permitting simulations at DOE's HPC)

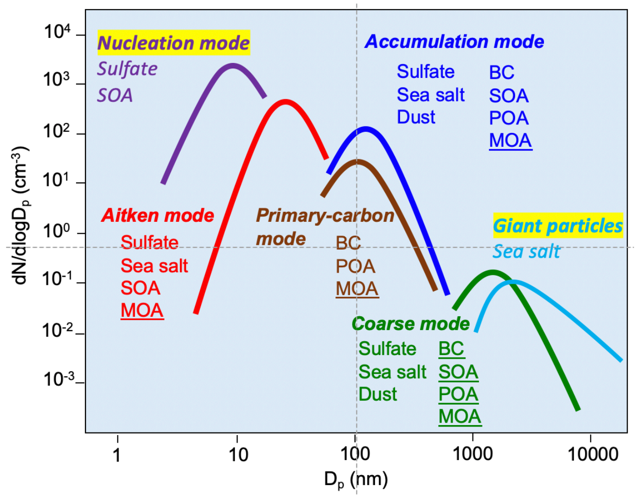
- Advection of cloud-borne aerosols
- Vertical mixing
- Wind-blown aerosols
- Aerosol water uptake
- Wet scavenging of aerosols
- Coupling of processes

Enhancement (from new process understanding that are critical and currently missing)

- Nucleation mode aerosols
- Giant particles
- Secondary organic aerosols
- Wildfire aerosols
- Dust

Nucleation mode aerosols in MAM

Kai Zhang, Jian Sun, Balwinder Singh, Po-Lun Ma, Bin Zhao, Hailong Wang, Guangxing Lin



Adapted from Wang et al. (2020)

Objective

- Better represent ultrafine aerosol particles in MAM and their interactions with cloud and precipitation at cloud-permitting scales

Approach

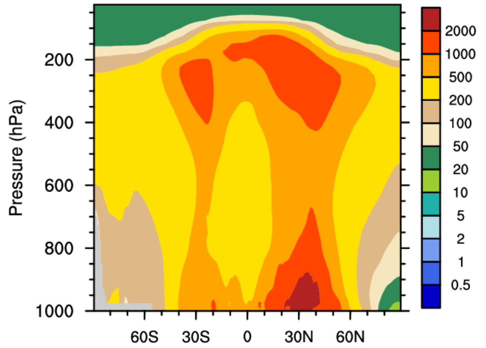
- Add a new (nucleation) mode in MAM
- Explicitly consider the growth, coagulation, and transport of newly-formed particles

Current Findings

- MAM5 (MAM4 + nucleation mode) reasonably simulates the global distribution of nucleation mode particles
- Overall, there are less Aitken mode particles in MAM5 compared to MAM4, except for upper troposphere.

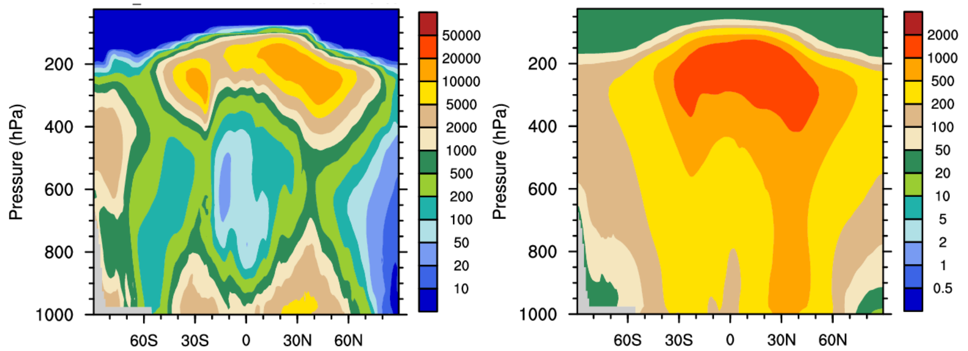
MAM4 ultrafine aerosol number

Aitken mode



MAM5 ultrafine aerosol number

Nucleation mode — Aitken mode



Ongoing work:

- Evaluate the model against in-situ measurements
- Adjust the model based on observational constraints

Evaluating ultra-fine aerosols

Jerome Fast, Shuaiqi Tang, Kai Zhang, Po-Lun Ma

Objective

- Evaluate ultrafine aerosols in E3SM

Approach

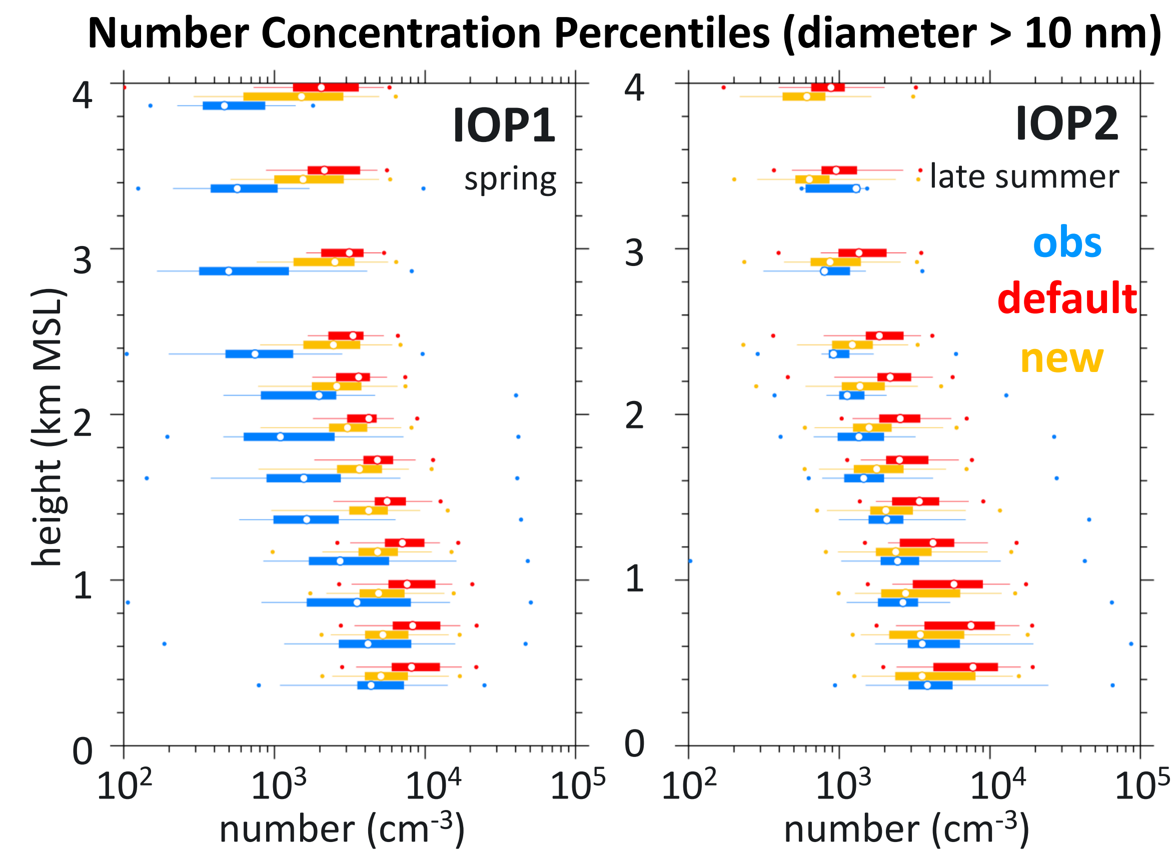
- Use ARM measurements to evaluate the new ultrafine aerosol treatment

New capabilities and scientific significance

- Merged aerosol size distribution from different instruments
- Python-based code package for model evaluation

Next Steps:

- Evaluate model simulations in different regions
- Assess the effects of adjustments to physics



New treatment (with the nucleation mode aerosols) produces better aerosol number simulations (in better agreement with observations)

Representing the organic-mediated new-particle formation (NPF) in E3SM

Bin Zhao, Manish Shrivastava, Kai Zhang, Po-Lun Ma, Balwinder Singh, Jerome Fast

Objective

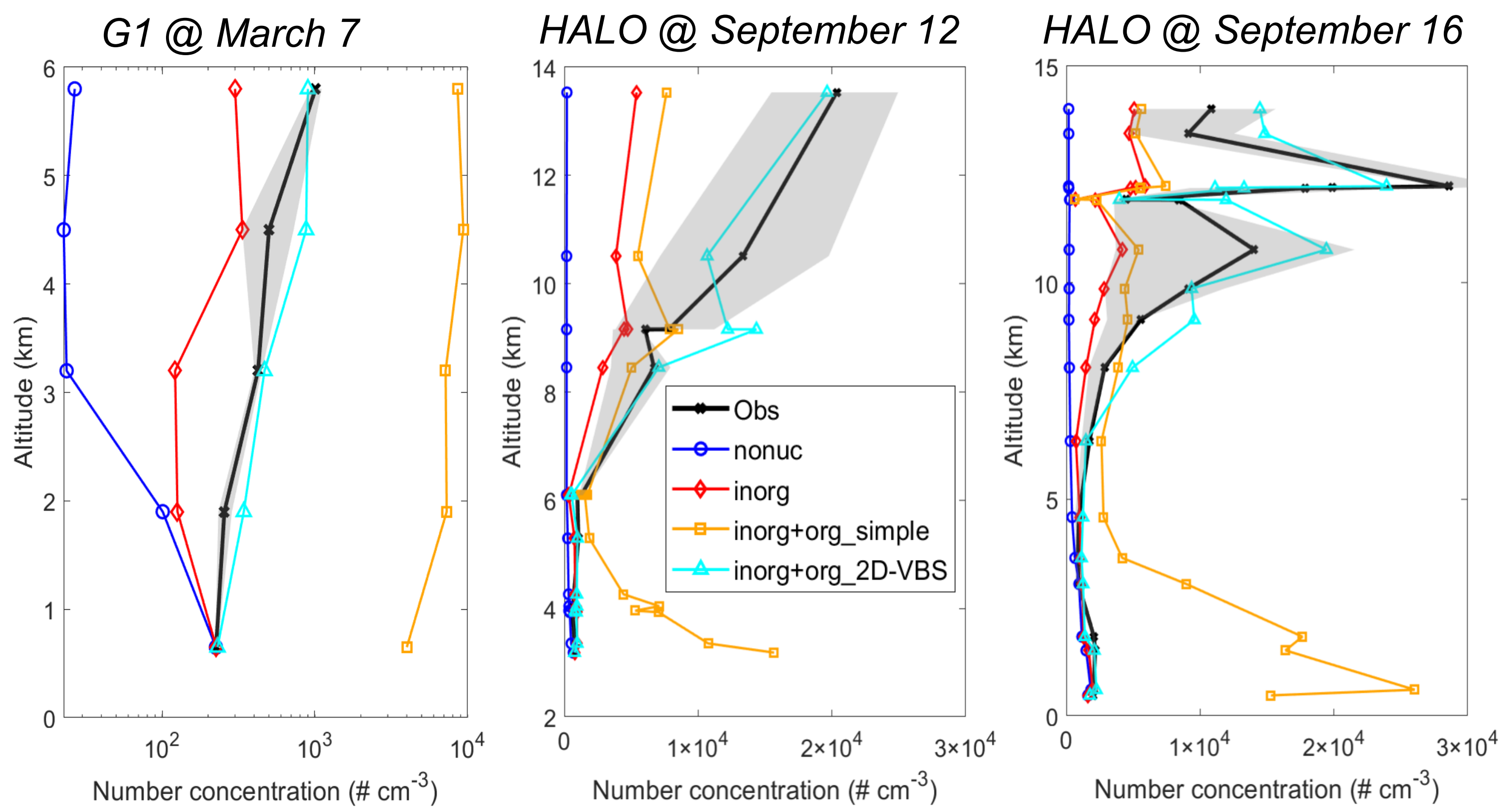
- To represent the organic-mediated NPF, an important and even dominant NPF pathway

Approach

- Incorporate an organic-mediated NPF parameterizations and a novel radical two-dimensional volatility basis set (2D-VBS) in E3SM to simulate the formation chemistry and thermodynamics of extremely low volatility organics that drive NPF.

New capabilities and scientific significance

- Developed the parameterizations of 3 organic-mediated NPF pathways
- Determined the chemical reactions that form the nucleating organics, based on the radical 2D-VBS with experimentally-constrained parameters
- The work is expected to improve the predictive understanding of global aerosol number budget and help better quantify aerosol radiative forcing



Zhao et al., PNAS, 2020

Incorporation of organic-mediated NPF improves simulation

Next Steps:

- Incorporate the organic-mediated NPF in E3SM
- Evaluate against observations in different testbeds

Fully prognostic treatment of cloud-borne aerosols

Guangxing Lin, Kai Zhang, Po-Lun Ma, Balwinder Singh, Jian Sun, Hailong Wang, et al

Motivation

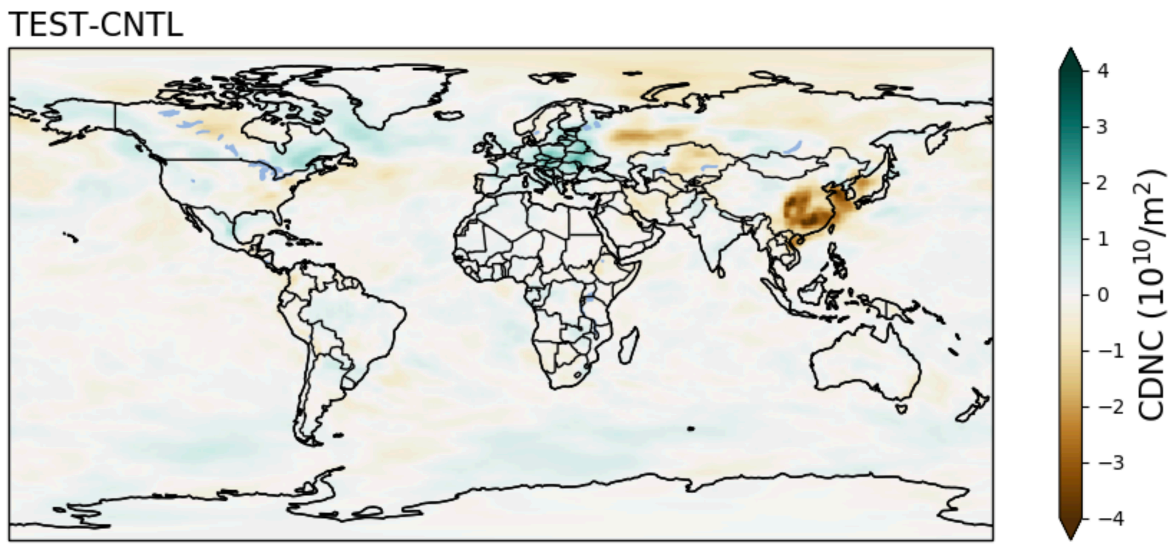
- The treatment of neglecting the advection of cloud-borne aerosols is designed for coarse-resolution models. At convection-permitting scales, this treatment is expected to produce large errors.

Approach

- Implement the advection of cloud-borne aerosols in E3SM
- Assess its impacts on aerosols, clouds, and aerosol radiative effects

Next Steps:

- Run RRM to assess the resolution sensitivity of the new treatment
- Evaluate the model against observations
- Assess the impacts on aerosol radiative effects



Significant reduction of cloud droplet number in East Asia after accounting for advection of cloud-borne aerosols in E3SMv1 running at ne30 resolution

Representing wildfire aerosols

Xiaohong Liu, Zheng Lu, Ziming Ke, Allen Hu, Jiwen Fan, Kai Zhang, Po-Lun Ma, et al

Objective

- Improve the representation of the injection height of wildfire aerosols

Approach

- Calculate fire plume rise and aerosol injection height based on fire properties and ambient meteorological conditions

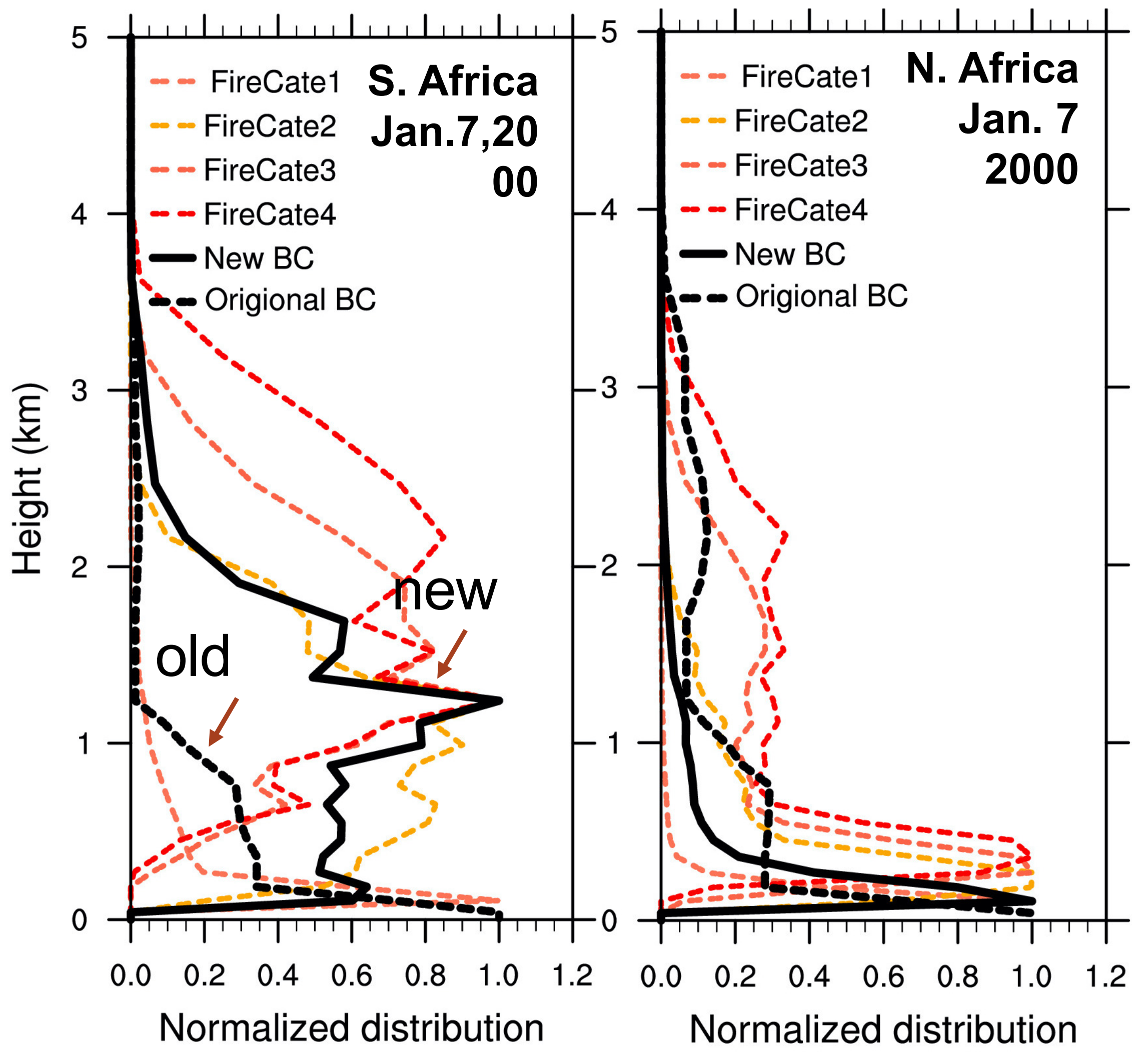
New capabilities and scientific significance

- Vertical distributions of wildfire aerosols are predicted rather than prescribed.
- The distribution of wildfire aerosols as well as their impacts on radiation and clouds are now better represented in E3SM.

Next Steps:

- Evaluate the plume-rise model with observations
- Incorporate fire diurnal cycle and generate new fire emission maps.

Calculated and prescribed BC profiles



Aerosols are elevated to higher altitude using the new (prognostic) treatment of wildfire aerosol injection height

Representing anthropogenic dust

Xiaohong Liu, Zheng Lu, Ziming Ke, Allen Hu, Jiwen Fan, Kai Zhang, Po-Lun Ma, et al

Objective

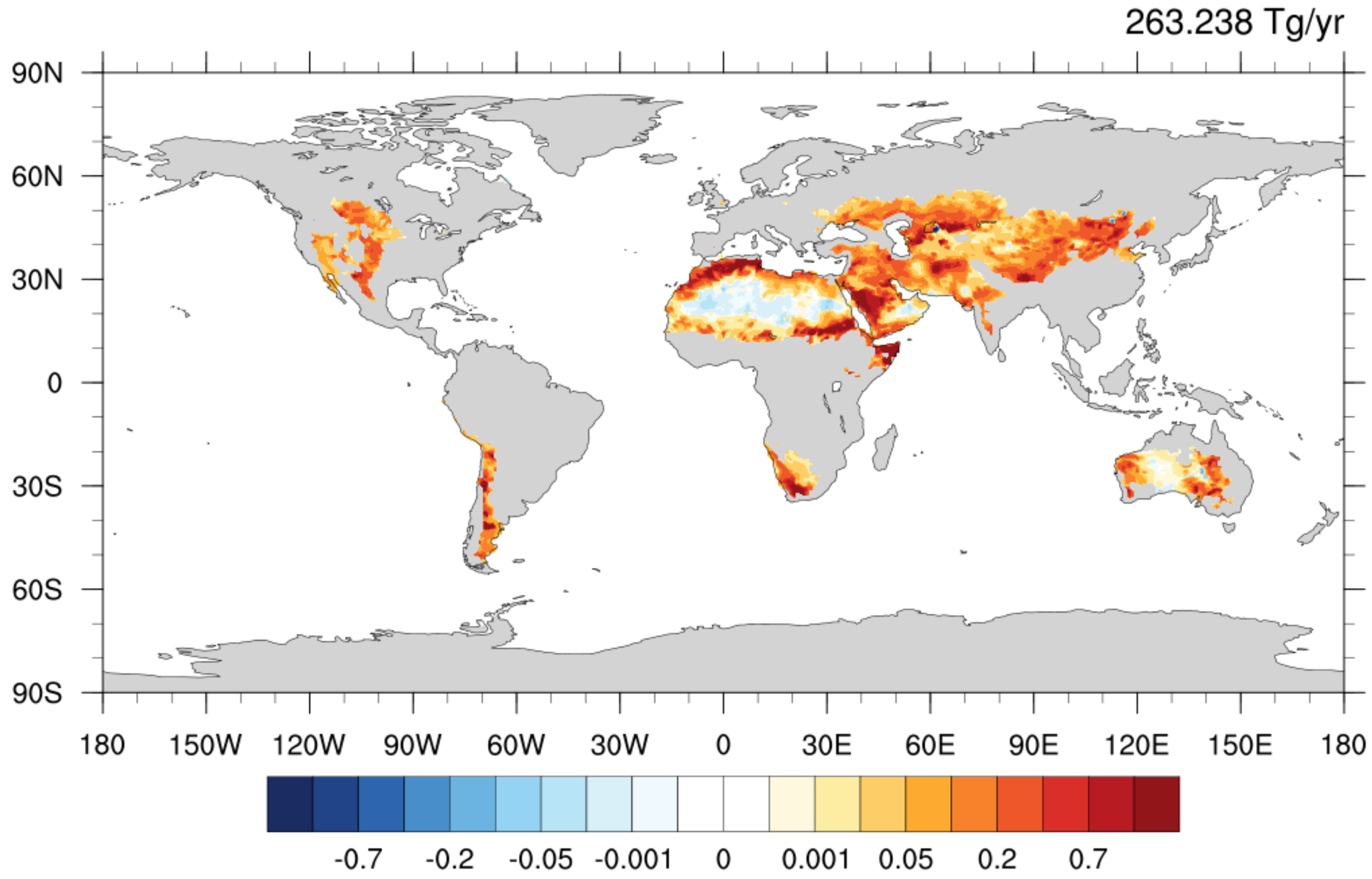
- Improve the representation of the anthropogenic dust

Approach

- Calculate anthropogenic dust emissions due to landuse based on HYDEv3.2 dataset
- Apply a correction factor to adjust total dust emissions

Next Steps:

- Evaluate dust aerosols against observations



Enhanced dust emissions due to landuse changes

A high-performance aerosol library

Jeff Johnson, Pete Bosler, Balwinder Singh, Hui Wan

Objective

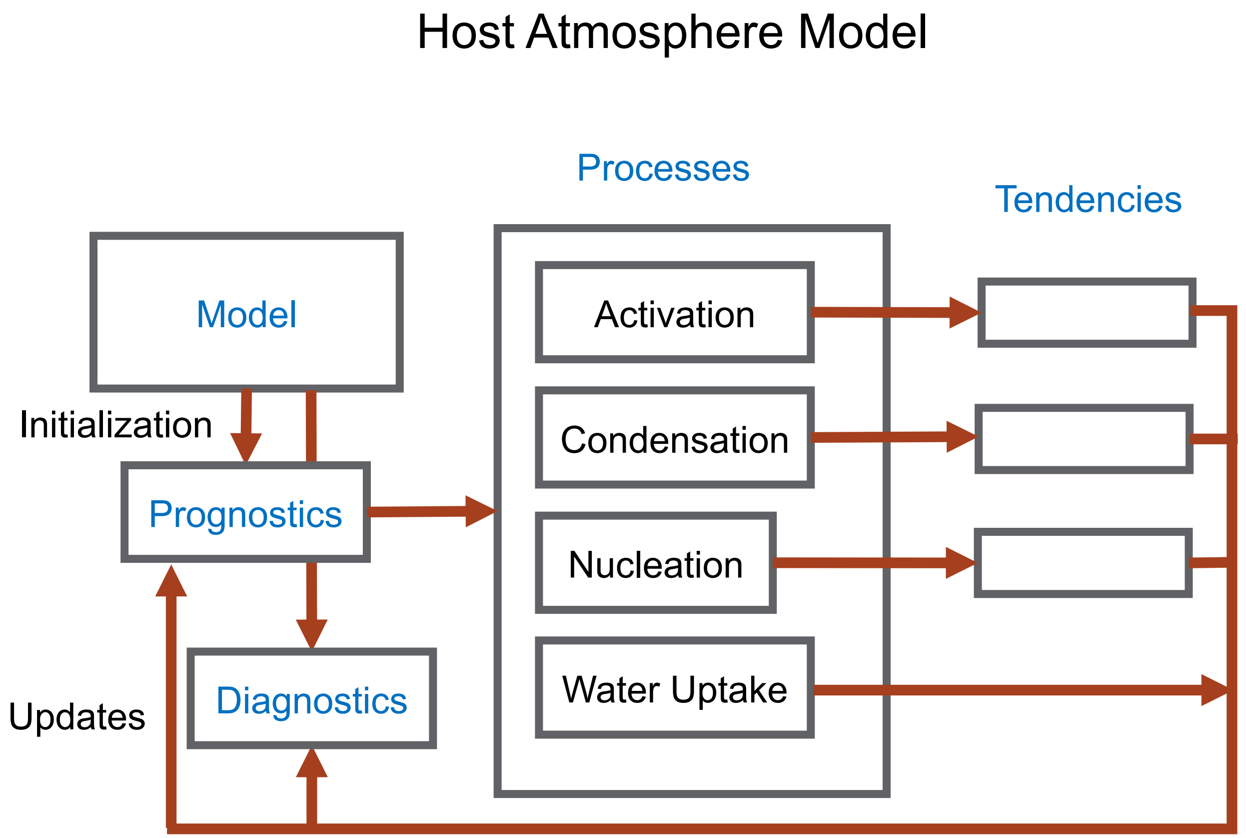
- Develop a modern software package for aerosols

Approach

- Develop a set of building blocks (library) and a driver to verify their correctness and performance

Software design

- Model – Stores parameters that define the physical characteristics of an aerosol system and the surrounding atmosphere
- Prognostics – Stores prognostic variables that define the system's instantaneous physical state (similar to physics_state)
- Diagnostics – Stores diagnostic variables needed by various parameterizations (similar to physics_buffer)
- Tendencies – Stores time derivatives for prognostic variables at a given time (similar to physics_ptend). Accumulated into Prognostics during time integration
- Process – Implements a parameterization that computes tendencies or updates diagnostics for a state at a given time



The host model assembles building blocks, allowing parameterization transplant!