Opportunities to better understand E3SM aerosol and CCN simulation biases (and their cloud impacts) using EPCAPE observations

June 22, 2021

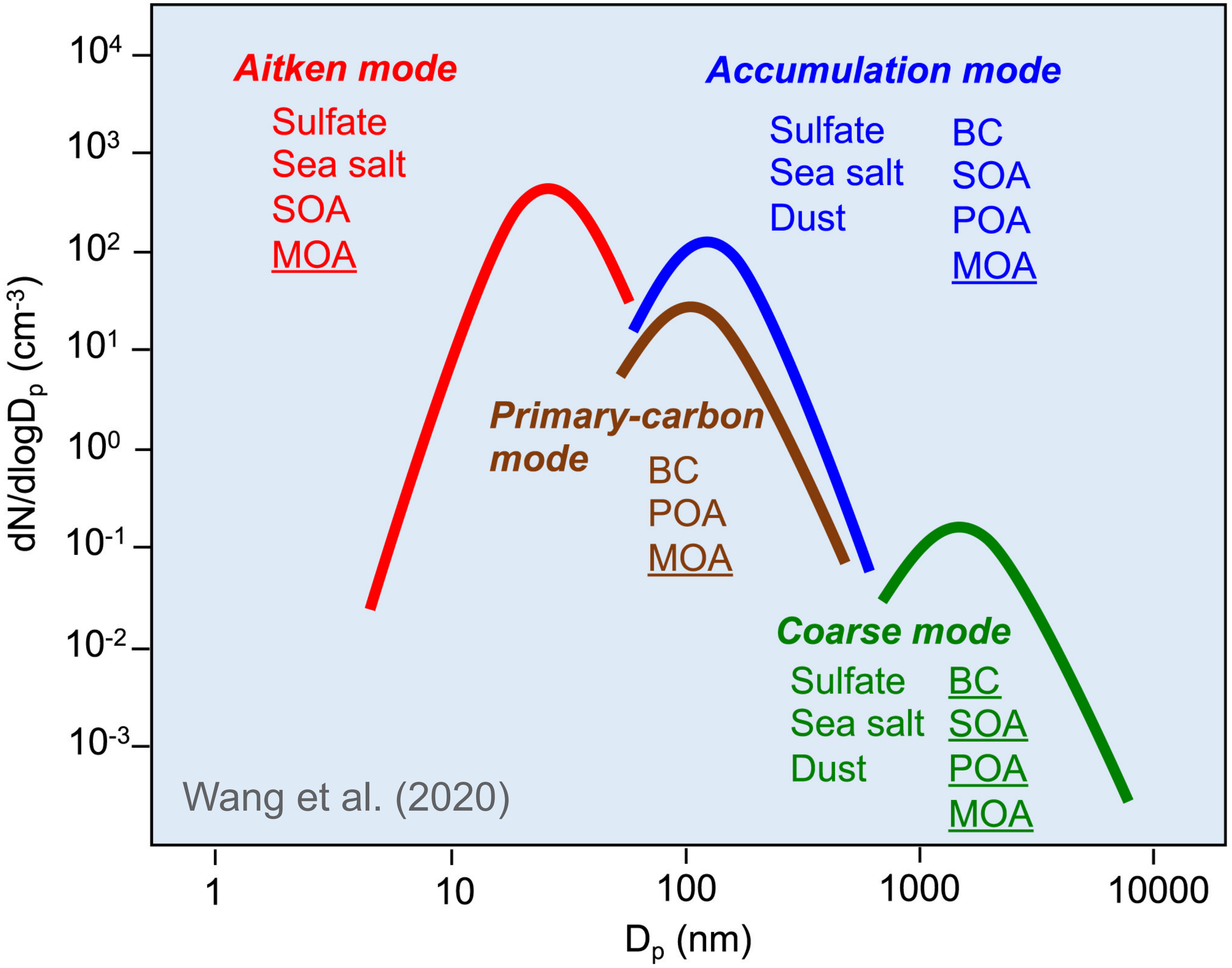
Susannah Burrows

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Aerosol representation in E3SM

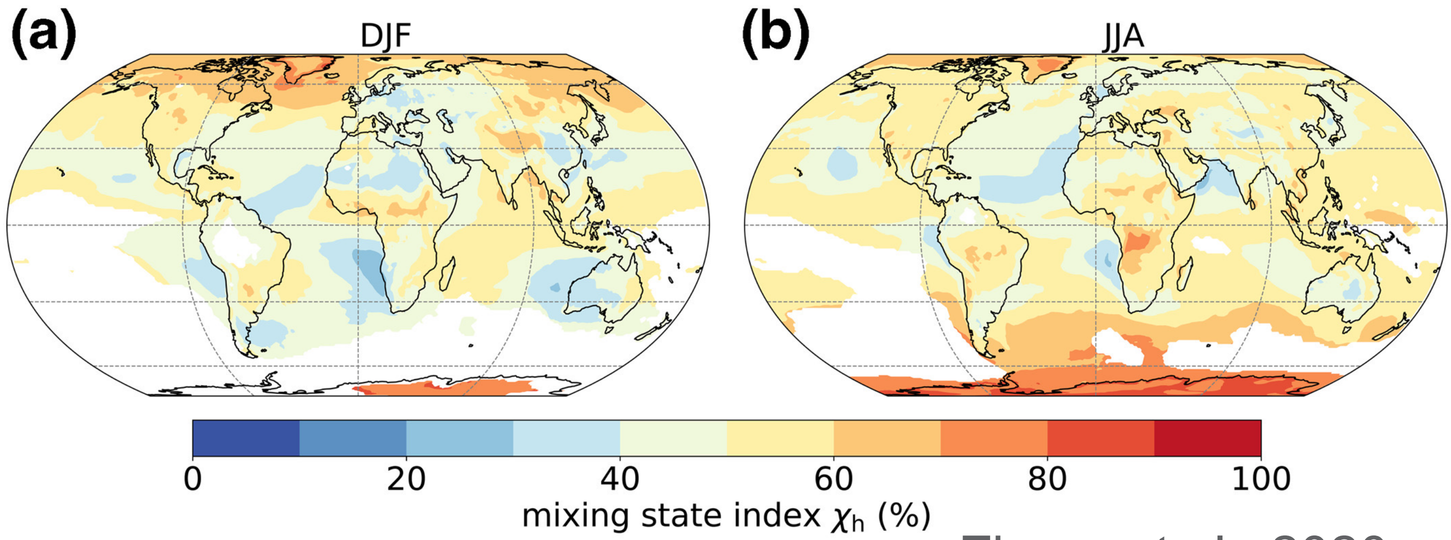
- 4 log-normal modes, each internally mixed (3 soluble, 1 insoluble)
  - 7-mode representation (non-default) provides more detailed size and mixing state information
- 7 chemical species:
  - Sulfate
  - Sea salt
  - Secondary organic aerosol (SOA)
  - Black carbon (BC)
  - Particulate organic aerosol (POA)
  - Marine organic aerosol (MOA)
    (Burrows et al., 2014; 2018)
  - Dust



Microphysical processes including nucleation, condensation, coagulation, resuspension.

Removal processes including wet and dry deposition.

Science question 1: How much do the structural limitations of E3SM aerosol impact the ability to adequately simulate CCN number?



Zheng et al., 2020

Model simplifications include:

- Size distribution
- Chemistry
- Mixing state (potentially important for CCN)

Observations needed:

- Aerosol composition (largely ACSM, also SP2, PSAP)
- Aerosol size distribution (SMPS, UHSAS, APS)
- Kappa-hygroscopicity and/or CCN number concentration (CCN counter, HTDMA, and potentially other instruments)

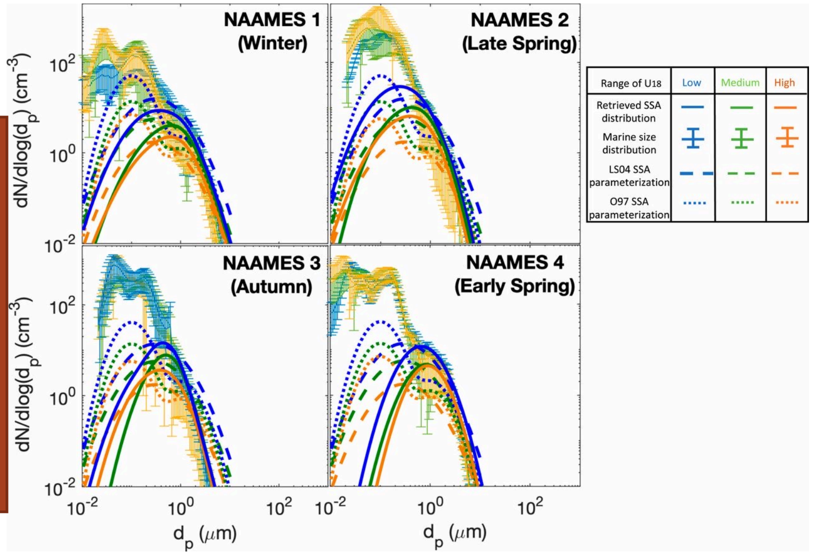
Some previous marine/coastal ARM campaigns (e.g., MAGIC, MARCUS, AWARE, …) measured either detailed aerosol chemistry, or CCN / cloud properties, but not both.

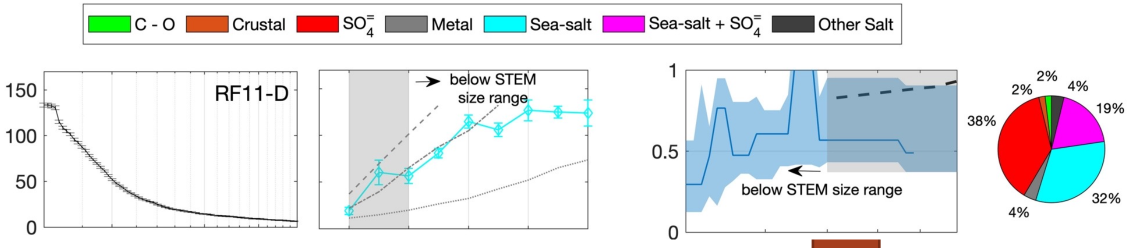
EPCAPE includes these measurements alongside measurements of cloud properties.

Quantifying impacts of model structure on CCN number

Pacific Northwest
NATIONAL LABORATORY

Observed size distribution and size-dependent composition or hygroscopicity





Figures from marine observations; Saliba et al. (2020a,b)

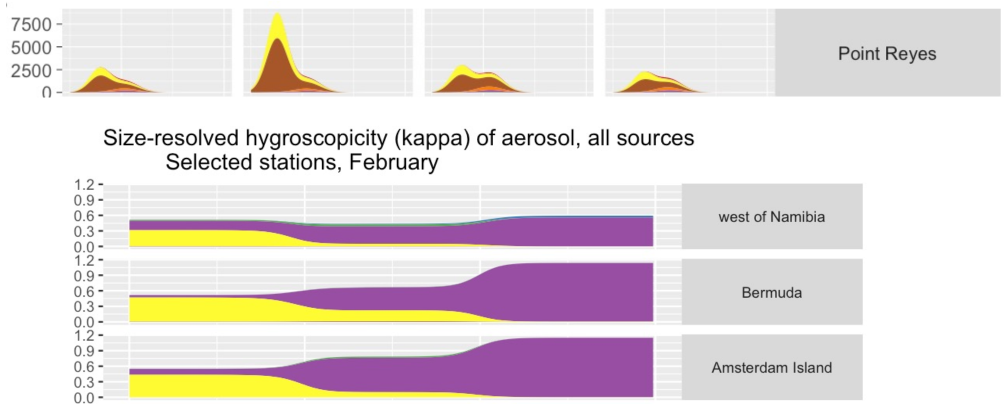


Figure: S. Burrows

Observed aerosol size distribution and hygroscopicity projected into 4 or 7 modes

Simulated aerosol in either 4 modes or 7 modes

Observed CCN(SS%), HTDMA

Errors due to unobserved properties

CCN number from observed aerosol size distribution (SMPS, APS, UHSAS) and chemistry (ACSM, SP2, PSAP)

Errors due solely to projection into the model's microphysics structure

CCN number from observed aerosol properties projected into MAM's 4 or 7 modes

Other simulation errors

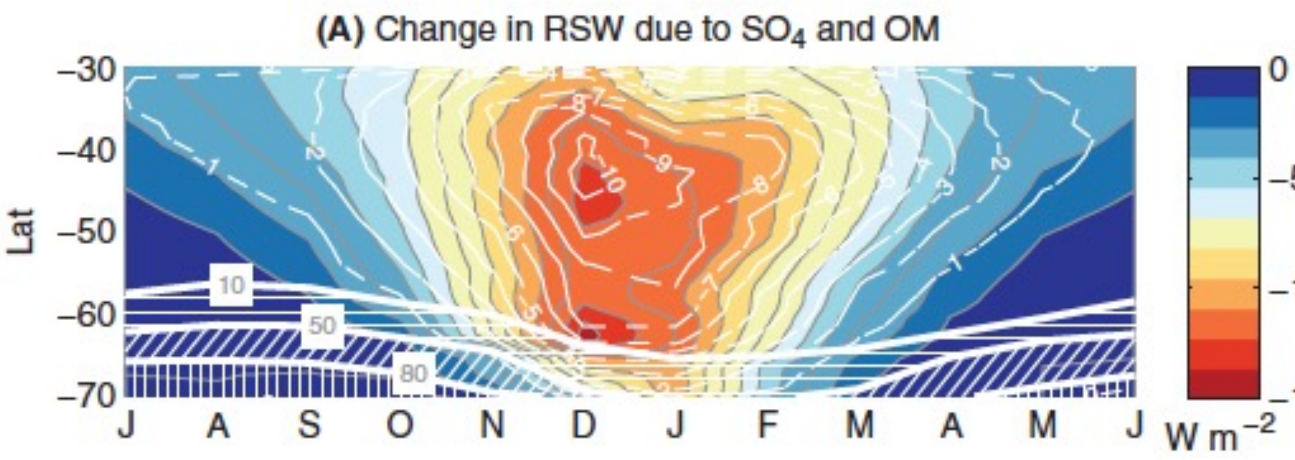
CCN number from simulated aerosol

How much do simulation errors in CCN matter to simulated clouds?

Possible strategies:

1. Apply double-call radiation methods to isolate the cloud droplet number concentration (N_d) response, after applying corrections based on:
   - Model-observation discrepancies in CCN
   - EPCAPE-observed CCN - N_d
2. Initialize Lagrangian LES simulations with aerosol conditions developed
   1. from observations, and/or
   2. from a 3D simulation (regional or global model)

   Compare with a single-column model (SCM; e.g., from E3SM) initialized similarly



McCoy, Burrows et al., Sci. Adv., 2015

More discussion of opportunities for LES-SCM comparisons:
Breakout session on Thursday morning, "High latitude marine post-frontal clouds"

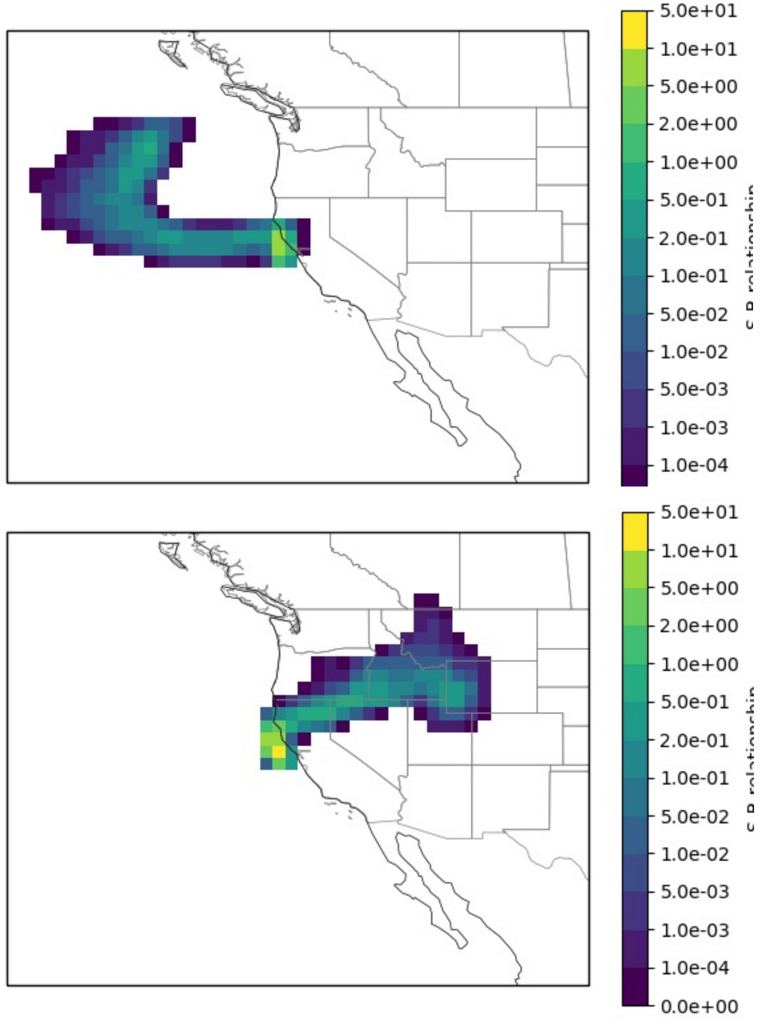
Science question 2: Can we separate the roles of aerosol and meteorology in determining cloud properties in marine and continental airmasses ?

Three approaches to measure “marine influence”:

1. Lagrangian footprint analysis (example at right)
2. Measures of “anthropogenically-influenced air” (AETH, PSAP, O3, SO2, CO2
3. Measures of meteorological influence (e.g., humidity and boundary layer structure)

Previous studies tend to use one or two of these methods.

- Do these three measures always correlate?
- Do cloud properties differ between observation times that have been grouped by the above metrics (either singly or in combination)?



Example: FLEXPART source influence footprints for two different days during the CalWater-2015 / ACAPEX campaign.

Figures by Gavin Cornwell

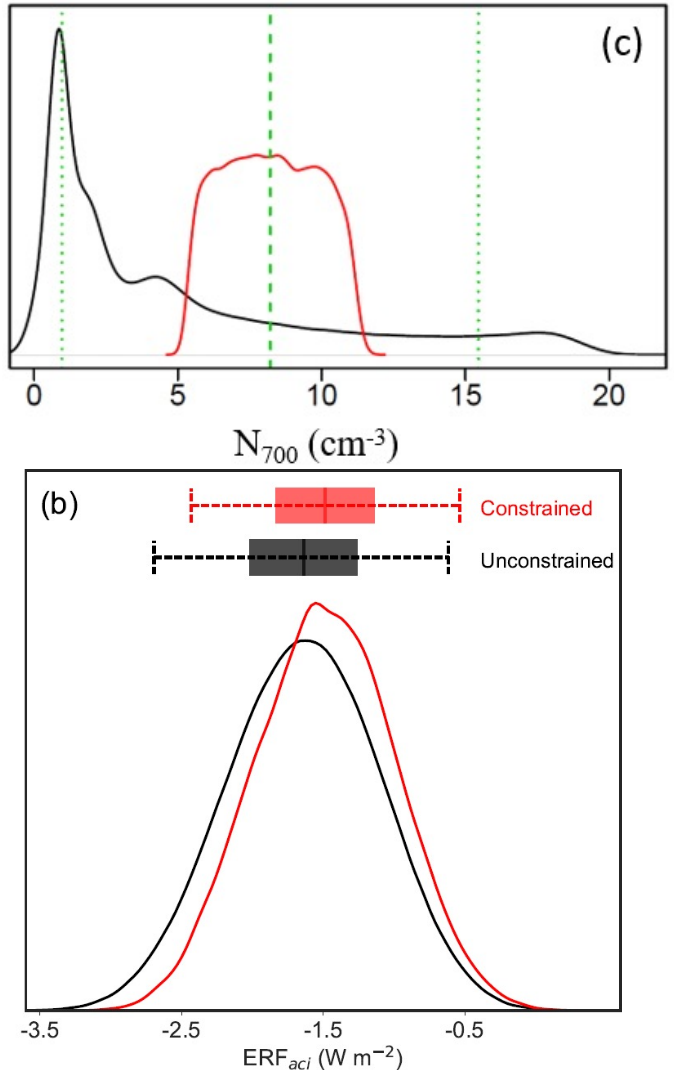
Science question 3: do process rate measurements provide stronger constraints on radiative forcing from aerosol-cloud interactions?

Acknowledgement: discussions with Johannes Mülmenstädt, Sam Silva

- Previous studies show that measurements of aerosol and CCN provide only small constraint on ERF_{aci} (shown at right; Regarye et al., 2020)
- Can we use EPCAPE to evaluate whether *process rate observations (e.g., rain rate)* provide stronger constraints on ACI than state variable observations (*e.g., thermodynamic structure*)?

Approach:

- Build *and emulate* (ML) a perturbed parameter ensemble (e.g., from LES & single-column model)
- Potential observable variables to use as constraints:
  - Rain rate (from multiple disdrometers)
  - CCN # (CCNC); total particle # (CPCF, CPCU)
  - Turbulence (Doppler Lidar)
  - Thermodynamic structure (balloon-borne sondes)



Regarye et al. (2020): constraints

Thank you

E3SM-simulated seasonal aerosol size distributions at marine, coastal, and island locations

- Accumulation mode aerosol largely controls CCN (e.g., at S=0.1%).
  - Largely composed of SOA and SO_4 at most sites
  - SSA plays an important role at remote SH sites
  - Dust is important in Saharan outflow region

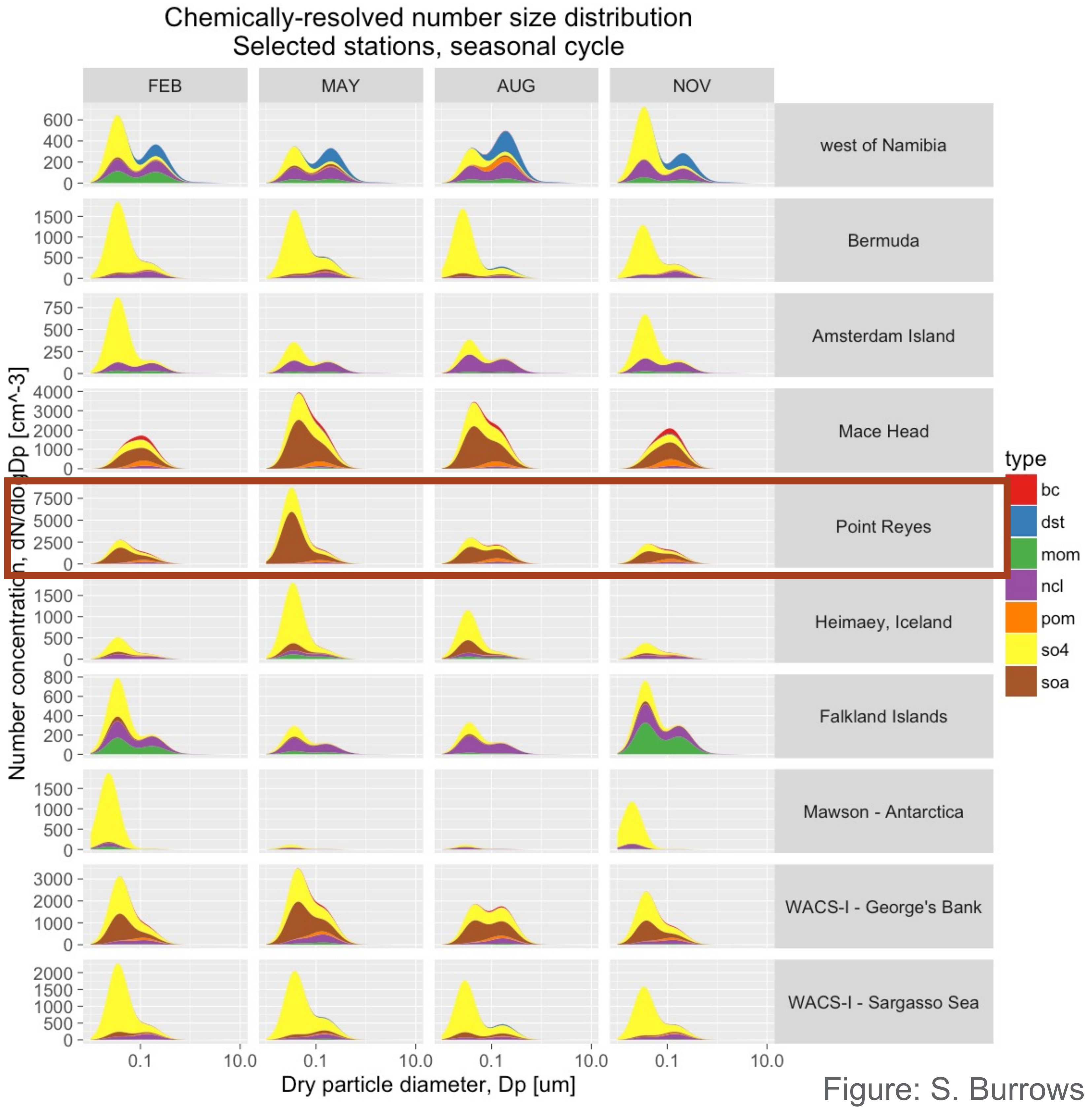


Figure: S. Burrows

Tools and approaches

For studying aerosol sources and long-range transport, and ACI impacts on climate:

E3SMv1 RRM: high-resolution (25 km) simulation over the continental United States (extending past coasts)

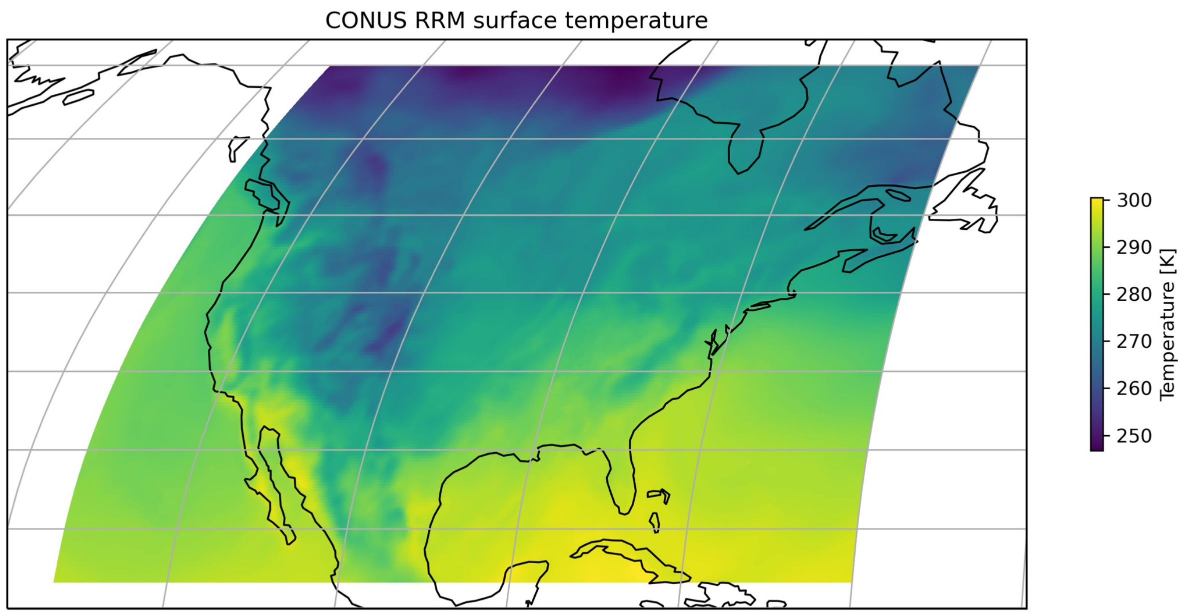


Figure: Aishwarya Raman

For studying boundary-layer turbulence and cloud processes:

- Single-column E3SM
- Doubly-periodic E3SM

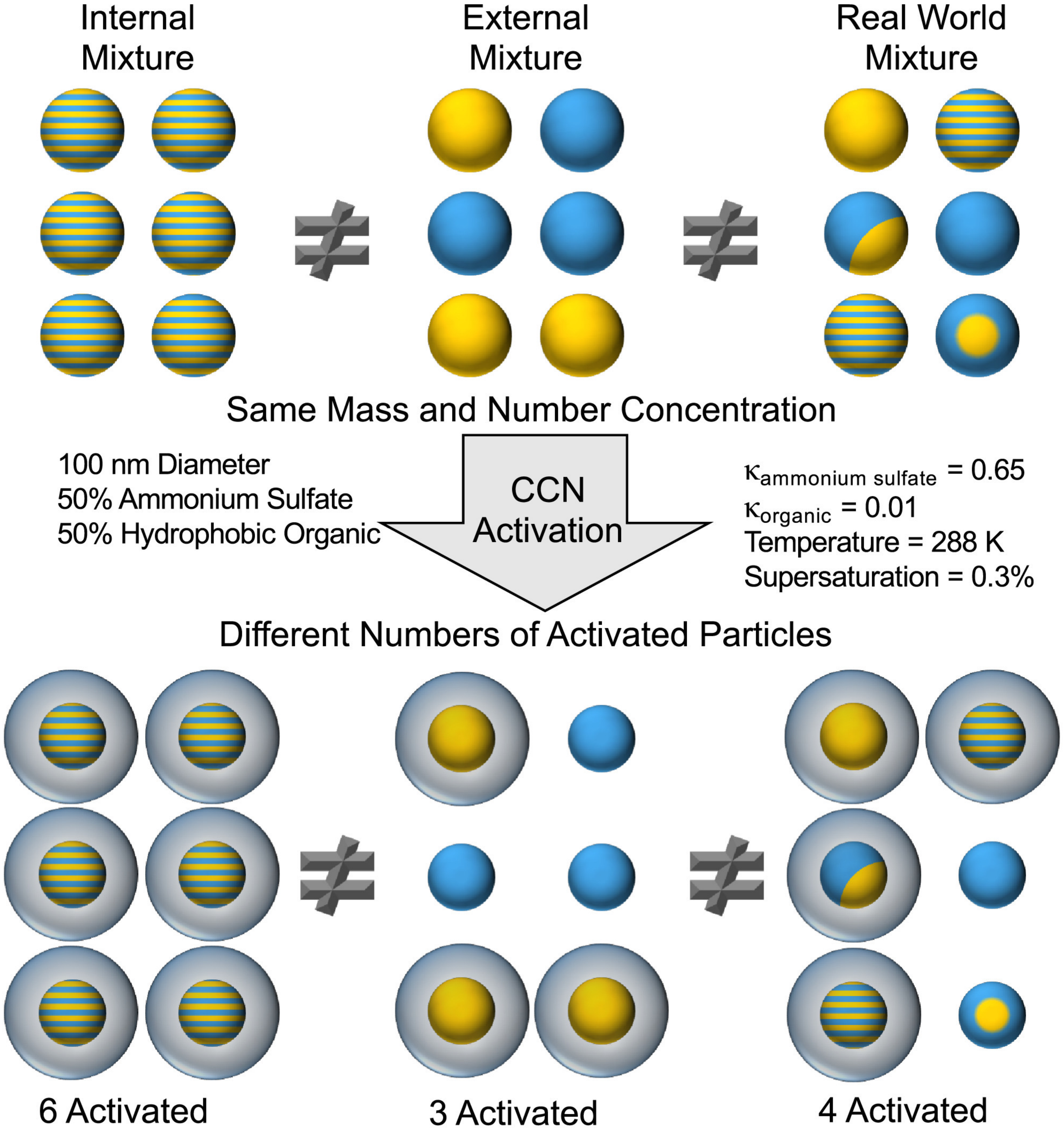
And comparisons of both with LES simulations

Science question 2: Can we separate the roles of aerosol and meteorology in determining cloud properties in marine and continental airmasses?

- Past approaches include:
  - Examine correlations between locally-observed aerosol and meteorological variables
  - Use air quality variables and wind direction to screen for “marine air” (e.g., by applying thresholds for pollution concentrations)
  - ….

- Limitations:
  - Local observations lack air mass history information
  - Difficult to distinguish time periods that are impacted by continental air that has recirculated over the ocean
    - ✓ This air has a mixture of continental and marine influences …
    - ✓ … on aerosol state, and
    - ✓ … on atmospheric thermodynamic state (e.g., boundary layer structure)

Impacts of mixing state on activation



(Riemer et al., 2019, Rev. Geophys.)