Pacific Northwest NATIONAL LABORATORY

ACTIVATE
Aerosol Cloud Meteorology Interactions Over the Western Atlantic Experiment

Single-Column Model Simulations: Results and Plan

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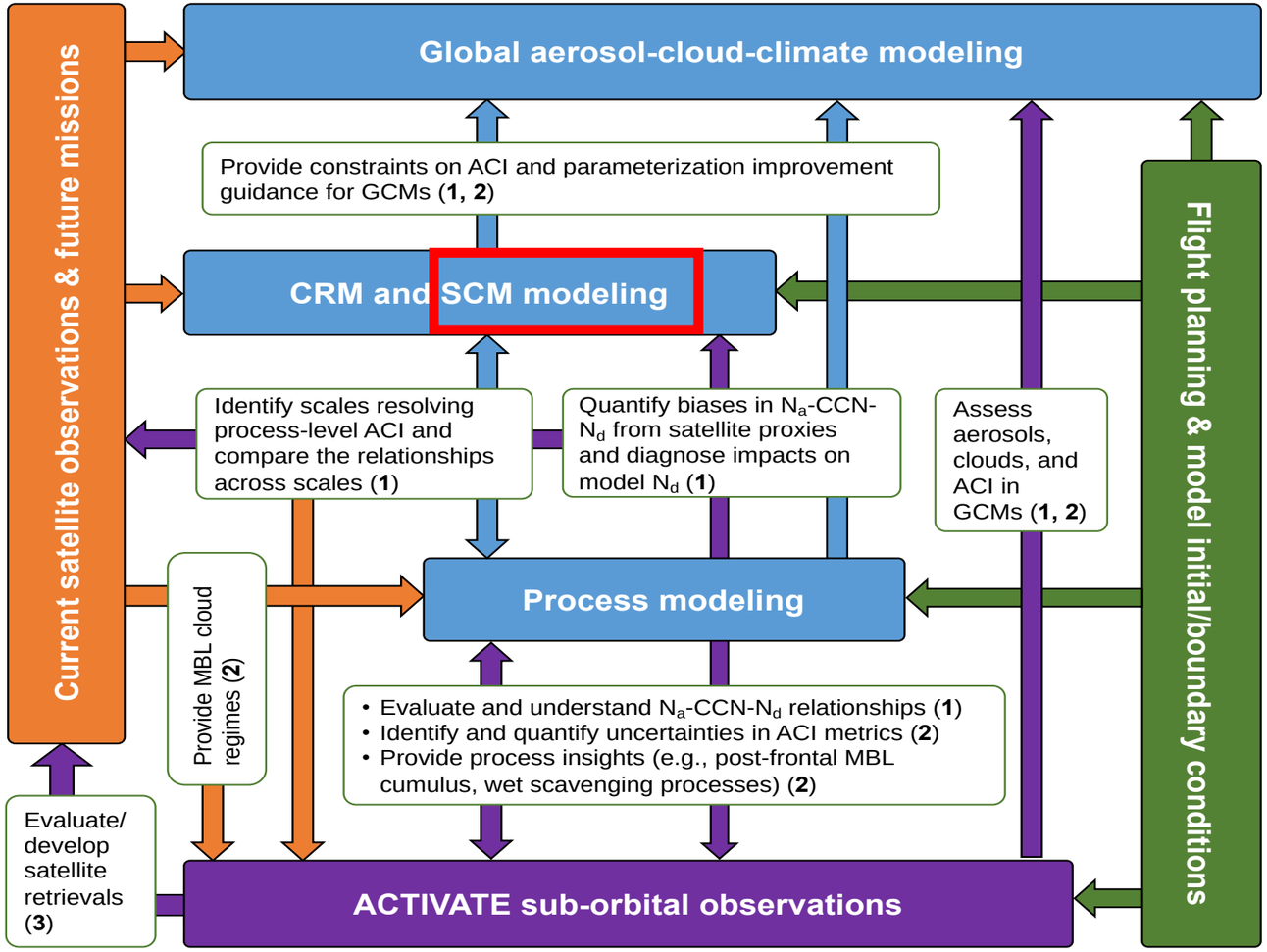
Motivation

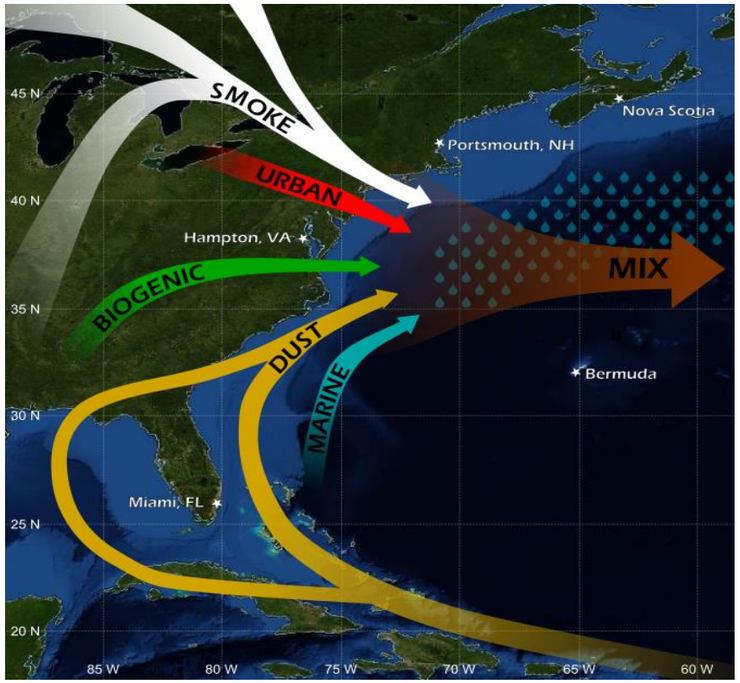
- Quantify and understand biases in N_a-CCN-N_d in GCMs and process models (LES, CRM).
- Understand ACI and cloud susceptibility in SCM.
- Provide constraints on ACI and parameterization improvement guidance for GCMs.

hierarchy of multi-scale **LES-CRM-SCM-GCM** model intercomparison

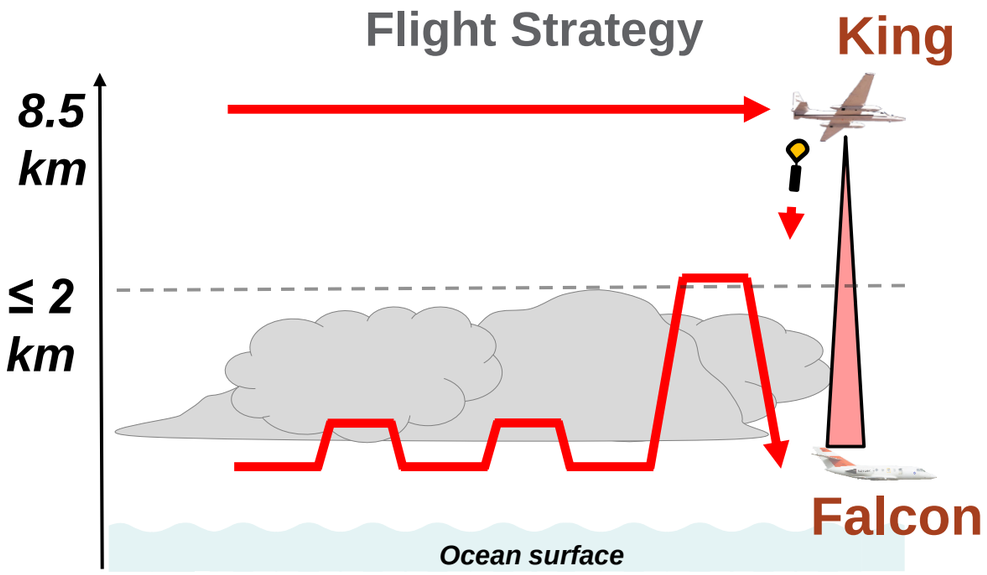


ACTIVATE field campaign

The Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (ACTIVATE)



Two simultaneous aircrafts providing "collocated" in-situ and remote-sensing measurements



162 flights in total during 2020-2022

E3SM SCM setups

SCM is an efficient way for debugging, detailed process-level understanding, and sensitivity testing

E3SMv2:

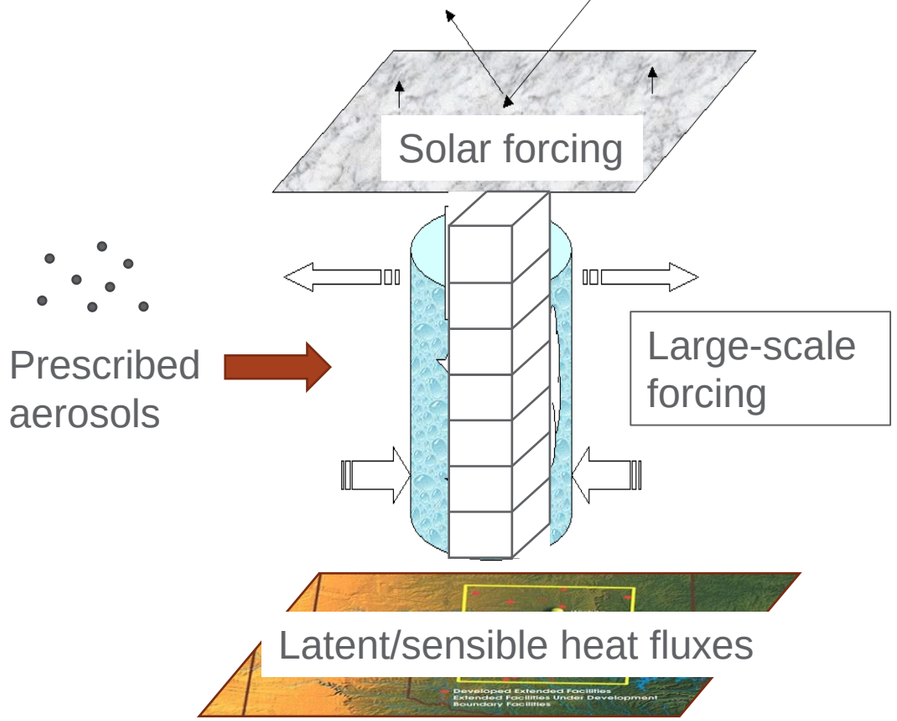
- Deep convection: **ZM**
- Shallow + turbulence + macro: **CLUBB**
- Micro physics: **MG2**
- Aerosol: **MAM4** (inactive in SCM mode)

SCM setup:

- prescribed large-scale forcing, surface LH/SH fluxes, and aerosols (from E3SM climatology run or from observation)
- Nudging run .vs. hindcast run (discuss later)

E3SM single-column model (SCM)

(Bogenschutz, Tang et al., 2020)



Case Study

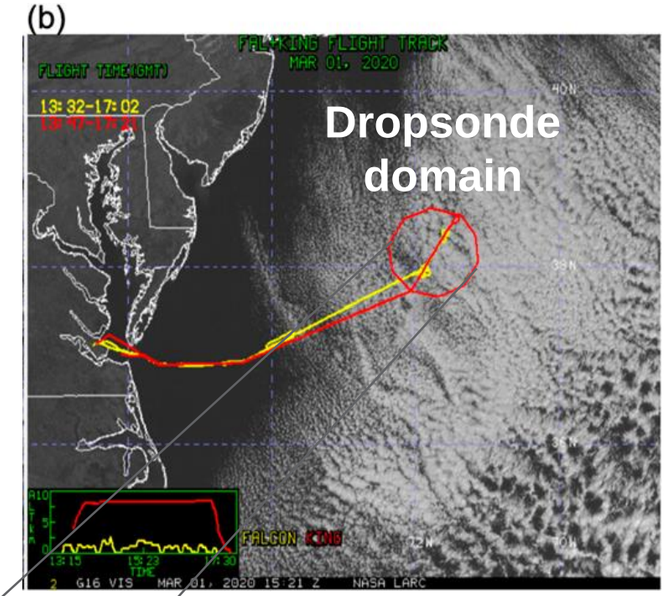
- Intercompare with LES and CRM
- Evaluate with aircraft measurements
- Sensitivity test for ACI understanding

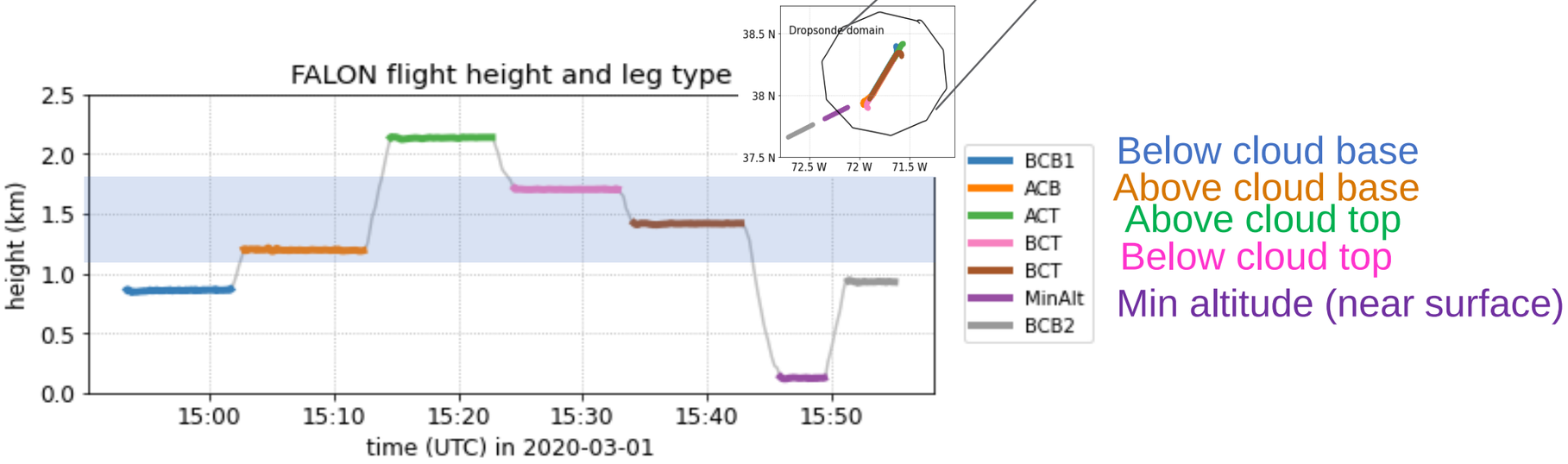
Long-term Simulations

- Statistical/robust analysis and evaluation
- Intercompare with full GCM simulations
- Provide guidance on model development

Case description (1 March 2020)

- 11 dropsondes
- ~ 110 km diameter
- 7 in-situ flight legs from near-surface to above-cloud (5 in the circle)

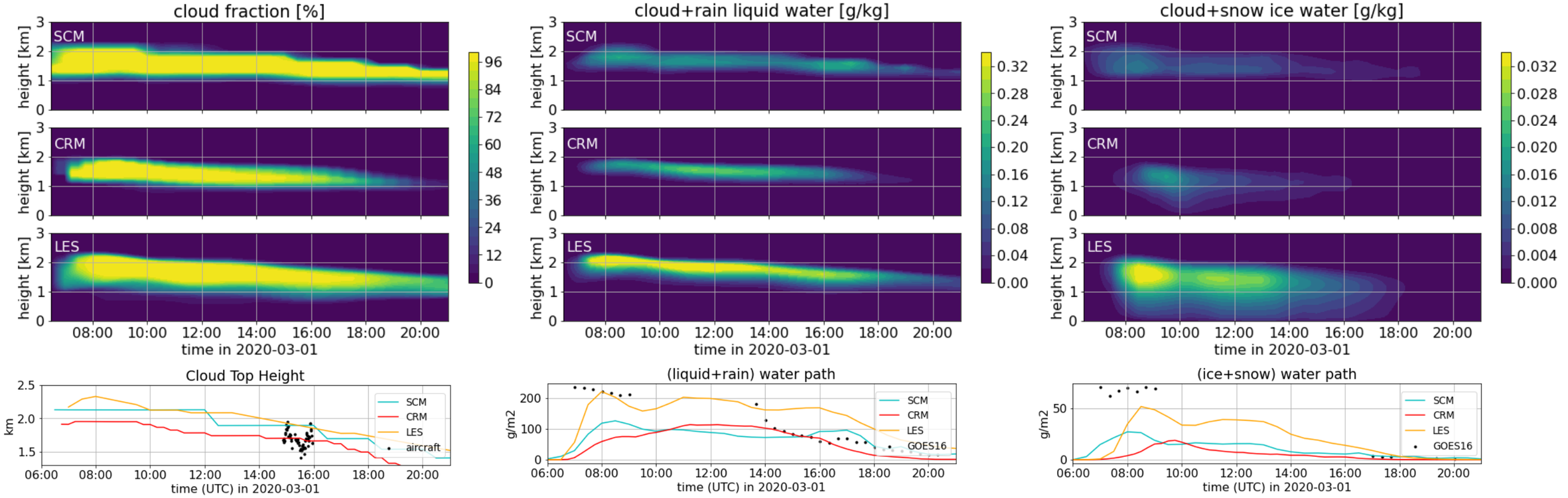




SCM performance and intercompare with LES/CRM

- **SCM**: E3SMv2 SCM, prescribed climatological aerosol.
- **WRF-CRM** (Chen et al., 2022): nesting regional simulation initialized with ERA5. inner domain resolution 1km. Prescribed Nd.
- **WRF-LES** (Li et al., 2022, 2023). 300m resolution. Prescribed Nd.

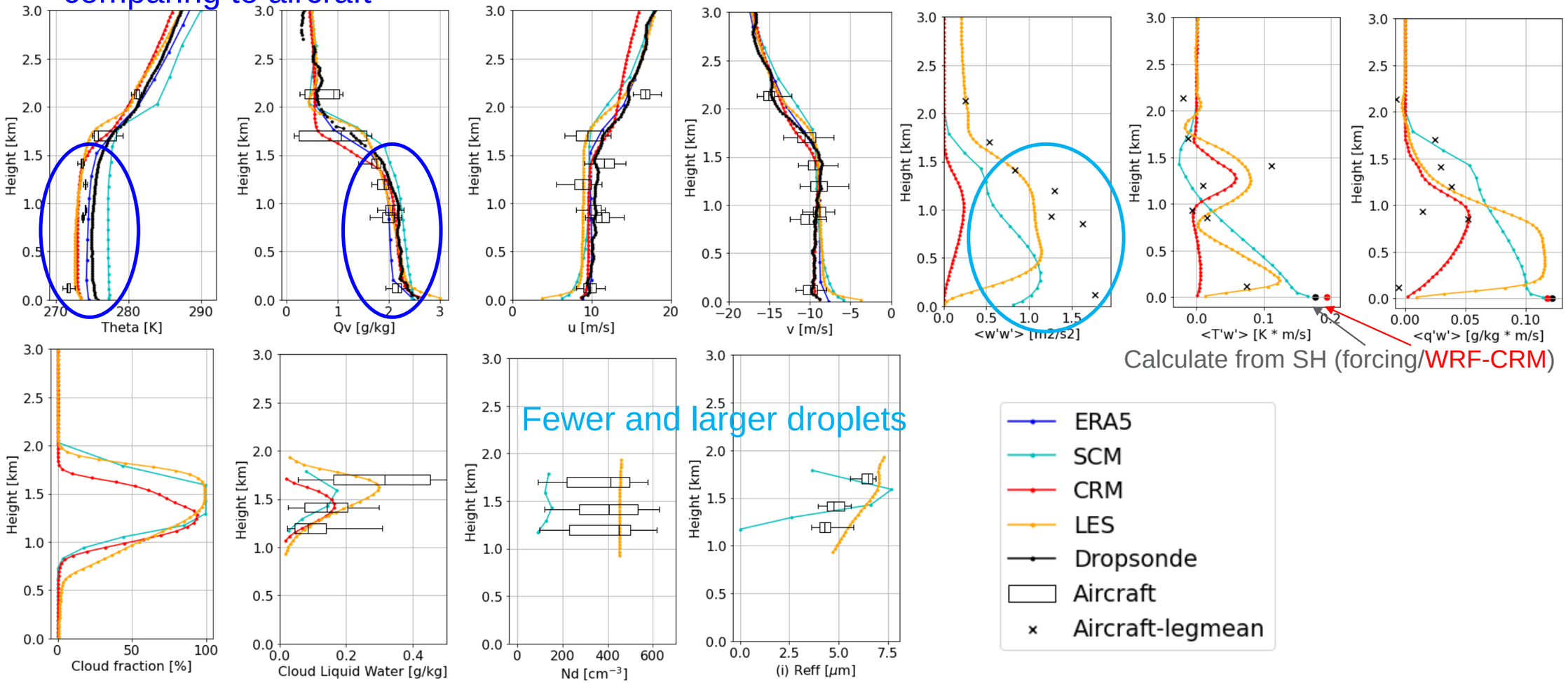
- Well simulated MBL cloud (CRM captures cloud rolls)
- Consistent with observed cloud height and water paths



SCM performance and intercompare with LES/CRM

ERA5 is reported colder and dryer than dropsonde, but not comparing to aircraft

Weaker turbulence



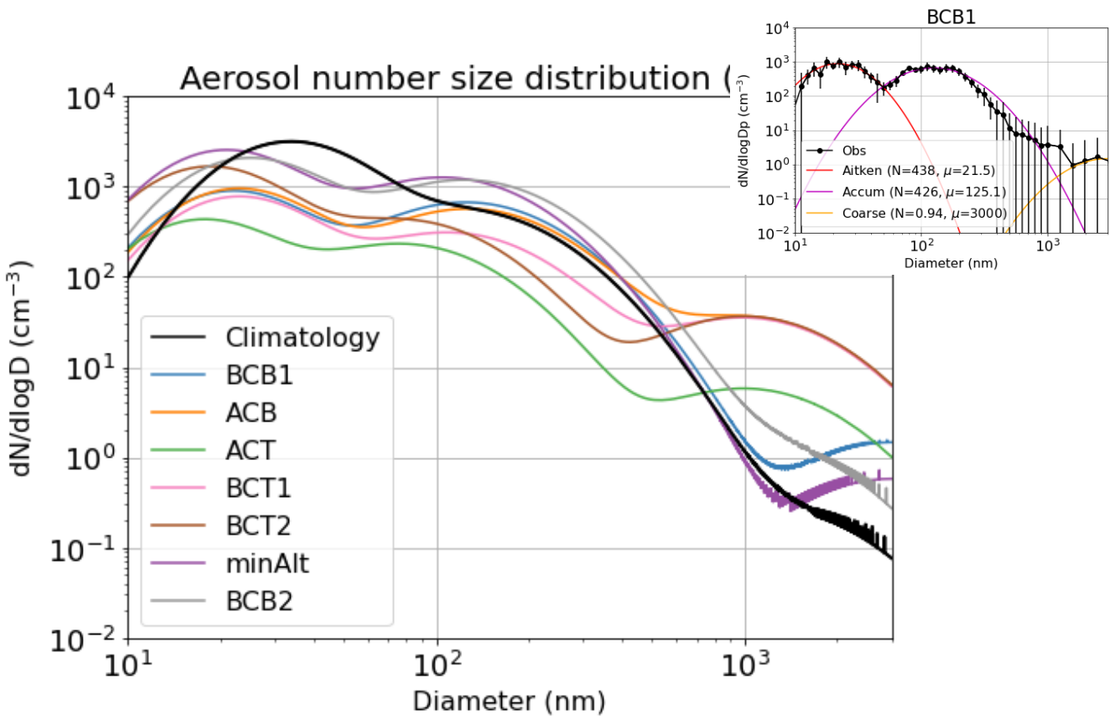
Calculate from SH (forcing/WRF-CRM)

Fewer and larger droplets

Sensitivity on aerosol properties

Sensitivity to aerosol number/size

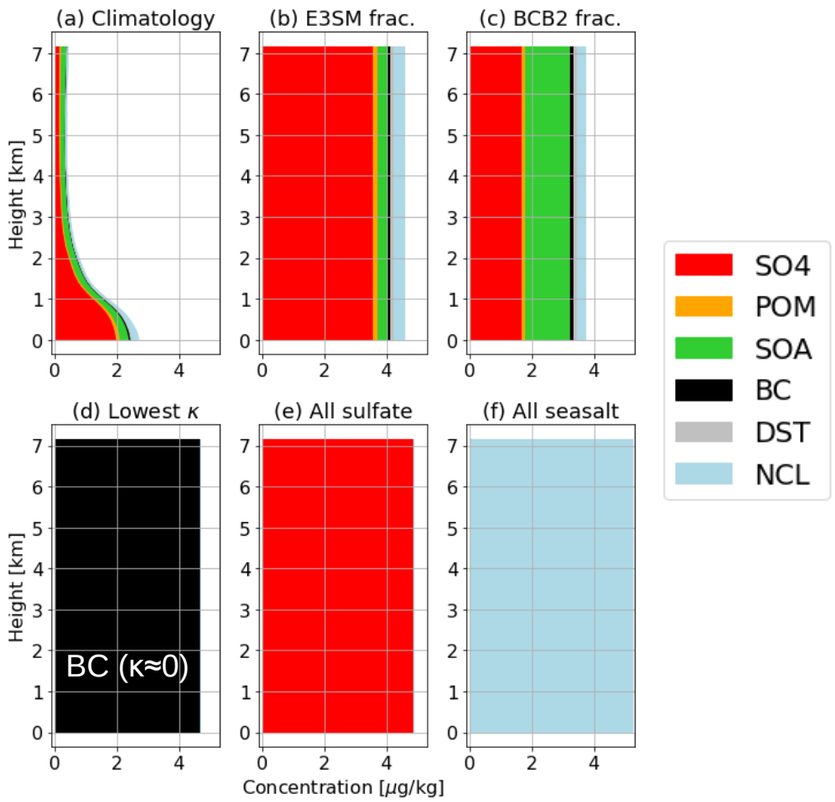
- Fit aircraft measurements (LAS+SMPS) from 7 legs into log-normal distribution



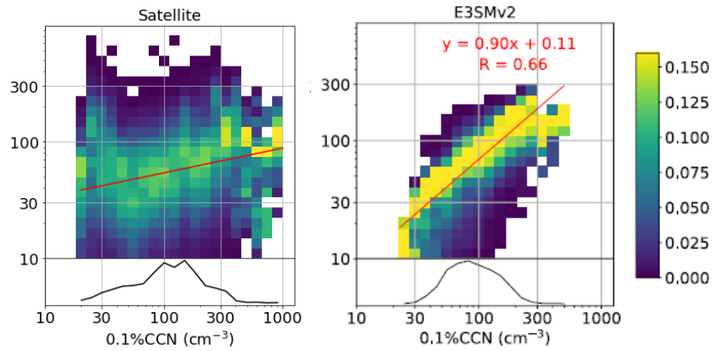
Sensitivity to aerosol composition/hygroscopicity

- Use BCB2 aerosol number and size
- Observed and idealized aerosol composition

Only change SO4 and SOA



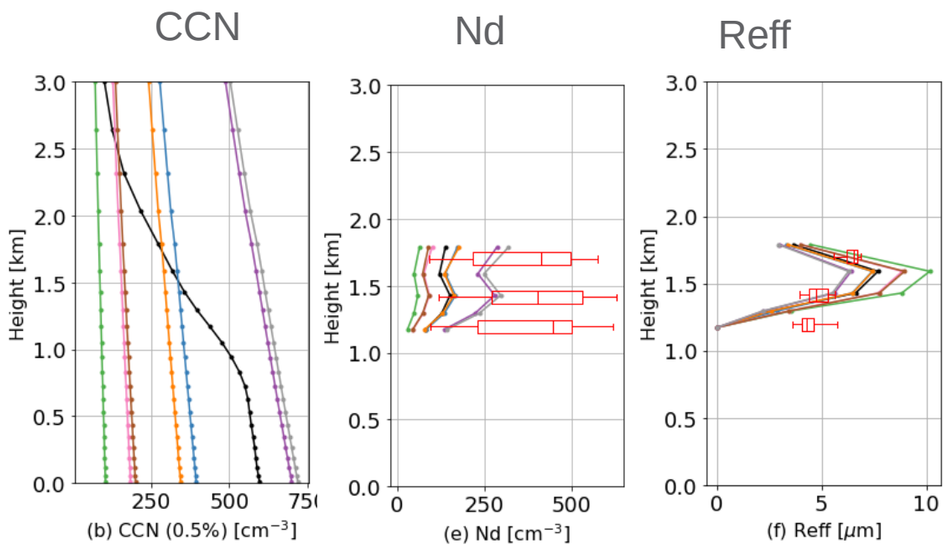
Clear Twomey Effect

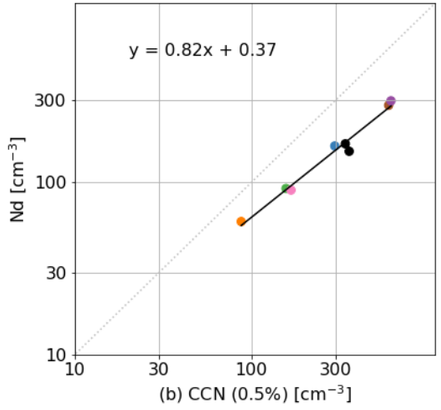


$\frac{dlnN_d}{dlnCCN}$ **OBS** **GCM@ENA**

Tang et al. (2023)

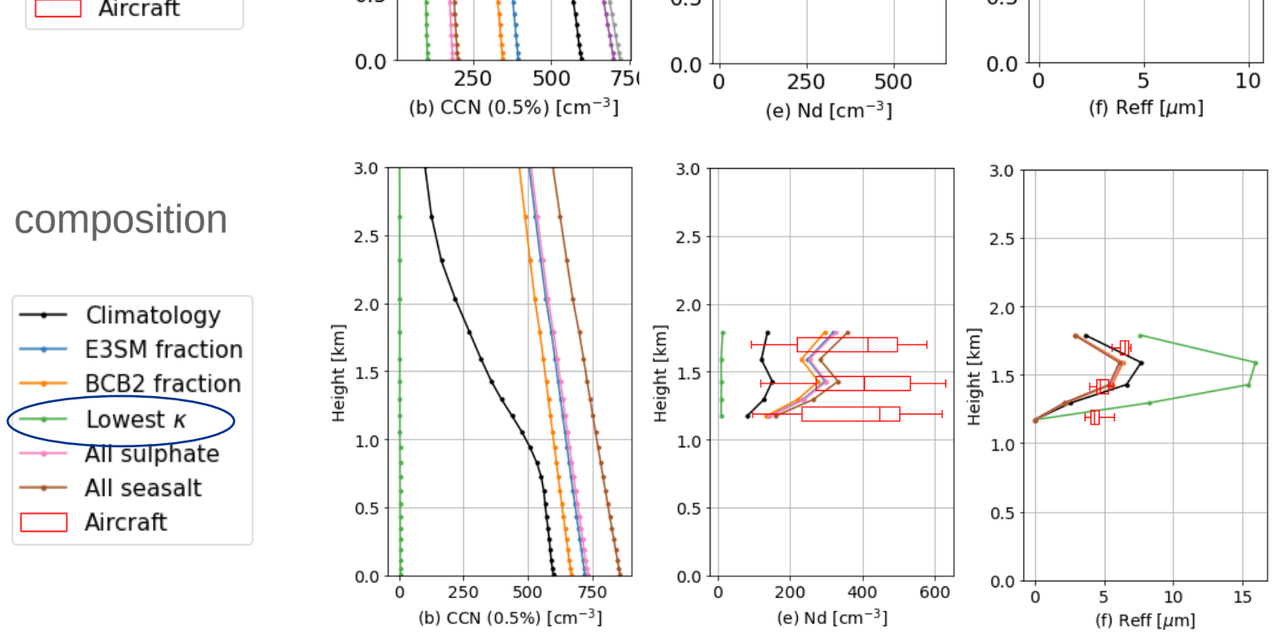
size distribution

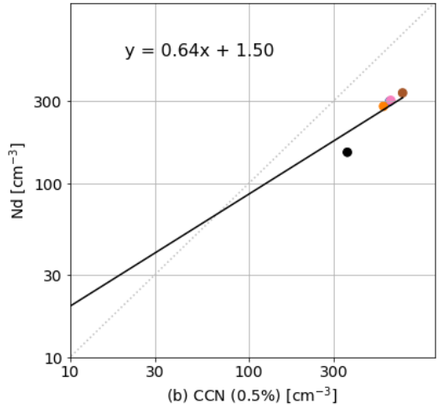




Clear $\frac{dlnN_d}{dlnCCN}$ relation similar to GCM results, too strong compared to observation

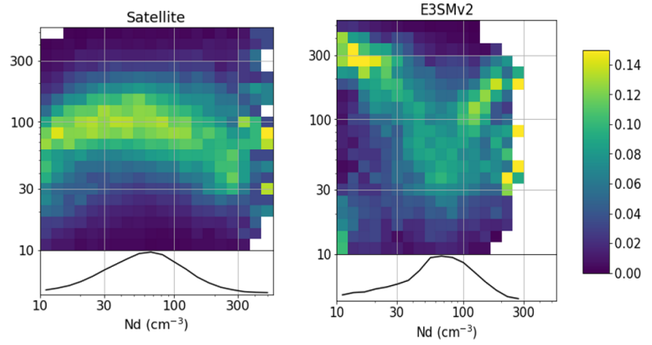
composition





κ values between 0.31 to 1.6 have minor impact

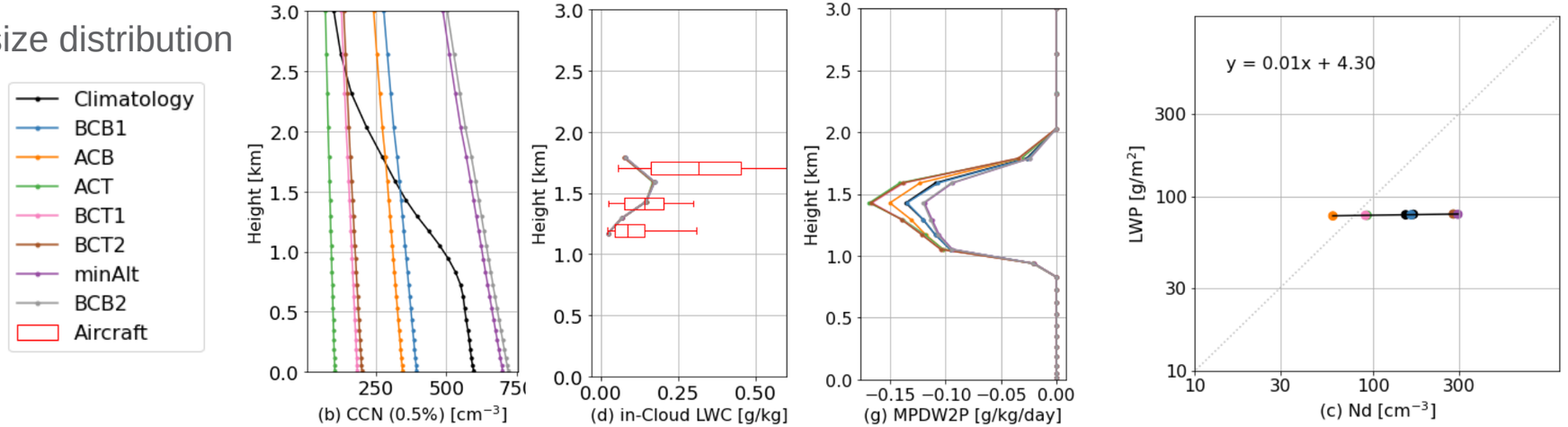
Weakly positive LWP adjustment



Tang et al. (2023)

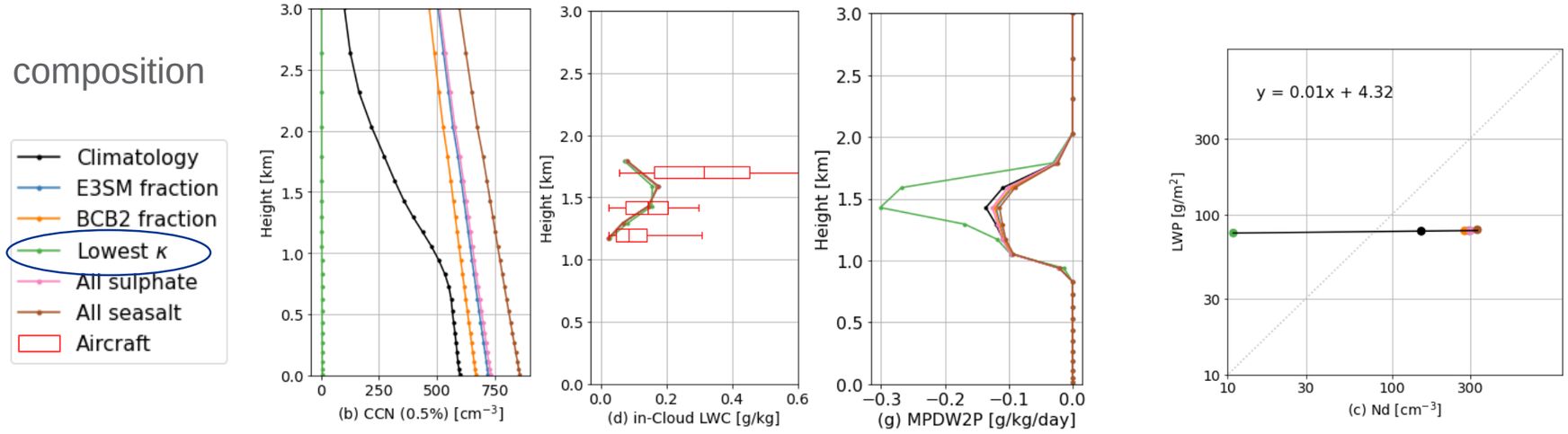
CCN | LWC | Water→Precip | $\frac{dlnLWP}{dlnN_d}$

size distribution



Inconsistent $\frac{dlnLWP}{dlnN_d}$ in SCM/GCM/OBS

composition



Weak positive LWP adjustment due to precipitation suppression

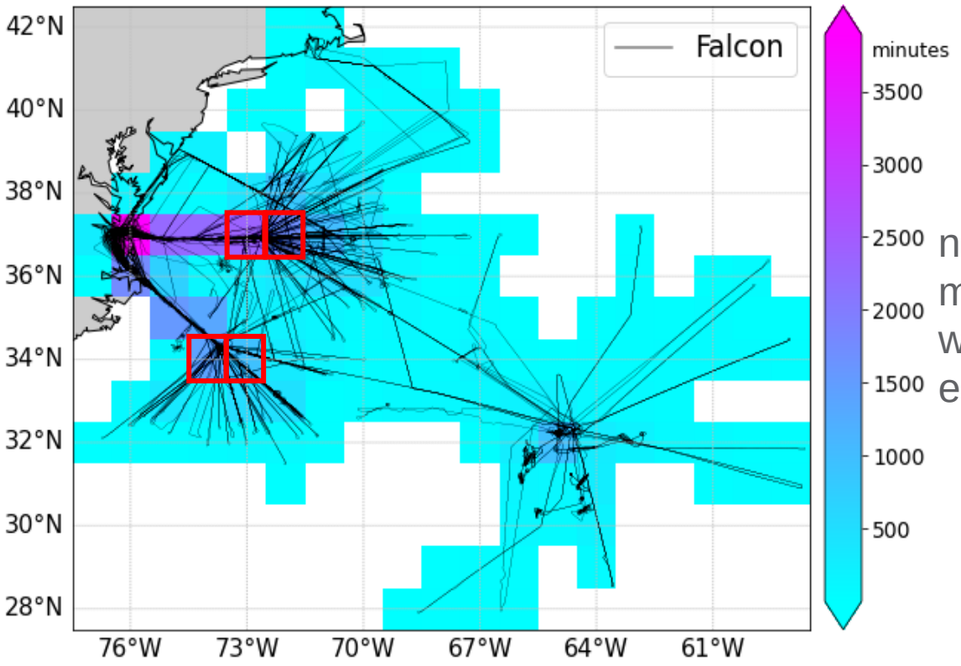
Long-term SCM simulations (ongoing)

- Why does SCM produce different LWP-N_d relation than full GCM?
  - Case specific?
  - Covariance with dynamical/thermodynamical fields?
  - Do technical treatments (nudging, prescribed forcing) impact LWP susceptibility?

Long-term SCM experiment design:

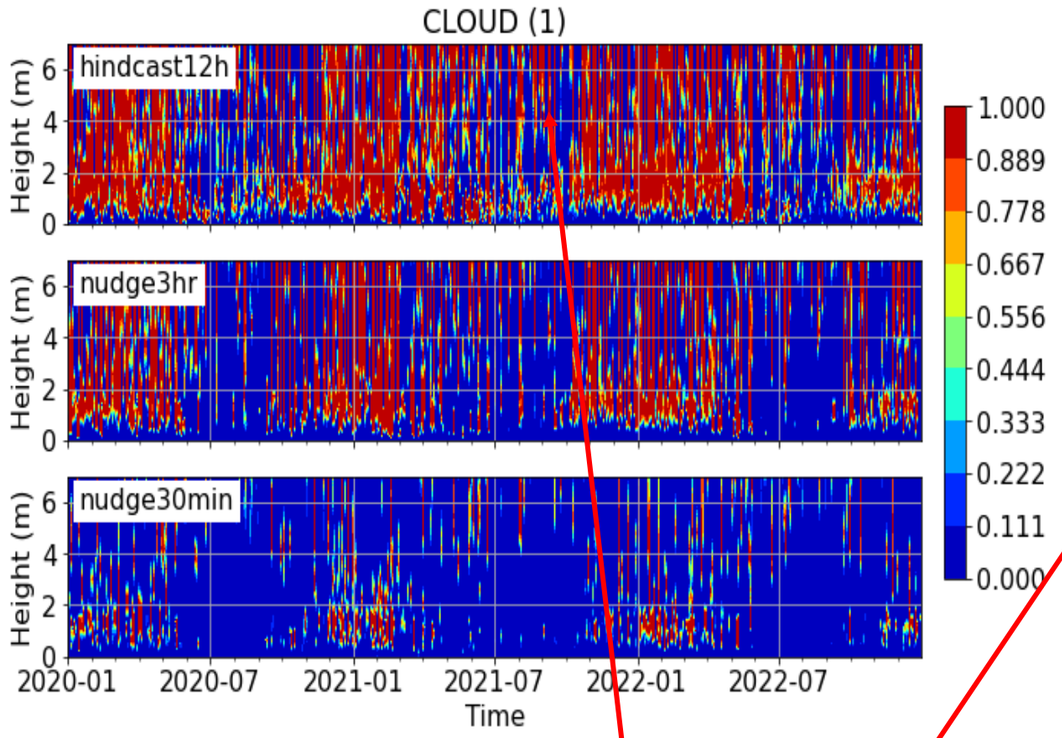
3-year continuous SCM simulations in a few high-traffic grids to create robust statistics

- **Nudging T, q**:
  - constrain environmental condition
  - impact feedback to thermodynamics
- **Hindcast run** (restart everyday and combine short-term simulations into a long timeseries):
  - T and q not drifting too far away (still greater than nudging run)
  - replicate biases in GCM



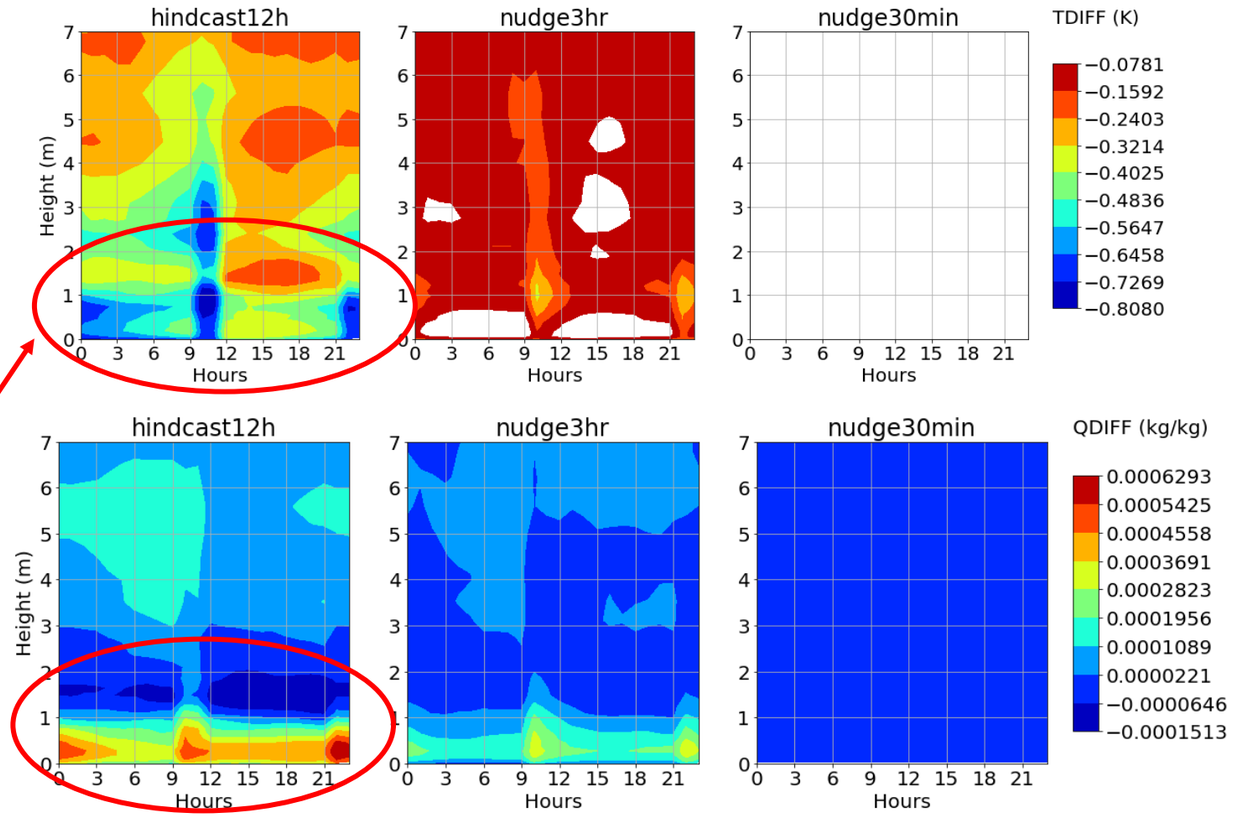
number of minutes Falcon was flying in each 1x1 grid

Preliminary results for long-term simulations



Hindcast12h
(free run)

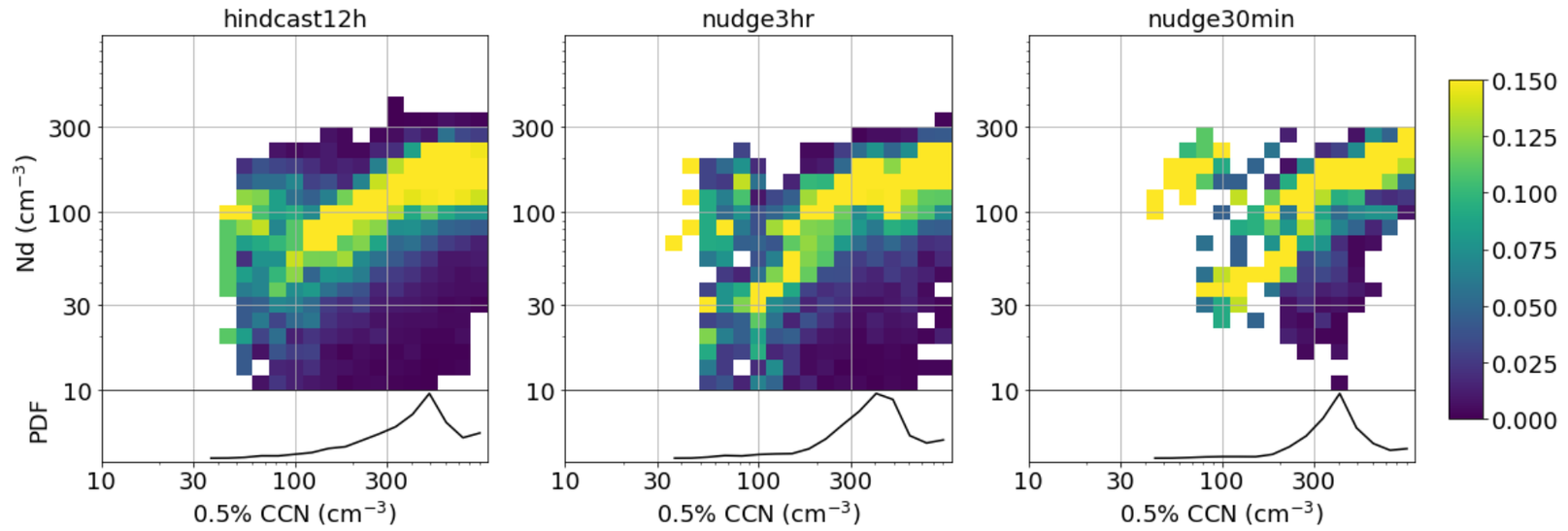
Nudge30min
(zero T and q bias)



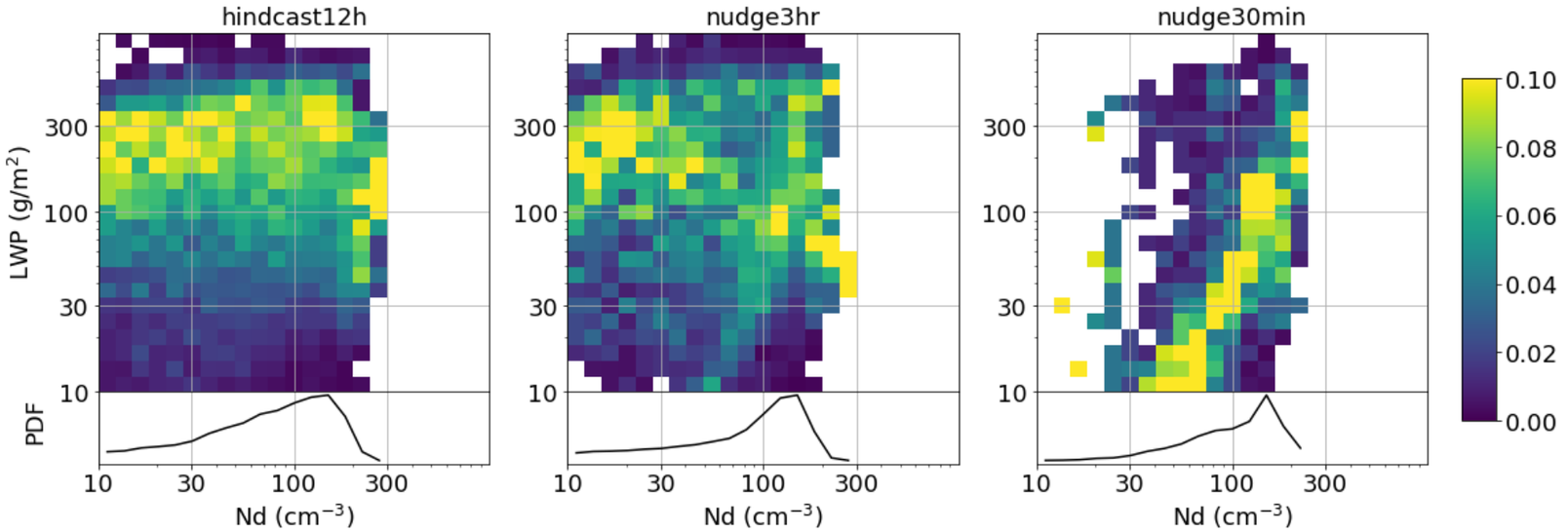
Colder, wetter and more cloudy in hindcast run

Cloud susceptibilities in different SCM setups

$$\frac{dlnN_d}{dlnCCN}$$



$$\frac{dlnLWP}{dlnN_d}$$



Summary and Discussions

- E3SM SCM reasonably reproduce the observed clouds in the 1 March case.
  - Fewer accumulation mode Na and CCN
  - Fewer Nd and greater droplet size
  - Weaker turbulence (w variance)
- Sensitivity study shows that
  - SCM produces **clear Twomey effect**, consistent with GCM but stronger than observations
  - SCM produces **very weak LWP adjustment**. dNd/dLWP is slightly positive, mainly due to rain suppression. This is different with E3SM GCM and observations.
- Long-term SCM simulations ongoing
  - A few sensitivity experiments designed
  - Different SCM setup strategies impact LWP susceptibility analysis
  - More diagnostics/analysis with satellite/aircraft measurements ongoing…