Atmospheric Process and Global Modeling and Evaluation Using ACTIVATE Data

PNNL Team:

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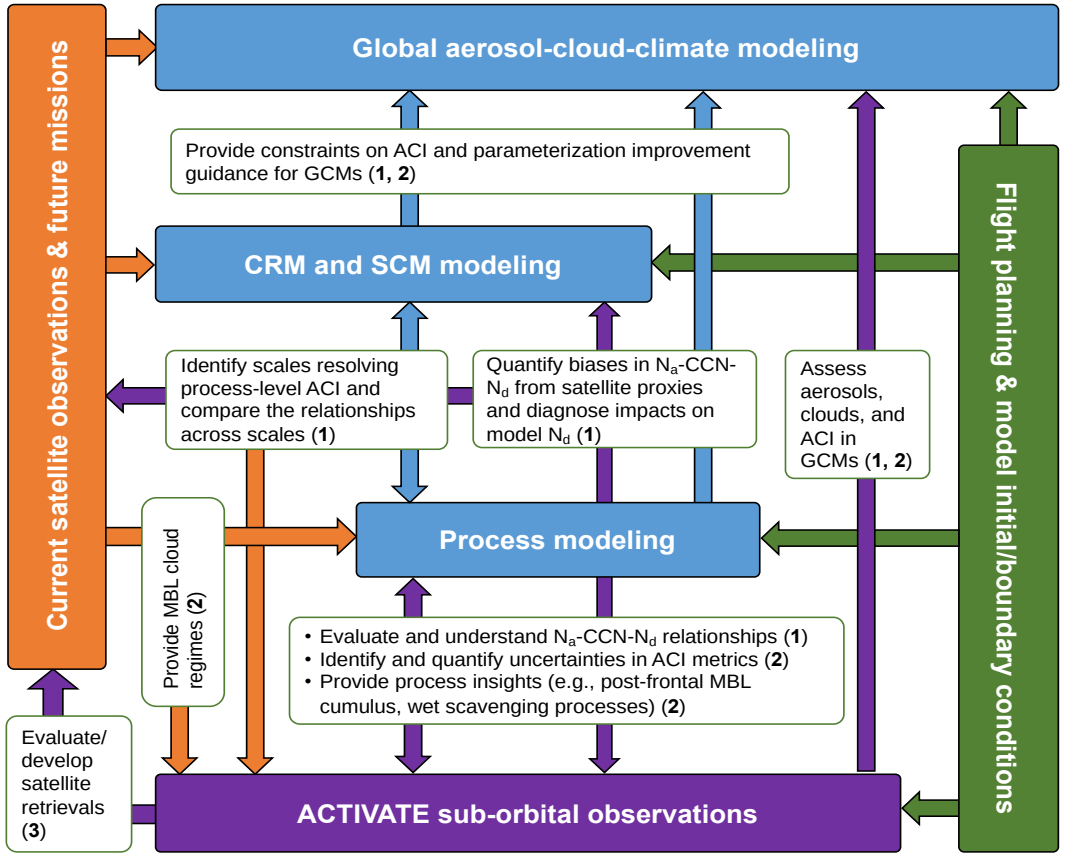
Outline/Objectives

- To provide process insights and quantify N_a-CCN-N_c relationships under different meteorological conditions with observational constraints from the measurements
  - WRF Large-Eddy Simulation (LES)
  - WRF Cloud-Resolving Modeling (CRM)
- To evaluate/improve the representation of ACI processes in ESMs
  - Diagnostic package for regional/global models
  - Sing-column E3SM simulation
  - Global model simulation



(Sorooshian et al., 2019)

WRF Large-Eddy Simulations (LES) for understanding AMCI in cold air outbreaks and summer precipitating clouds

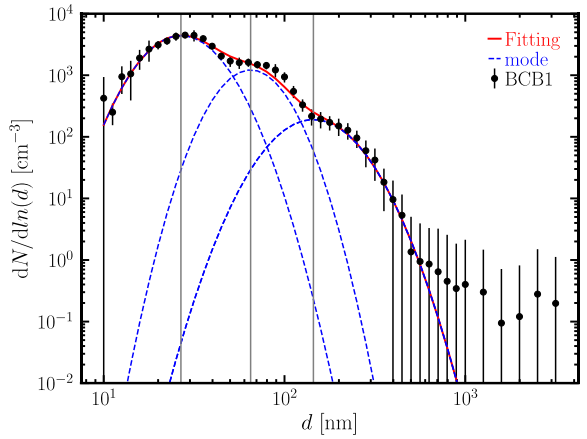
Idealized-case WRF-LES:

- Domain: 60x60 km^2 with periodic boundary conditions
- Resolution: 300 m and 100 m, 152 layers (up to 7 km)
- Meteorological profiles, advective forgings and surface fluxes from ACTIVATE and/or ERA5
- N_a, N_c and other measurements from ACTIVATE and satellite

Science objectives:

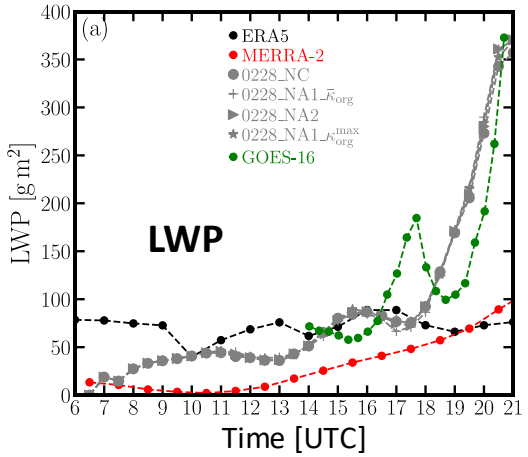
- Quantify sensitivities of CAO clouds and MBL structures to large-scale forcings (Li et al., 2022)
- Study AMCI in CAO clouds (Li et al., revised)
- Study AMCI in summer precipitating clouds (Li et al., in prep; poster)

Aerosol size distribution

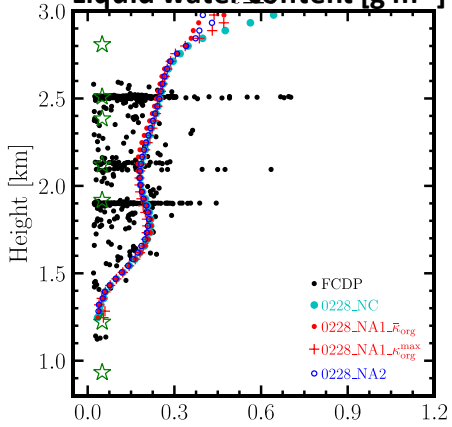


Susceptibility

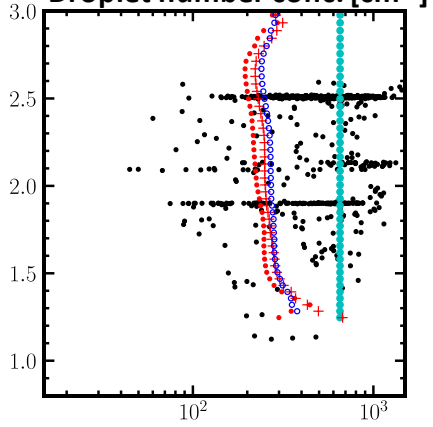
Case	$\Delta \ln \overline{\mathrm{LWP}} / \Delta \ln \langle \overline{N_c} \rangle$	$-\Delta \ln \langle \overline{r_{\mathrm{eff}}} \rangle / \Delta \ln \langle \overline{N_c} \rangle$	$\Delta \ln \overline{\tau_c} / \Delta \ln \langle \overline{N_c} \rangle$
28 February	0.150	0.269	0.419
1 March	-0.002	0.318	0.316



Liquid water content [g m^{-3}]



Droplet number conc. [cm^{-3}]



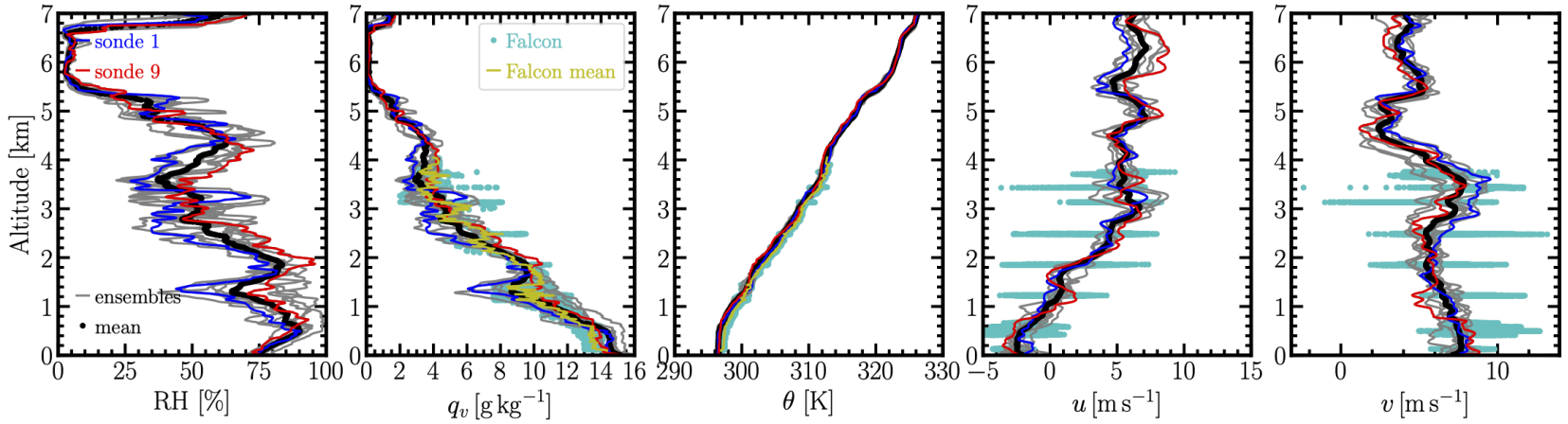
WRF-LES study of summer precipitating cumulus cases

- Simulated four summer precipitating cases:
  - June 2, 2021 (example)
  - June 7, 2021
  - June 10, 2022
  - June 14, 2022

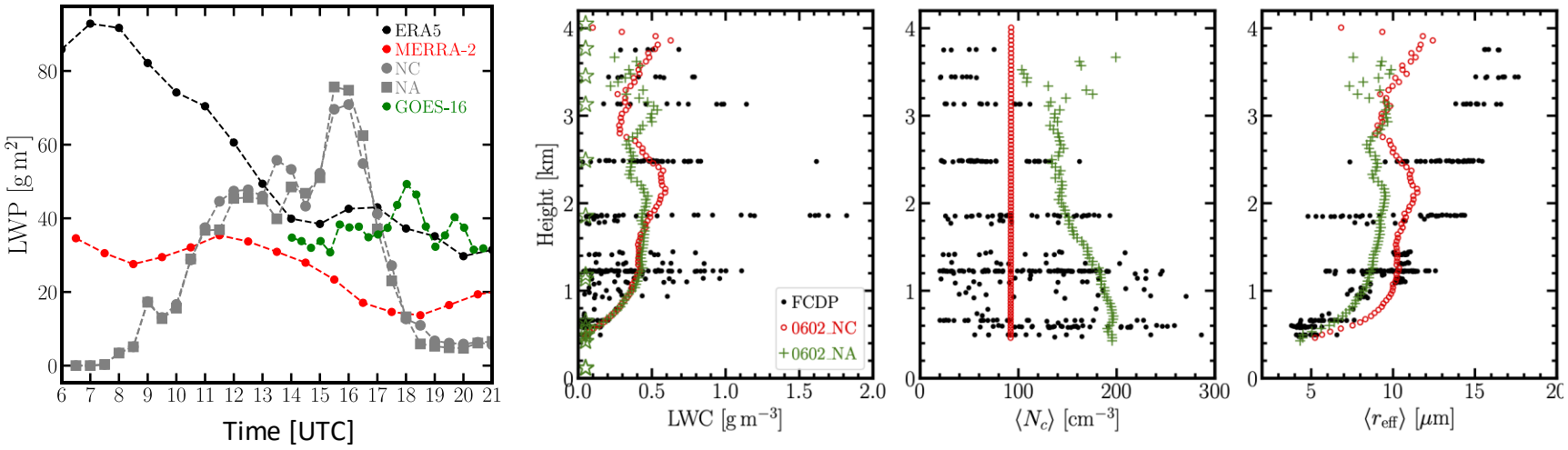
- More challenging for LES to capture the measured clouds (i.e., depth and evolution)
  - Forcing conditions
  - Spatial variability (e.g., large spread in obs)

(Li et al., in prep; Poster)

Vertical profiles from dropsondes and Falcon



Modeled cloud properties in comparison with measurements



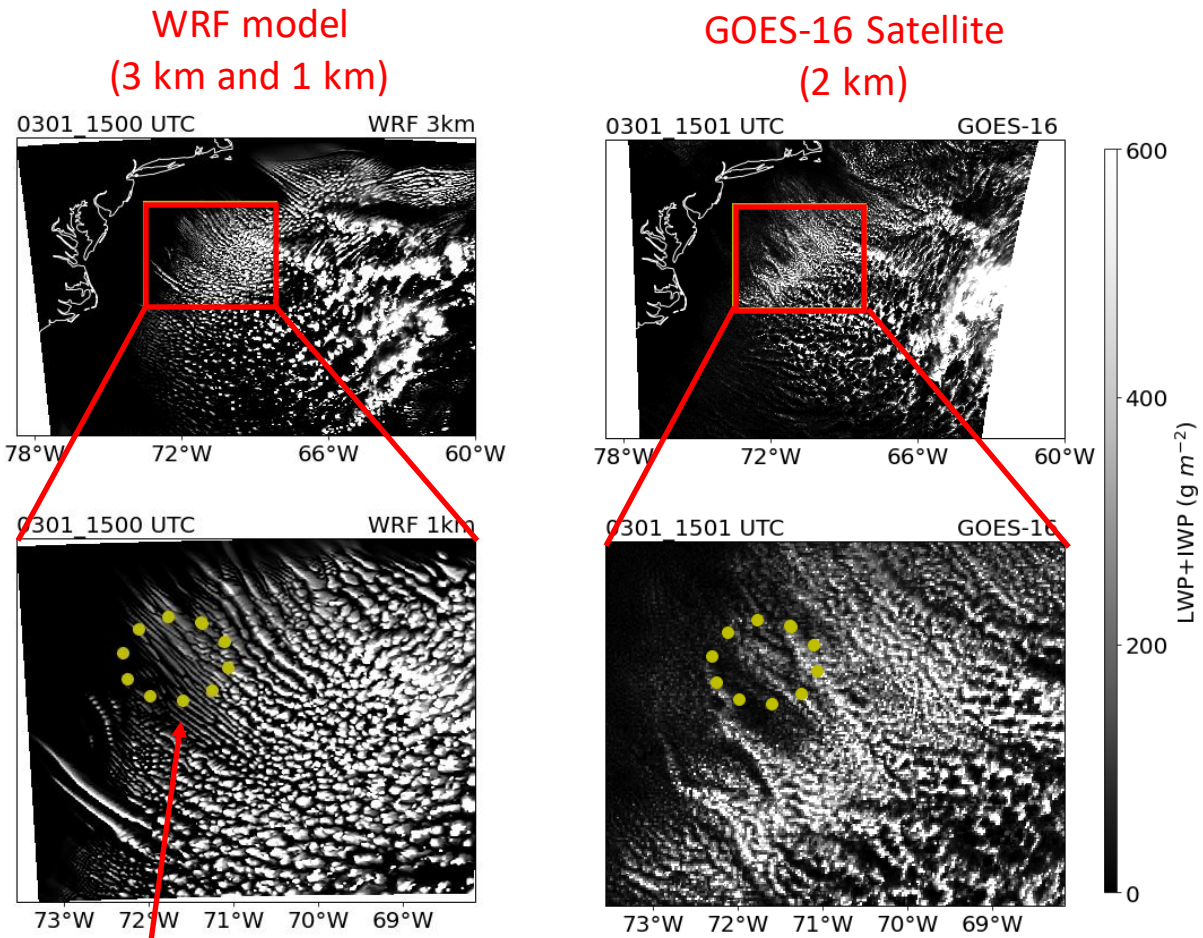
WRF Cloud Resolving Model (CRM) study of organized mesoscale convective cloud structures during cold air outbreaks (CAO)

Nested-domain WRF-CRM:

- Domain: 1650x1650 km^2, 450x450 km^2
- Resolution: 3 km, 1 km
- Vertical: 150 layers up to 16 km; 130 layers in the lower 6 km
- Realistic boundary conditions and SST (ERA5, FNL)

Science questions to answer:

- What are the meteorological factors that determine the CAO cloud morphology and control the roll-to-cell transition? (Chen et al., 2022)
- What is the role of cloud top entrainment and mixing? (Chen et al., in prep; poster)
- What are the roles of aerosols and cloud microphysics? (Future work)

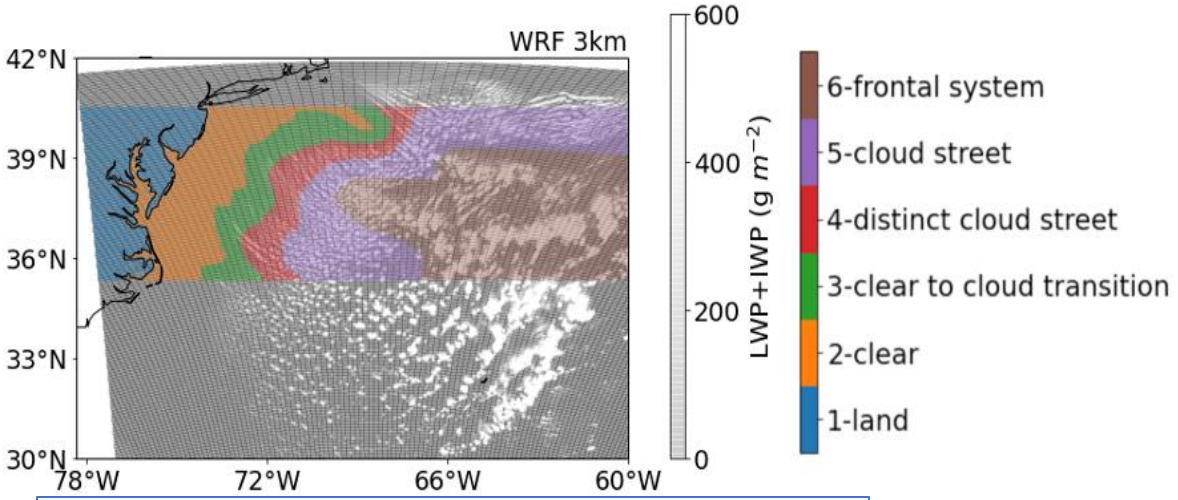


(Chen et al., 2022)

WRF-CRM study of organized mesoscale convective cloud structures: during CAO: Role of Cloud Top Entrainment

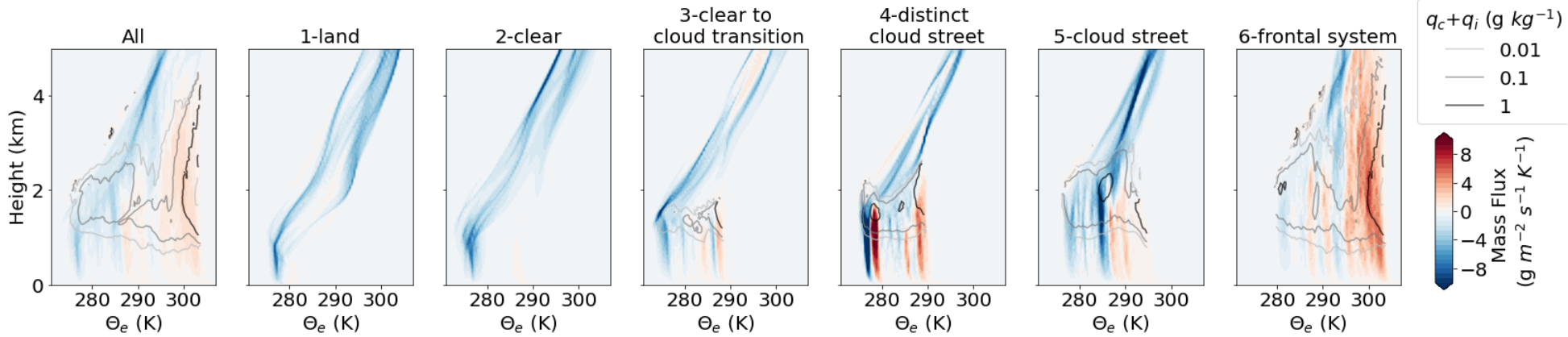
(Chen et al., in prep; Poster)

- WRF-CRM simulations shows distinct transitions between clear, cloud rolls, and broken cumulus
- Band structures in the roll-to-cell transition indicate a shift to a stronger mixing (more convective state) of the MBL, a less important role of the surface fluxes, and a more important role of FT entrainment
- Comparison of WRF-CRM results and ACTIVATE aircraft measurements of air parcel properties (invite contributions)

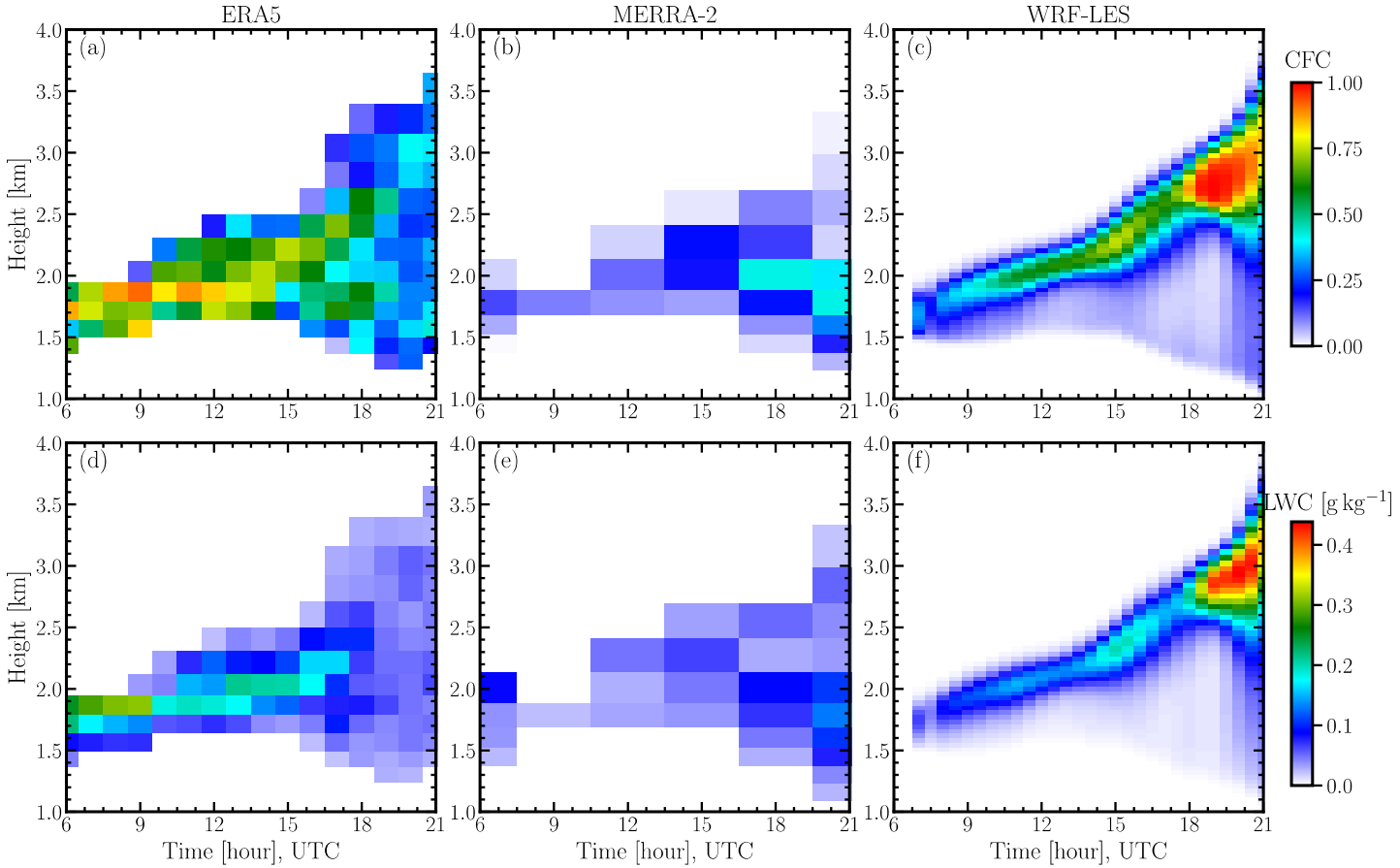


Six zone of the WRF domain based on the surface types and cloud patterns

Mass flux in θ_e-height space showing the evolution with MBL, temperature, and cloud structures



Preliminary evaluation of clouds in climate models

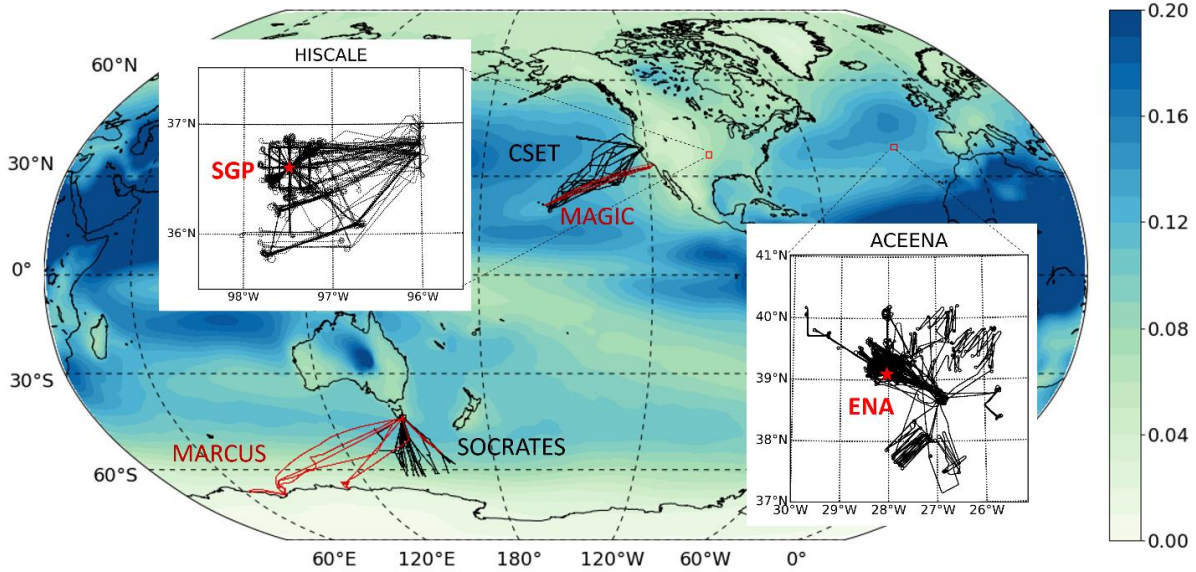


02/28/2020 CAO case (Li et al., revised)

- With the same grid-scale model states and forcing, ERA5 and MERRA-2 can capture the evolution of cloud fraction and LWC during a CAO case, as simulated in LES
- Magnitude and vertical structure are different from LES results
- Issues with model physics, resolution or both?

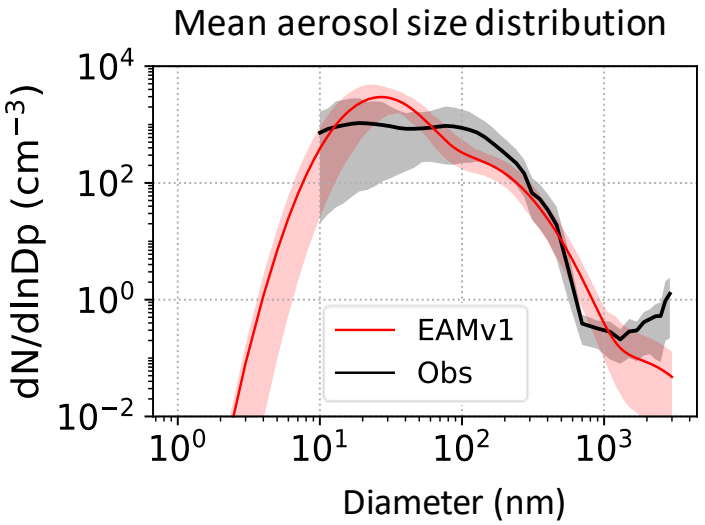
Earth System Model Aerosol-Cloud Diagnostics Package (**ESMAC Diags**)

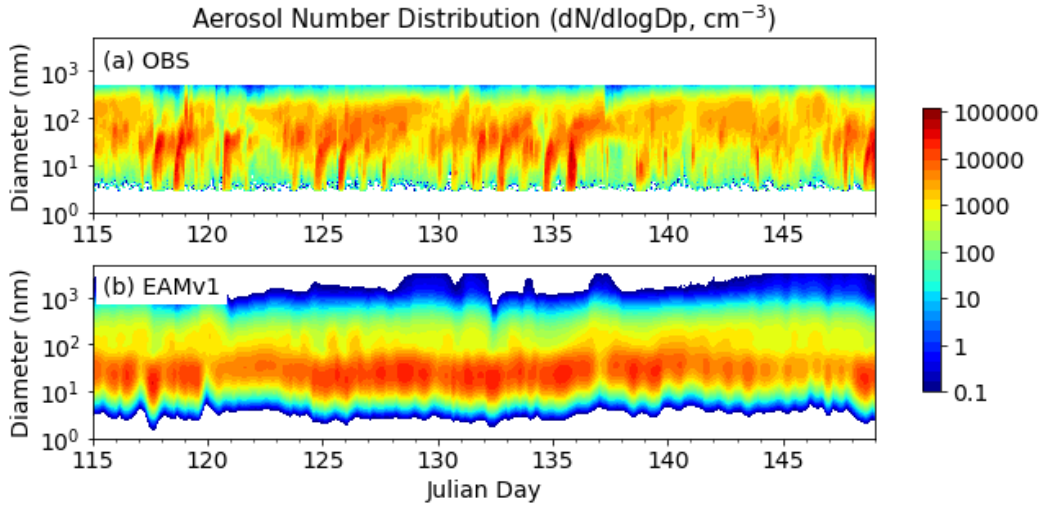
- **ESMAC Diags** is a Python-based diagnostics package to facilitate the routine evaluation of aerosols, clouds and aerosol-cloud interactions in E3SM.
- Currently cover six field campaigns and two long-term ARM sites with aircraft, ship, surface and satellite measurements.



Aircraft (black) and ship (red) tracks of the six field campaigns.

Overlaid shading is mean AOD in E3SMv1





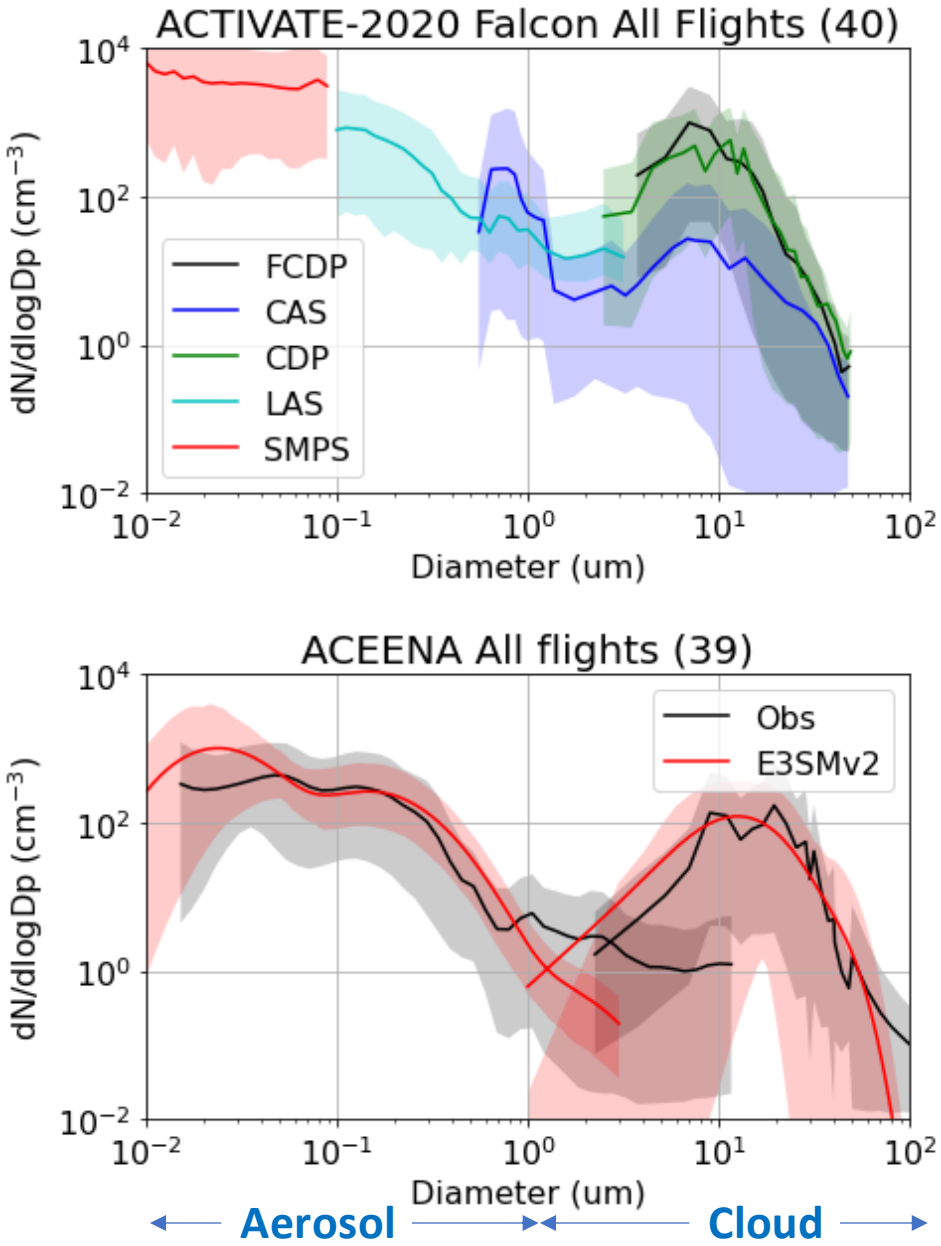
Tang et al. (2022) *Geosci. Model Dev.*

Preparation of ACTIVATE aircraft data for ESMAC Diags

- **Aircraft data preparation**:
  - Initially applied to Falcon in-situ measurements (will extend to King Air data)
  - Quality control
  - Rescaled to 1-min resolution for contemporary aerosol and cloud measurements
  - Standardized data format (netcdf)

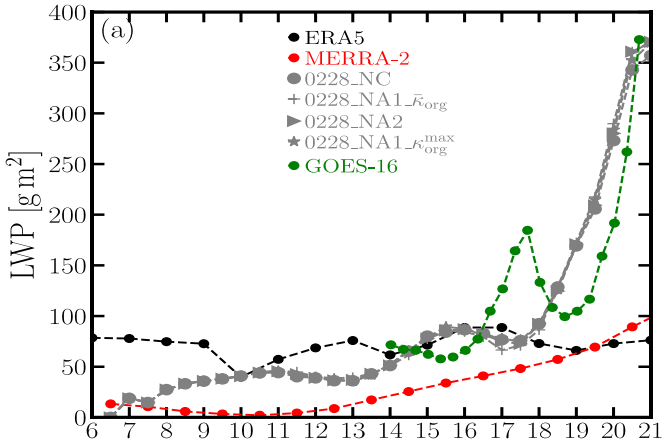
- **Model evaluation (To do next)**:
  - Need high-frequency model output along flight tracks to allow direct comparison

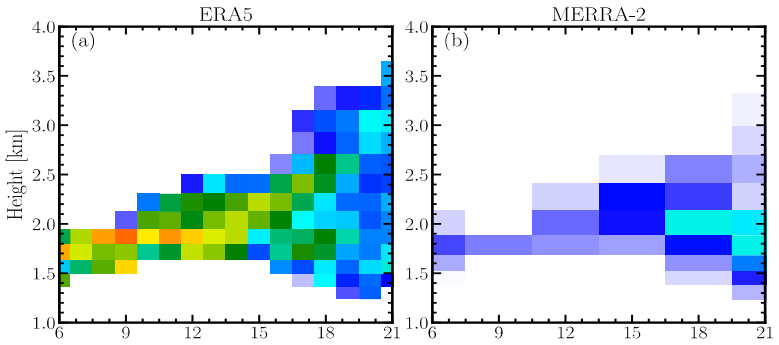
ACE-ENA: 2017 summer and 2017-2018 winter at Eastern North Atlantic

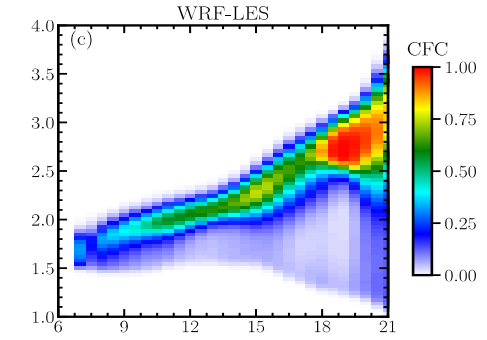


E3SM single-column model (SCM) setup for ACTIVATE case study

- Model: E3SMv2 (100 km) SCM (Bogenschutz, Tang et al.)
- Large-scale forcings: derived from ERA5 (same as LES in Li et al., 2022)
- A smoke test (02-28-2020) has been successfully conducted, but the preliminary results are not comparable to LES and reanalysis.

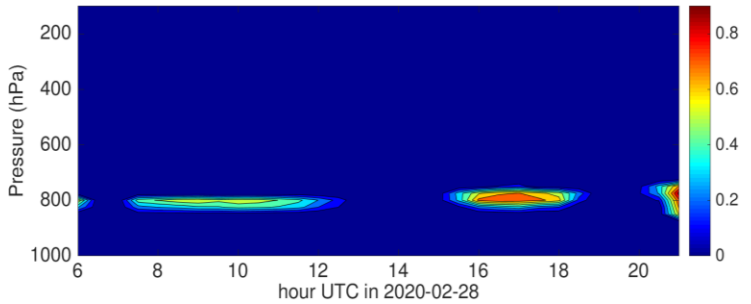


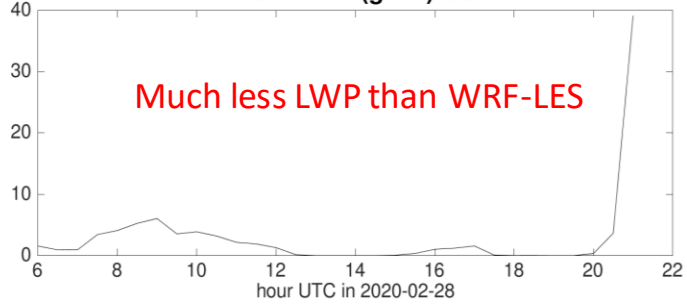


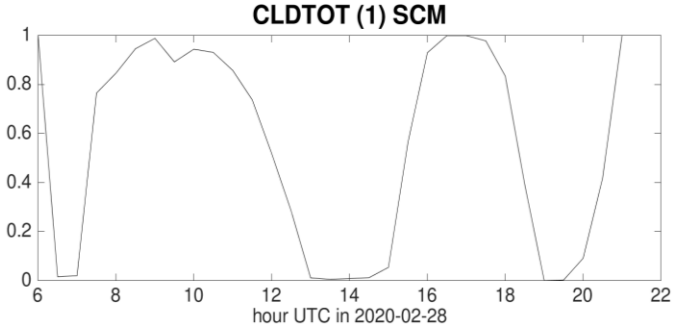


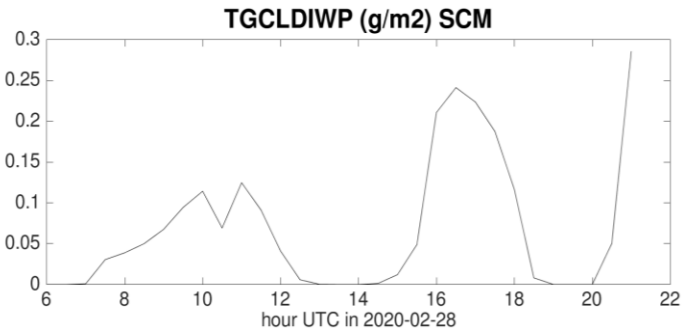
Cloud layer is thinner in SCM and BL is lack of growth.

Preliminary SCM results









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Summary of model output and diagnostic package

- **Idealized-case WRF-LES**
  - Winter cases: 28 February, 1 March 2020 (06–21 UTC)
  - Summer cases: 2/7 June 2021, 10/14 June 2022 (06–21 UTC)
- **Real-case WRF-CRM**
  - Winter case: 1 March 2020 (06–00 UTC)
  - Sensitivity tests with different boundary conditions (ERA5 and FNL)
- **WRF output in netcdf**
  - State variables (T, P/Z, Q, U, V, W)
  - Shortwave and longwave radiative fluxes
  - Turbulent fluxes, cloud and other hydrometeors
  - Every 30 minutes
- **Climate model simulations and diagnostic package**
  - E3SM Diags
  - E3SM SCM results (the LES cases)
  - E3SM and CESM simulations