# New Observational Constraints for Aerosol and Aerosol-Cloud Interactions in E3SM

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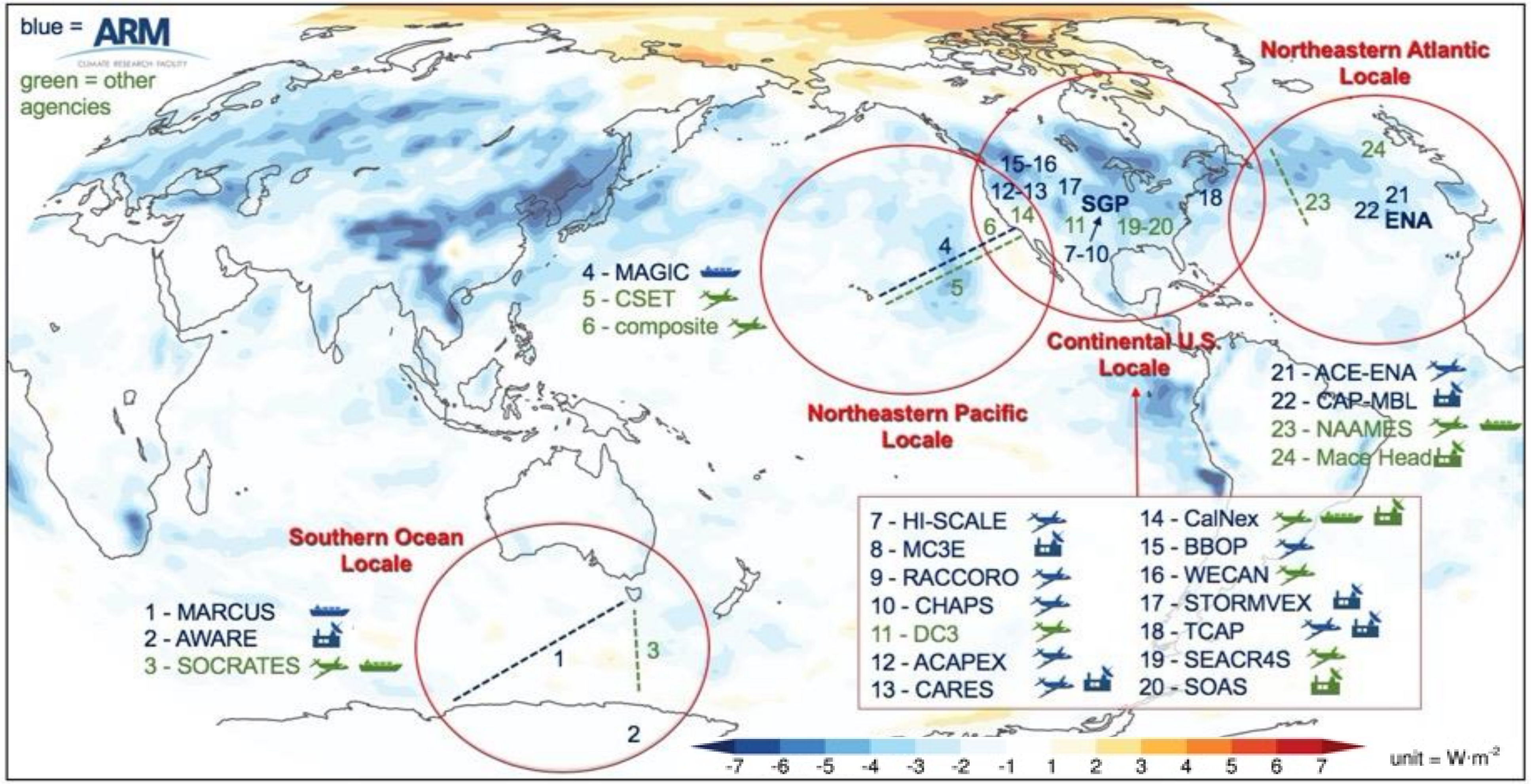
# EAGLES Liquid Cloud Testbed




- Cover a wide range of cloud/meteorological regimes and aerosol conditions
- Abundant observational data
- Combine E3SM-RRM, LES, and observational data for model evaluation and analysis

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# Earth System Model Aerosol–Cloud Diagnostics (ESMAC Diags) package

## *Tang et al., 2022; 2023, GMD*

Motivation: The *ESMAC Diags package was developed to facilitate routine evaluation of aerosols, clouds, and ACIs simulated in the Energy Exascale Earth System Model (E3SM) from the US Department o Energy (DOE).*

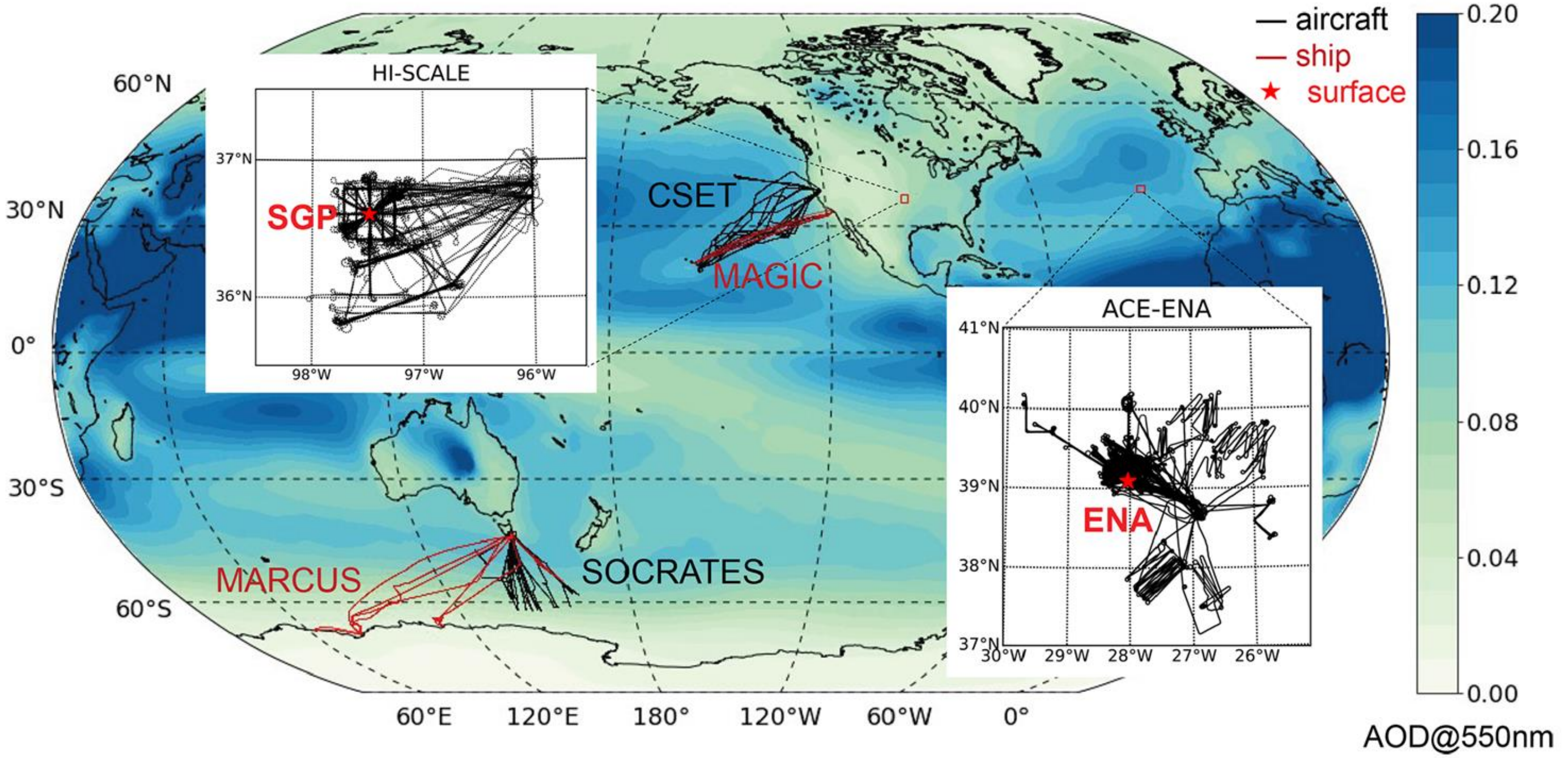
Dataset:

1. Field campaigns
    - HI-SCALE, ACE-ENA, MAGIC, CSET, MARCUS, SOCRATES
2. Satellite observations
    - Geostationary (VISST algorithm)
3. Permanent ARM sites
4. Ship – MAGIC & MARCUS

Geographical regions

- Eastern North Atlantic (ENA)
- Central US
- Northeastern Pacific
- Southern Ocean

Cloud regimes: Frequent liquid- or mixed-phase clouds with extensive measurements.

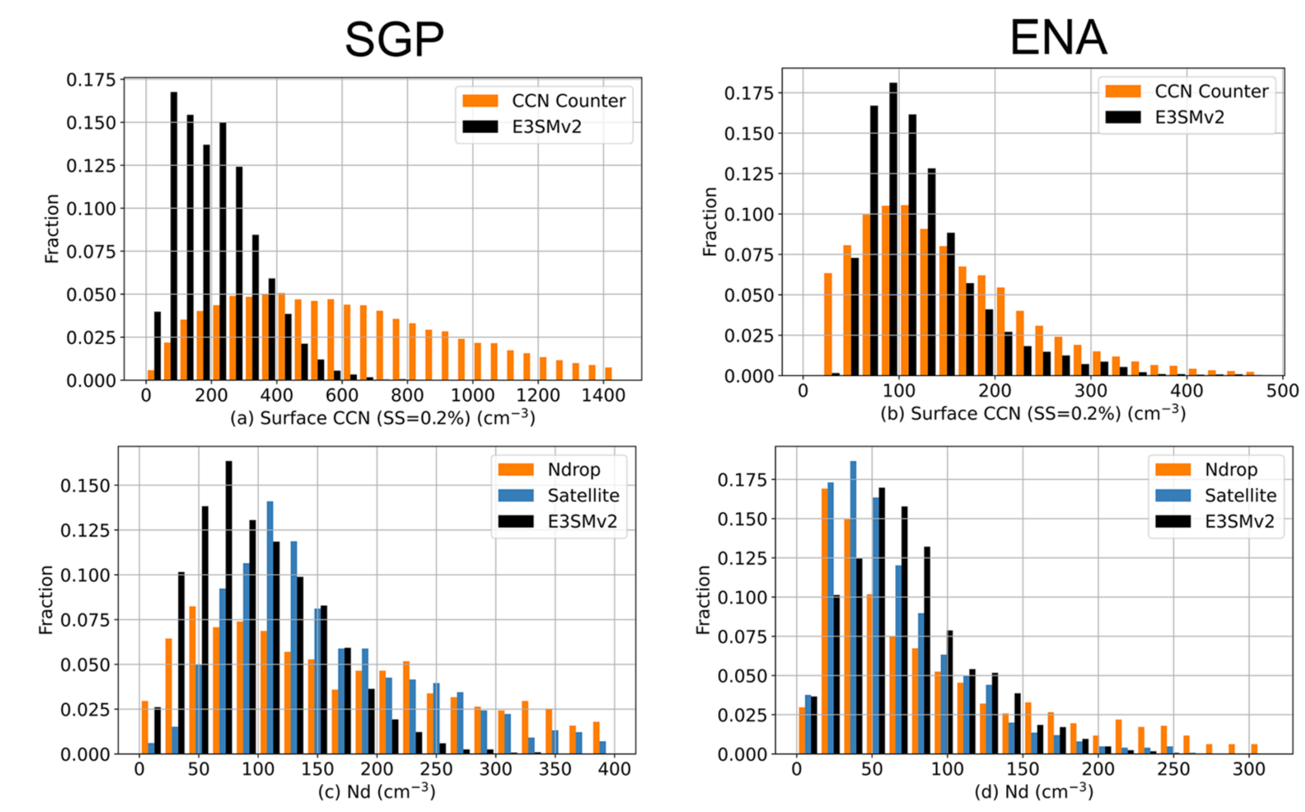



Measuremnts: Meteorology, aerosol size distribution, composition, and CCN, cloud properties (droplet size, concentration, geometrical thickness), TOA radiation.

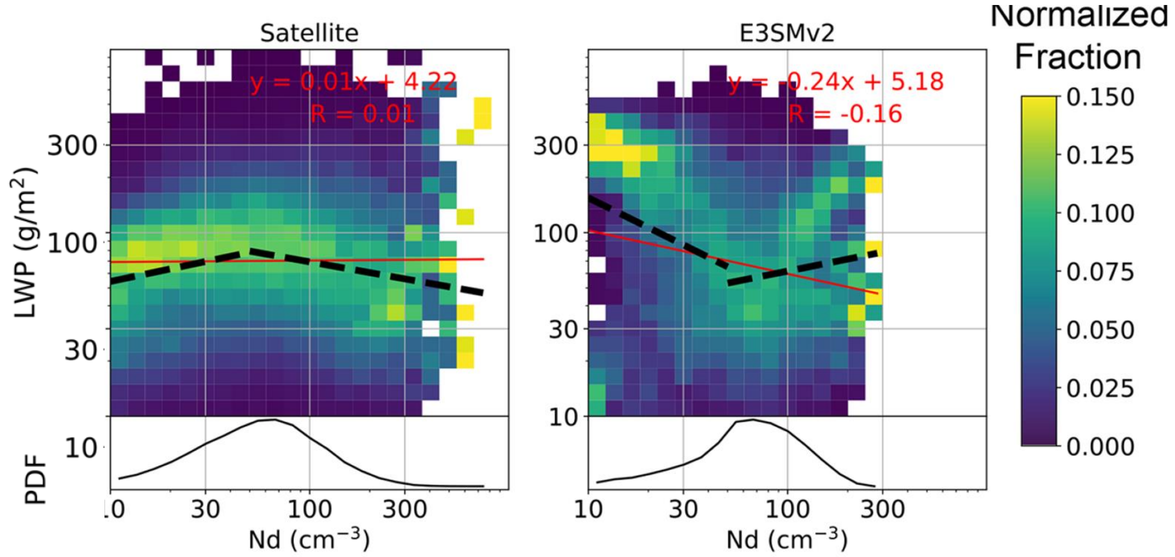
Statistical Outputs: Single-variable & multivariable diagnostics, Percentiles, Histograms, Joint-histograms, Heatmaps

# ESMAC Diags provides insights into E3SM state and process deficiencies

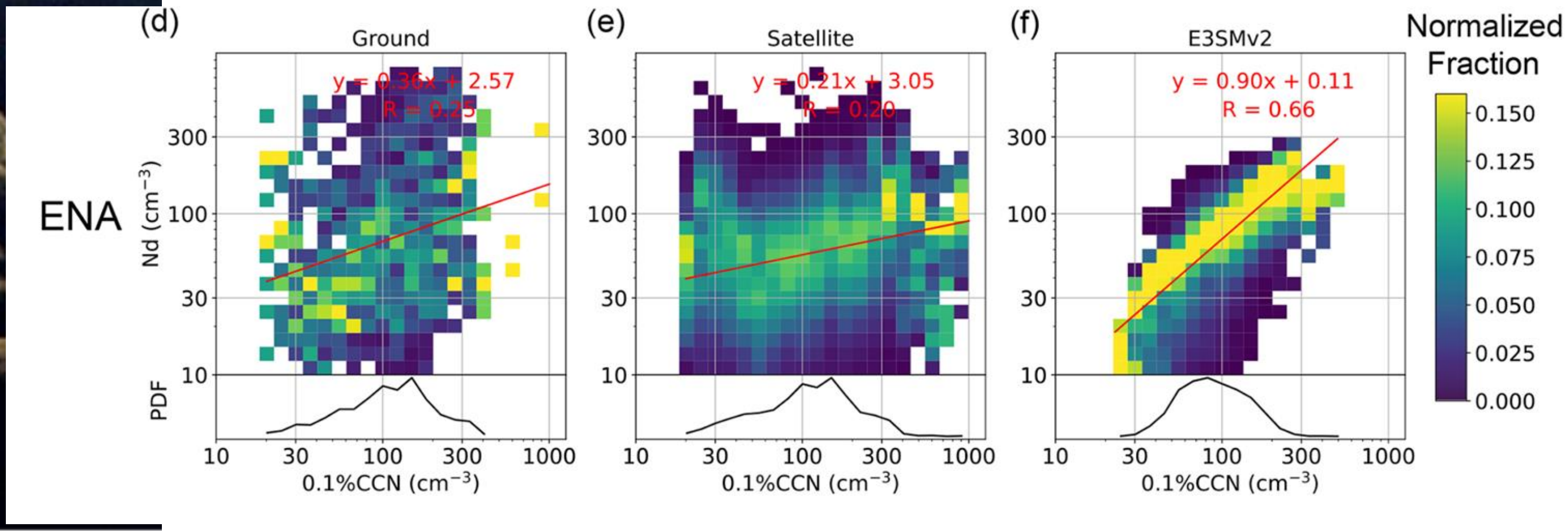
*Tang et al., 2022; 2023, GMD*




- E3SMv2 reasonably reproduces many observed aerosol and cloud properties




- And… liquid water path response to a perturbed cloud droplet number concentration behaves differently in E3SMv2 than in observations.




- But… coupling of aerosol & cloud number concentrations is too strong.
  - Bias in processes which control **aerosol activation**.

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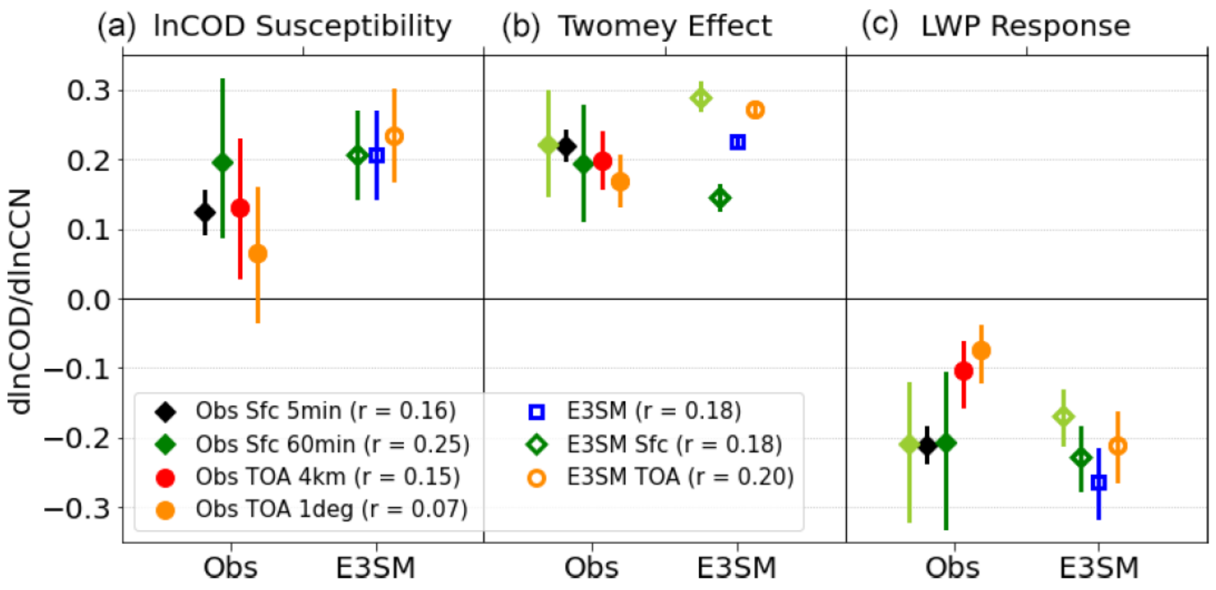
# Estimating aerosol radiative forcing from different observations and models depends on assumptions of cloud water holding capacity

***Varble et al (2023), ACP***

## *Radiative Forcing*

- Generally good agreement found with regards to the Twomey effect and LWP response albeit with slightly positive bias in E3SM.
- Large variability in radiative effect depends on how the data is aggregated.
- Cloud adiabaticity generally increases as droplet number concentration increases (in observations).

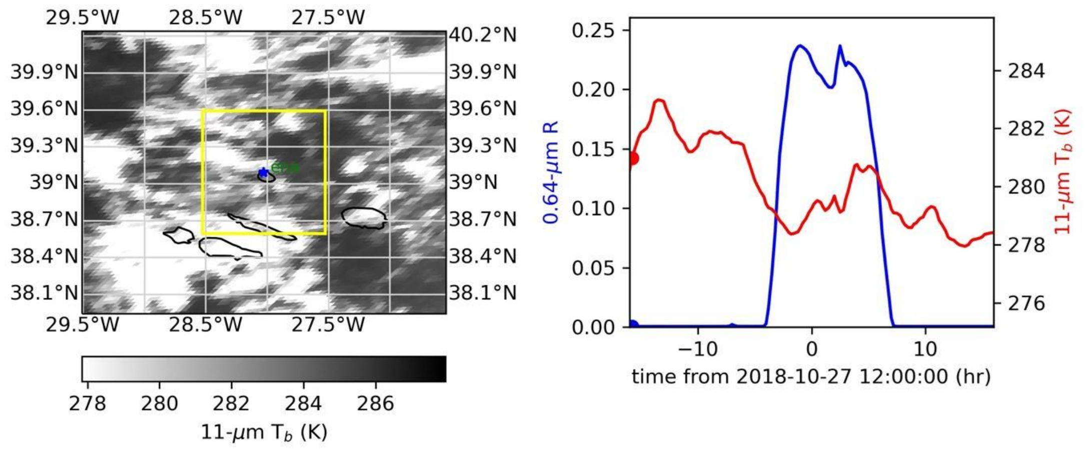


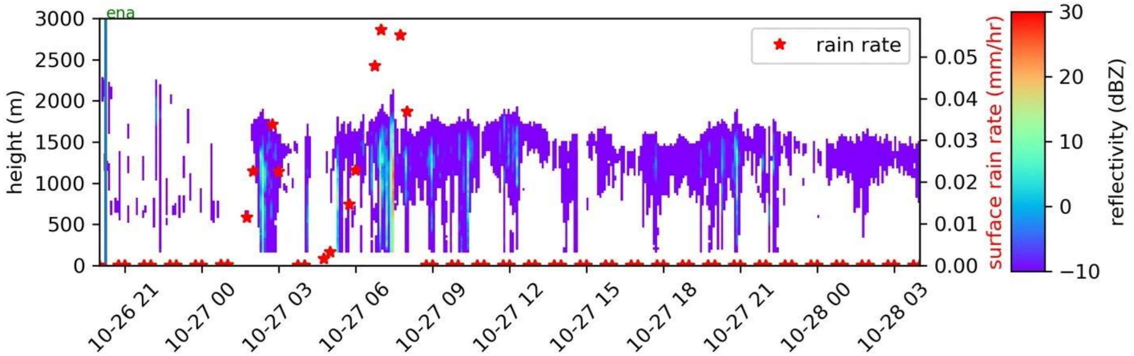

- Cloud adiabaticity in E3SM is too small and there is no dependence on it as a function of Nd.
- Observational TOA retrievals assume a constant cloud adiabaticity of 0.8, while surface retrievals do not assume constant adiabaticity.
  - More work needed to quantify this from space to determine meteorological drivers responsible for sub-adiabatic clouds and implement improvements in E3SM.

# Use Lagrangian framework to quantify ACI throughout cloud lifetime

*Christensen et al (2023), ACP*

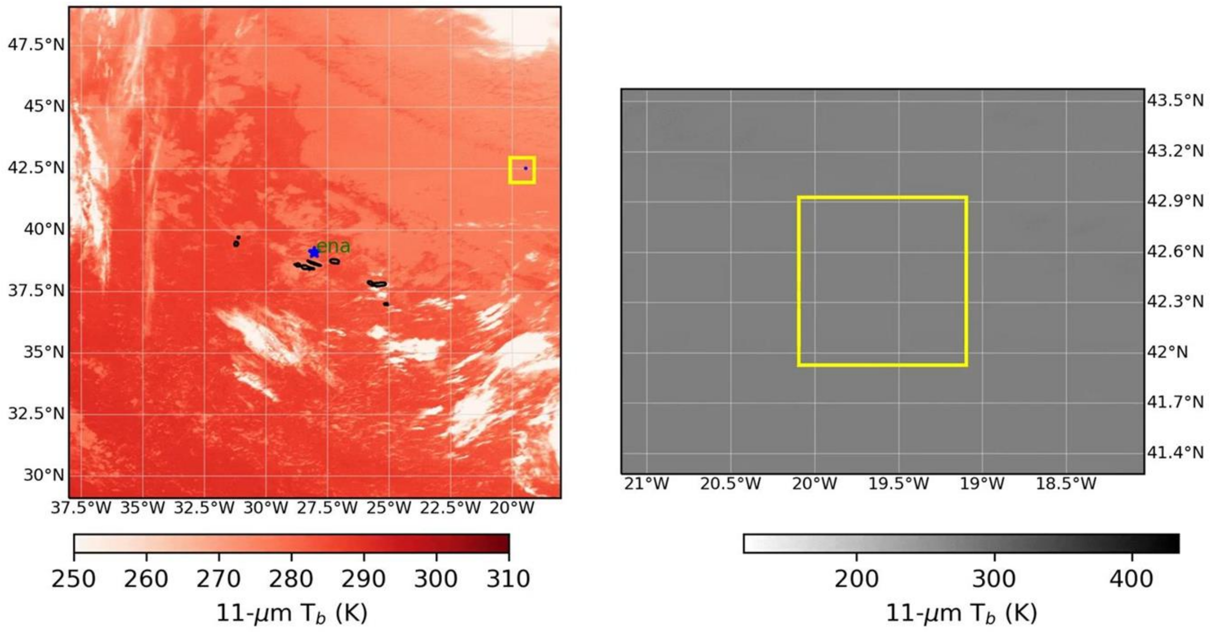
## Eulerian Framework




Clouds are not static and adjust to aerosol and meteorological changes over their lifetime thus necessitating a Lagrangian framework…

## Lagrangian Framework



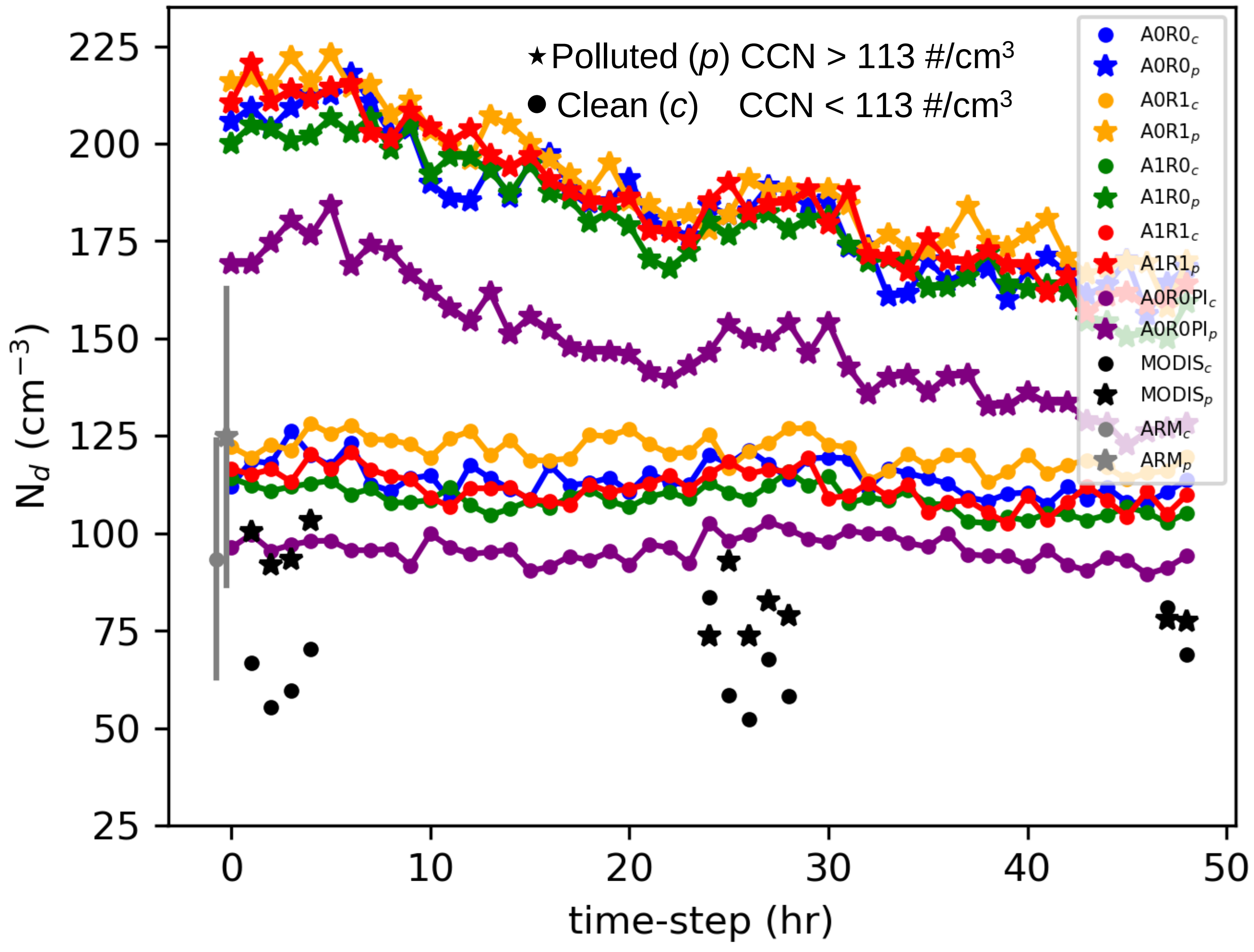

**Scientific Questions:**

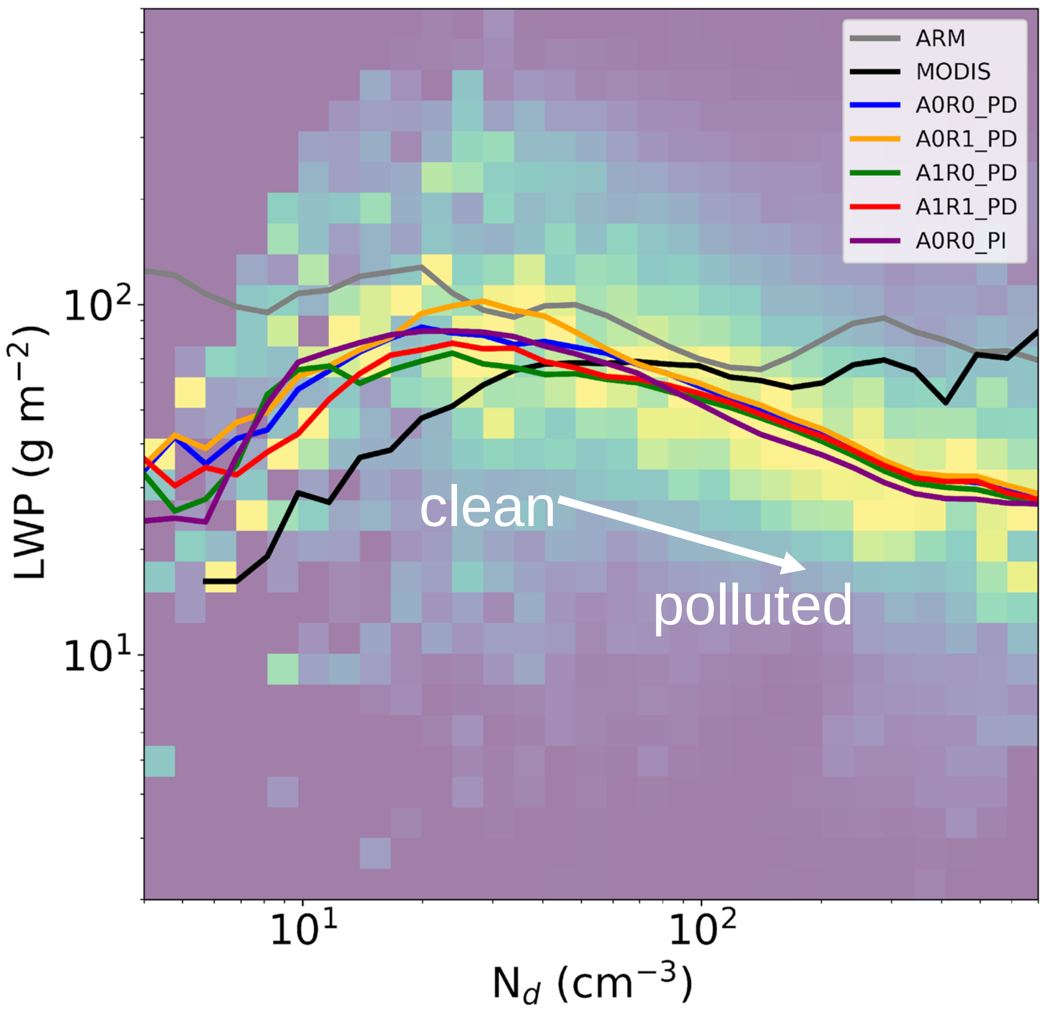
1. Can changes in surface CCN concentration affect the radiative properties and lifetime of clouds passing by Azores?

1. How well does E3SMv1 represent aerosol-cloud interactions in a Lagrangian framework?

# LWP-$N_d$ Relationship

*Christensen et al (2023), ACP*



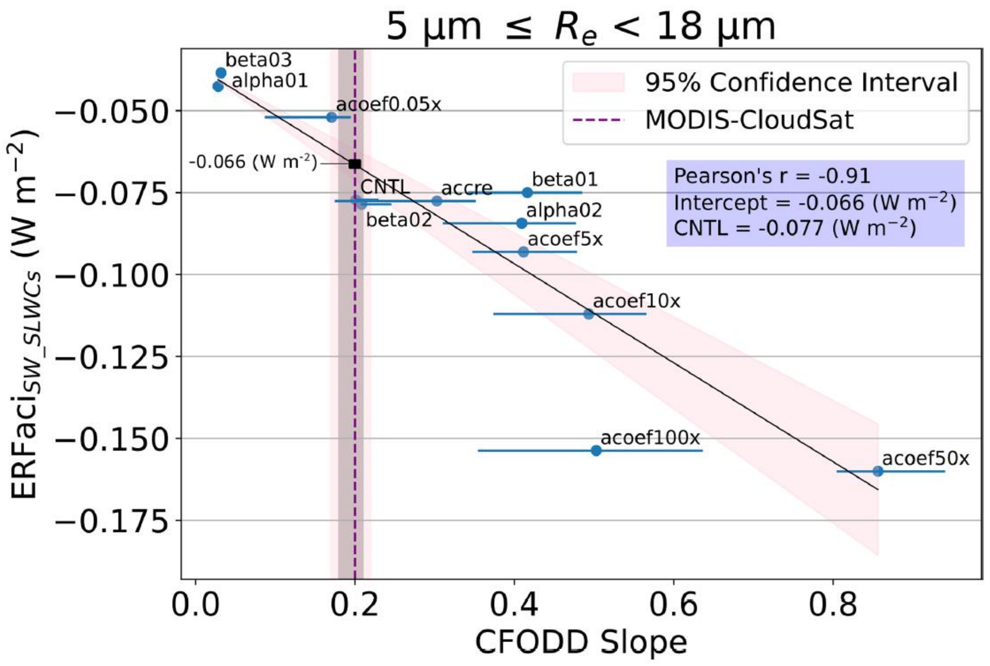

- Polluted clouds have larger droplet concentrations for up to 2-days.
- E3SMv1 captures $N_d$-LWP relationship but it is not sensitive to warm-rain experiments.
- Positive bias simulated in E3SMv1 $N_d$ with respect to observations.
- Polluted clouds are too thin in E3SM.

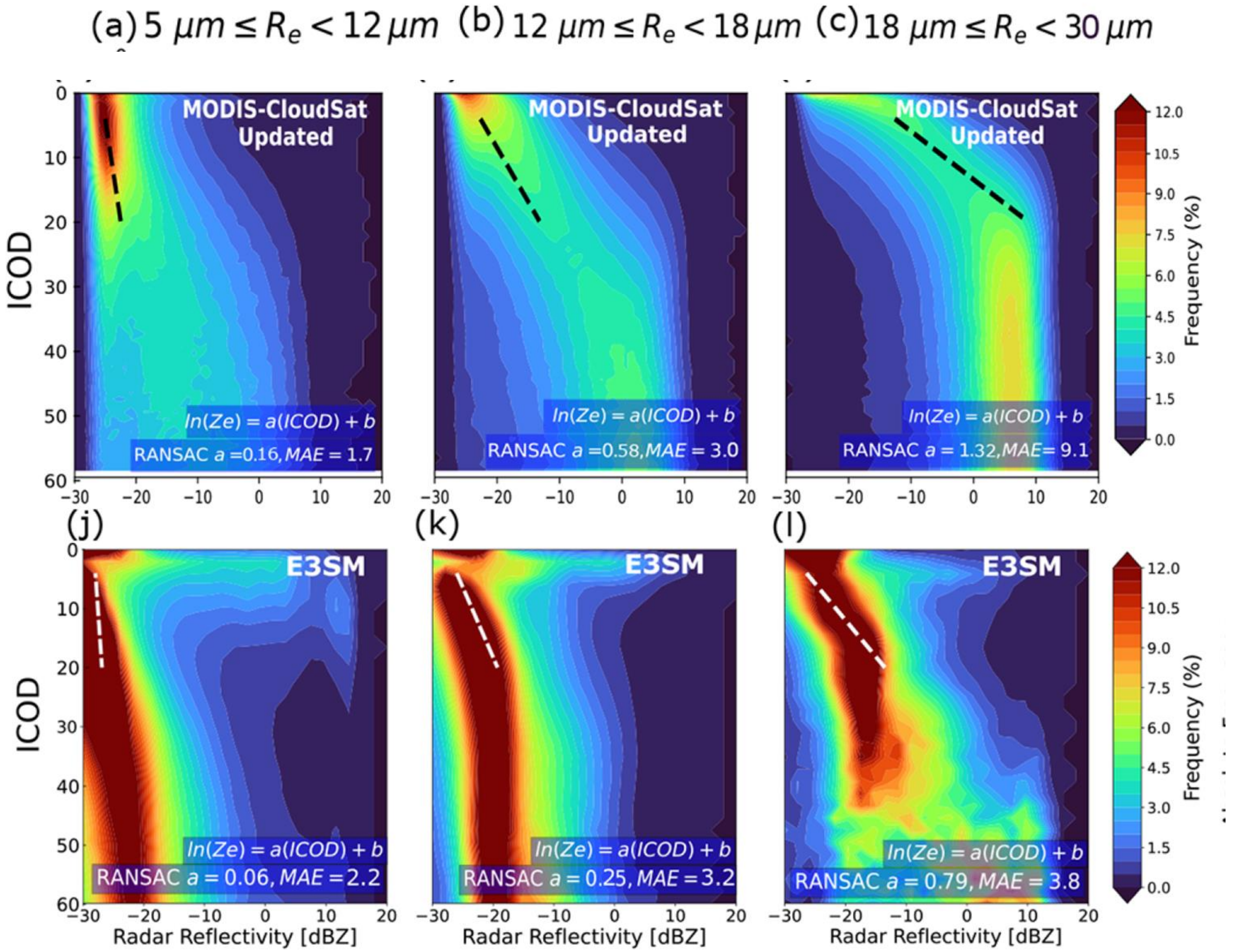
# ERFaci Constraint using Contoured Frequency by Optical Depth (CFODD) Analysis

## Beall et al (2024), ACP

**New Constraint for ERFaci**

- Slope of the CFODD provides and estimate of cloud droplet collection efficiency in single-layer warm liquid clouds.
- Derived from millions of retrievals of cloud optical properties from MODIS and CloudSat global observations.




- E3SMv2 droplet collection efficiencies and ERFaci are highly sensitive to autoconversion.
- E3SMv2 CFODD slope (0.2 ± 0.04) is in agreement with observations (0.2 ± 0.03). The model represents boundary cloud processes with sufficient skill to make accurate predictions of ACI.

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# Summary

- **The EAGLES project has created a suite of observational metrics and diagnostics.**
  - ESMAC Diags combining a suite of aircraft, satellite, and ARM data from permanent and mobile sites.
  - Aggregated ARM and satellite datasets and tools to compute adiabaticity and radiative forcing
  - Lagrangian tools to evaluate temporal changes in cloud and aerosol processes.
  - New constraints on ERFaci from A-train satellite sensors.

- **These new metrics have been used to diagnose model deficiencies and advance parameterizations necessary for improving E3SM predictions of aerosol and ACI across scales.**
  - Polluted clouds have larger droplet concentrations for up to 2-days.
  - E3SM captures $N_d$-LWP relationship but it is not sensitive to warm-rain experiments.
  - Positive bias simulated in E3SMv1 $N_d$ with respect to observations.
  - Polluted clouds are too thin in E3SM.
  - E3SMv2 appears to have opposite liquid water path Nd relationship to v1.
  - Subadiabatic clouds are highly prevalent compared to observations.