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Integrating observations and process-oriented diagnostics to constrain aerosol-cloud interactions in Earth system model development

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Objective and Methods

- Motivated by the need to better integrate ACI observational constraints and process understanding into model development, we have begun development of **a new Python-based liquid cloud ACI diagnostics package focused on evaluating *processes***.
  - Surface-based and aircraft measurements are coupled with satellite retrievals.
  - Analyzed variables are extensive to account for covariabilities.
  - Various retrievals and outputs are intercompared to address potential biases.
- Evaluate 1-year of hourly 1º E3SMv1 (to start) aerosol, cloud, meteorology, and radiation variable probabilities, joint distributions, and diurnal and seasonal cycles for the ARM ENA site (to start).
- E3SM simulation year and observations year are not time matched but our purpose for now is building the comparison framework.
  - In the process, interesting differences may emerge that we may want to investigate further.
- Observations are hourly 0.5-1º satellite retrievals and hourly-averaged surface measurements, so scales are not matched.

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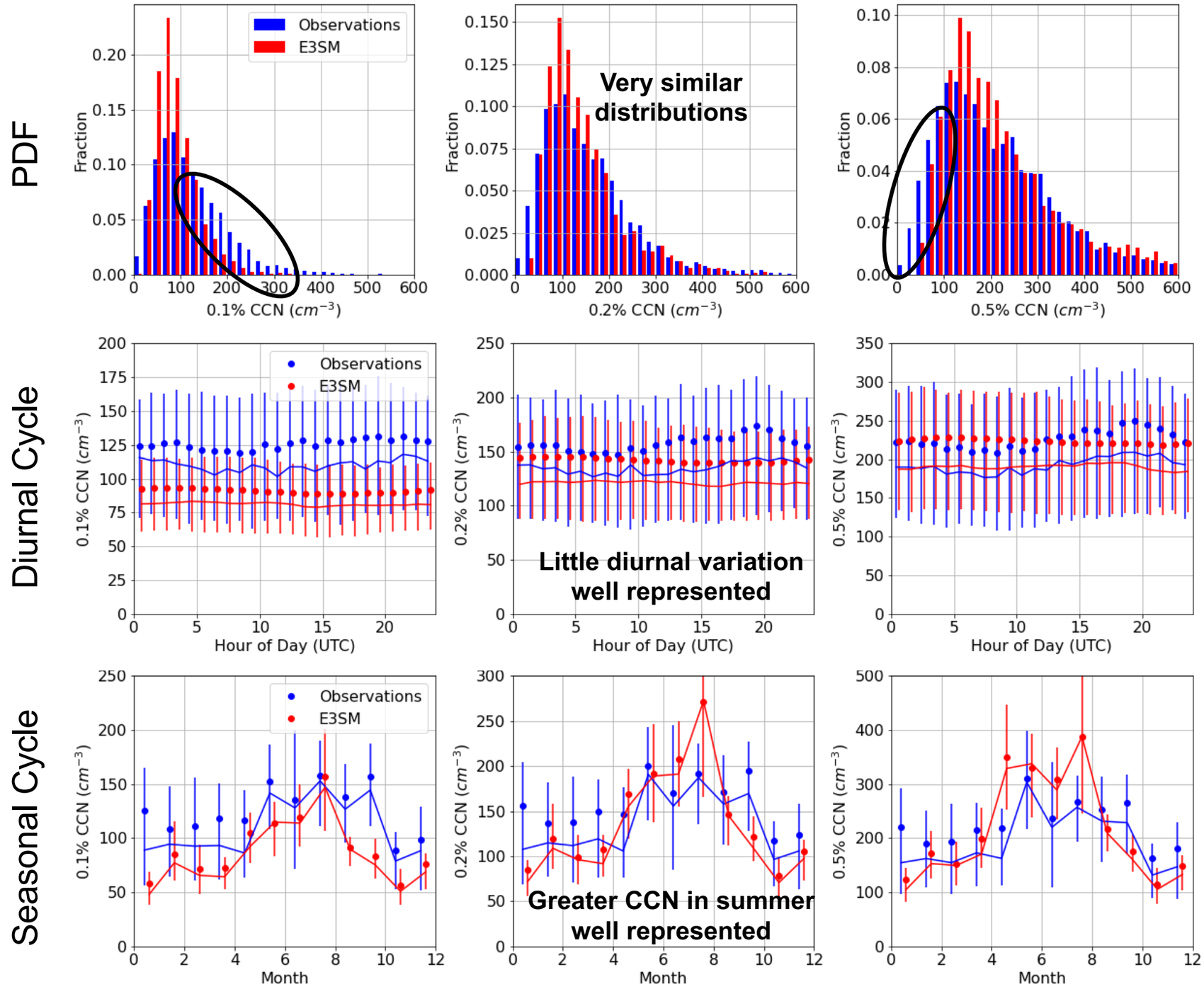
Surface CCN PDFs, Diurnal Cycles, and Seasonal Cycles

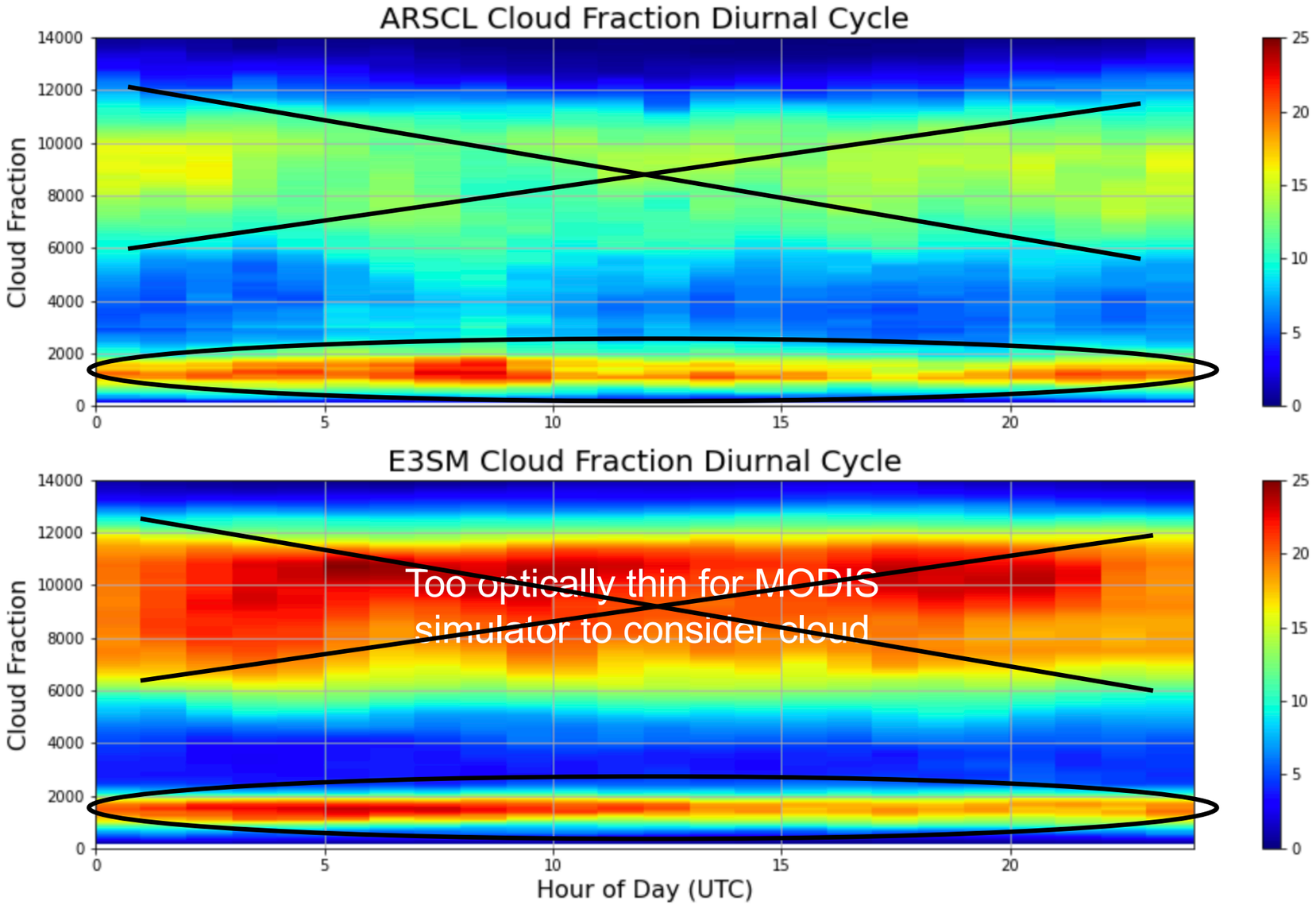


Cloud Fraction

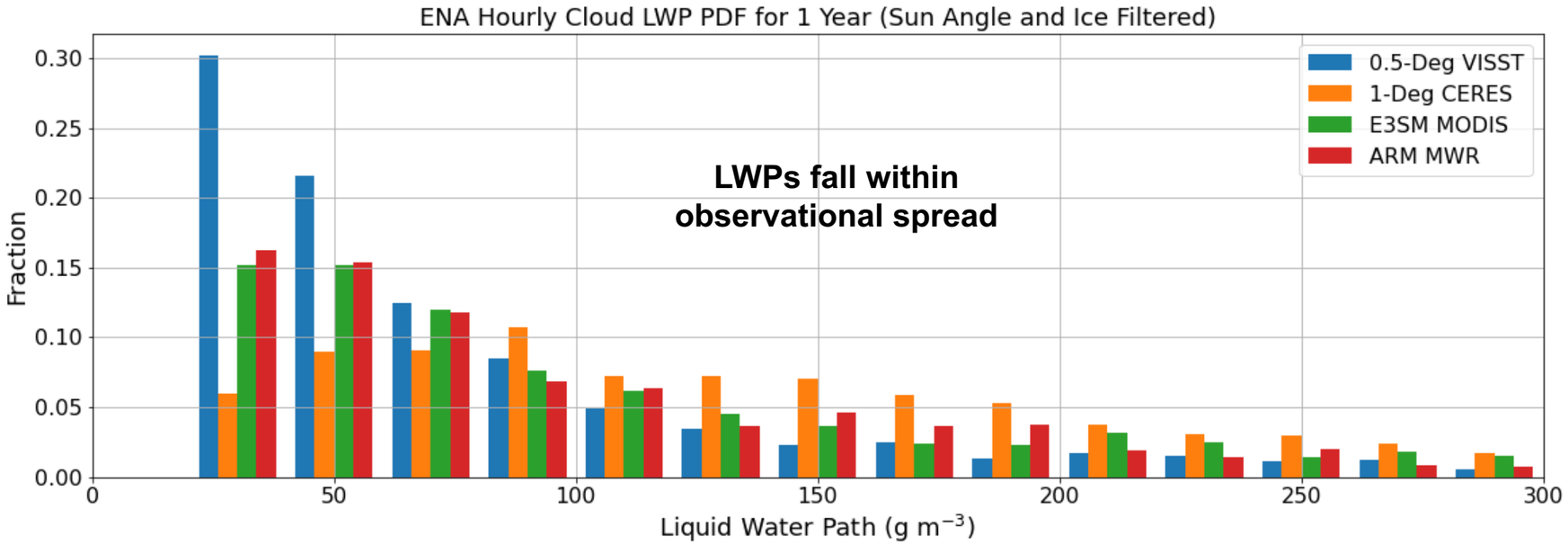
Despite MODIS and ISCCP simulators showing less cloud cover in E3SM, the E3SM outputted grid scale cloud fractions are higher than observed at upper levels

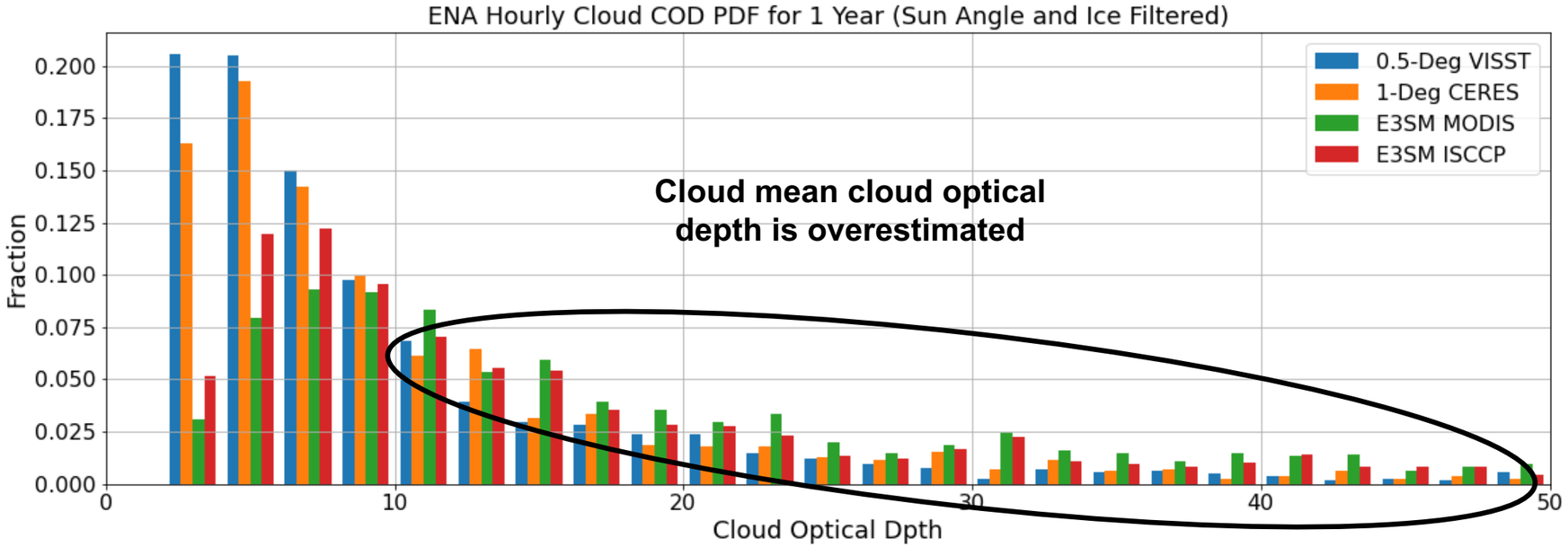
Low level cloud fraction is handled well in terms of vertical positioning and thinning during the afternoon hours

We filter out columns with ice to focus on liquid cloud processes



Cloud Mean LWP and Optical Depth PDFs (CF > 90%)





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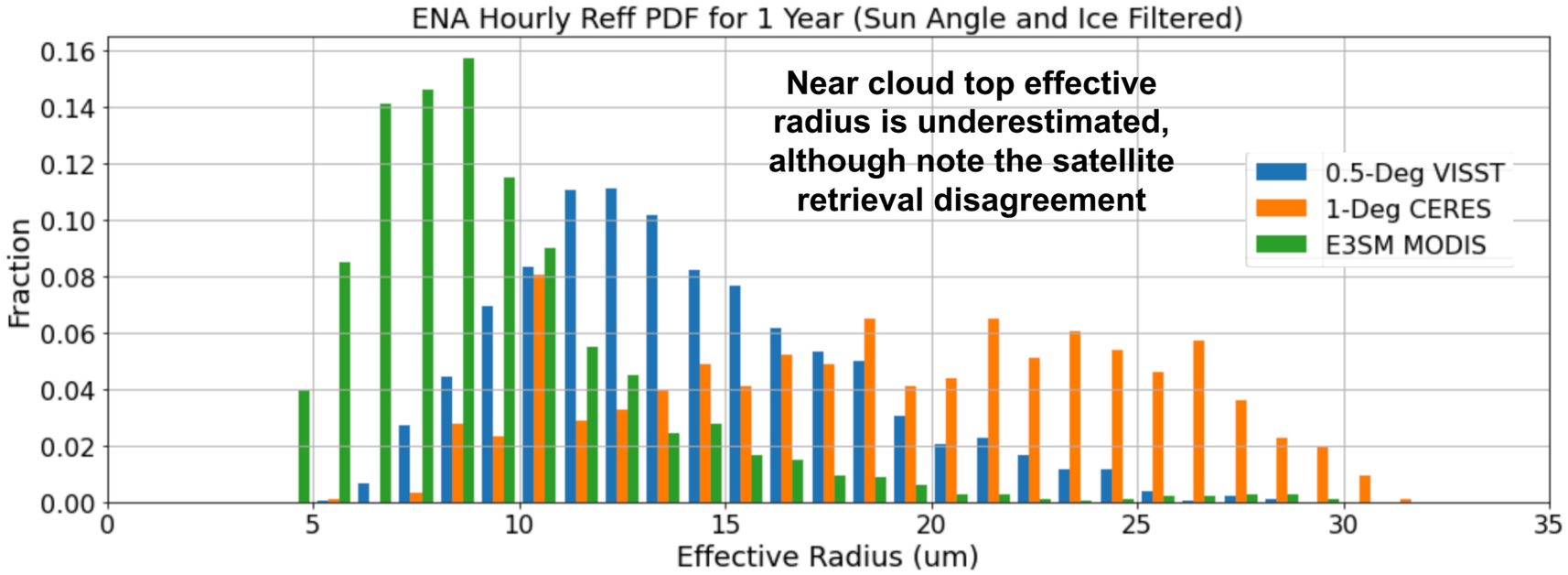
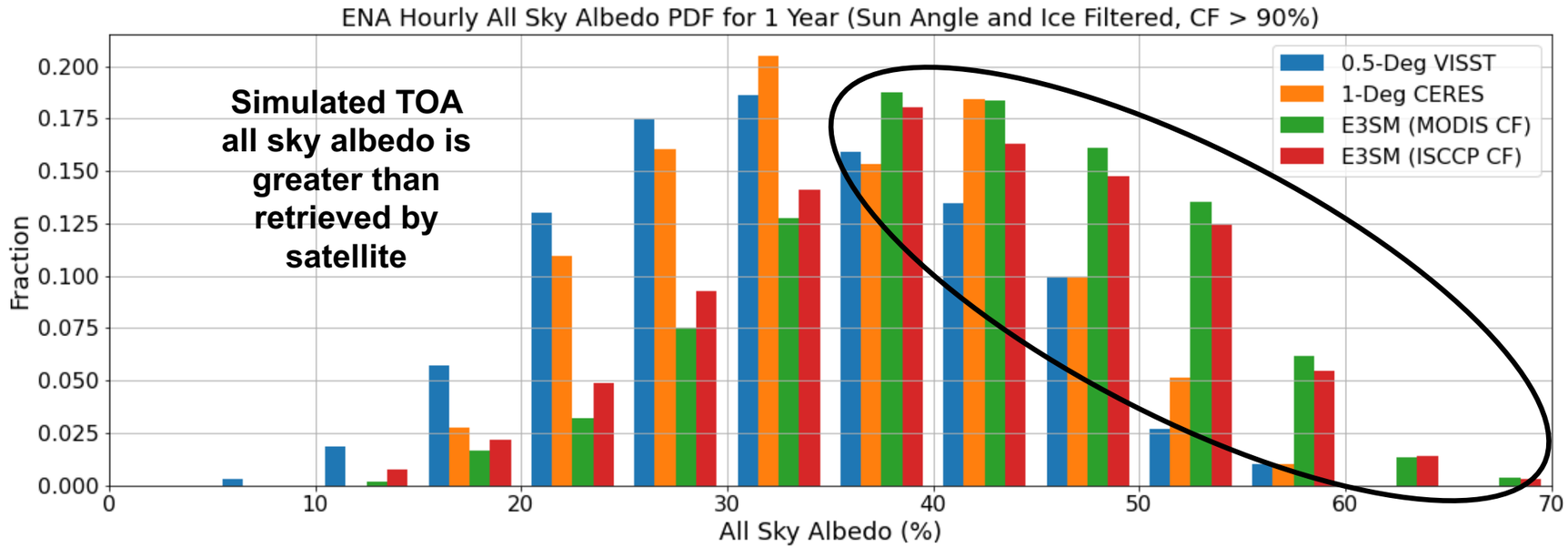
Near Cloud Top Effective Radius and TOA All Sky Albedo (CF > 90%)



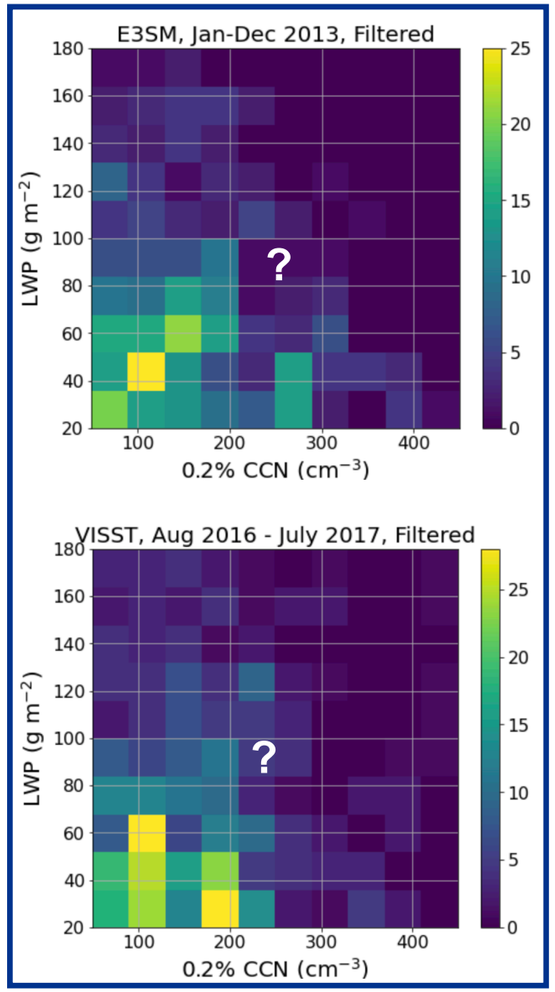


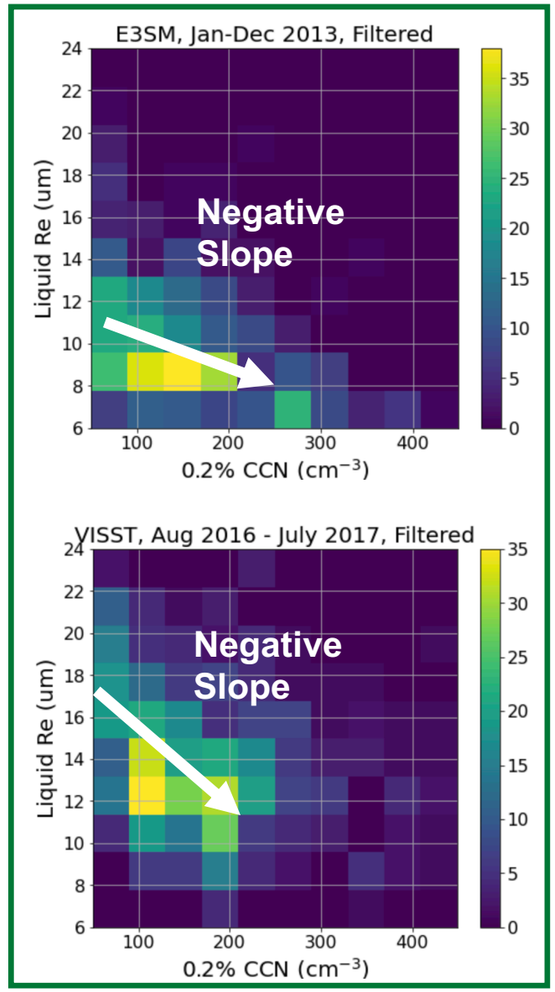
LWP, Effective Radius, and Albedo vs. Surface 0.2% CCN (CF > 90%)

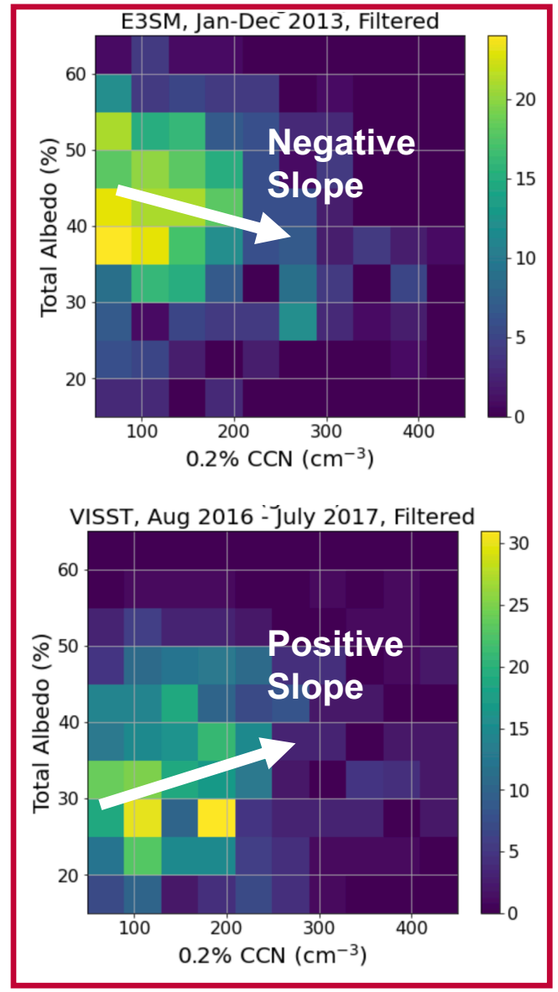
LWP-CCN relationships are unclear.

E3SM and VISST have decrease effective radius with increasing CCN.

E3SM albedo decreases with CCN whereas retrievals have the opposite relationship.



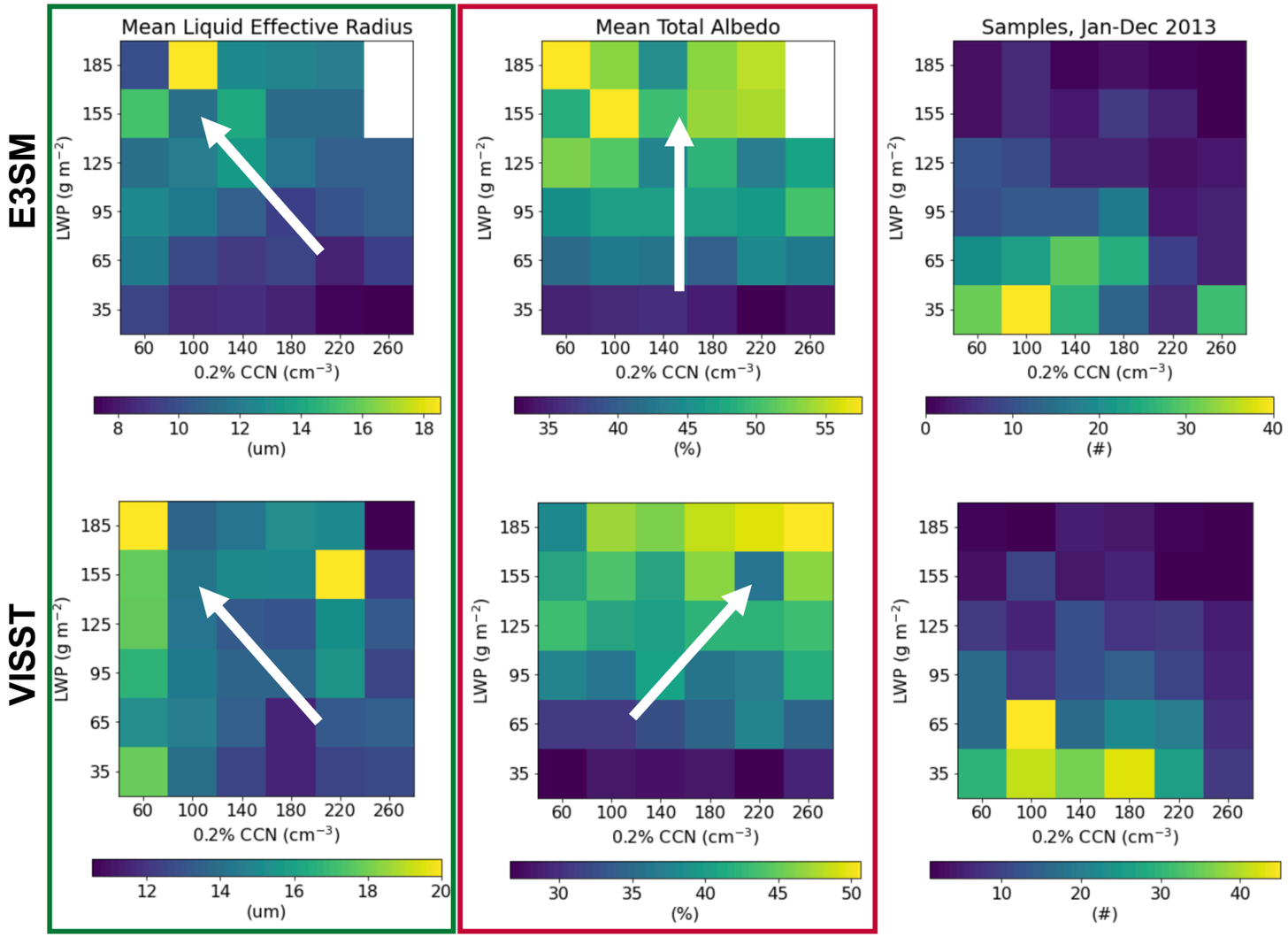




Mean Effective Radius, Mean All Sky Albedo, and Samples vs. LWP and Surface CCN (CF > 90%)

Effective radius appears to increase with LWP and decrease with CCN in both E3SM and satellite retrievals although current sampling is limited as LWP and CCN increase.

All sky albedo increases with LWP and CCN in satellite retrievals but the increase of albedo with CCN for E3SM is not clear.



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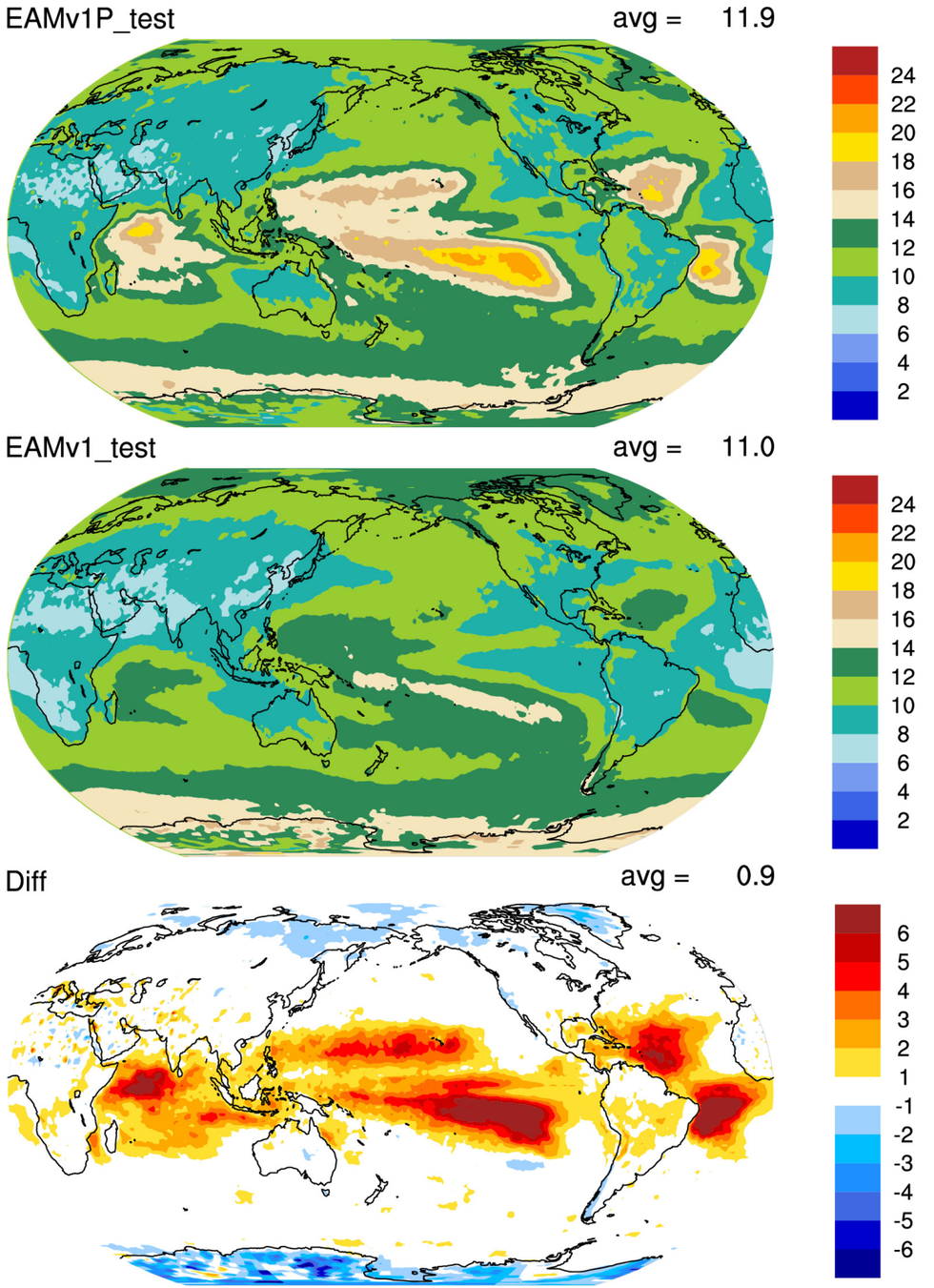
Process Causes for E3SM-Retrieval Differences

- We are investigating how insufficient treatments in cloud and aerosol parameterizations contribute to model-retrieval differences.
- Overly small cloud droplets in E3SMv1 may be partially associated with excessive aerosol activation due to strong turbulence.
- Weakening turbulence and increasing sub-grid vertical velocity PDF skewness reduces a potential bias, but more so in trade cumulus regions than stratocumulus regions.
- Further investigation and model-retrieval comparisons are ongoing.



Summary

Underestimated	Well Simulated	Overestimated
Detectable Cloud Fraction	Surface CCN	Cloud Optical Depth
Cloud Effective Radius	Cloud LWP	TOA Albedo
Lower Tropospheric Stability	Rain Rate Magnitudes	Rain Frequency

For no ice situations with solar zenith angle < 65º and cloud fractions > 90% when retrievals are valid:

- For a given CCN: Effective radius increase with LWP in both E3SM and retrievals.
  All sky albedo increases with LWP in both E3SM and retrievals.
- For a given LWP: Effective radius decreases with CCN in both E3SM and retrievals.
  All sky albedo increases with CCN in retrievals, but this is not clear in E3SM.

Vision

- Incorporate additional comparisons such as **cloud droplet number concentrations**, **aerosol size distributions, cloud updrafts,** and **cumulative aircraft aerosol and cloud statistics** put within the context of longer-term surface observations.
- Incorporate **further joint distributions**, model-observation **difference plots**, controls for thermodynamic **coupling of clouds to the surface.**
- Address dataset/model **resolution** and **sampling** differences as best we can.
- Organize code into individual functions within a **Python, open source diagnostics software package** that can be easily run to produce all or some of the plots (think ARM-Diags developed at Livermore).
- This new process-oriented diagnostics package for ACI will facilitate routine model evaluation during development, bridging the gap between process understanding and Earth system modeling.

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Thank you

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