ESM Process-Oriented Evaluation with the Earth Model Column Collaboratory (EMC^2)

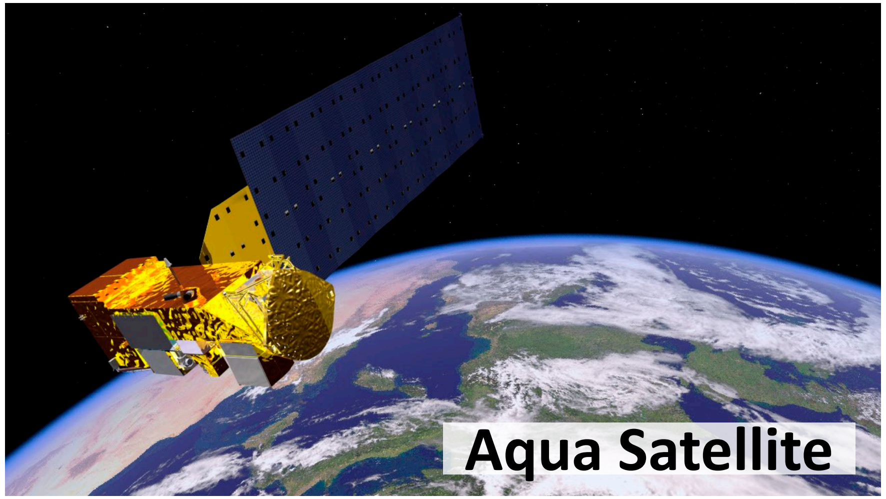
Israel Silber[1], Ann M. Fridlind[2], Yang Shi[3], Robert C. Jackson[4], Andrew S. Ackerman[2], Scott Collis[4], Xiaohong Liu[3], Florian Tornow[2,5], McKenna W. Stanford[2,5], Timothy W. Juliano[6], Johannes Verlinde[1], and Jiachen Ding[3]

[1]Penn-State U., [2]NASA GISS, [3]Texas A&M U., [4]ANL, [5]Columbia U., [6]NCAR

Email: ixs34@psu.edu

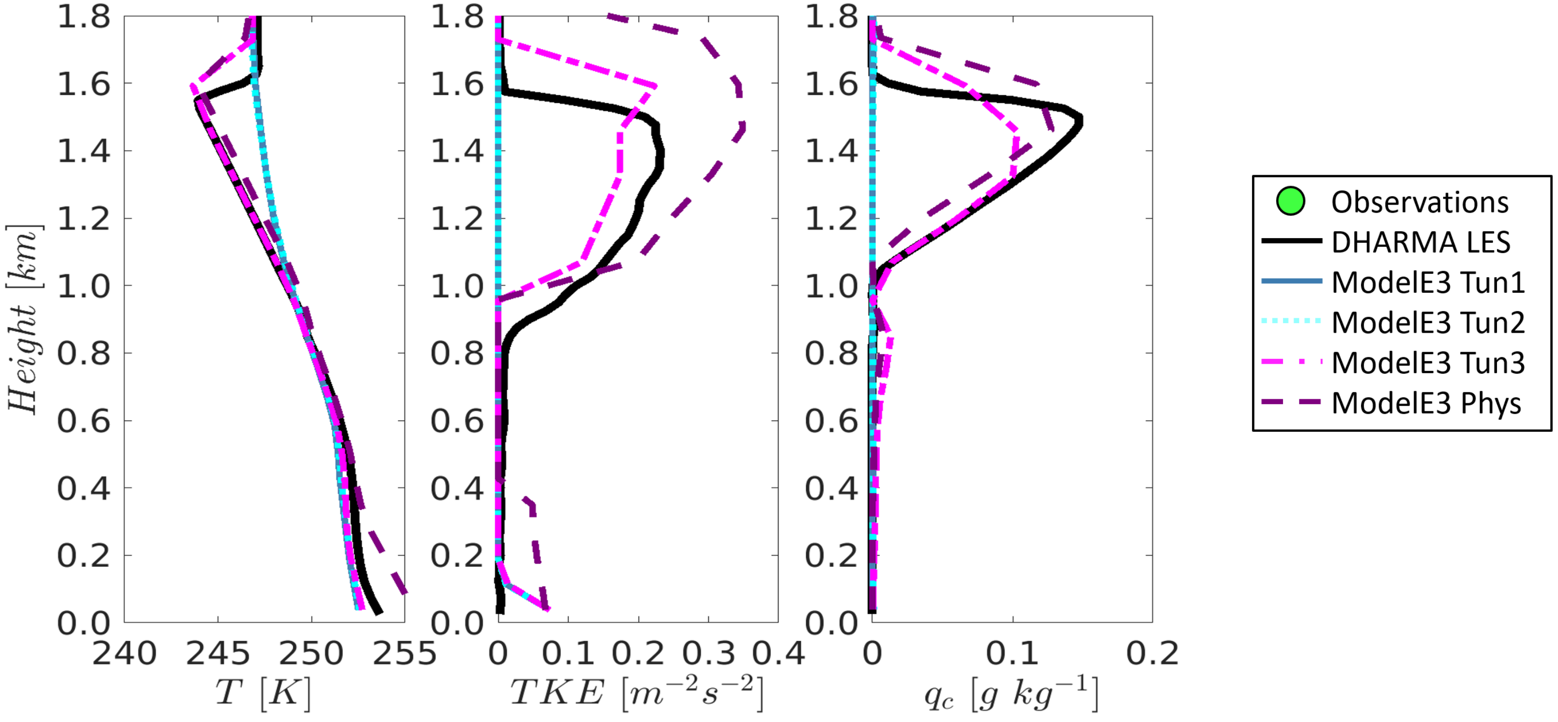
Background

- ESM evaluation requires using two approaches:
  1. Case study (contextual) evaluation to examine model physics representation (e.g., using SCM simulations)
  2. Bulk statistics (quantitative) evaluation to examine “natural” model behavior (e.g., using global free-running ESM simulations)
- Implementation of both approaches benefits from the use of instrument simulators, which facilitate direct comparisons
- Here, we demonstrate both approaches using the Earth Model Column Collaboratory (EMC²) together with ARM datasets to evaluate:
  - Polar mixed phase cloud microphysical properties and thermodynamic profile
  - Cloud base precipitation rates, which could serve as the dominant cloud moisture sink (e.g., Mülmenstädt et al., 2020; Solomon et al., 2011)



Case Study Evaluation Using ESM SCMs

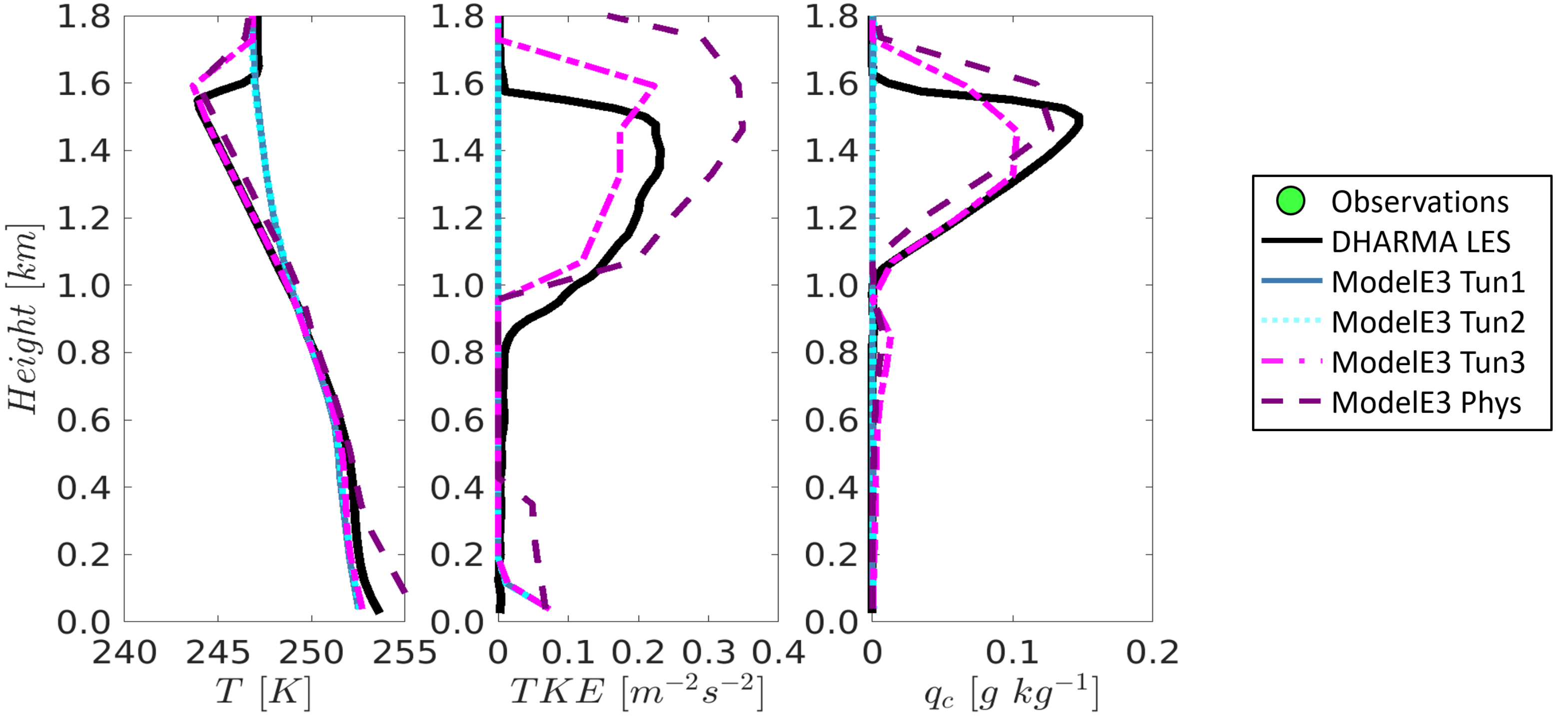
- A wealth of information can be gathered without a simulator, e.g., by comparing model output to an LES
- Lagrangian case study describing the formation and evolution of a highly supercooled Antarctic cloud during AWARE (see Silber et al., JGR, 2019)



Silber et al., ***GMD, 2022***

Case Study Evaluation Using ESM SCMs

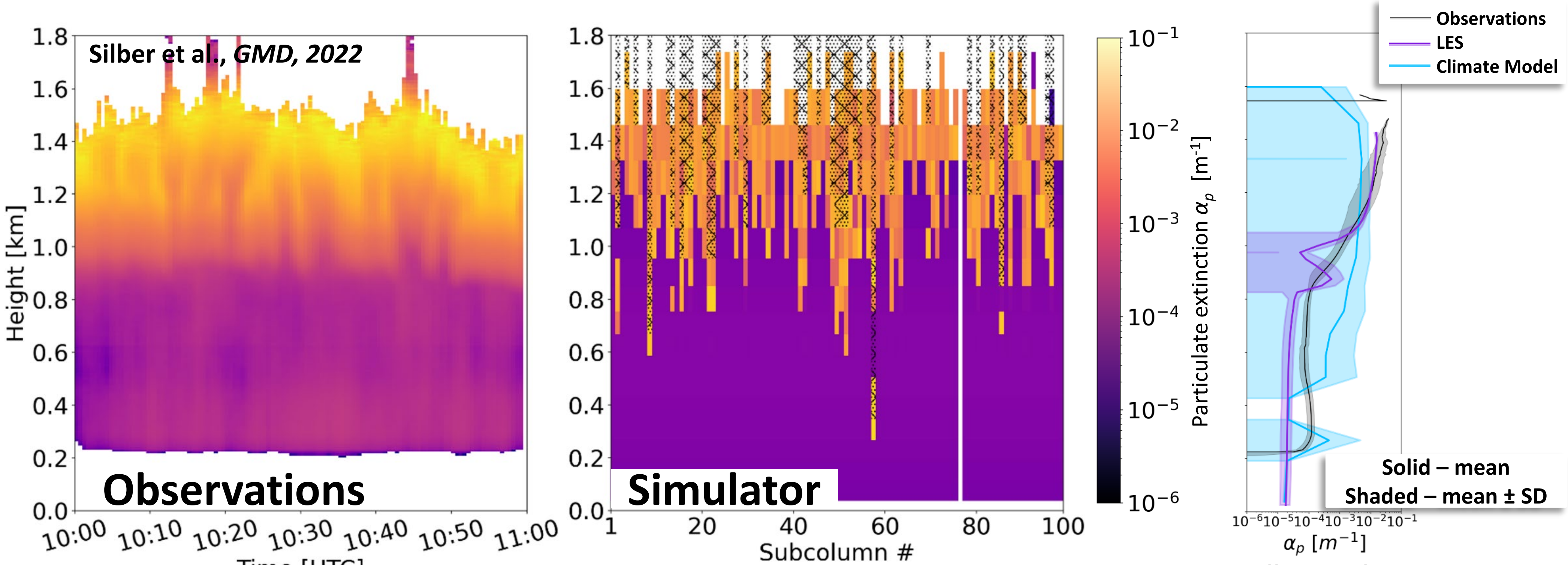
- A wealth of information can be gathered without a simulator, e.g., by comparing model output to an LES
- Lagrangian case study describing the formation and evolution of a highly supercooled Antarctic cloud during AWARE (see Silber et al., JGR, 2019)
- Two of the four ModelE3 configurations manage to form and maintain the highly supercooled cloud, induce TKE and generate a cloud-top temperature inversion via radiative cooling
- Additional insights can be collected by using instrument simulators



Silber et al., *GMD, 2022*

Case Study Evaluation Using ESM SCMs

- E3 Tun3 SCM output processed with EMC^2 output using 100 subcolumns
- The particulate extinction roughly equals twice the projected area of sampled hydrometeors

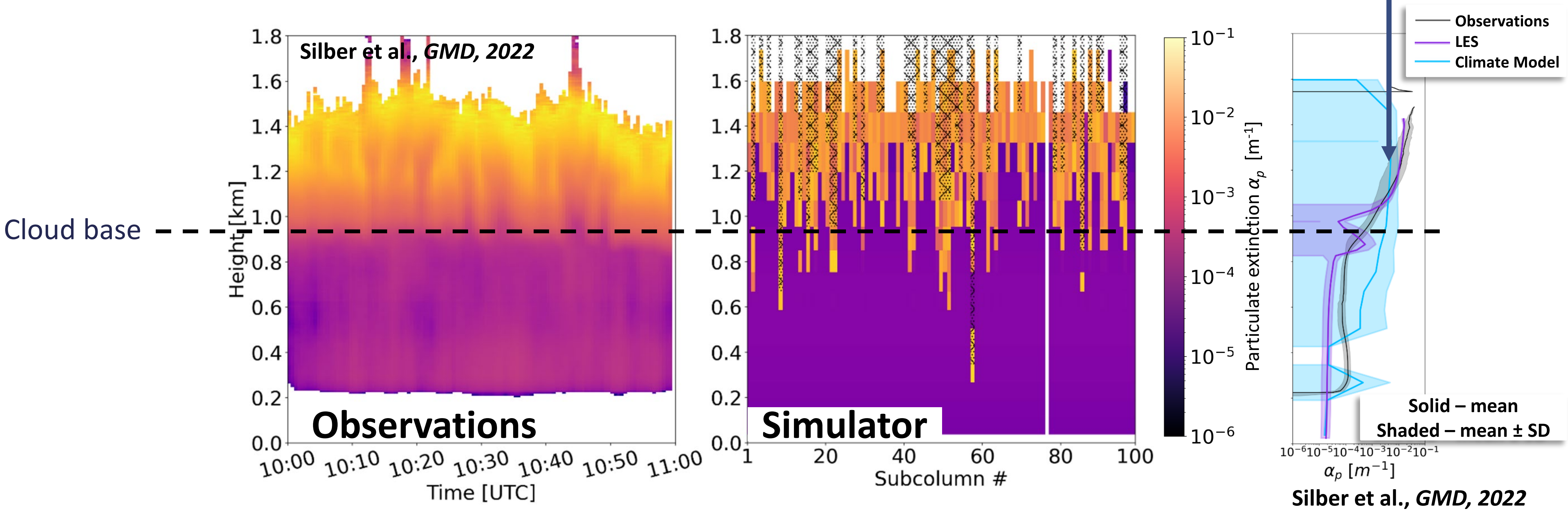


Silber et al., *GMD, 2022*

Case Study Evaluation Using ESM SCMs

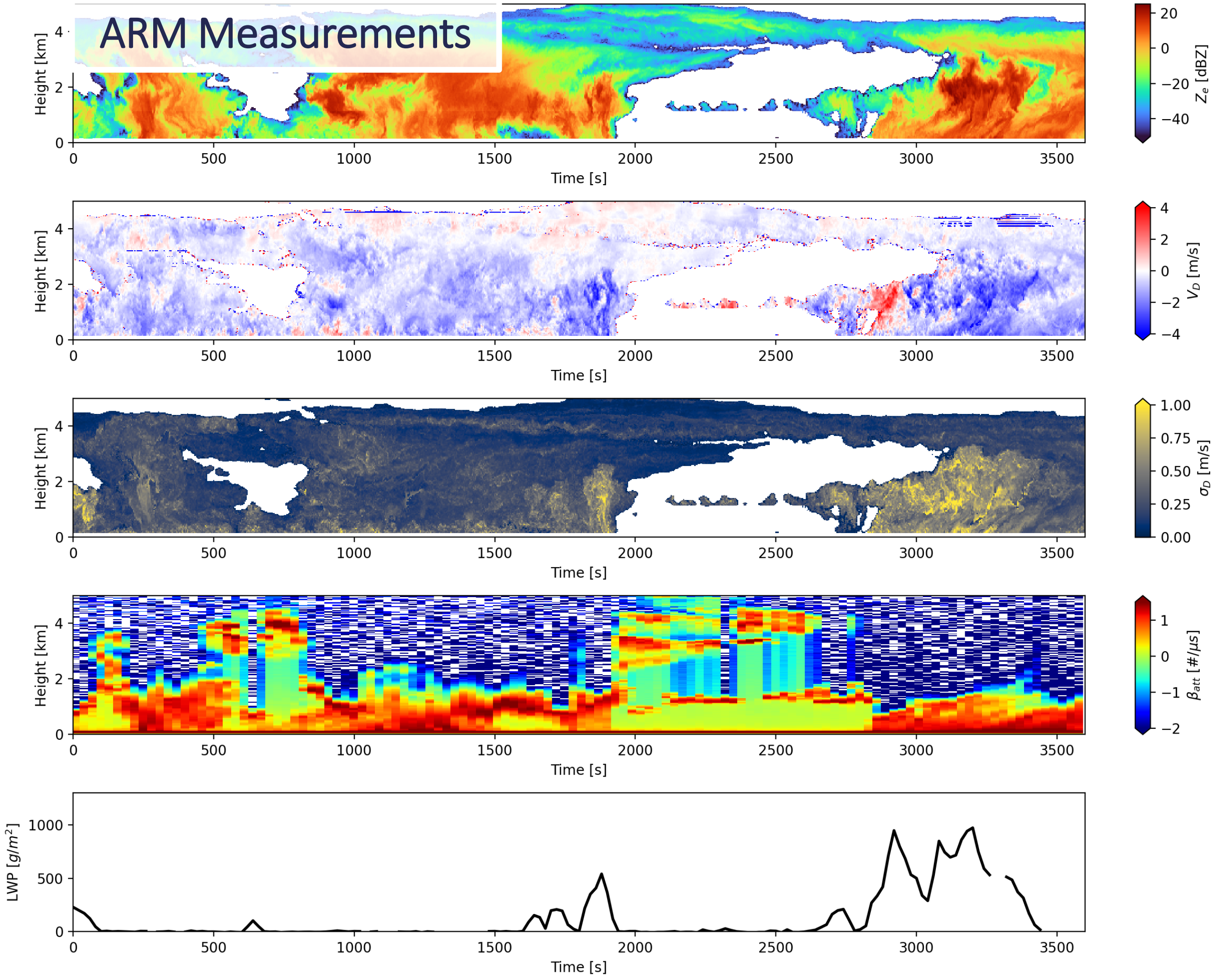
- E3 Tun3 SCM output processed with EMC^2 output using 100 subcolumns
- The particulate extinction roughly equals twice the projected area of sampled hydrometeors

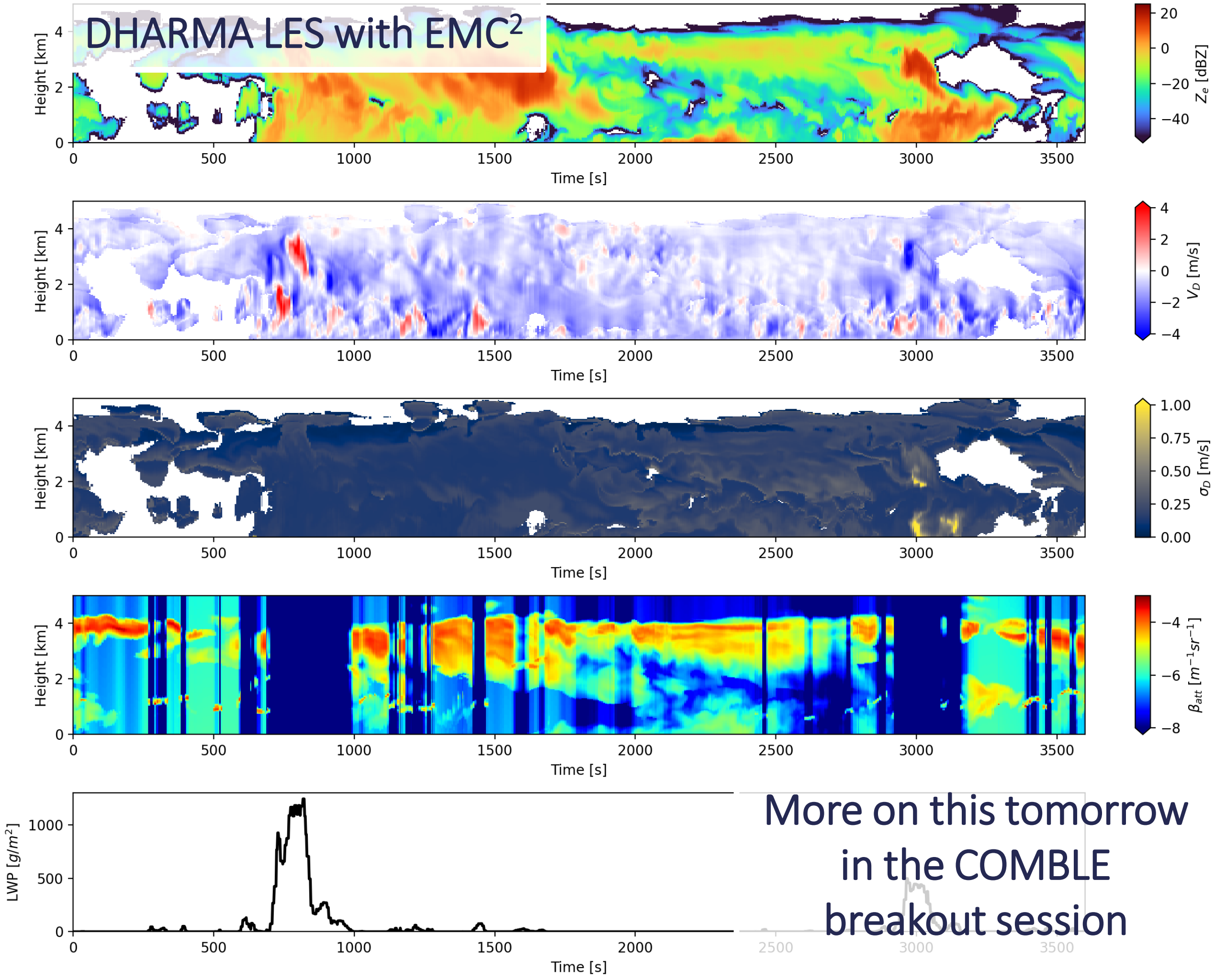
LES in-cloud extinction in agreement with observations but too low in the climate model – activated droplet concentrations is likely too low



Silber et al., *GMD, 2022*

Case Study Evaluation Using ESM SCMs

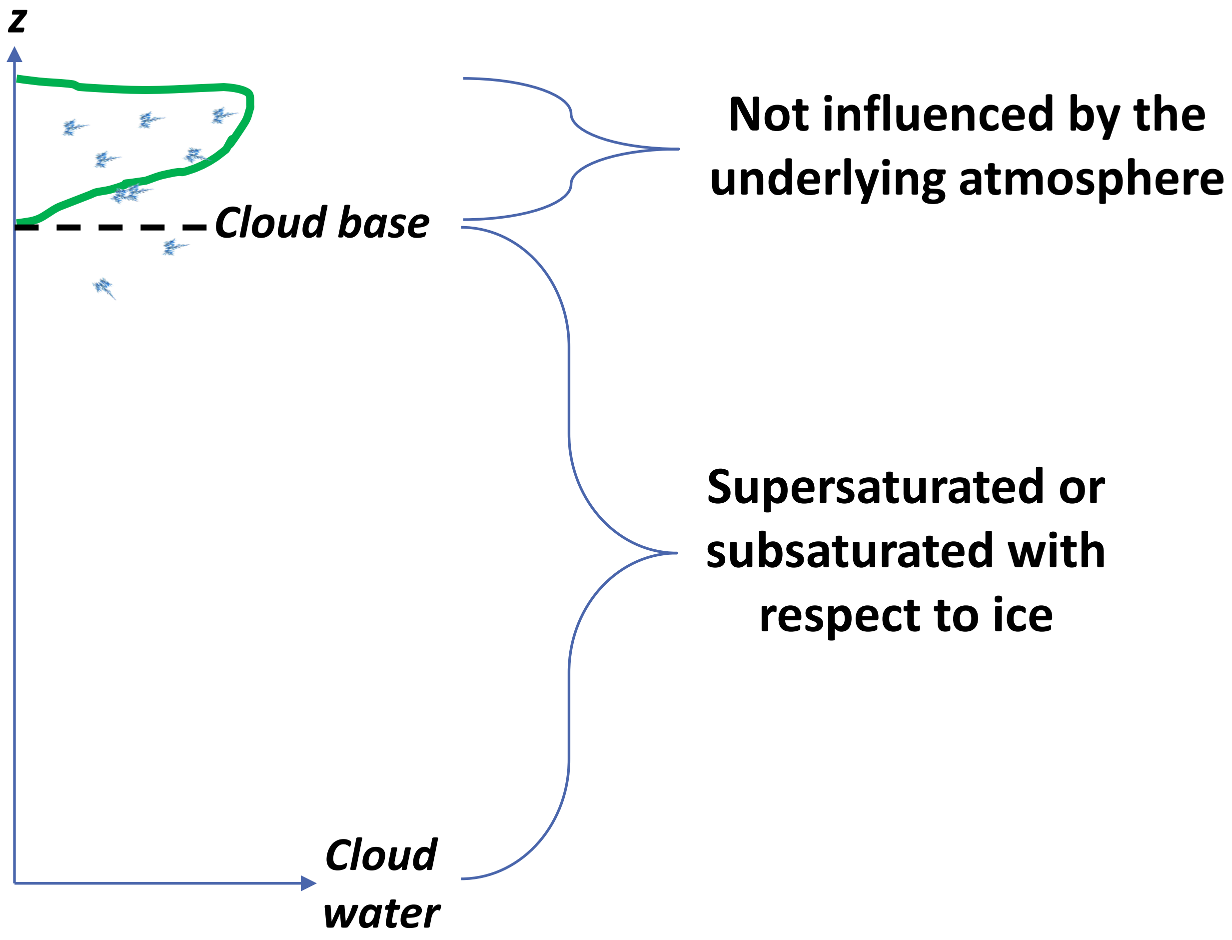




More on this tomorrow in the COMBLE breakout session

Statistical Evaluation of Cloud Base Ice Precipitation Rates in ESMs

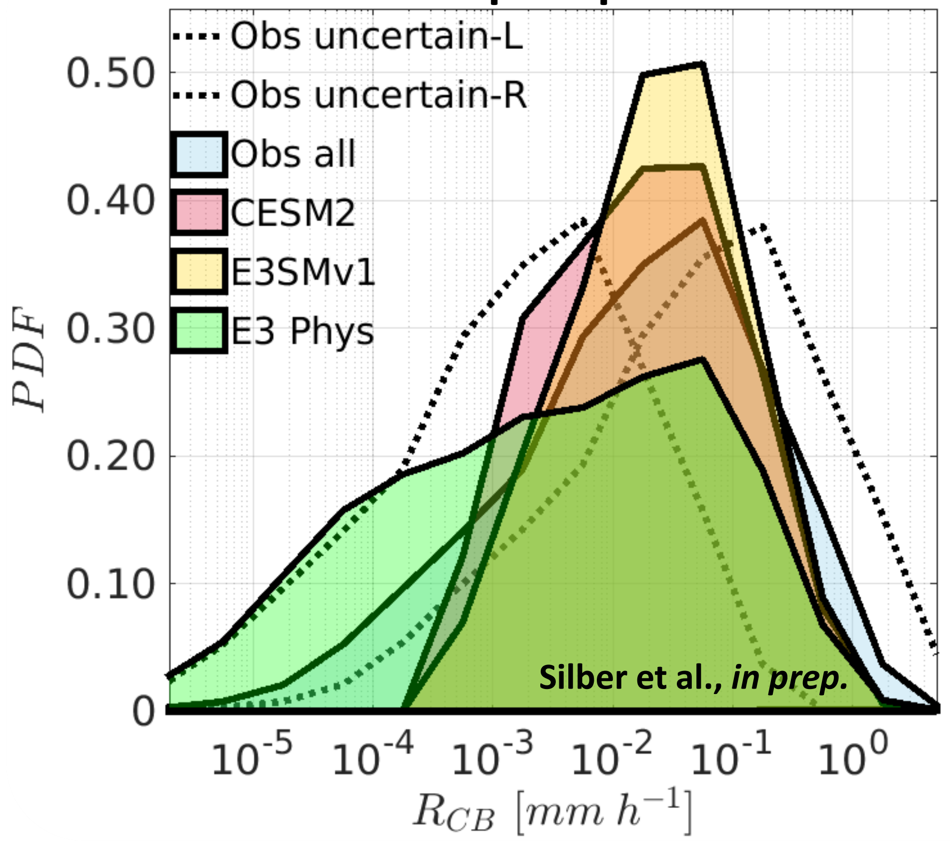
- The atmosphere underlying an ice-generating cloud can be supersaturated, subsaturated or a combination of both.
- This could result in inconsistencies when comparing ESM output to observations.
- Cloud base precipitation statistics are not influenced by the underlying atmosphere, and hence, provide a strong observational process constraint for large-scale models (Silber et al., ACP, 2021).
- Ground-based measurements provide an unmatched sensitivity and range gate separation required to estimate precipitation rates at accurately-determine cloud base



Statistical Evaluation of Cloud Base Ice Precipitation Rates in ESMs

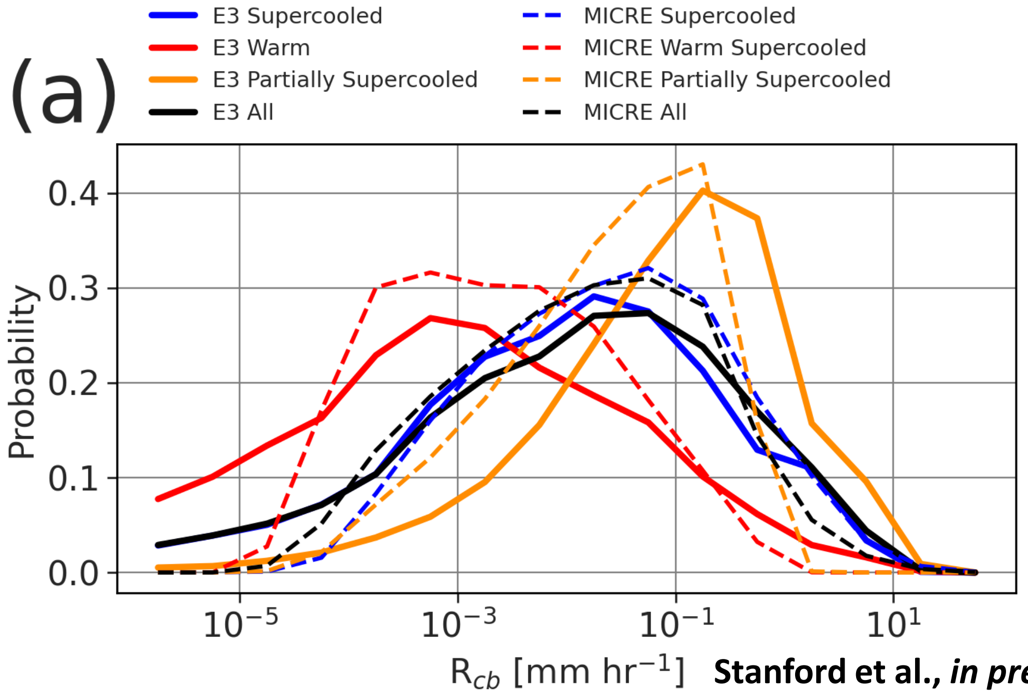
- 9-year (2012-2020) free-running global simulation:
  - ModelE3 Phys configuration (to be included in CMIP6)
  - CESM2
  - E3SMv1
- Output data extracted for the NSA site coordinates and processed using the EMC[2] is compared to precipitation rate retrievals using ARM measurements from 2011 to 2019
- 58% (E3SMv1) to 86% (ModelE3) of simulated supercooled clouds precipitate from cloud base (85% in observations; see Silber et al., ACP, 2021)
- Cloud base precipitation rates are largely within the range of the observation uncertainty

Cloud base precipitation rate



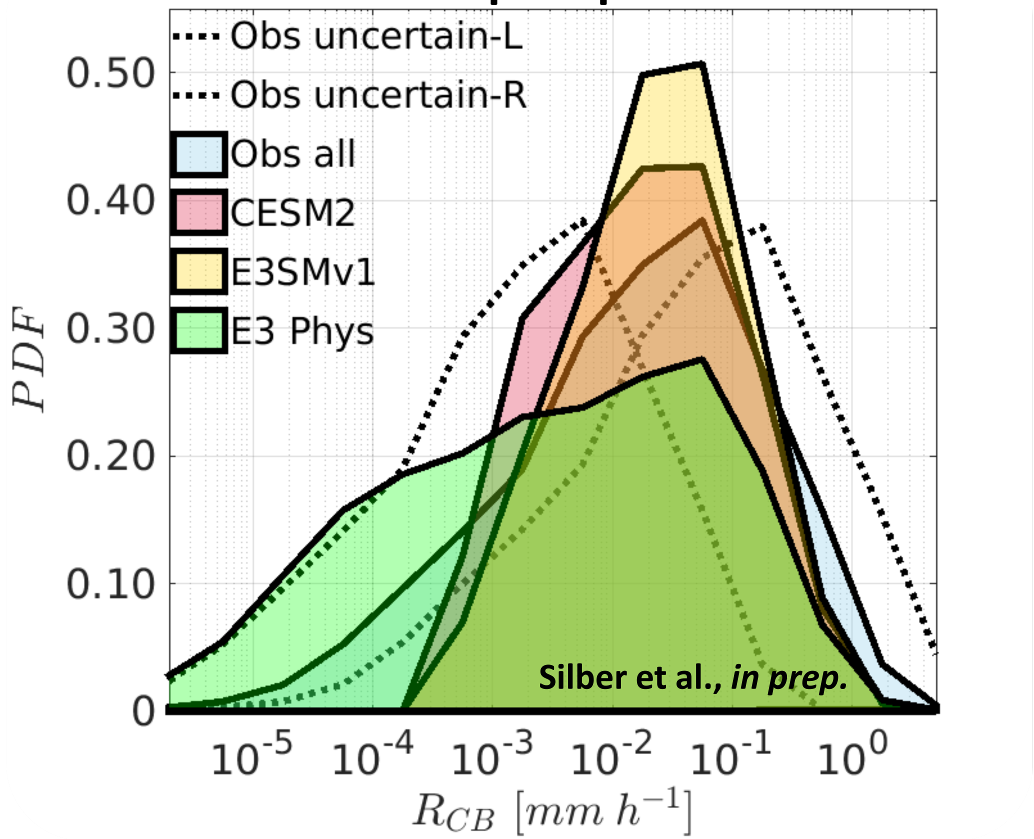
Statistical Evaluation of Cloud Base Ice Precipitation Rates in ESMs

Evaluation of warm, and partially and fully supercooled cloud precipitation rates in ModelE3



Stanford et al., *in prep.*

Cloud base precipitation rate



Silber et al., *in prep.*

Summary

- Instrument simulators facilitate the evaluation of process representation in models using observations and can augment model inter-comparisons
- The drizzle event demonstrates contextual ESM SCM/LES/observation evaluation of polar stratiform cloud microphysical, dynamical, and radiative feedbacks
- Ground-based statistics such as cloud base precipitation rates offer valuable guidance for ESM process-level evaluation, demonstrated here by directly comparing global ESM output with long-term observations

Silber, I., A. M. Fridlind, J. Verlinde, A. S. Ackerman, Y. S. Chen, D. H. Bromwich, S.-H. Wang, M. Cadeddu, and E. W. Eloranta (2019), Persistent supercooled drizzle at temperatures below -25°C observed at McMurdo Station, Antarctica, J. Geophys. Res.: Atmos., doi: 10.1029/2019JD030882

Silber, I., A. M. Fridlind, J. Verlinde, A. S. Ackerman, G. V. Cesana, and D. A. Knopf (2021), The Prevalence of Precipitation from Polar Supercooled Clouds, Atmos. Chem. Phys., doi: 10.5194/acp-21-3949-2021

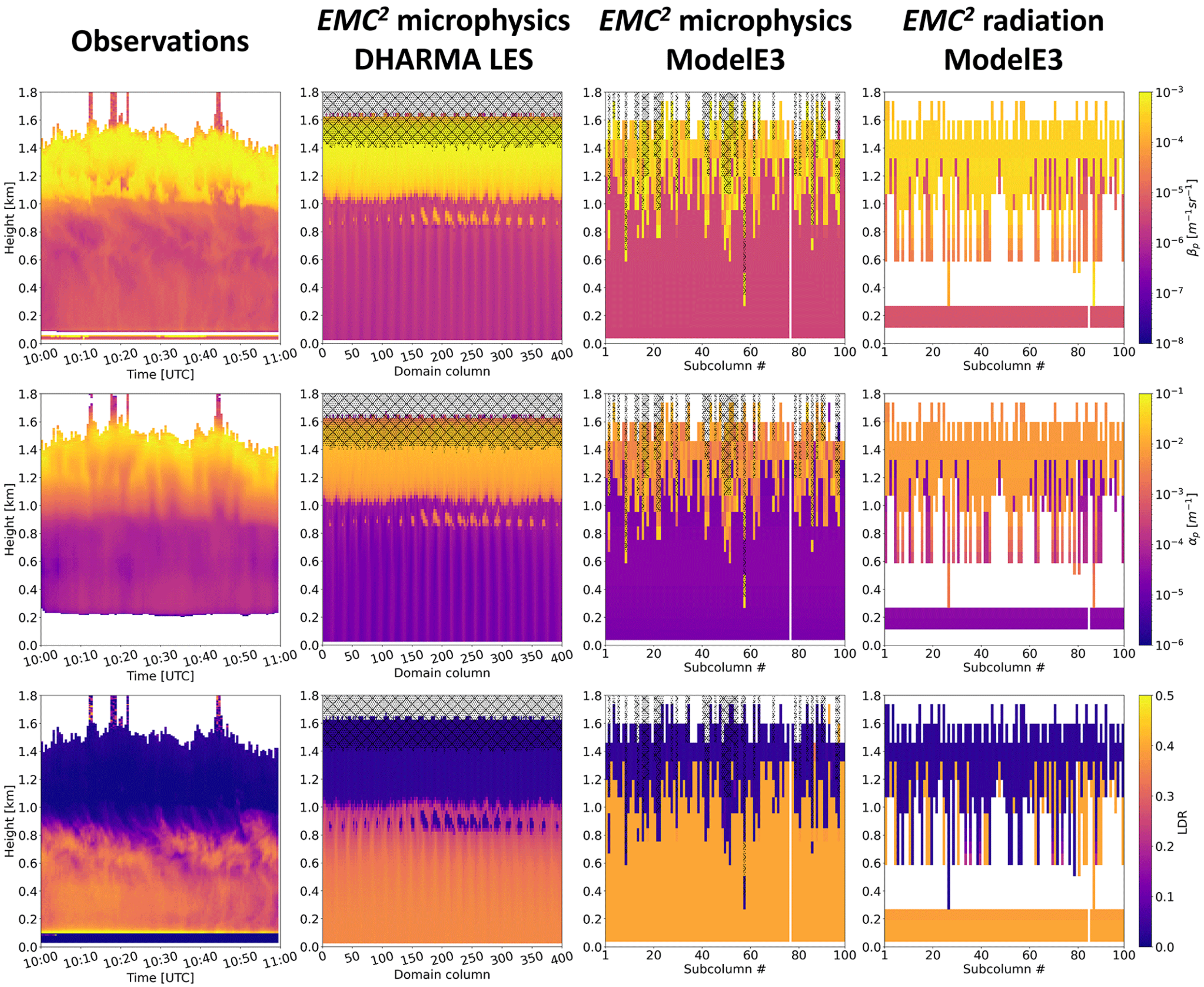
Silber, I., R. Jackson, A. M. Fridlind, A. S. Ackerman, S. Collis, J. Verlinde, and J. Ding (2022). The Earth Model Column Collabratory (EMC²) v1.1: An Open-Source Ground-Based Lidar and Radar Instrument Simulator and Sub-Column Generator for Large-Scale Models, Geosci. Model Dev., doi: 10.5194/gmd-15-901-2022.

Acknowledgements:

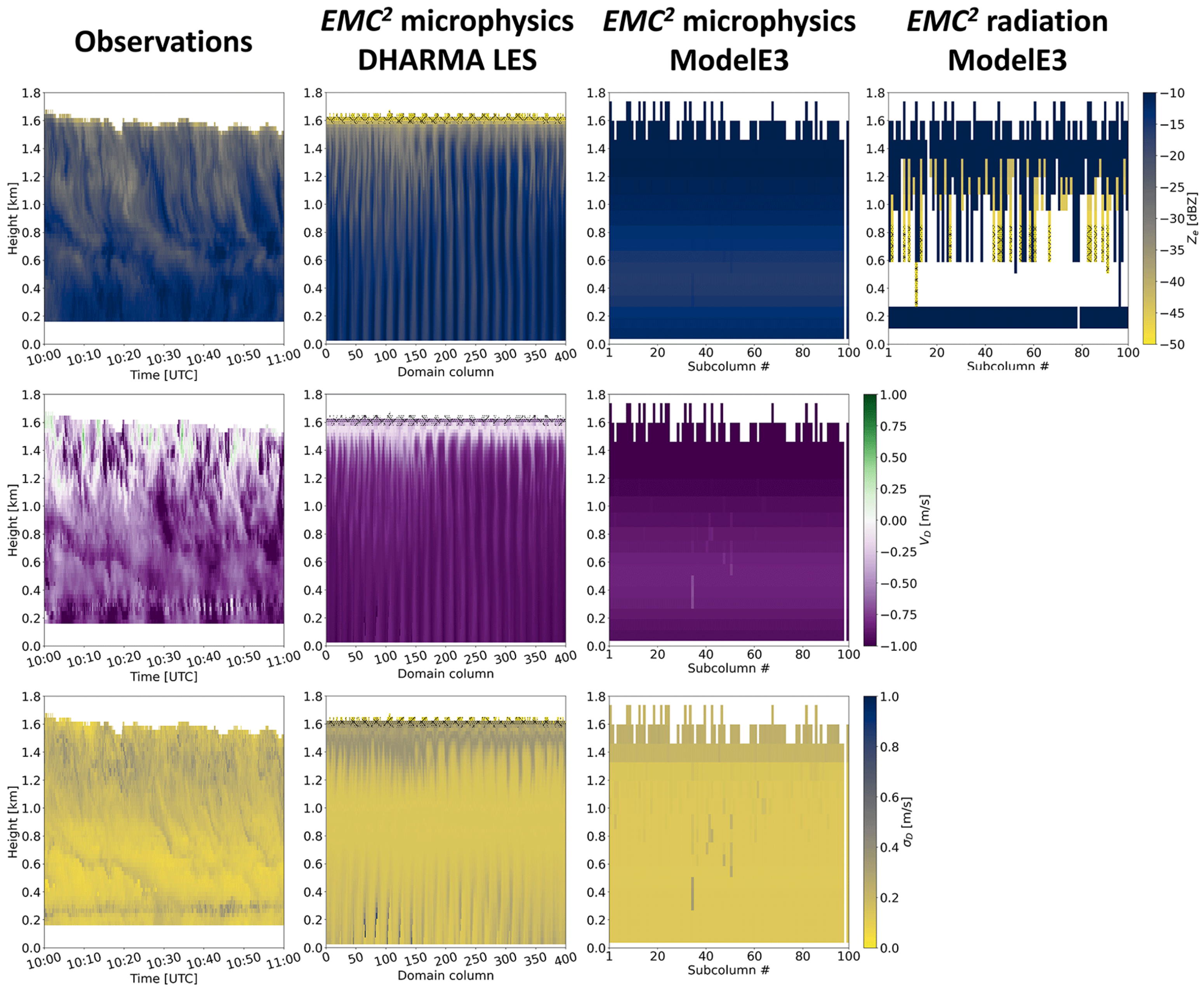
This study is supported by the DOE ASR grants DE-SC0021004 and DE-SC0018046

ASR
Atmospheric System Research

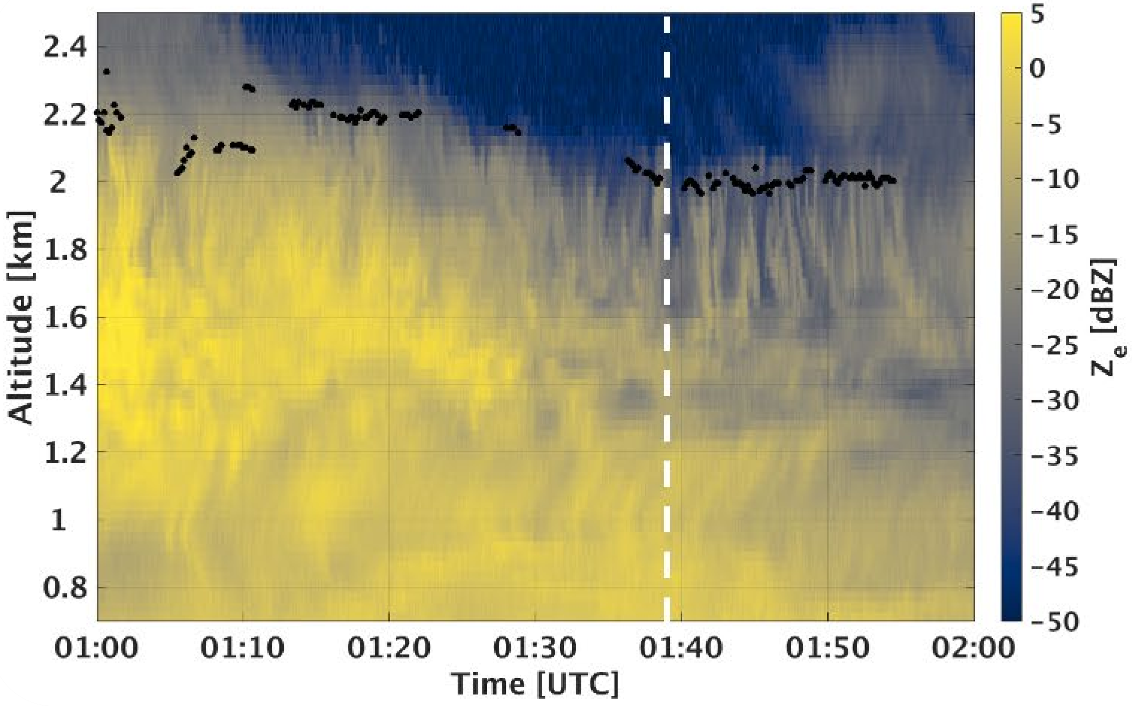
Instrument simulator (lidar)

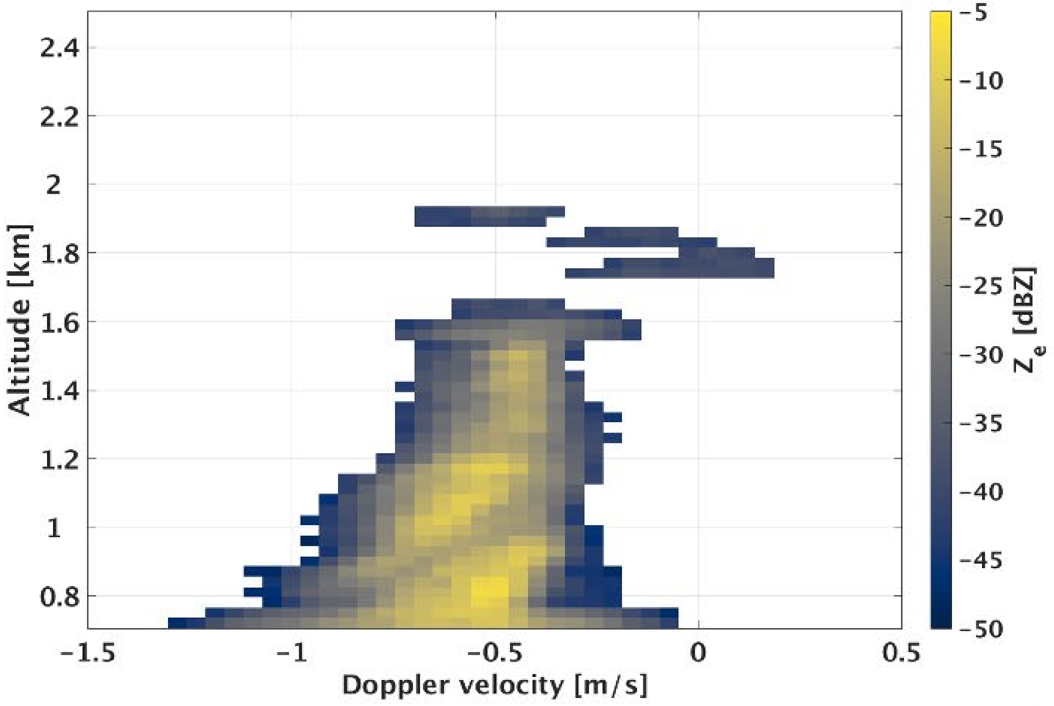


Instrument simulator (radar)



Weak Cloud Base Reflectivity Rapidly Increasing Below





Silber et al., *ACP*