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Summertime Cloud Morphology over the Eastern North Atlantic:

Thermodynamics, Drizzle Evaporation, and Surface fluxes

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Introduction, Background, and Goals

The transition in cloud morphology over the Eastern North Atlantic (ENA) from single layer stratocumulus to cumulus-coupled stratocumulus is primarily determined by the surface fluxes and vertical turbulent transports, which are impacted by drizzle evaporation.

Our goal is to:

- **Quantify and classify the cloud morphology over the ENA**.
- **Investigate the characteristics of each morphological classification and the transition process from stratocumulus to cumulus-coupled marine boundary layer to broken cells**.

Data and Methods

- The **G-1 aircraft** was deployed during two intensive measurement periods during the ARM **ACE-ENA** (Aerosol and Cloud Experiments in the Eastern North Atlantic) field campaign:

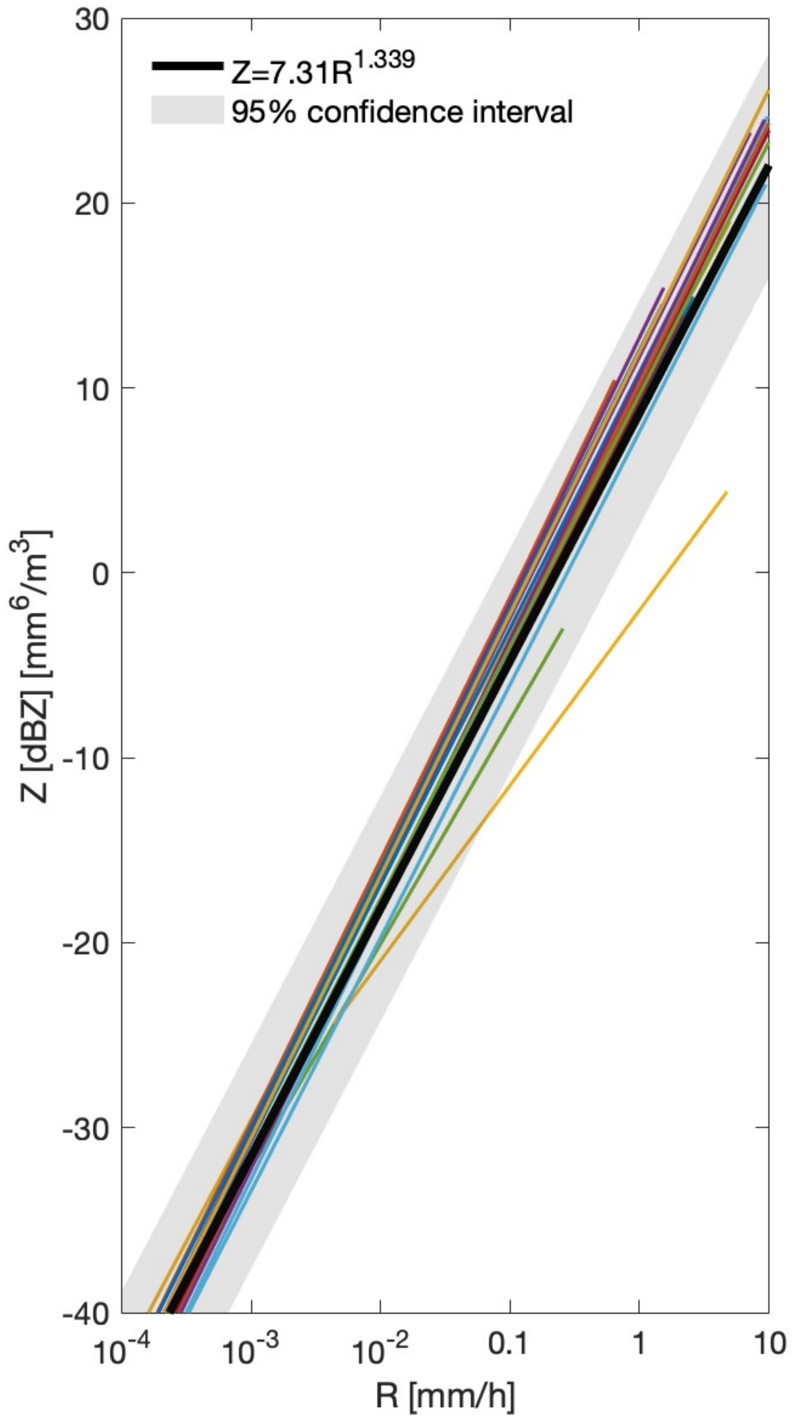
  June 21– July 20, 2017 (used here)

  Jan 15 – Feb 18, 2018

- Data collected by a **K-a band, Zenith-pointing Radar (KAZR)** and **Laser Ceilometer (CEIL)** during 2016 – 2019 summer were used.

- A **reflectivity – rain rate (Z-R) relationship** $\boldsymbol{Z = 7.31R^{1.339}}$ was computed from droplet size distribution measured by the G-1 aircraft.

- The Z-R relation was used to compute the drizzle evaporation rate and latent heat flux over four years.



ACE-ENA summertime Z-R relationship*

* 20 flights during the ACE-ENA summer observation period are shown by the colored lines.

K-Means analysis for cloud classification

- A K-Means clustering analysis was used to classify cloud morphology every 6-hours, producing total of 1464 cases (366 days) based on:

Cloud complexity (CI)

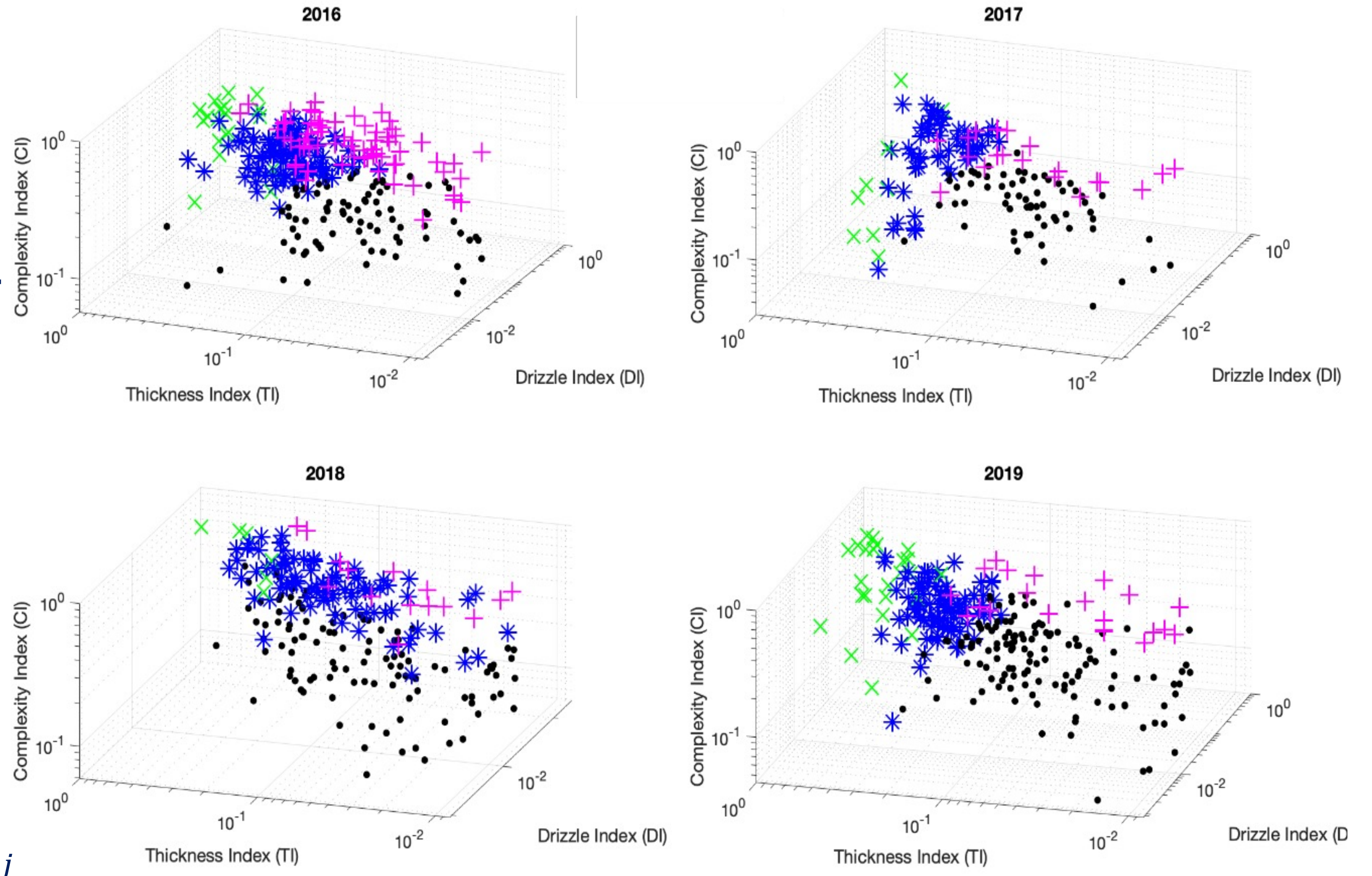
$$= \frac{h_{c\_max}(m) - h_{c\_min}(m)}{Z_{max}}$$

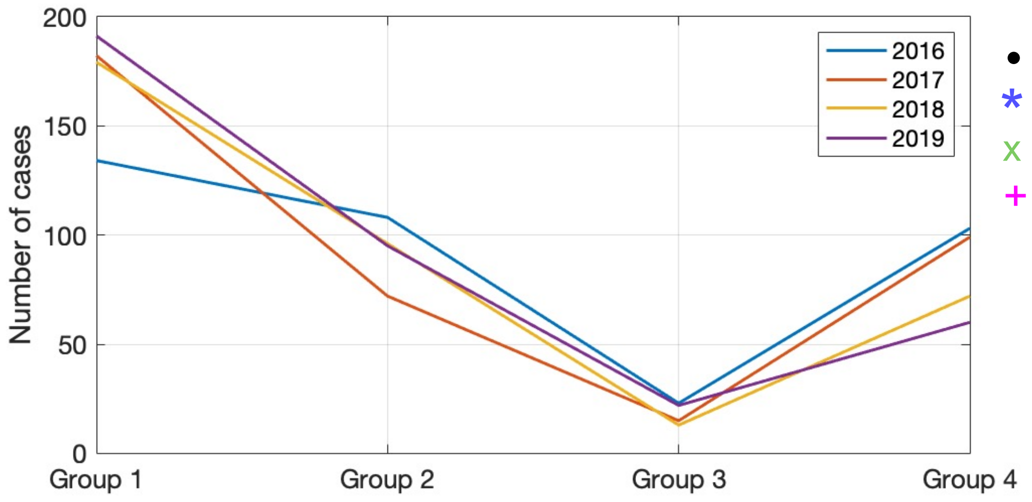
Drizzle depth (DI)

$$= \frac{1}{N}\sum_{j=1}^{N}\left[10\left(\left(\bar{Z}_{\Delta h_{DD}} + 35\right)/45\ dBZ\right)\left(\Delta h_{DD}(m)/z_{max}\right)\right]_j$$

Cloud thickness (TI)

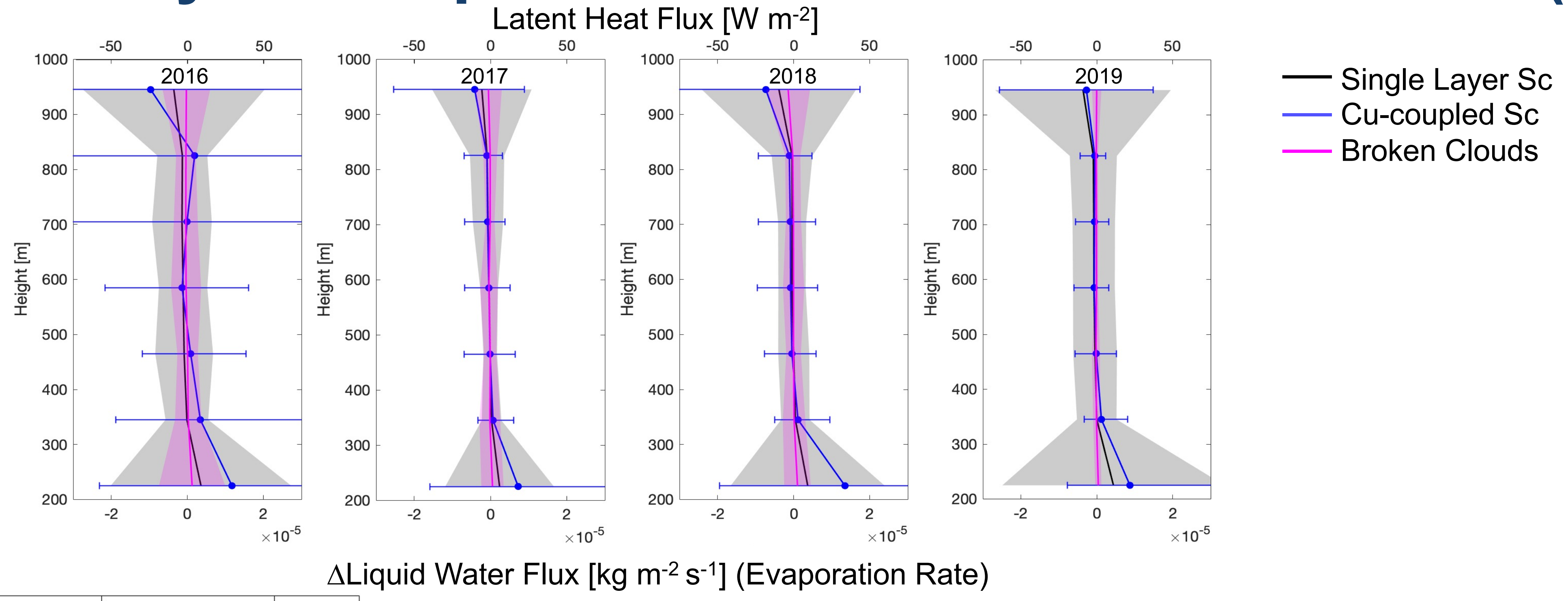
$$= \frac{1}{N}\sum_{j=1}^{N}\left[\left(\sum_{i=i_b}^{i=i_t} k_i \cdot \Delta z\right)/z_{max}\right]_j \quad \begin{cases} k_i = 1 & Z > -35\ dBZ \\ k_i = 0 & Z < -35\ dBZ \end{cases}$$

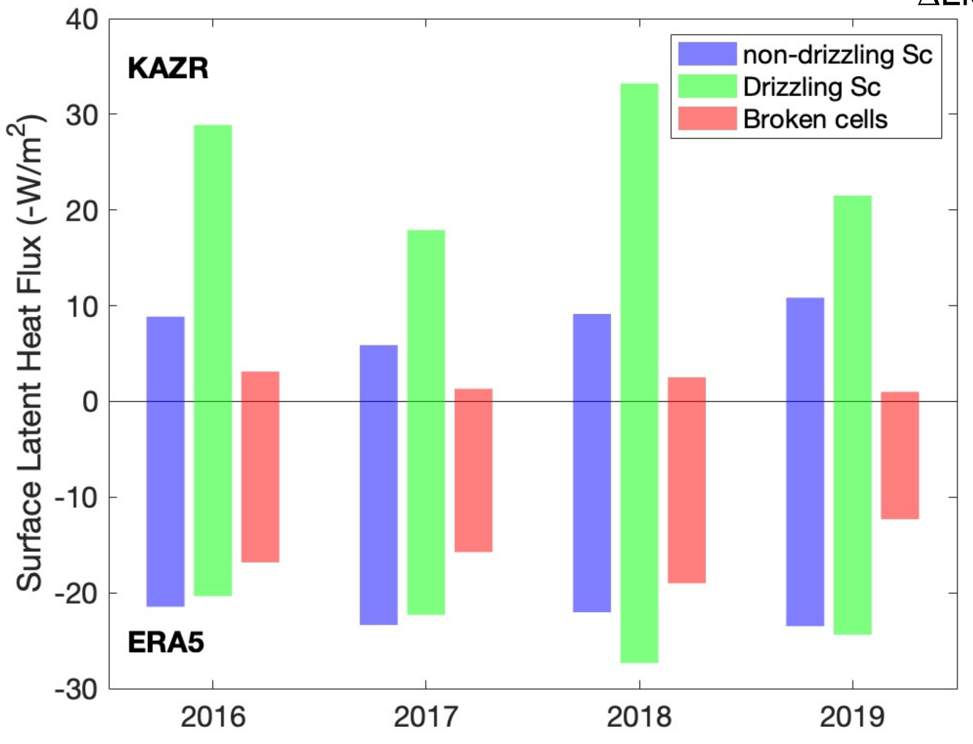




- • Group 1: Single layer Sc
- * Group 2: Cu-coupled Sc
- x Group 3: Deep Clouds
- + Group 4: Broken Clouds

Four-year evaporation rate and latent heat flux (LHF)



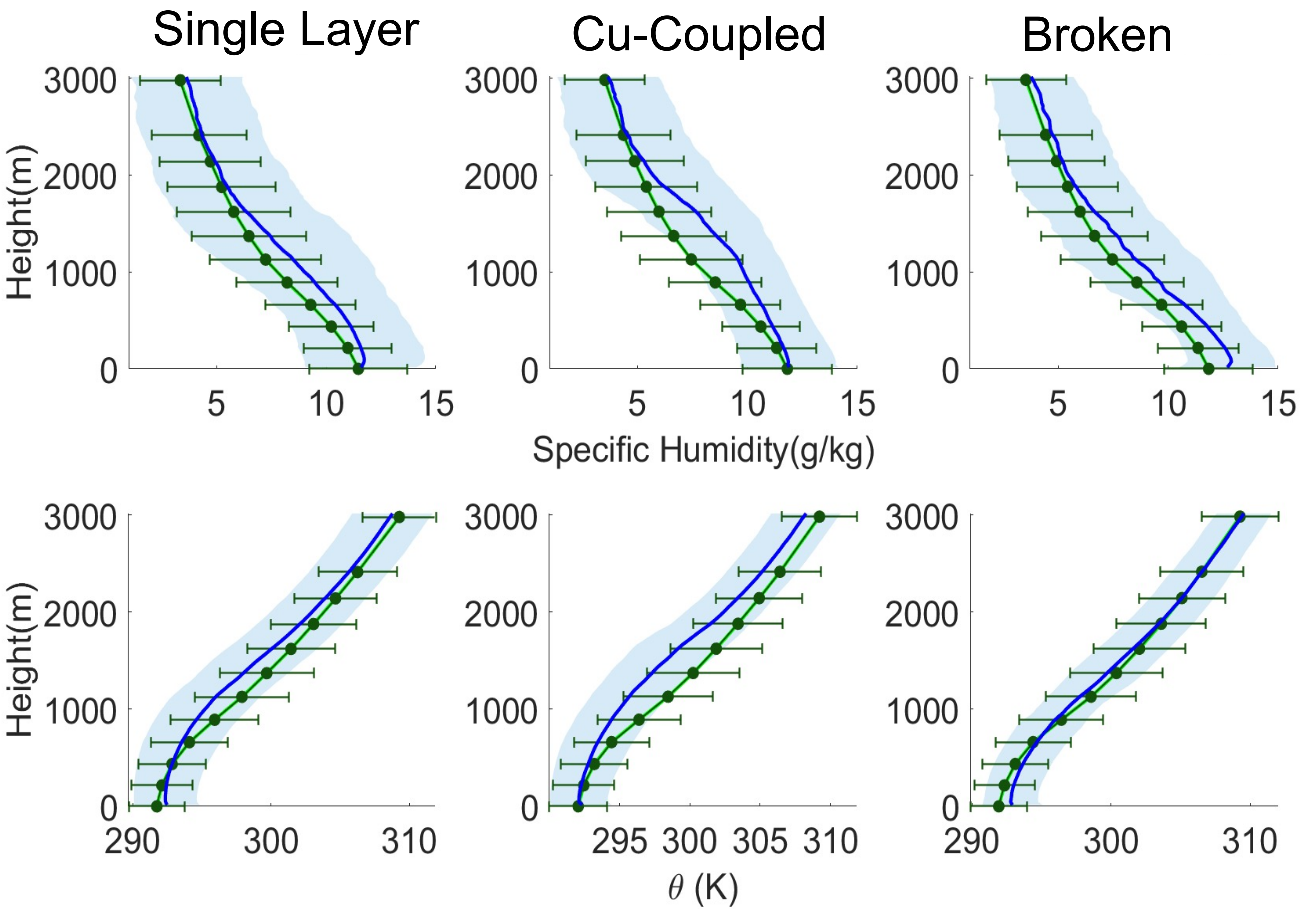


Four-year averaged near-surface LHF from ENA (top) vs. surface LHF from ERA-5 reanalysis (bottom)

- Cu-coupled Sc* has the highest sub-cloud evaporation rates, followed by single layer Sc and broken clouds.
- The near-surface LHF caused by drizzle evaporation for drizzling and Cu-topped Sc is the largest, which almost offsets the LHF from the surface.
- Drizzle evaporation contributes modestly to the near surface latent heat budget in single layer Sc and is negligible in broken clouds.

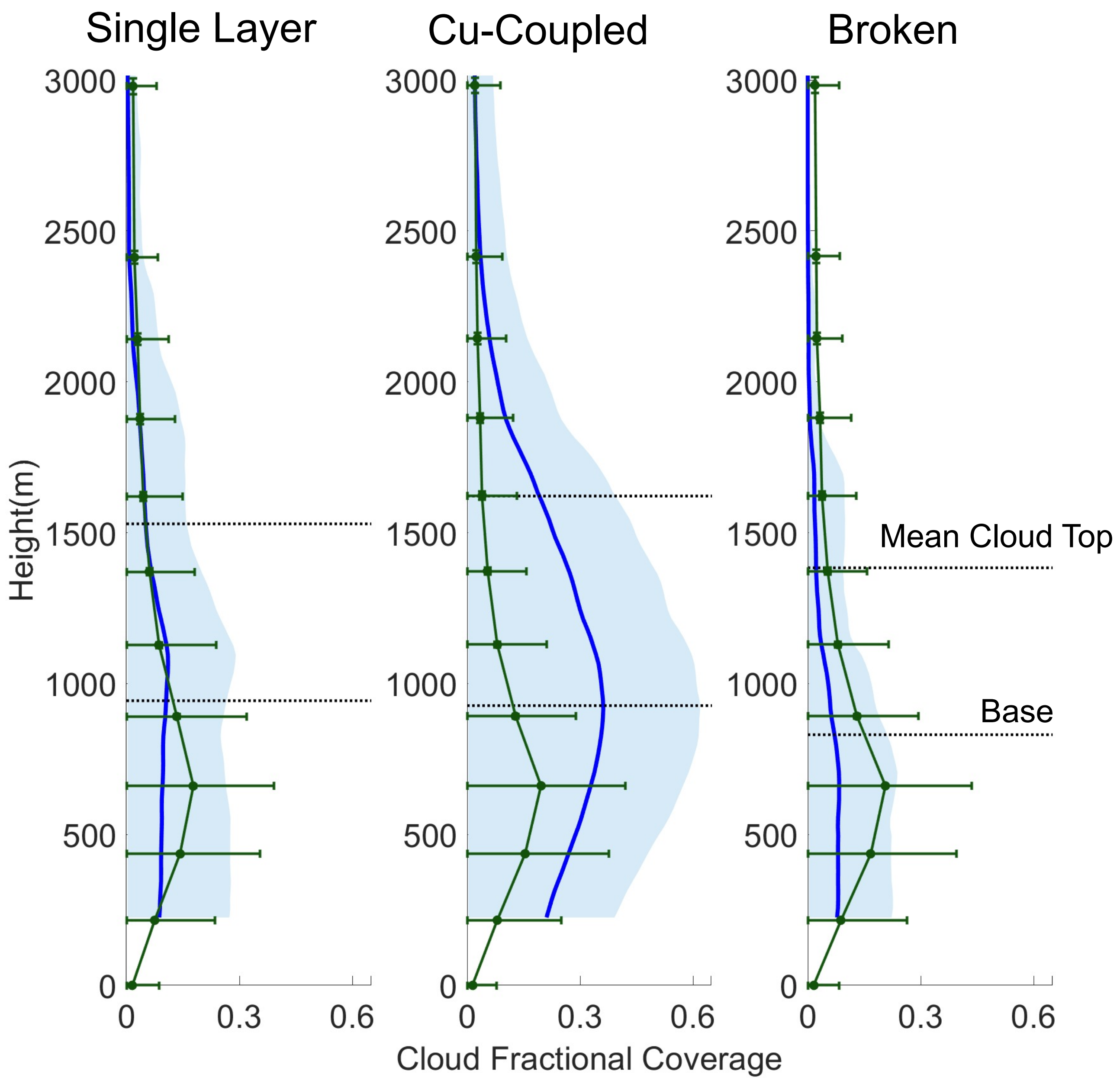
* Sc: Stratocumulus; Cu: Cumulus

ENA vs. ERA-5 thermodynamics(left) and cloud coverage (right)



Four-year averaged specific humidity and potential temperature for ENA (blue) vs. ERA-5 (green)

- Single layer Sc and broken clouds well-represented in ERA5
- **Cu-Coupled Sc significantly underrepresented in ERA5**
  - **600m-2000m too dry and too warm**



Four-year averaged cloud fractional coverage of ENA (blue) vs. ERA-5 (green)

Summary

- We used a K-Means clustering analysis based on cloud geometry and reflectivity to classify boundary layer clouds over the ENA into four groups: single-layer Sc, Cu-topped Sc, deep clouds, and broken clouds.
- Cu-topped Sc has the highest sub-cloud evaporation rate, and broken clouds have the lowest evaporation rate.
- The near-surface LHF caused by the evaporation of Cu-topped Sc almost offsets the LHF from the surface.
- ERA-5 reanalysis is generally warmer and drier than ENA observations. Significant disagreement was found in cloud fractions between ERA-5 and the ENA for Cu-topped Sc.

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