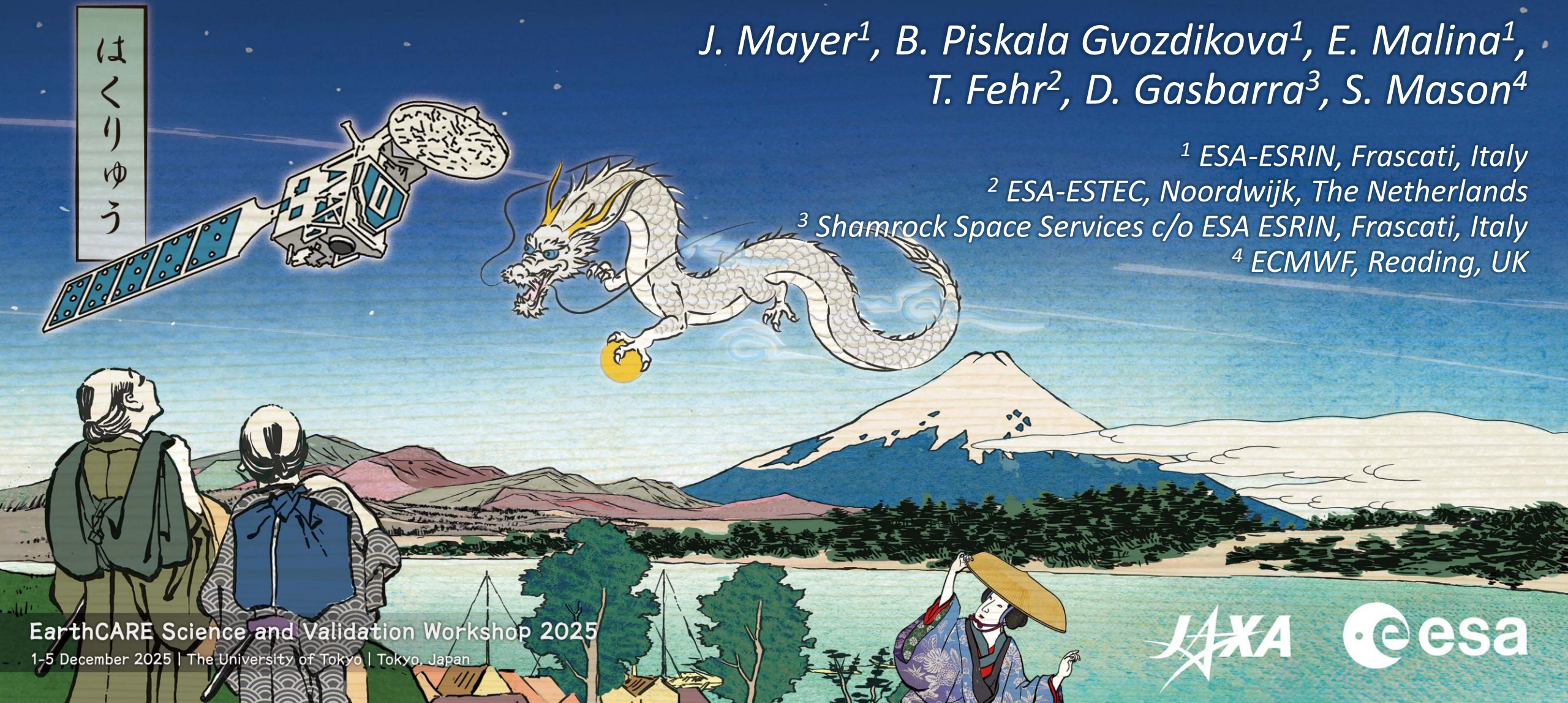
EarthCARE Reveals the Interplay of Rain and Mesoscale Structure in Marine Stratocumulus

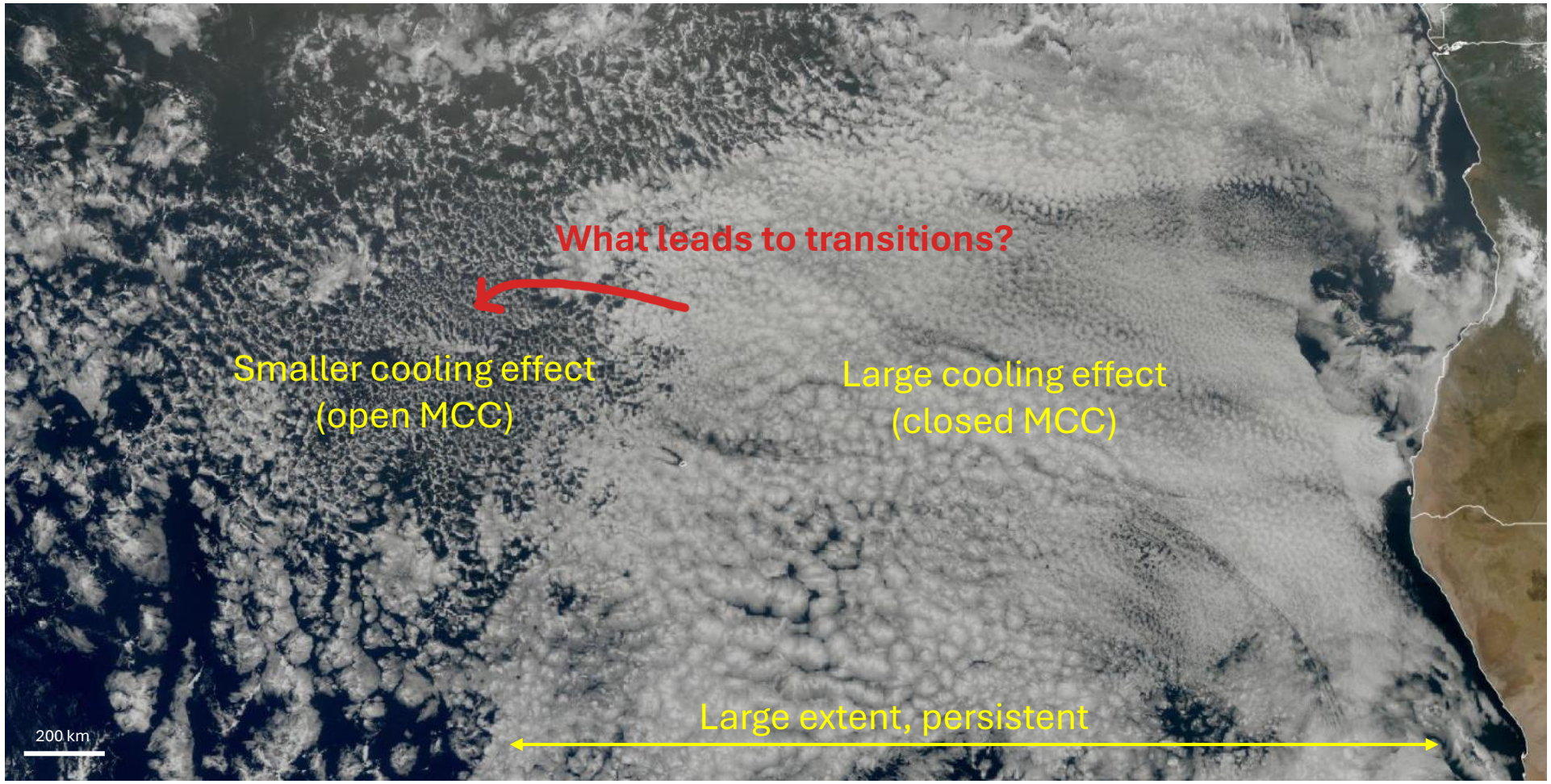
J. Mayer[1], B. Piskala Gvozdikova[1], E. Malina[1], T. Fehr[2], D. Gasbarra[3], S. Mason[4]

[1] ESA-ESRIN, Frascati, Italy
[2] ESA-ESTEC, Noordwijk, The Netherlands
[3] Shamrock Space Services c/o ESA ESRIN, Frascati, Italy
[4] ECMWF, Reading, UK



EarthCARE Science and Validation Workshop 2025
1-5 December 2025 | The University of Tokyo | Tokyo, Japan

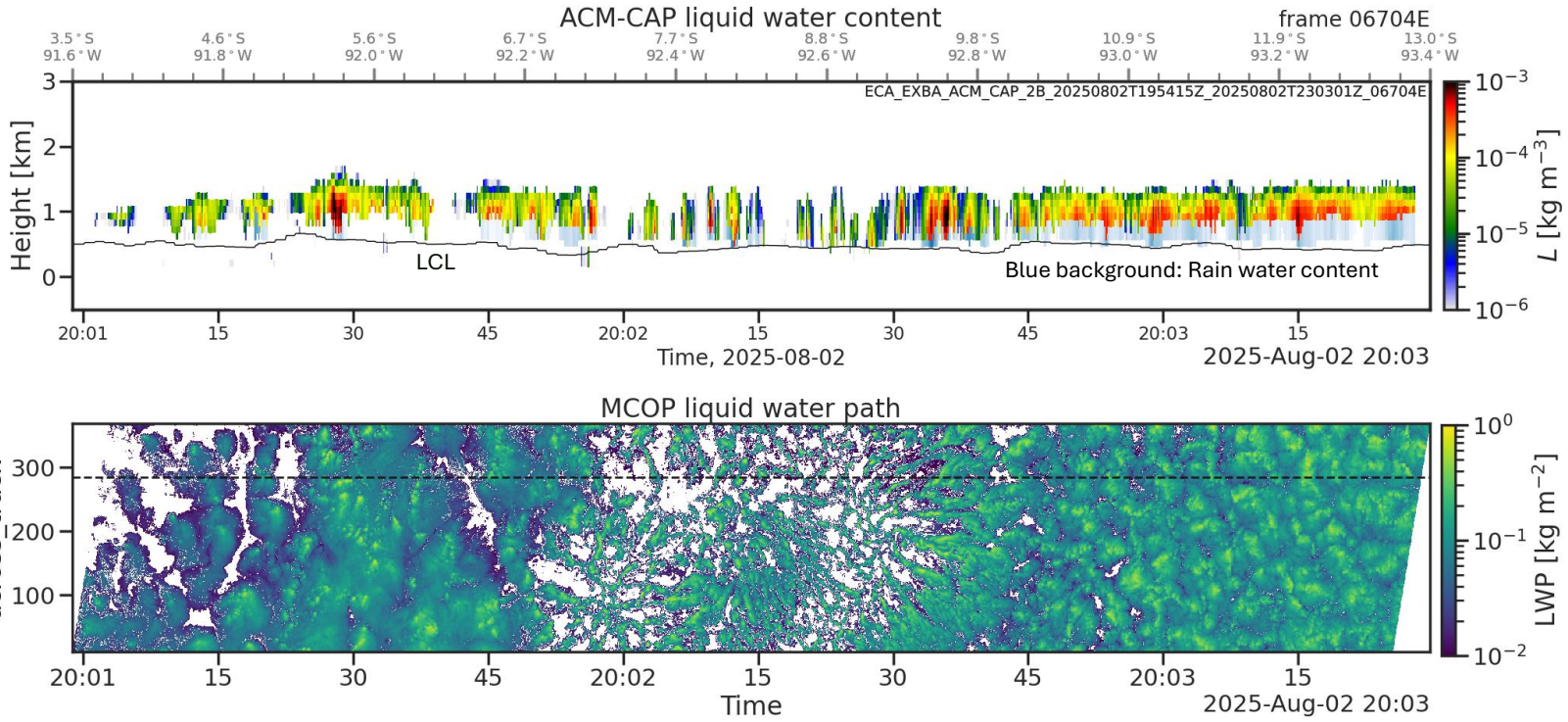
Why are we interested in stratocumulus (StCu) clouds?



MTG, FCI (True Colour RGB), 27.09.25, 13 UTC

EarthCARE offers new insights into vertical and horizontal structure

EarthCARE enables for the first time detailed observations of the vertical structure of low clouds.



ACM-CAP: Synergistic L2 product (ATLID, CPR and MSI), providing a unified retrieval of clouds, aerosol and precipitation; developed by S. Mason and R. Hogan*

M-COP: L2 product (MSI), providing cloud optical and physical products and the spatial context for active observations; developed by A. Hünerbein*

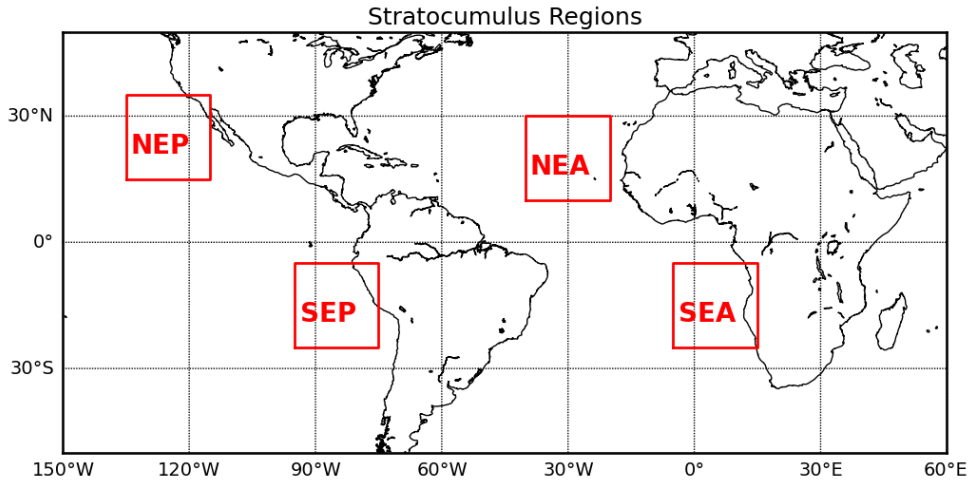
ECMWF: interpolated to EarthCARE resolution (1km) along track

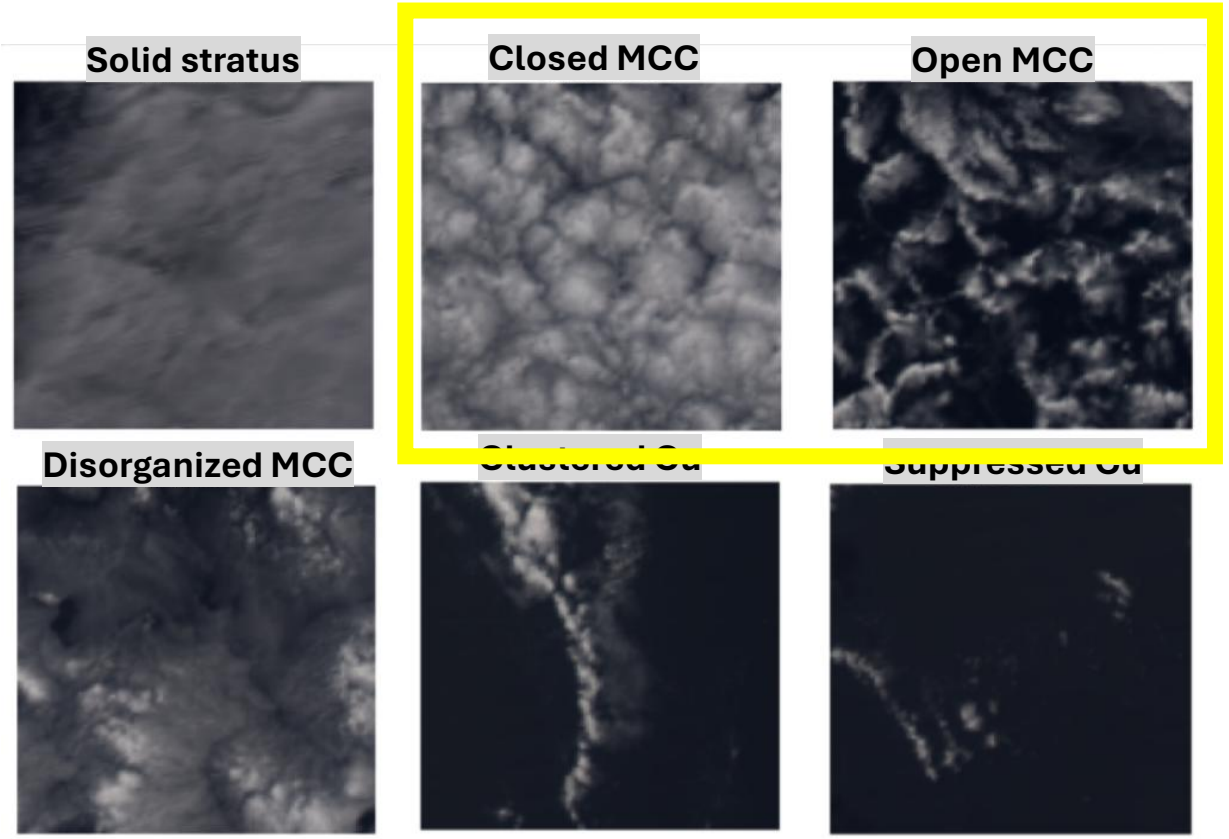
* AMT EarthCARE Special Issue (2024)

Mesoscale structures are classified using a CNN

- **Convolutional Neural Network (CNN) of Wu et al. (2025),** applied on two months of data (Jul-Aug 2025; baseline BA)

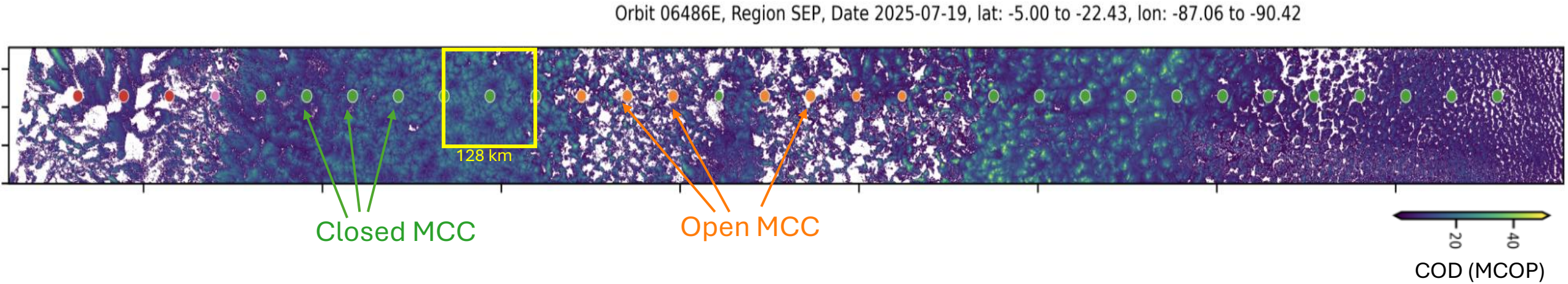
- Inputs:
  - COD and three IR window channels → daytime only!
  - coarsened to 1km resolution
  - scenes of 128 x 128 km





Adapted from Wu et al. (2025)

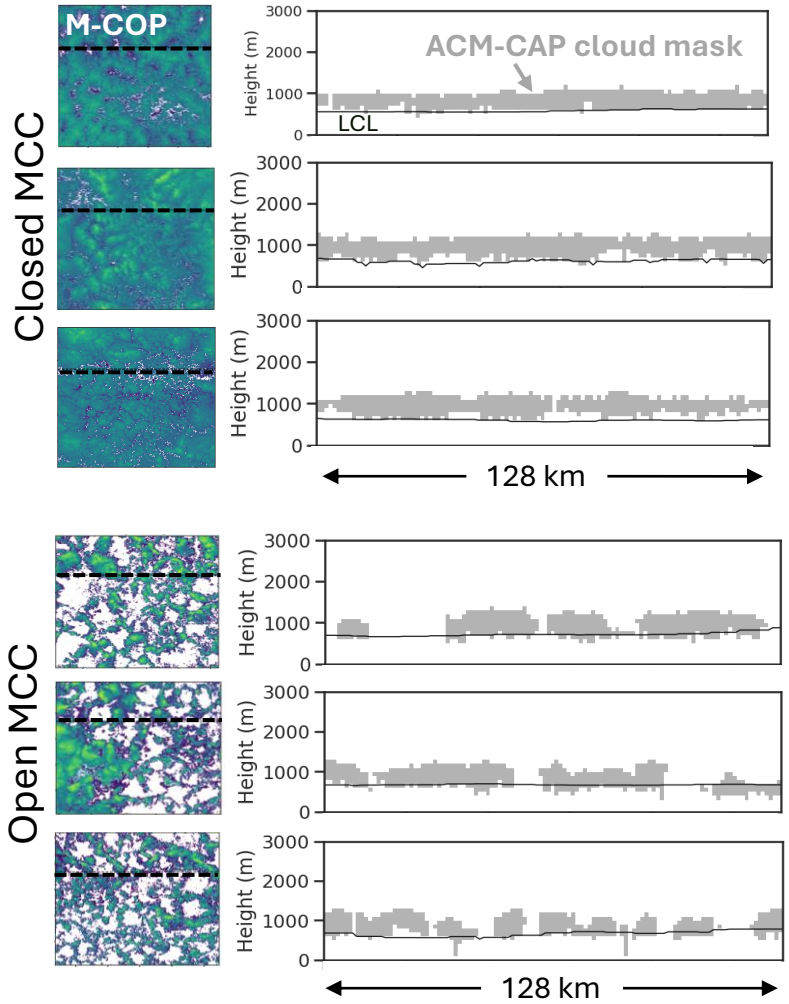
Mesoscale structures are classified using a CNN



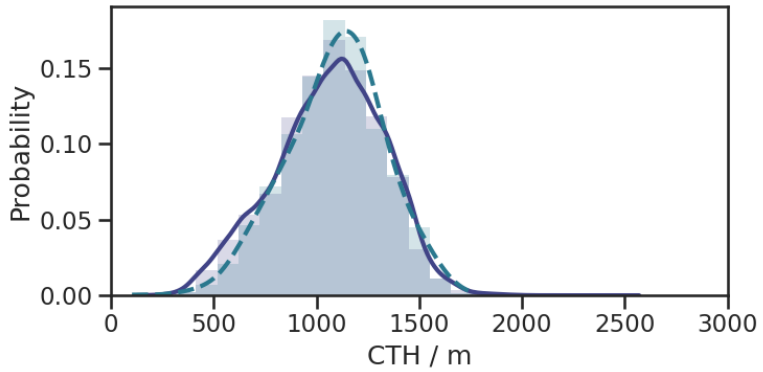
1. What are the properties (microphysical, vertical structure) of closed and open MCC?
2. What leads to transitions from closed to open MCC?

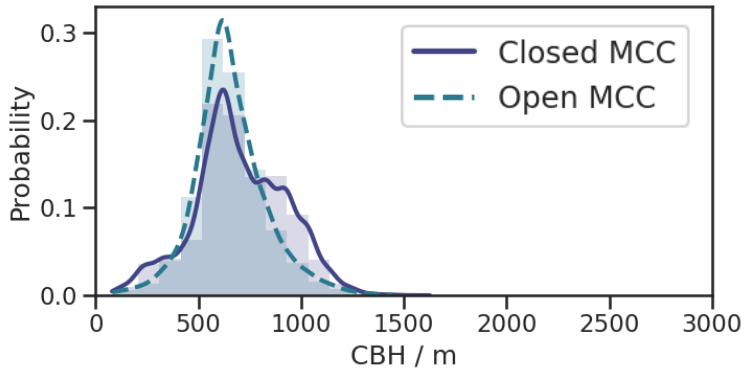
Closed MCC vs open MCC

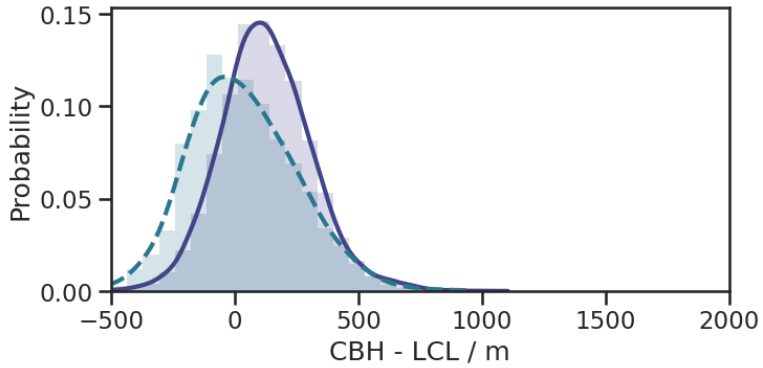
Examples for typical cloud scenes



Vertical structure (statistics over data from Jul to Aug 2025)



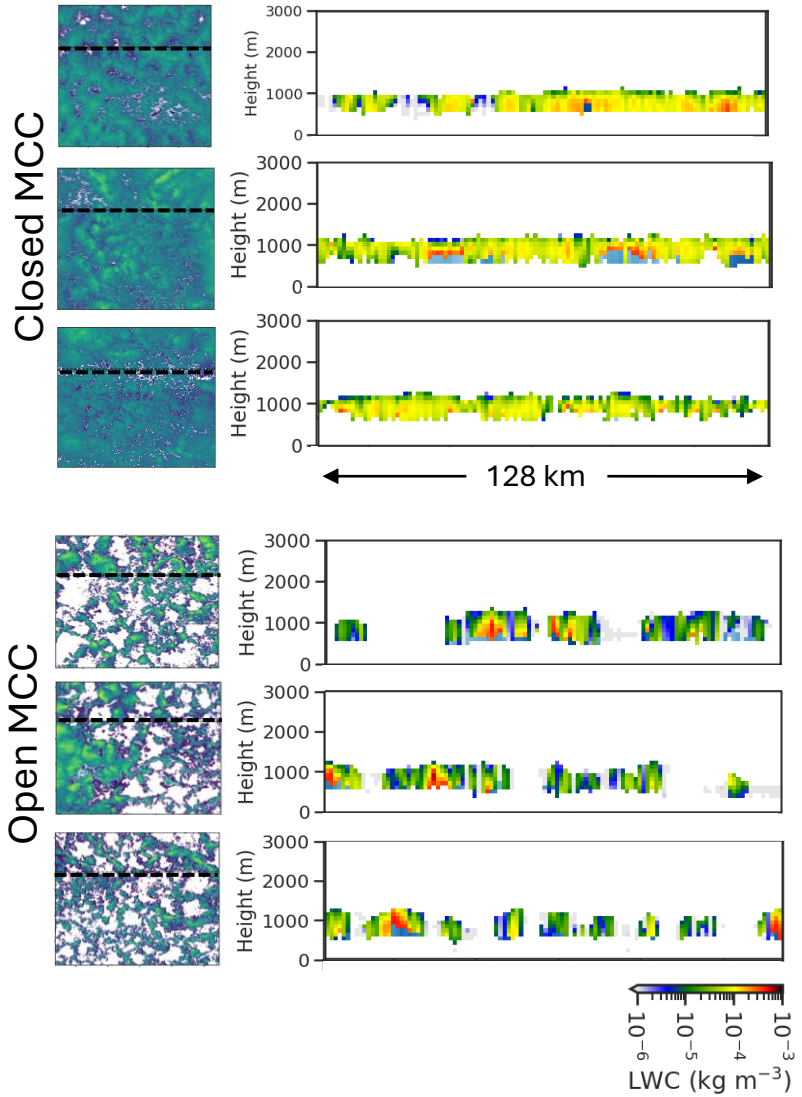




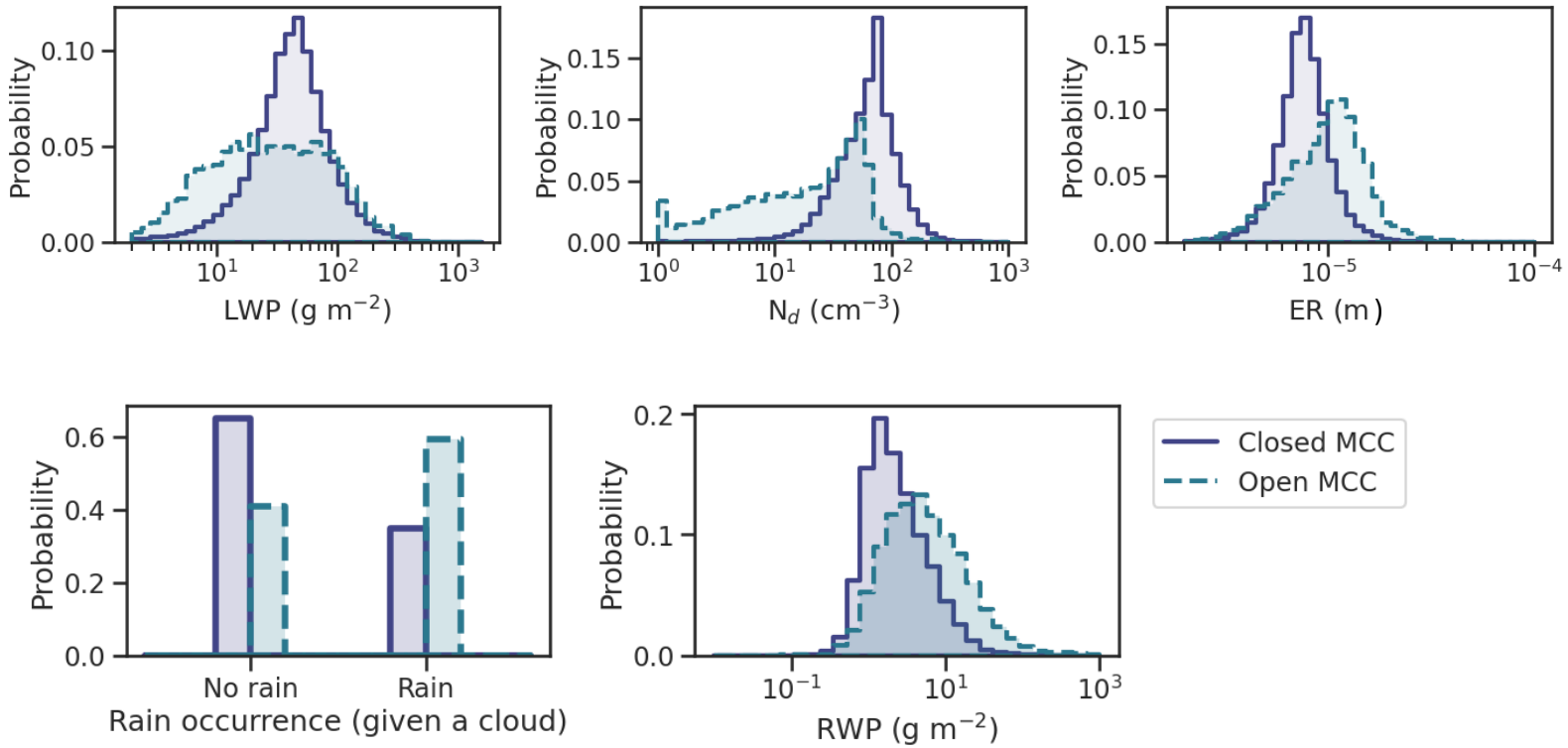
→ Similar vertical extent
→ Open MCC are coupled

Closed MCC vs open MCC

Examples for typical cloud scenes



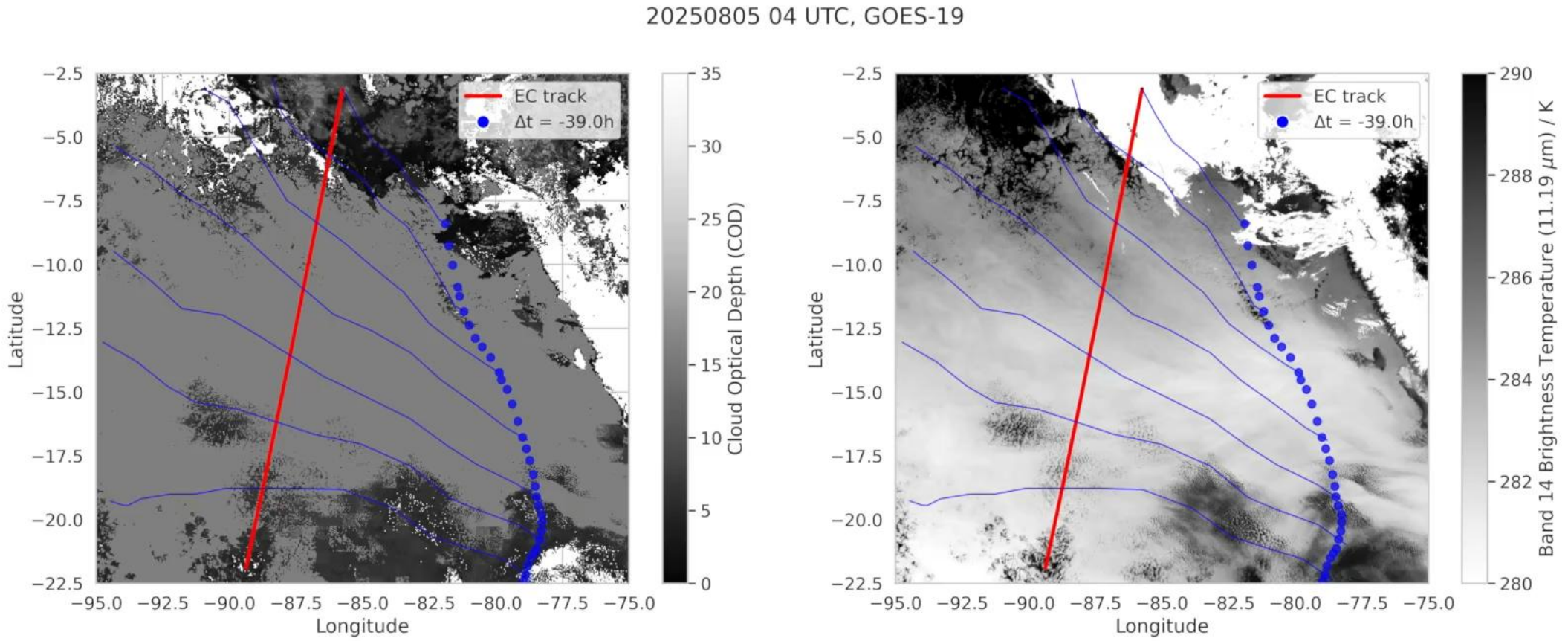
Microphysical properties (statistics over data from Jul to Aug 2025)



→ Higher ER and RWPs for open compared to closed MCC

What happens before, during and after a transition from closed MCC to open MCC?

- Compute trajectories using wind data from ERA5 for August 2025
- Apply CNN on GOES data in SEP (daytime only!)
- Filter for clouds that transition from closed MCC to open MCC, and record time of transition



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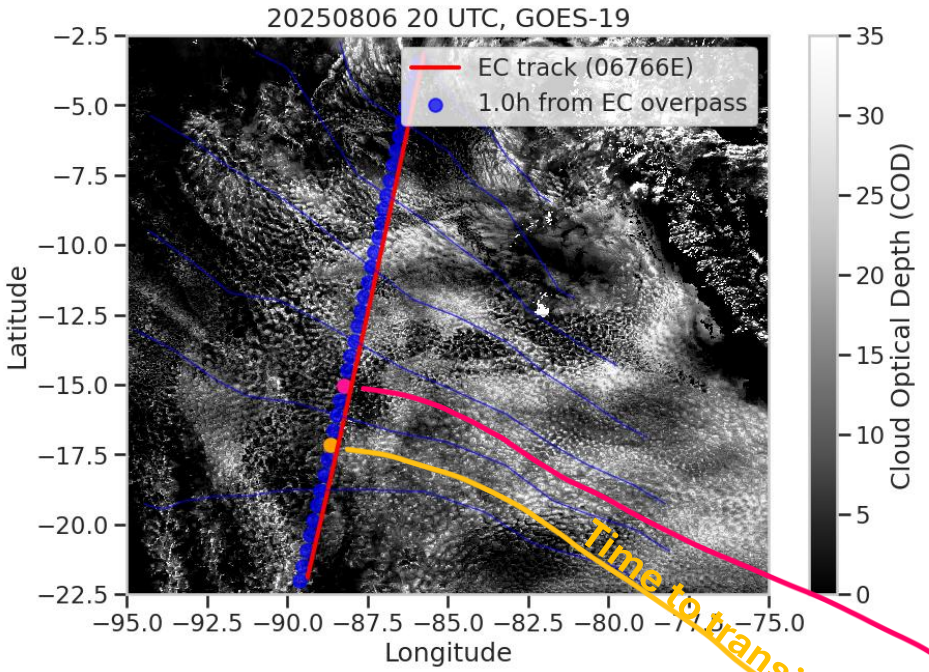
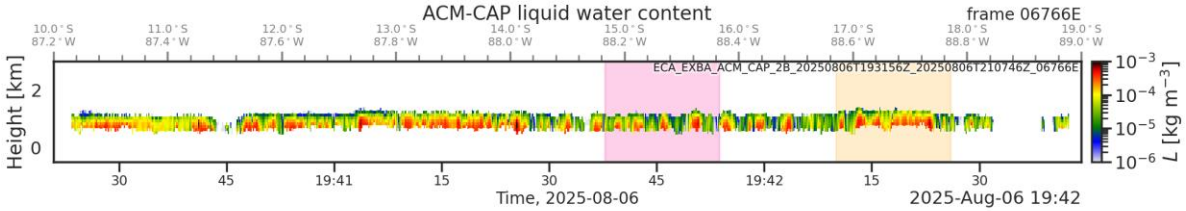
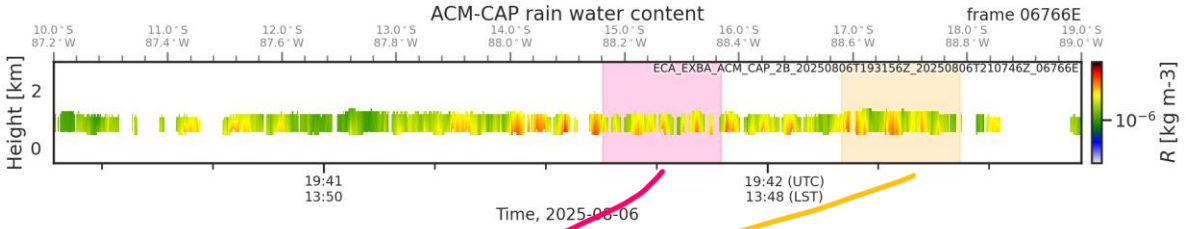
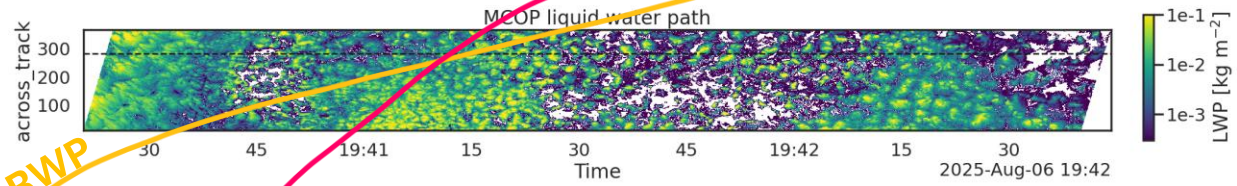


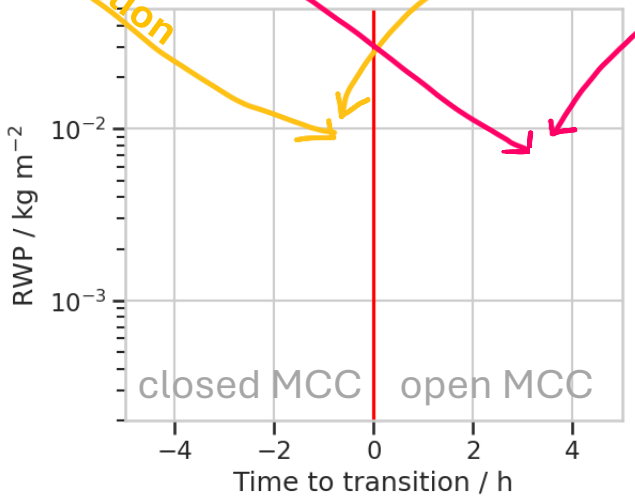




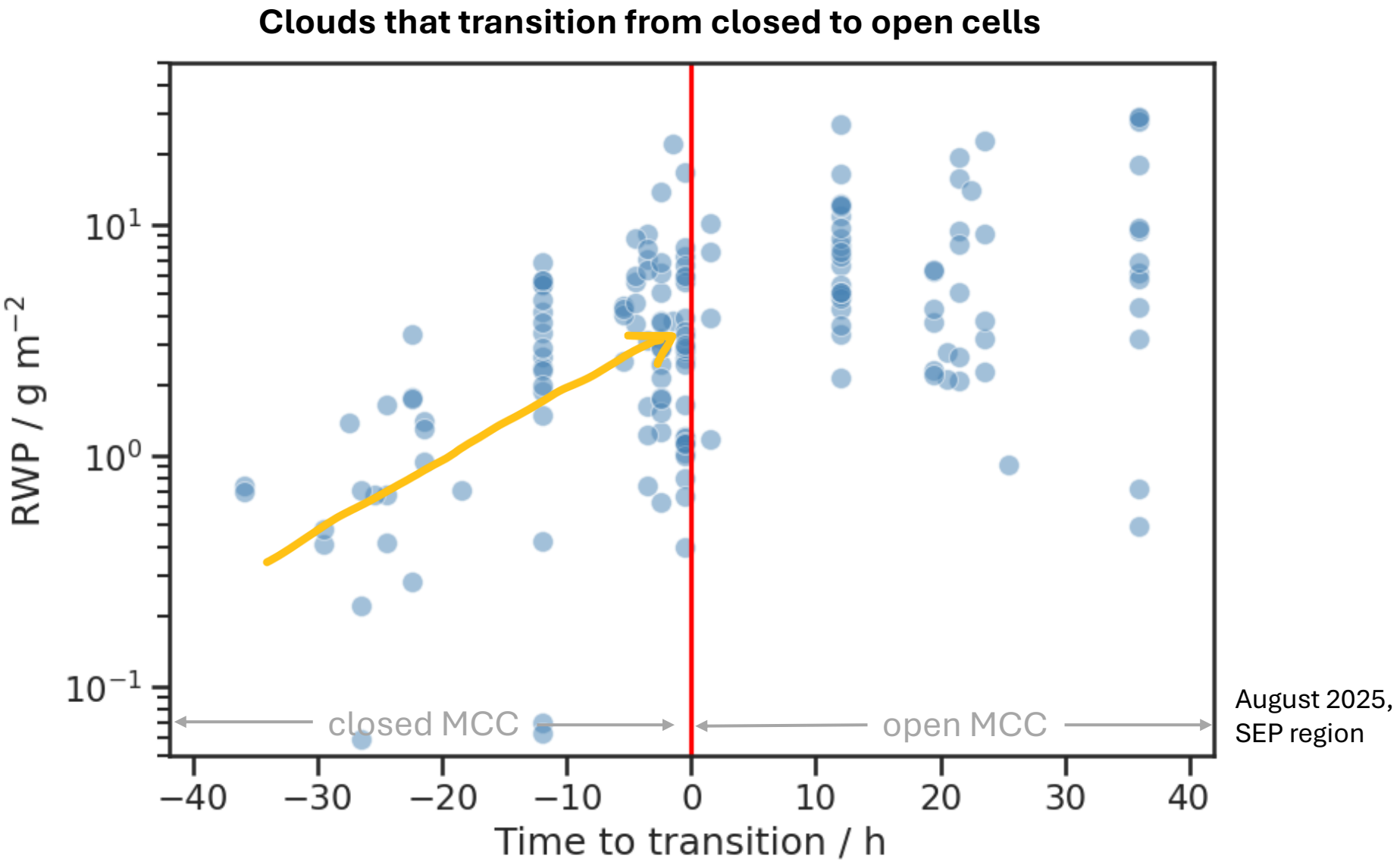


Time to transition

RWP



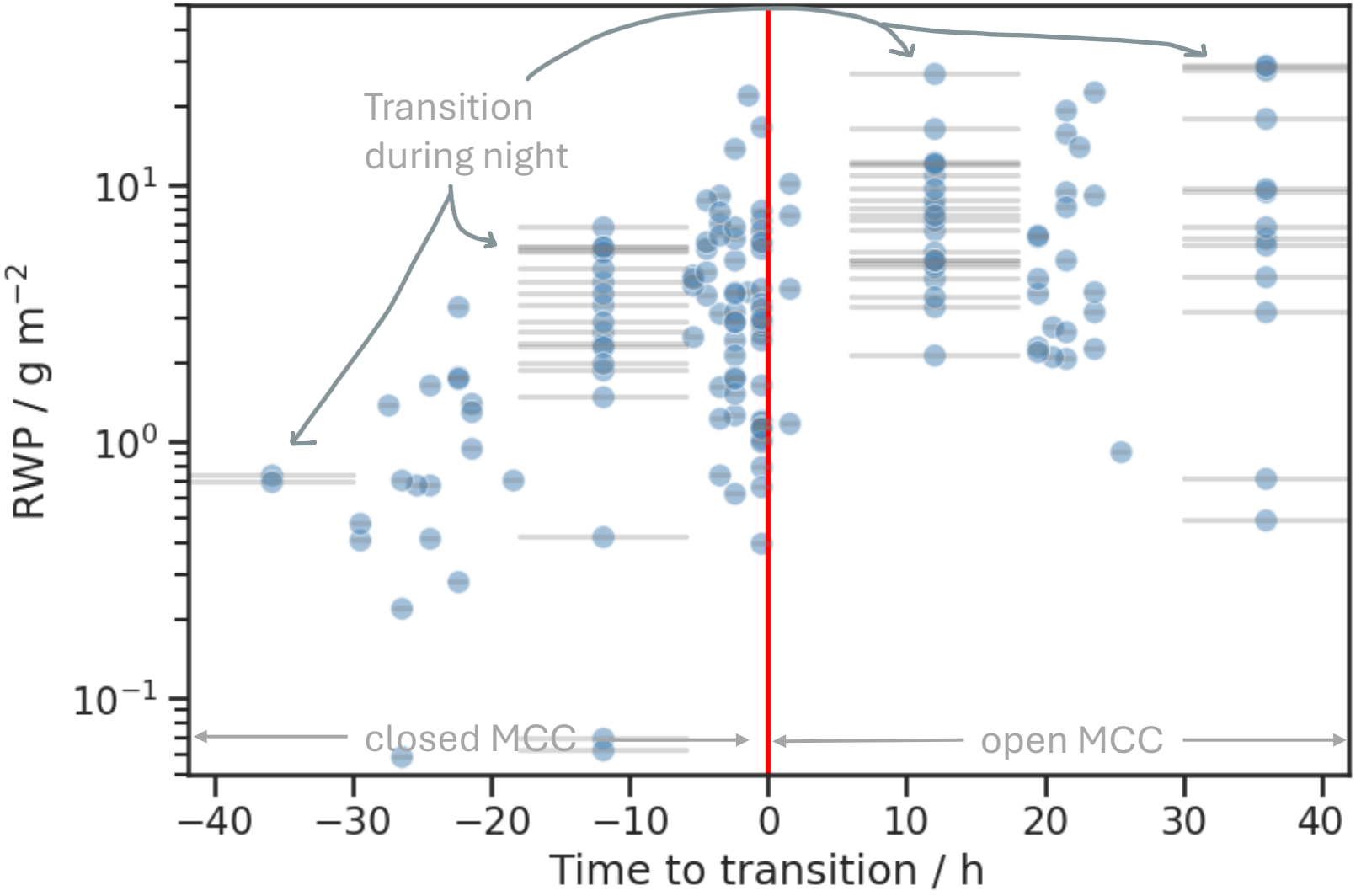
Rain water path (RWP) increases before transition from closed to open cells



August 2025,
SEP region

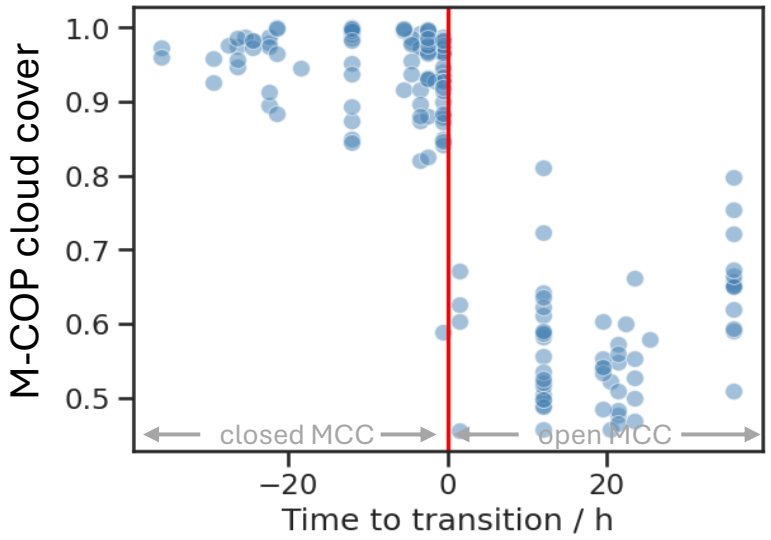
Rain water path (RWP) increases before transition from closed to open cells

Clouds that transition from closed to open cells

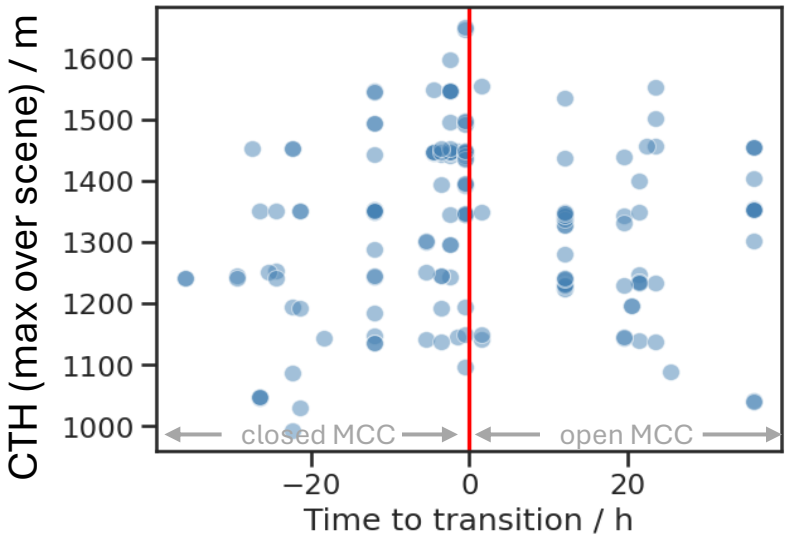


August 2025,
SEP region

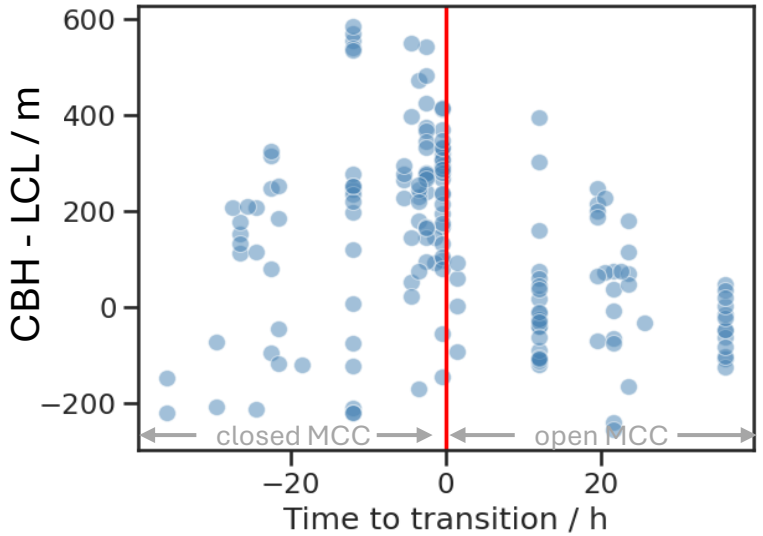
CTH and coupling do not change around the transition from closed to open cells



→ Change in cloud cover happens fast



→ No change in CTH

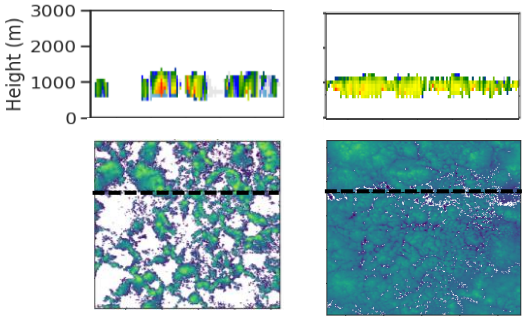


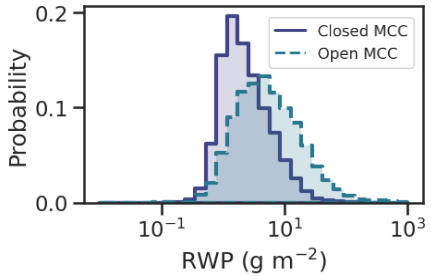
→ No change in coupling

→ unchanging vertical structure and enhanced rain before the transition hints towards **rain as the dominant factor for the closed-to-open MCC transition**

Conclusions

The combination of EarthCARE's passive and active instruments enables observations of the **vertical structure and microphysics** of clouds with **different mesoscale structures** at unprecedented levels of detail

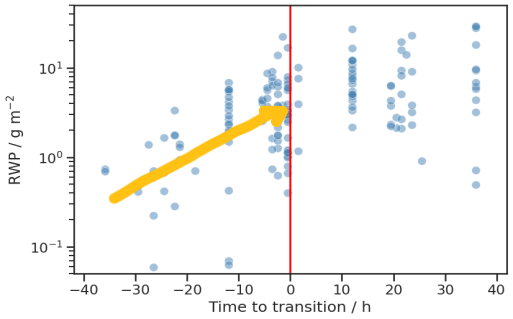




Closed MCC and open MCC have similar CTHs and coupling values, but differ in microphysics, with **higher effective radii and RWPs for open MCC**

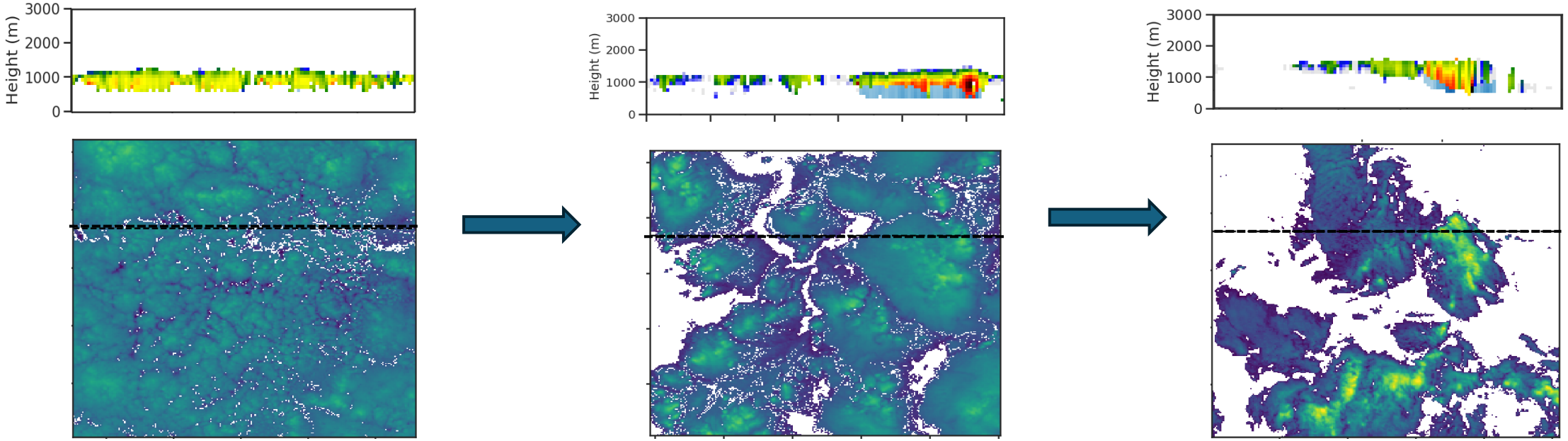
Transitions from closed to open MCC are **preceded by enhanced RWPs**, while CTH and coupling remain constant

→ hints towards **rain** as the **dominant factor** for the transition



Outlook

- Extend analysis to longer time period
- Improve performance of CNN for geostationary imagers and include MTG
- Transition from closed MCC to disorganized and cumuliform structures

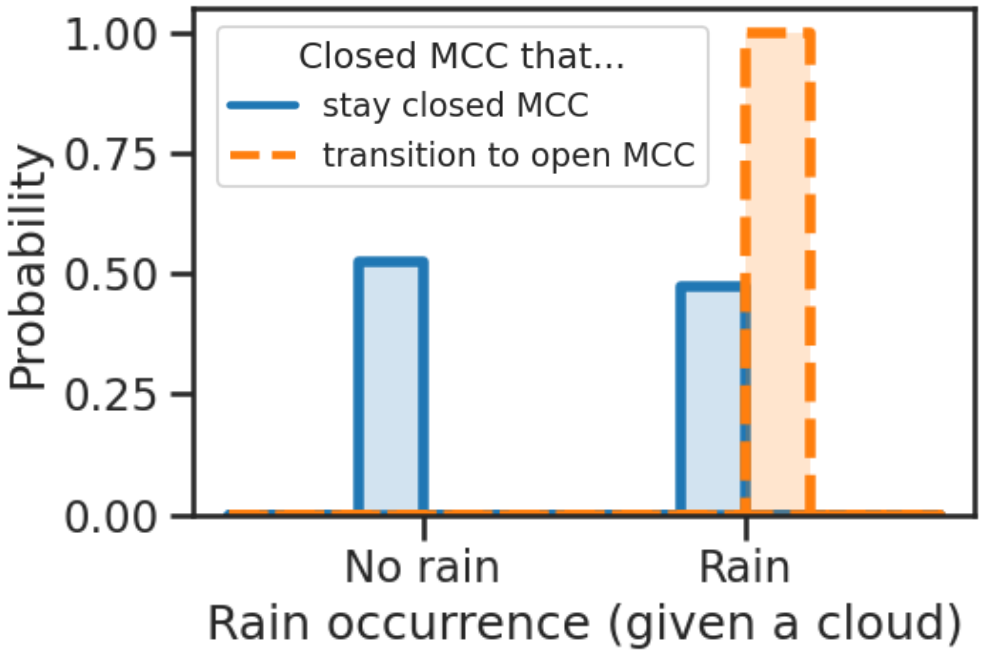


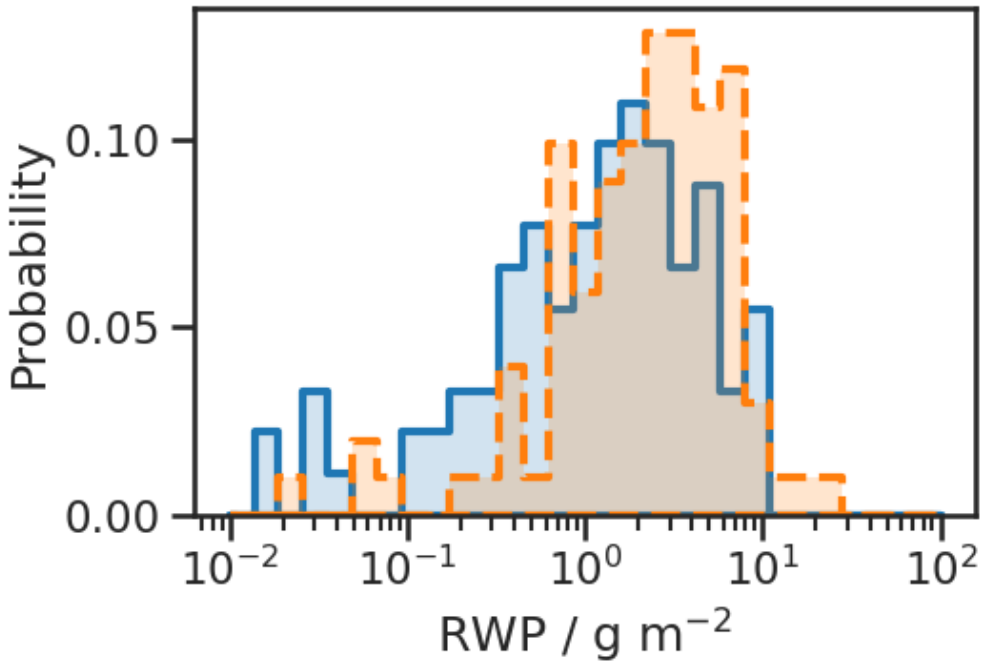
Thank you.

Johanna.Mayer@esa.int

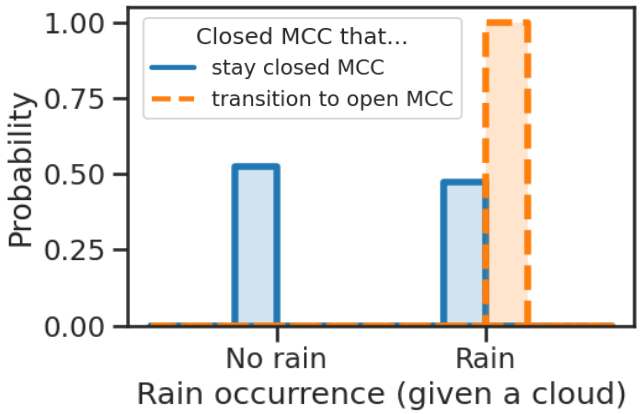
Backup slides

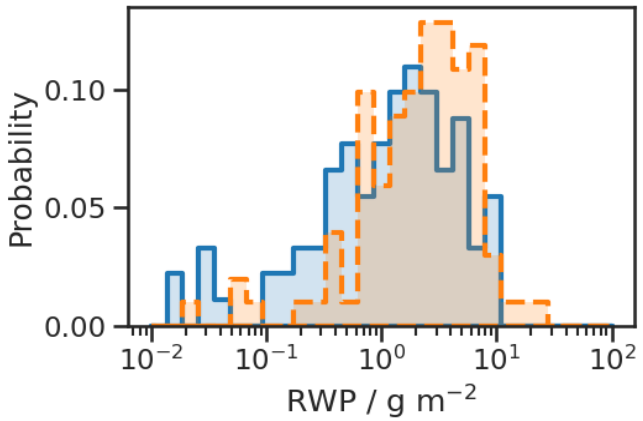
Transitioning closed MCC show enhanced rain compared to non-transitioning closed MCC





Transitioning closed MCC show enhanced rain compared to non-transitioning closed MCC

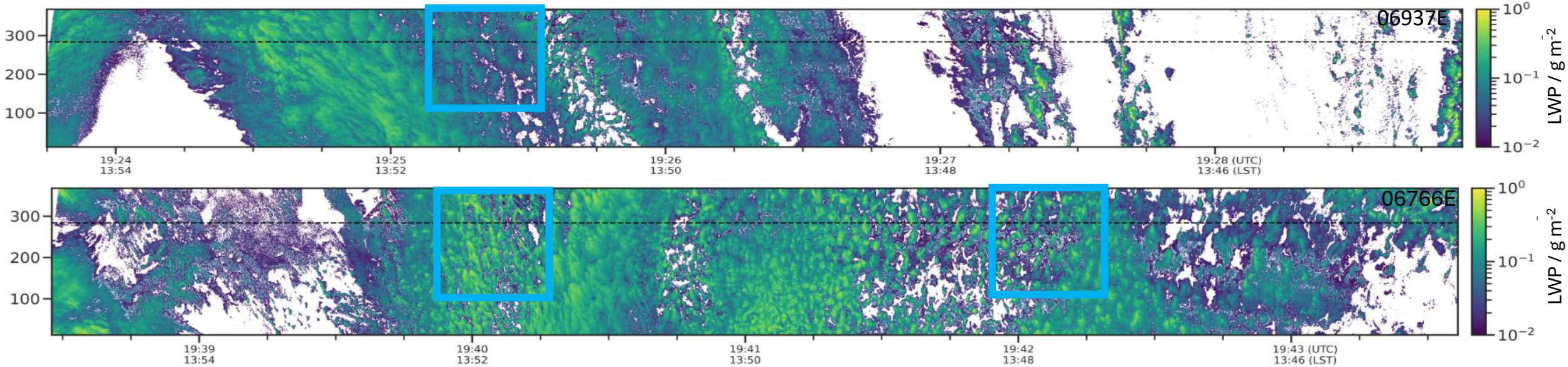




→ High-RWP closed MCC are often edge cases to open MCC

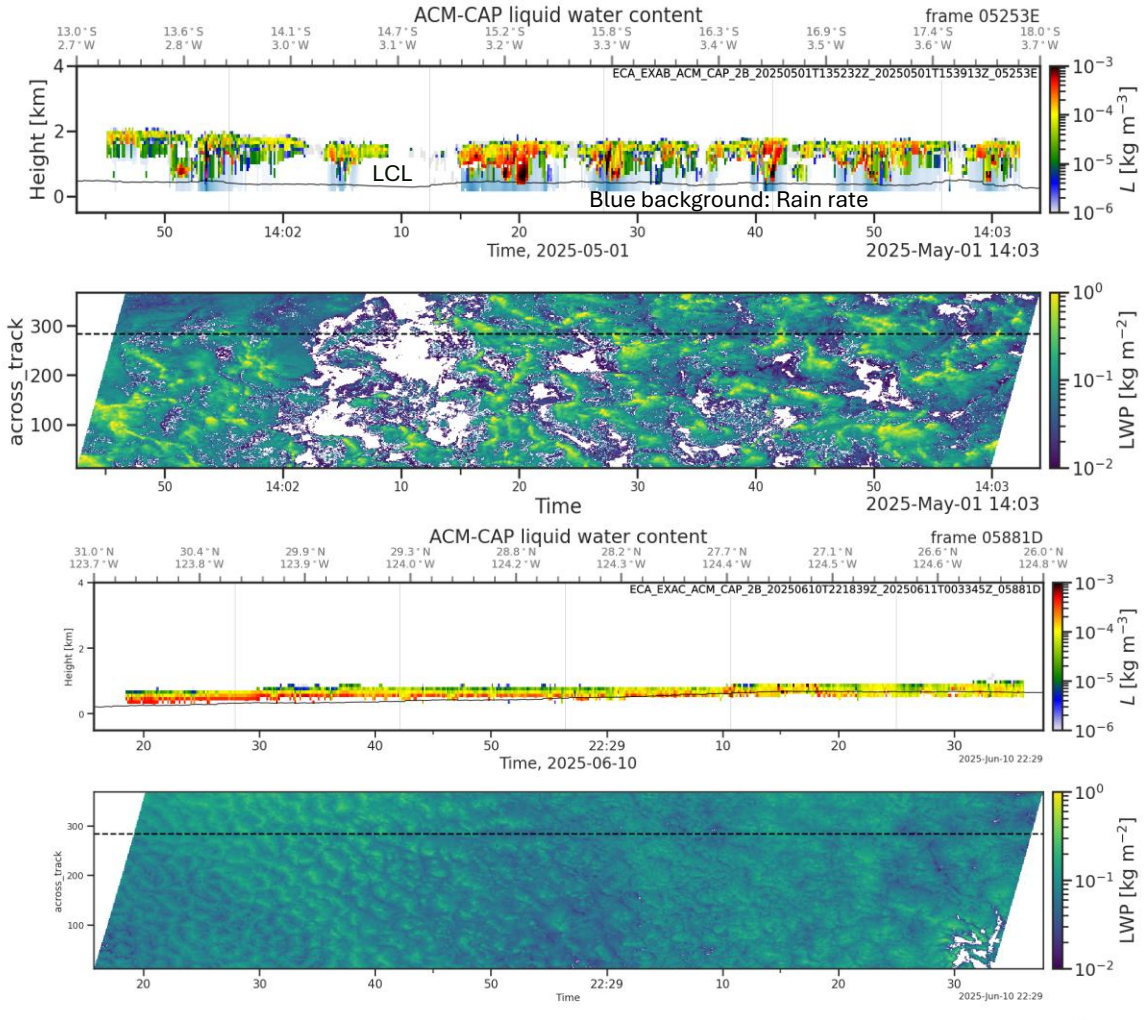
→ the RWP difference btw. transitioning and non-transitioning closed MCC might be even larger

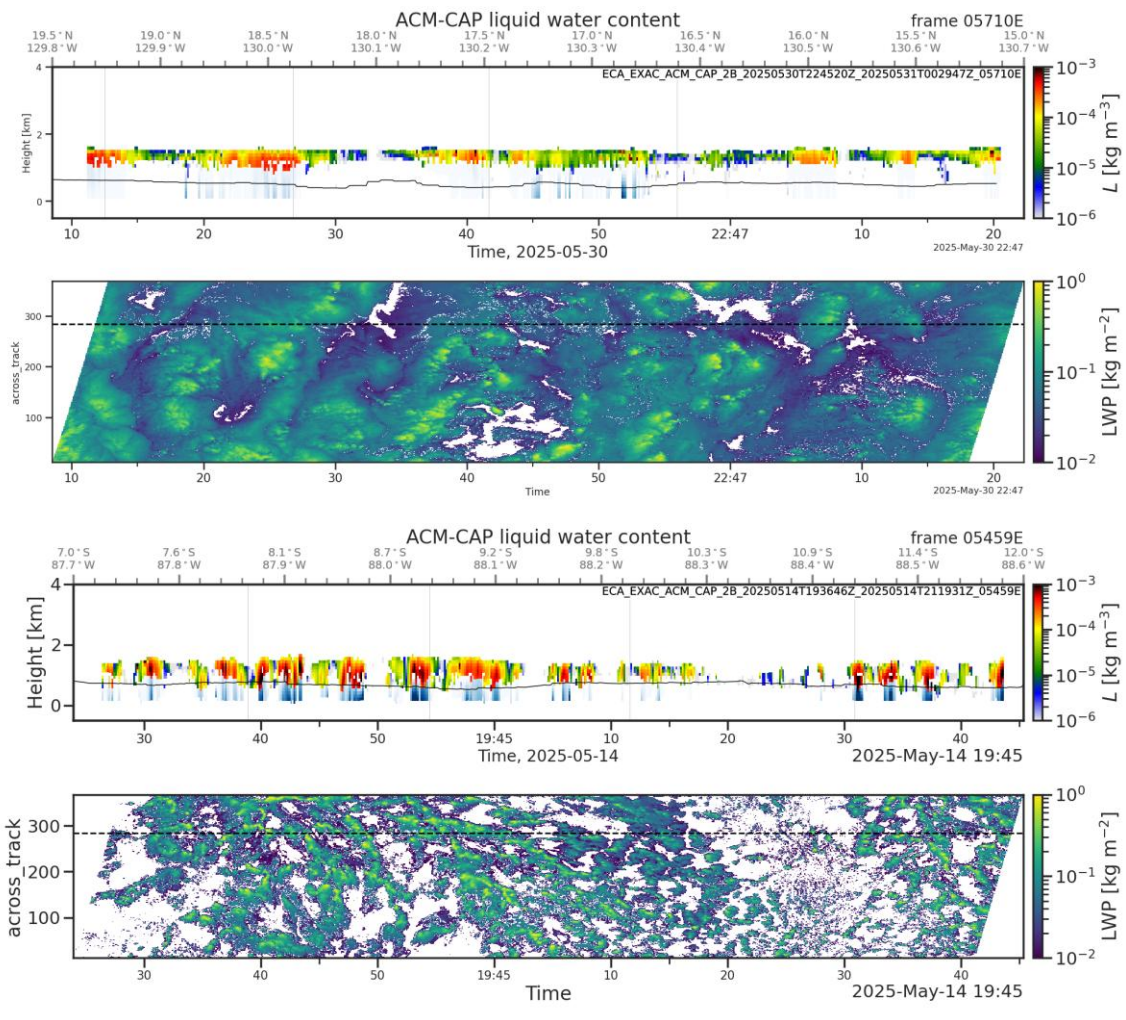
Examples for scenes classified as closed MCC with high RWP



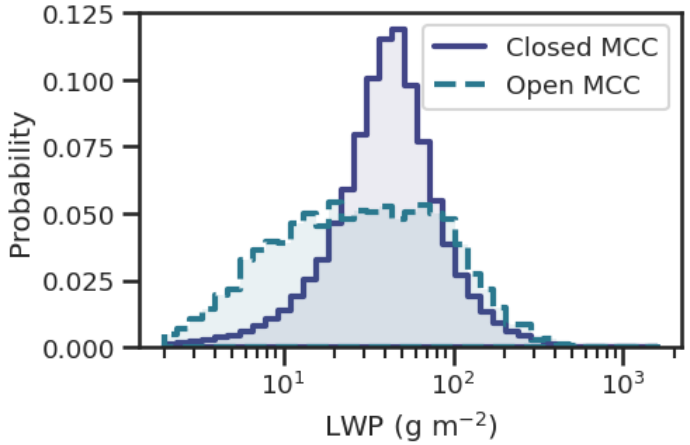
EarthCARE offers new insights into vertical and horizontal structure

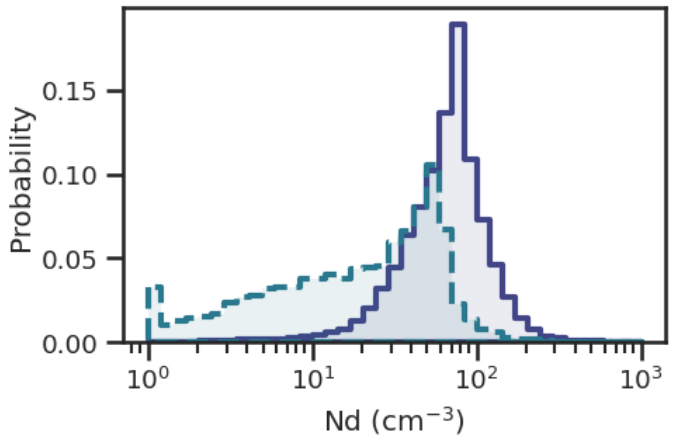
EarthCARE enables for the first time detailed observations of the vertical structure of low clouds.

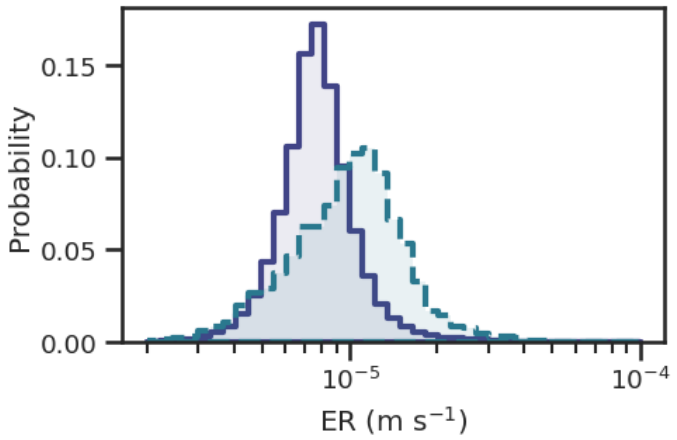


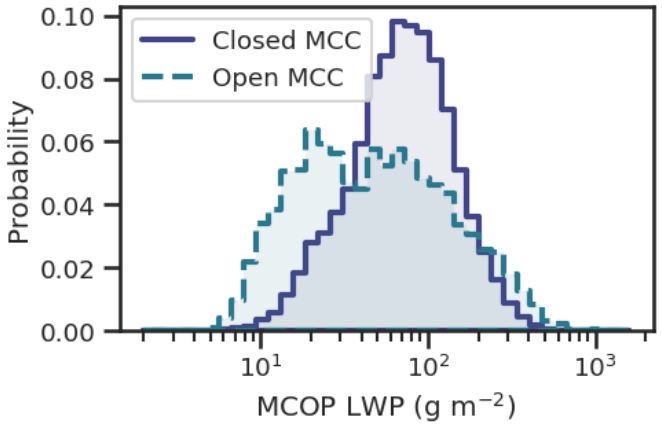


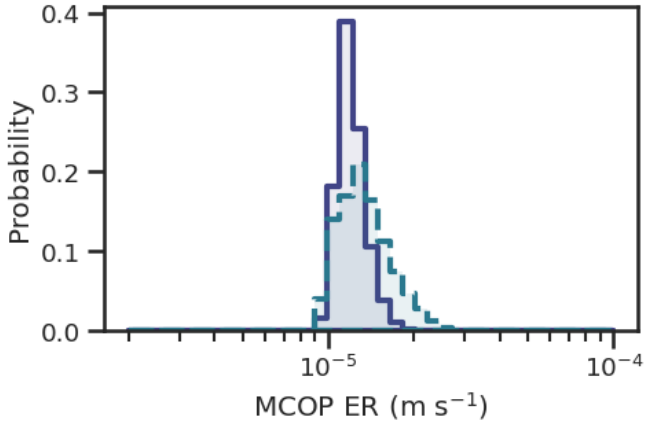
ACM-CAP vs M-COP











Transitions happen due to changes in environment and/or microphysical processes

- 1. **Deepening-warming** mechanism (large-scale meteorologically driven)

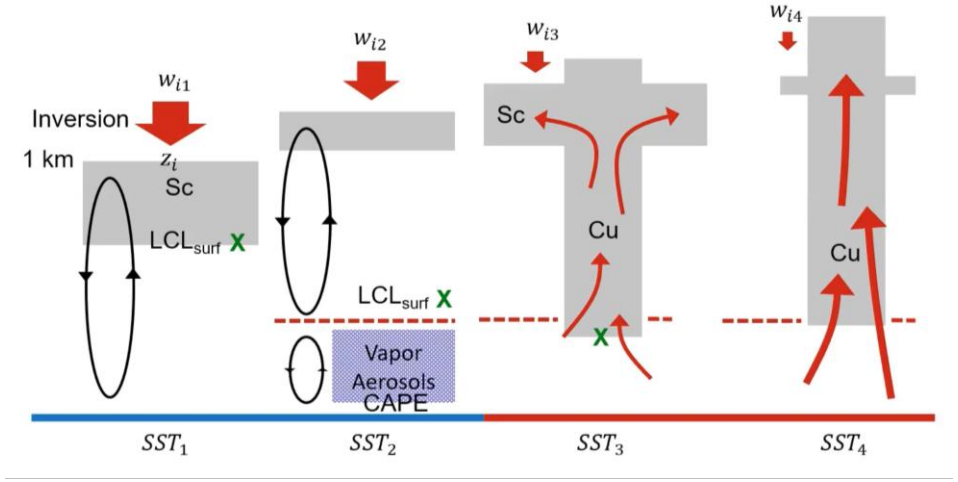
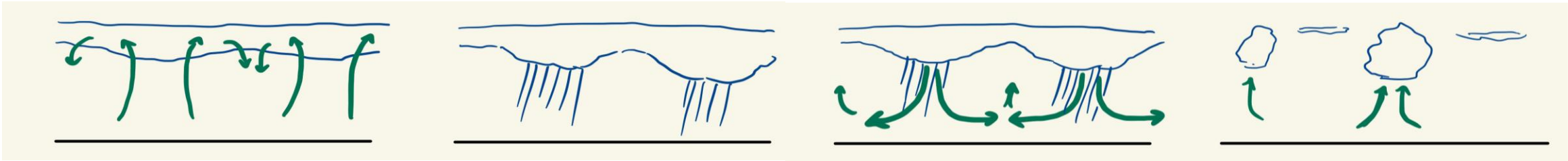


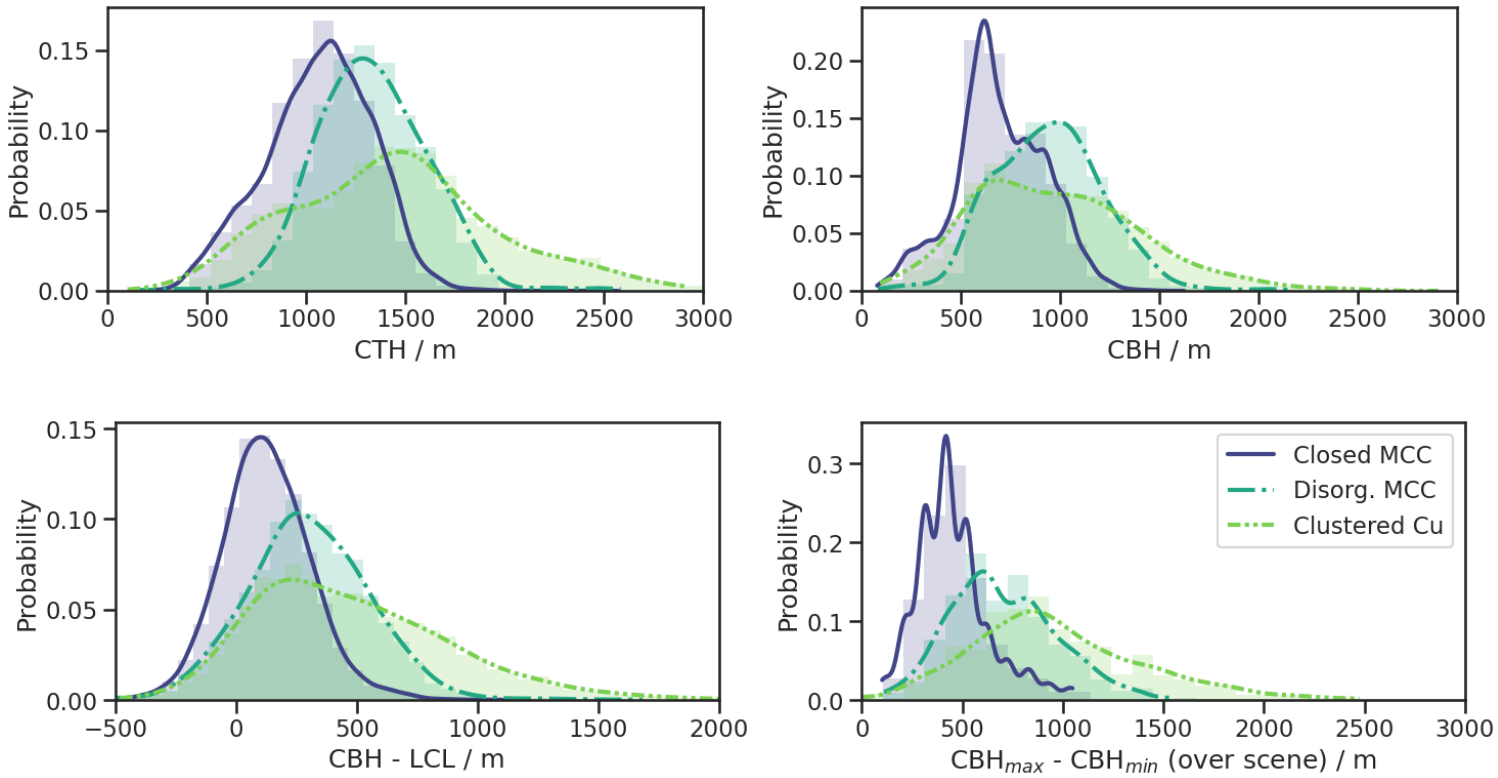
Figure from a presentation of Miller et al. (2022)

2. **Precipitation** can lead to break up through cold pools (microphysically driven)



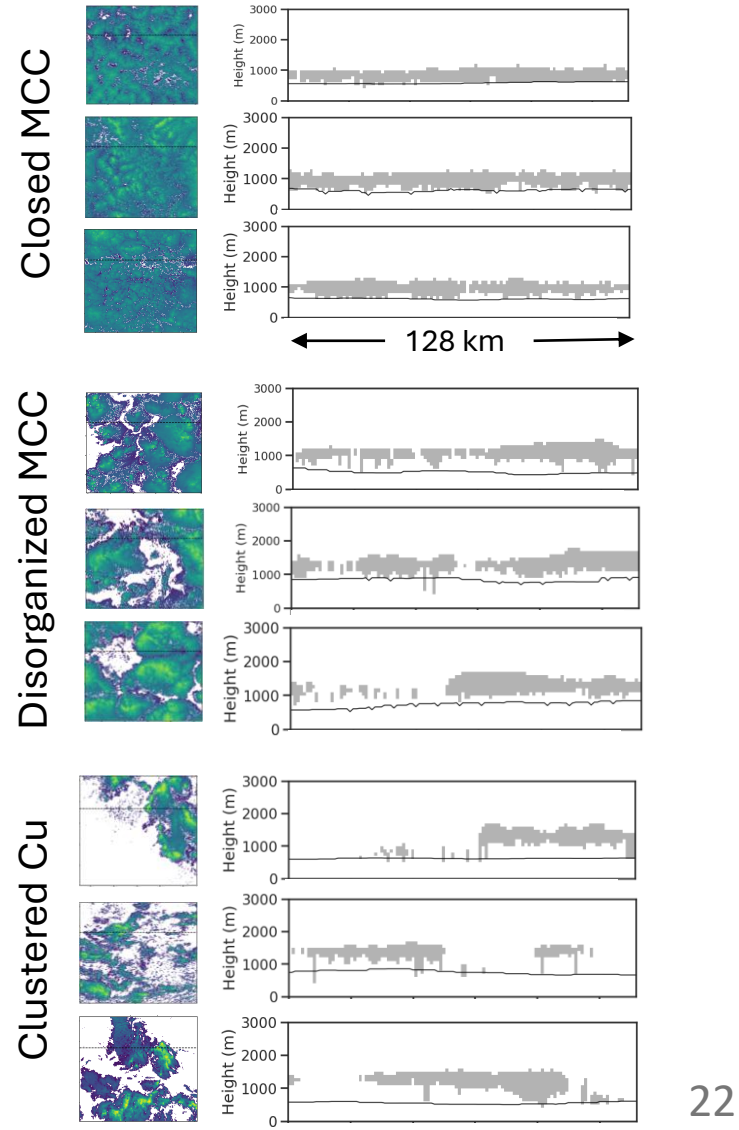
→ Observations below the cloud top are important to understand transitions between mesoscale structures!

Closed MCC vs disorganized MCC and Clustered Cu

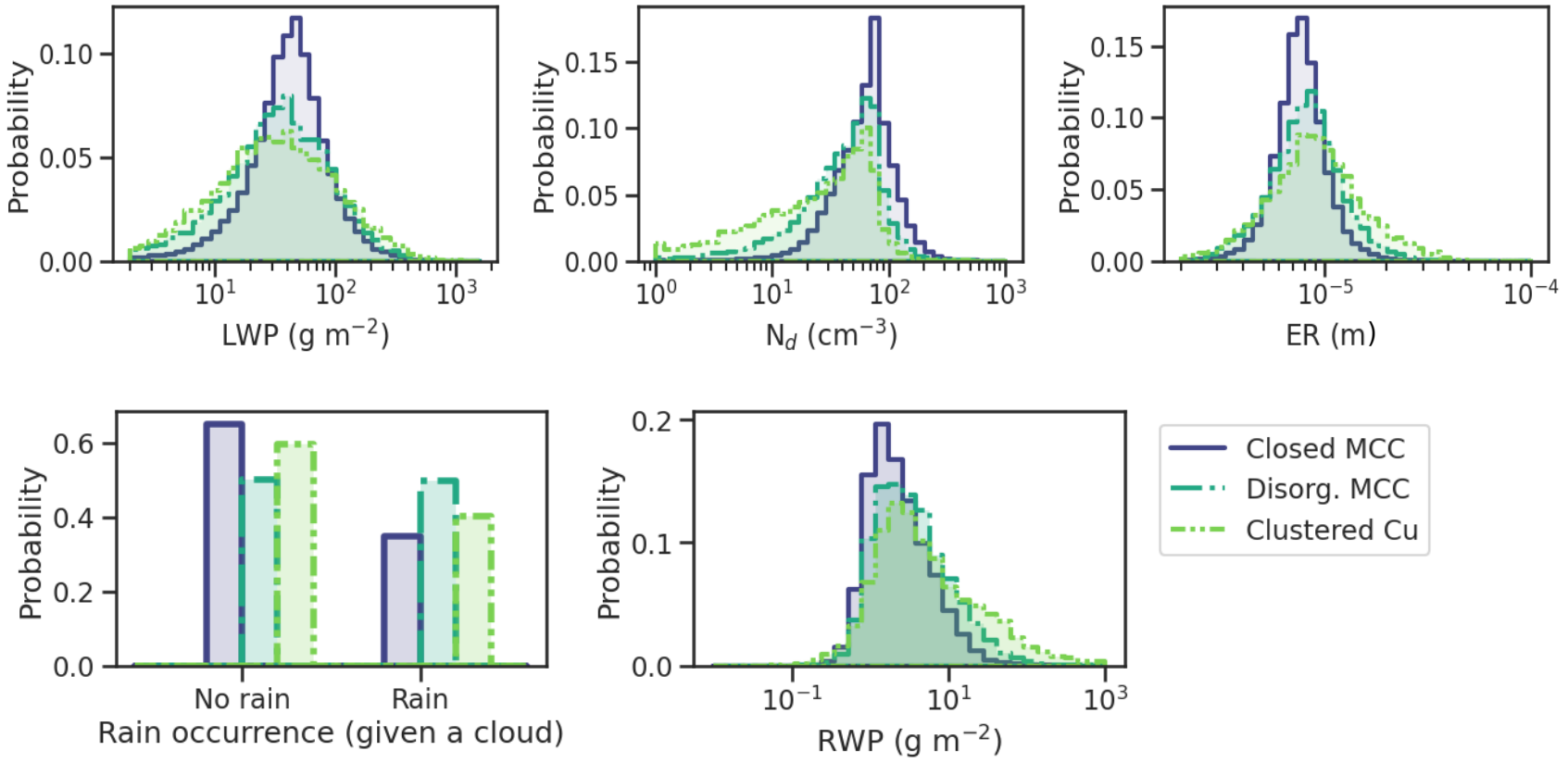


→ From closed MCC to disorg. MCC to clustered Cu, clouds get higher, cloud bases more variable (Cumulus-coupling) with parts of the clouds being decoupled

Examples for typical cloud scenes



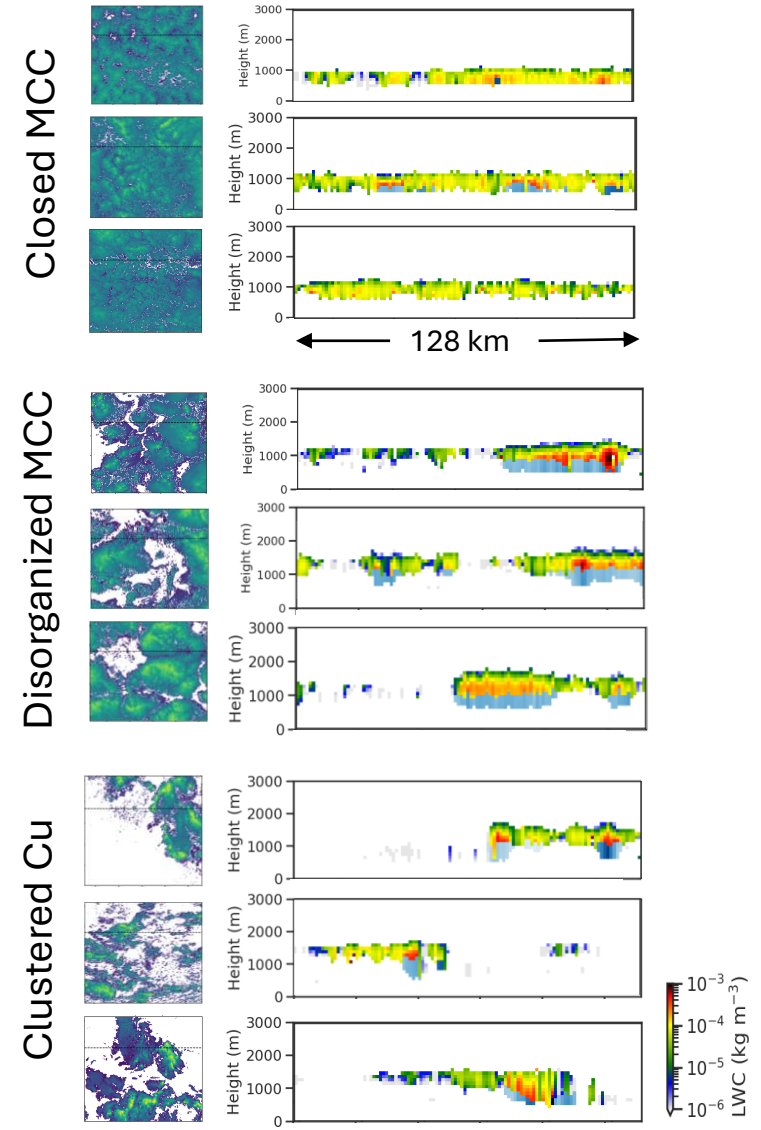
Closed MCC vs disorganized MCC and Clustered Cu



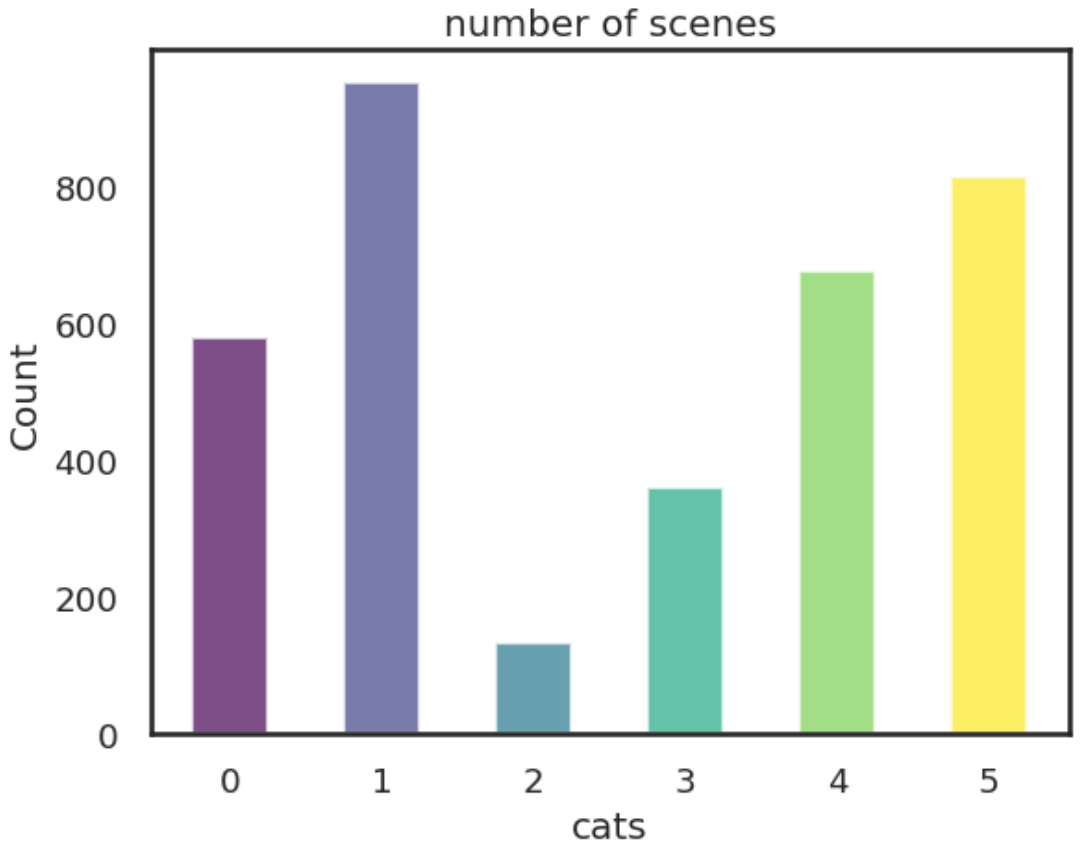
→ From closed MCC to disorg. MCC to clustered Cu, LWP gets more variable, ER and RWP larger

→ Differences mainly in the “extremes”

Examples for typical cloud scenes

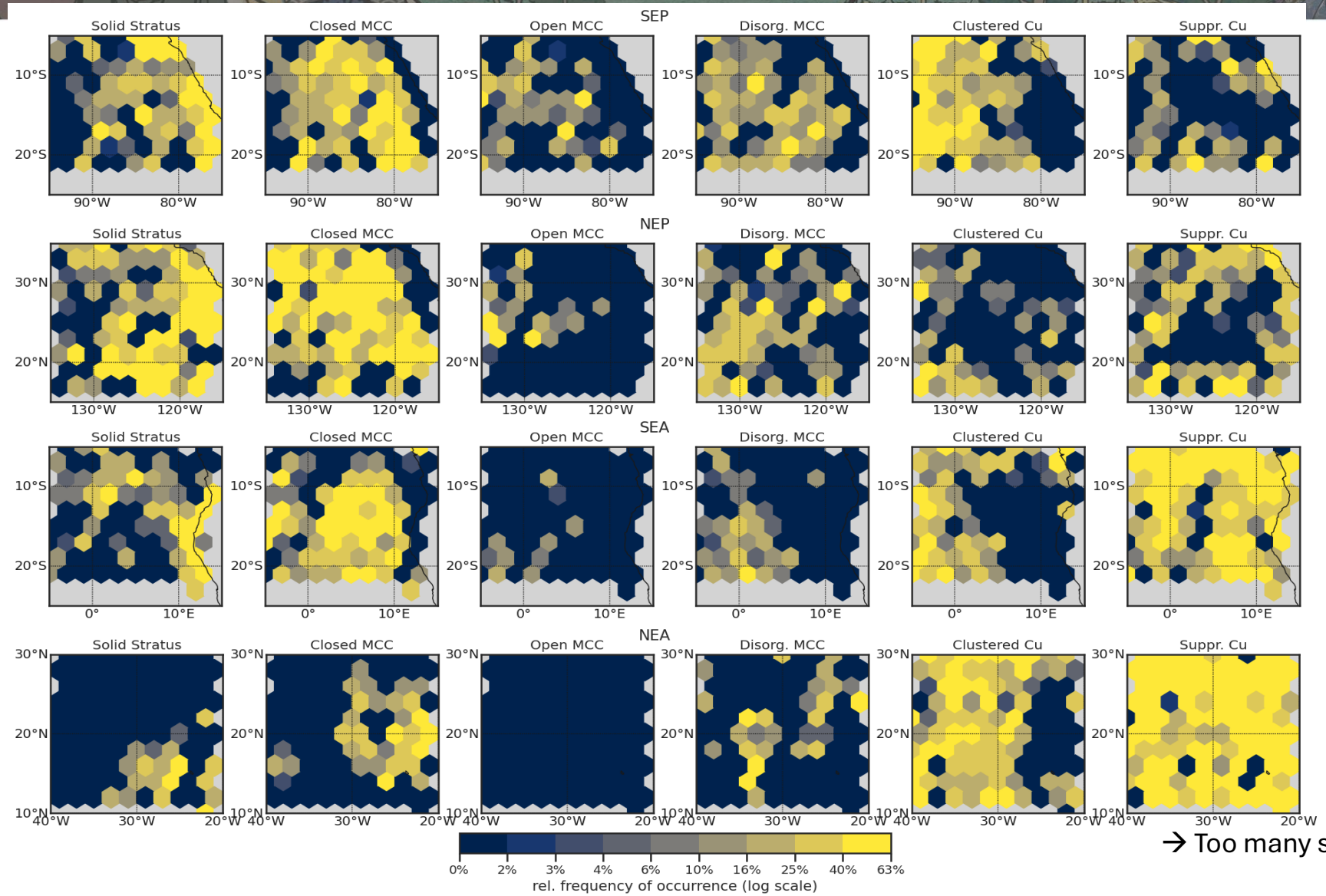


For three months of data: > 3500 classified scenes

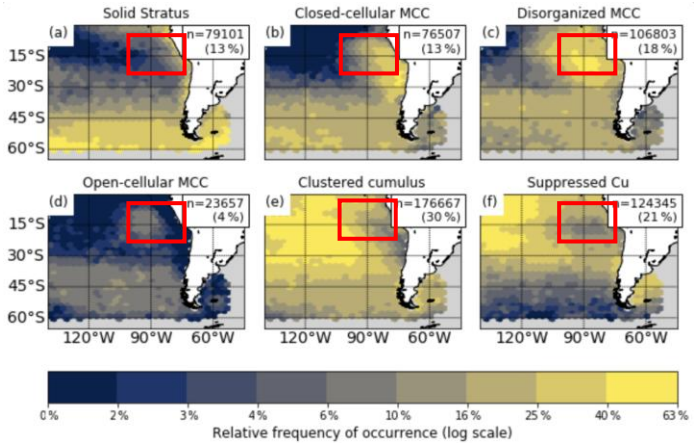


0: Solid stratus
1: Closed MCC
2: Open MCC
3: Disorganized MCC
4: Clustered Cu
5: Suppressed Cu

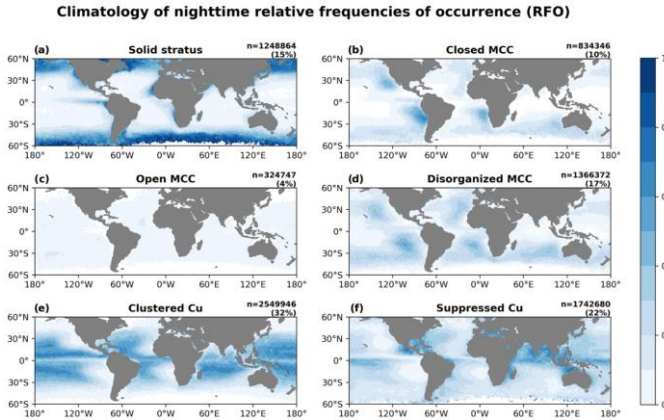
The classification makes sense in terms of geographical distribution



Mohrman et al (2021)

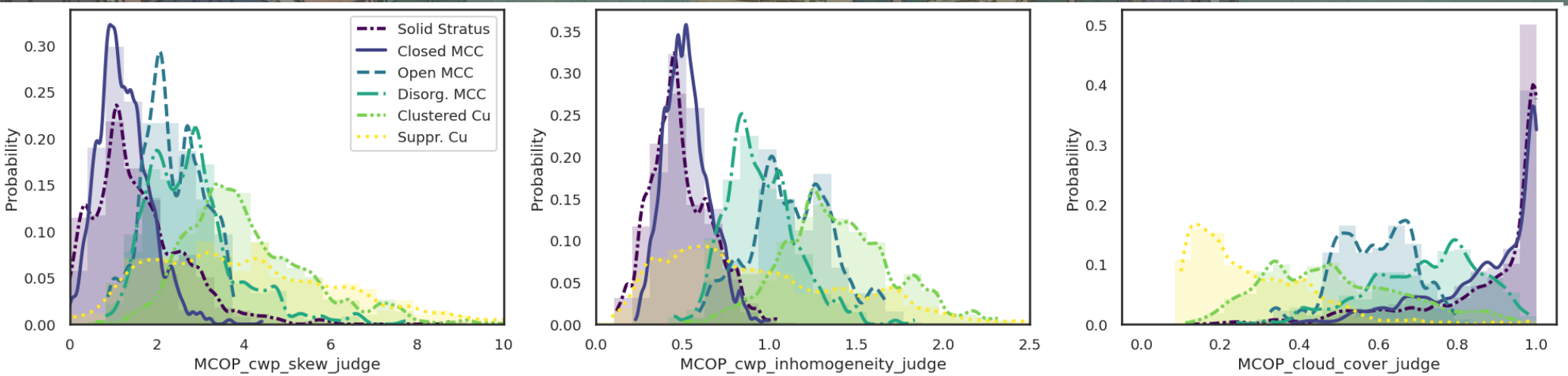


Wu et al. (2025)

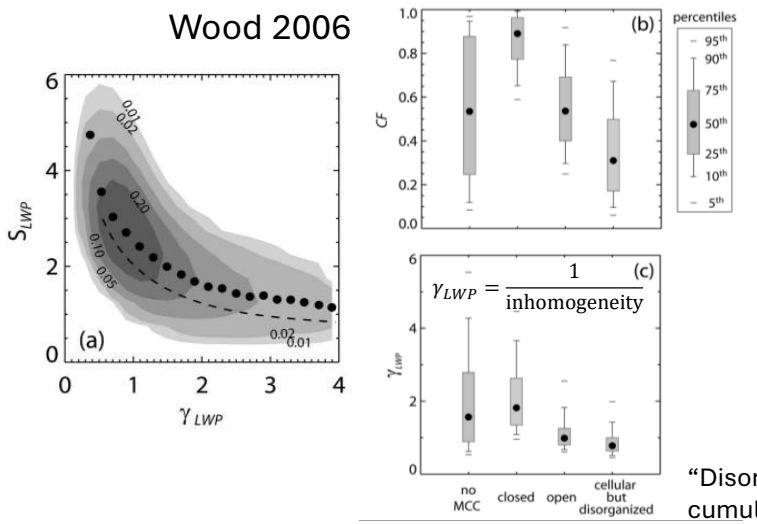


→ Too many suppressed cumulus?

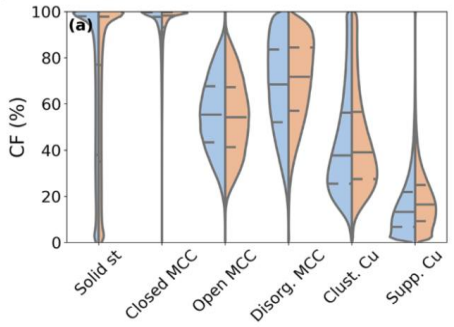
The classification makes sense in terms of cloud morphological parameters



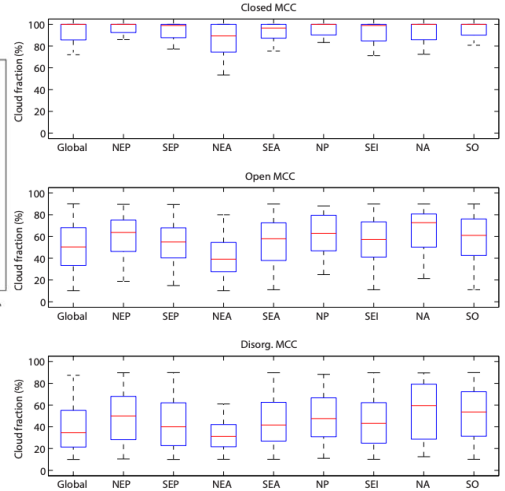
Wood 2006



Wu 2025



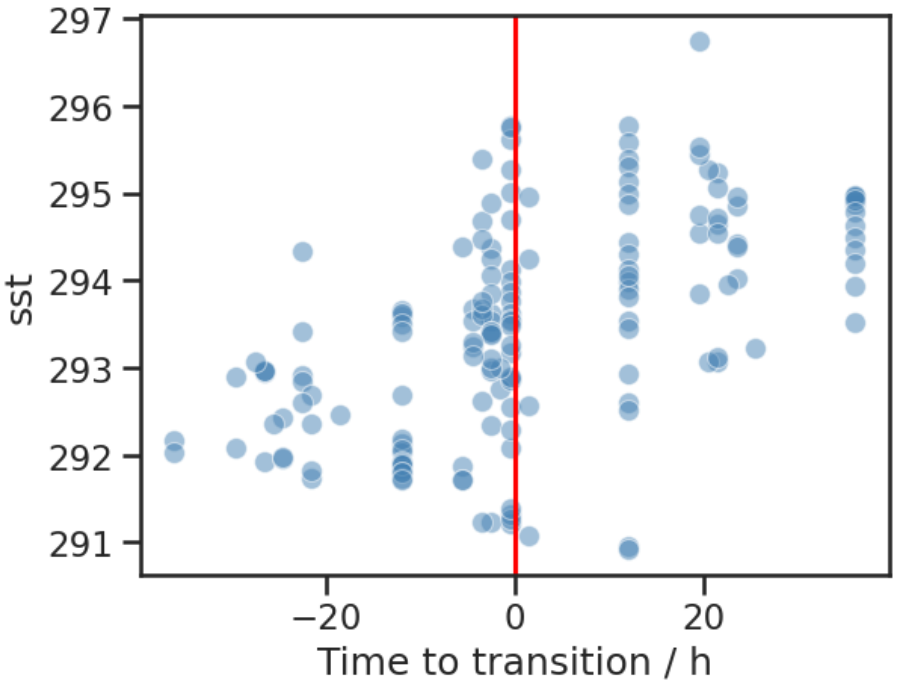
Muhlbauer 2014

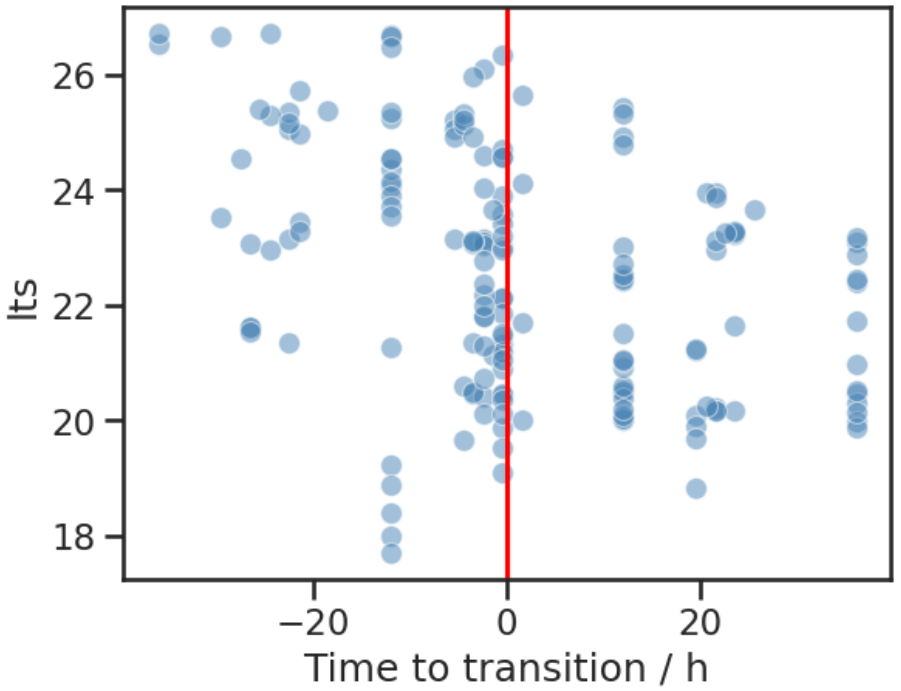


"Disorganized" in Wood et al. includes also cumuliform types (?)

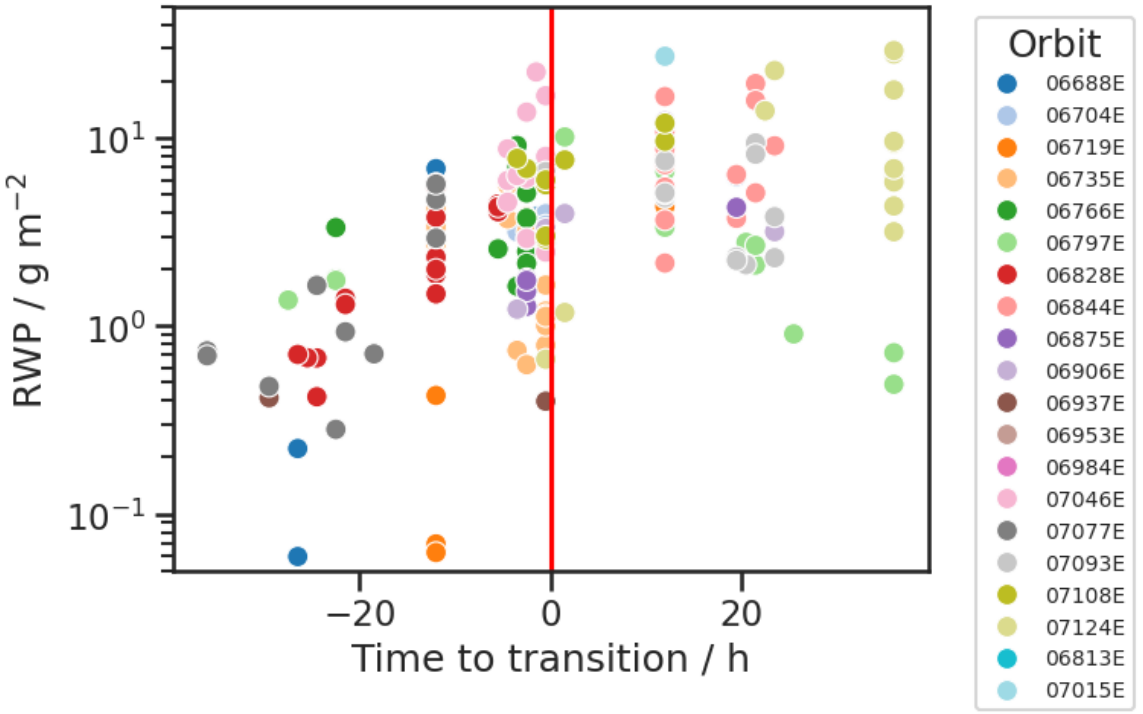
→ similar morphological values to literature

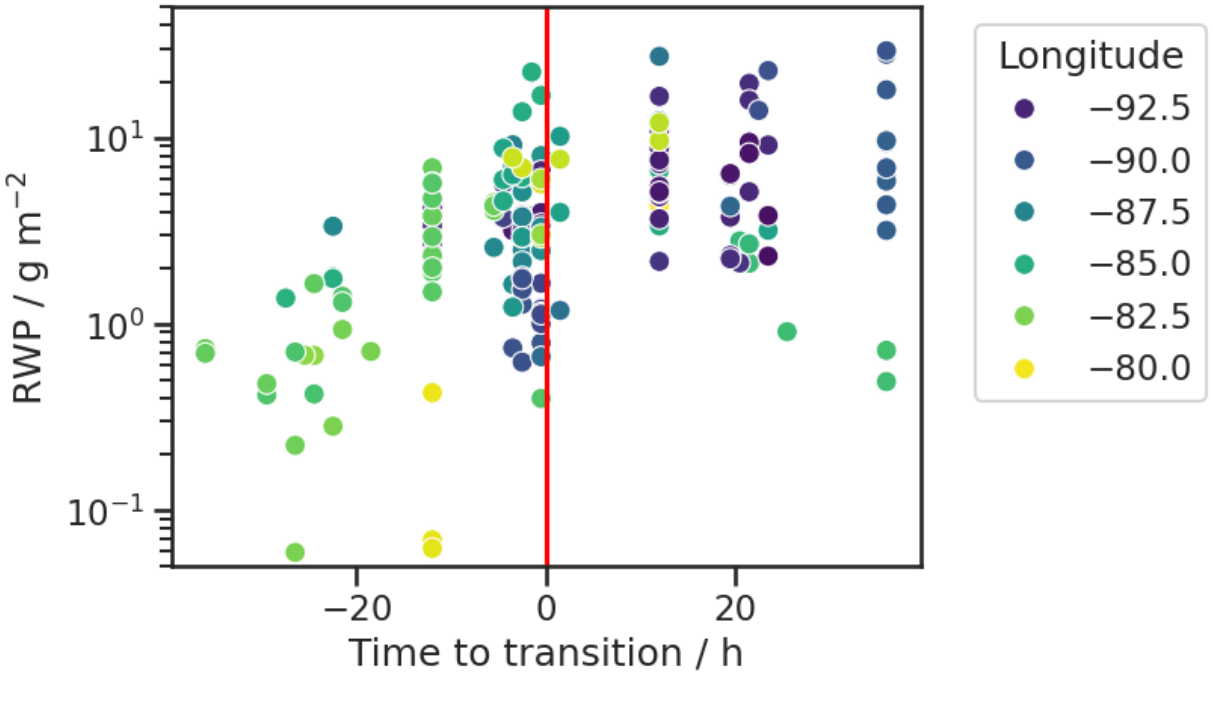
meteorological variables change as clouds move towards the West



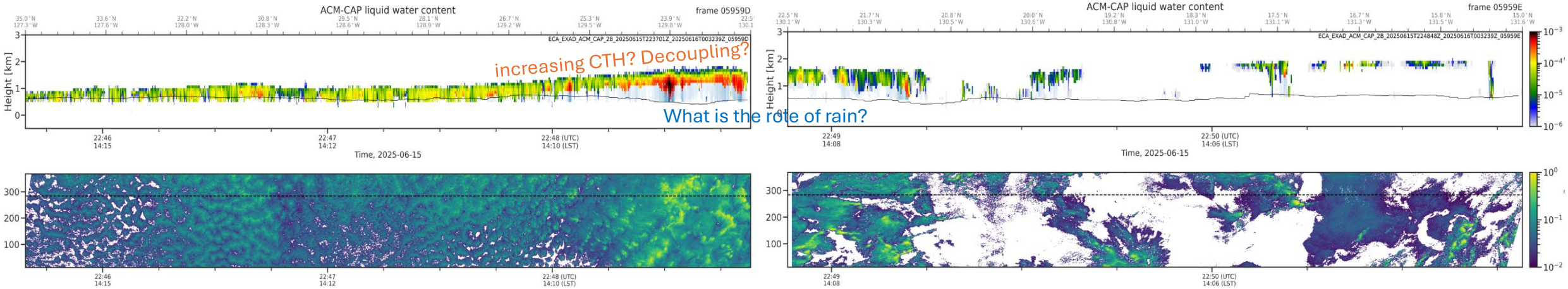


Rain water path (RWP) increases before transition from closed to open cells

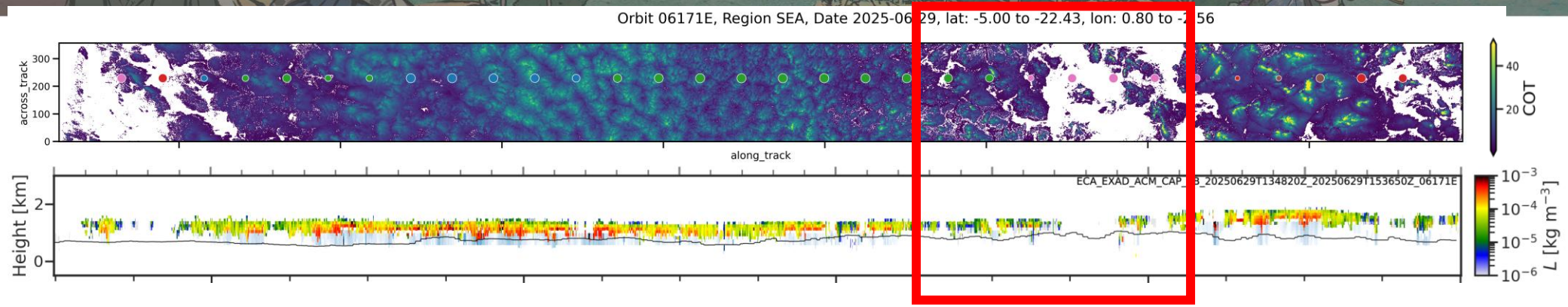


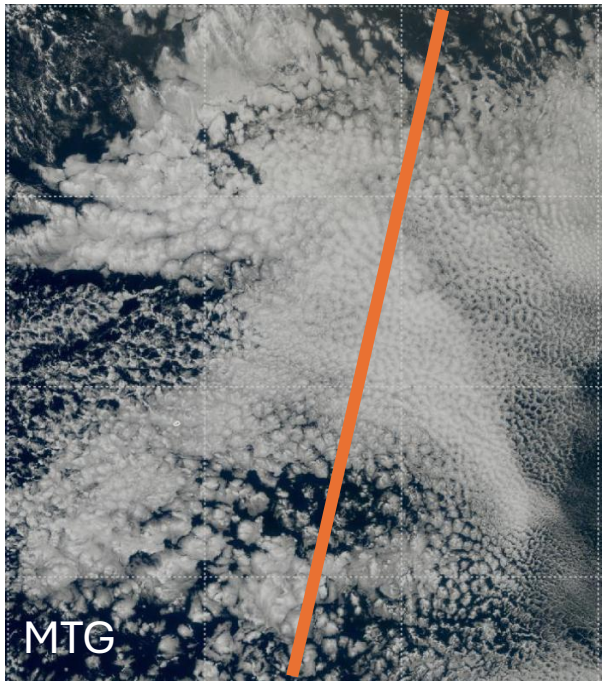


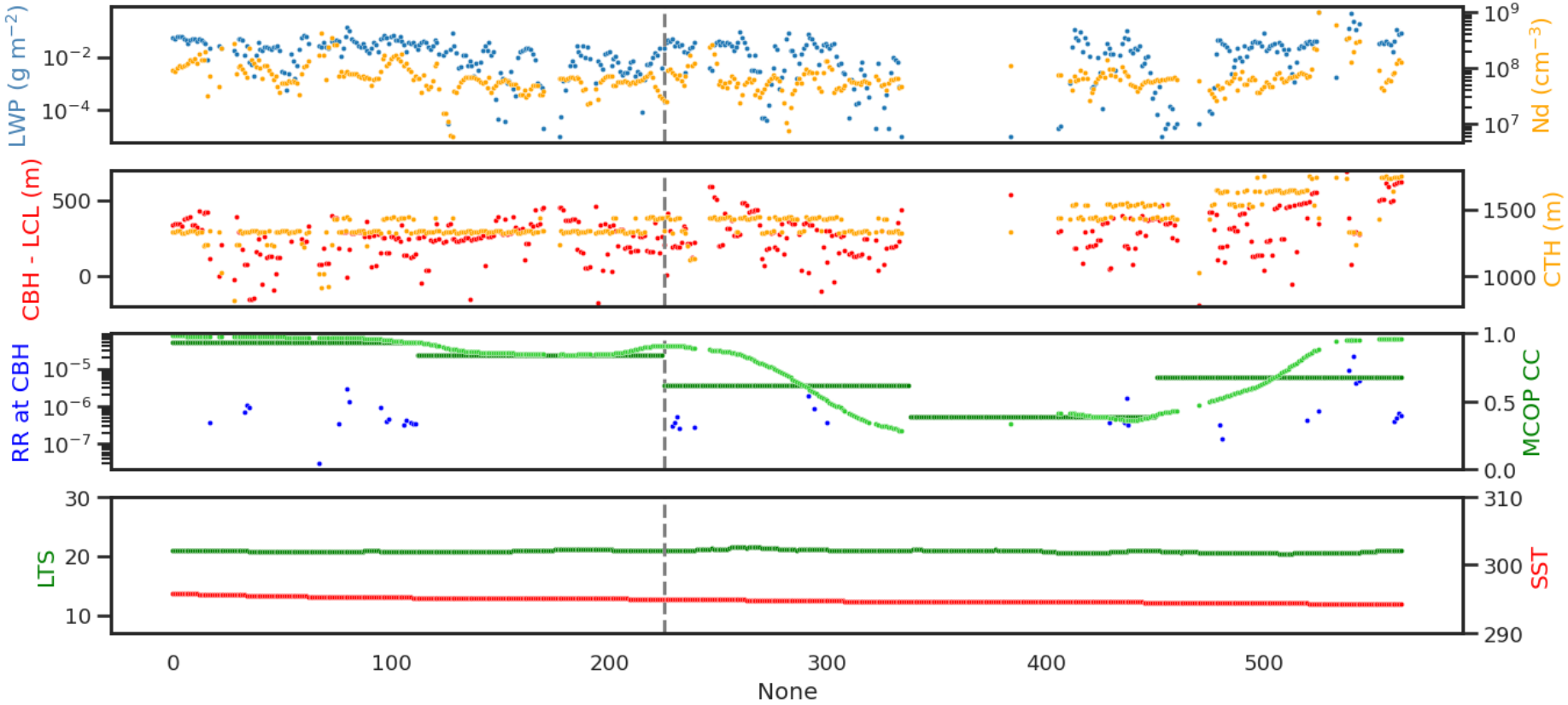
Closed MCC to disorg MCC and Cu



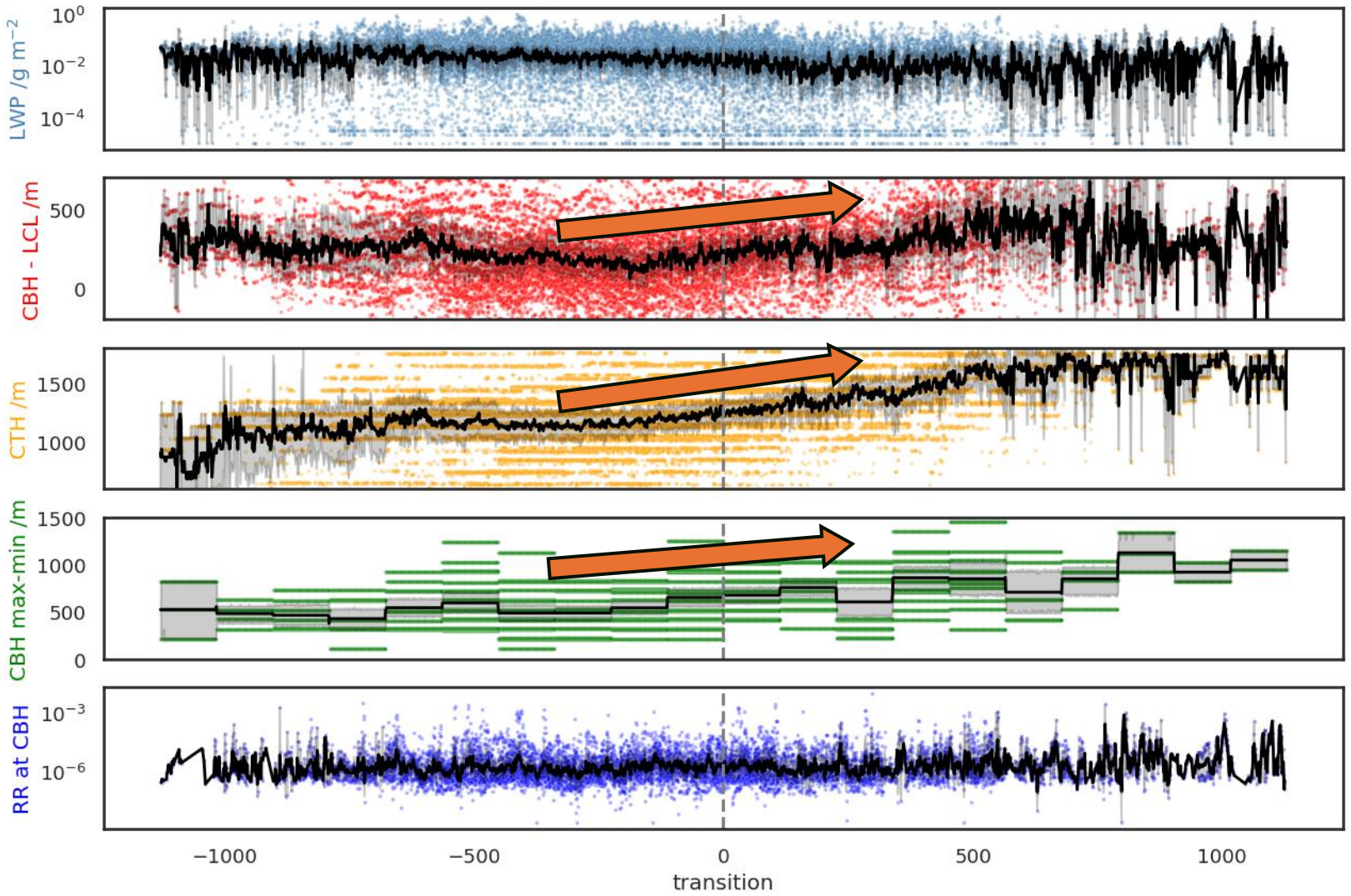
Look for transitions within overpasses: from Closed MCC to disorganised or cumuliform

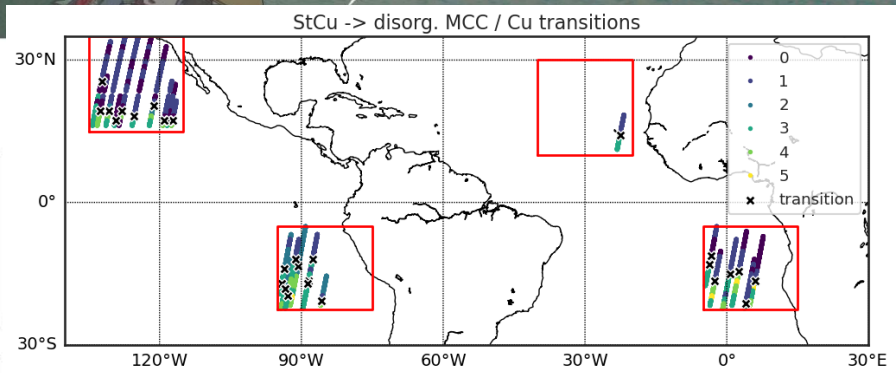




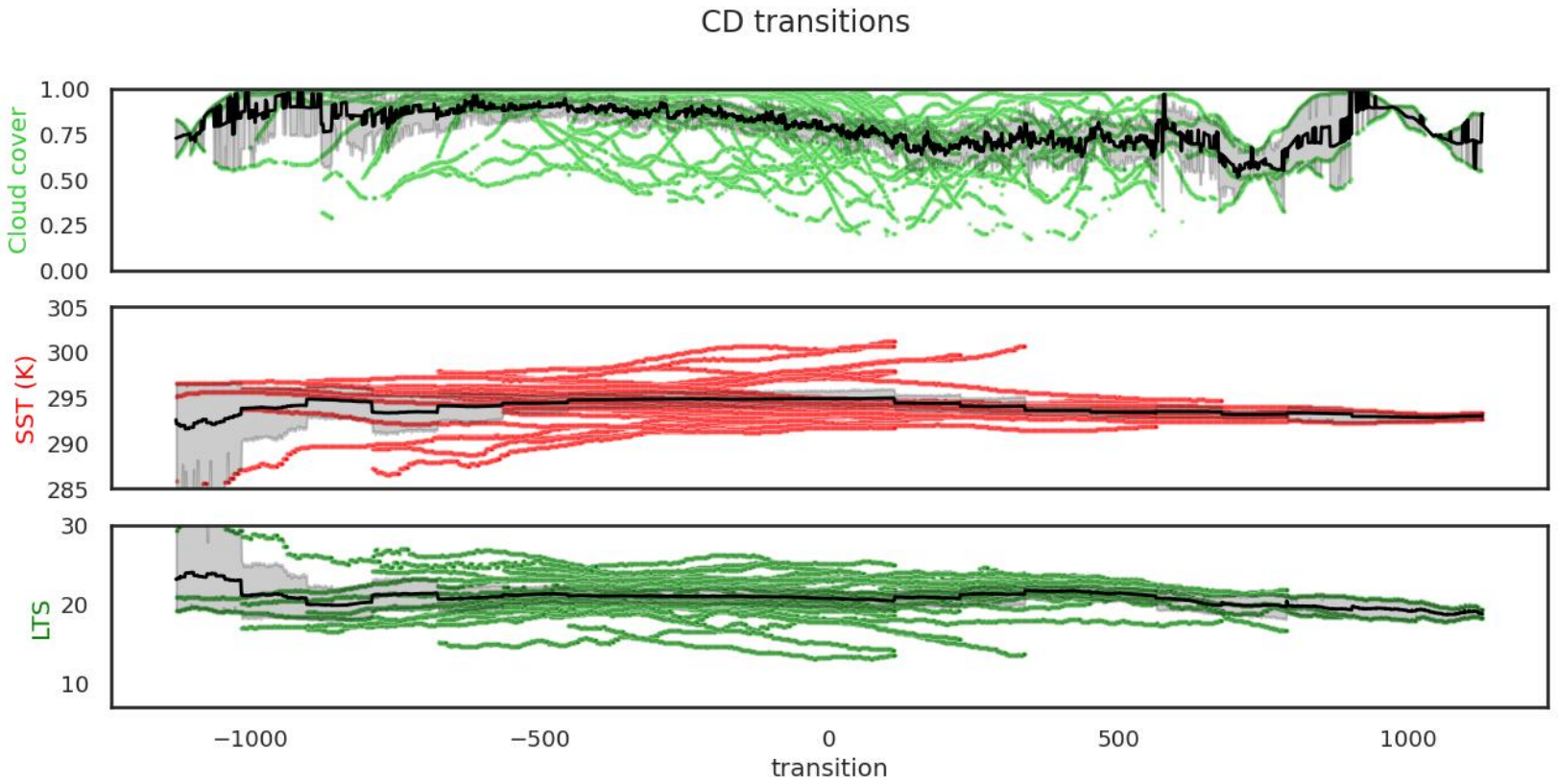


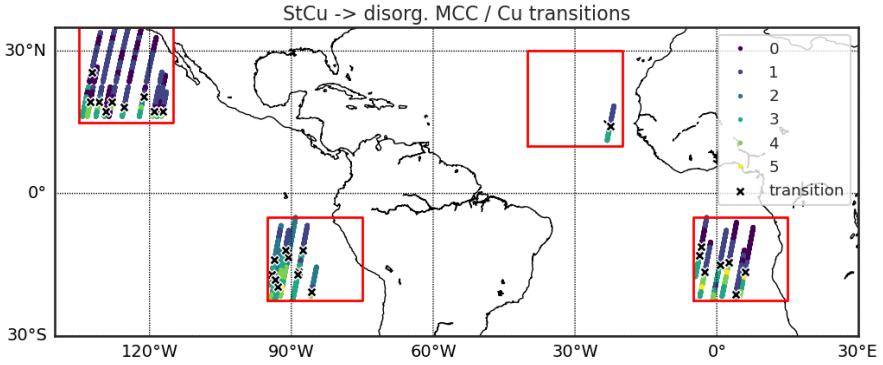
Average over 27 transitions: Closed MCC → Disorg. MCC or Cu

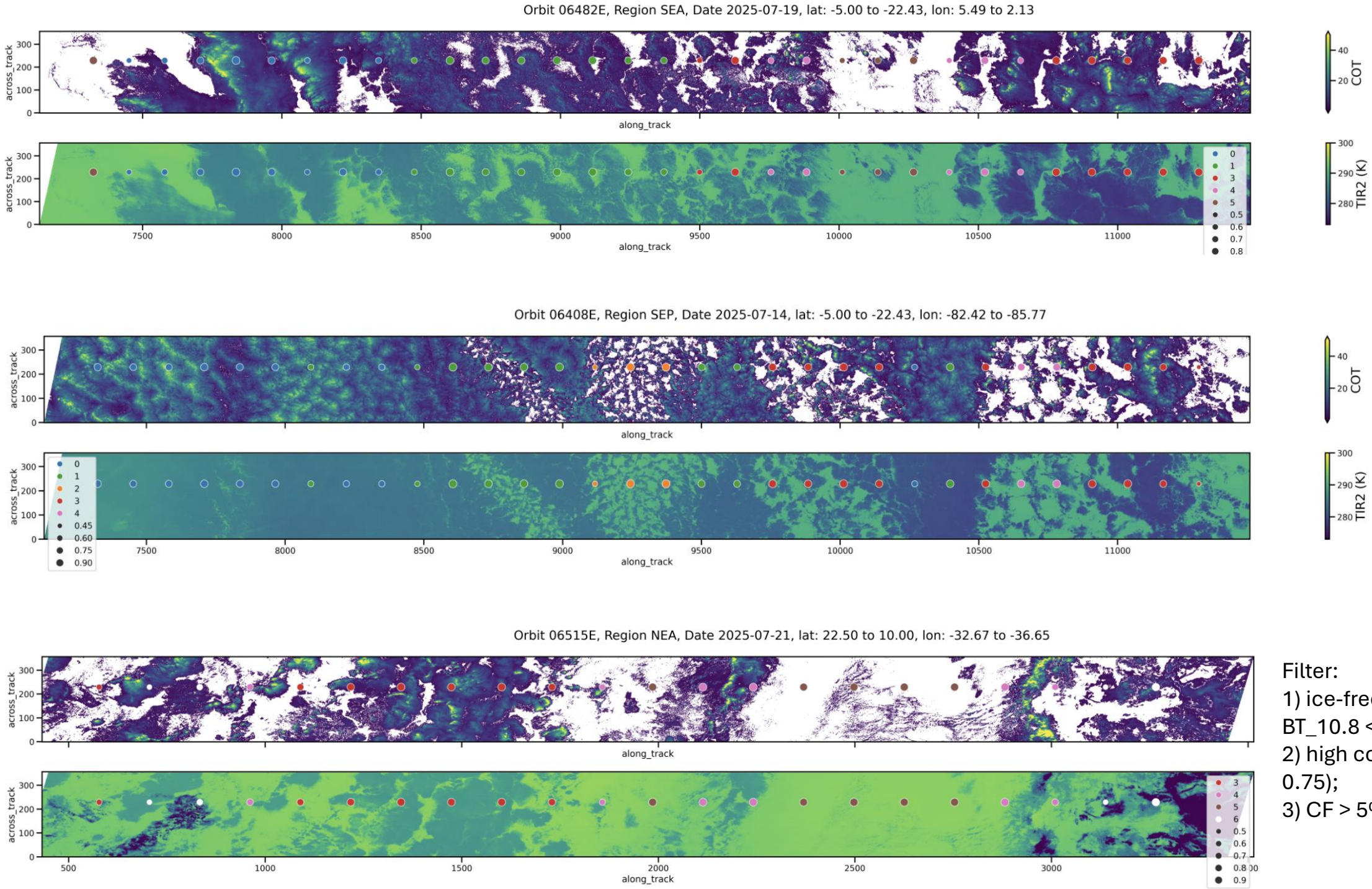




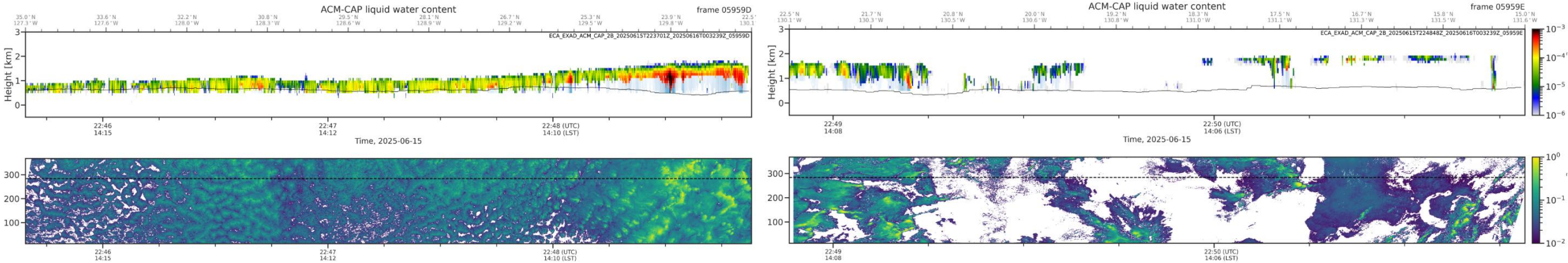
Average over 27 transitions: Closed MCC → Disorg. MCC or Cu







Filter:
1) ice-free (no pixels with BT_10.8 < 273K);
2) high confidence (cert > 0.75);
3) CF > 5%


ACM-CAP liquid water content
frame 05959D
ECA_EXAD_ACM_CAP_2B_20250615T223701Z_20250616T003239Z_05959D
Height [km]
Time, 2025-06-15
ACM-CAP liquid water content
frame 05959E
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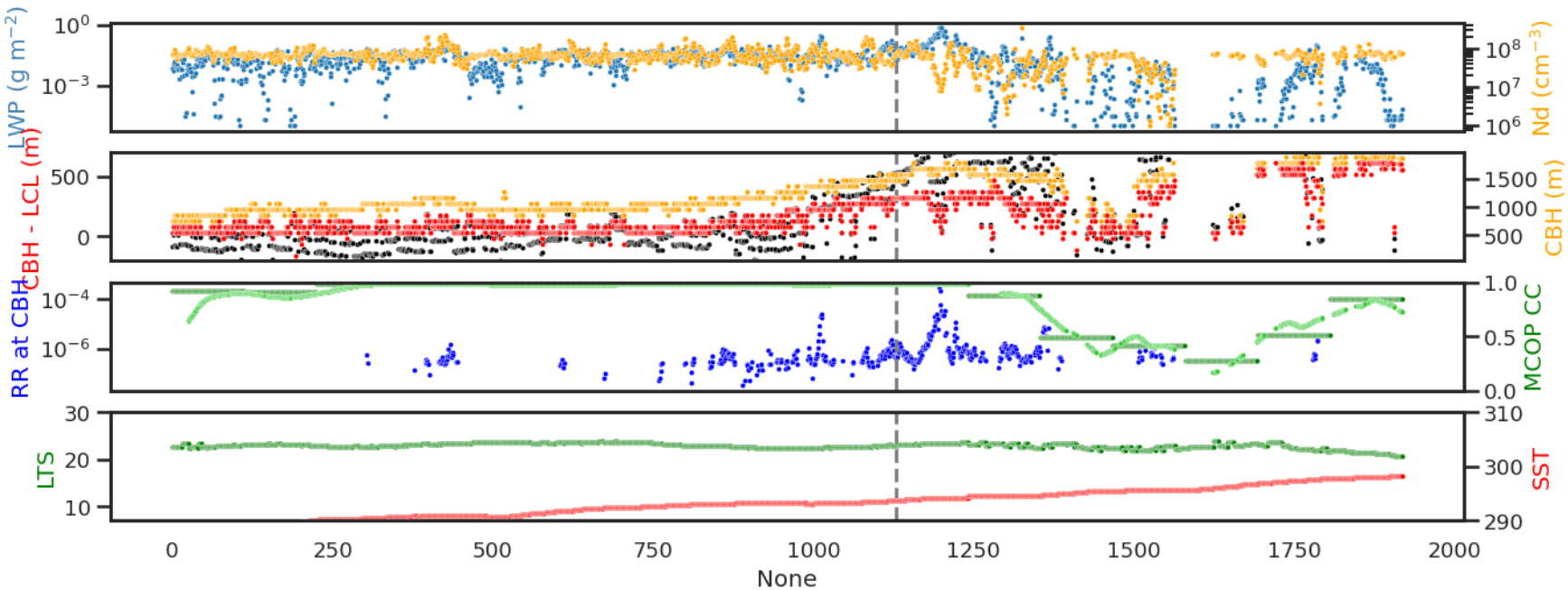
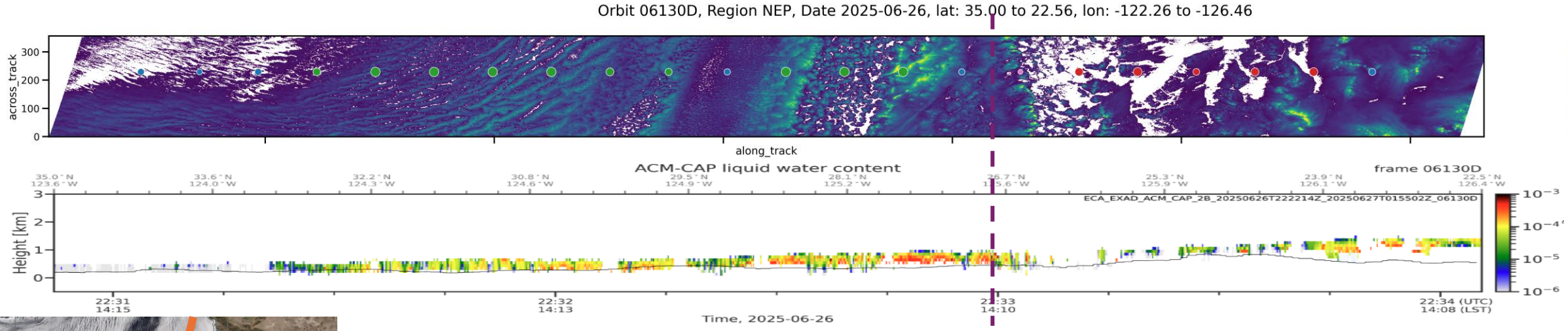
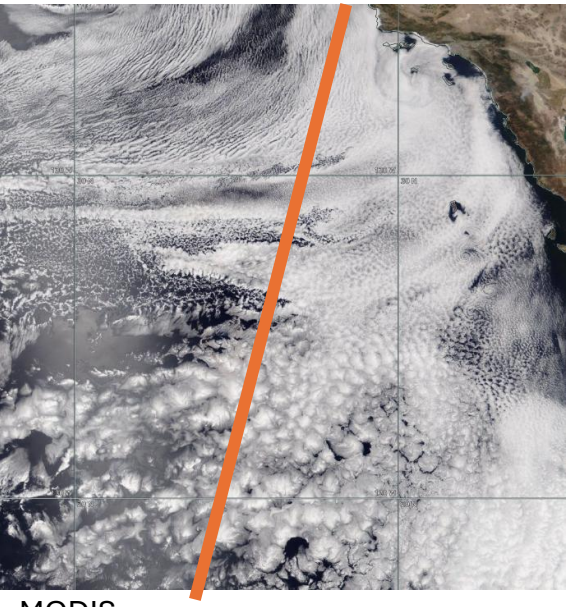
Height [km]
Time, 2025-06-15


LWP (g m^{-2})
Nd (cm^{-3})
CBH - LCL (m)
CBH (m)
RR at CBH
MCOP CC
LTS
SST
None

Look for transitions within overpasses: from Closed MCC to disorganised or cumuliform





MODIS
(→ not exact temporal fit)