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EUROPEAN SPACE AGENCY

EarthCARE 2026 Science and Validation workshop

8–12 June 2026 | Rhodes House | Oxford, UK

Evaluating a Global Storm-Resolving Model with EarthCARE and ORCESTRA Observation

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Introduction

EarthCARE provides unprecedented observations of the vertical structure of clouds, precipitation, and atmospheric motions.

Global Storm-Resolving Models (GSRMs) explicitly resolve deep convection and simulate cloud and precipitation processes in much greater detail than conventional climate models.

Using EarthCARE and ORCESTRA observations, we investigate how these observations can be used to constrain GSRMs and evaluate the vertical structure of convectivea systems.

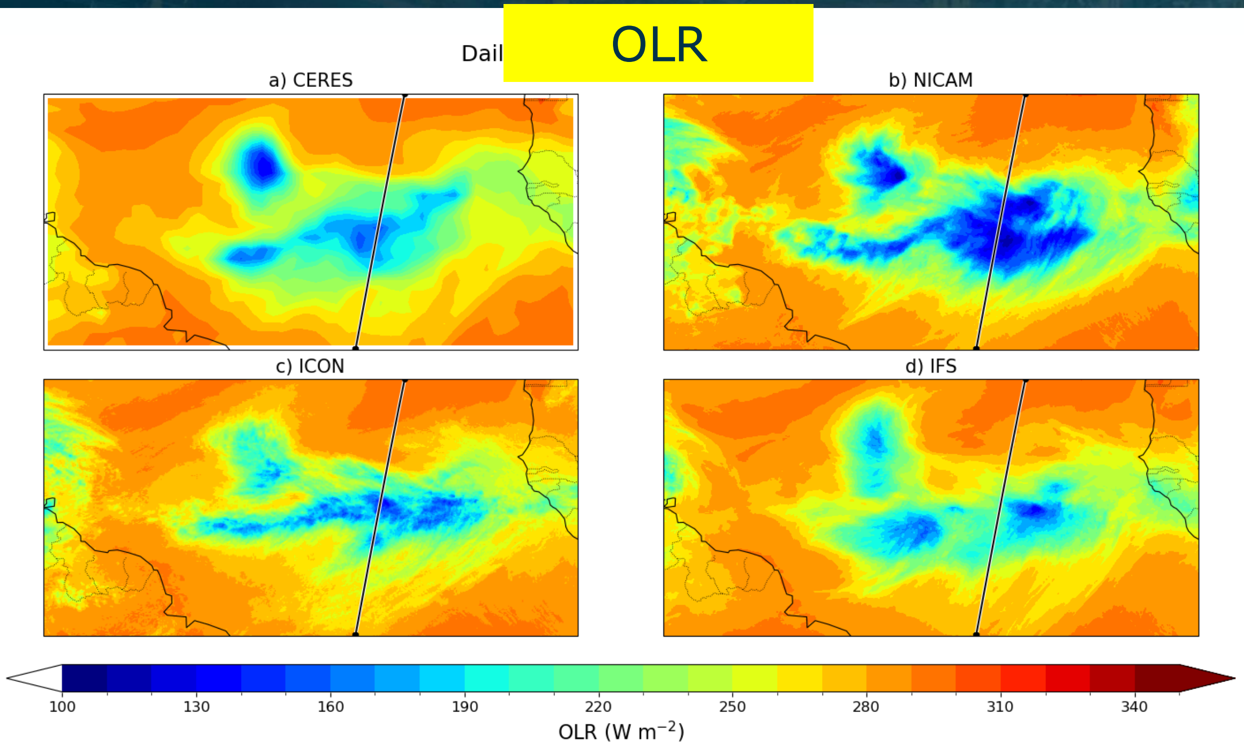
I present recent evaluation results from NICAM, ICON, and IFS for the ECOMIP project.

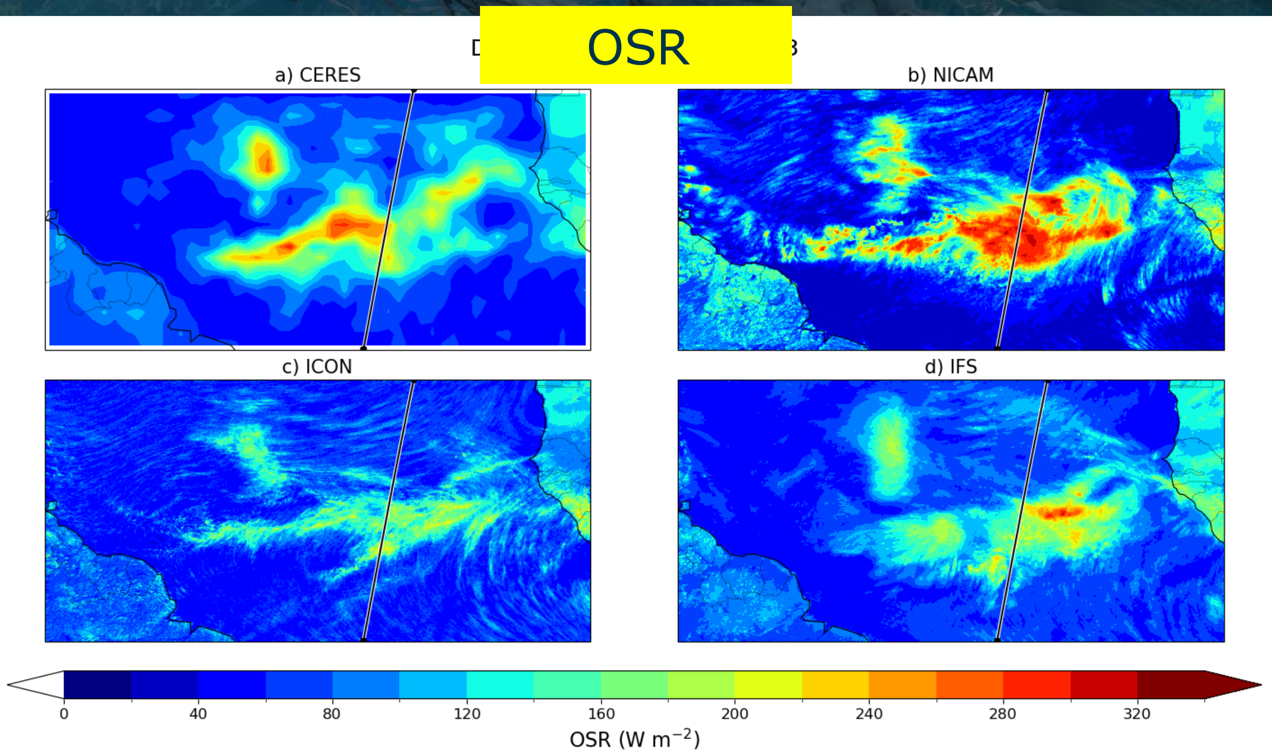
My key questions:

1. Cloud structures and radiations?
2. Link to cloud dynamics and cloud structures?

Evaluation of NICAM, ICON, and IFS

Horizontal distributions of daily OLR and OSR



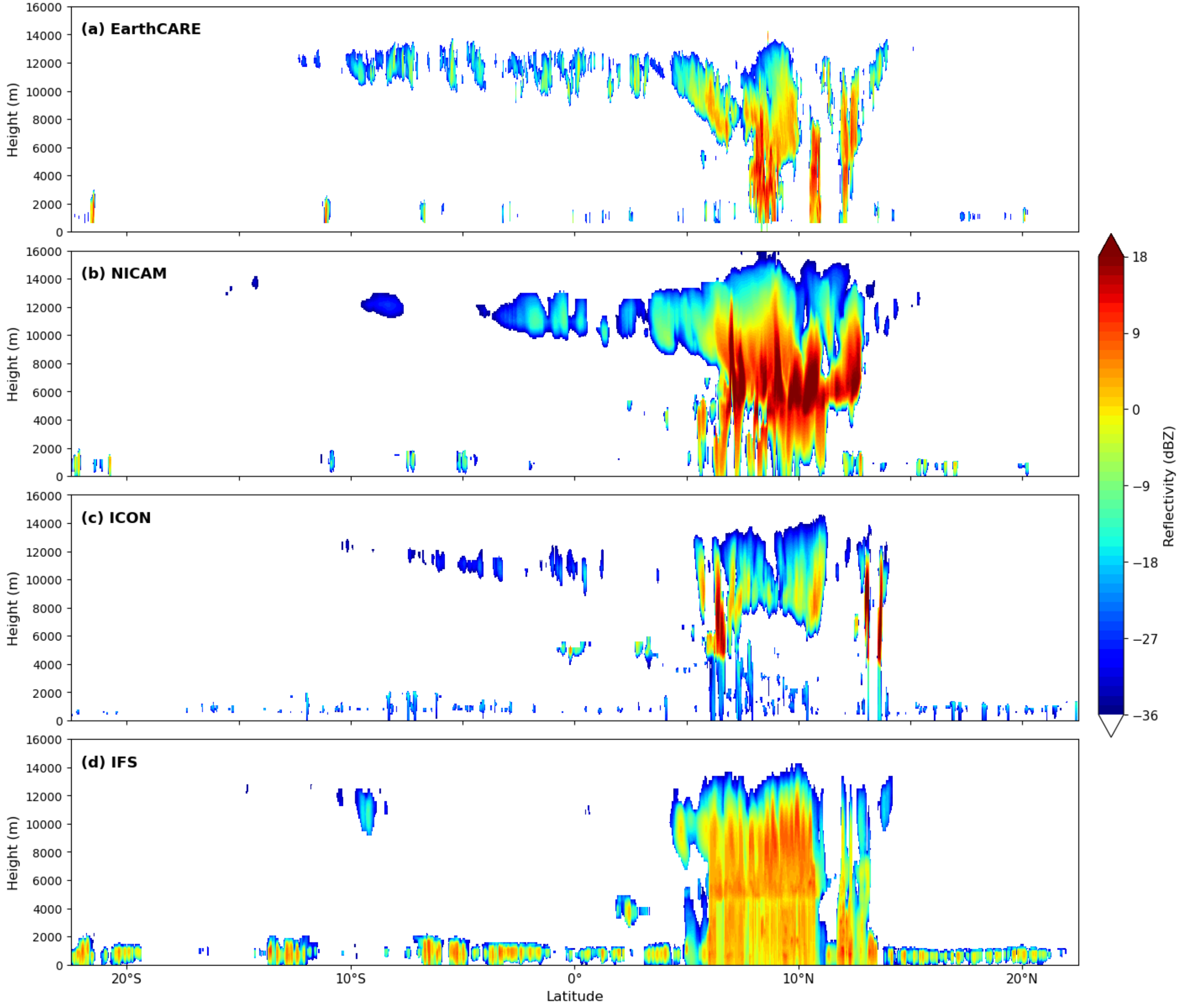


- EarthCARE CPR observations are used to evaluate and compare the simulated cloud and precipitation structures in NICAM, ICON, and IFS. Model horizontal resolutions:
  - NICAM: 3.5 km
  - ICON: 2.5 km
  - IFS: 4.4 km
- NICAM and ICON are global storm-resolving models without deep-convection parameterization. IFS employs a cumulus convection parameterization scheme.

- All models capture the observed large convective systems in OLR and OSR.
- OSR shows much larger inter-model differences.
- Understanding the 3D structure of clouds and precipitation is essential for interpreting the differences in OLR and OSR among the models.

Evaluation using EarthCARE CPR

Radar reflectivity



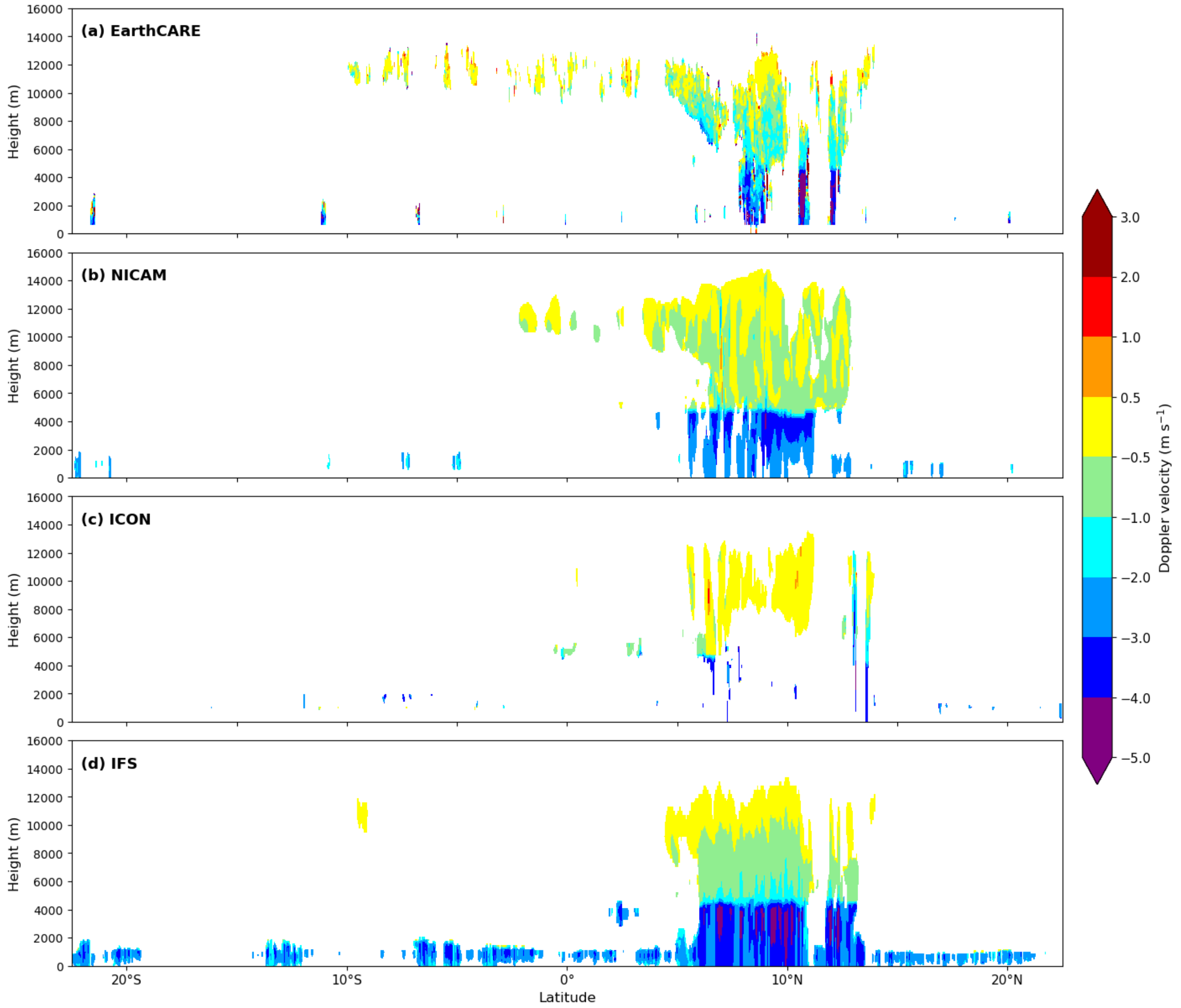
- All models reproduce the observed MCS and Southern Hemisphere anvil cirrus clouds reasonably well.

- Significant differences remain in the detailed cloud morphology.
- NICAM and IFS simulate larger and more organized MCS structures than observed. ICON and IFS tend to overestimate low-cloud occurrence.
- The results indicate substantial model-dependent differences in cloud microphysics and convective organization.

- The thickness and cloud fraction of the Southern Hemisphere anvil cirrus vary substantially among the models, indicating differences in the representation of ice microphysics and detrainment processes.

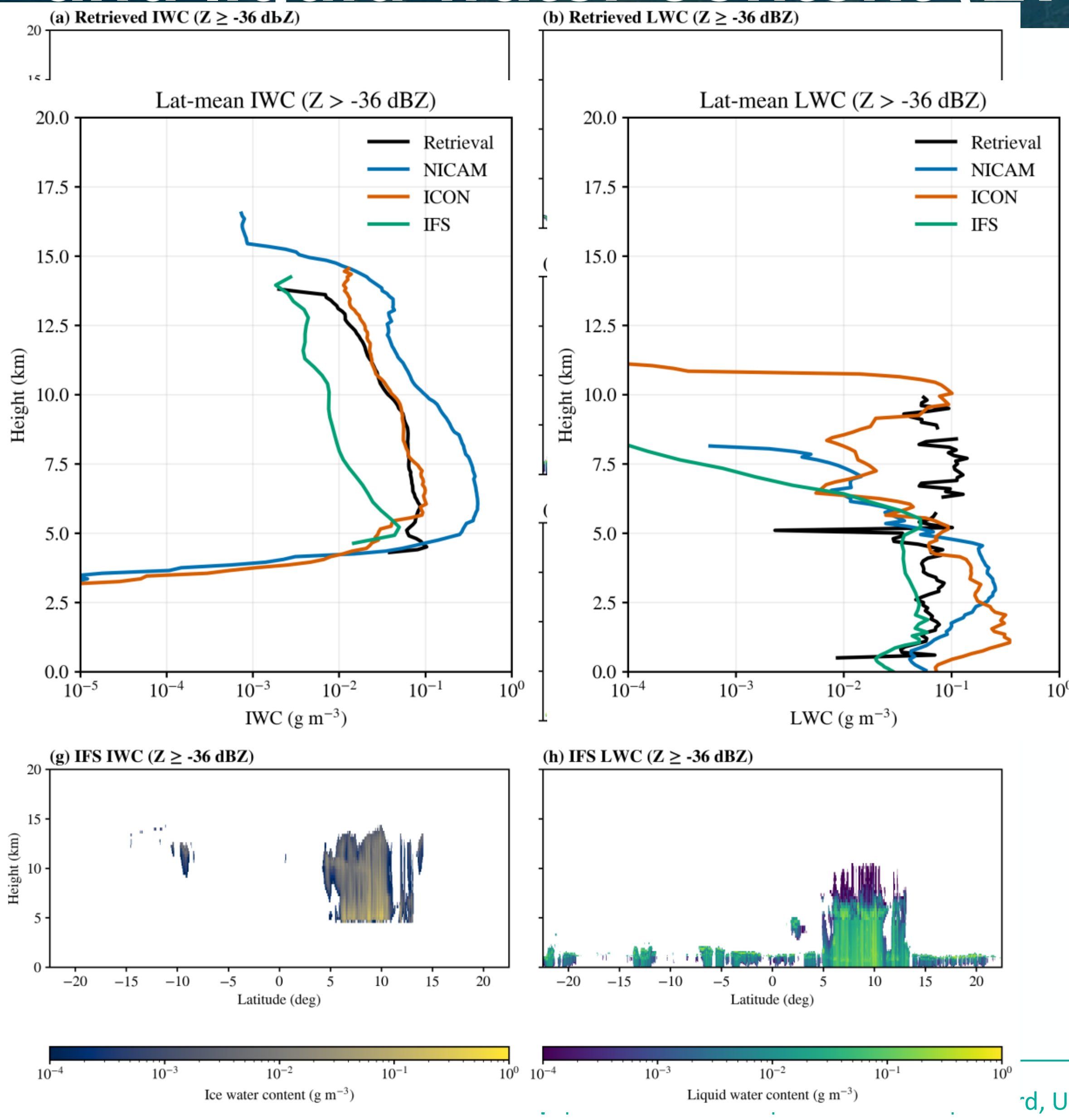
Evaluation using EarthCARE CPR

Doppler velocity



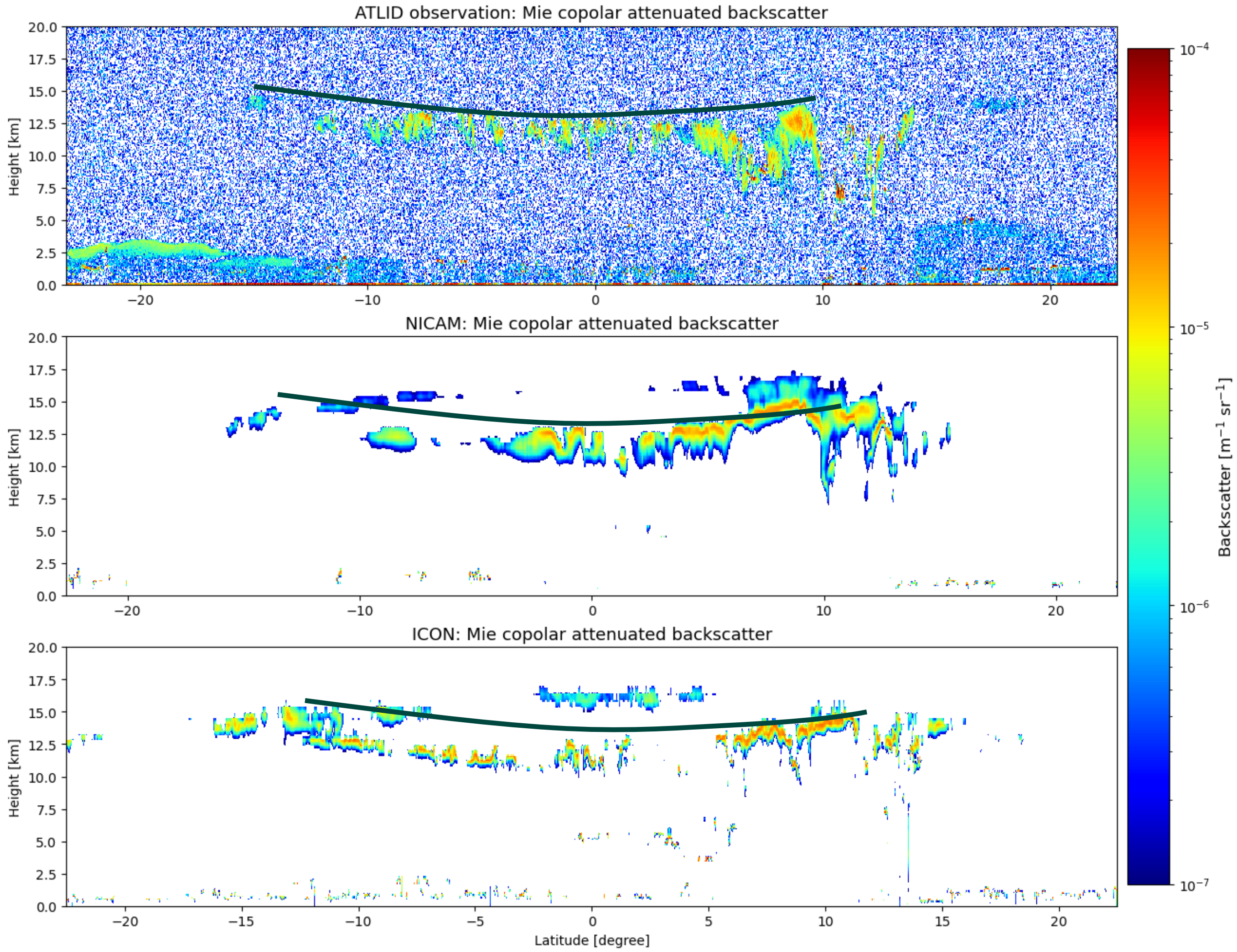
- A clear contrast between rain and ice particle fall speeds is observed near the melting layer (~5 km).
- All models reproduce the overall Doppler velocity structure.
- NICAM shows a single convective core, while ICON exhibits multiple smaller convective cores.
- IFS simulates faster hydrometeor fall speeds than observed.
- EarthCARE Doppler observations provide valuable constraints on vertical motion and cloud microphysics.

Evaluation of Ice water content (IWC) and liquid water content (LWC)



- EarthCARE CPR retrievals (JAXA CPR_CLP vBb) and model simulations (NICAM, ICON, and IFS) show generally consistent vertical distributions of ice and liquid hydrometeors.
- The overall cloud microphysical structure is reasonably well reproduced by all models.
- NICAM tends to overestimate IWC, while IFS tends to underestimate IWC relative to the EarthCARE retrievals.
- Supercooled liquid water is observed above the melting layer in both the observations and simulations.
  - The amount and vertical distribution of supercooled liquid water differ substantially among the models, indicating differences in mixed-phase cloud microphysics.
  - These differences may influence radar observables, including Doppler velocity and path-integrated attenuation (PIA).

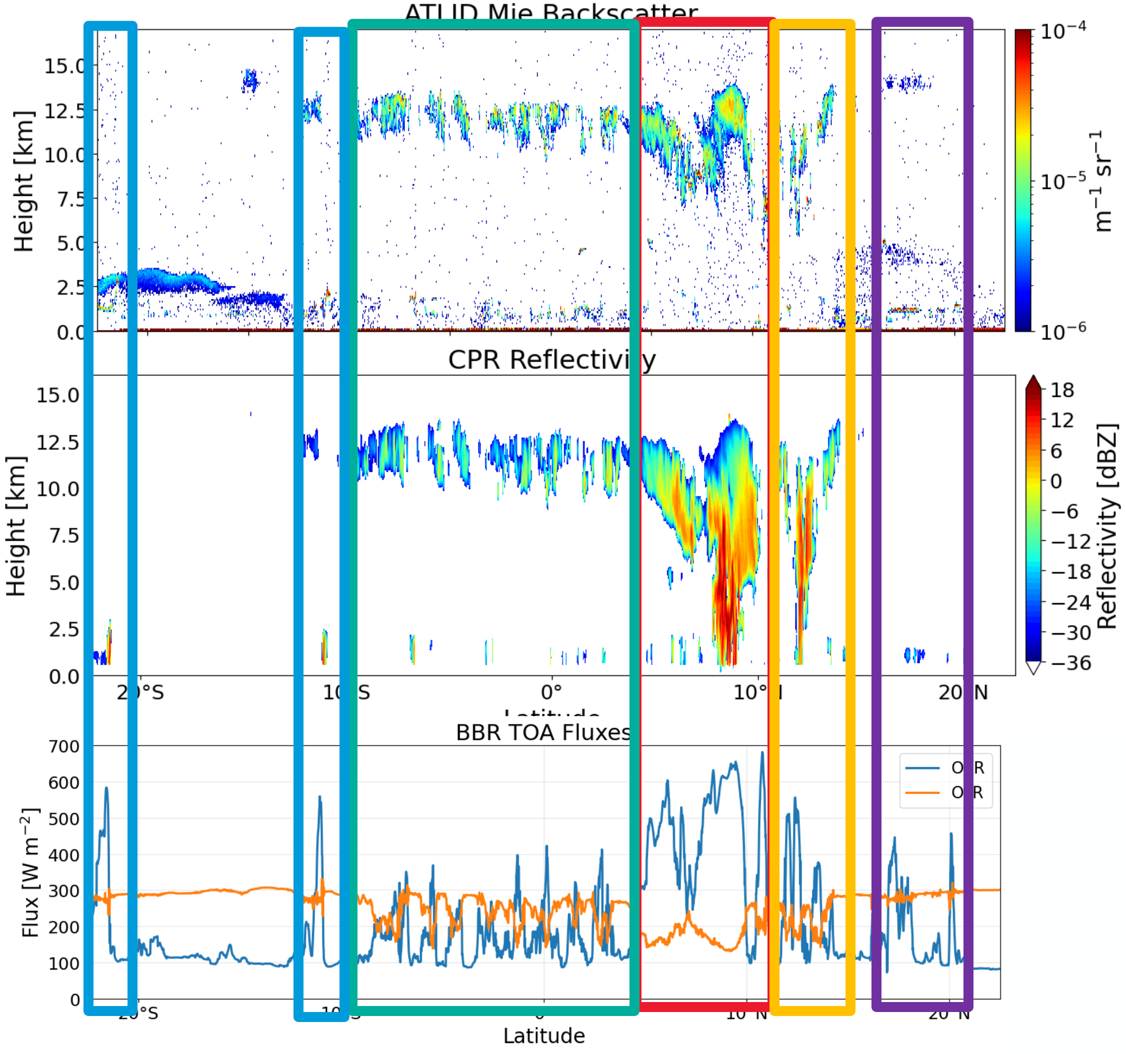
Preliminary evaluation using ATLID



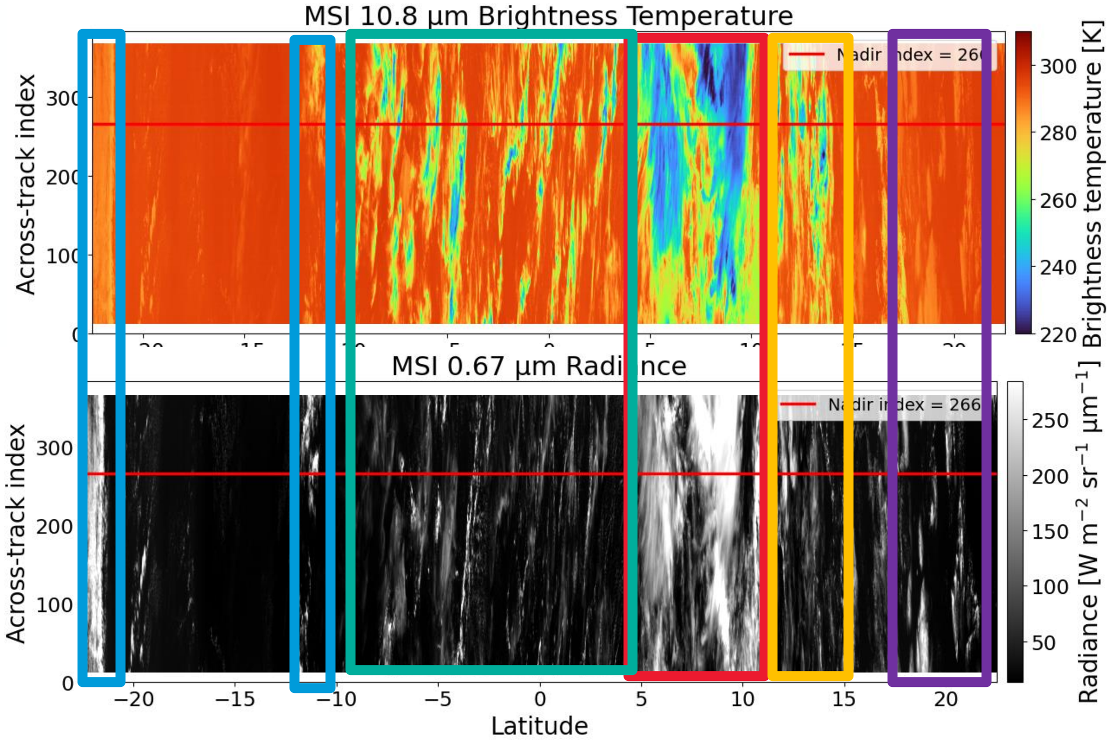
- ATLID provides observations of thin cirrus, cloud phase, ice crystal shapes, and aerosols.
- NICAM and ICON reproduce the overall cloud-top distribution and liquid cloud occurrence reasonably well.
- The observed meridional variation of cloud-top height is captured by the models.
- NICAM produces higher MCS cloud tops than observed.
- NICAM and ICON simulate a double-layer cirrus structure that is not evident in the ATLID observations.

EarthCARE Observations of 3D Cloud and Aerosol Structures and Their Radiative Effects for Model Evaluation

Vertical distribution of clouds



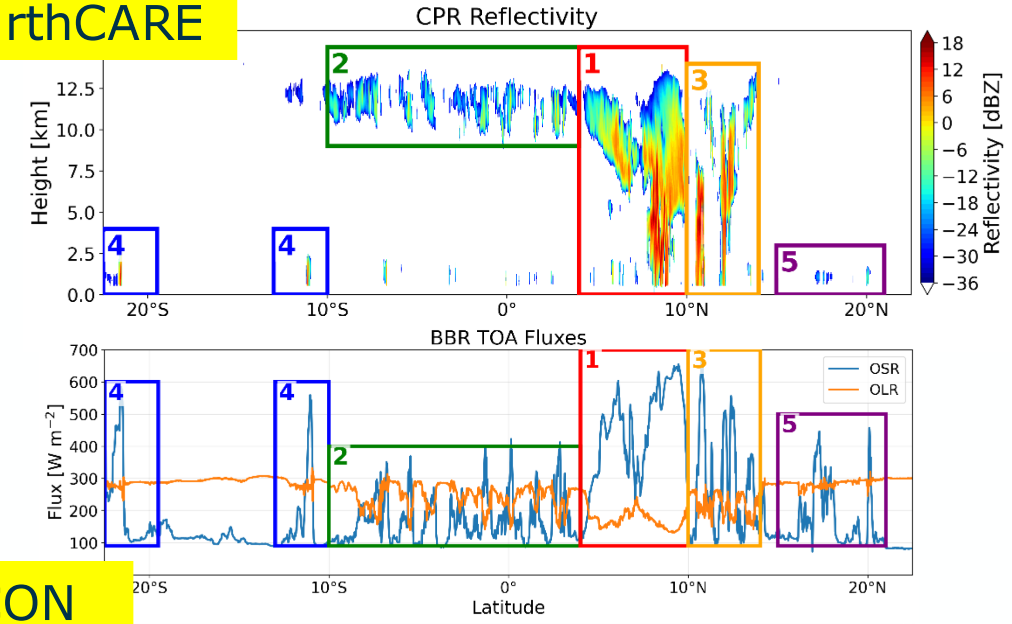
Horizontal distribution of clouds



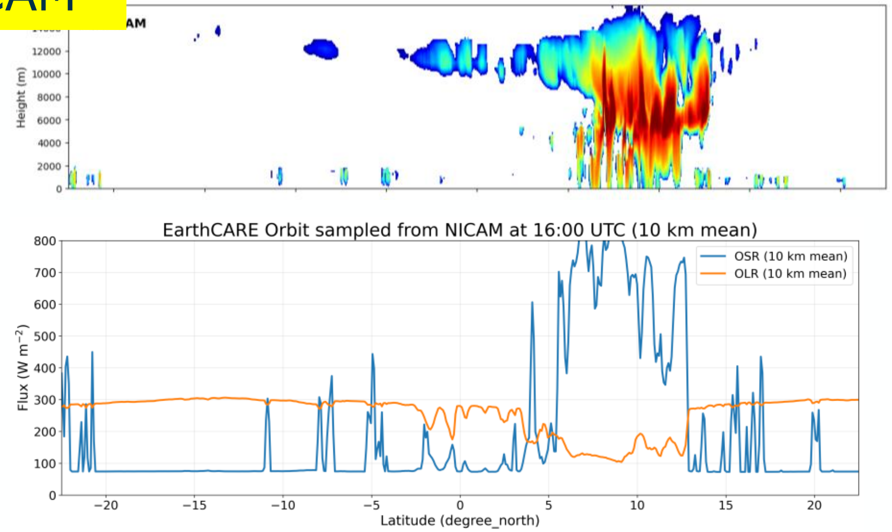
1. MCS (Mesoscale Convective Systems)
→ Low OLR (120–200 W/m²), high OSR (up to ~600 W/m²)
2. Anvil / Thick Cirrus (Deep Clouds)
→ Low OLR, moderate OSR (~350 W/m²)
3. Isolated Convection
4. Shallow Convection (~2.5 km height)
→ High OSR (~600 W/m²)
5. Boundary Layer Clouds

Evaluation of NICAN and ICON using CPR and BBR data

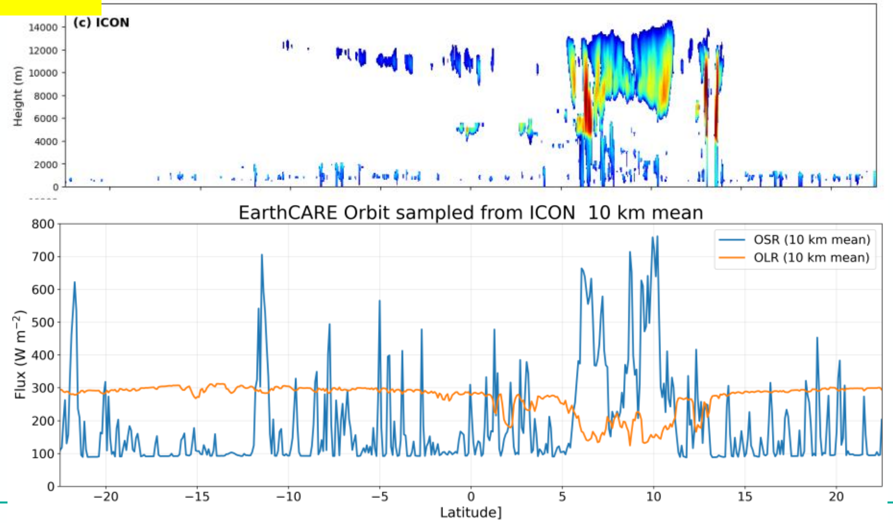
EarthCARE



NICAM

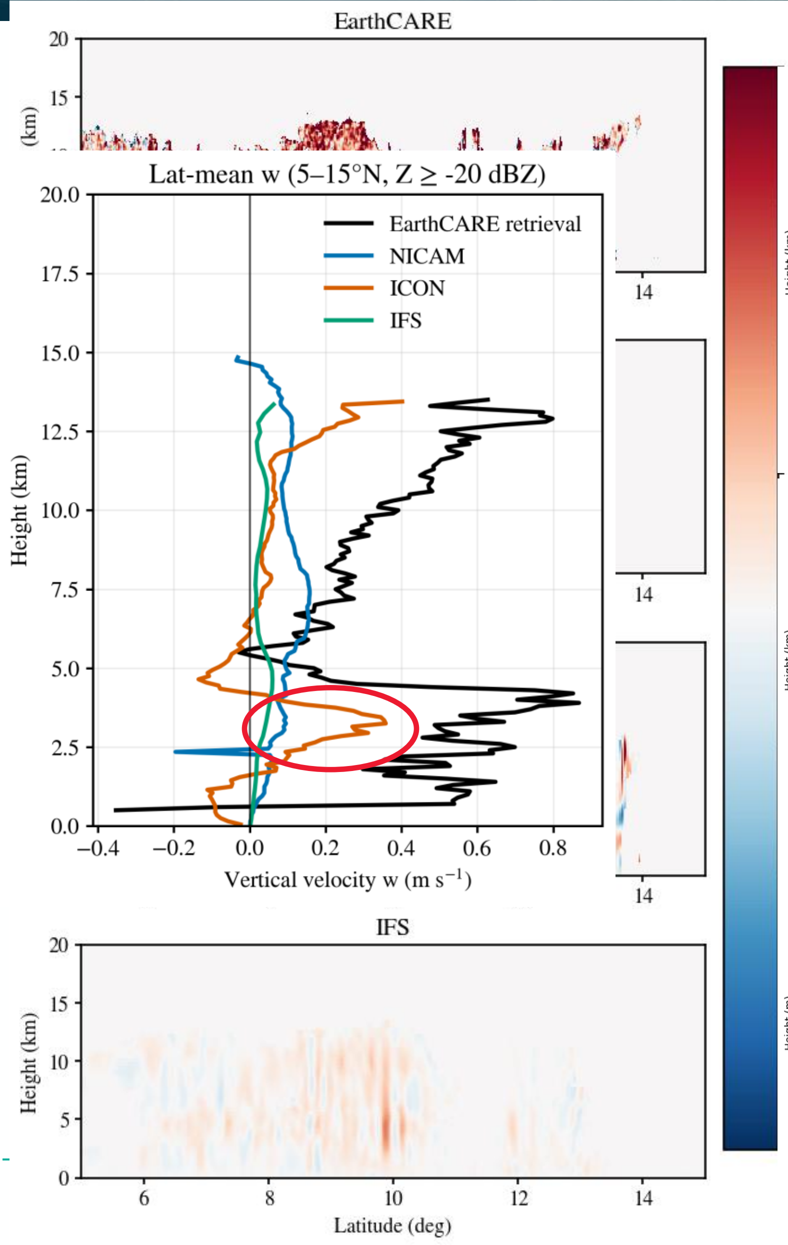


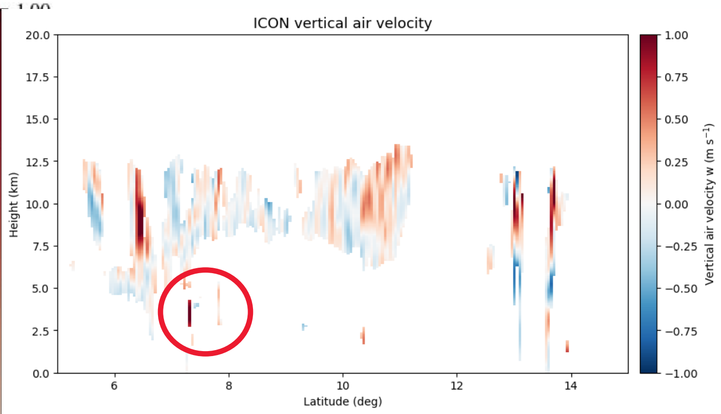
ICON

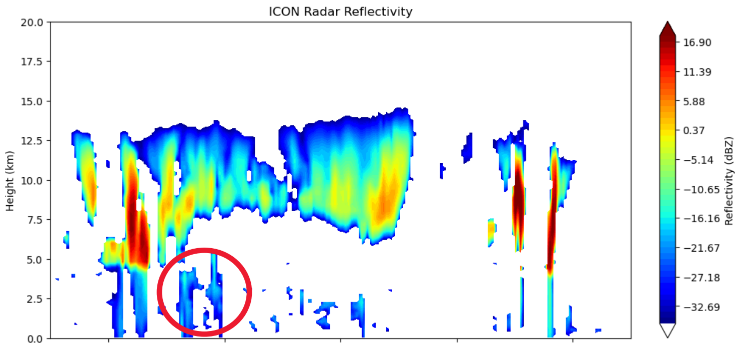


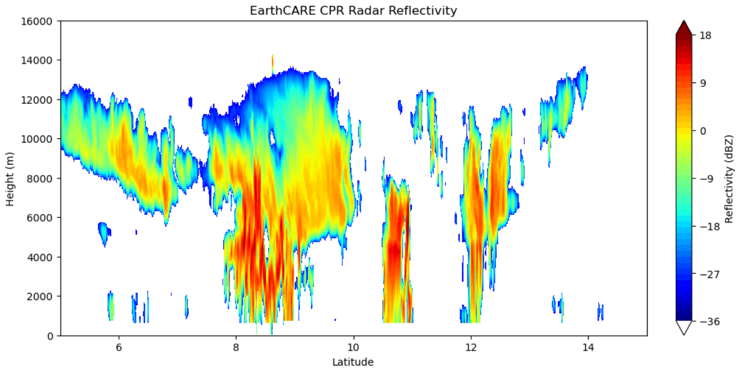
- NICAM and ICON reproduce MCSs, anvil clouds, and boundary-layer clouds reasonably well.
- Model differences are apparent in convective organization and low-cloud coverage.
- Shallow convection (~2.5 km) is underestimated in both models.
- EarthCARE CPR and BBR observations offer a powerful framework for cloud and radiative process evaluation

Can we link CPR observations to cloud dynamics and structure?









profiles are compared between EarthCARE
the NICAM, ICON, and IFS simulations.

d vertical velocity shows substantially larger
model results, partly due to retrieval
bservational noise.

rtainties, EarthCARE provides valuable
raints on the magnitude and vertical
pheric motions within convective systems.

es are found among the models.

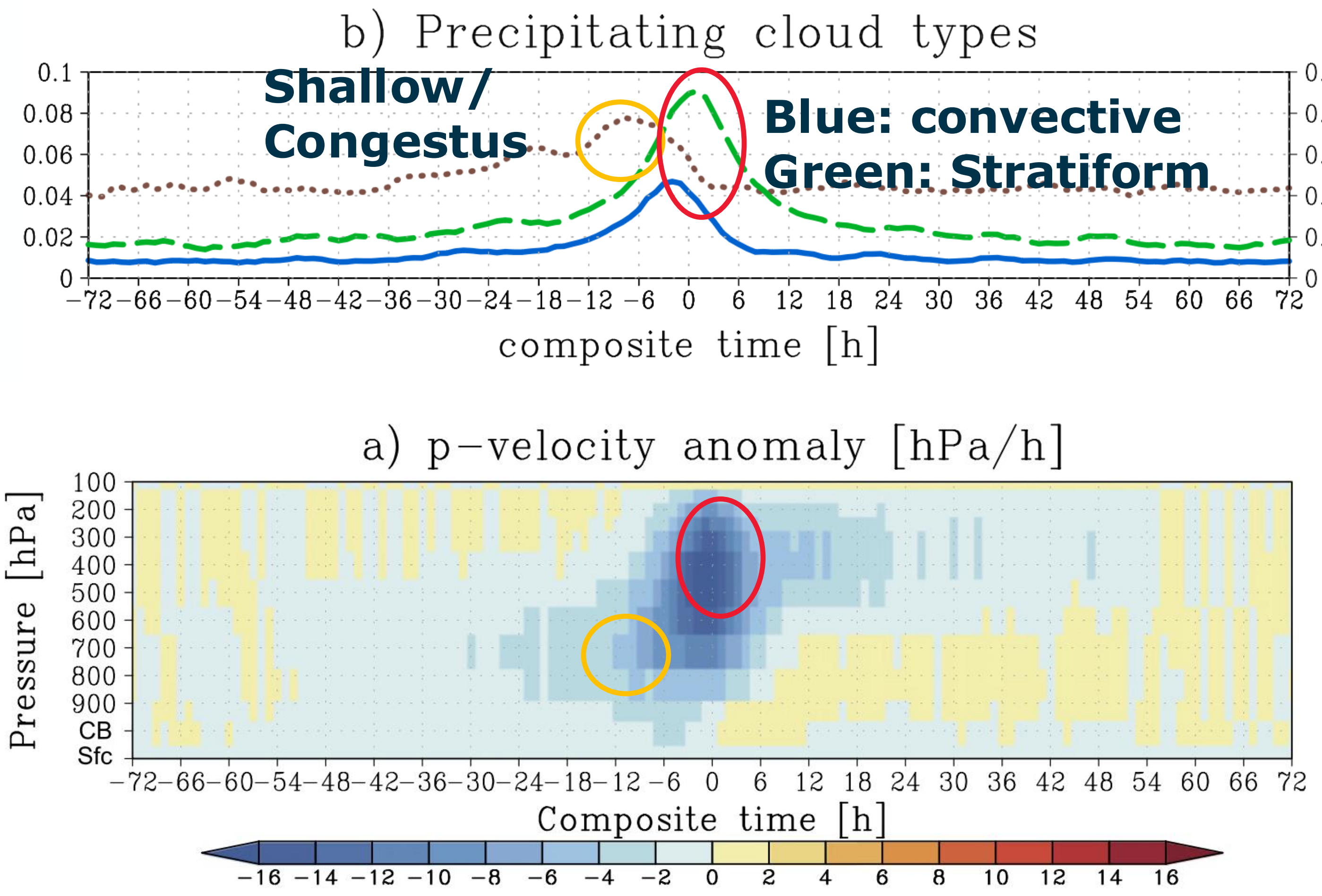
the strongest updrafts.

more small-scale updraft and downdraft structures, likely
r horizontal resolution.

ker vertical motions compared with NICAM and ICON.

eflect model-dependent representations of

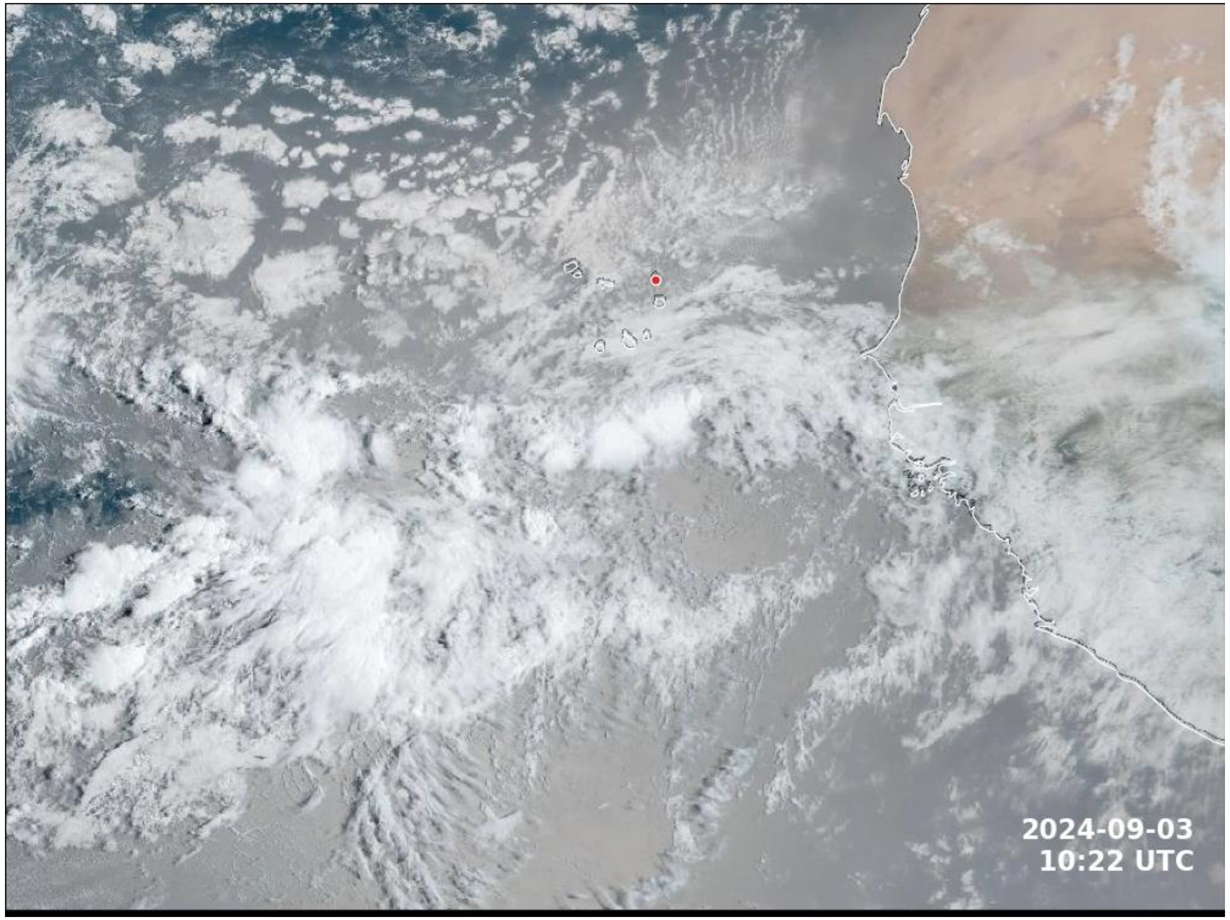
Masunaga and L'ecuyer 2014

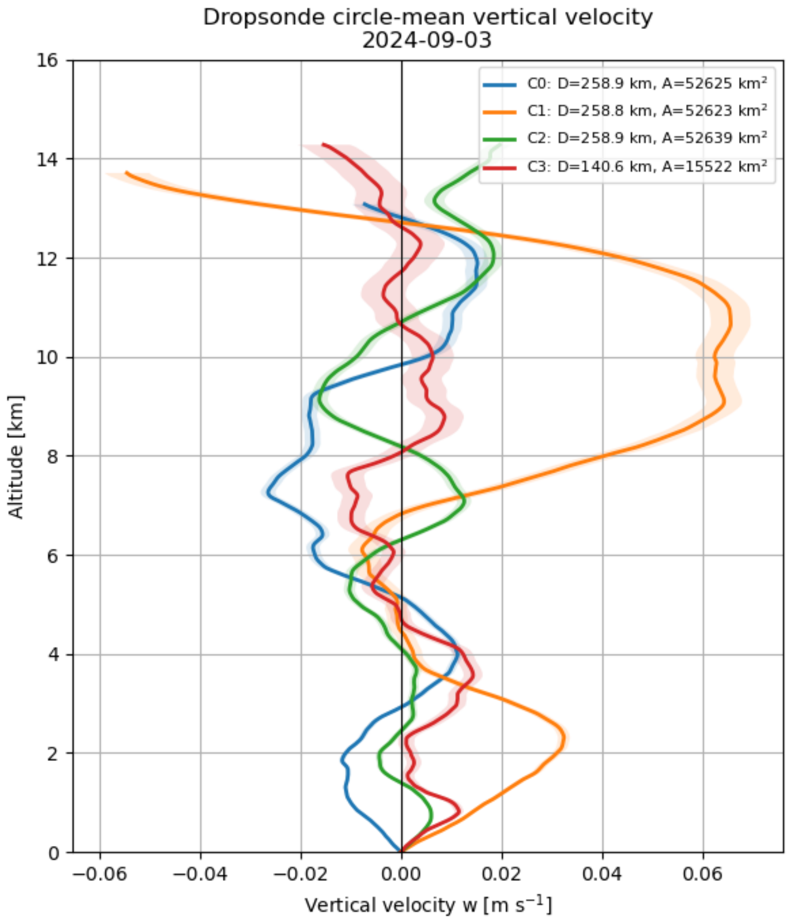


Masunaga and L'Ecuyer (2014) used satellite observations and moist static energy (MSE) budget analyses to investigate the temporal evolution of tropical convection.

Their results showed a transition of vertical motion from a bottom-heavy congestus stage to deep convection prior to the development of mature convective systems using CloudSat.

Dropsonde observation from ORCESTRA field campaign





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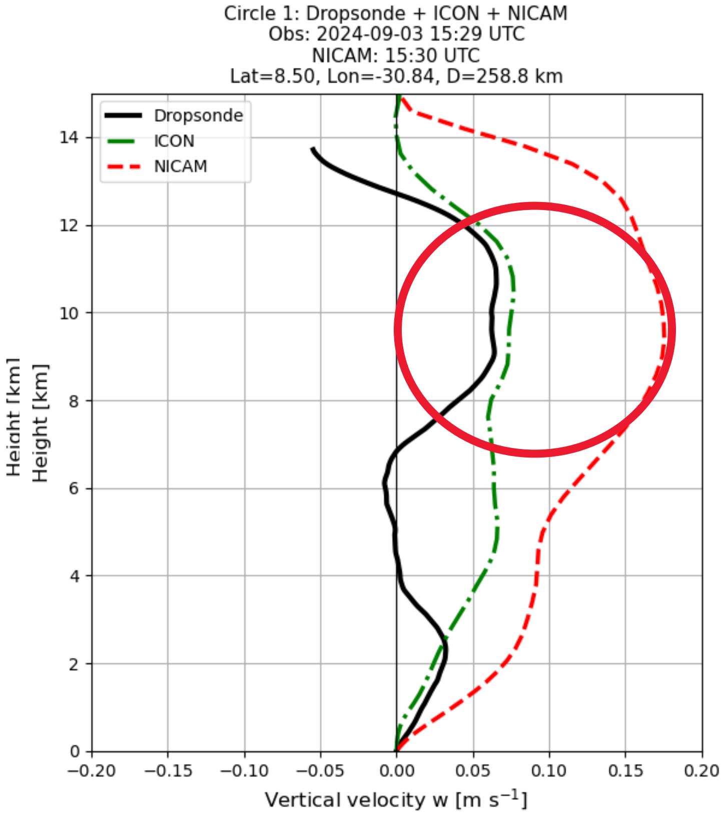
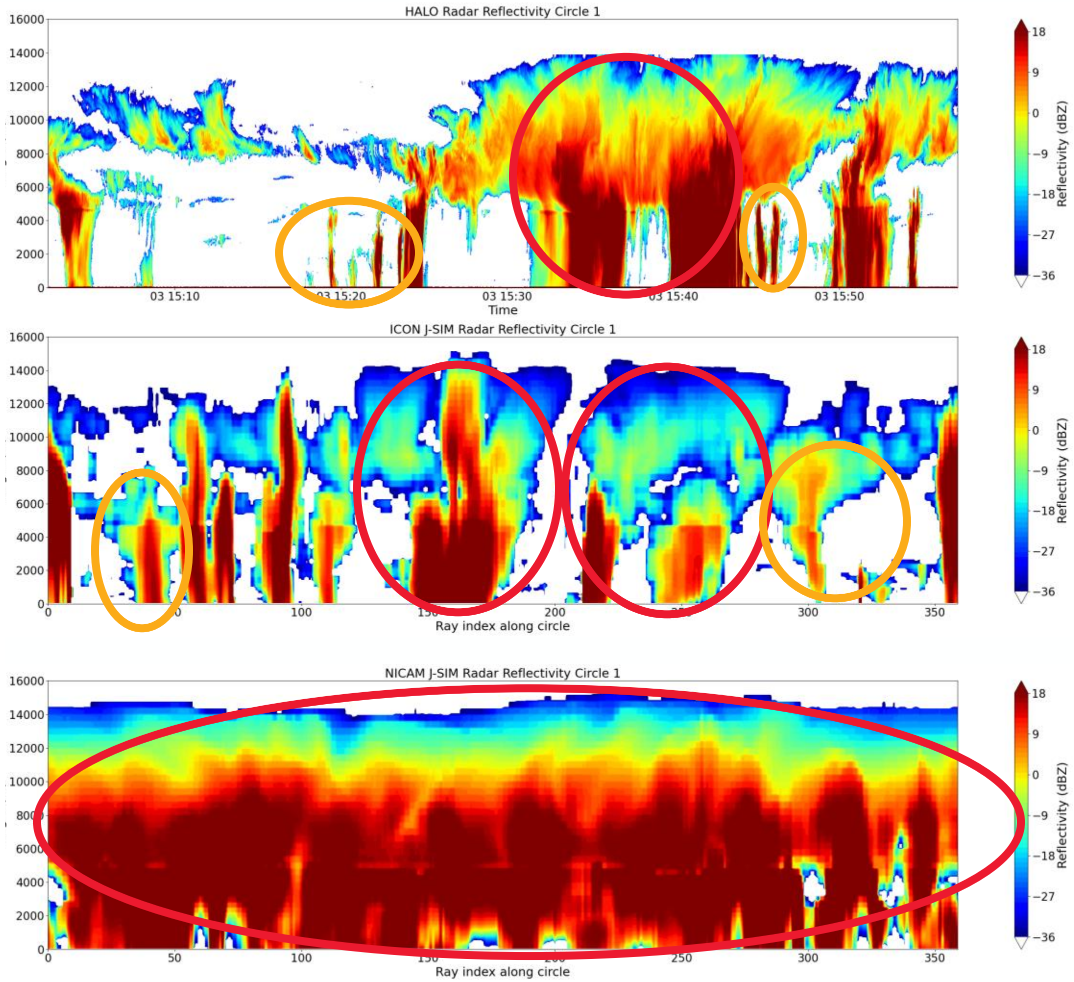
Helene Gloeckne

https://orcestra-campaign.org/reports/HALO-20240903a.html

Circled dropsondes can observe the large-scale upward/downward motion in the circle areas

Preliminary evaluation results using Dropsonde data





- The bimodal vertical velocity structure may reflect the coexistence of congestus-type bottom-heavy convection and deep convective/MCS-type cloud systems, although further analysis is required to establish a relationship (?).
- These observations and also simulation results provide valuable support for understanding cloud systems associated with upward motion.

Summary

- We evaluated NICAM, ICON-MPI, and IFS using EarthCARE observations.
- All models successfully reproduced the major cloud systems, including MCSs, anvil clouds, and shallow cloud fields.
- However, notable differences remain in low-cloud occurrence, anvil cloud coverage, IWC/LWC, and vertical air motions.
- EarthCARE BBR observations offer complementary information on the radiative impacts of cloud vertical structure, helping to improve model representations of cloud–radiation interactions.
- Dropsonde and HALO radar observations provide valuable constraints on large-scale vertical motion and cloud structure, complementing EarthCARE observations.

→ Retrieving vertical air velocity from EarthCARE CPR observations alone remains challenging, but model simulations provide valuable support for their interpretation and evaluation.