Multi-layer cloud conditions in trade wind shallow cumulus

Confronting models with airborne observations

Marek Jacob[1], S. Crewell[1], P. Kollias[1,2], V. Schemann[1], F. Ament[3]
[1]Institute for Geophysics and Meteorology, University of Cologne, Germany
[2]School of Marine and Atmospheric Sciences, Stony Brook University, NY, [3]Meteorological Institute, Universität Hamburg, Germany

1 Motivation

The treatment of shallow clouds over the vast, sub-tropical oceans remains a large source of uncertainty in climate models. Therefore, cloud-resolving kilometer-scale resolution models are applied in climate studies as a means of improving the cloud representation. But...

Fig. 1: Shallow cumulus clouds. Small size – high impact.

- ... how do those models represent marine shallow cumuli compared to observations?
- What is the best way to asses the clouds?
- And how does the liquid water path help to interpret differences between observed and simulated cloud structures?

The research aircraft HALO offers us the opportunity to answer this question with respect to two cloud-resolving models.

2 Airborne observations and atmospheric models

Nadir pointing instruments on-board the High Altitude and LOng range research aircraft (HALO):

- Aerosol backscatter lidar: Backscatter ratio (BSR) detects cloud top height of small cloud droplets.
- Cloud and precipitation radar: Radar reflectivity is scattered back by large droplets and precipitation from cloud top to base.
- Microwave radiometer: Retrieval of integrated liquid water path.

ICOsahedral Nonhydrostatic storm resolving model (SRM)

- Forced with ECMWF data
- 1.25 km grid, 75 levels
- One-moment microphysics
- Resolves deep convection

ICON large eddy model (LEM)

- Nested in SRM
- 300 m grid, 150 levels
- Two-moment microphysics
- Resolves cloud circulation

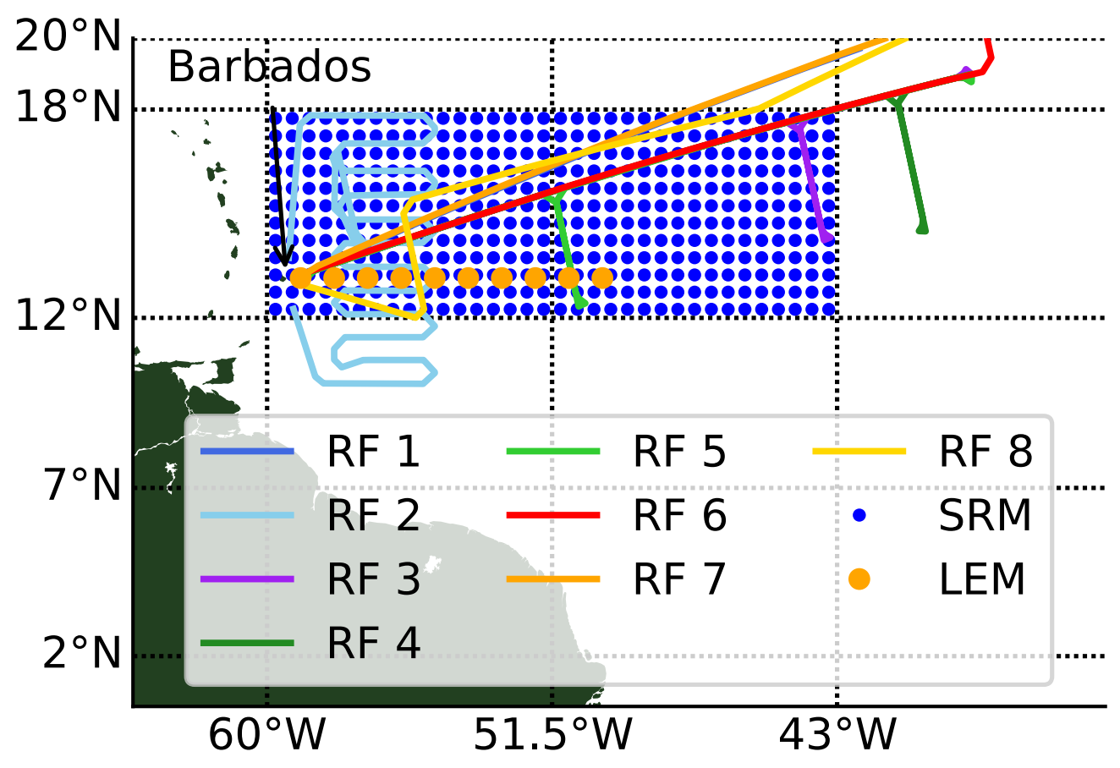

Fig. 2: Research flights (RF) on top of sub-sampled SRM and LEM grid points.

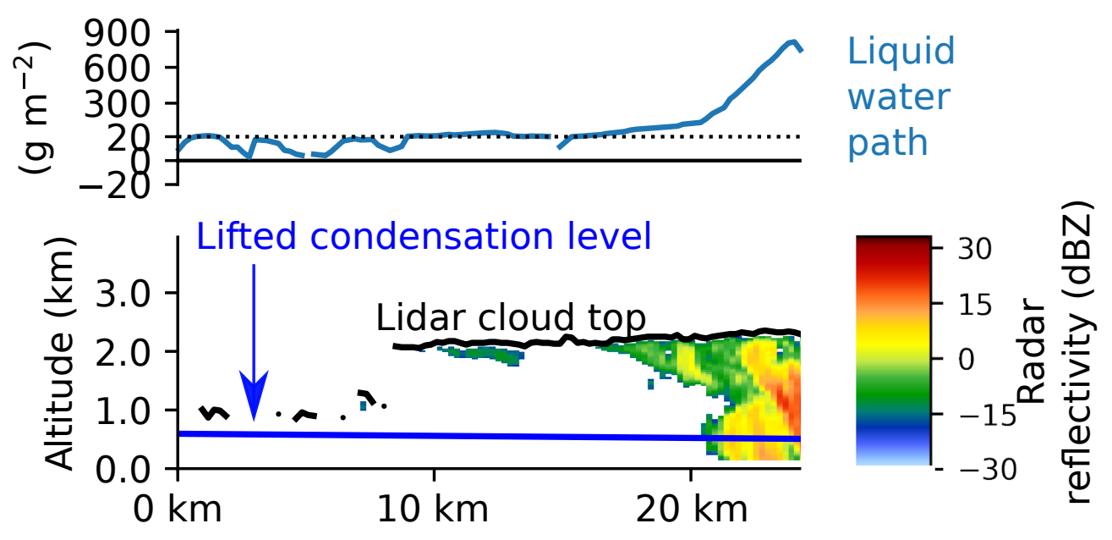

Fig. 3: Example scene observed from HALO during RF 6 along flight track.

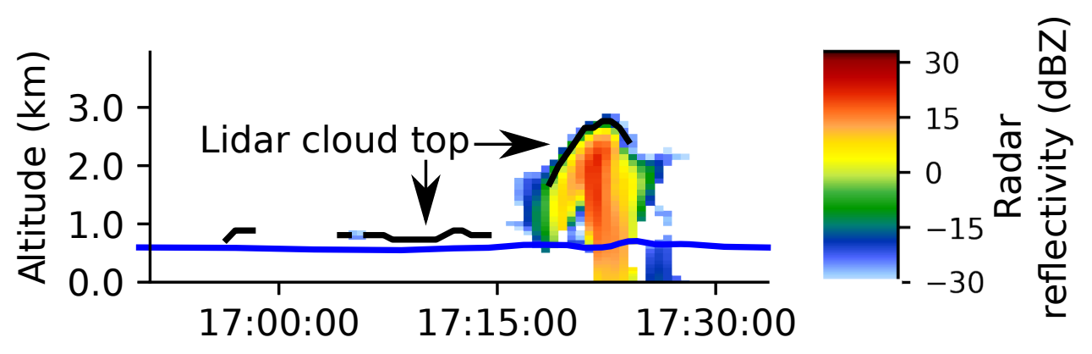

Fig. 4: Example scene from ICON LEM. Forward simulated radar signal and lidar cloud top height from meteogram output.

3 Benefit of forward simulations

The observable signals are forward simulated from drop size distributions of cloud and rain water given by the models. The lidar signal is sensitive to the number of droplets and therefore depends only on the high number of small cloud droplets. The radar signal is more sensitive to large droplets and thus detects rain or thick clouds.

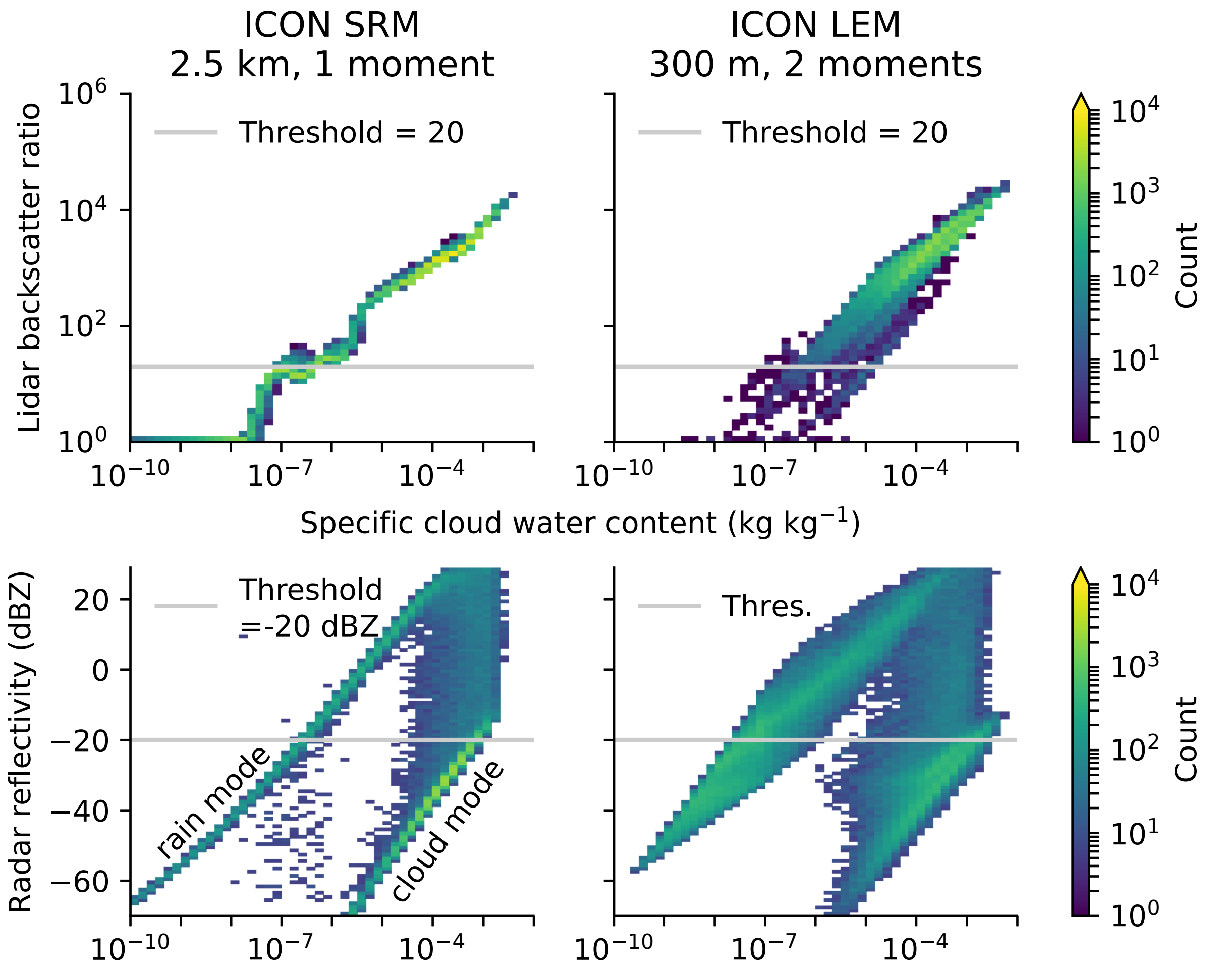

Fig. 5: Simulated lidar and radar signals as function of hydrometeor contents.

4 Overview: Cloud boundaries – The influence of different sensors

- Observation of cloud tops in two layers. Lower layer is mostly visible to lidar only.
- Both models reproduce lower layer, but only LEM clearly develops upper layer.

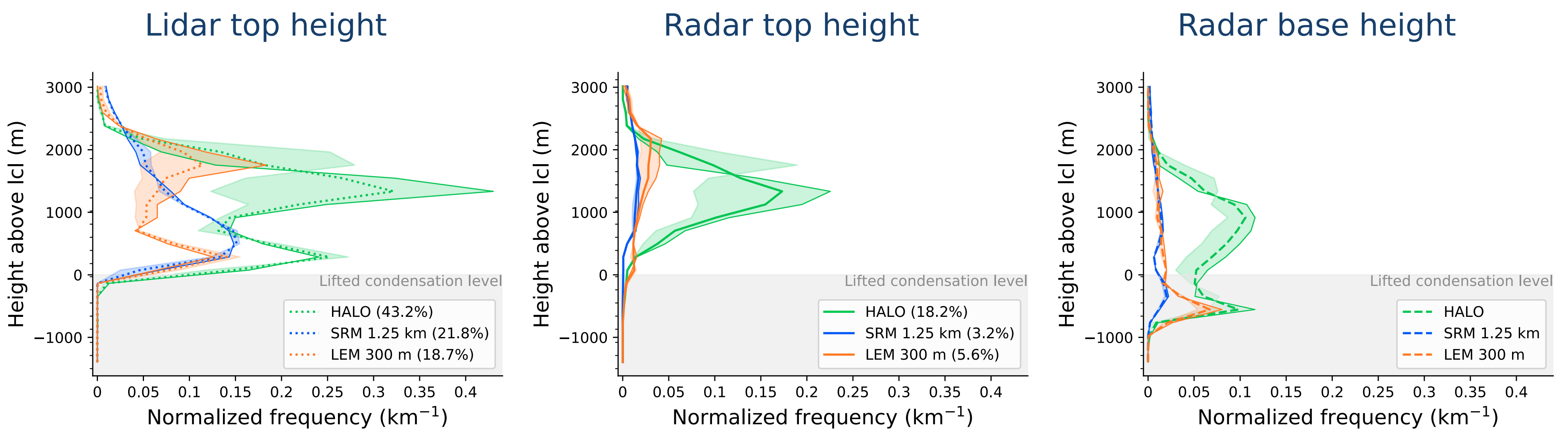

Fig. 6: Cloud boundaries in all observations and forward simulated radar and lidar signals. Same thresholds for cloud detection are used for the observed and simulated radar and lidar signals. Height is in relation to the lifted condensation level (lcl). Shadings depict western (bright edge) and eastern (dark edge) half of each dataset. Observations are from RF 1 to 8. SRM data are sub-sampled (0.5°, hourly) for 24 days. LEM data are taken from 10 grid points at high temporal resolution (every 36 s) for 4 days. All data is during daytime (~ 8 AM to 5 PM local time).

5 Details: Liquid water path enriches cloud analysis

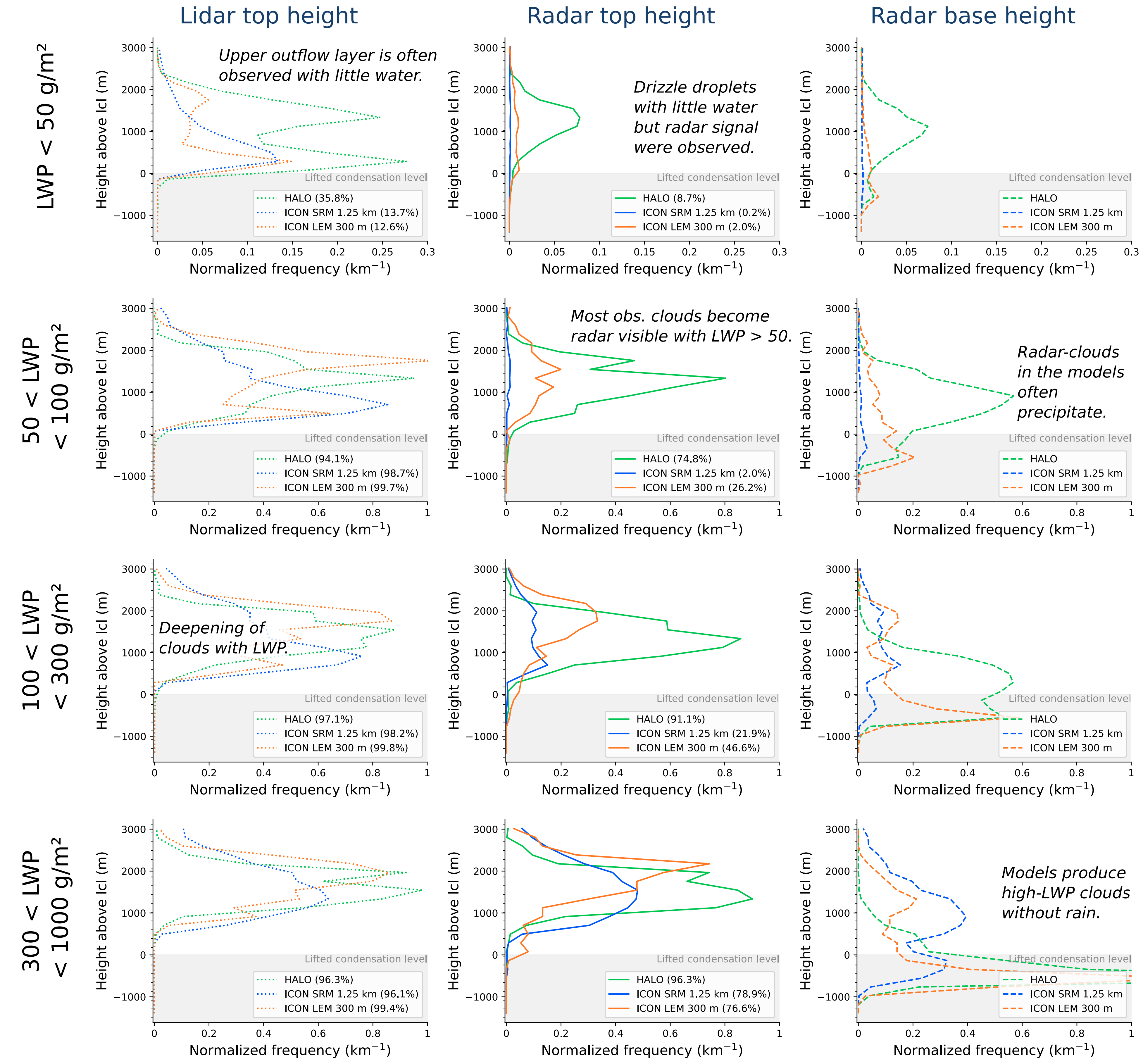

Fig. 7: Cloud boundaries classified by liquid water path (LWP) in observations and forward simulated radar and lidar signals.

6 Conclusions and outlook

- Lidar and radar forward simulates allow to impose instrumental thresholds to model data.
- Connection with retrieved LWP helps to understand differences between models and observations.
- Comparison reveals lack in clear layer separation in SRM.
- Both models are unable to represent larger but non-raining droplets (drizzle).
- Methods are ready to be applied on even more coordinated model and observation activities during the upcoming EUREC^{4}A campaign Jan/Feb 2020.

Fig. 8: EUREC^{4}A: Elucidating the Role of Cloud-Circulation Coupling in Climate.

Acknowledgments

- The work has been supported by the German Research Foundation (DFG) within the DFG Priority Program (SPP 1294) “Atmospheric and Earth System Research with the Research Aircraft HALO” under grants CR 111/10-11 an CR 111/12-1.
- We would like to thank Daniel Klocke and Matthias Brück for running the ICON simulations and the German Climate Computing Centre (DKRZ) for storing and supplying the data.

Data references

- Gutleben et al. (2019), *Atmos. Chem. Phys.*, DOI: 10.5194/acp-19-10659-2019.
- Jacob et al. (2019), *Atmos. Meas. Tech.*, DOI: 10.5194/amt-12-3237-2019.
- Klocke et al. (2017), *Nature Geos.*, DOI: 10.1038/s41561-017-0005-4.
- Konow et al. (2019), *Earth Syst. Sci. Data.*, DOI: 10.5194/essd-11-921-2019.

A51L-2847, AGU Fall Meeting 2019, 9 - 13 December 2019, San Francisco, CA

marek.jacob@uni-koeln.de