Multi-layer cloud conditions in trade wind shallow cumulus clouds

Confronting models with airborne observations

Marek Jacob[1], S. Crewell[1], P. Kollias[1,2], V. Schemann[1]
[1]Institute for Geophysics and Meteorology, University of Cologne, Germany
[2]School of Marine and Atmospheric Sciences, Stony Brook University, New York

1 Motivation

The treatment of shallow clouds over the vast, sub-tropical, oceans remains a large source of uncertainty in climate models. HALO offers us the opportunity to answer the following questions

Fig. 1: Shallow cumulus clouds.

- What is the best way to match clouds in the ICON model and observations?
- How do two cloud resolving versions of the ICON model represent shallow cumuli in comparison to observations?
- How does the liquid water path help to interpret differences between observed and simulated cloud structures?

2 Airborne observations and atmospheric models

HALO nadir pointing observations:

- 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.

ICON storm resolving model (SRM)

- Forced by a numerical weather forecast
- At 2.5 km grid spacing
- One-moment microphysics
- Resolves deep convection

ICON large eddy model (LEM)

- Nested in SRM
- At 300 m grid spacing
- Two-moment microphysics
- Resolves cloud circulation

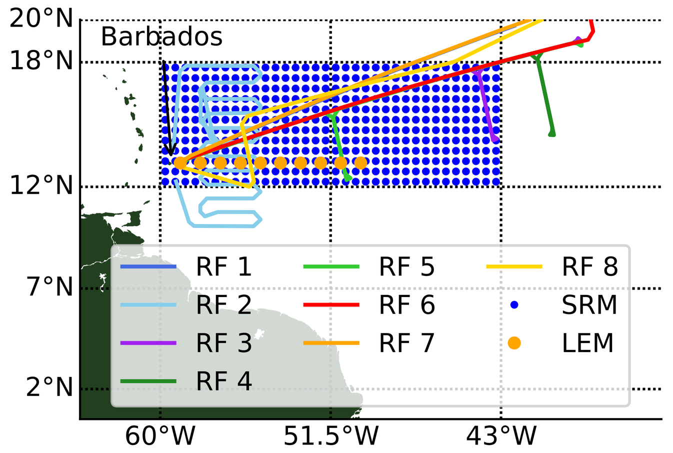

Fig. 2: Research flights (RF) on top of sub-sampled SRM and LEM grid points.

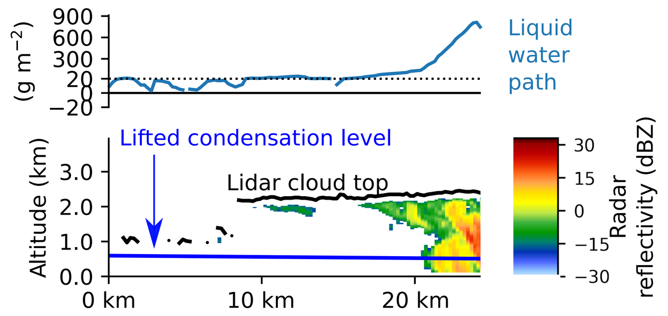

Fig. 3: Example scene observed from HALO during RF 6 along flight track.

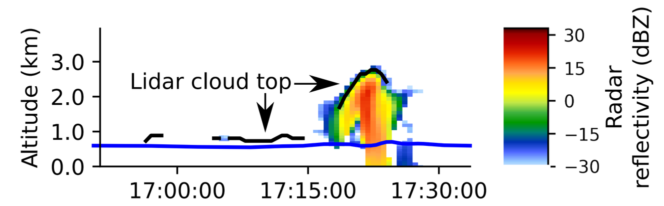

Fig. 4: Example scene from ICON LEM. Forward simulated radar signal and lidar cloud top height from meteogram output.

3 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.

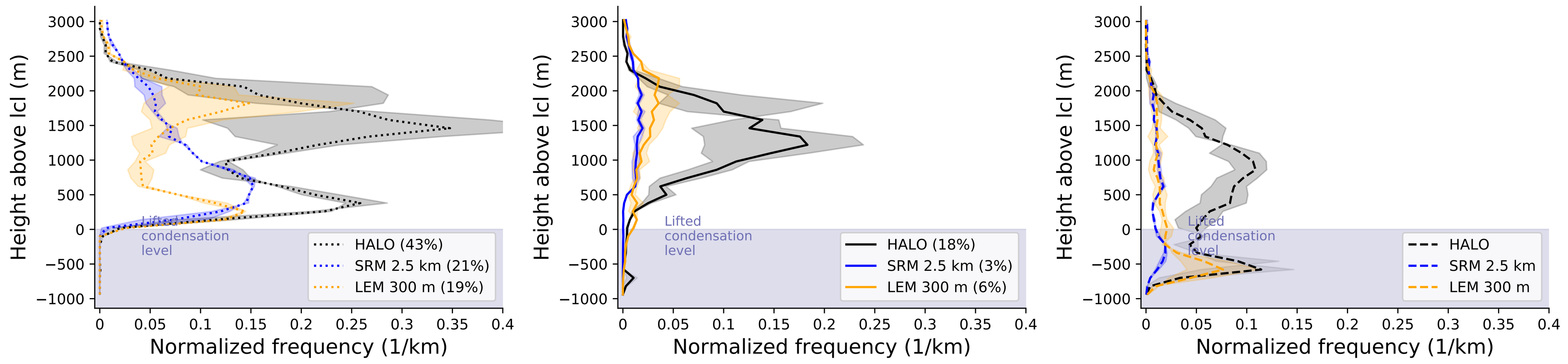

Fig. 5: Cloud boundaries in all observations and forward simulated radar and lidar signals. Same thresholds for cloud detection are used for the observed and simulated radar and lidar signals. Height is in relation to the lifted condensation level (lcl). Shadings depict western and eastern half of each 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 3 days. All data is during daytime (~ 8 AM to 5 PM local time).

4 Liquid water path enriches cloud analysis

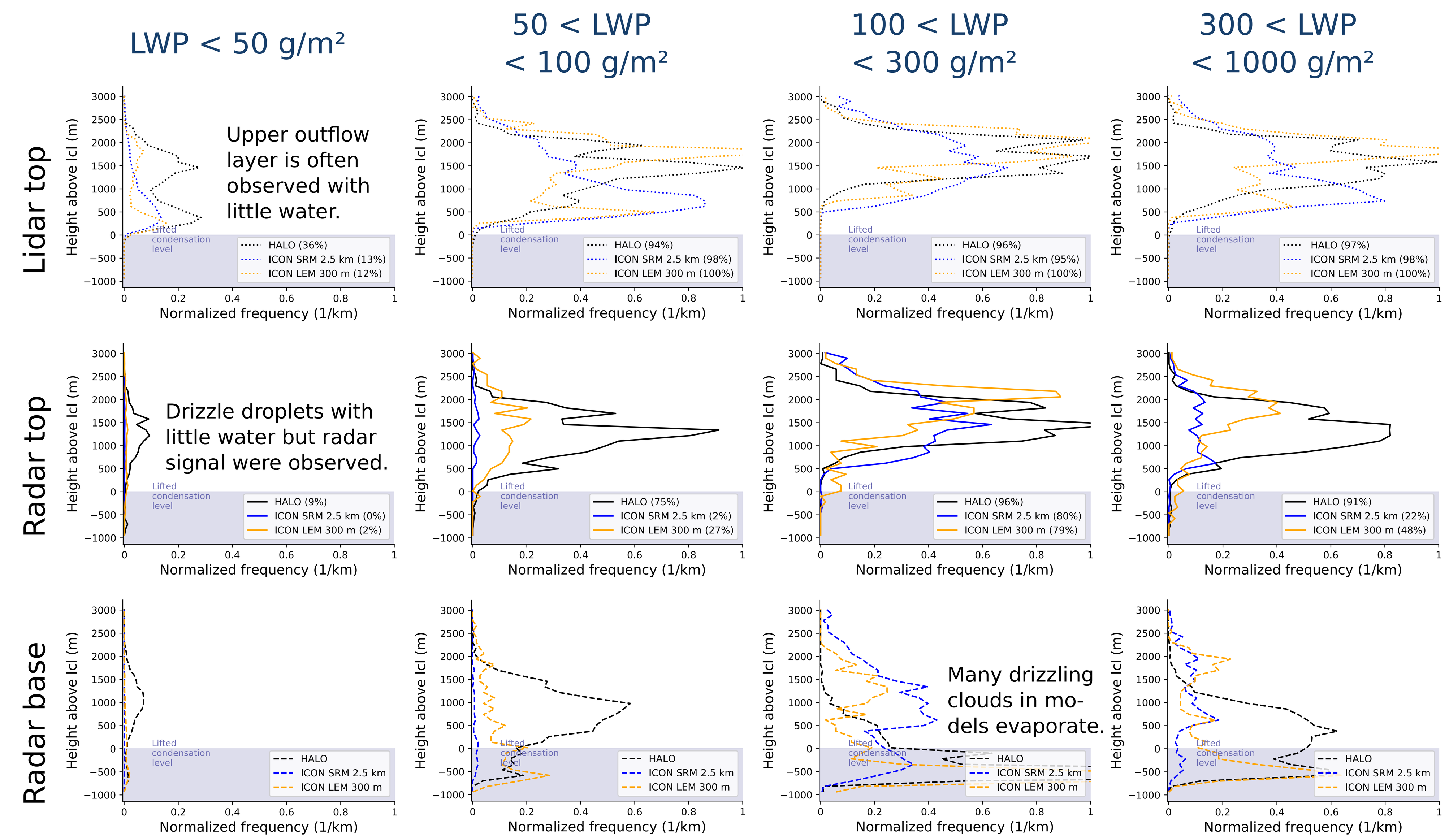

Fig. 6: Cloud boundaries classified by liquid water path (LWP) in observations and forward simulated radar and lidar signals.

5 Benefit of forward simulations

CR-SIM (lidar) and PAMTRA (radar) simulate the observable signals from drop size distributions of cloud and rain water given by both ICON 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.

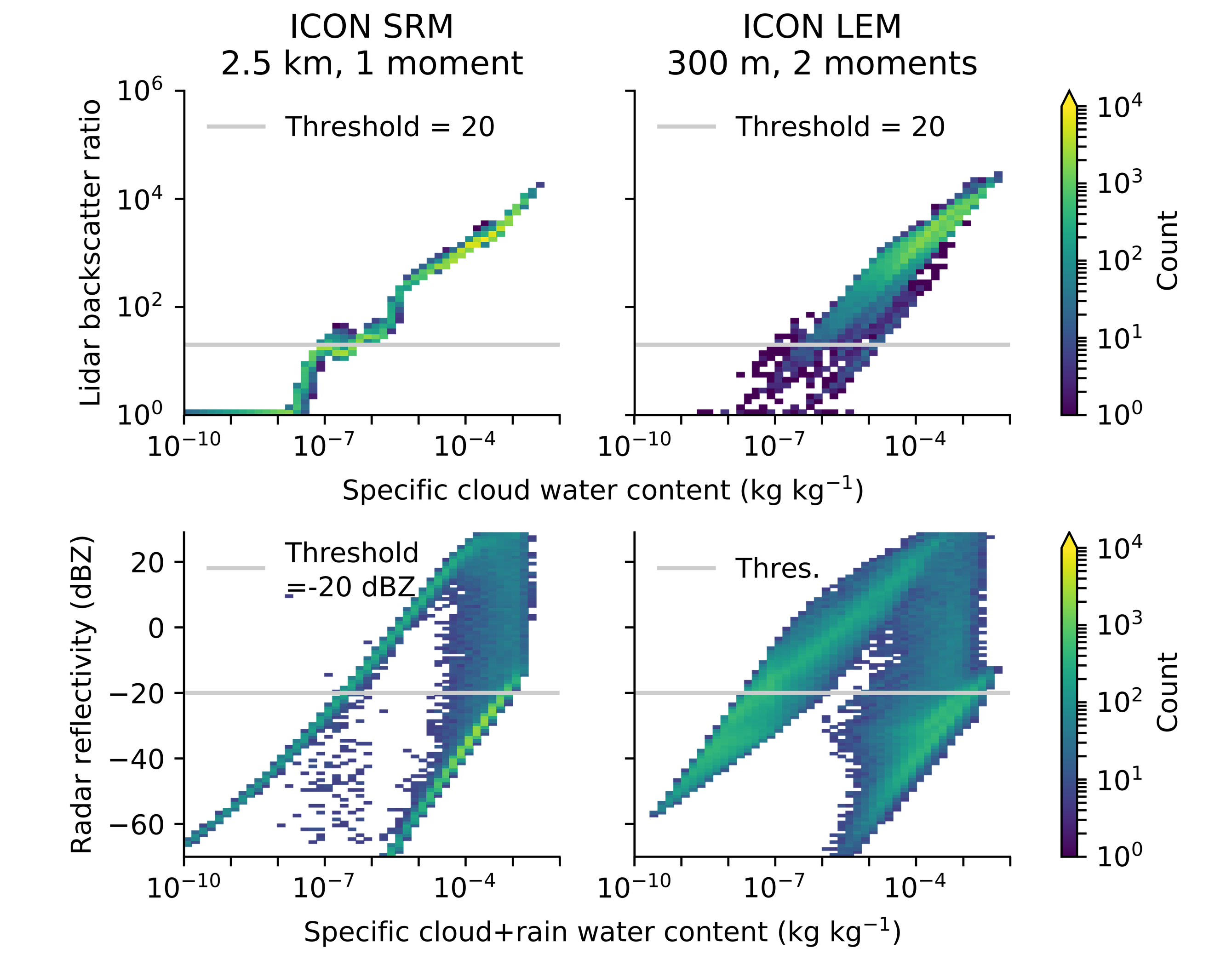

Fig. 7: Simulated lidar and radar signals as function of hydrometeor contents.

6 Conclusions and outlook

- Lidar and radar forward allow to impose instrumental thresholds to model data.
- Connection with retrieved LWP helps to understand differences between models and observations.
- Comparison reveals lack in outflow layer in SRM and general overestimation of precipitation evaporation in models.

Fig. 8: Looking forward for ...

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 grant CR111/10-11.
- 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.

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

marek.jacob@uni-koeln.de