Airborne remote sensing observations of Arctic low-level clouds and precipitation during cold air outbreaks

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1. Marine cold air outbreaks (CAOs)

- cold and dry air flows from the central Arctic southward
- close to sea ice over open water, roll convection is triggered in the boundary layer
- convection forms cloud streets and transforms to cellular convection under extreme surface heat fluxes and mixed-phase processes
- understanding air-mass transformation is crucial for weather and climate models
- however, only few observations of macro- and microphysical cloud properties exist especially near the sea ice edge, i.e. the initial state of cloud formation

2. Data and Methods

- **What** airborne data from the research aircraft Polar 5 (P5) and HALO
- **Where** 01.04.2022 during the HALO-(AC)3 campaign (Wendisch et al., 2023; Fig. 1)
- **Instruments** clouds and precipitation: Microwave Radar/radiometer for Arctic Clouds (MiRAC; Mech et al., 2019) operating at 94 GHz; thermodynamics: dropsondes
- **Method**

  lagrangian back trajectories over previous 12 hours
    - input: ERA5 wind fields
    - origin: horizontal location of P5 at 1000 hPa height for every minute
    - model: Lagranto (Sprenger and Wernli, 2015)

  convection categories: over sea ice, sharp and fluffy cloud streets, advected over land

  cloud objects derived from cloud top height
- **Parameter** integrated distance over open ocean (fetch) that is weighted by AMSR2 sea ice concentration (Melsheimer and Spreen, 2019) as a proxy for the influence of the open ocean

During CAOs, distance over open water determines atmospheric boundary layer transformation, formation of cloud streets, their morphology, microphysics and precipitation.

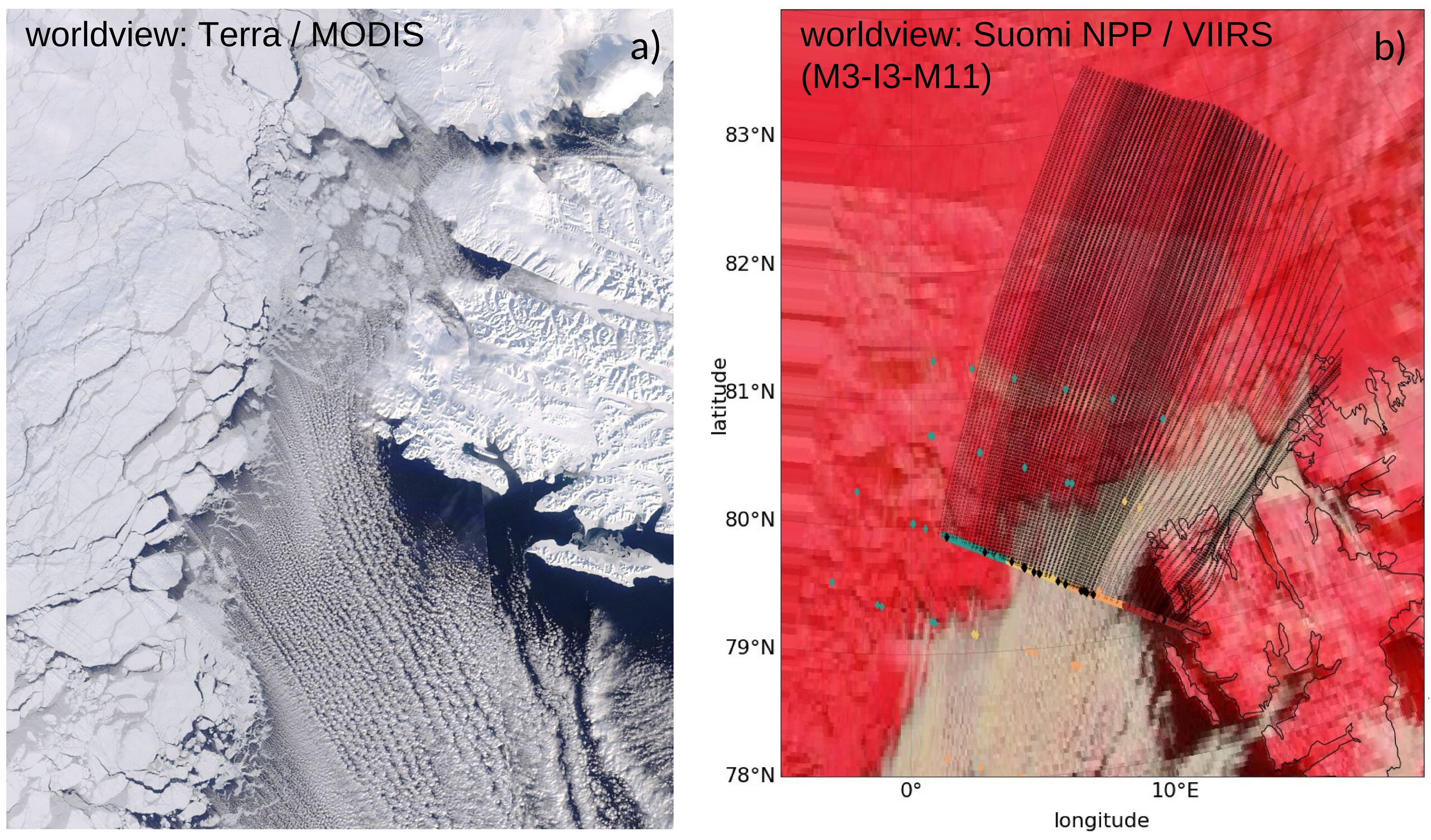

Fig. 1: Cloud conditions on 01.04.2022 (a). P5 flight track (circles), dropsondes (diamonds; color: HALO; black: P5) and calculated air mass trajectories (black lines; b).

3. Results

thermodynamic profiles

with increasing fetch, mixing ratio and wind speed within the boundary layer, and boundary layer height increase (Fig. 2)

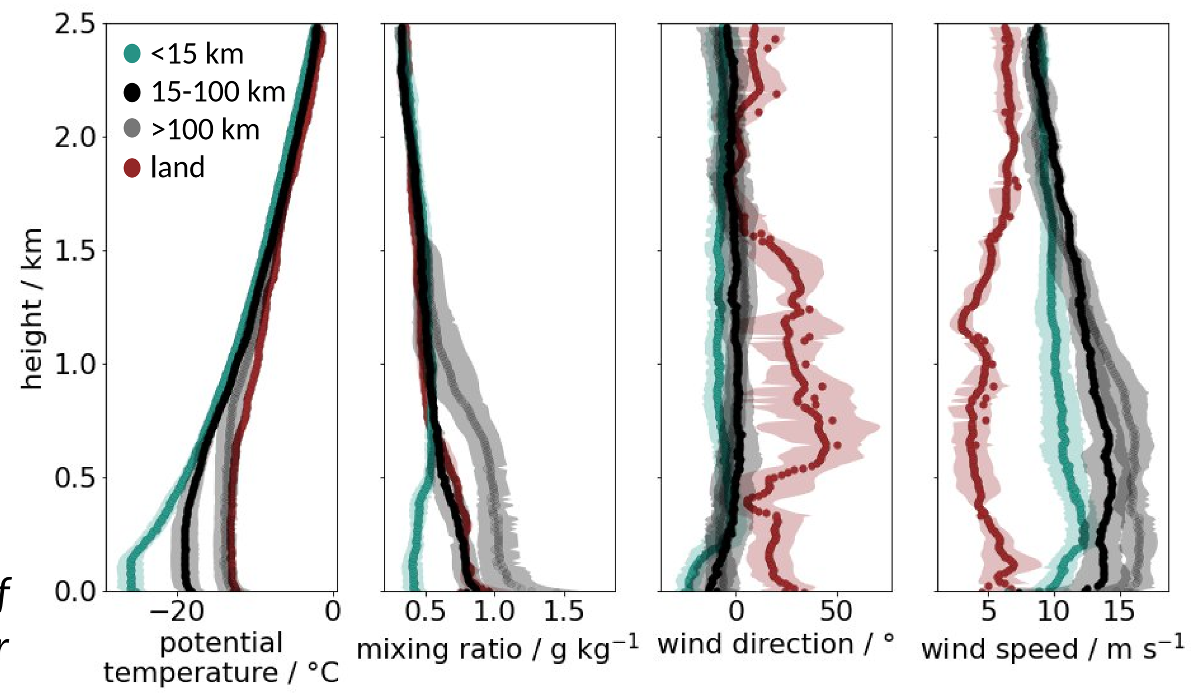

Fig. 2: Dropsonde profiles of HALO and P5 averaged over several fetch bins. Fetch increases with green, black, gray.

cloud macrophysics and precipitation

- cloud width does not depend on fetch (Fig. 3a)
- bimodal distribution of maximum cloud top height (cth) for sharp cloud streets (Fig. 3b): low cth -> non-precipitating clouds (Fig. 4a)
- precipitation occurs at minimum 25 km fetch
- fluffy cloud streets (more marginal sea ice) have larger spread in cth (Fig. 4a, b)
- cth increases with fetch, even stronger for precipitating clouds (Fig. 4b)
- number of cloud free areas decreases with fetch
- aspect ratio of circulation increases with fetch (Fig. 4c)
- mean aspect ratio of circulation is 2.1

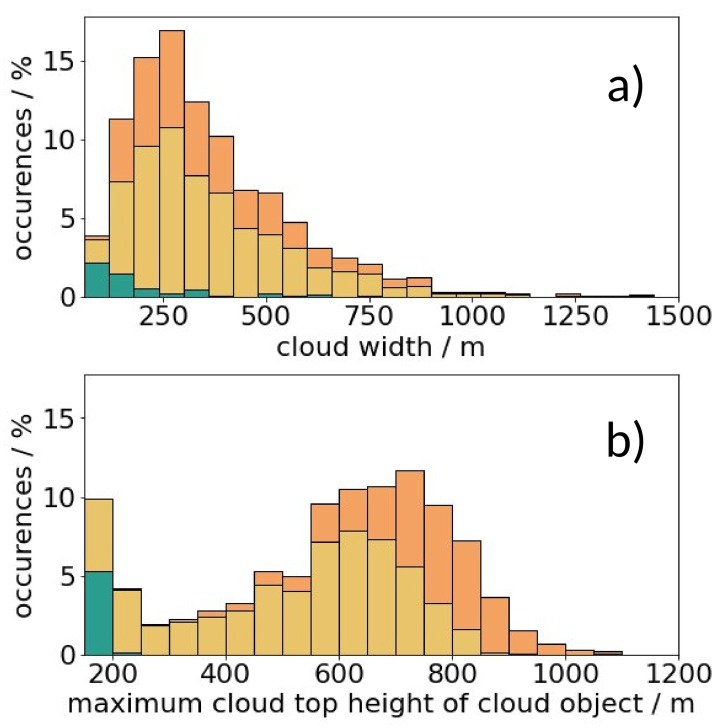

Fig. 3: Histogram of relative occurrence for cloud width (a) and maximal cloud top height (b) over all cloud objects.

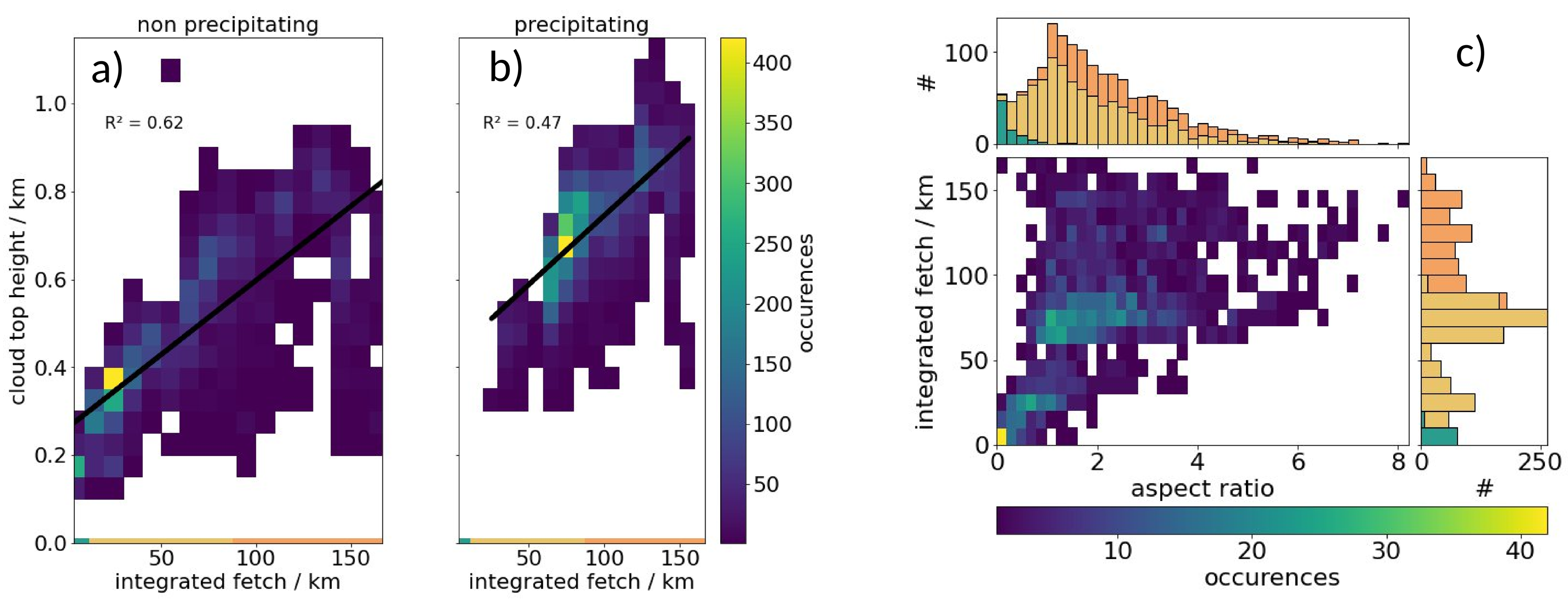

Fig. 4: Cloud top height per profile with fetch for non-precipitating (a) and precipitating (b) clouds. Aspect ratio of the circulation for each cloud object with fetch (c).

cloud microphysics

- over sea ice Ze_{mean} per profile is generally lowest (-20 dBZ; Fig. 5a)
- such low Ze_{mean} occur even for larger fetches
- Ze_{mean} increases with cth: rate is constant within cloud street categories, but even though fluffy clouds have higher cth, Ze_{mean} distribution is similar (Fig. 5a)
- normalized vertical Ze_{max} position within the cloud (including precipitation) is mainly around 0.5 (Fig. 5b)
- for some non-precipitating clouds Ze_{max} is at cloud top (Fig. 5b)
- for precipitating clouds sublimation is visible (Fig. 5b)

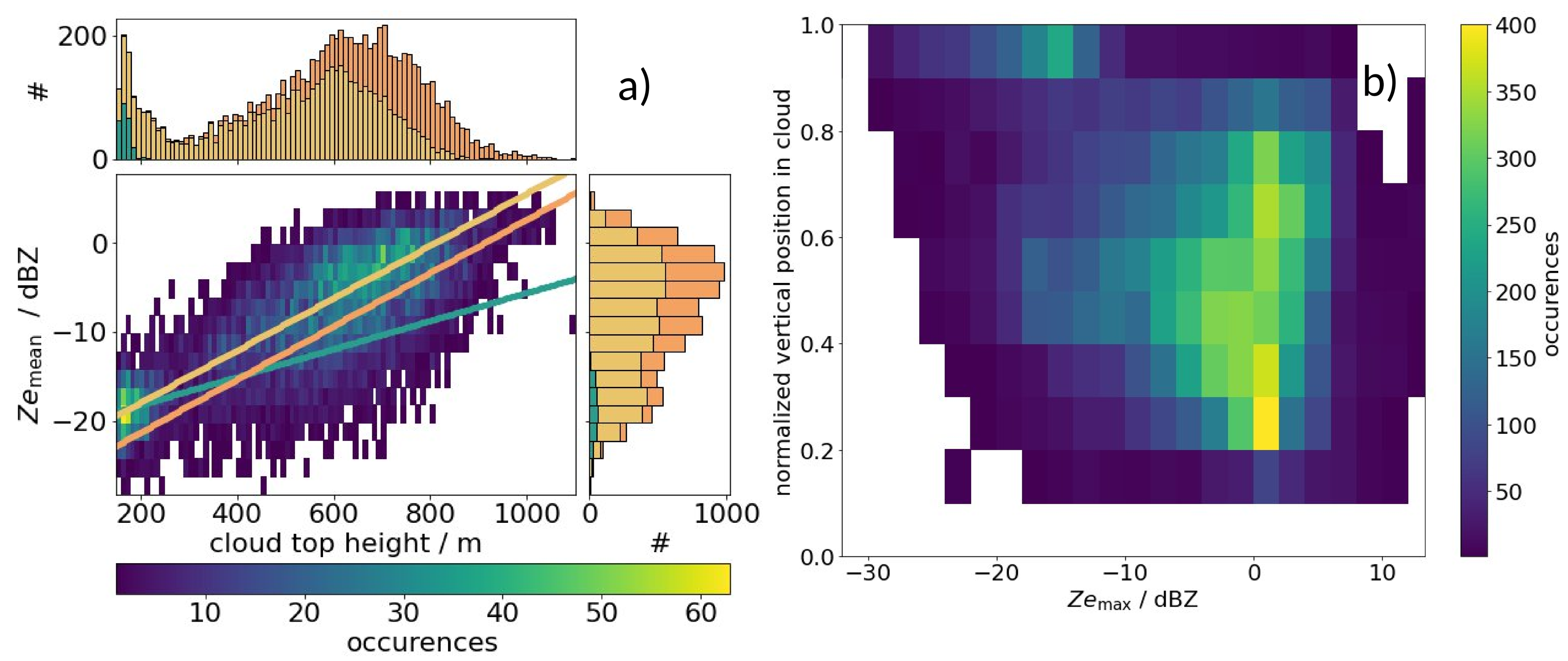

Fig. 5: Cloud top height per profile against mean radar reflectivity (Ze; a). Maximum Ze per profile against the normalized vertical position inside the cloud profile (including precipitation; cloud top=1, bottom=0; b).

4. Conclusions and outlook

- analyzed CAOs with airborne radar and dropsonde data
- clear boundary layer evolution with fetch that triggers higher convection, whereas cloud width stays constant
- marginal sea ice zone influences Ze_{mean}

- determination of cloud morphology by *Ze*
- expand microphysical investigation: effective radius, liquid water path, and evolution of riming

Literature

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