CHARACTERISATION OF ARCTIC CIRRUS BY AIRBORNE WATER VAPOR AND HIGH SPECTRAL RESOLUTION LIDAR

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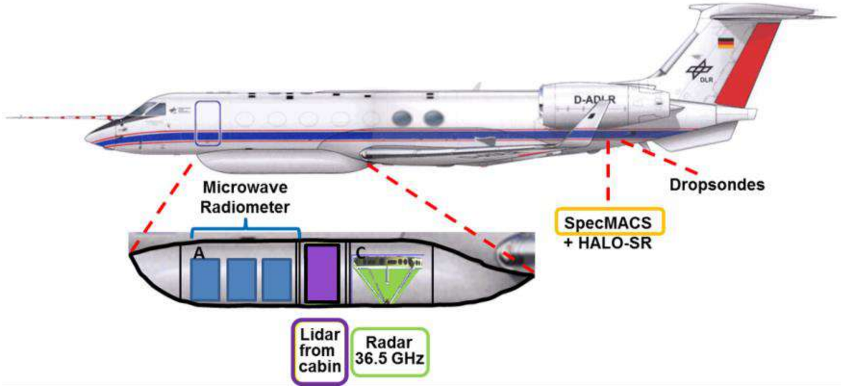
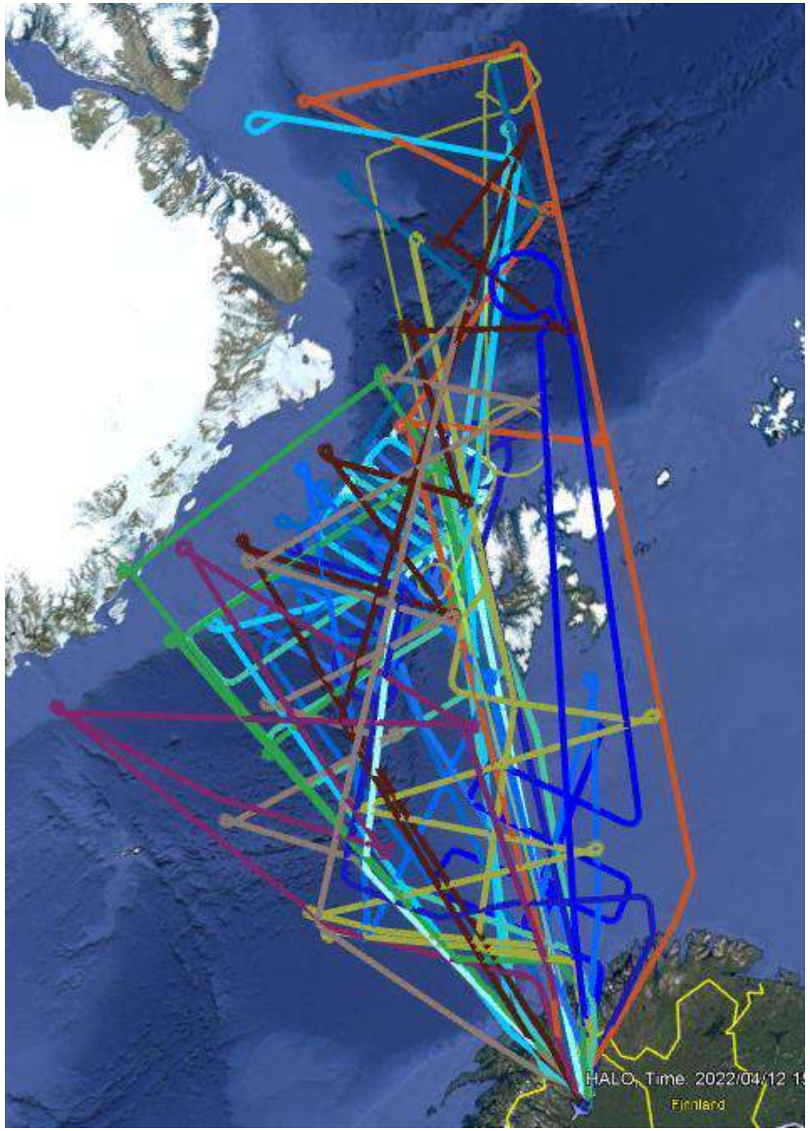
Ice Clouds in the Arctic

- Ice clouds in the Arctic have different radiative impact compared to Mid-Latitudes
  - T, q and aerosol profiles are different, resulting in different number concentration, size and shape distributions
  - Sign of net radiative impact depend on details
- In a changing climate warm air intrusions are expected to be more frequent, which may also change the radiative impact of ice clouds in high latitudes
- Ice cloud observations have to be classified according to the background atmospheric state, the formation mechanism and the state of the cloud within its life-cycle
- RH_{ice} is one key parameter, but difficult to measure by remote sensing

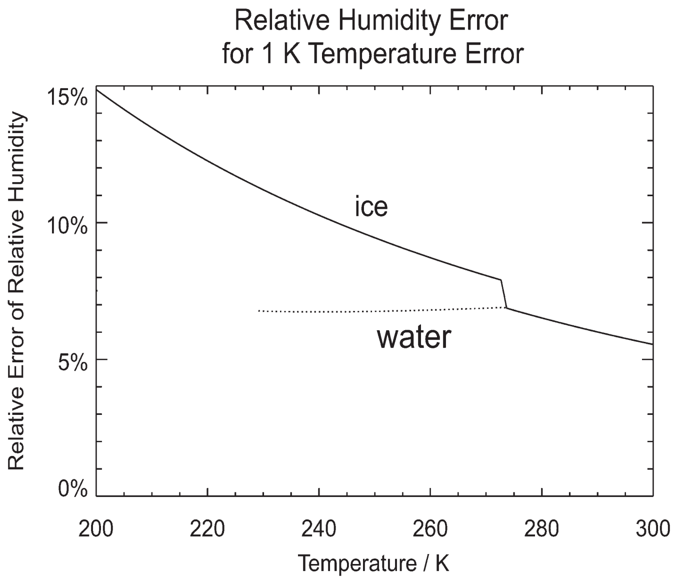
HALO-(AC)³ Airborne Campaign

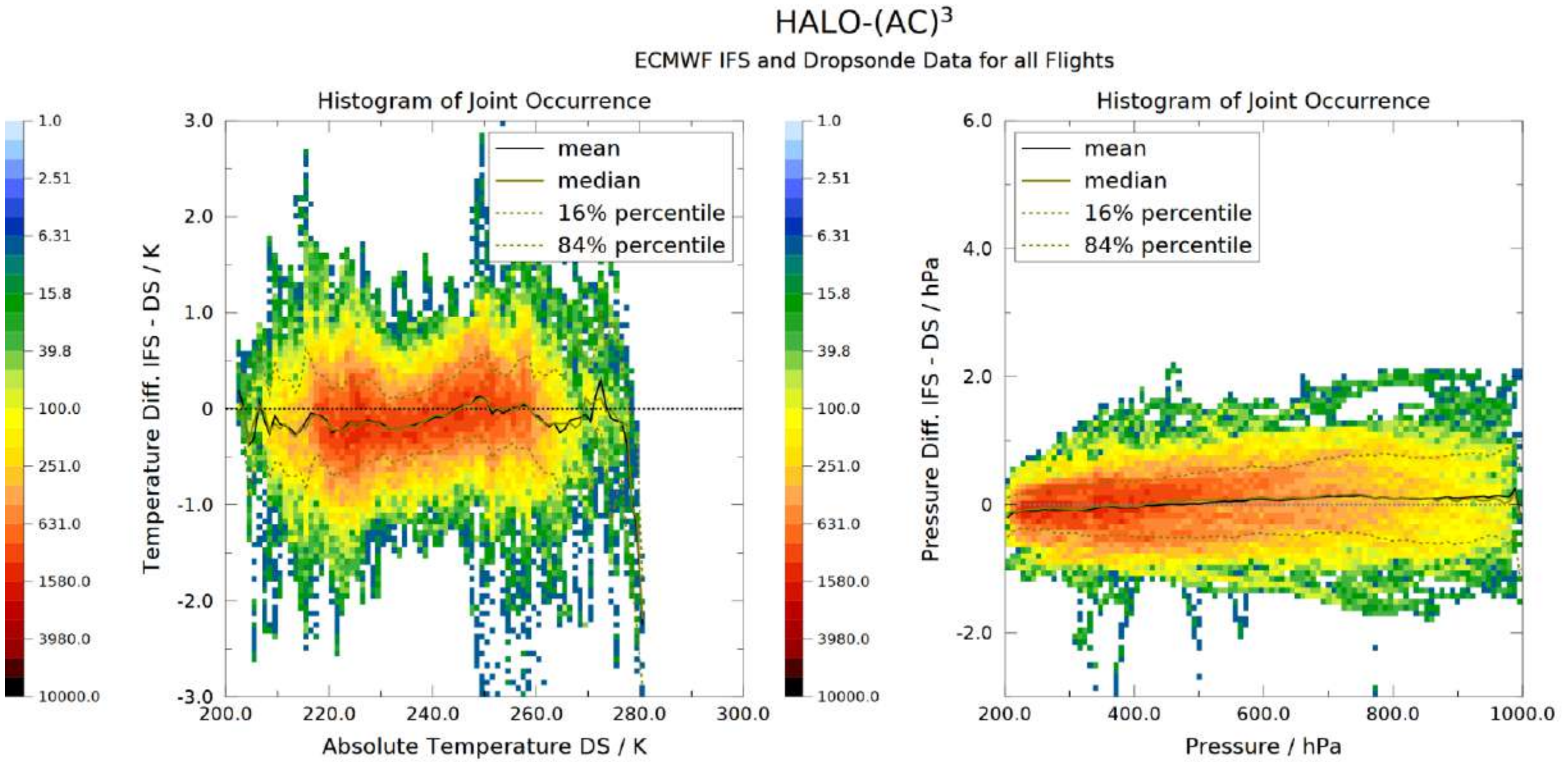
- Field experiment in March/April 2022 out of Kiruna northern Sweden
- Deployment of the German Research Aircraft HALO with a remote sensing payload: H_2O-DIAL/HSRL, Cloud Radar, Microwave Radiometers, Passive imaging and integration radiation measurements in various spectral bands and a drop-sonde system
- A total of 19 research flights over the sea between Svalbard and Greenland and up to nearly 90°N





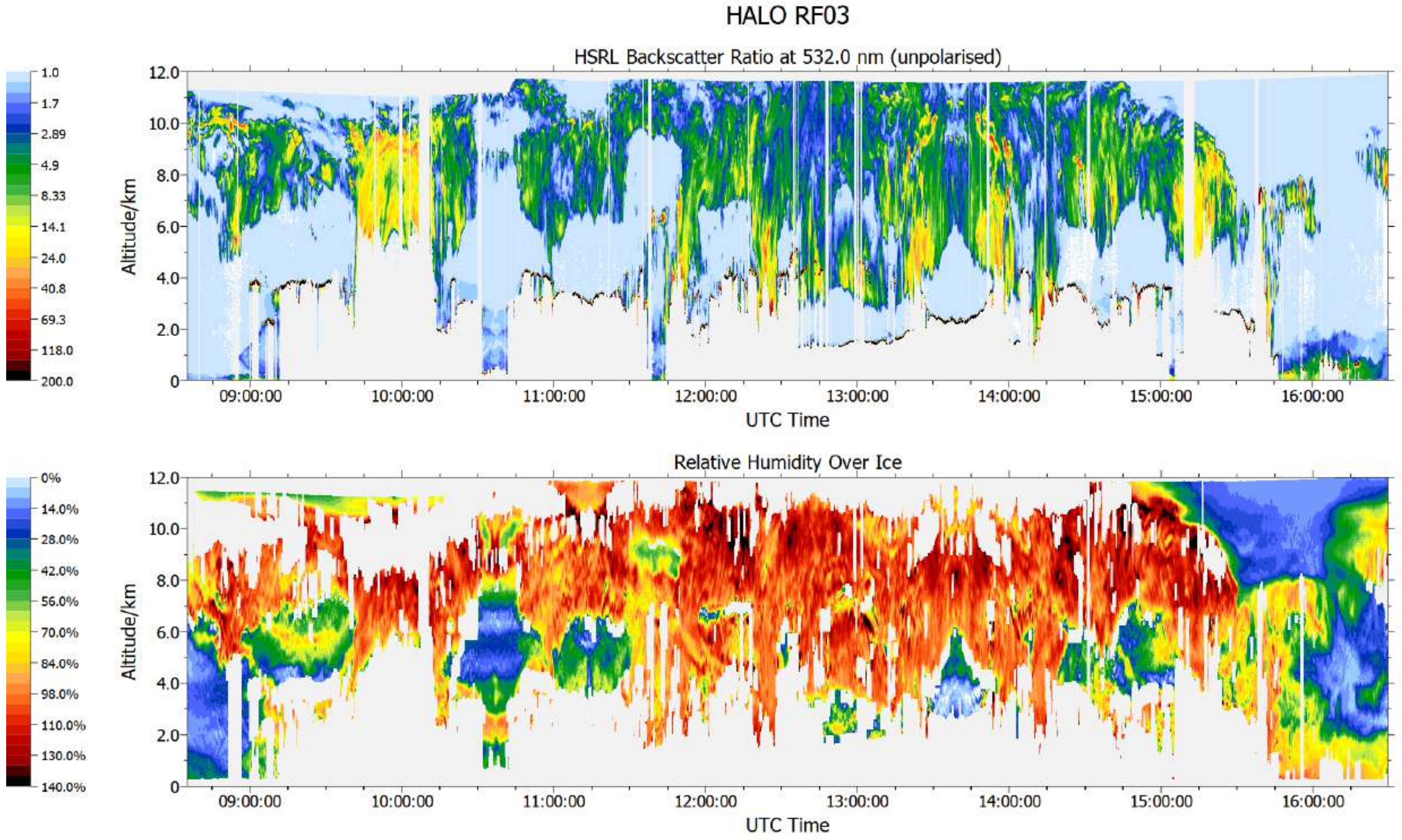
Determination of Relative Humidity from DIAL Measurements of q and Model Data of T

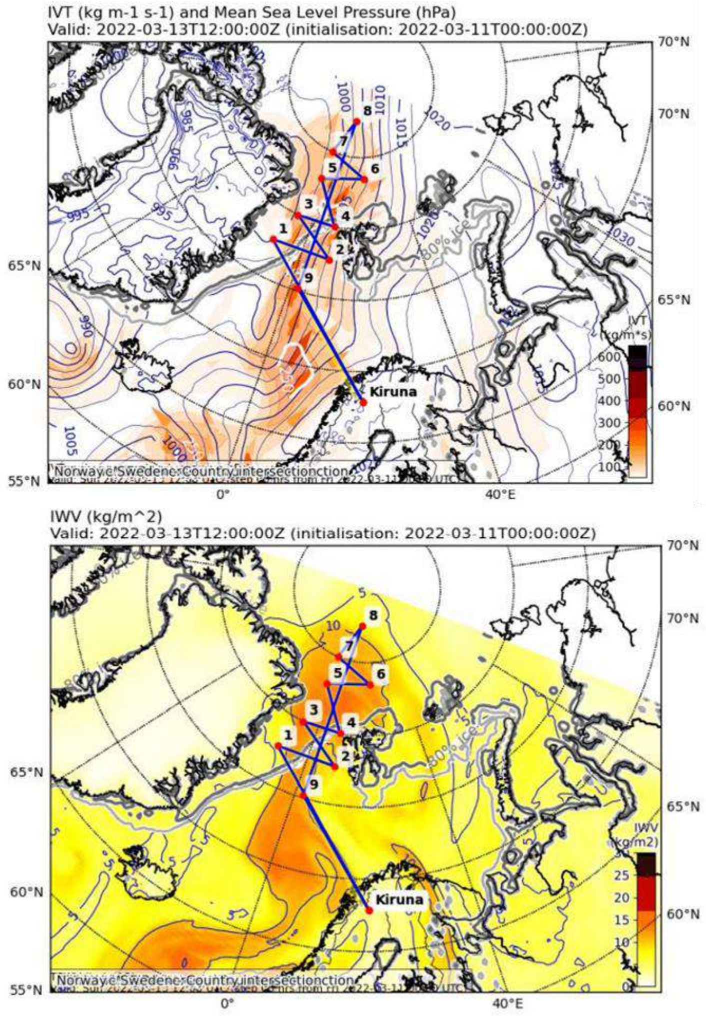




- From comparison with **339** dropsondes: T-bias ≈ 0.2 K, precision ≈ 0.4 K
- Translates to a T-induced RH_{ice} error of: 2% bias and 4% precision
- No relevant bias in pressure (important for correct geometrical altitude assignment)

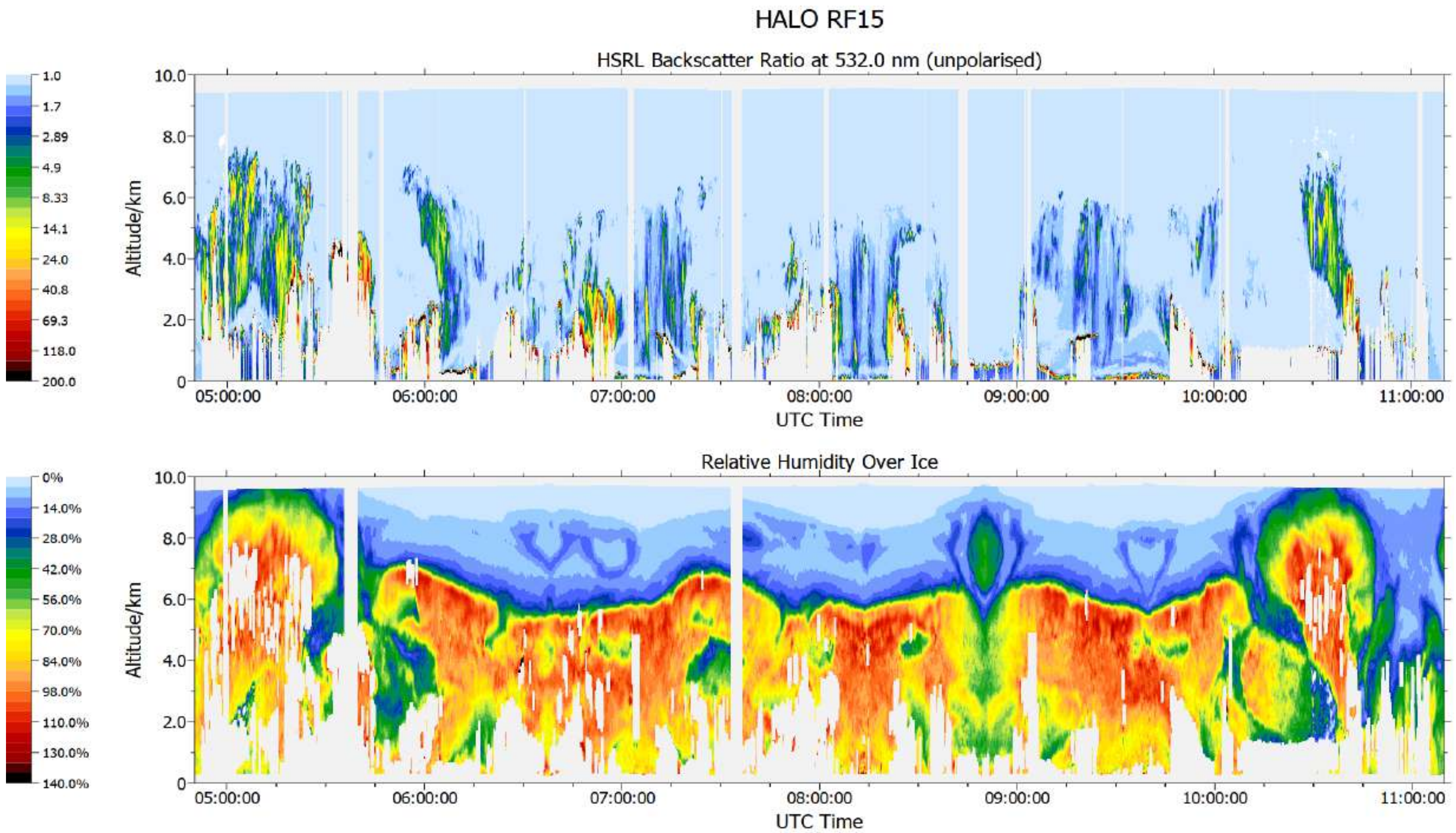
HALO-(AC)[3] RF03 13.03.2022: Warm Air Intrusion

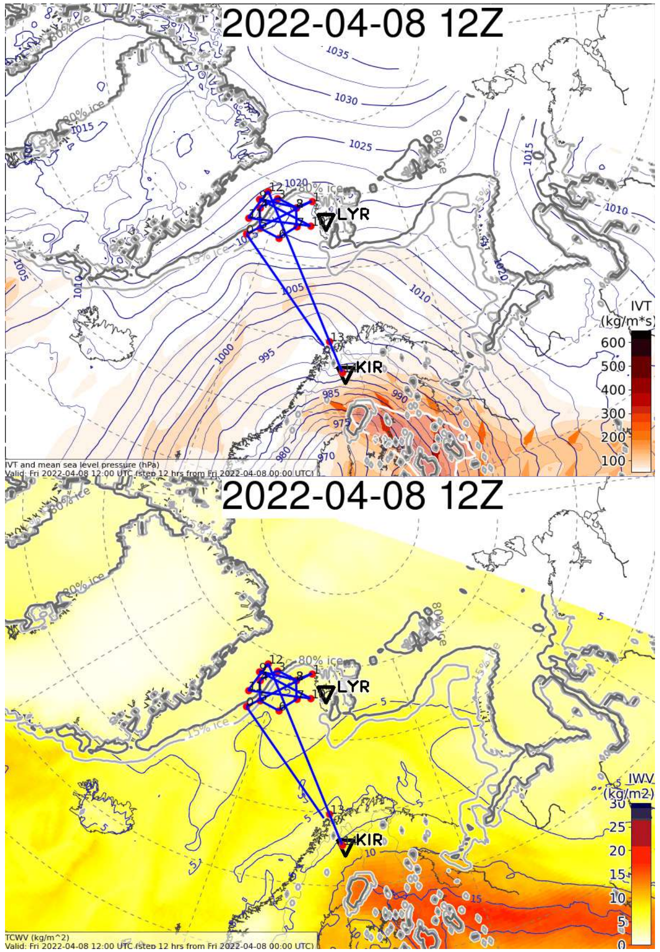




- Strong intrusion of warm and moist mid-latitude air up to the pole
- Cloud tops reach 12 km altitude (4 km more than typical)
- Cirrus is strongly structured with imbedded regions of high super-saturation (> 140%)

HALO-(AC)³ RF15 08.04.2022: Arctic Origin Cirrus

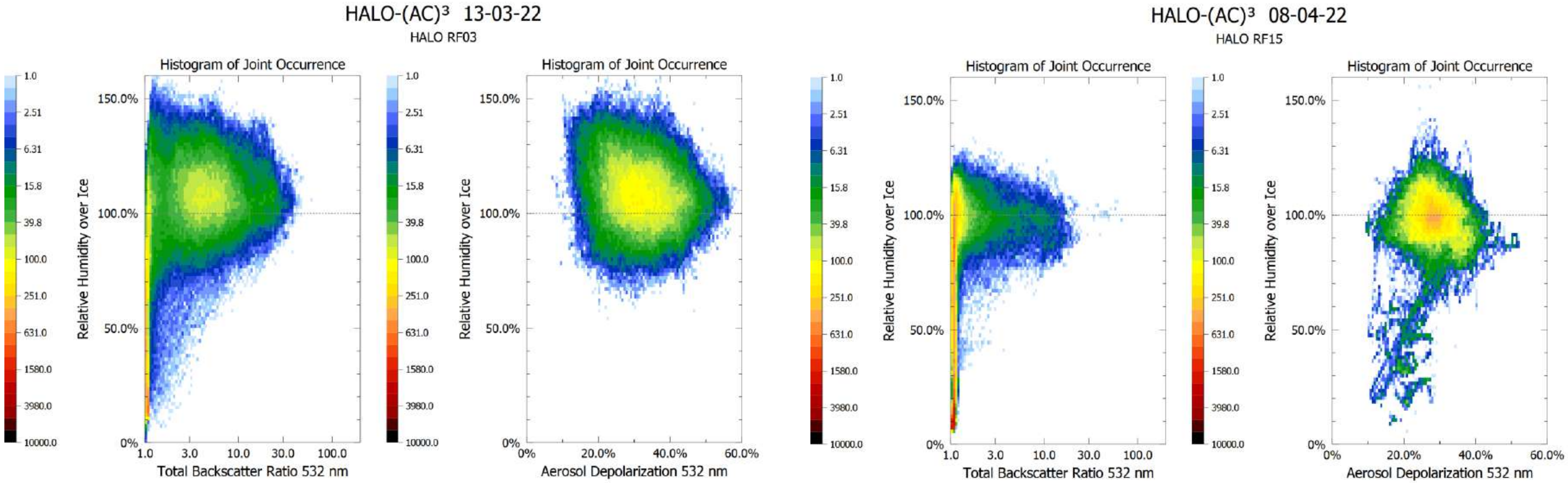




- Cloud tops only up to 6-7 km. Low optical thickness of cirrus part
- Very smooth RHi-field with only moderate supersaturation

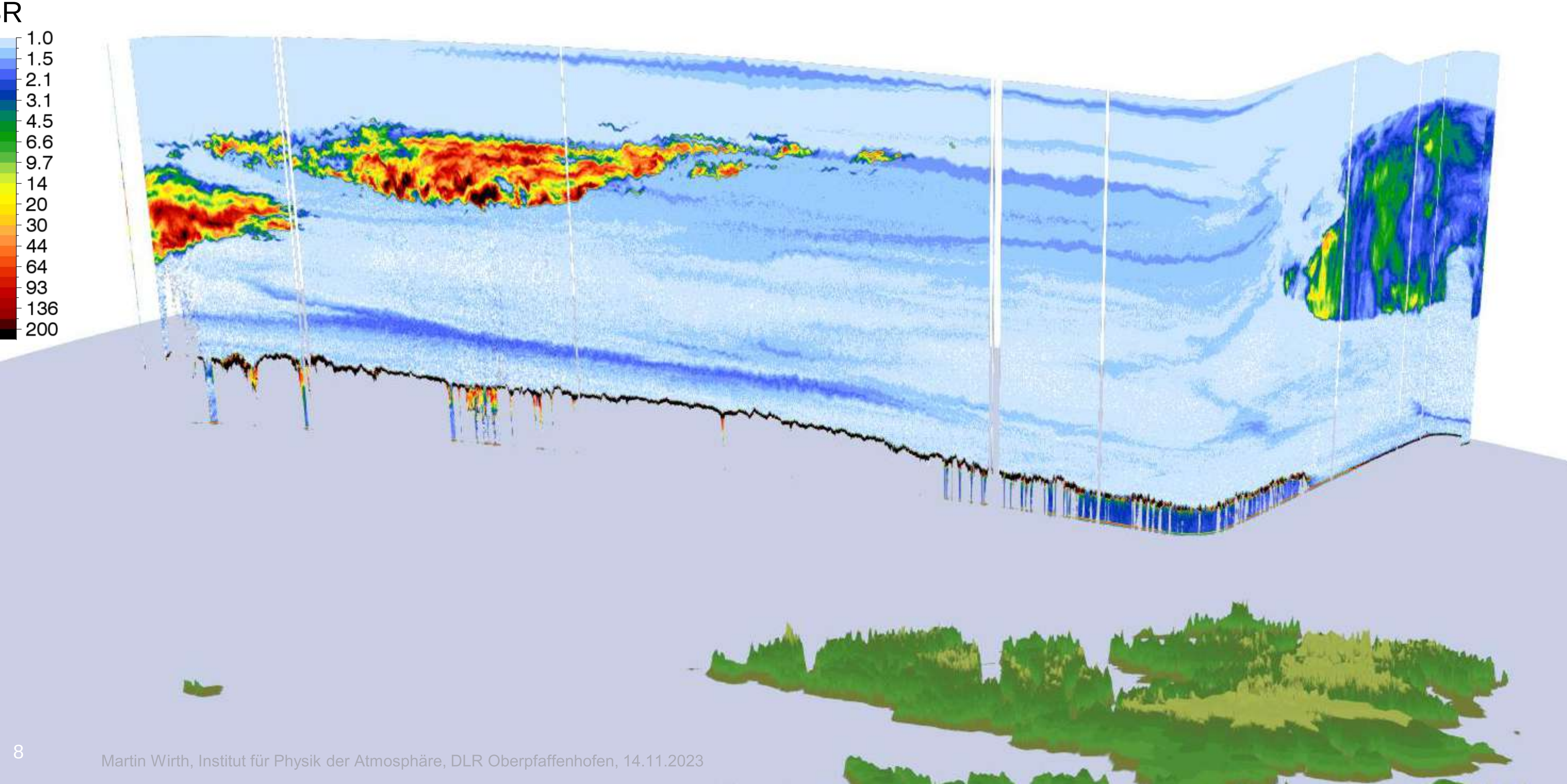
HALO-(AC)³: Warm Air Intrusion vs. Arctic Origin

RF03 compared to RF15

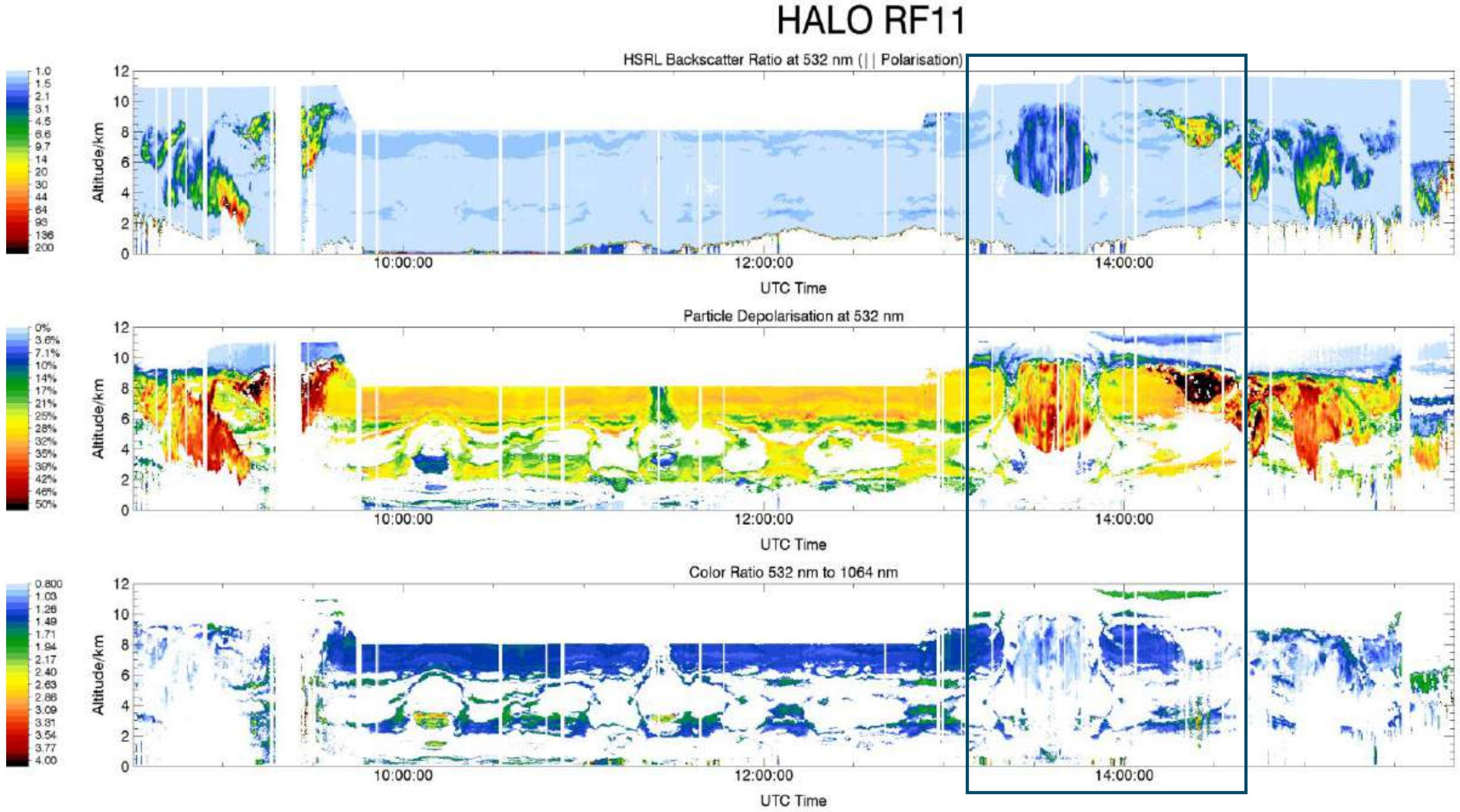


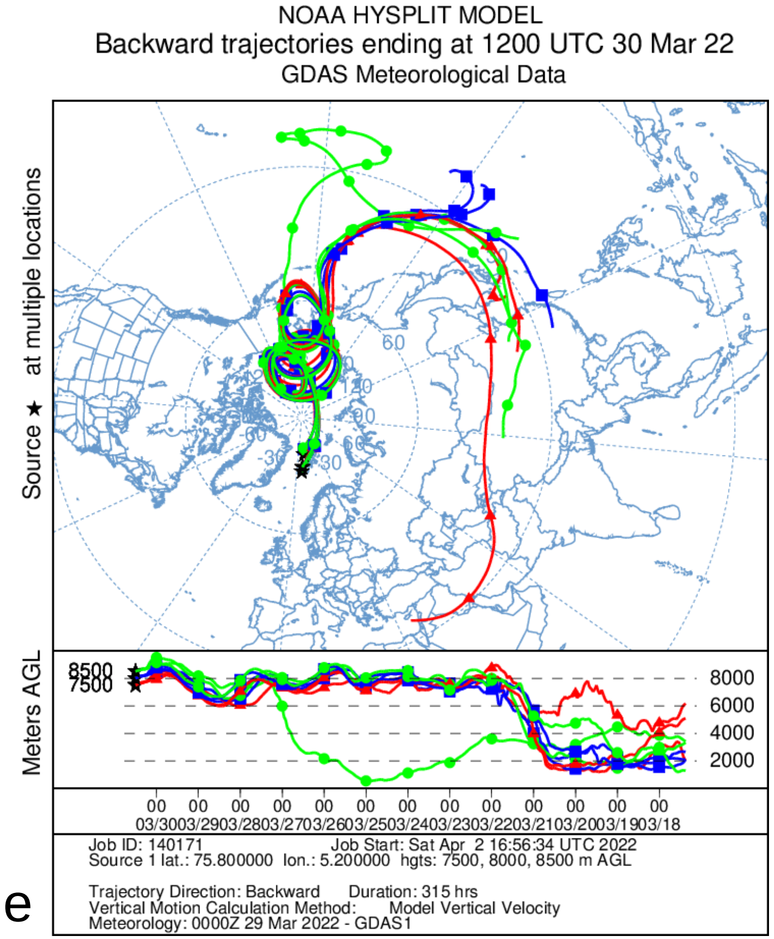
- Higher backscatter and depolarization ratios in the intrusion case (more available H_2O → larger crystals)
- Significantly higher super-saturations in the intrusion (freshly formed cirrus ↔ aged clouds?)

Mixed Scene Case on 30. March 2022…



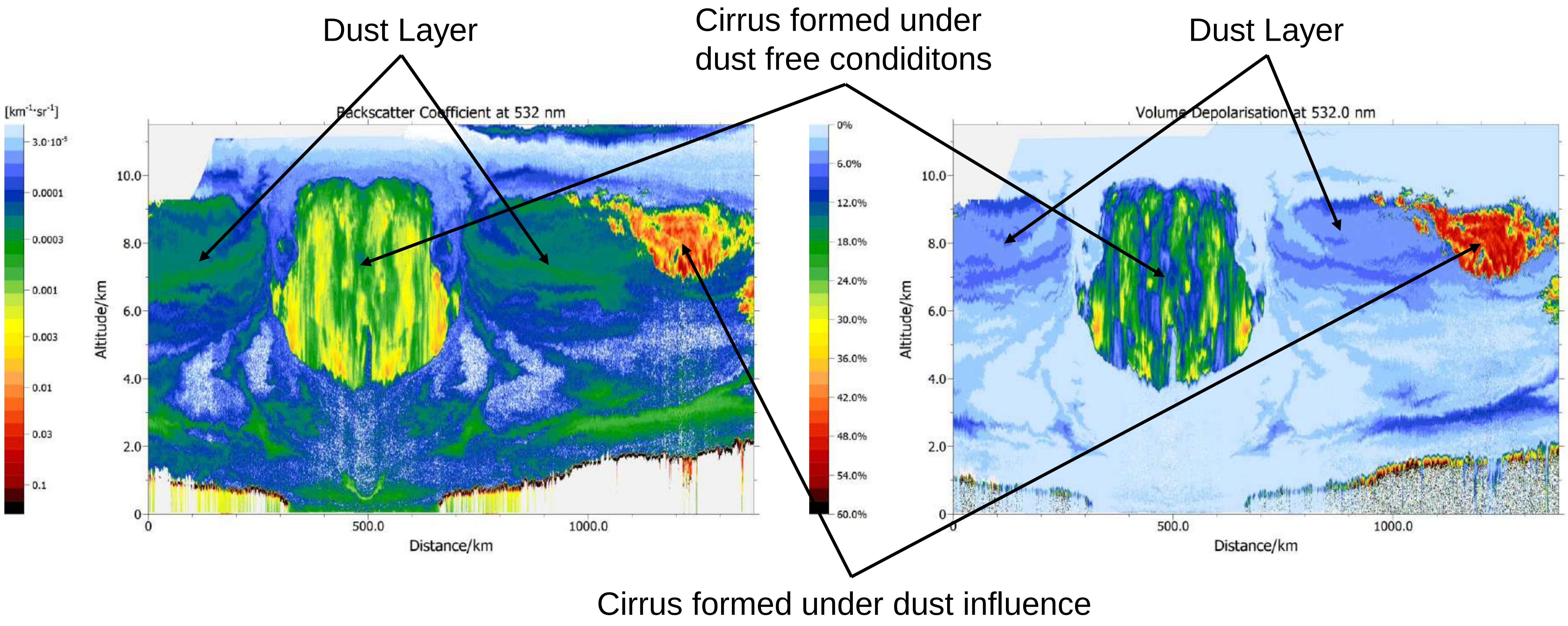
HALO-(AC)³ RF11 30.03.2022: Aerosol Trapped in the Arctic





- Airborne Lidar shows extend aerosol layer between 6-8 km altitude
- Depolarization, color ratio (and lidar ratio) point to aerosols of desert dust type
- Backward trajectories link to previous strong Saharan dust outbreak

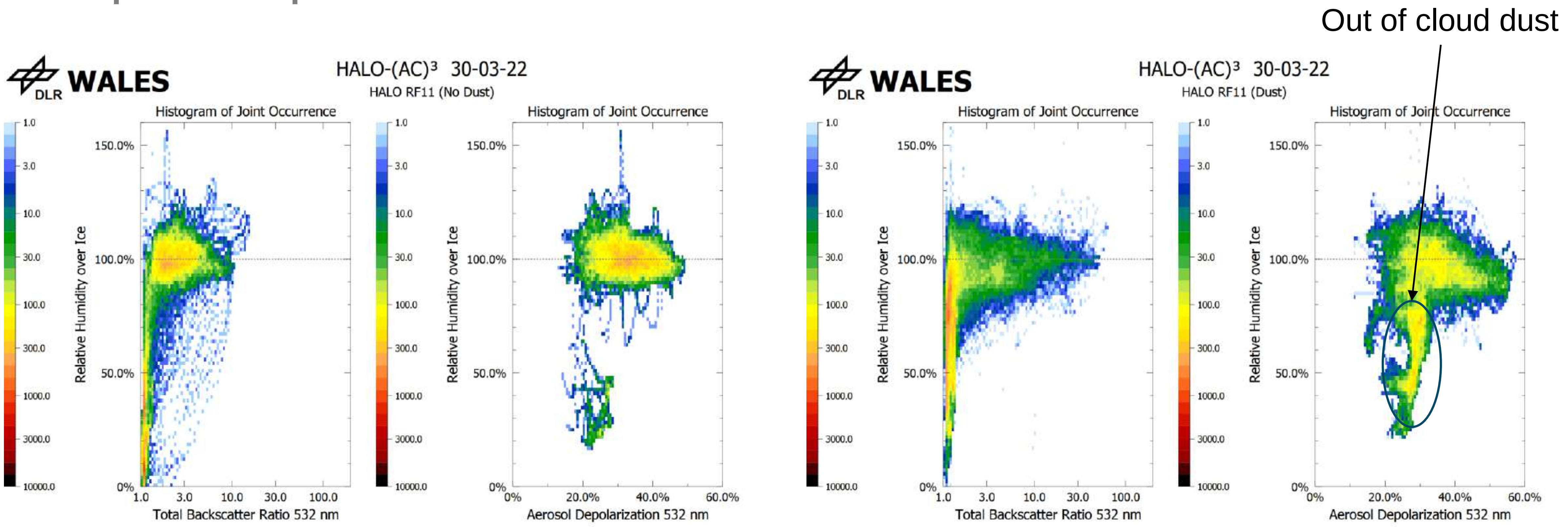
HALO-(AC)³ RF11 30.03.2022: Aerosol Trapped in the Arctic



- Ice clouds embedded in the aerosol layer show higher backscatter
- Particle depolarization has comparable median but higher peak-value for the dust-case

HALO-(AC)³ RF11 30.03.2022: Aerosol Trapped in the Arctic

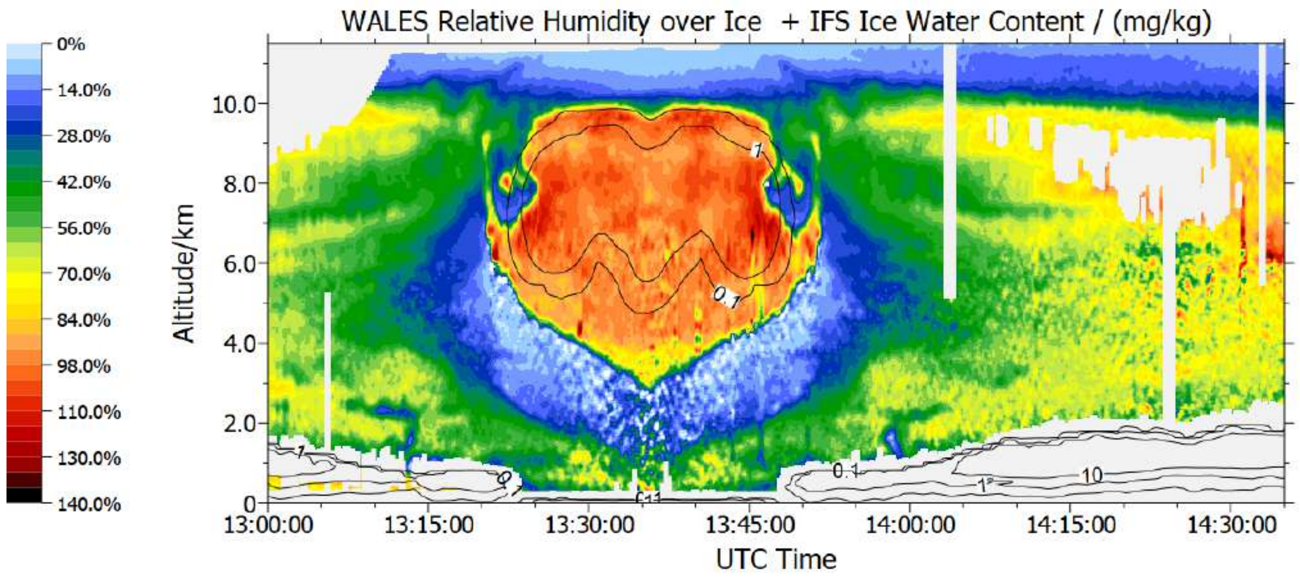
Comparison of pristine cirrus vs. dust influenced cirrus

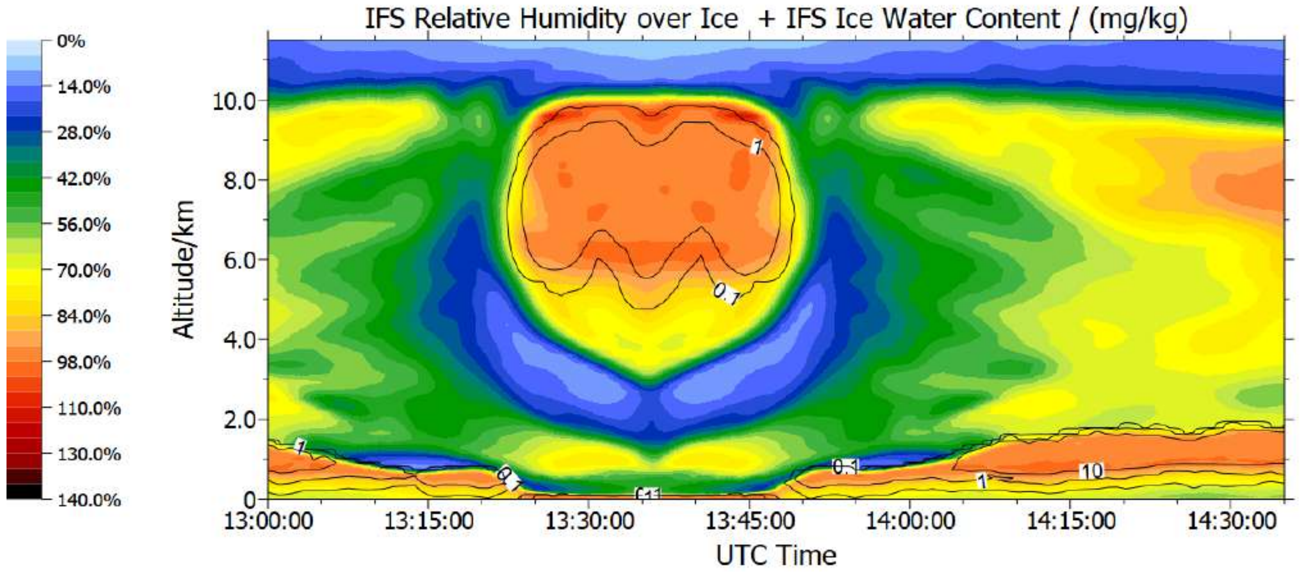


- Dust influenced cirrus shows lower supersaturations, higher backscatter and depol. ratios
- Points to domination of nucleation process by heterogenous freezing on dust particles

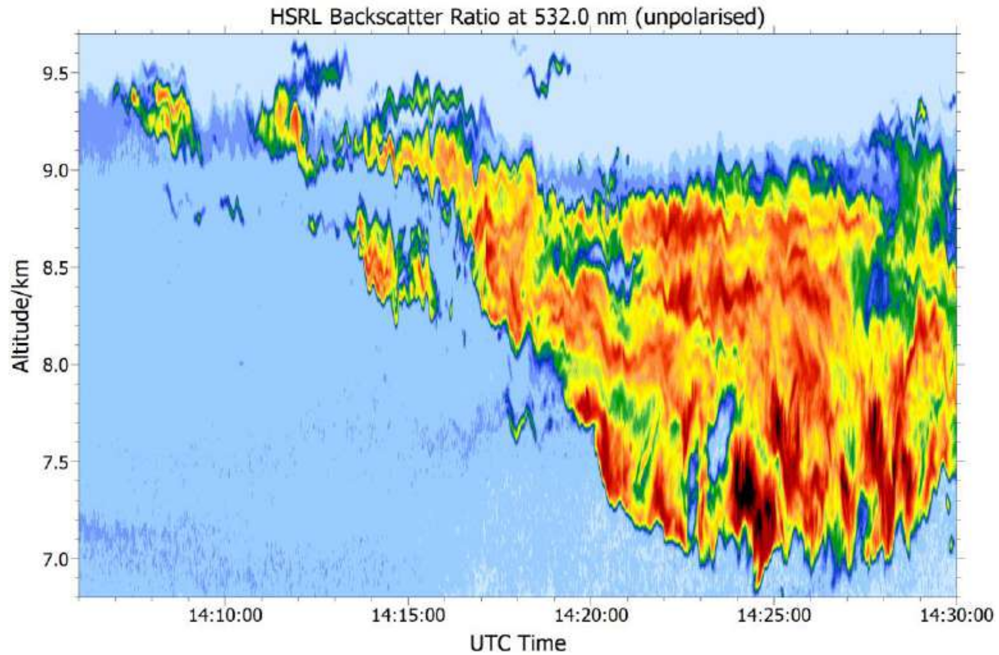
→ Fewer, but larger ice crystals show different radiative properties

HALO-(AC)^3 RF11 30.03.2022: Aerosol Trapped in the Arctic



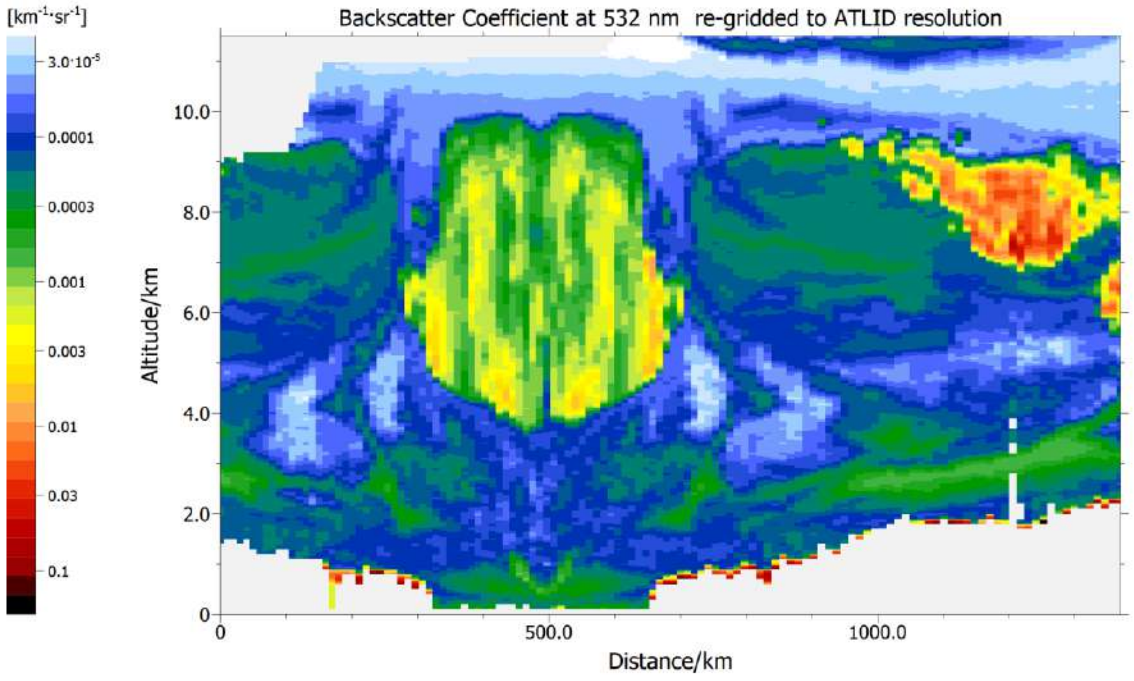


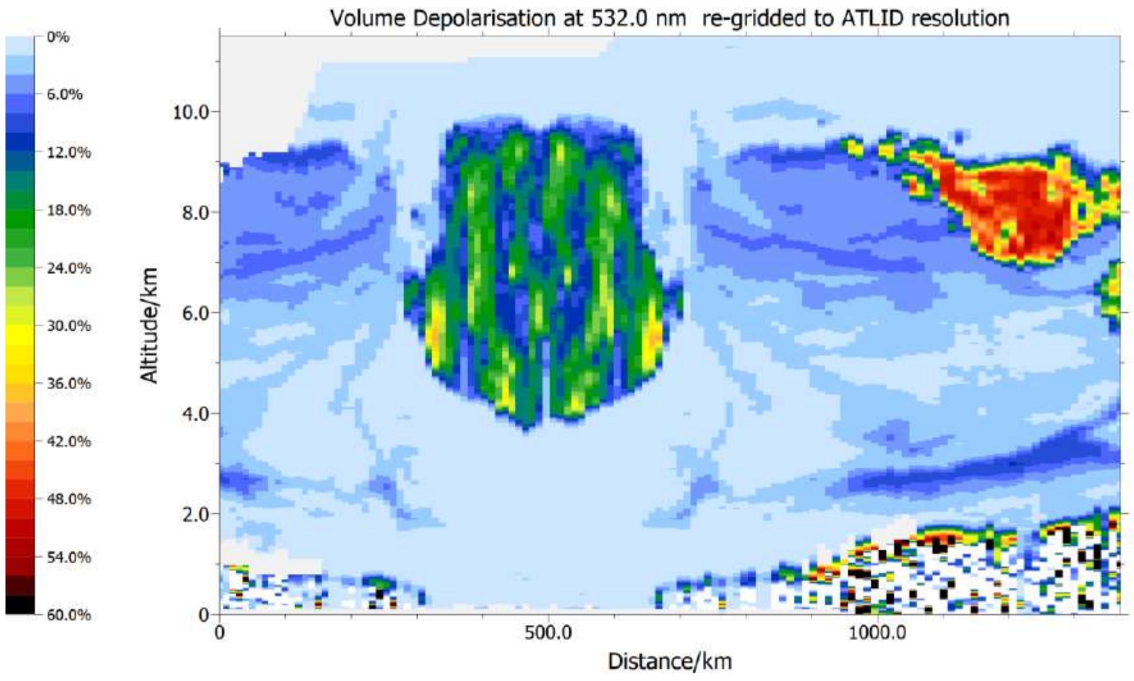
- Cirrus for *No Dust* case represented quite well in ECMWF IFS analyses
- Model RHi for *Dust Case* is slightly lower which seems to suppress cloud formation in the model
- Missing Elements could be: heterogenous nucleation on dust particles and/or subscale T fluctuations (e.g. in gravity waves)



HALO-(AC)^3 RF11 30.03.2022: Aerosol Trapped in the Arctic

What would see ATLID?





- Vertical resolution set to 100 m
- Horizontal resolution set to 10 km (1.4 s integration) for S/N reasons

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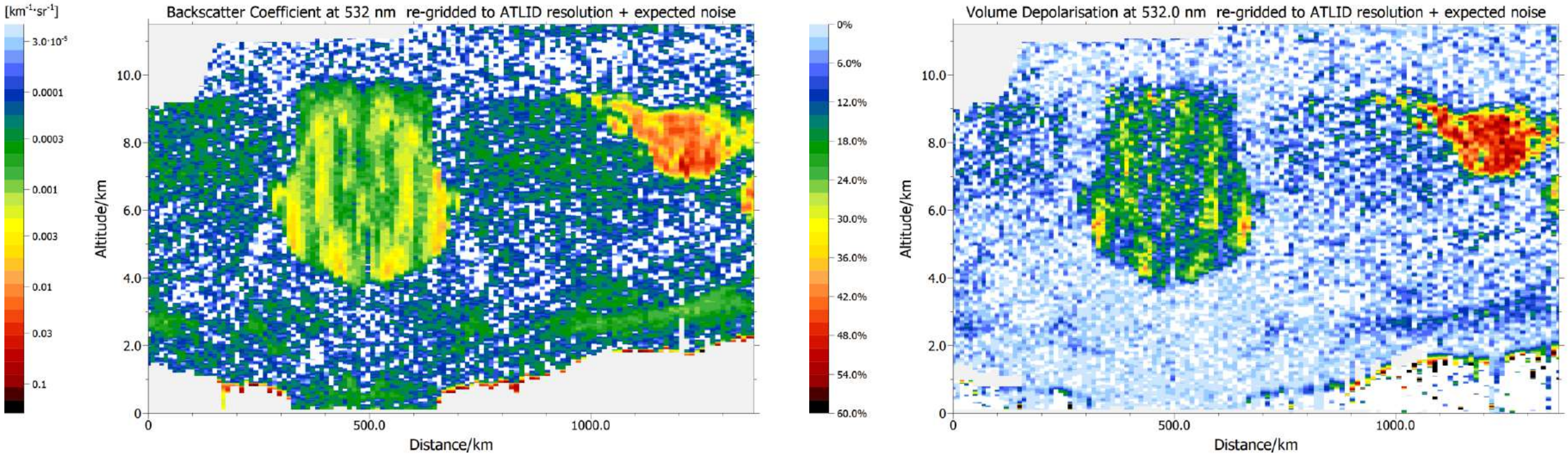
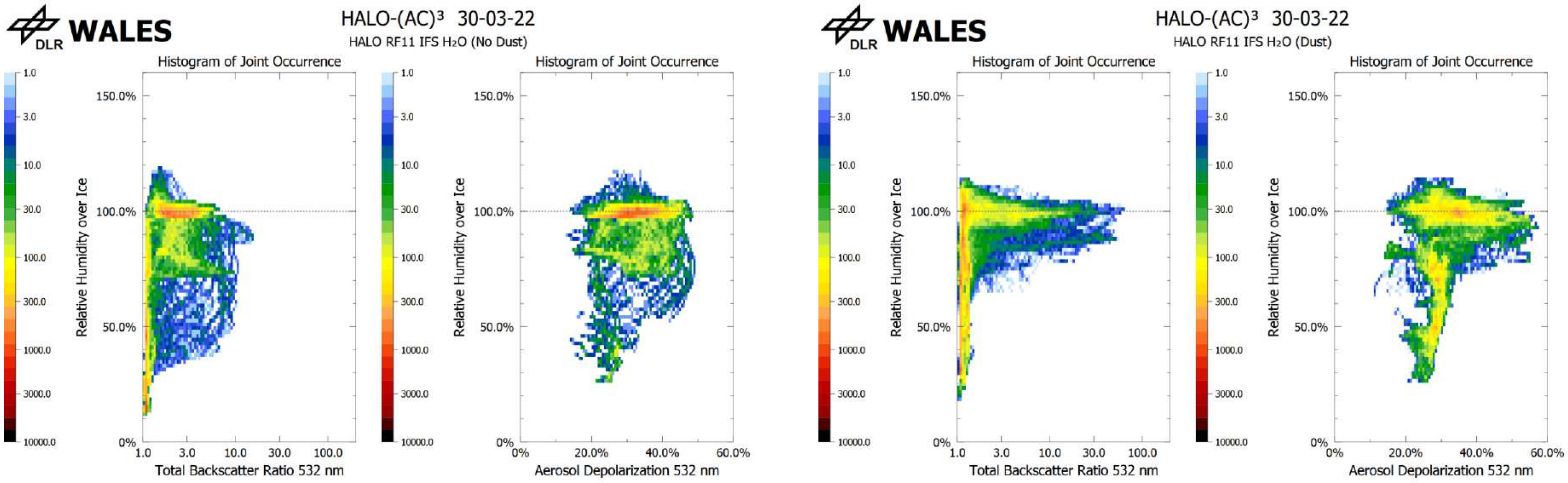
What would see ATLID?



- Noise data from ATLID ground validation
  (Pereira do Carmo et al. https://doi.org/10.3390/atmos12010076)
- Equivalent noise level for 532 nm applied (with color ratio of 1.5 for aerosol)

HALO-(AC)³ RF11 30.03.2022: Aerosol Trapped in the Arctic

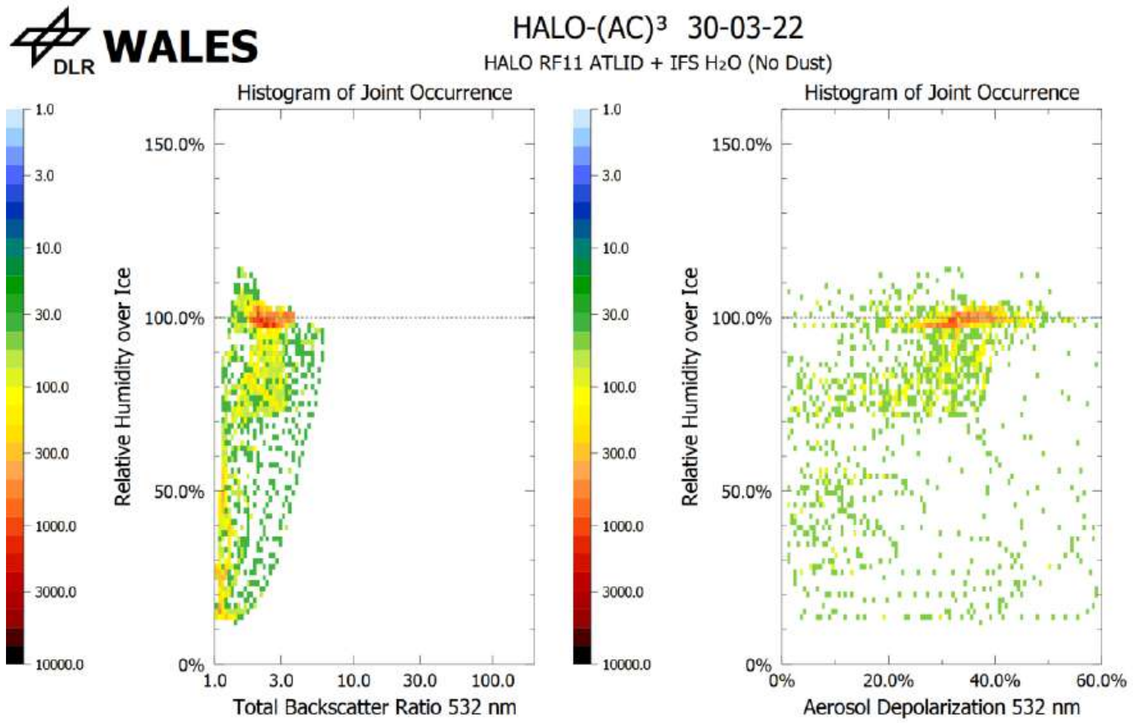
Comparison of pristine cirrus vs. dust influenced cirrus with IFS H_2O

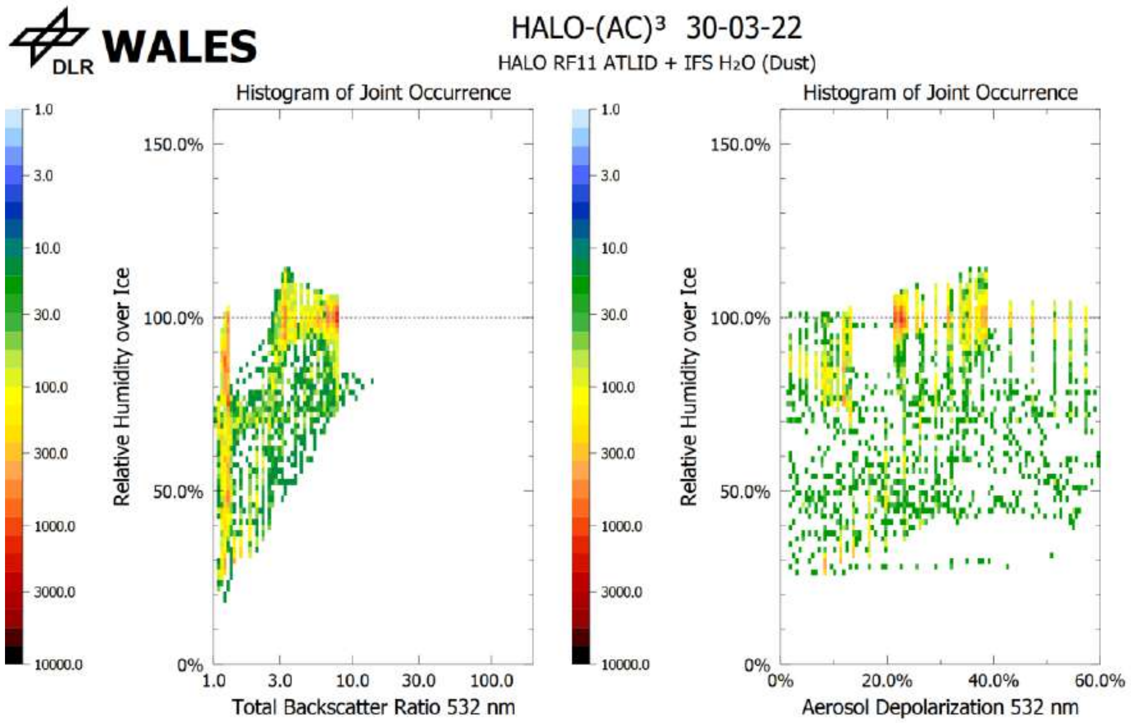


- In-Cloud Rhi clamped to 100% → no distinction wrt nucleation process possible!!!

HALO-(AC)³ RF11 30.03.2022: Aerosol Trapped in the Arctic

Comparison of pristine cirrus vs. dust influenced cirrus with IFS H_2O + ATLID data





- Very hard to draw conclusion wrt. to cloud microphysics…

Summary & Outlook

This Talk

- Joint 2-d measurements of optical properties of ice clouds and humidity enable the detailed characterization of cirrus clouds
- RH-ice determined form DIAL and Model-T give reliable results
- Similar studies may be possible using EarthCARE data, provided adaptive signal smoothing is applied and better RHi data is available

Next Steps

- Combination with radar to retrieve eff. radius and ice water content
- Comparison with in-situ measurements for verification (joint flights with FAAM)
- Combination of trajectories and satellite images to link optical properties to life-cycle of clouds
- Statistical analyses of all flights