Zooming in on Arctic clouds:

A case study comparing A-Train and airborne remote sensing measurements.

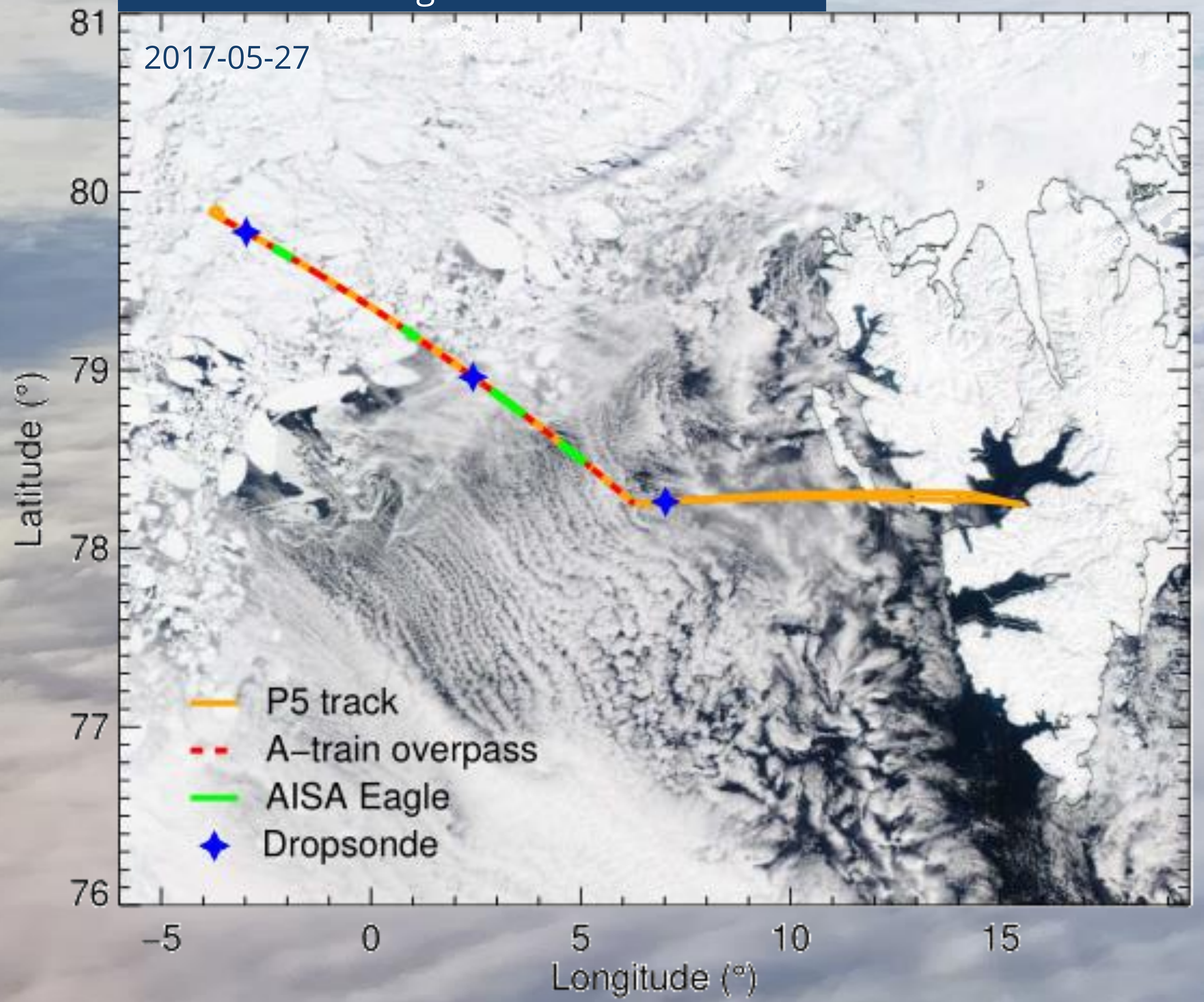
Birte Solveig Kulla, Elena Ruiz-Donoso, Leif-Leonard Kliesch, Mario Mech , Christoph Ritter, Vera Schemann and Susanne Crewell

Click on the topic you are interested in.

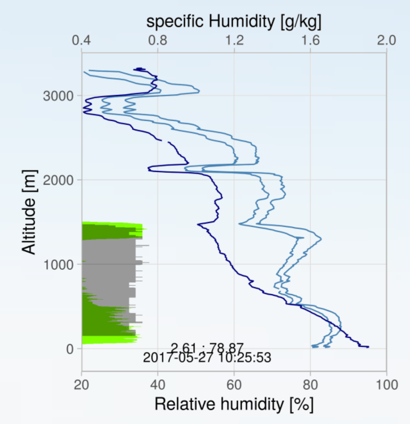
If you have any comments or questions we are happy if you contact us: birte.kulla@uni-koeln.de

Campaign set up

Modis & AISA Eagle

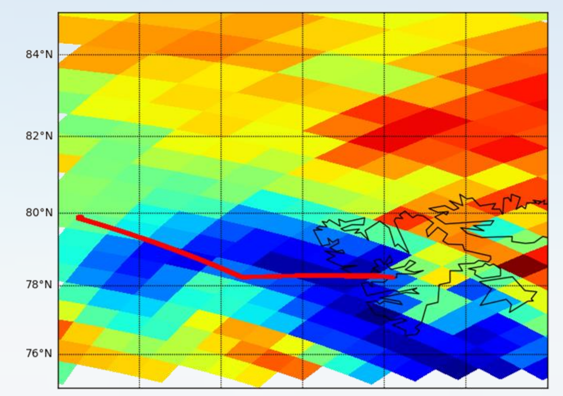


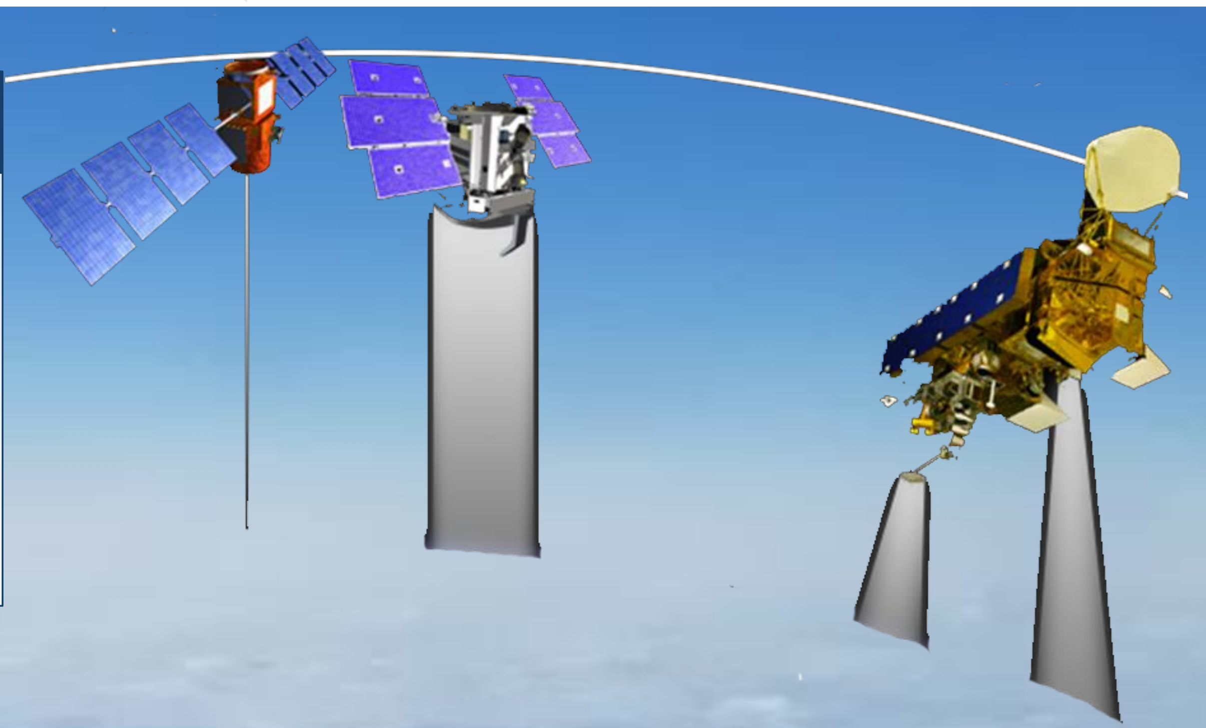
Dropsondes



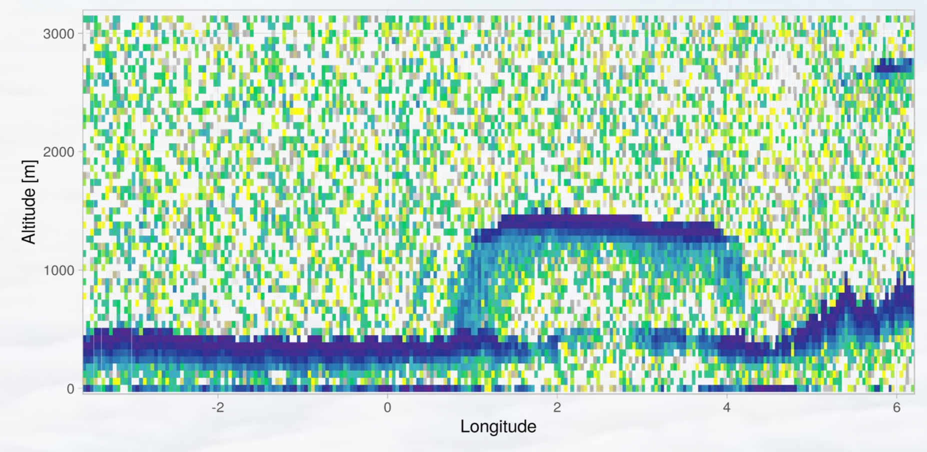
Synoptic situation on 2017-05-27

AMSU & MiRAC - passive

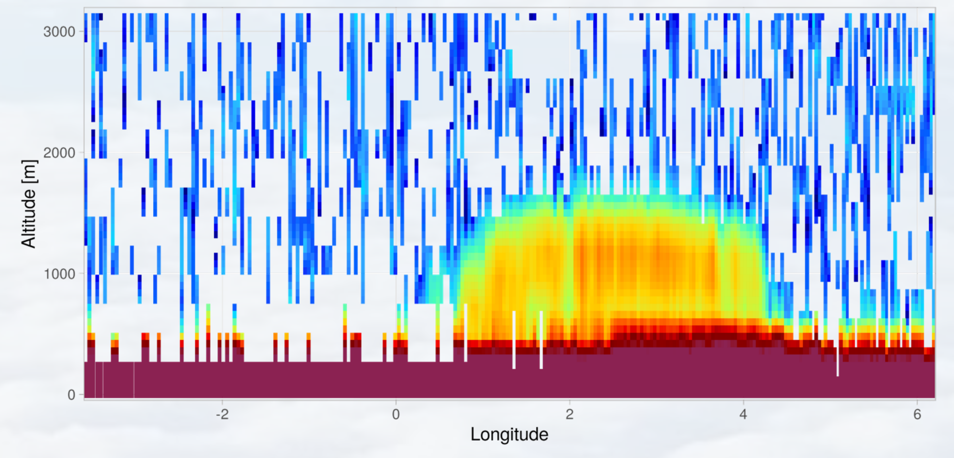




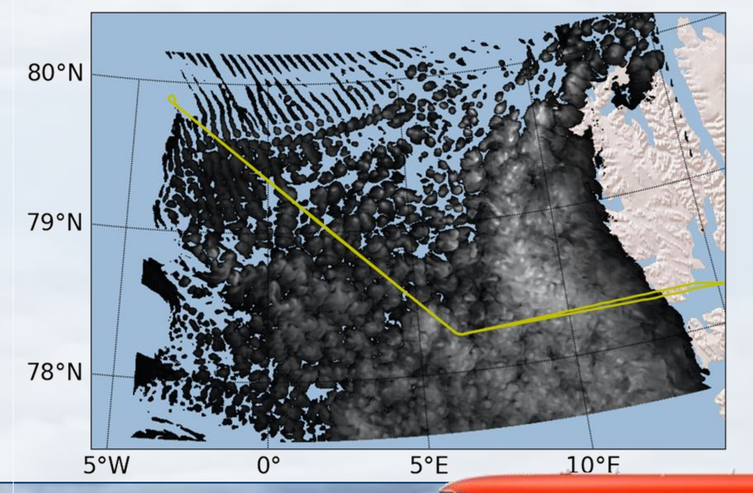
CALIOP & AMALi

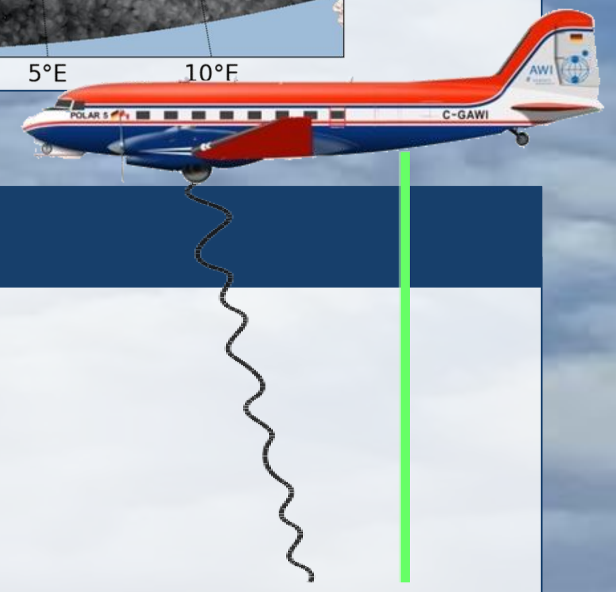


Cloudsat & MiRAC - active



Virtual World





Findings

High resolution airborne measurements show **more detailed structures.**

Thin clouds are below noise level in satellite data.

Blind zone CLOUDSAT → **precipitation** in the boundary layer is frequent and thus **often missed.**

Satellite **overestimation** of average **backscatter and reflectivity** due to non-uniform beam filling
→ potential overestimation of derived quantities

Overestimation of **cloud top** in CLOUDSAT due to the coarse resolution
thus, also potential overestimation of ice content in liquid layer in synergistic retrievals from satellite

Pattern in overestimation of reflectivity appears to be very uniform over **several instruments**.

Modelling allows us to investigate processes leading to remote sensing signal.

EGU2020: AS2.8 Clouds, moisture, and precipitation in the Polar Regions: Sources, processes and impacts https://doi.org/10.5194/egusphere-egu2020-21307

Zooming in on Arctic clouds: **ACLOUD Campaign**

A case study comparing A-Train and airborne remote sensing measurements.

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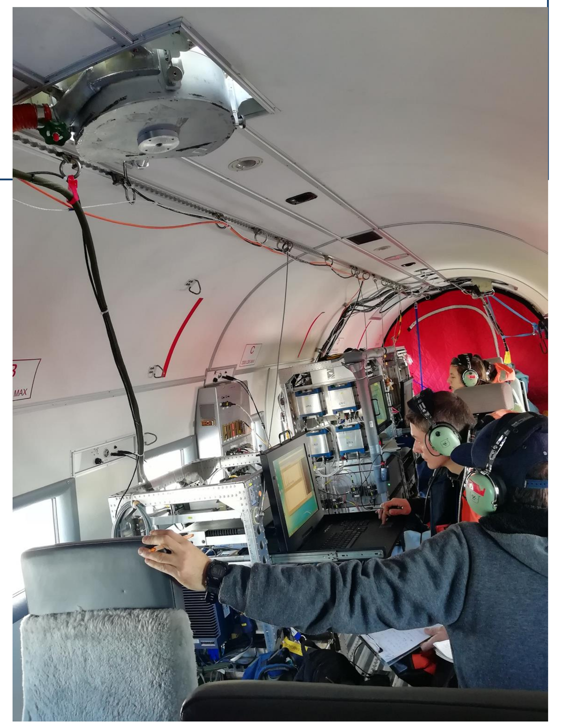
Campaign details

ACLOUD Campaign:

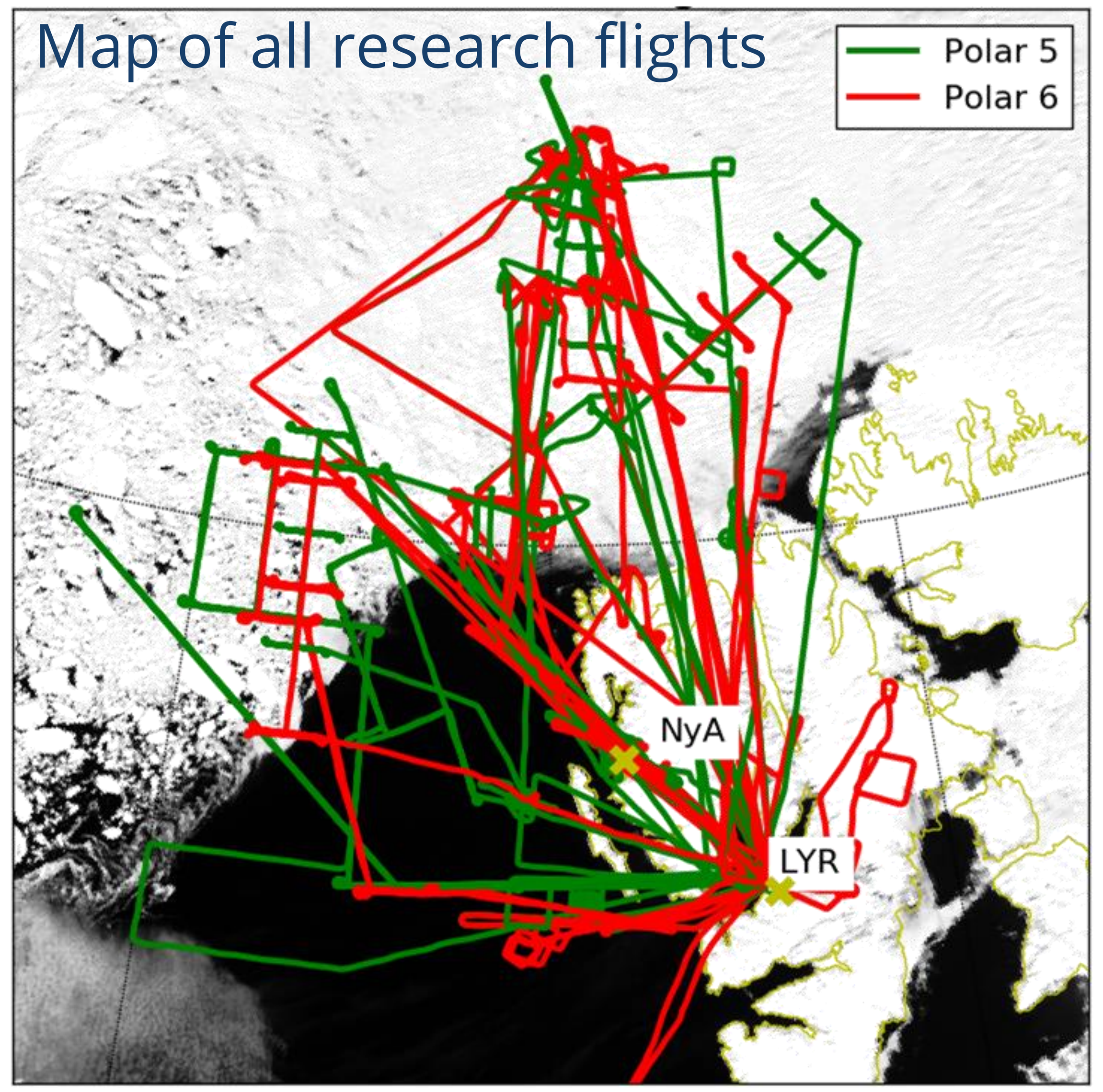
Intensive measurement campaign
with detailed measurements for ground (Ny-Alesund),
Ship (Polarstern) and Aircrafts (POLAR 5 & 6)
On and in the vicinity of **Svalbard** at the marginal sea ice zone

Main Goal: Investigate the Role of Clouds and Aerosol in Arctic Amplification.

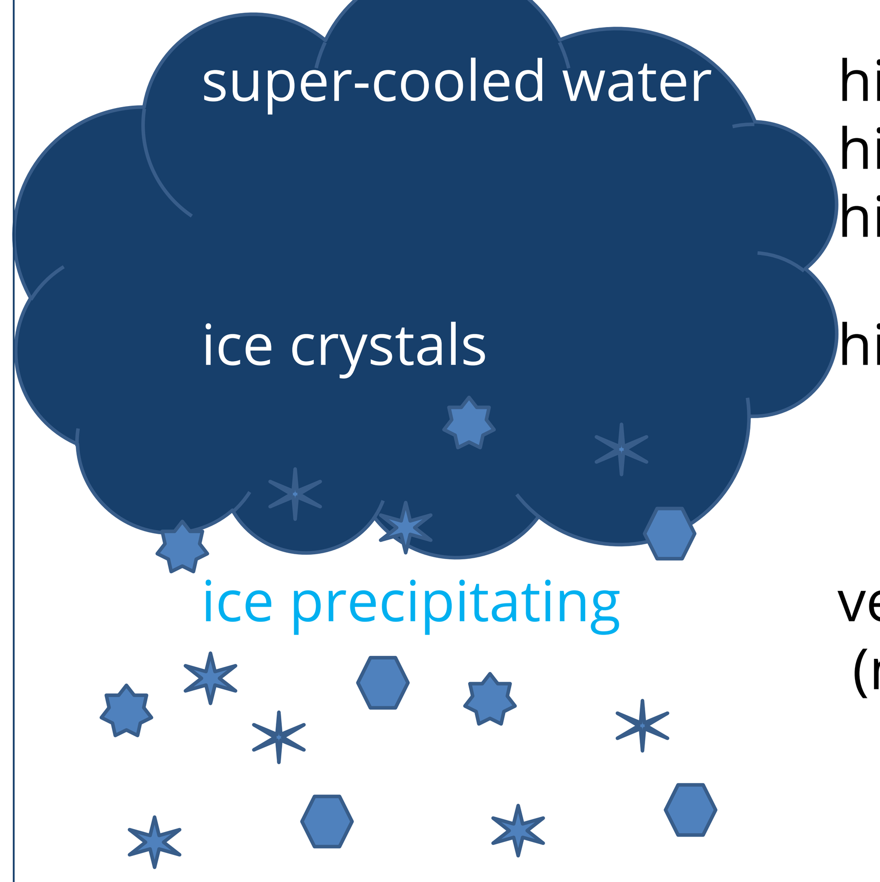
More Details: [Wendisch et al. 2020]



Case study on research flight 06.
2017-05-27 A-TRAIN overpass during a cold air outbreak.



Measuring **Arctic mixed phase clouds**
we expect to see:



high lidar signal
high reflectivity (VIS)
high reflectivity 89GHz

high Ze

very high Ze
(microwave reflectivity)

Measurements onboard **POLAR 5** (remote sensing aircraft)

Basic Meteorology at aircraft
Dropsondes

Turbulence Measurements (Nose Boom)

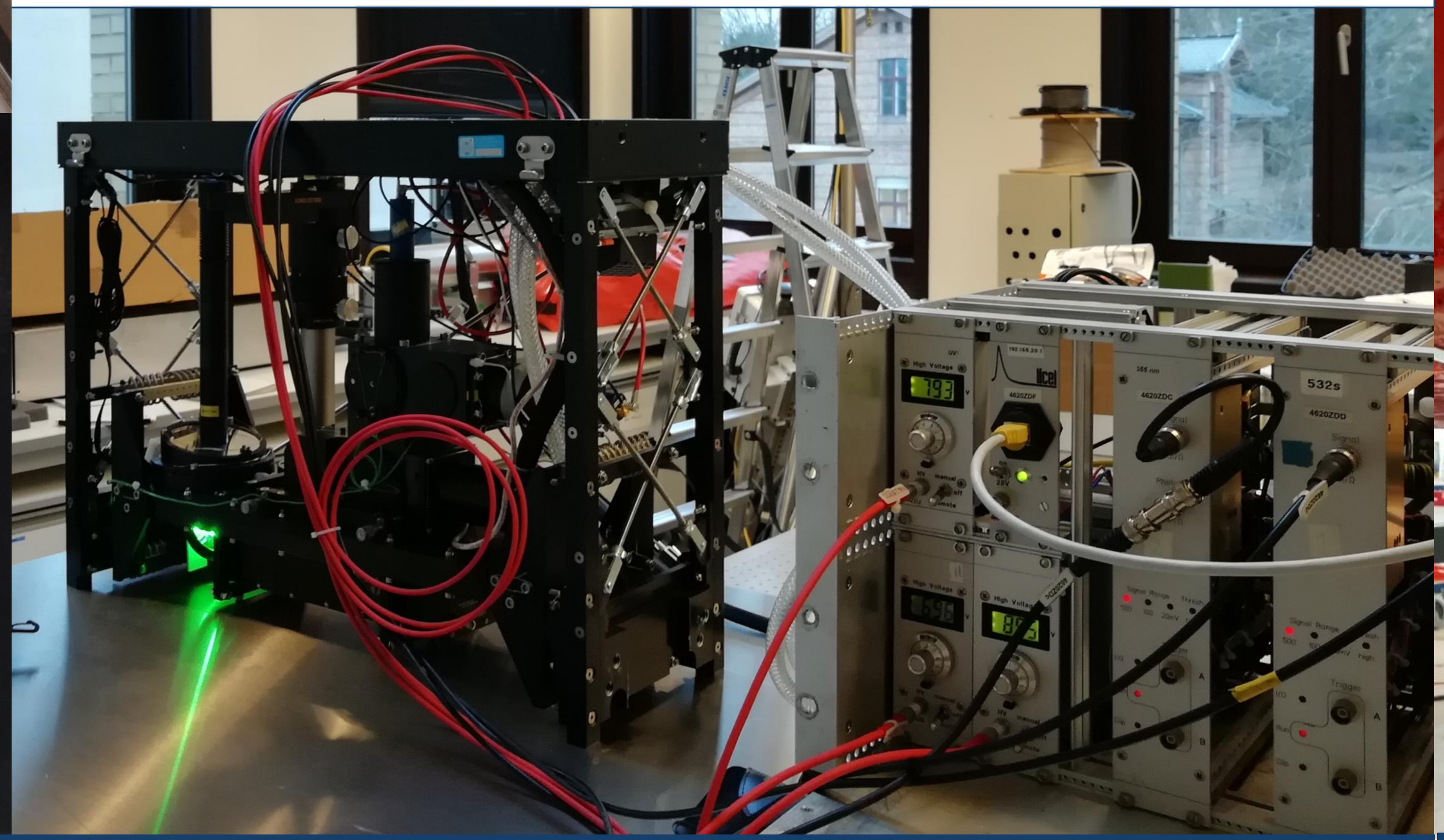
Broadband Radiation measurements
Spectral Radiation measurements

Spectral radiance → AISA Eagle/Hawk

Backscatter at visible and UV wavelength → AMALi

Brightness temperatures in microwave spectrum &
Radar Reflectivity at 94 GHz → MiRAC

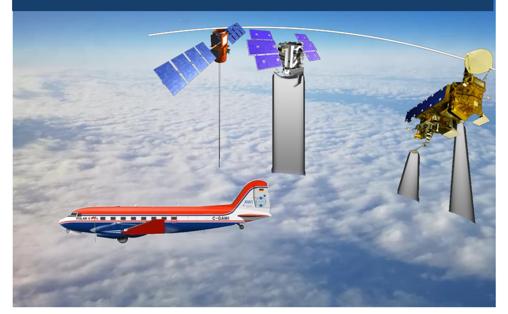

AISA Eagle



AMALi


MiRAC

Overview



Zooming in on Arctic clouds: **Dropsonde Measurements & Synoptic Situation**

A case study comparing A-Train and airborne remote sensing measurements.

Birte Solveig Kulla, Elena Ruiz-Donoso, Leif-Leonard Kliesch, Mario Mech , Christoph Ritter, Vera Schemann and Susanne Crewell

Temperature

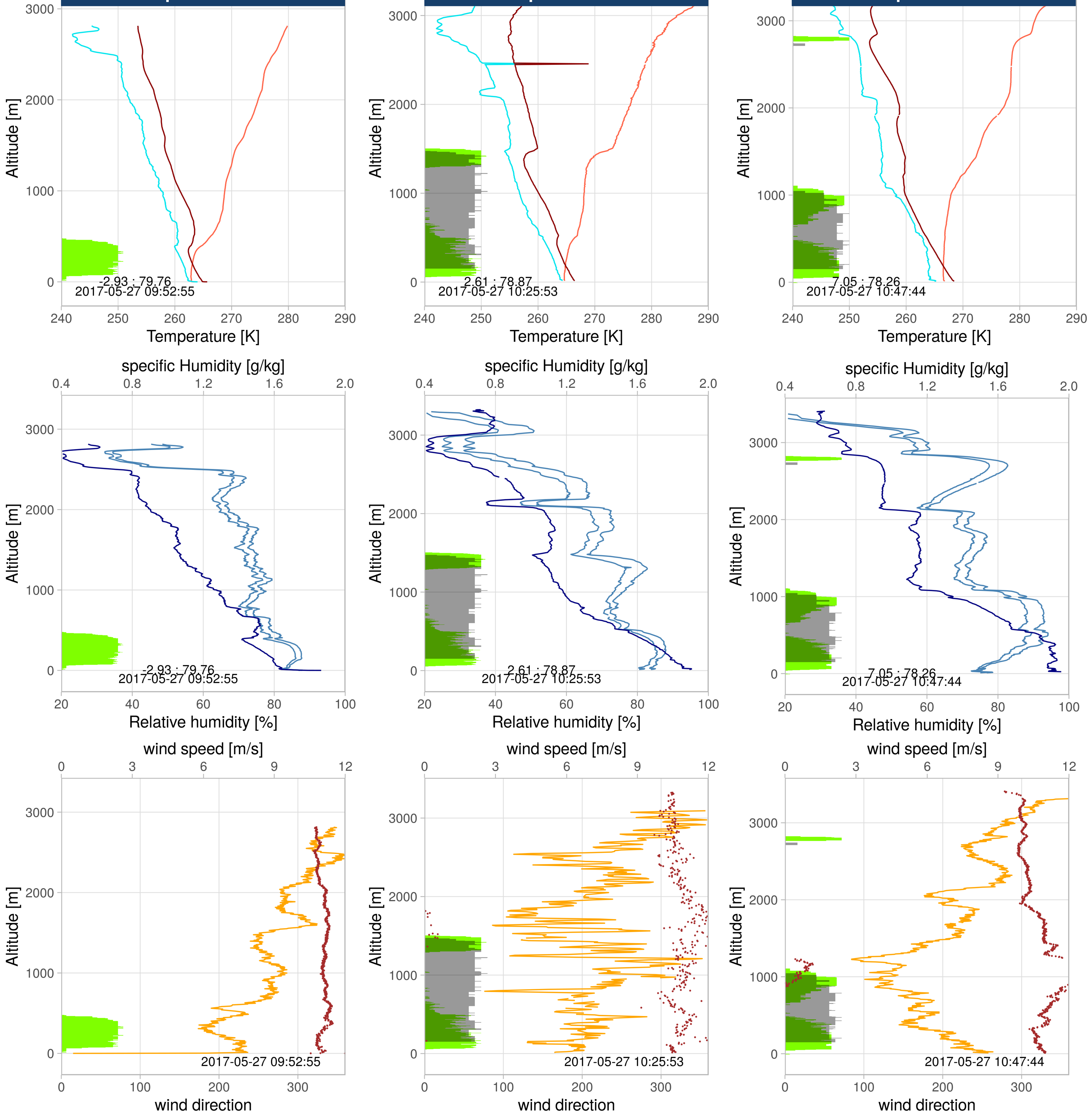
Humidity

Wind

Dropsonde 1

Dropsonde 2

Dropsonde 3



occurrence of lidar signal

occurrence of radar signal

10 sec around DS launch

Air Temperature [K]

Dewpoint [K]

Potential Temperature [K]

Multiple, lifted inversions, including moisture inversions

Boundary layer height rises from DS1 (over sea ice) towards DS3 (over open ocean)

dry bias in clouds is a known issue
→ relative humidity does reach 100%

relative Humidity o.w.

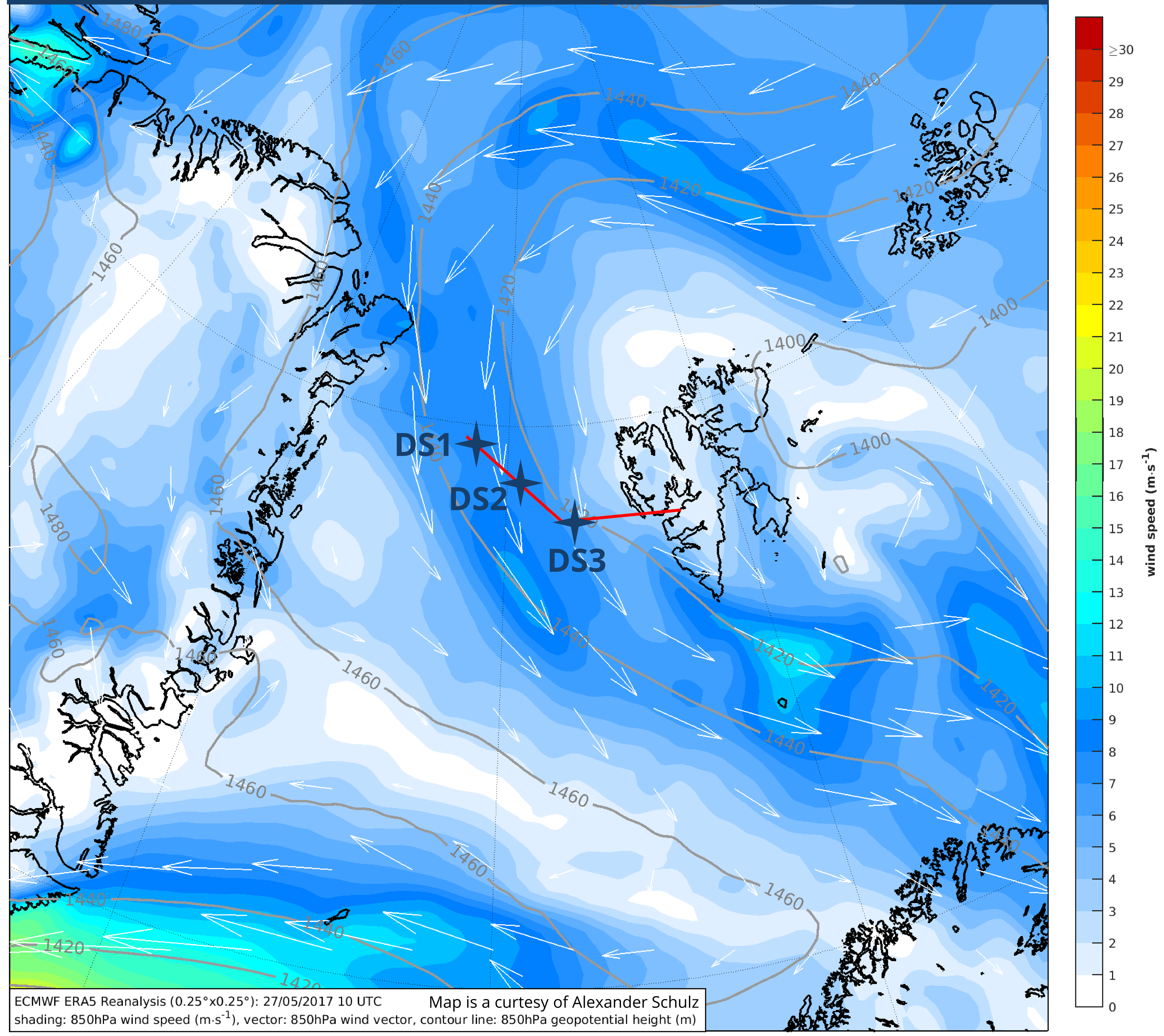
specific Humidity[g/kg] (top axis)

Acceleration of wind in boundary layer over the ocean, wind shear at cloud top (DS3)

wind direction [deg]

wind speed [m/s] (top axis)

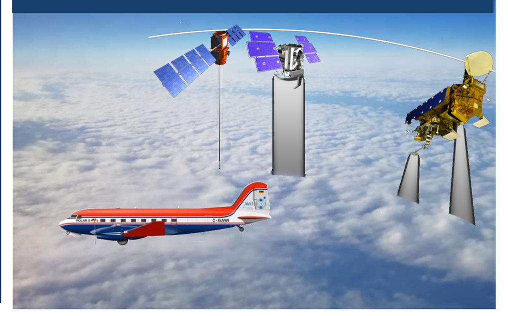
Synoptic situation



Northwesterly winds coming from the ice edge: Cold air outbreak advecting cold and dry air masses over a relatively warm ocean surface

KNUDSEN et al. 2018 give an overview over the synoptic situation during the entire ACLOUD campaign.

Overview



Zooming in on Arctic clouds: **Modis & AISA Eagle**

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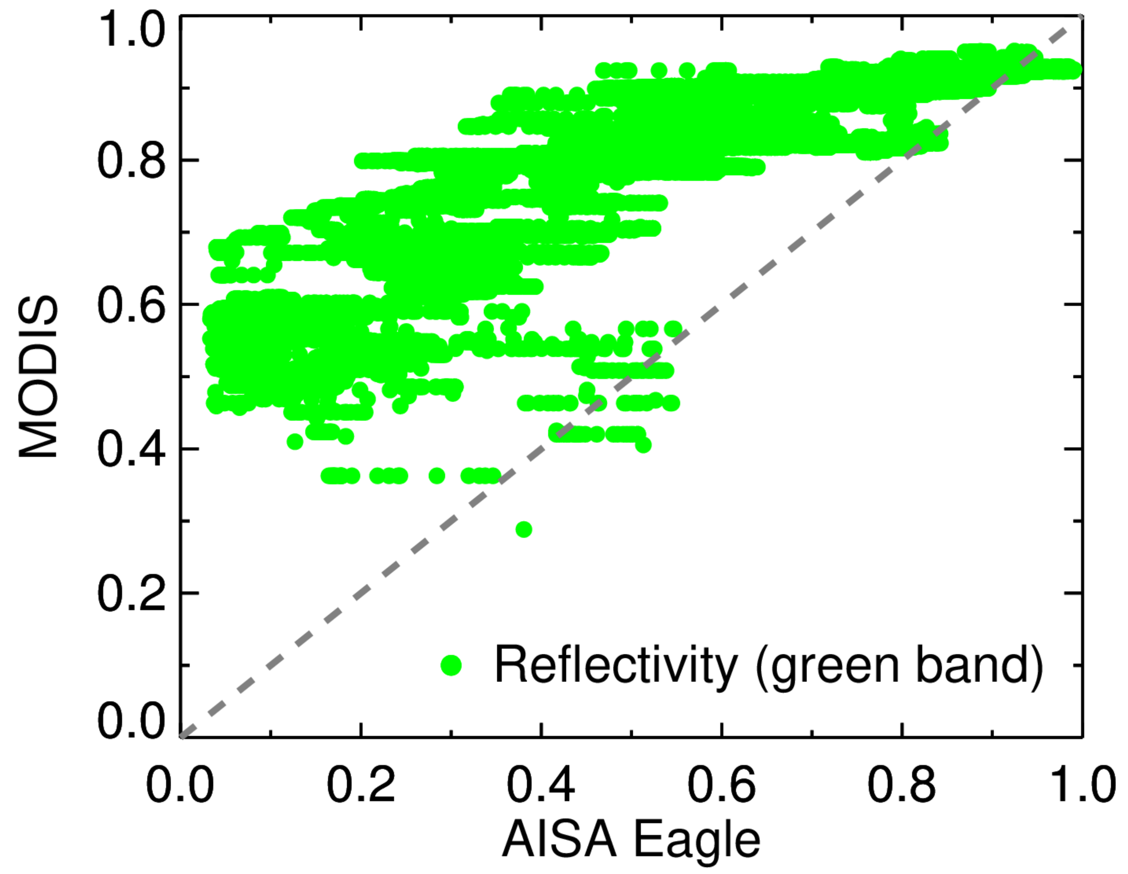
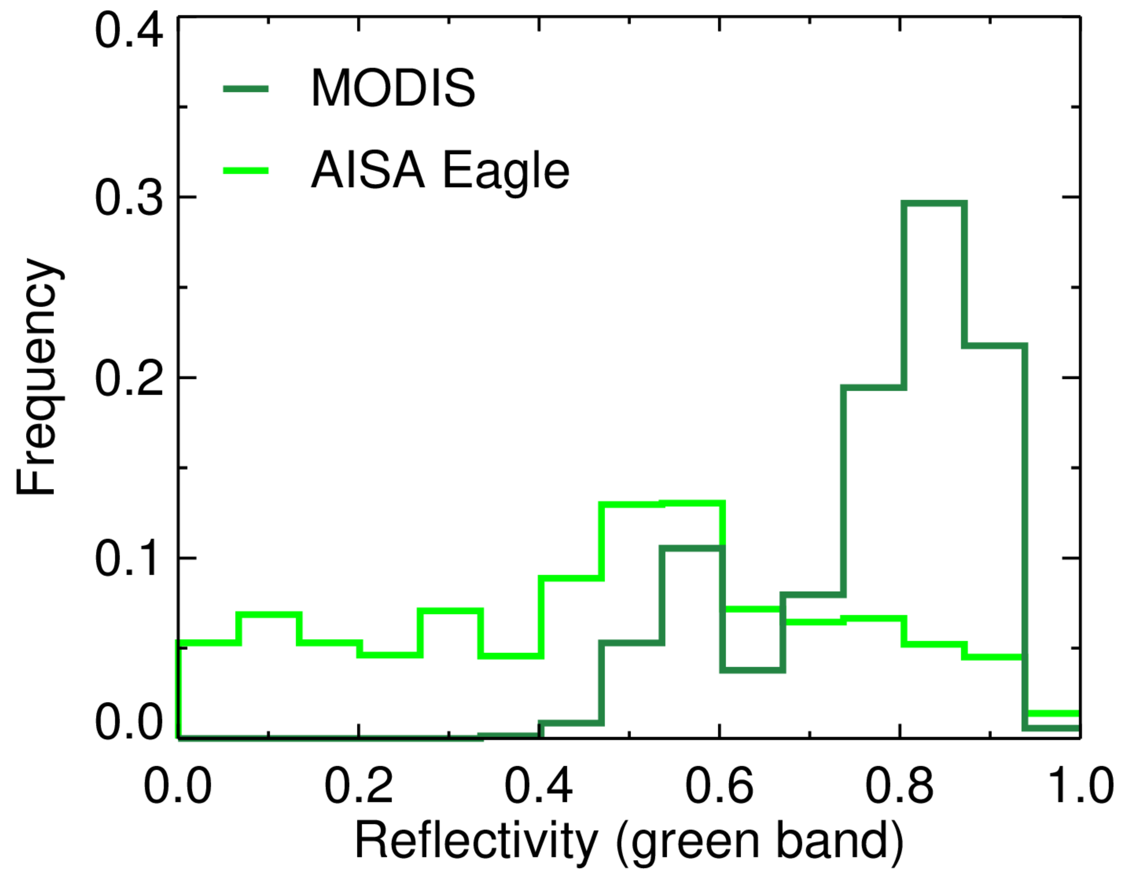
AISA Eagle

- Reflectivity 400 – 995 nm
- FWHM: 1.25 nm
- FOV: 29.9°
- Cross-track pixel: 1.5 m (3 km to target)
- Swath: 1.6 km (3 km to target)
- Products (combination with AISA Hawk):
  - Cloud thermodynamic phase
  - Optical thickness
  - Effective radius

Pixel by pixel comparison





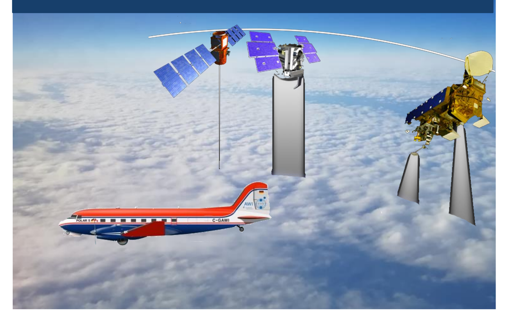
Modis (Aqua)

- RGB reflectivity (R: 620-670 nm; G: 540 – 570nm; B: 460-480 nm)
- Horizontal resolution R: 250m; G: 500 m; B: 500 m
- Swath: 2330km (cross track) x 10 km (along track nadir)
- Products:
  - Cloud thermodynamic phase
  - Optical thickness
  - Effective radius
  - Cloud top properties (height, temperature…)

Nadir pixel of comparison

For more detail and cloud phase retrievals see RUIZ-DONOSO et al. 2019

Overview



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Zooming in on Arctic clouds: **Fine Resolution**

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Why we need passive and active remote sensing: getting an idea of the actual cloud structure

Homogeneous and optically thin lower cloud layer.

The upper cloud layer appears to precipitate down into the lower cloud layer.

Upper cloud layer evolves towards an optically thicker and homogeneous state. Lower cloud layer becomes harder to detect.

The upper cloud layer dissipates. The lower layer evolved, now broken and optically thinner.

 https://doi.org/10.5194/egusphere-egu2020-21307

Zooming in on Arctic clouds: **CALIOP & AMALi - Lidar**

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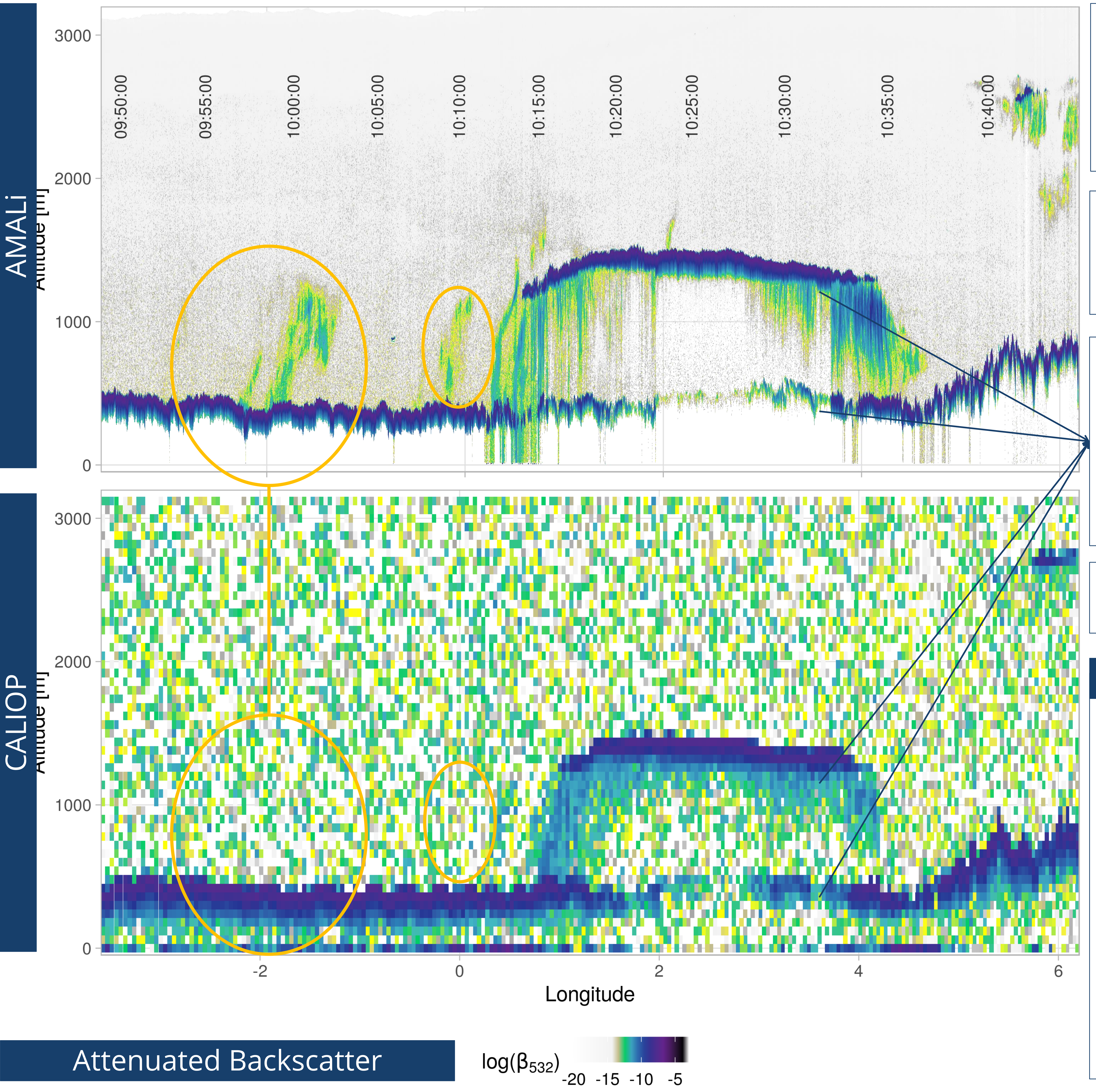


Attenuated Backscatter

Lidar measurements are sensitive to number concentration
→ high values (dark blue) where we find many small droplets
→ **liquid cloud top**

Lower values (greenish/yellow) → optically thinner clouds

Here, **attenuated backscatter** for comparison
Distinctive attenuation and backscatter are derived using an iterative, reverse Klett-approach, data publication in prep.

2 Cloud layers

Similar penetration depth into cloud

Cloud top altitudes align very well,
cloud top structure better resolved in airborne data

Optically thinner clouds below noise level in CALIOP data

AMALi

Lidar operating at
532 nm dual pol. & 355nm

Resolution:
vertical: 7.5m
horizontal 1s -> ca. 70m

Footprint: 0.15 ° FOV → 7.8 m
at 3000m flight altitude

More details: STACHLEWSKA 2010

CALIOP

Lidar operating at
532 nm dual pol. & 1064nm

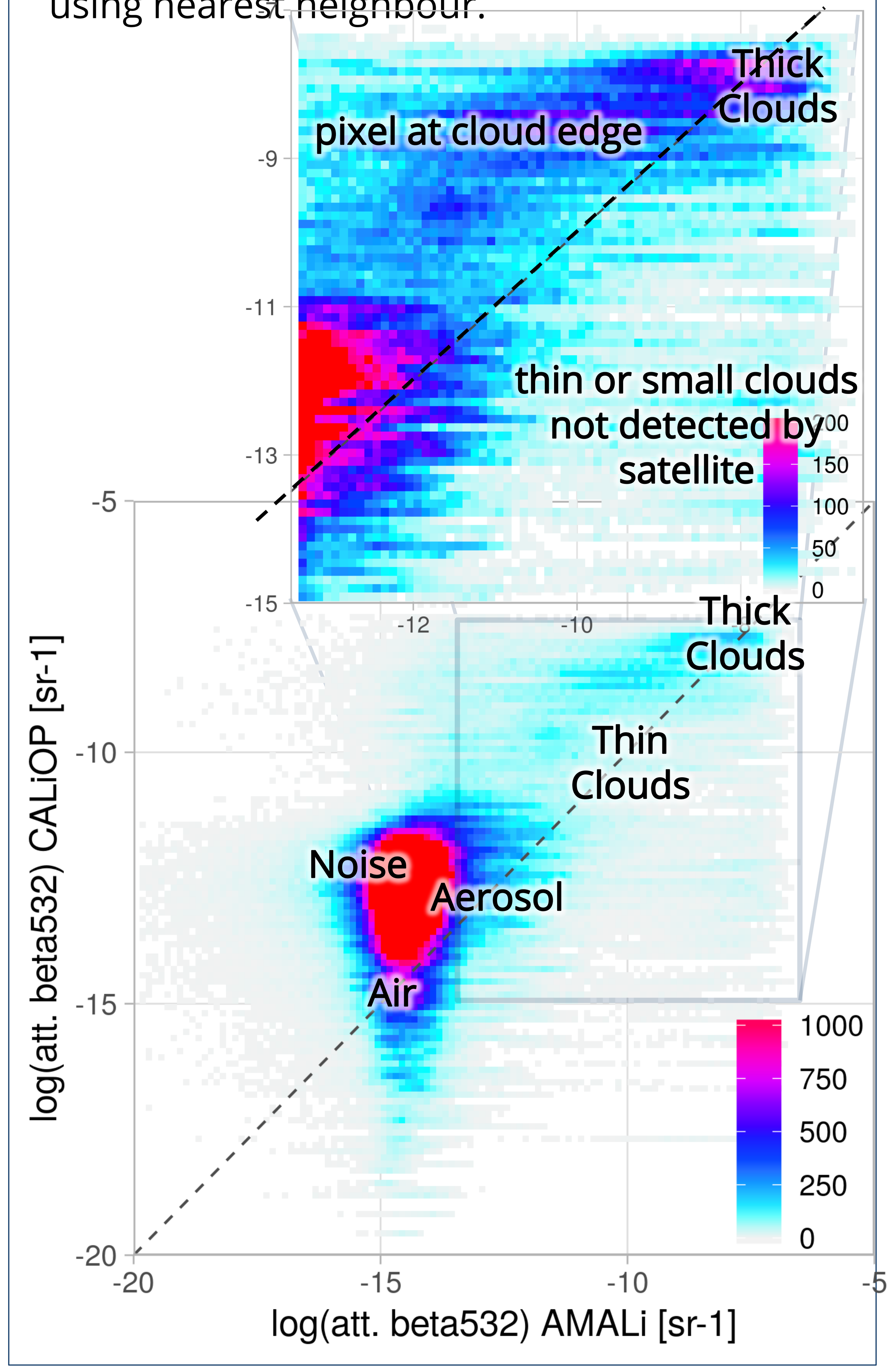
Resolution:
vertical: 33m
horizontal : 333m

Footprint: 100 m

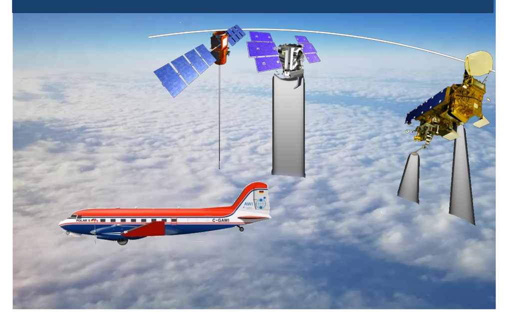
More details: WINKER et al. 2007

Pixel by pixel comparison

CALIOP data resampled to the AMALi grid using nearest neighbour.



Overview



Zooming in on Arctic clouds: **CLOUDSAT CPR & MiRAC - Radar**

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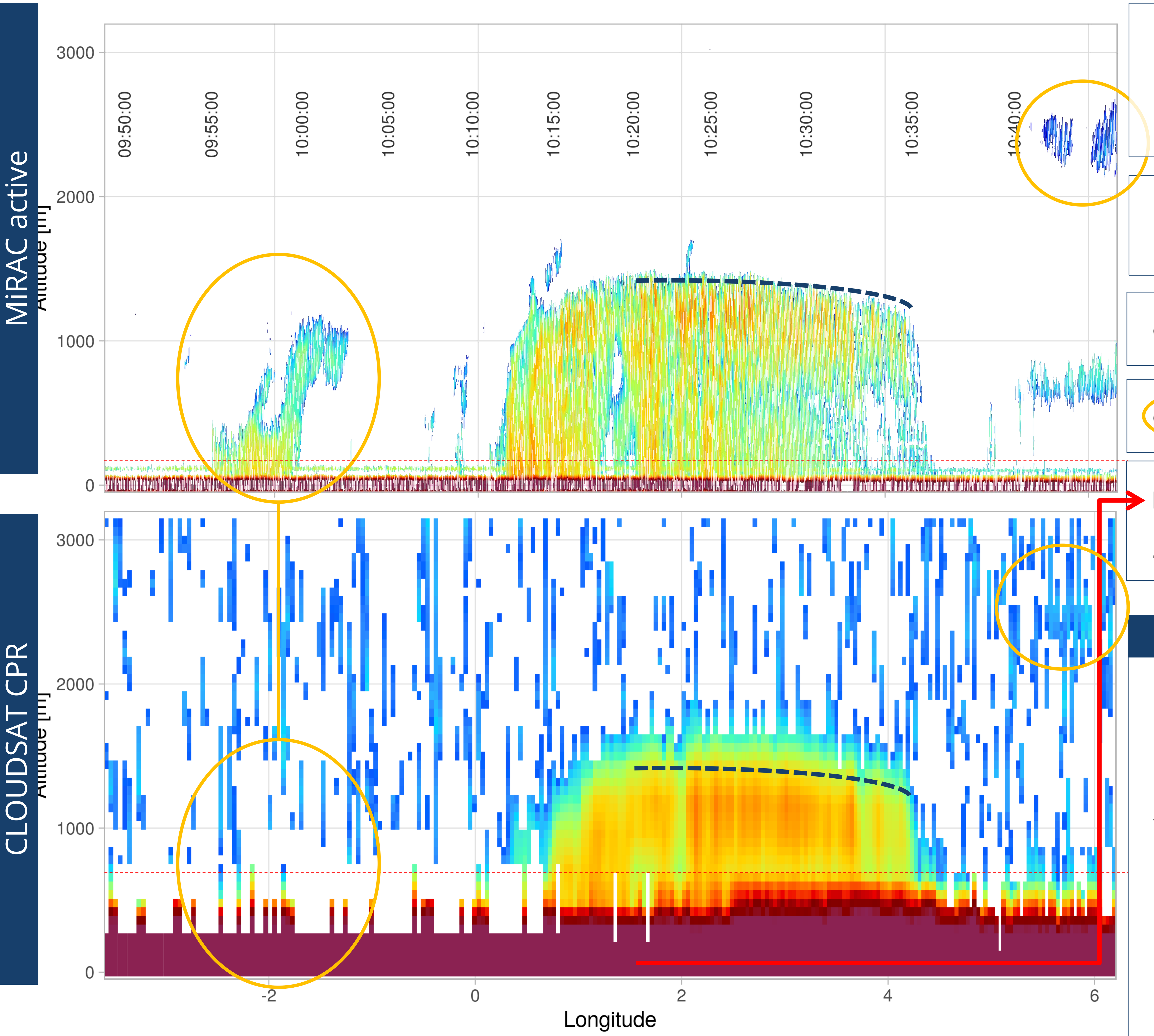


Radar reflectivity Ze

Radar measurements are sensitive to particle size. Large particles will dominate the signal
→ high reflectivity (orange) where we observe large **ice crystals**
→ high reflectivity at low altitudes indicates snowfall

Single streaks visible, more distinct in airborne measurement

Cloud top overestimated by a few hundred meters.

Optically thinner clouds below noise level in CALIOP data

Blind zone (ground clutter influence): 600 – 1200m (MAHN et al. 2014, LIU et al. 2015)
→ here signal above **800m** looks reasonable. **150m** for MiRAC

MiRAC

Frequency Modulated Continuous Wave (FMCW) Radar at 94 GHz

Resolution (at current setting):
vertical: 13.5m
at 25deg inclination → 12.2m
horizontal: 1.3s -> ca. 90 m

Footprint: HPBW : 0.85 ° → approx. 44.5m at ground

Sensitivity: -40dBZ

More details: MECH et al. 2019

CLOUDSAT CPR

Cloud Profiling Radar short-pulse profiling at 94 GHz

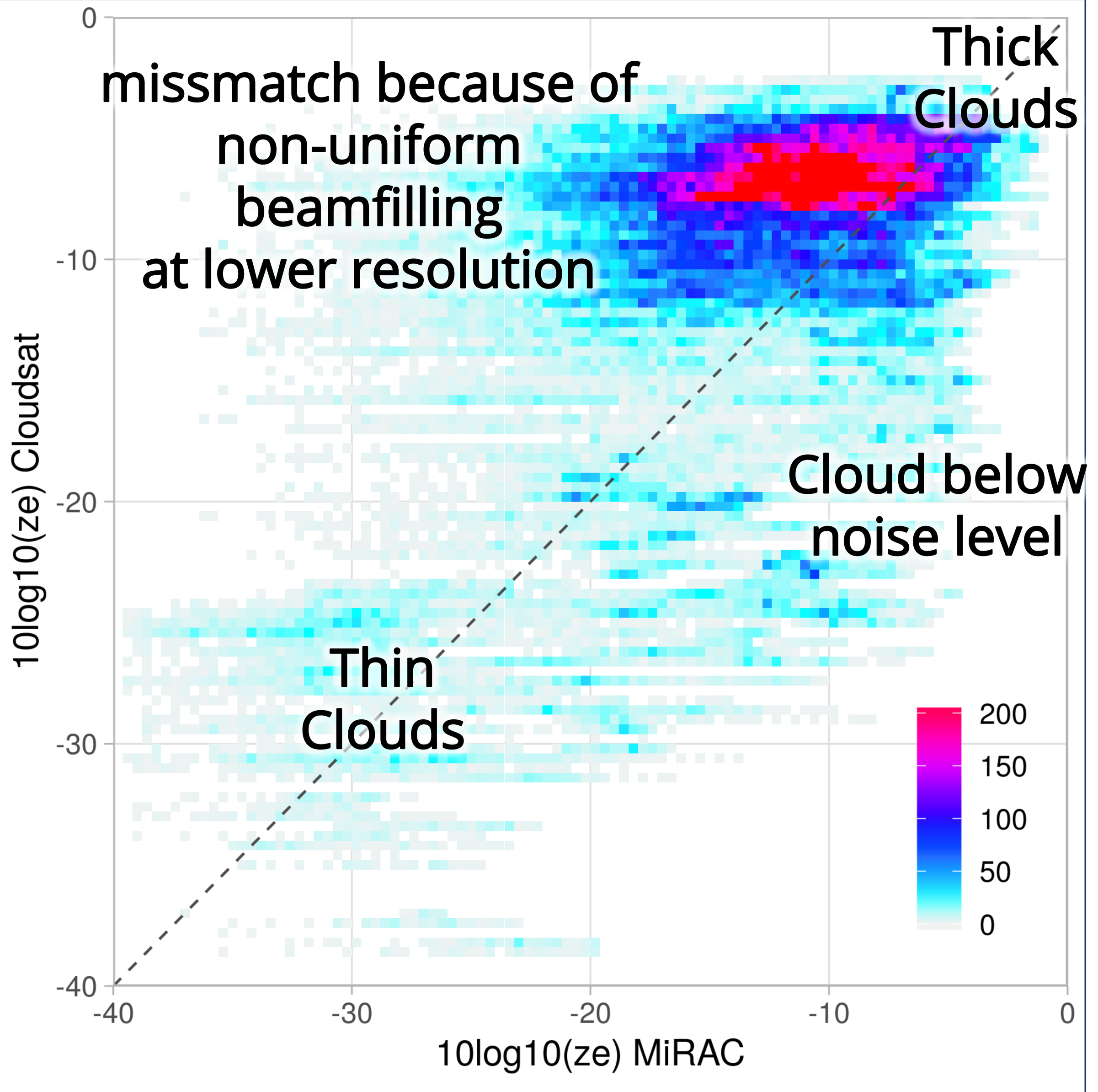
Resolution:
vertical: 485 m
(Range Sampling 240m)
horizontal : 0.16 s → 1.09 km

Footprint: 1.3*1.7km at ground

Sensitivity: -30dBZ

More details: STEPHENS et al. 2008

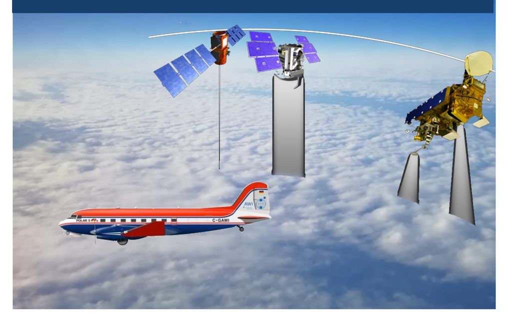
Pixel by pixel comparison



CLOUDSAT data above 800 m resampled to the MiRAC grid using nearest neighbour.

CLOUDSAT tends to show higher reflectivities

Overview



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Zooming in on Arctic clouds: **AMSU-A & MiRAC-passive 89 GHz**

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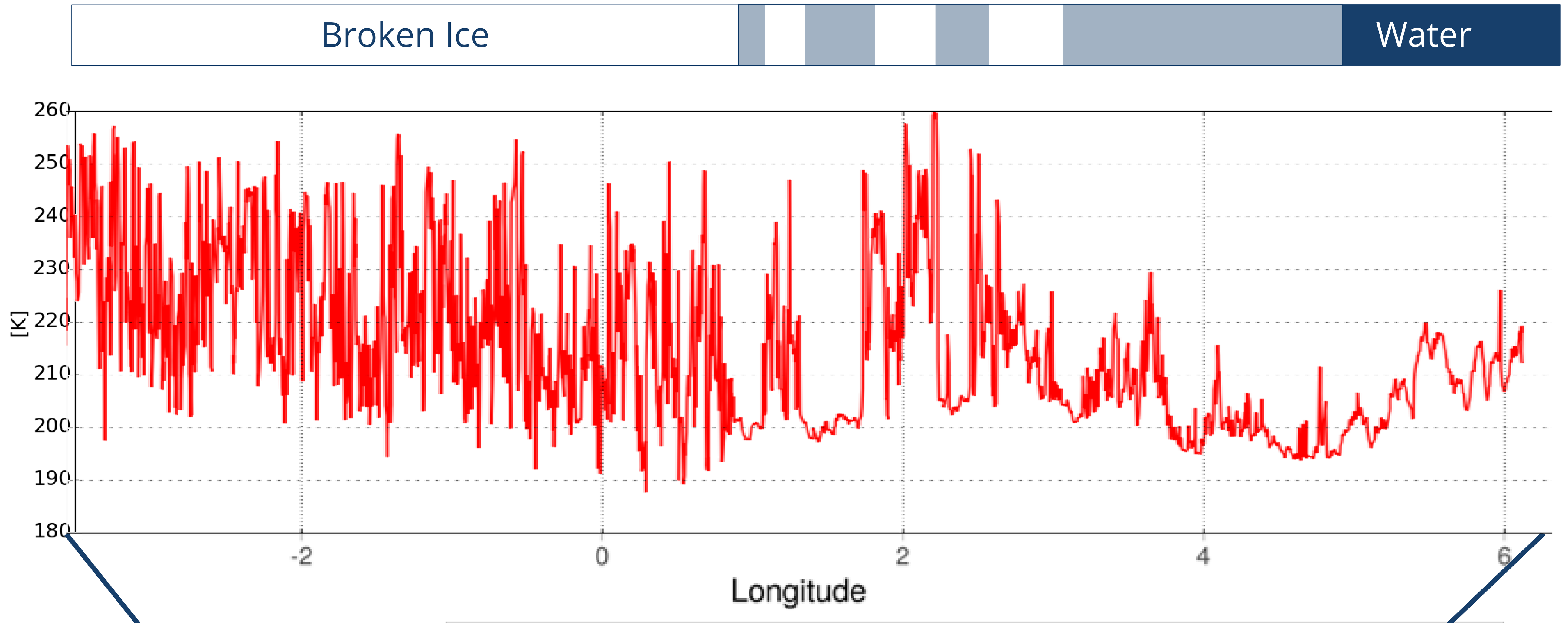
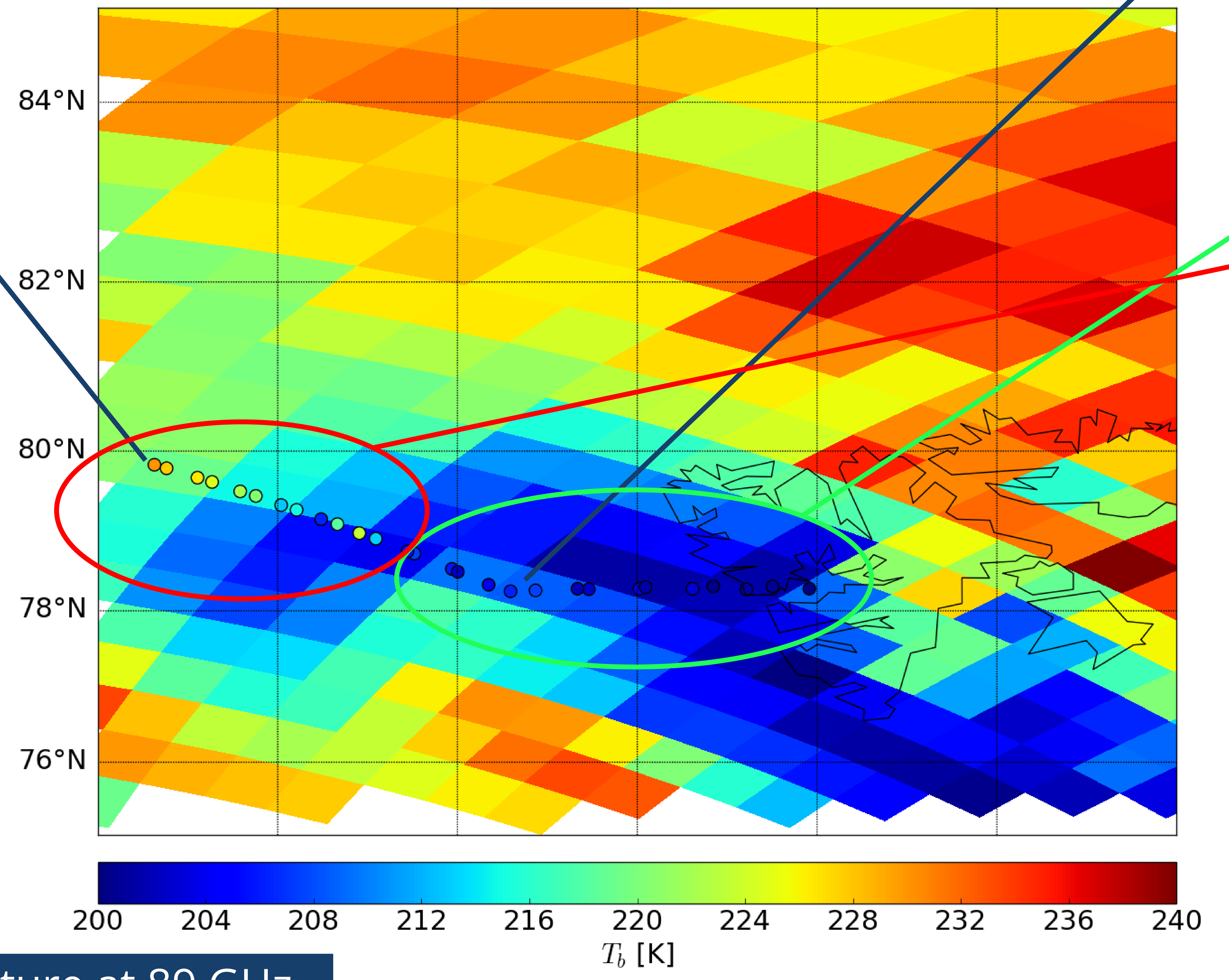
Mirac-Passiv



AMSU-A with averaged Mirac-Passiv



Brightness temperature at 89 GHz

Sharp increase: change of surface from water to ice. Very high variability over sea ice.

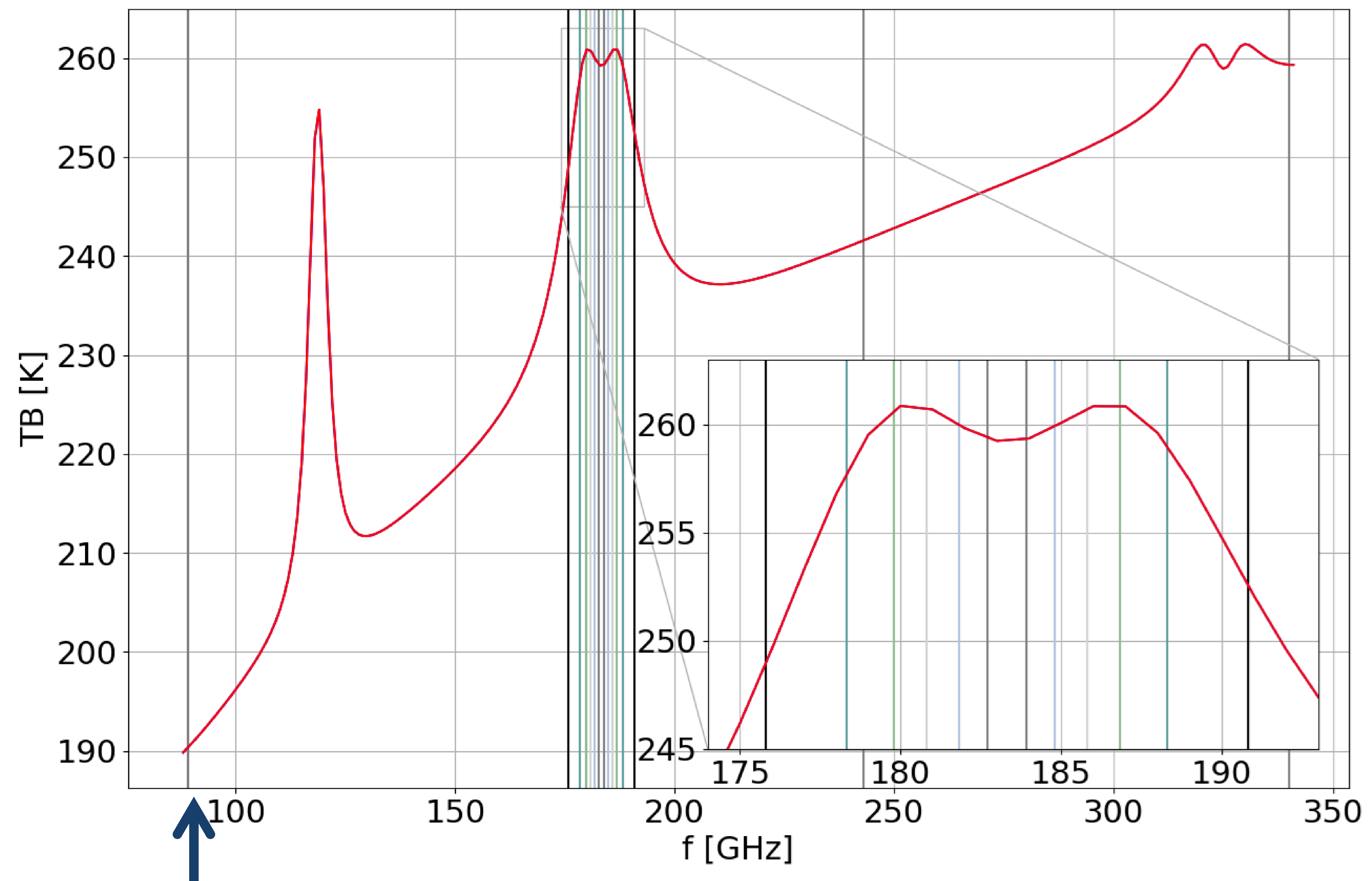
More gradual changes: changes in liquid water content.

The map shows the brightness temperature TB at 89 GHz which results from emission by the surface (strongly depending on type, i.e. ocean, sea ice, land) and atmosphere (mainly by water vapor and liquid).

Dots: resampled MiRAC-P 89 GHz measurements to 30 km-steps, corrected for inclination.

Good agreement over ocean

Larger deviations over broken sea ice due to spatial averaging by satellite



TB of Standard Atmosphere

89 GHz – Window channel

Sensitive to ground emissivity
liquid water
water vapour

MiRAC - passive

MiRAC-P 89 GHz: horizontally polarized, 25° inclined

Corrected for TB bias (5.5 K) inferred from dropsonde intercomparison

Resolution: 1.3s → ca. 90m

Footprint: 1.3 °

To compare both products an offset correction for polarization and inclination difference of 8.2 K was added to MiRAC-P.

AMSU-A

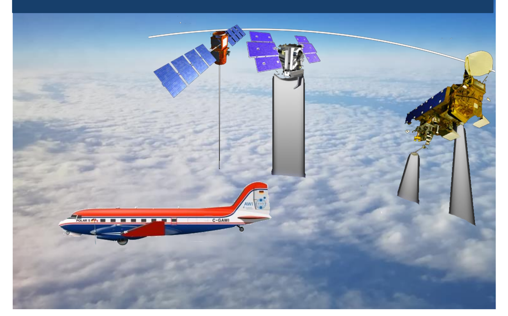
AMSU-A 89 GHz: vertically polarized

Resolution: 48 km
cross-track scanning with 48 km resolution at nadir increasing towards the edge of the 2000 km wide swath

Footprint: 3.3 ° beam width

Also deployed on operational polar orbiting meteorological satellites from NOAA and EUMETSAT

Overview



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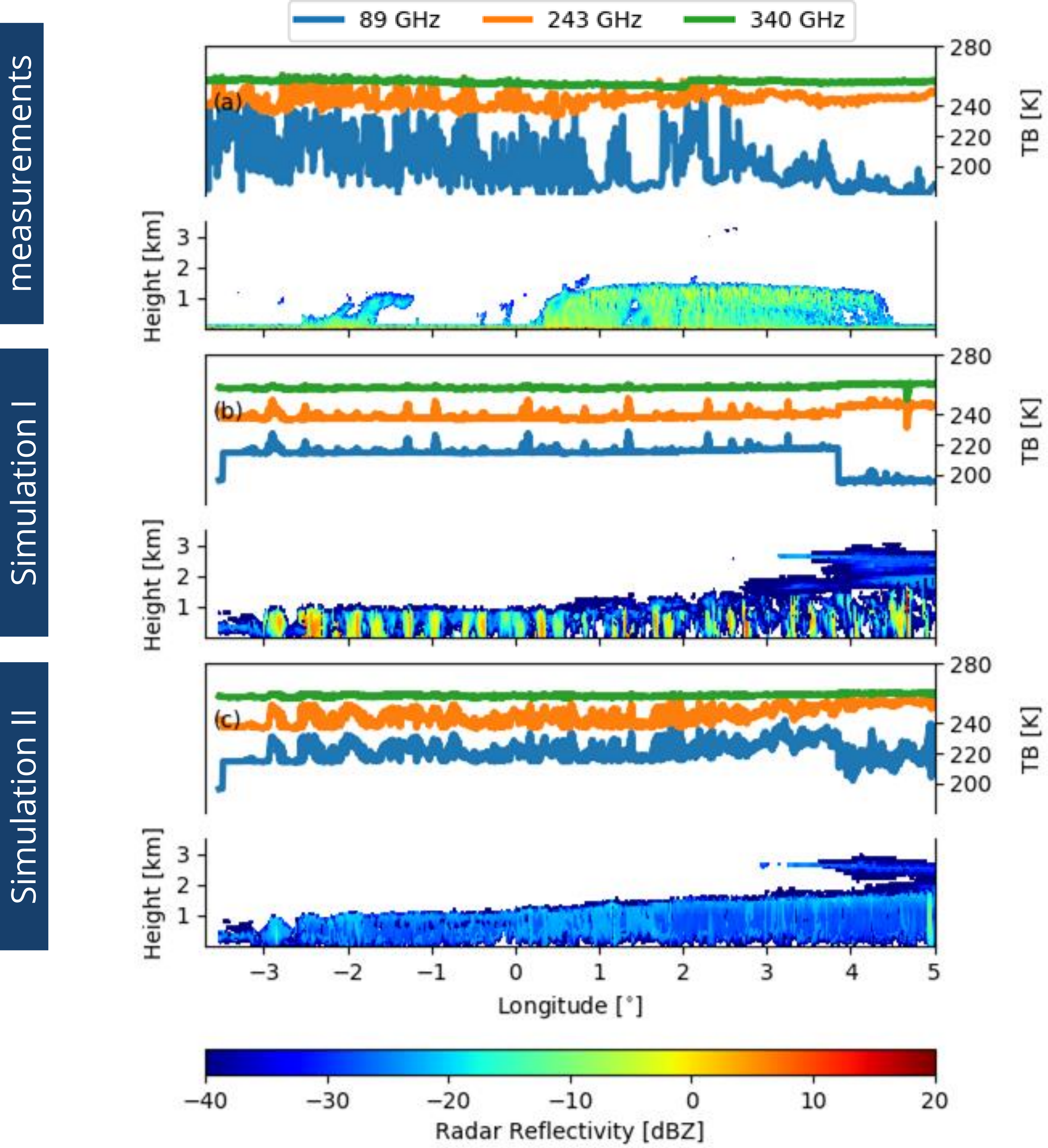


Radar reflectivity at 94 GHz and TB at 89 GHz (blue) with horizontal polarization and 243 (orange) and 340 GHz (green) with mixed polarization as measured by the MiRAC instrument (a) and simulated radar reflectivity and TB with ICON-LEM and PAMTRA with two different assumptions on CCN and IN activation: parameterized (b) and vertically fixed (c).

Why using models?

Applying models allows to manipulate the nature in virtual world: individual processes can be switched off and on or a different parameterization can be applied.

Using high quality measurements in connection to state-of-the-art forward models, gives the possibility to evaluate and to eventually improve atmospheric models by comparison with measurements in the observation space.

Models and setup

ICON-LEM (Large-Eddy-Model):

- Forced at the boundaries by ECMWF IFS data
- Local simulations are one-way nested (600, 300, and 150 m)
- Two-moment microphysics scheme by Seifert and Beheng

PAMTRA (Passive and Active Microwave TRAnsfer model; Mech et al., 2020)

- Importers for a large variety of models and inclusion of their hydrometeor/psd assumptions State-of-the-art treatment of surface emissivity, gaseous absorption, hydrometeors, particle size distributions, and single scattering properties
- Full radar Doppler spectrum and higher moments and 1D polarized brightness temperatures

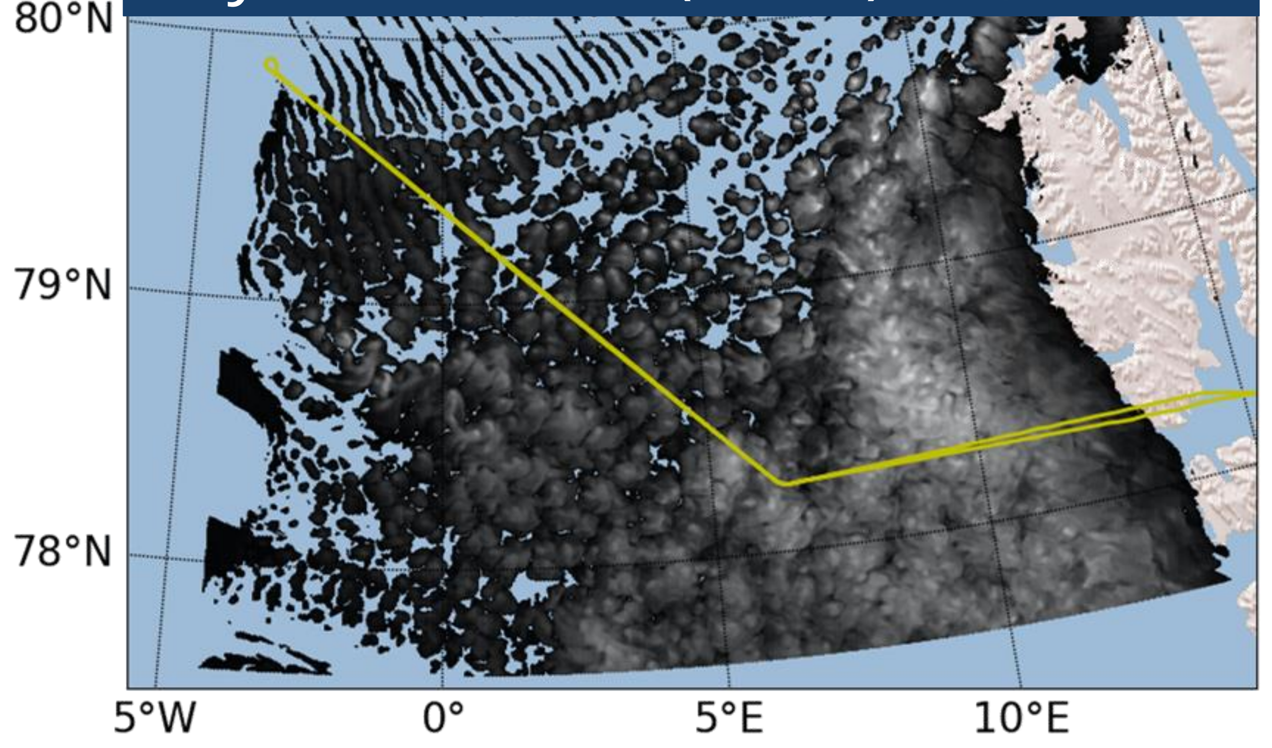
Analysis

PAMTRA has been set up to mimic the MiRAC measurements based on ICON-LEM runs with two different simulations: the first with a parameterization for CCN/IN activation (**S I**) and second one with fixed vertical profiles for cloud condensation nuclei (CCN) and ice nuclei (IN) (**S II**).

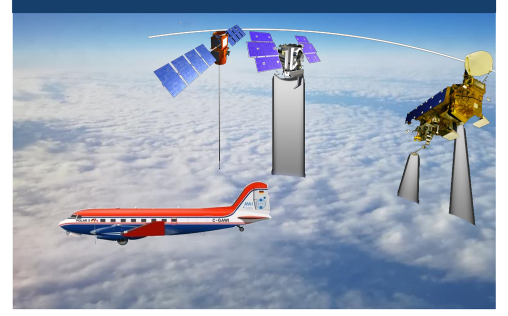
Differences between model and observations and next steps:

- Synoptic situation produces very variable cloud field; direct comparison difficult - *statistical approach for comparison*
- Vertically fixed CCN/IN overestimates ice water content (high reflectivity) and underestimates (variability in 89 GHz); variable CCN/IN results in to few ice - *test further parameterizations*
- Surface emissivity assumption (ε = 0.75 for coverage > 50%) in transitional sea ice zone to coarse in PAMTRA - *more complex assumption*
- Vertical and horizontal resolution of measurement and model do not match - *folding of measurements required*

hydrometeors (ICON) S II, 600



Overview



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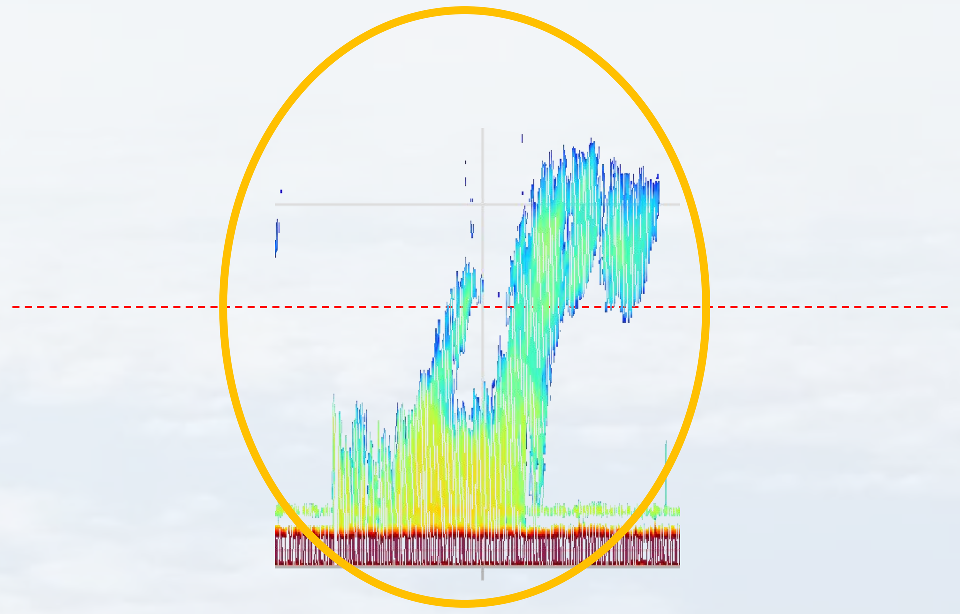
Findings

High resolution airborne measurements show **more detailed structures** of clouds
For example here (passive VIS), here (Lidar) or here (Radar).

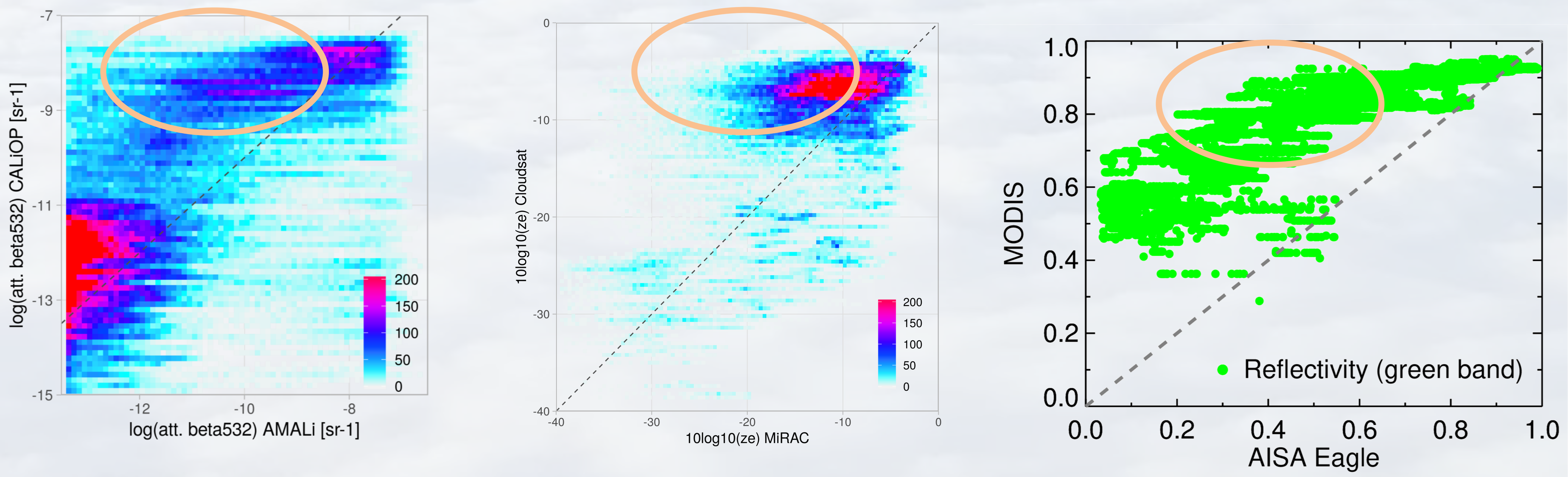
Thin clouds may be below noise level.
Compare the orange circles here (Lidar) and here (Radar).

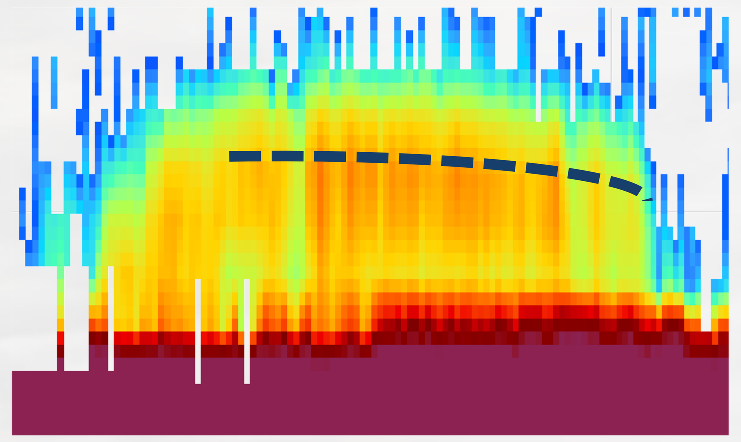


Blind zone CLOUDSAT → **precipitation** in the boundary layer is frequent and thus **often missed**
Here we only observe one case of a low, precipitating cloud.
However, for other scenes we frequently observe clouds below 800m precipitating ice. (e.g. 2 days earlier MECH 2020 p.19)

Overestimation of average **backscatter and reflectivity** due to non-uniform beam filling
Due to the nonlinear function between scattering particle distributions and resulting reflectivity, we get a higher reflectivity at the cloud edge from the coarser resolving satellite.
→ potential overestimation of quantities derived from satellite products

The **pattern in overestimation** of reflectivity appears to be very similar over **several instruments**.
(compare the top right distribution plot here (Lidar) and here (Radar) and the scatterplot here (passive VIS))





Overestimation of **cloud top** in CLOUDSAT due to the coarse resolution
(compare the darkblue dashed line here)
thus, also potential overestimation of ice content in liquid layer in synergetic retrievals from satellite for clouds above the blind zone of CLOUDSAT

Ice cover makes the retrieval of **liquid water** path in the Arctic very challenging.
(compare the high variability of the measurement in the North-West with the lower variability in the South-East here)

Modelling allows us to investigate processes leading to remote sensing signal
For this case study ICON LEM does not represent the situation well, yet. See first results and here and at SCHEMANN 2020.

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Data

Modis data : https://worldview.earthdata.nasa.gov/

AISA Eagle data :Ruiz-Donoso, Elena; Ehrlich, André; Schäfer, Michael; Jäkel, Evelyn; Wendisch, Manfred (2019): Spectral solar cloud top radiance measured by airborne spectral imaging during the ACLOUD campaign in 2017. Leipzig Institute for Meteorology, University of Leipzig, PANGAEA, https://doi.org/10.1594/PANGAEA.902150

ERA5-Daten: CDF copernicus data storage, pressure level data, download 28.4.2020, DOI: 10.24381/cds.bd0915c6

CALIOP and CLOUDSAT CDR data: AERIS/ICARE Data and Services Center: http://www.icare.univ-lille1.fr/archive?dir=CLOUDSAT/DARDAR-MASK.v2.11/2017/2017_05_27/

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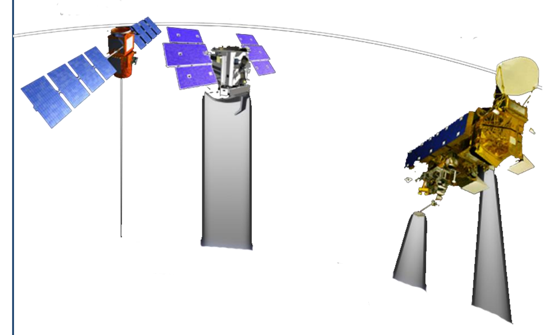
Images



Adjust image from NASA 2003 https://atrain.nasa.gov/historical_graphics.php

Adjusted image from
https://www.drawdecal.com/wp-content/uploads/2013/07/72s_DC3_8polar-300x251.jpg

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