Remote sensing of clouds in Ny-Ålesund (with radars)

RiS 10523, 12554

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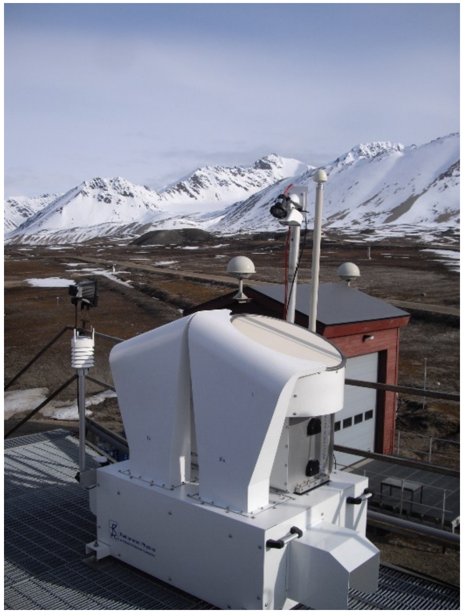
Cloud and precipitation radars at AWIPEV



94 GHz cloud radar (JOYRAD94 or MiRAC-A)
06/2016 – 10/2018
06/2019 –

→ **vertical distribution of clouds, precipitation (up to 12 km height)**

35 GHz cloud radar (NYRAD35)
10/2021 – 03/2024
02/2025 –

→ **vertical distribution of clouds, precipitation (up to 10 km height)**
→ **polarimetric variables**
→ **elevation scanning capability**
→ **in combination with 94 GHz cloud radar, info on ice habit, particle concentration and sizes**

continuous operation, 24/7

24 GHz Micro Rain Radar (MRR)
05/2017 –

→ **vertical distribution of precipitation in lowest 1 km**

Quicklook browser
https://atmos.meteo.uni-koeln.de/~hatpro/dataBrowser/dataBrowser3.html?site=Ny-Alesund&date=0&UpperLeft=Joyrad94-Overview&UpperRight=NyRAD35-Overview&LowerRight=MRR-IMProToo

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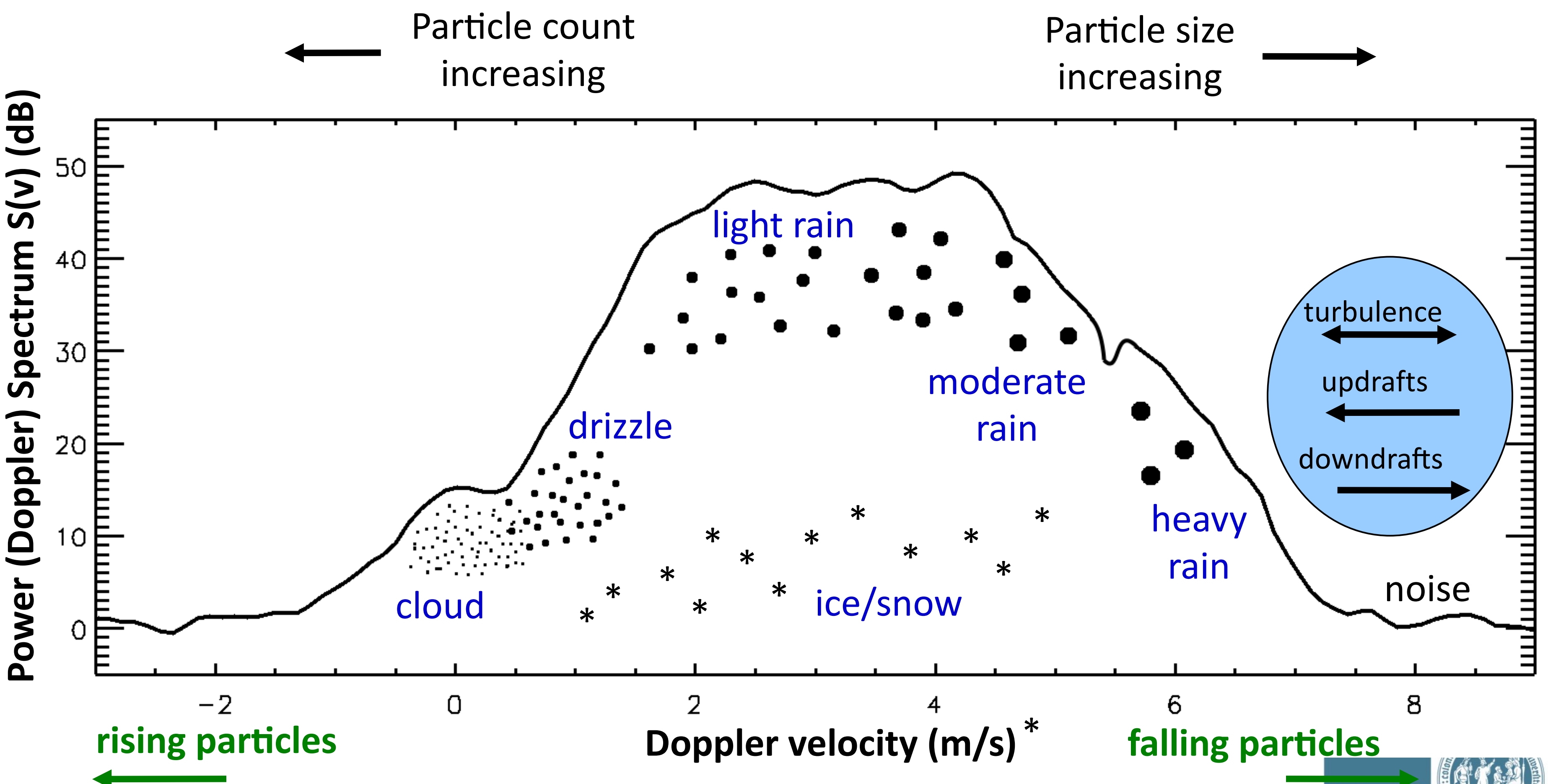
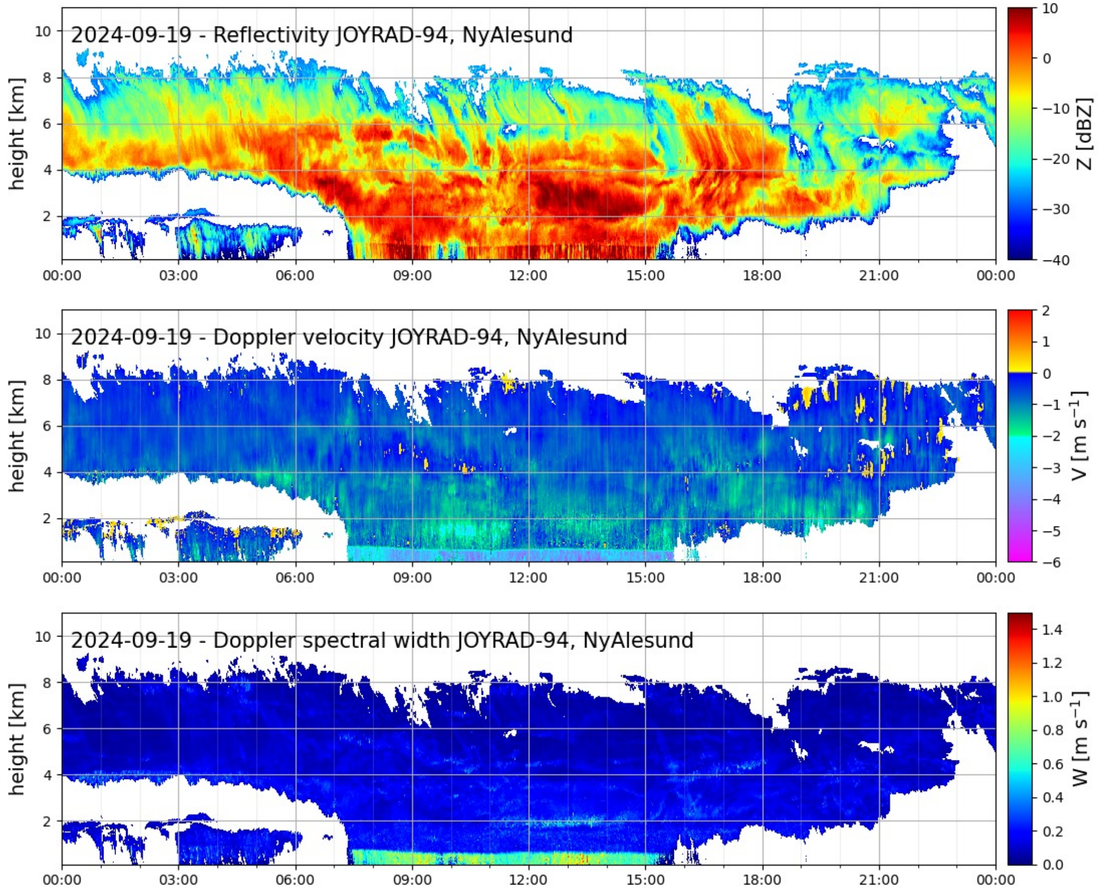
Cloud radar Doppler spectrum

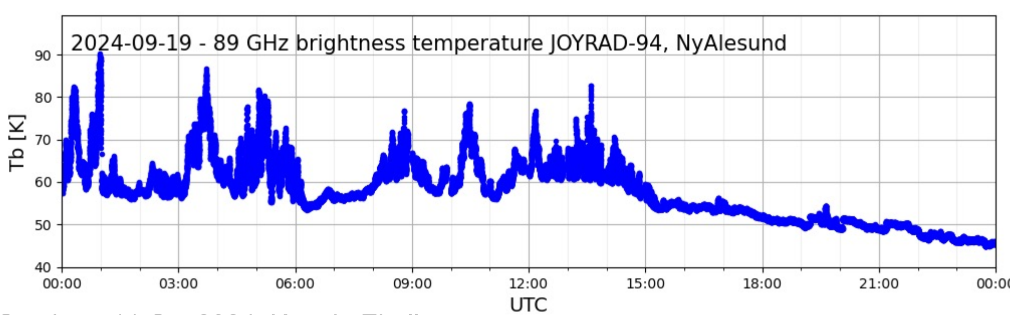
The Doppler spectrum S(v) is ordinarily regarded as a reflectivity-weighted distribution of the radial velocities of the scatterers in the pulse volume



* different conventions for pos/neg values

Cloud radar moments of Doppler spectrum





0th moment: mean received power

$$\bar{P} = \int_{-\infty}^{\infty} S(v) v^0 \, dv \propto Z$$

$$\rightarrow Z_e = 10\log\left(\frac{z_e}{1 mm^6/m^3}\right)$$

1st moment: mean Doppler velocity

$$\bar{v}_D = \frac{1}{\bar{P}} \int_{-\infty}^{\infty} S(v) v \, dv$$

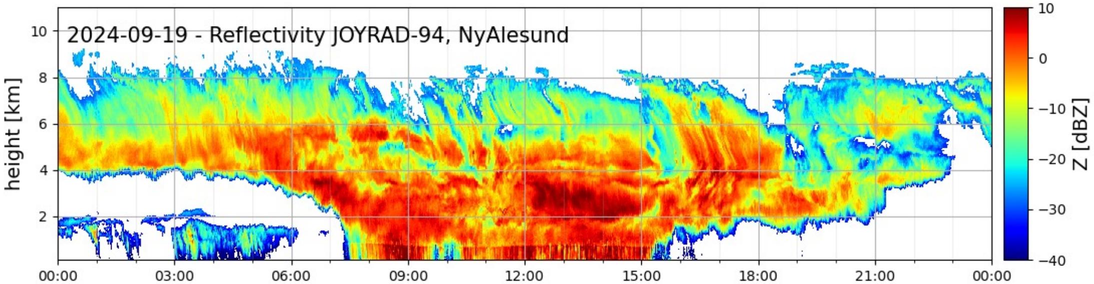
2nd centered moment: variance of Doppler velocity

$$\sigma_D^2 = \frac{1}{\bar{P}} \int_{-\infty}^{\infty} S(v)(v - \bar{v})^2 \, dv$$

passive 89 GHz channel
→ detection and amount of column liquid water

Cloudnet products

https://cloudnet.fmi.fi



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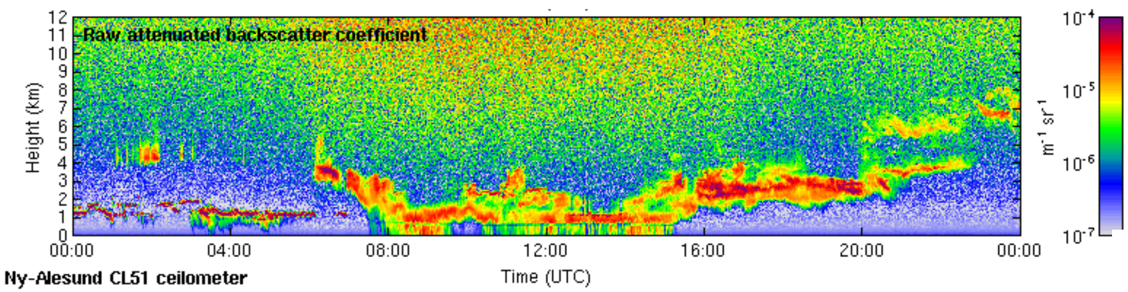

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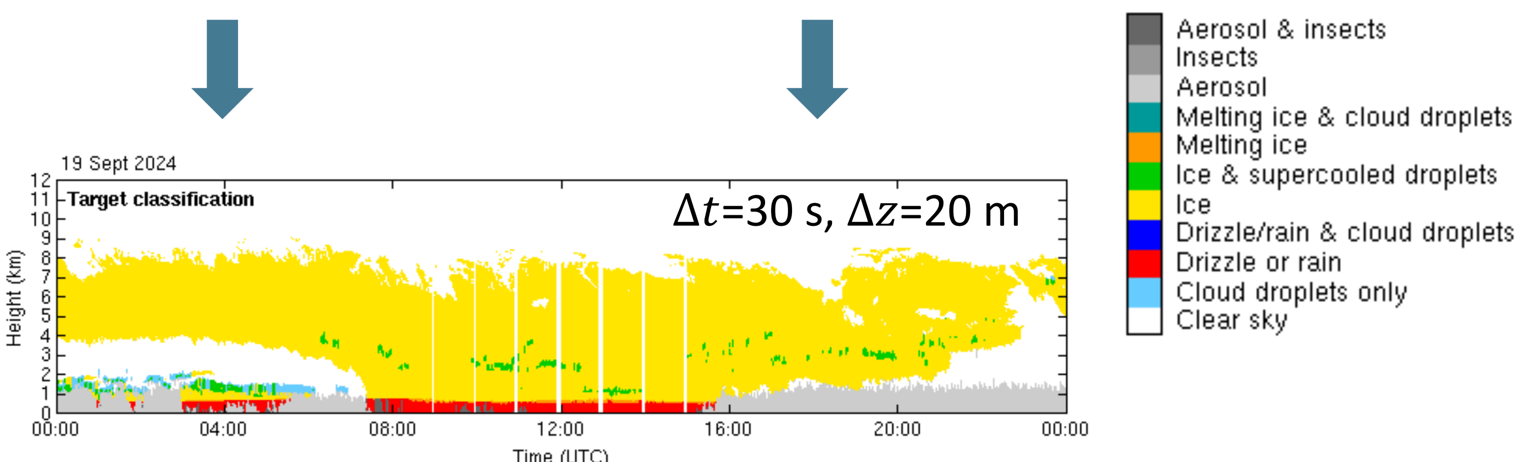
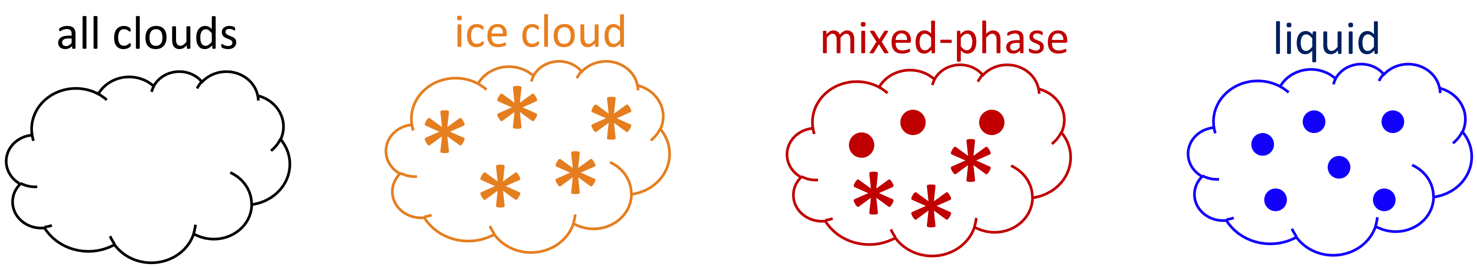
temperature and humidity profiles from NWP model

microwave radiometer liquid water path

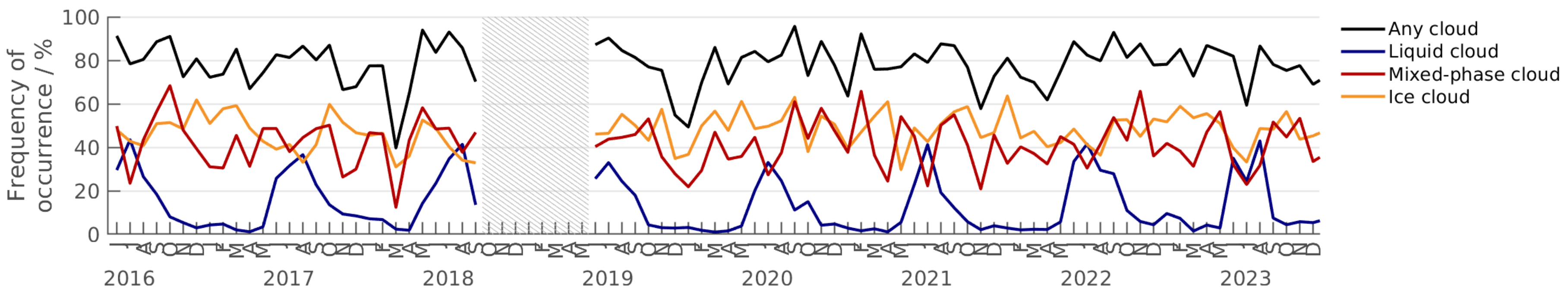


Illingworth et al. (2007)

Cloud occurrence at Ny-Ålesund



Monthly frequency of cloud occurrence at Ny-Ålesund June 2016 - Dec 2023



adapted/updated from Wendisch et al. (2023)

average monthly cloud occurrence

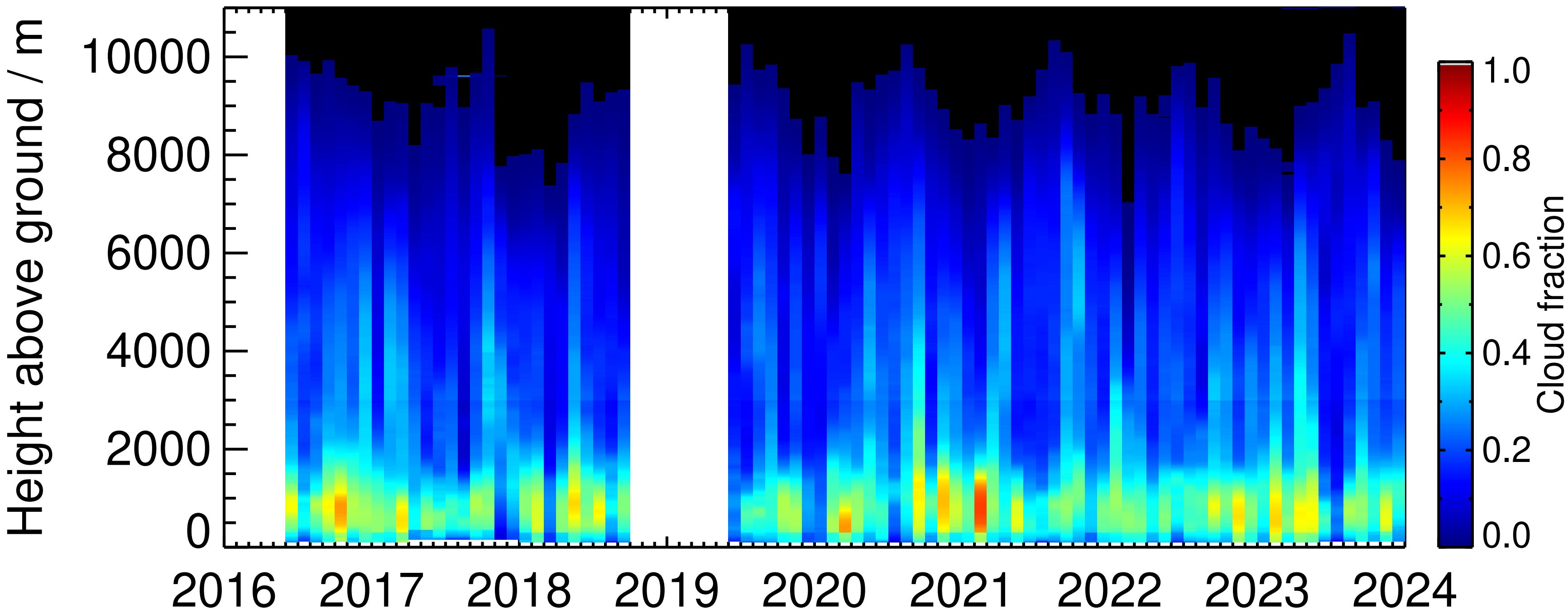
any cloud	78.2 %
liquid	13.3 %
ice cloud	47.5 %
mixed-phase	41.8 %

→ liquid water in clouds frequently occur in winter, even at temperatures well below 0°C!

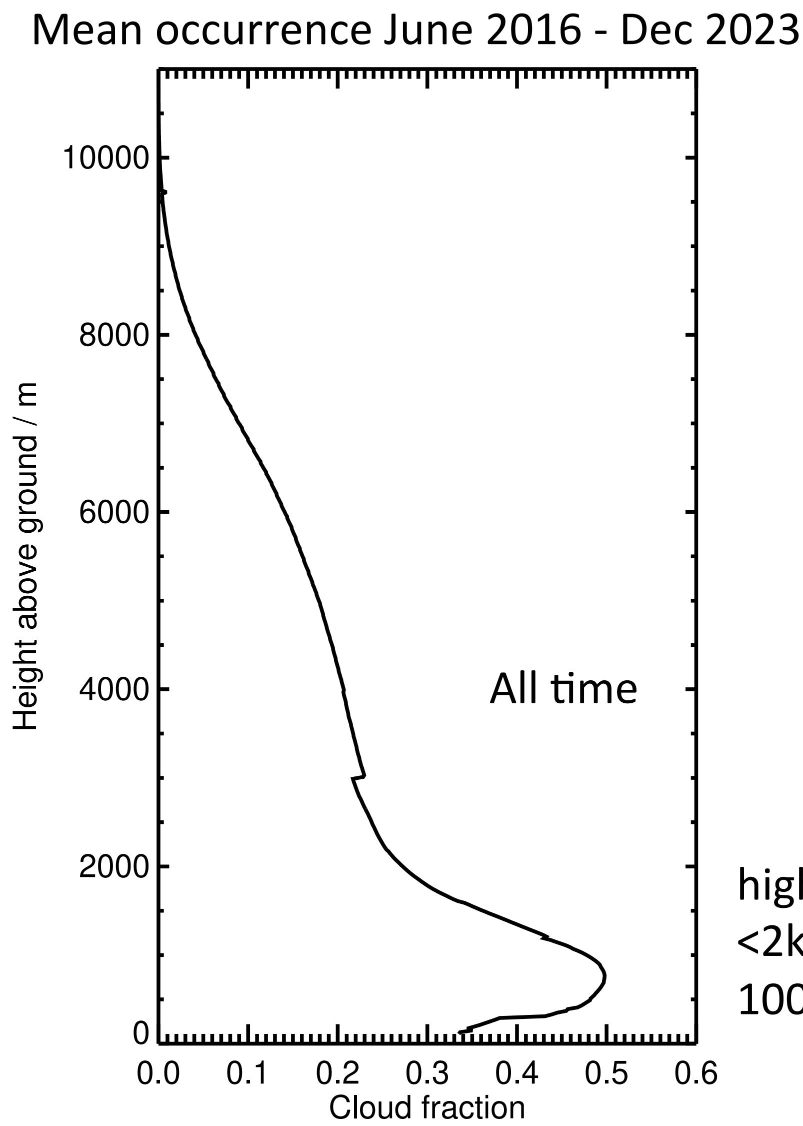
Vertical hydrometeor occurrence

attention: no discrimination between cloud and precipitation

Monthly frequency of hydrometeor occurrence at Ny-Ålesund June 2016 - Dec 2023



Vertical hydrometeor occurrence



highest cloud occurrence <2km: 50% between 500 – 1000 m

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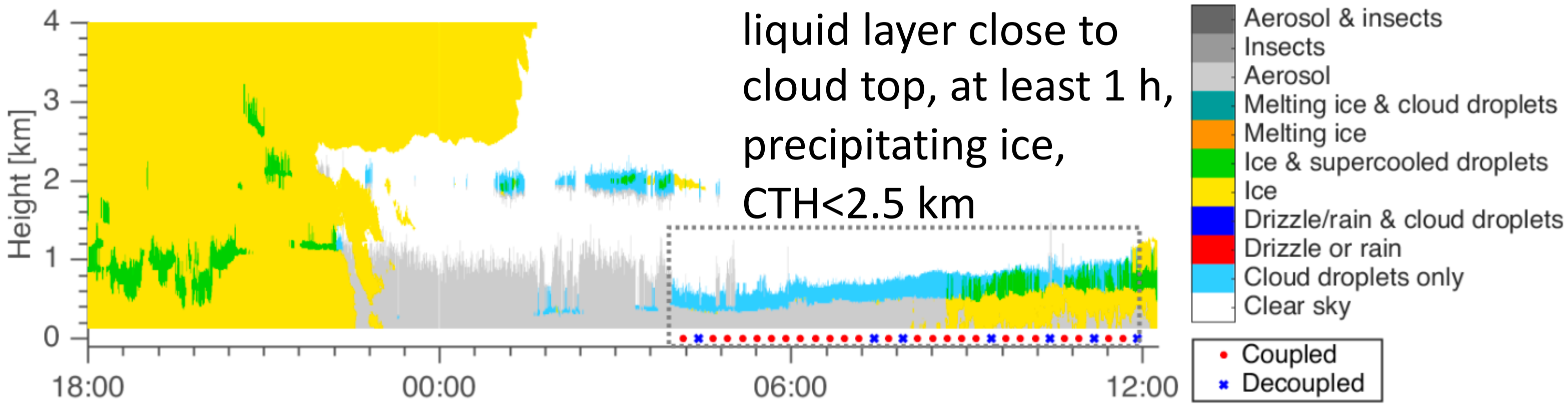
Persistent low-level mixed phase clouds (P-MPCs)



liquid layer close to cloud top, at least 1 h, precipitating ice, CTH<2.5 km

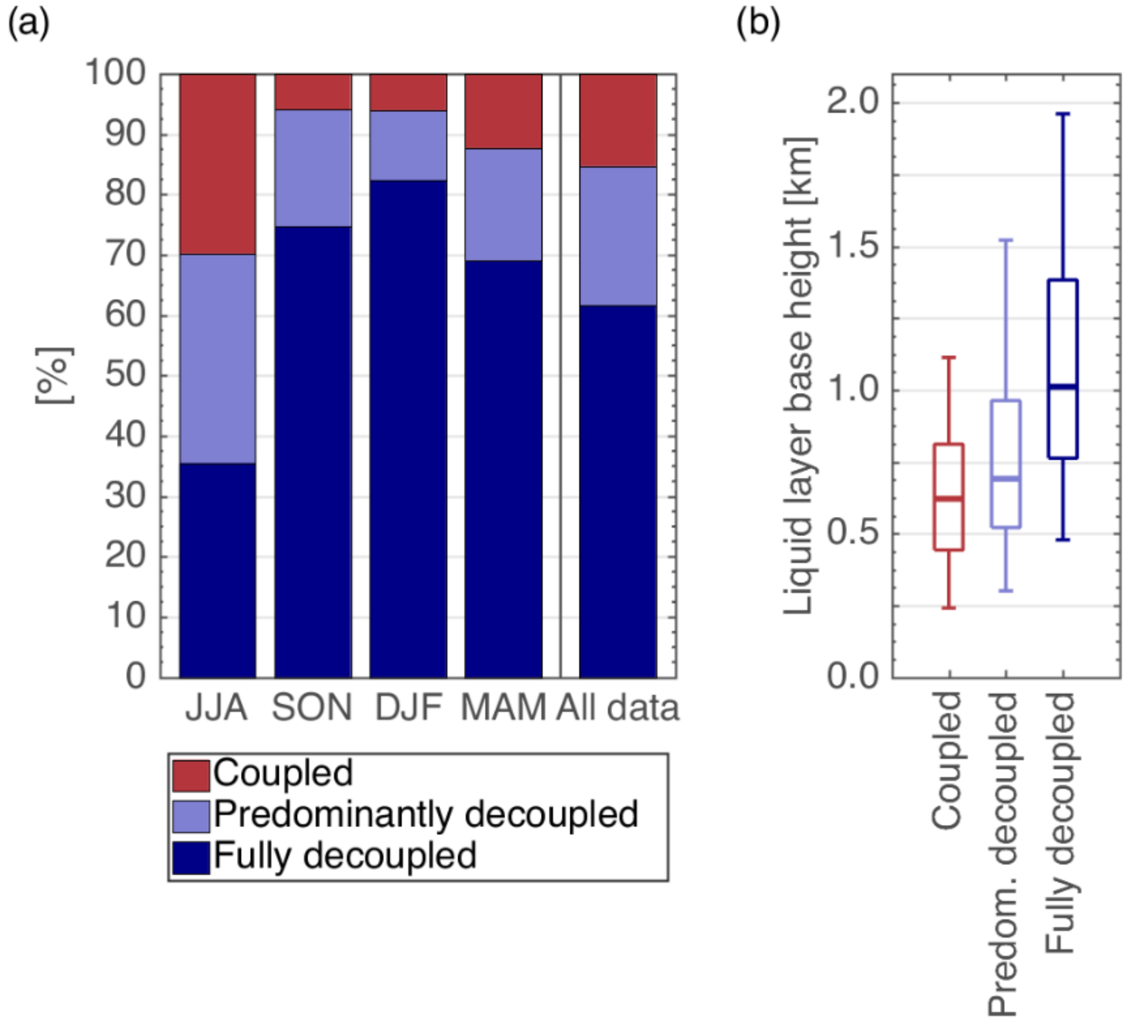
Gierens et al. (2020)

- Analysis period: June 2016 – October 2018
- auxiliary information from microwave radiometer, ceilometer, radiosondes, reanalysis (→ circulation weather type classification)

- P-MPCs occur 23% of the time, most common in summer (32%)
- most often during westerly free-tropospheric winds

Impact of surface coupling state on P-MPCs

- coupling state from θ-profile from surface obs, MWR, radiosonde
- 63% of P-MPCs decoupled
  → particularly in autumn and winter (higher lower tropospheric stability)
- 15% coupled
  → higher values in summer (~30%)
- coupled P-MPCs are closer to the surface
- coupled P-MPCs have a higher LWP



Gierens et al. (2020)

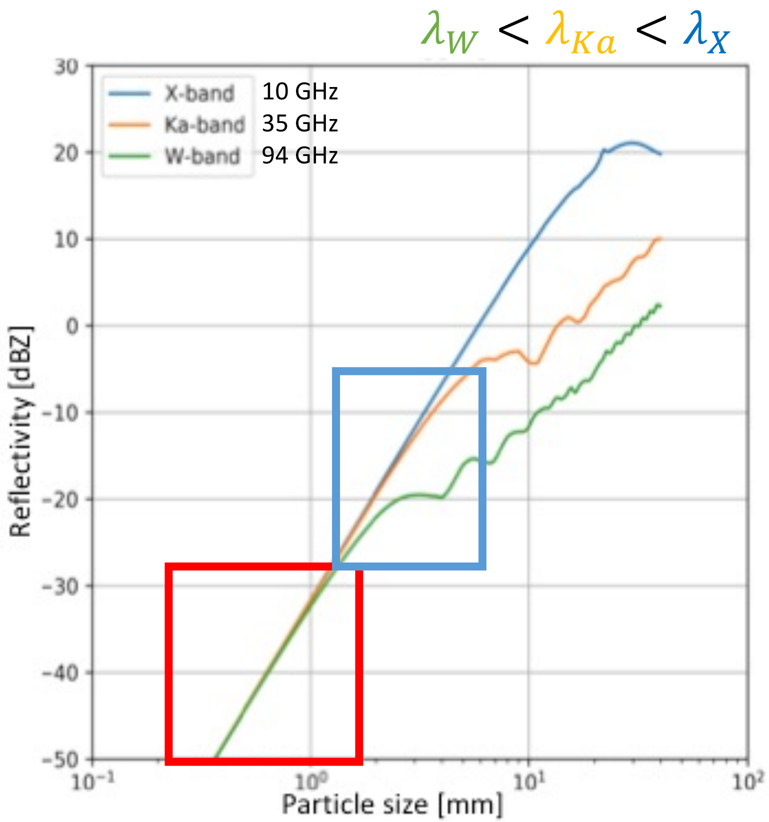
Precipitation formation in low-level MPCs

- role of individual ice-growth processes (aggregation, riming,..) still unclear
- Doppler radar obs. at mutliple wavelength can constrain the microphysical processes → particle size, fall speed

How?

Radar reflectivity factor and scattering

- (Equivalent) Radar reflectivity factor (Z_e) is defined in a way that Z_e is independent of frequency (for Rayleigh scattering! → $D \ll \lambda$)
- Once λ≈D, resonance effects cause a slower and more complex increase of Z_e with size



- Transition region of two frequencies, with one still in the Rayleigh regime and the other one not
→ information on particle size

Dual-wavelength ratio

- dual-wavelength ratio DWR (in dB) gives information about mean particle size

$$DWR_{\lambda_1,\lambda_2} = 10log\frac{z_{e,\lambda_1}}{z_{e,\lambda_2}}$$

(with z_e in linear units of mm^6/m^3)

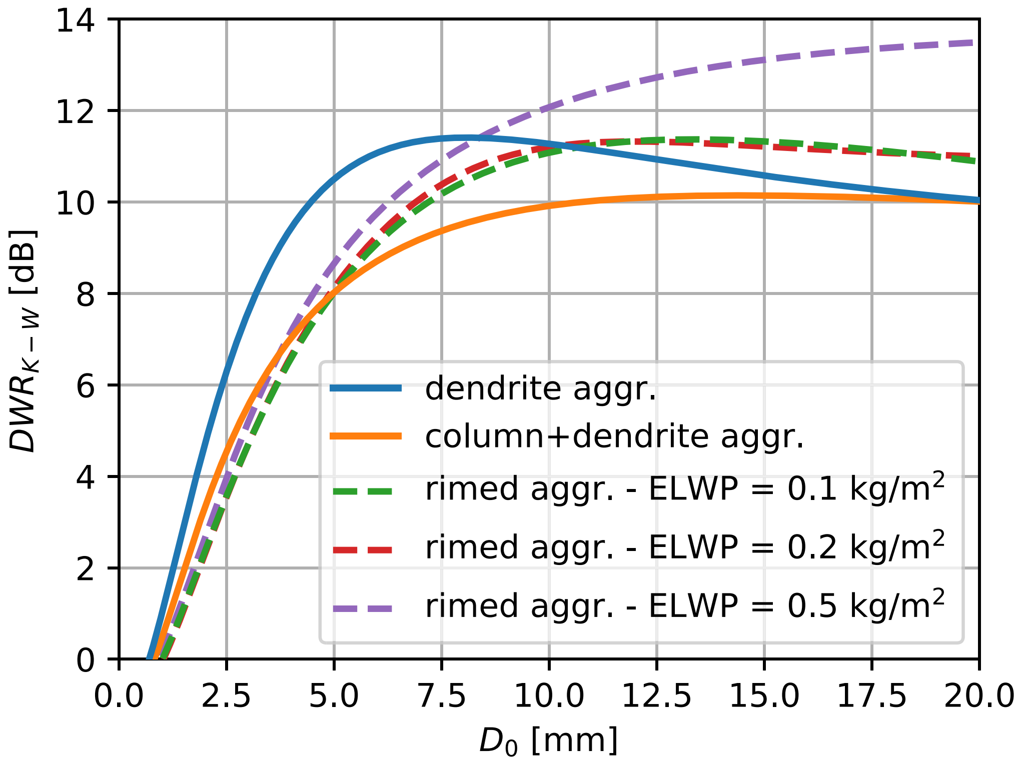
$\lambda_1 > \lambda_2$

$$DWR_{\lambda_1,\lambda_2} = Z_{e,\lambda_1} - Z_{e,\lambda_2}$$

(with Z_e in dBZ)

Reminder:

$$Z_e = 10\log\left(\frac{z_e}{1\,{mm^6}/{m^3}}\right)$$



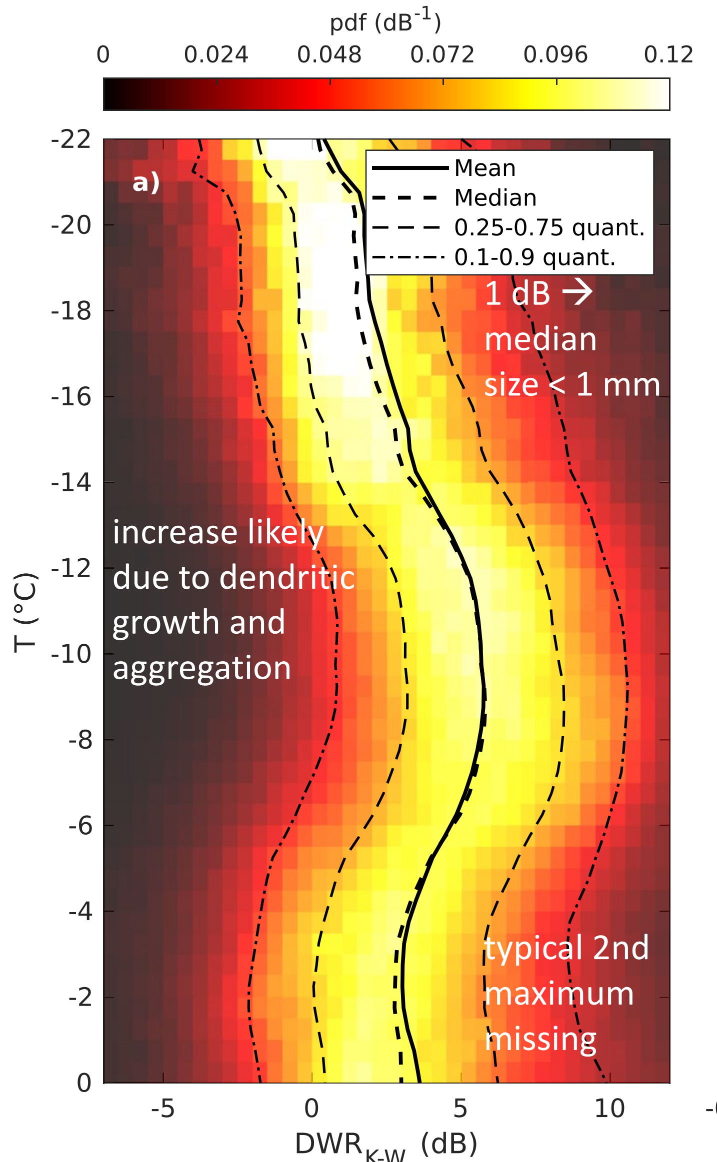
Chellini et al. (2022)

→ relation between DWR and particle size is not unique

→ depends on particle shape, density, and PSD shape

→ DWR is also enhanced by differential attenuation which accumulates with increasing distance from the radar (can be corrected)

DWR and T in low-level MPCs



Chellini et al. (2022)

- 3-year data set
- enhanced DWR signatures in low-level MPCs whose mixed-phase layer is at temperatures between −15 and −10°C
  → enhanced aggregation due to mechanical entanglement of ice particles with dendritic branches
- dynamical processes relevant to the formation of these larger aggregates
  → *Chellini and Kneifel (2024)*

Low-level mixed-phase clouds at the high Arctic site of Ny-Ålesund: a comprehensive long-term dataset of remote sensing observations
Chellini et al. (2023a,b)

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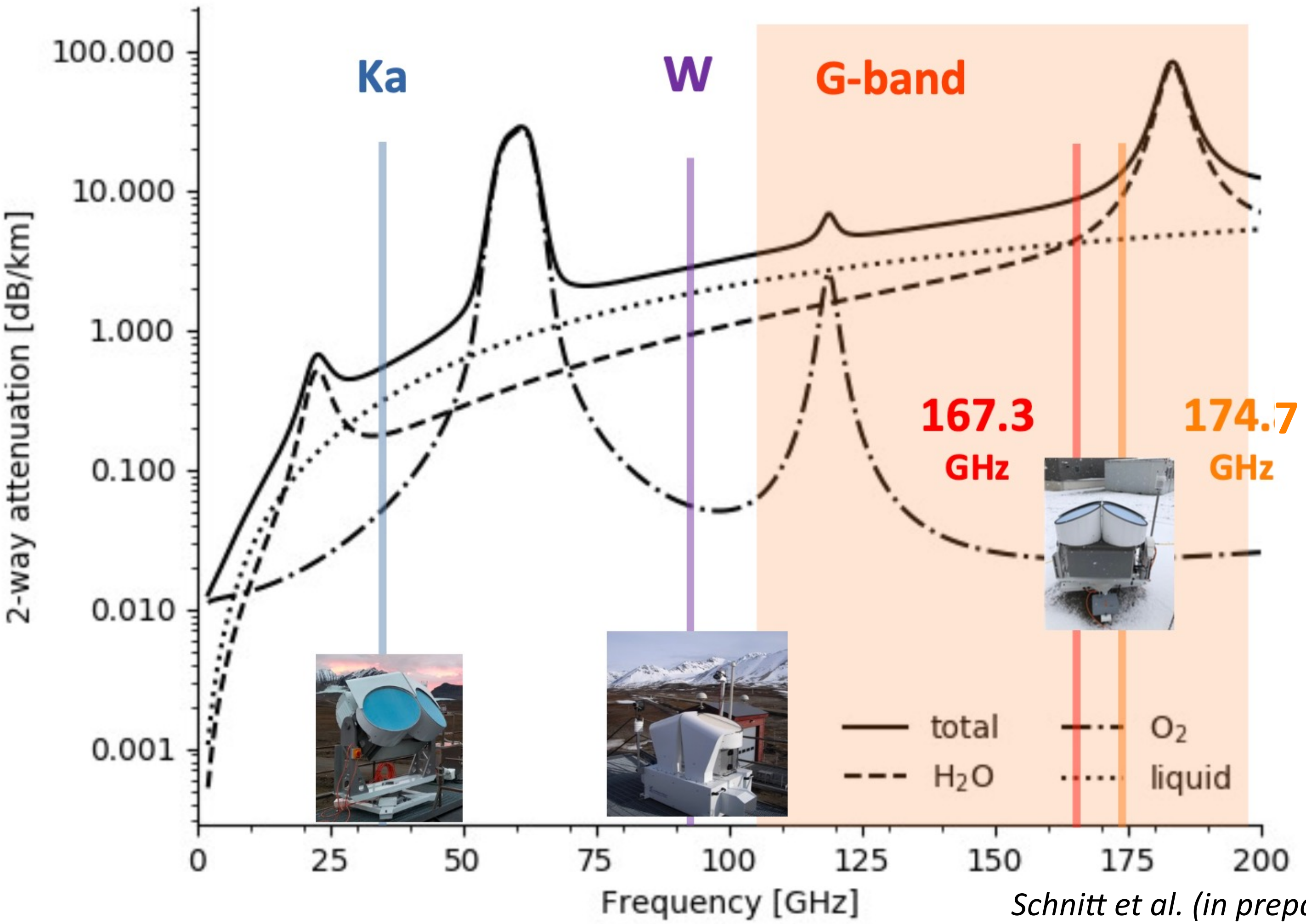
New measurement highlight

GRaWAC: G-band Radar for Water Vapor and Arctic Clouds

- Differential Absorption Radar (DAR)



Schnitt et al. (in preparation)

→ water vapor amount below cloud base
→ vertical profile of water vapor in cloud layer

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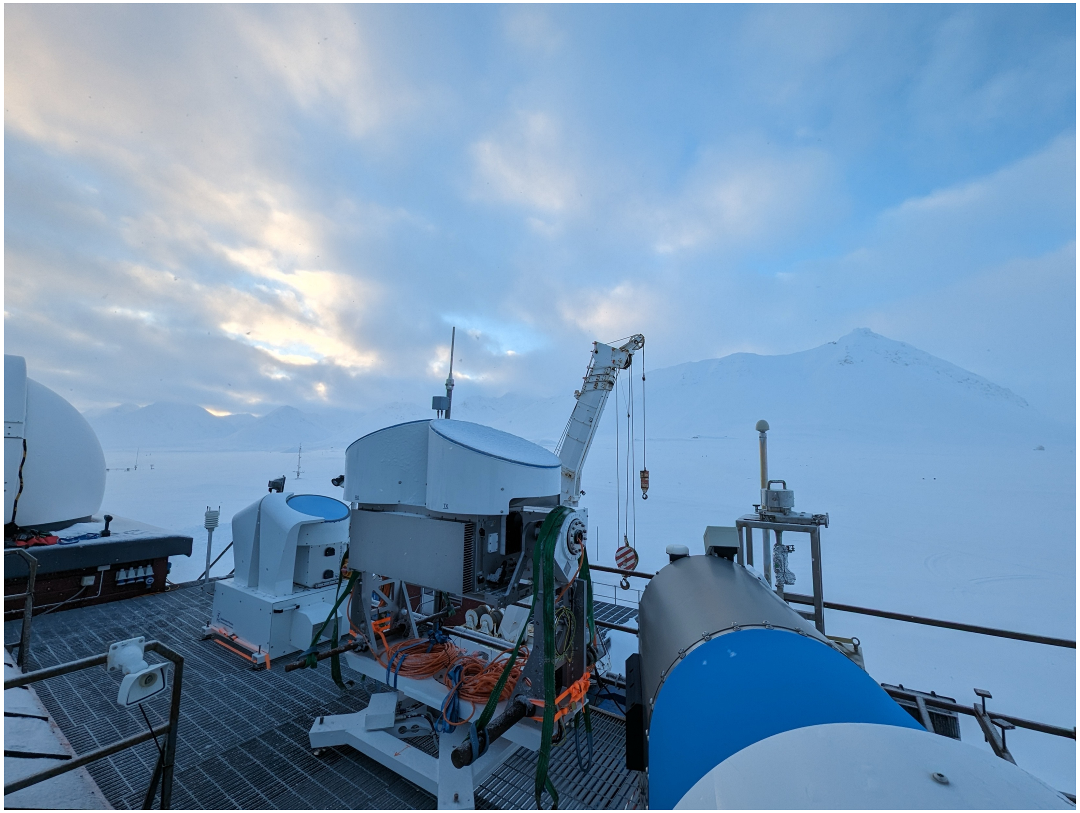
Outlook: campaign activities

Intensive Observation Period: Water Vapor in all its phases IOP4H2O (with University of Leipzig), Feb–March 2025, Ny-Ålesund
→ 35 GHz (K), 94 GHz (W), and 167/174 GHZ (G) radar
→ additional radiosonde launches



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Schnitt et al. 2024 in prep for AMT: GRaWAC: **G-band Radar for Water Vapor Profiling and Arctic Clouds**, in preparation for *Atmos. Meas. Tech.*