Investigation of Ice Microphysics using Simultaneous Measurements at C- and Ka-Band

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DLR

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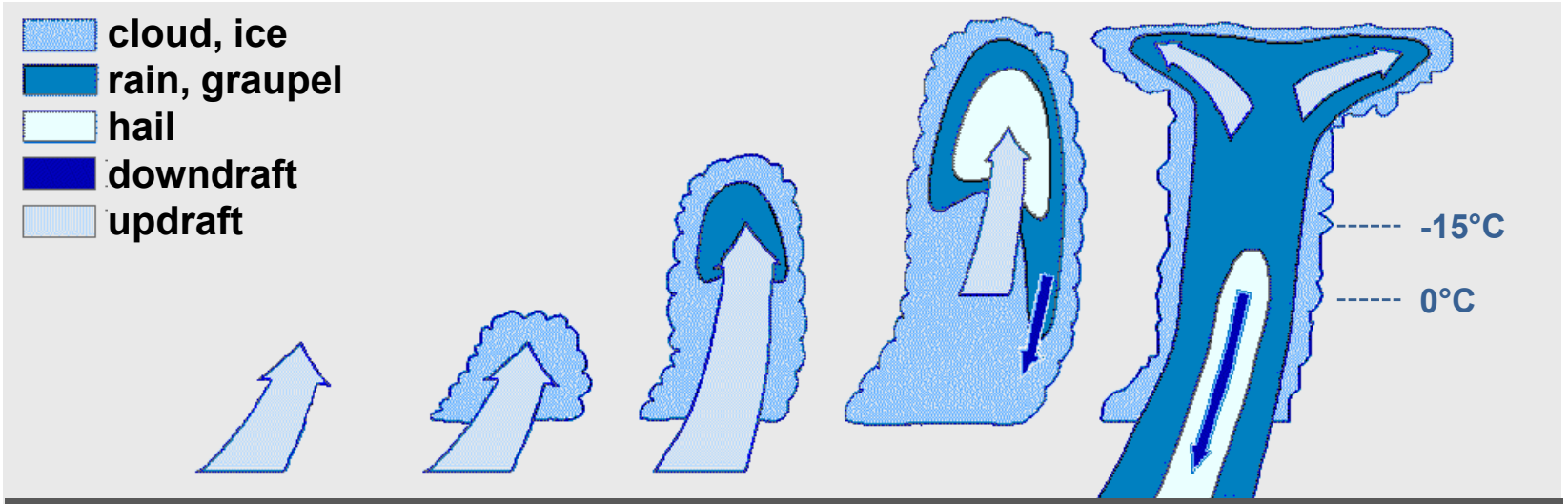
Understanding Precipitation Initiation in Mixed Phase Clouds



development of an single isolated convective cell

after Höller, 1994

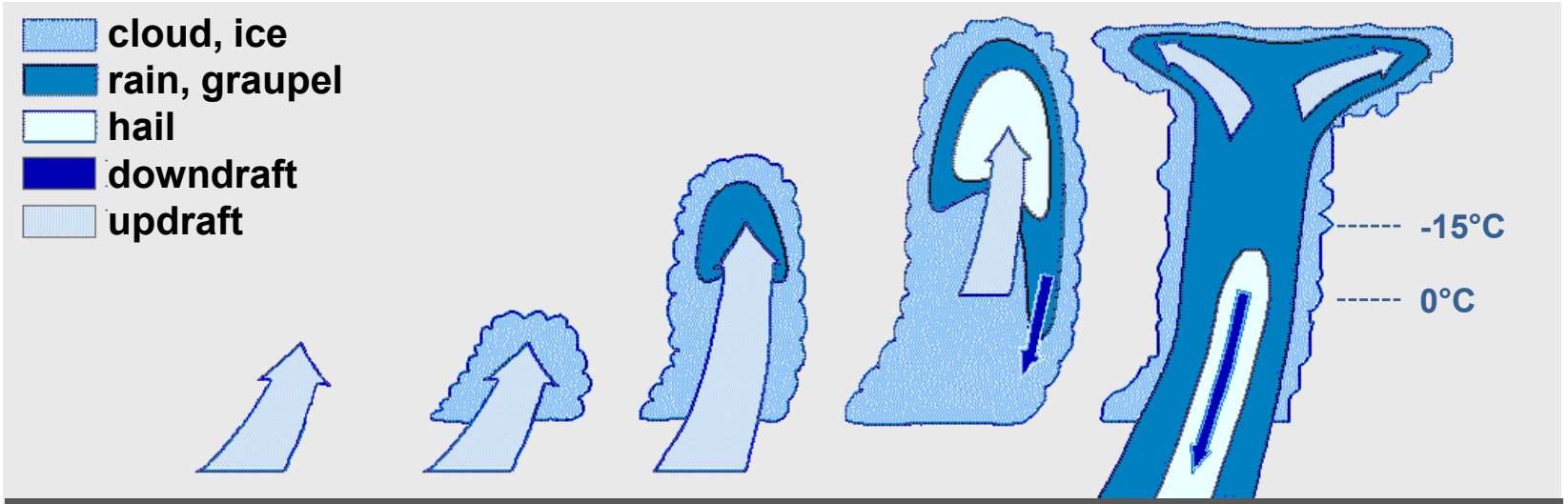
Key Questions:

- when does precipitation initiation take place?
- when will ice be formed?
- how is precipitation initiation related to ice formation?

Answer from Radar Point of View:

- dual-polarization hydrometeor classification
- reflectivity gives water / ice content
- ZDR, KDP, … tells about particle habit

Understanding Precipitation Initiation in Mixed Phase Clouds



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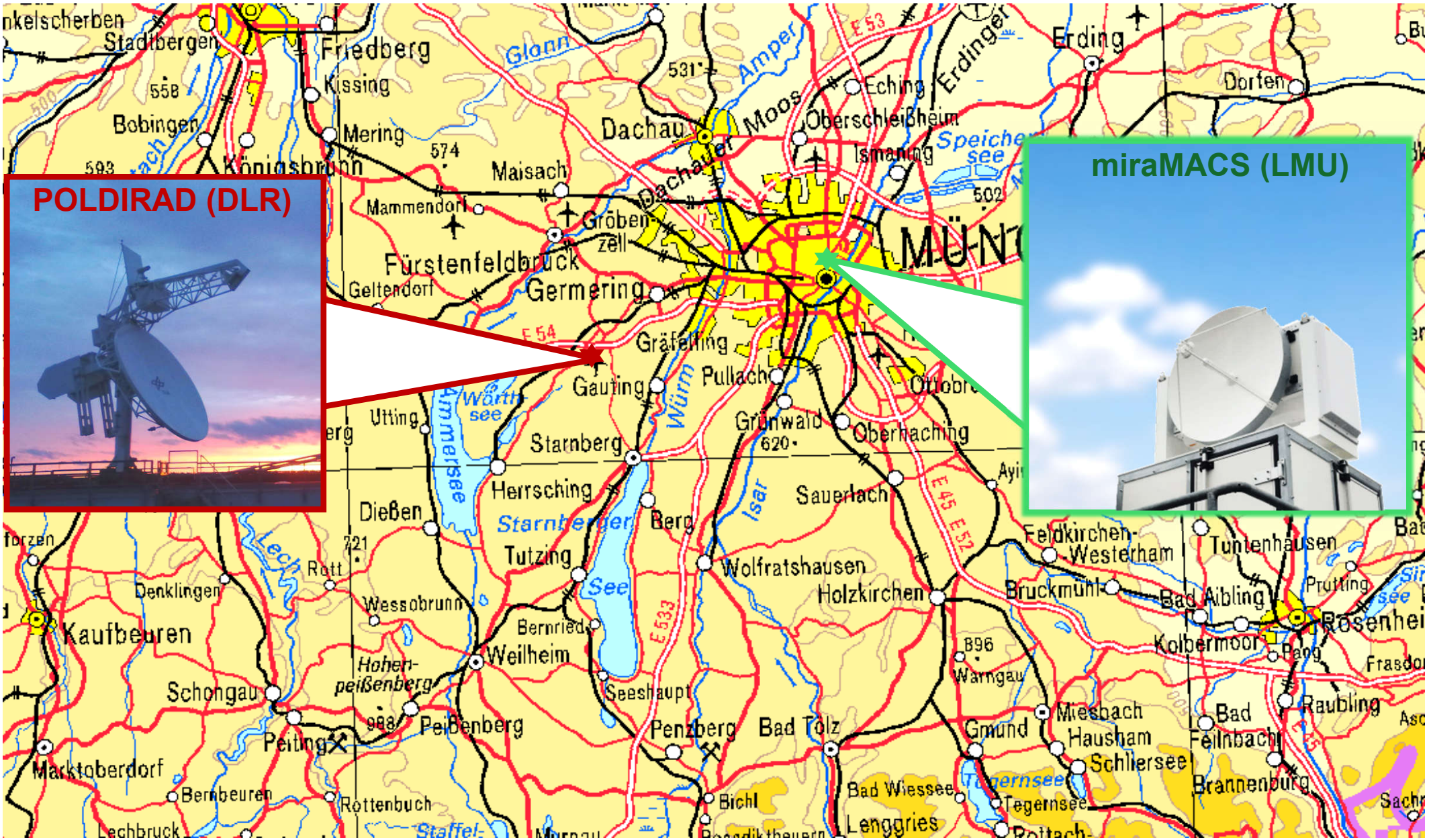
Limitation:

- C-band radar is not sensitive enough for small cloud particles
- cloud radar (Ka- or W-band) is limited in range and suffers from attenuation
- both can derive only partly microphysical quantities or particle habits

Coordinated Measurements Poldirad – MIRA35



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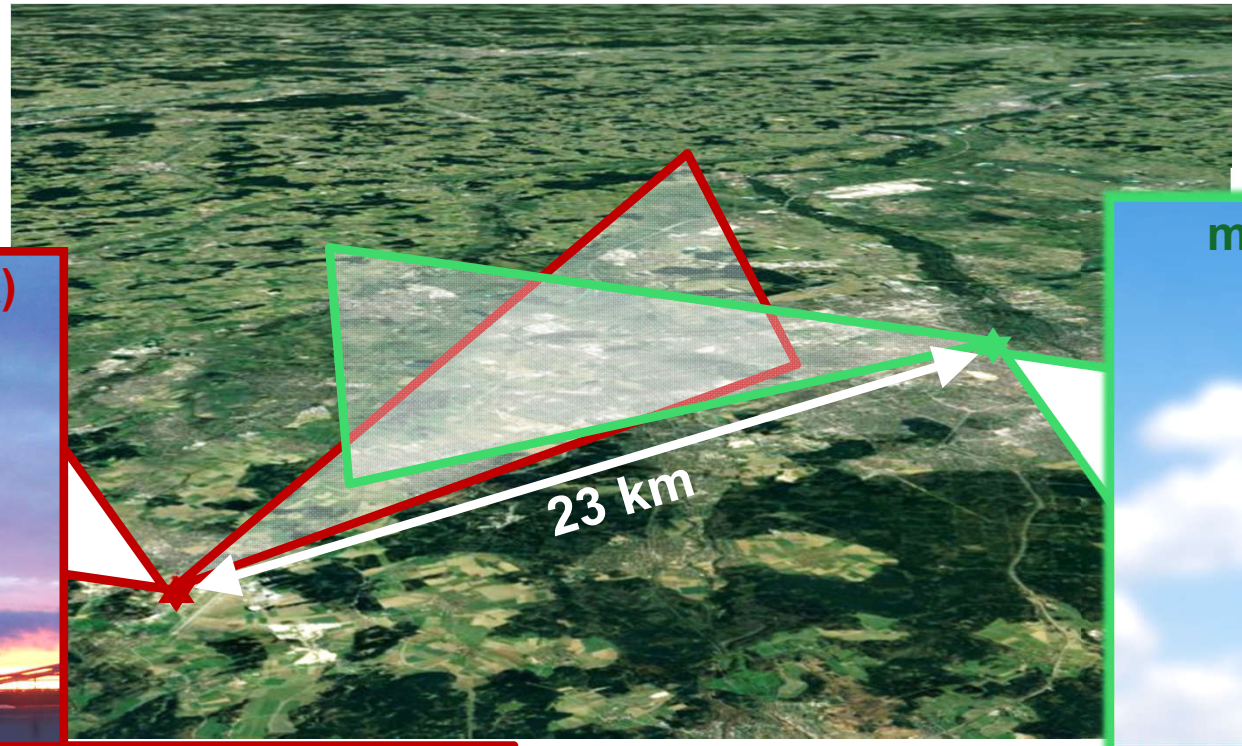


POLDIRAD (DLR)

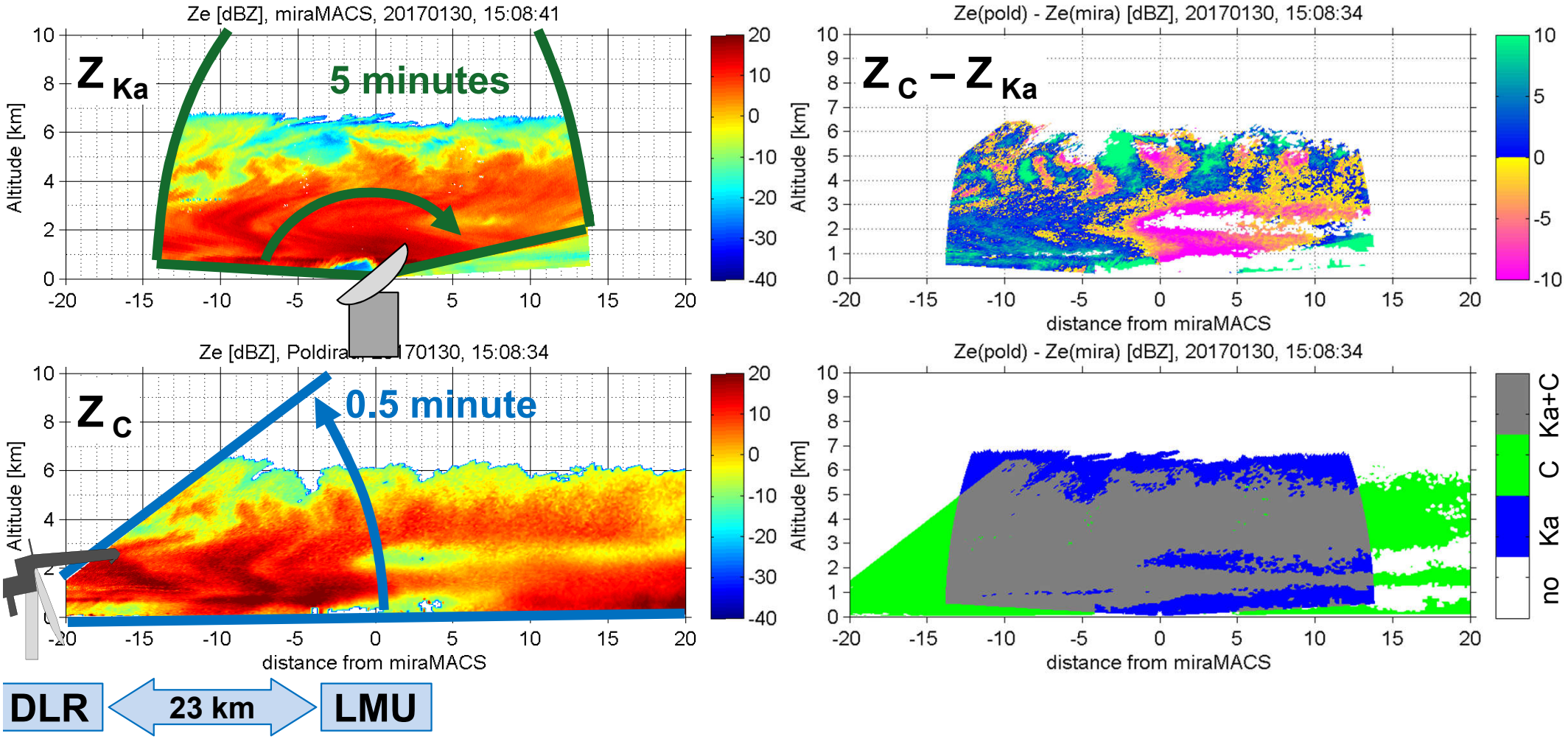
- C-band weather radar (5.5 GHz, 250 kW)
- operated at DLR Oberpfaffenhofen
- 4.5 m antenna 1° beam-width
- range res. 150 m, max 120 km
- full polarimetric (STAR and AltHV) (ZDR, LDR, KDP, rho_{HV})

miraMACS (LMU)

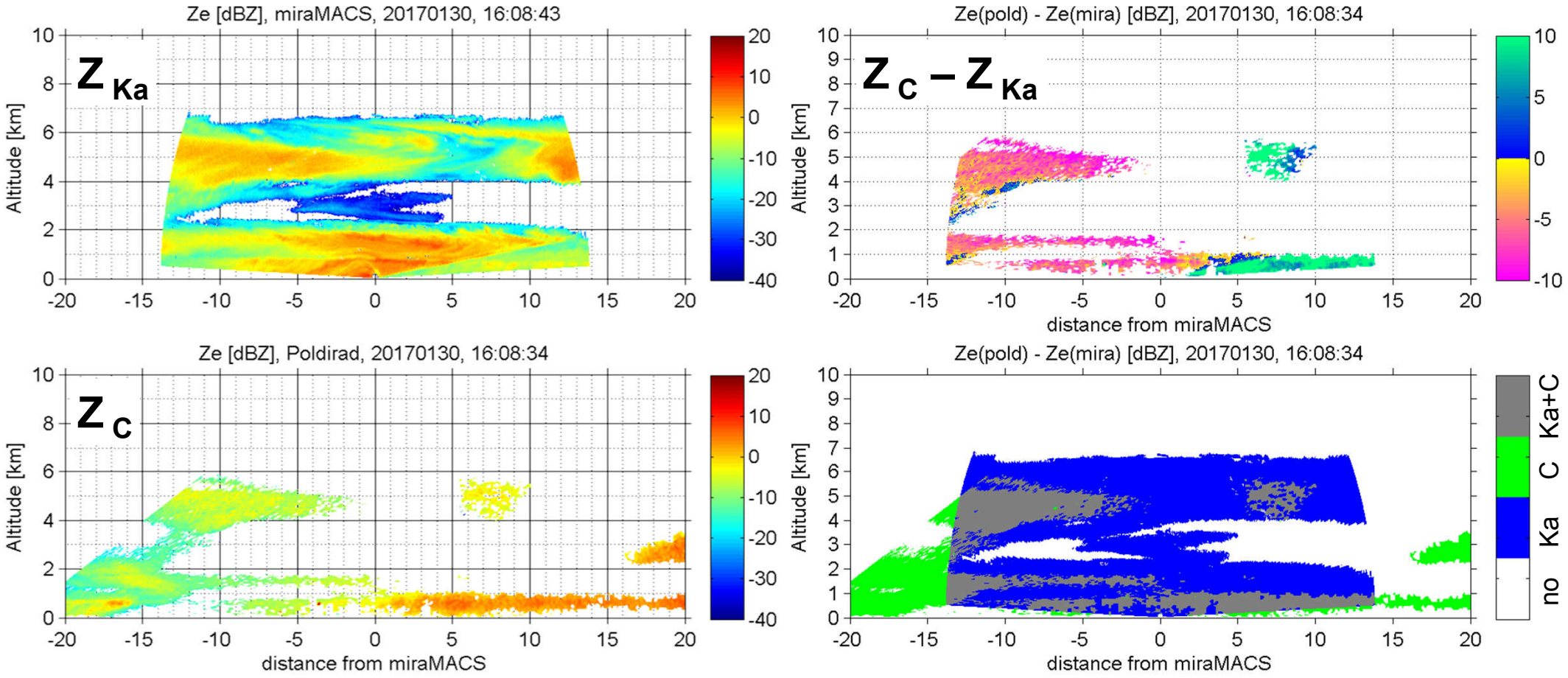
- Ka-band cloud radar (scanning) (36 GHz, 30 kW)
- operated at LMU Munich city
- 1 m antenna 0.6° beam-width
- range res. 30(60) m, max 15(30) km
- linear depolarization ratio LDR

STAR: simultaneous transmit and receive
AltHV: alternate transmit and receive horizontal and vertical

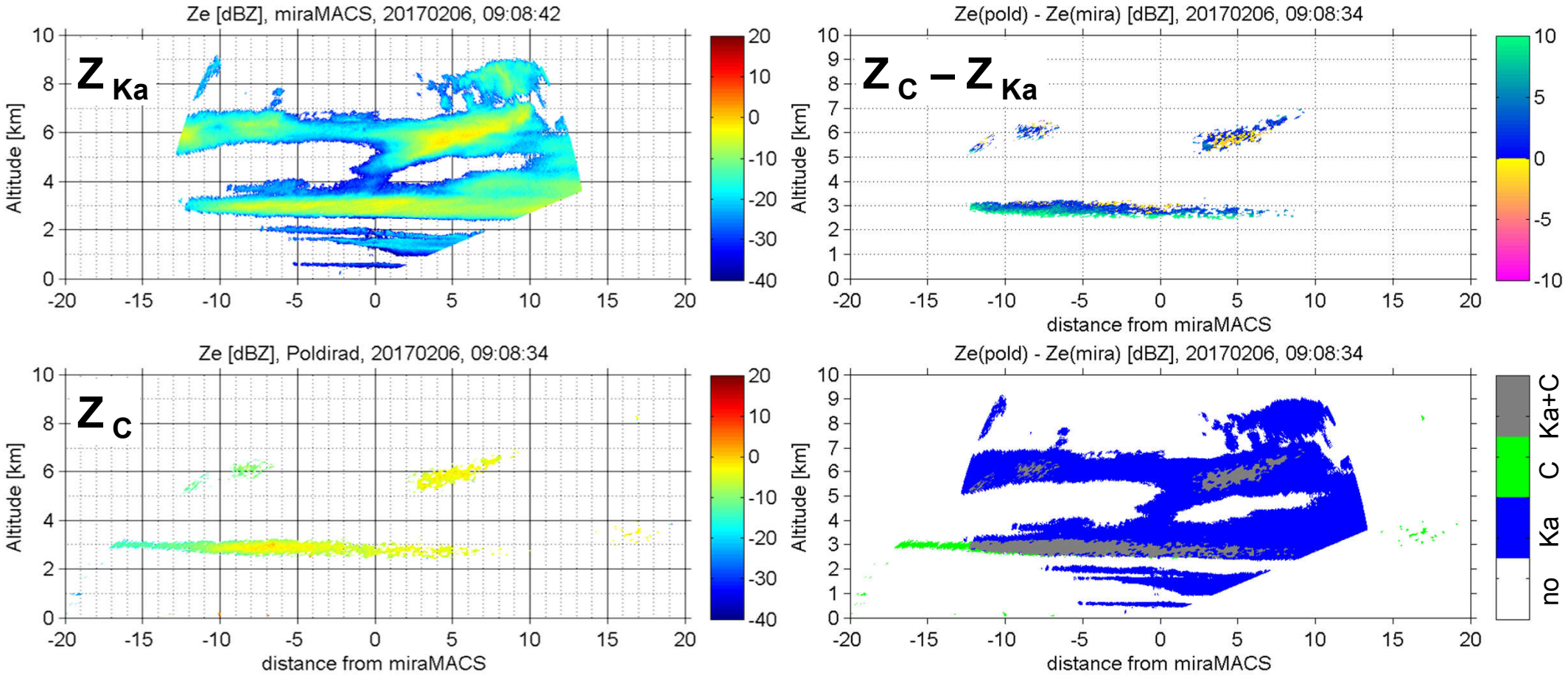
Example Measurement 2017-01-30 15:08



Example Measurement 2017-01-30 16:08



Example Measurement 207-02-08 09:08

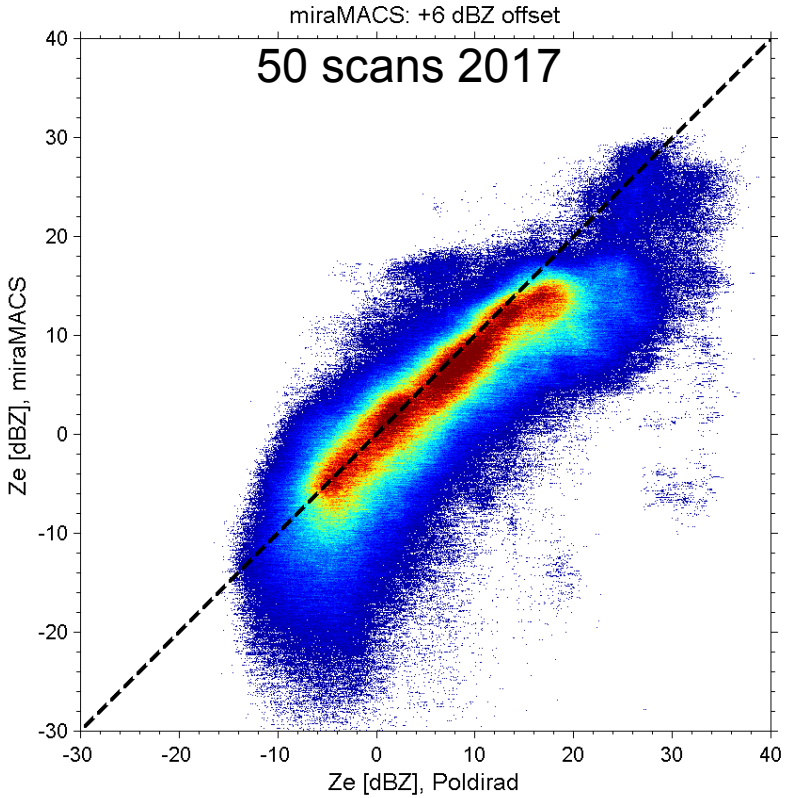


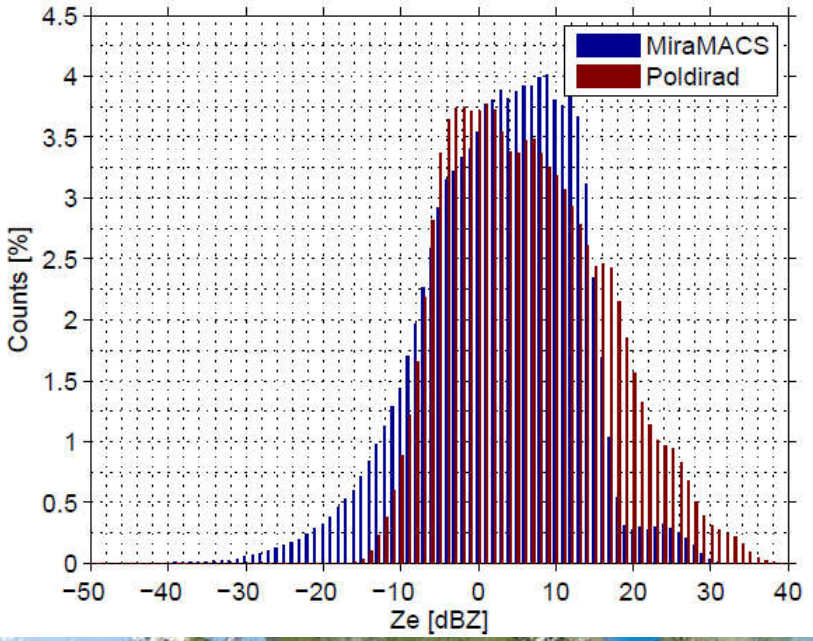
Sensitivity Issue – MDS

Minimum detectable/discernable signal (MDS):

- C-band POLDIRAD:
  (1 µs pulse, 64 samples)
  ~ -26 dB at 5 km
  ~ -17 dB at 15 km

- Ka-band miraMACS:
  (0.2 µs pulse, 256 samples)
  ~ -40 dB at 5 km
  ~ -31 dB at 15 km





Towards Ice Particle Effective Radius

Effective Radius commonly used for optical remote sensing
(Lidar or passive remote sensing with satellites)

$$r_{eff} = \frac{m(3)}{m(2)} = \frac{\text{volume}}{\text{area}} \qquad r >> \lambda$$

Hansen (1971)

Schumann et al. (JAS, 2011):

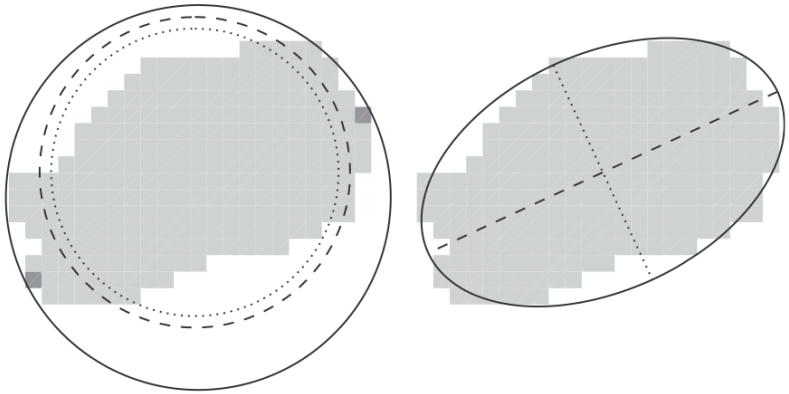
- *"The effective particle radius is defined such that the extinction coefficient (optical depth) is proportional to the ice water content (IWC) [ice water path (IWP)] divided by the effective radius (Hansen and Travis 1974; Garrett et al. 2003)"*
- *"While the volume mean radius can be computed for given IWC, ice bulk density, and number of ice particles, the effective radius depends on details of the particle habits and the particle size distribution (PSD) (McFarquhar and Heymsfield 1998)"*

Towards Ice Particle Effective Radius

Mass-size relationship

- spheroid approximation
  (Hogan et al., 2011)

  aspect ratio 0.6



- mass approximation
  based on various world-wide field campaigns
  (Brown and Francis, 1995)

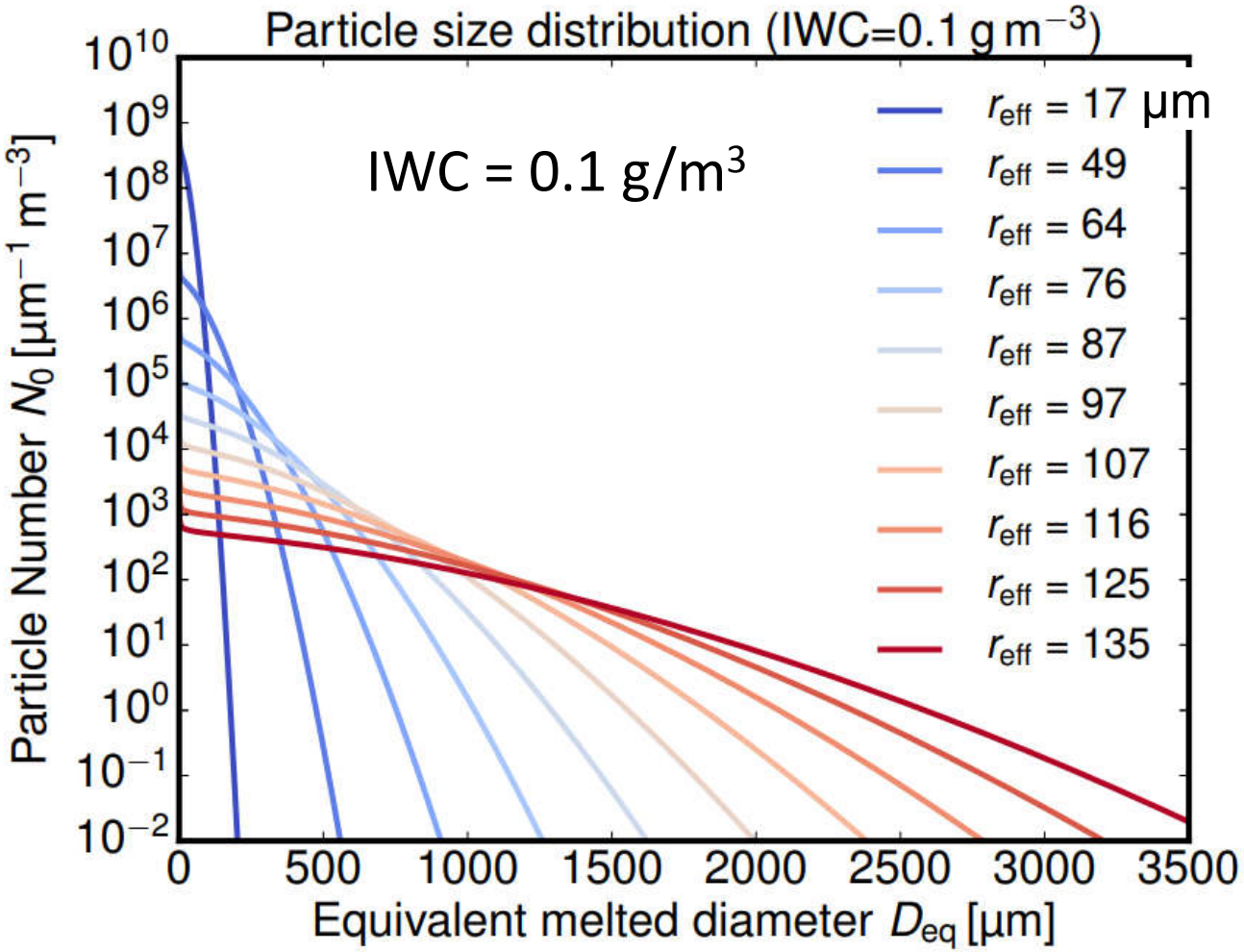
$$M(D) = 1.677\ e^{-1}\ D^{2.91} \qquad D <= 0.01\ cm$$
$$M(D) = 1.66\ e^{-3}\ D^{1.91} \qquad 0.01 < D <= 0.03\ cm$$
$$M(D) = 1.9241\ e^{-3}\ D^{1.9} \qquad D > 0.03\ cm$$

Towards Ice Particle Effective Radius

Particle size distribution

modified gamma function fitted to same in-situ data used for *M(D)* normalized by the volume-weighted diameter D_m and the intercept parameter N_0

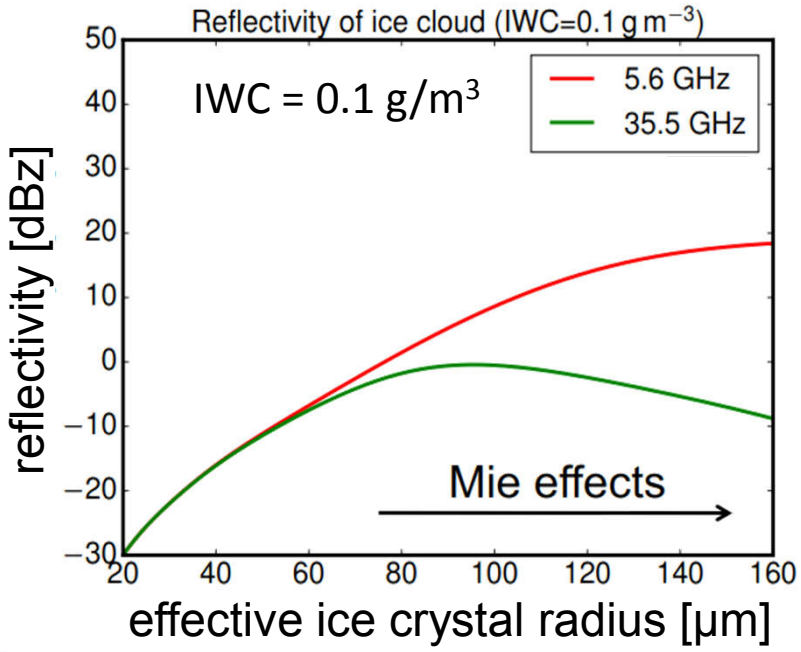
(Delanoë et al., 2014)

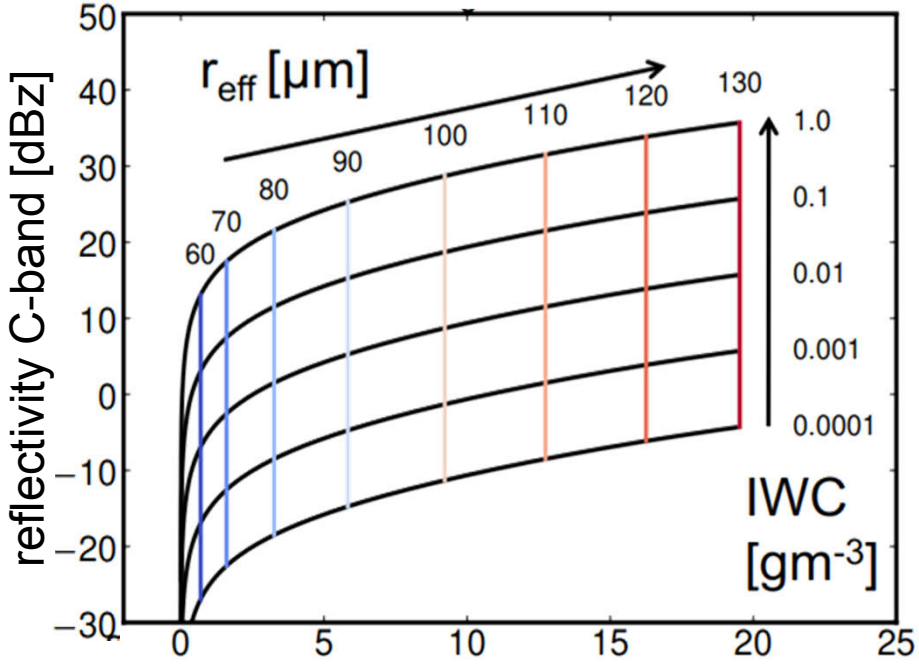


Towards Ice Particle Effective Radius

Particle size sensitivity of the Dual Wavelength Ratio

- Mie effects cause lower reflectivities for larger r_{eff}
- dual wavelength ratio (DWR) for retrieval of effective radius
- reflectivity (C-band) for retrieval of ice water content (IWC)
- attenuation is negligible for ice





Multi-Wavelength Microphysics Retrieval

Dual-polarization C- and Ka-band Retrieval:

- dual-wavelength reflectivity ratio → effective radius of ice particles
- reflectivity (long wavelength) → ice water content IWC
- dual-polarization → hydrometeor classification
  → particle habit

Lessons learned:

- calibration of both radars essential
- optimizing of C-band sensitivity necessary
- scan timing / advection to be considered
- additional W-band radar could improve retrieval