Study on Microphysics of Stratiform Precipitation Based on Dual-Polarization Radar and Airborne Observations

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https://radar.nju.edu.cn

Outline

1. Introduction

2. Optimized microphysical retrieval

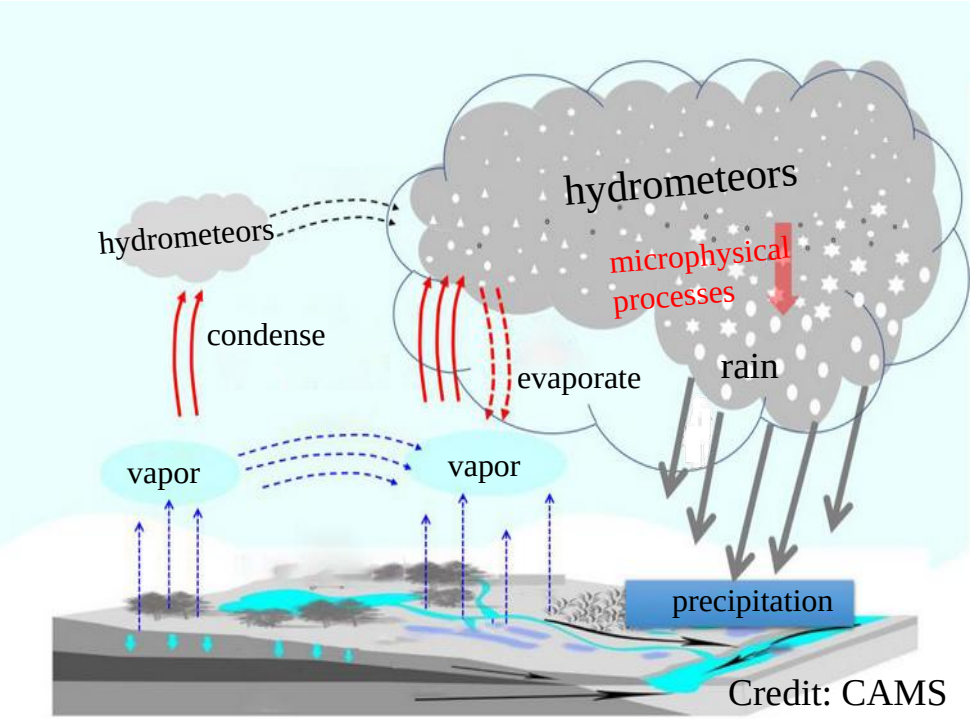
3. Microphysics of Stratiform Precipitation

4. Conclusion and discussion

Cloud microphysics

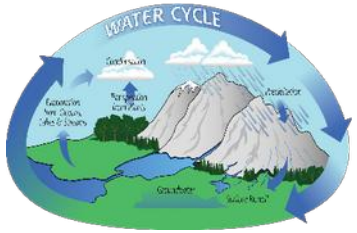
- Precipitation and cloud microphysics are crucial in research areas of meteorology and weather modification

Water Resources



Credit: CAMS

Rainfall and Flooding



WMO

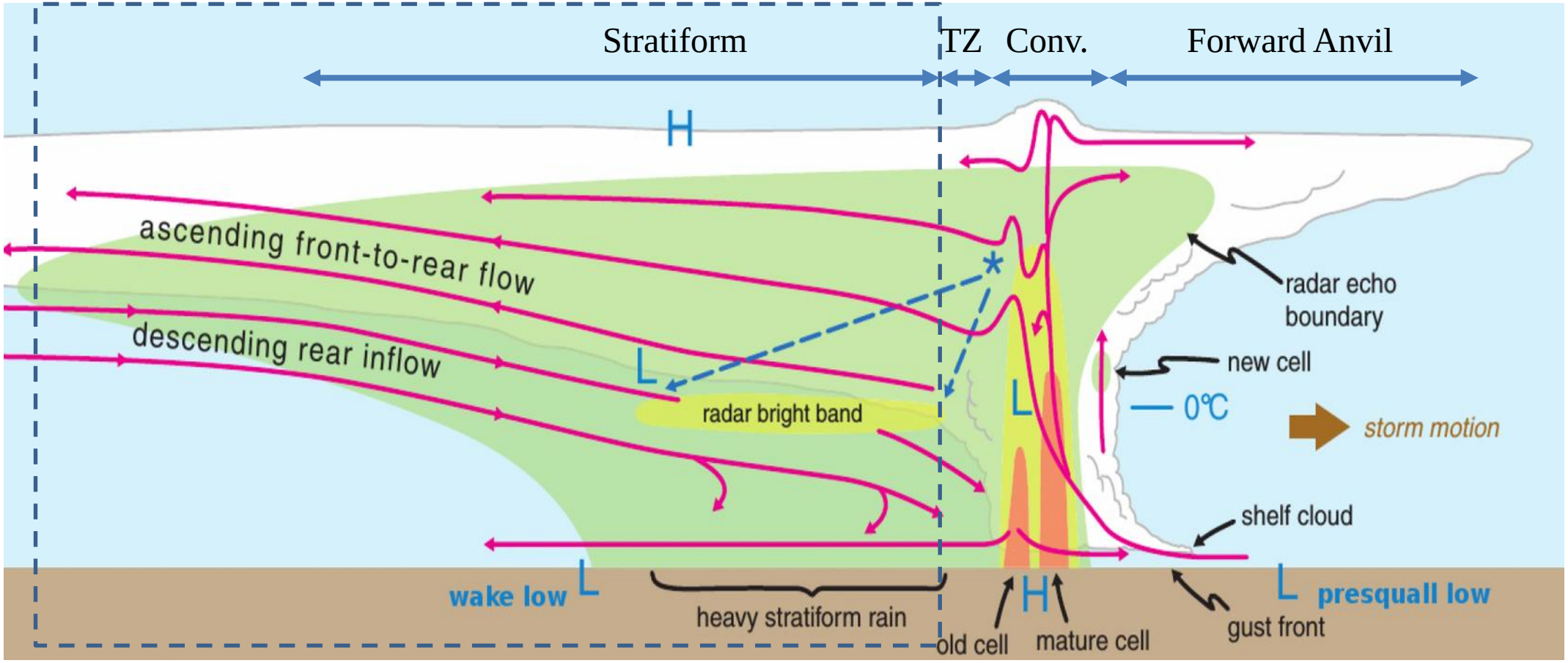
WWRP WORLD WEATHER RESEARCH PROGRAMME

Importance of stratiform precipitation

Stratiform precipitation occurs more frequent than convection, affecting

1) atmospheric latent heat profile, and 2) storm development environment

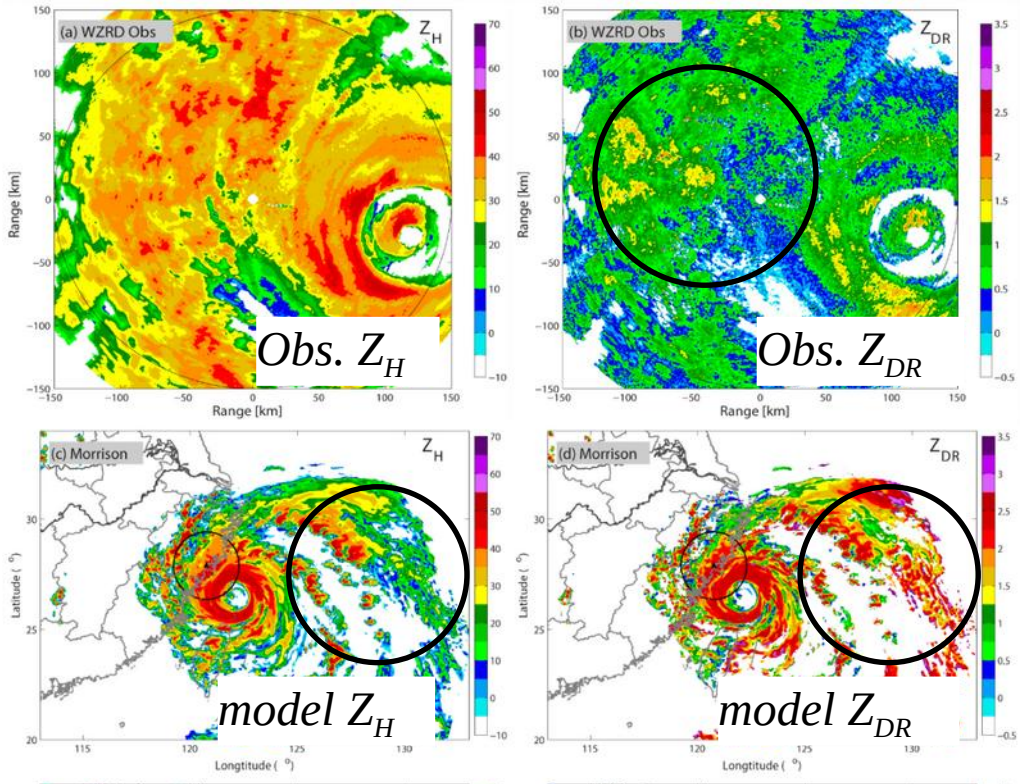
Stratiform fraction underestimated in numerical models



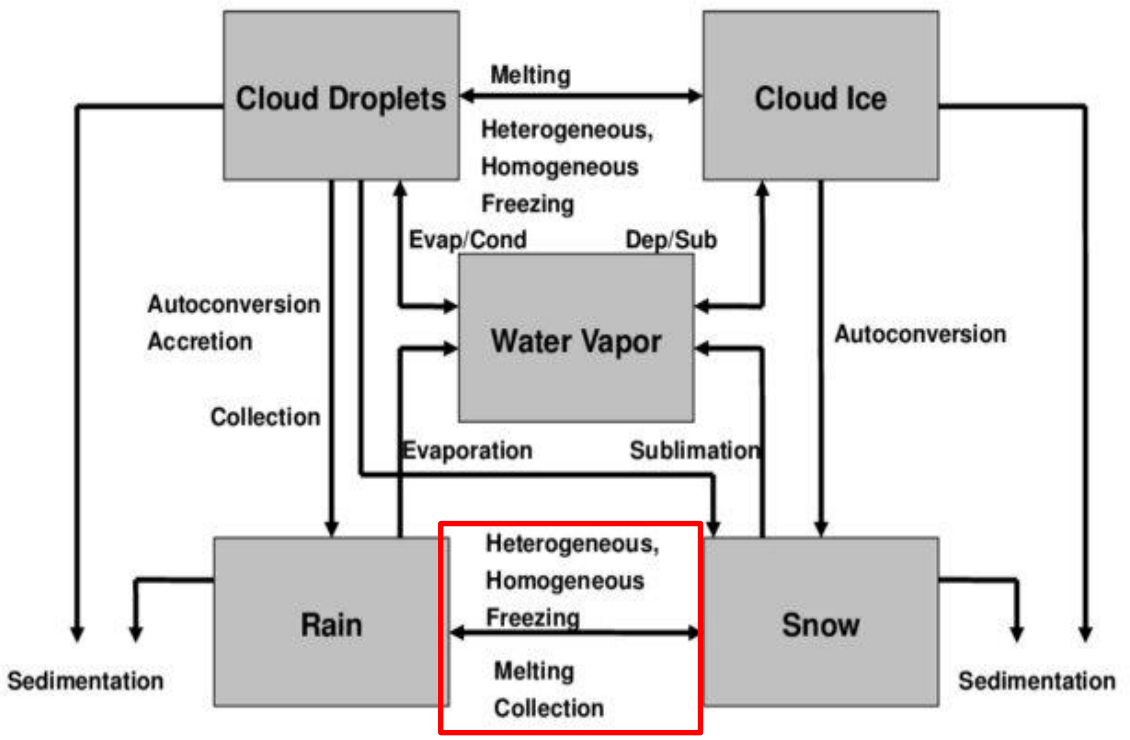
Uncertainty in stratiform parameterization

- Large uncertainty in stratiform forecast from microphysical perspective
- Considering instantaneous melting effect but no explicit representation of melting particles

Stratiform simulation in Lekima 2019



Processes in the Morrison and Gettelman (2008)



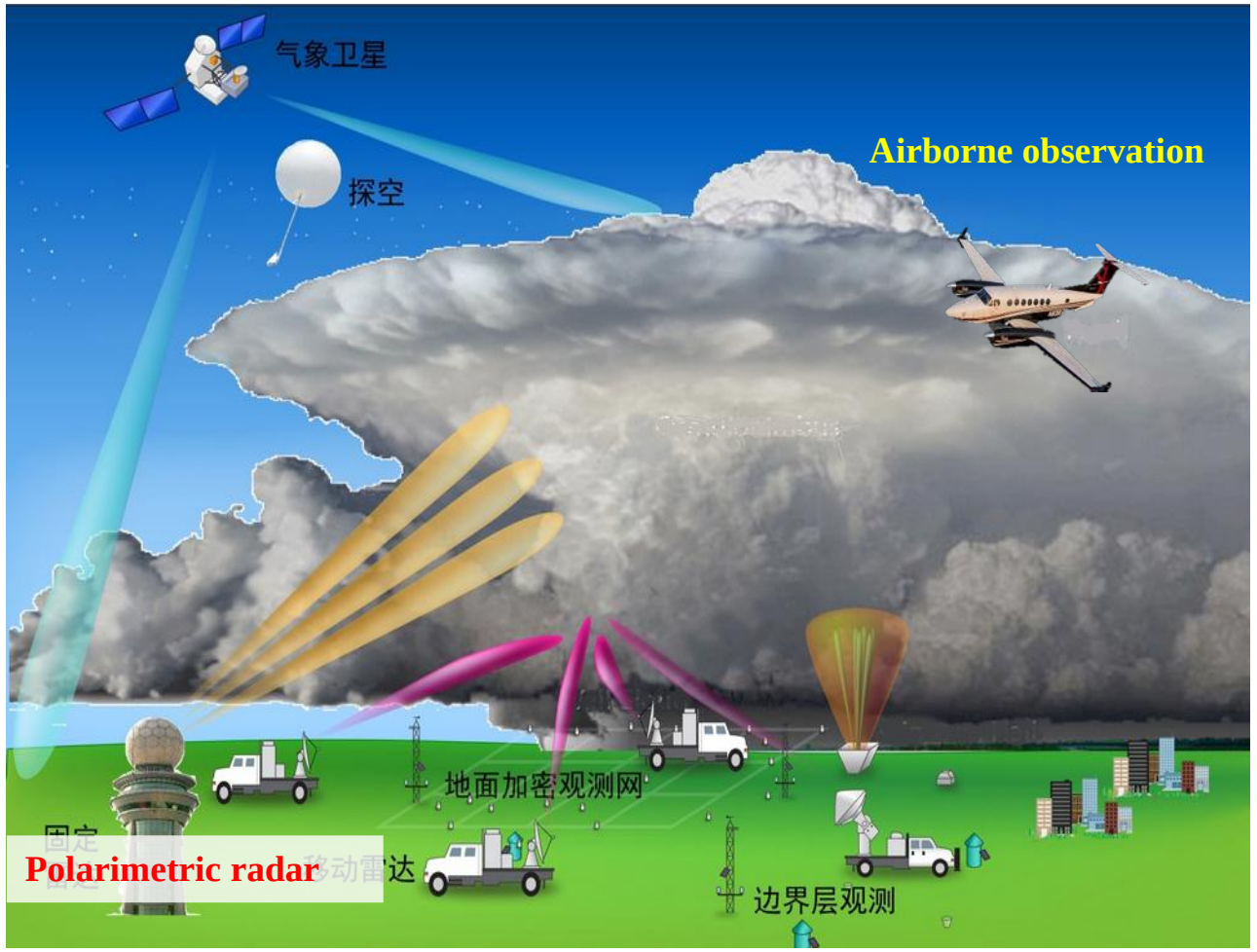
instantaneous effect but no melting particles

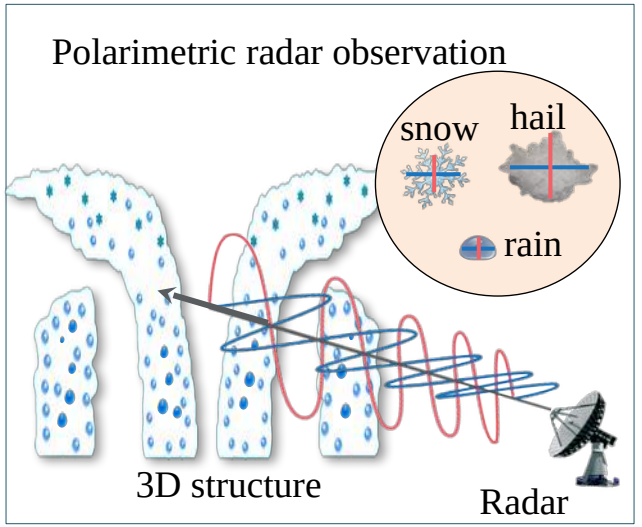
Salzmann et al.

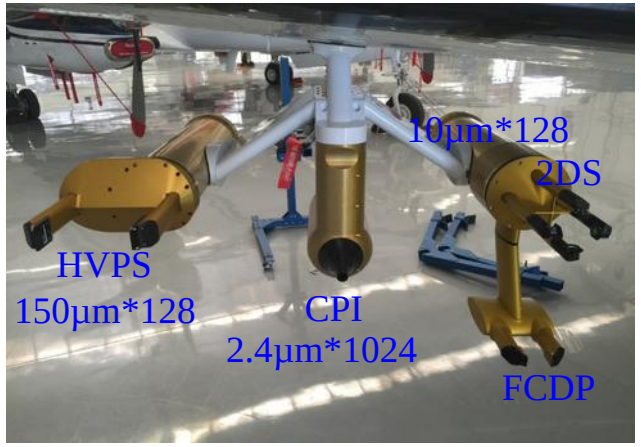
Microphysics observations

- Incomplete information and errors in both airborne and radar remote sensing observations

  —radar retrieval and multi-platform collaboration







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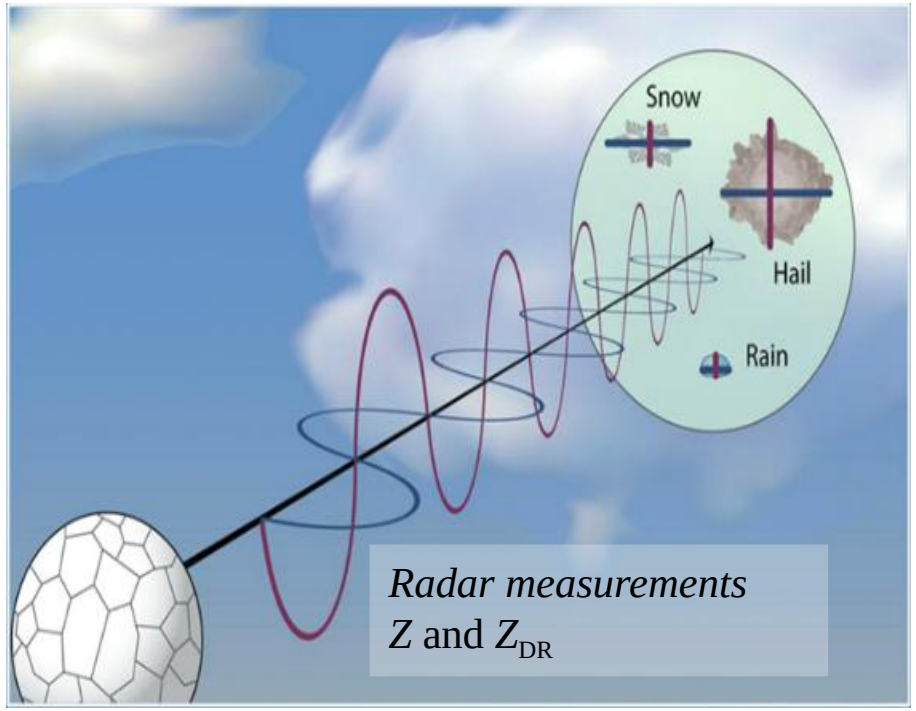
Key problem in microphysical retrieval

- Two independent observations from radars, three unknown parameters in raindrop size distribution model, with more uncertainty by attenuation

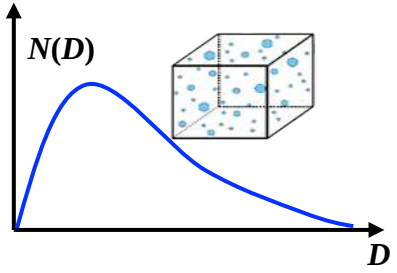


2 independent observations (Z and Z_{DR})

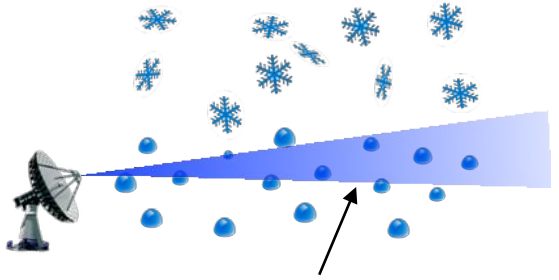
insufficient

Three-parameter Gamma DSD

$$N(D) = N_0 D^{\mu} \exp(-\Lambda D)$$



Precipitation attenuation



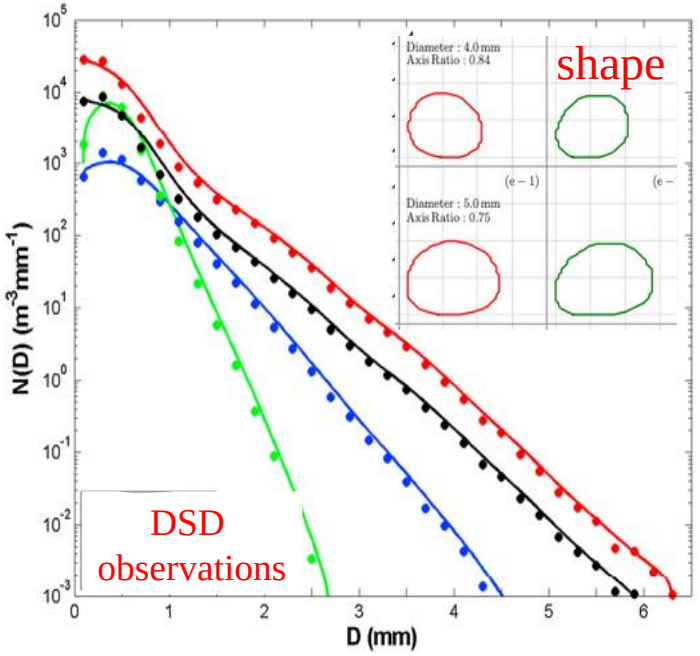
power decrease in propagation

3+1 unknowns (N_0, μ, Λ, and A)

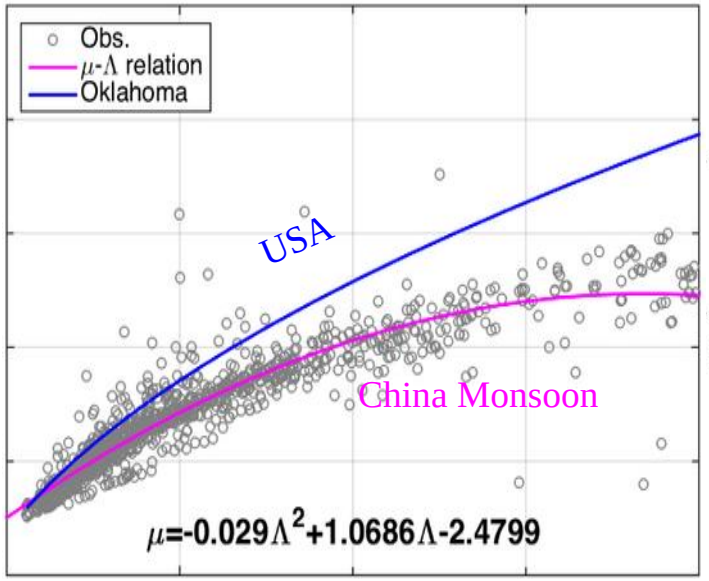
Improvement in physical constraints

- With long-term DSD observations, constrained DSD models updated and relationships between DSD parameters and radar parameters built, which help decrease the uncertainty in retrieval model, and increase the retrieval reliability

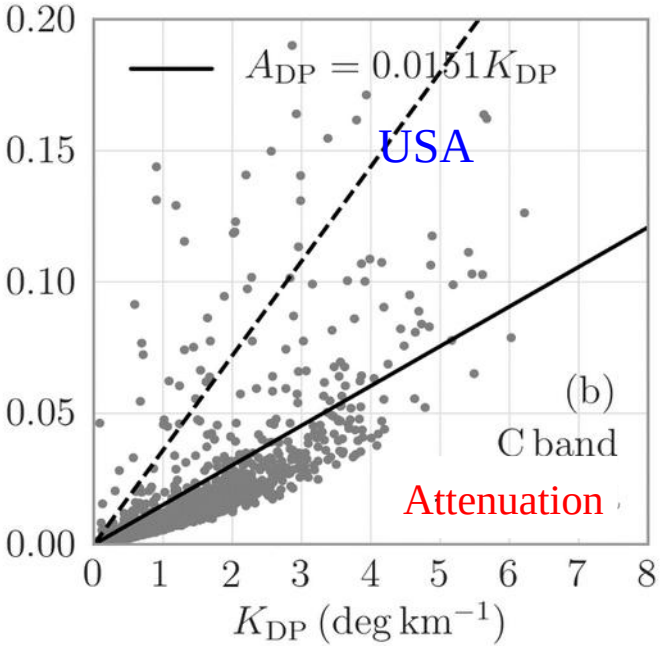
2-D video disdrometer observations in field experiments



μ-Λ relationship for monsoon



Radar relationships



Huang et al. 2017, 2021, Wen et al. 2018

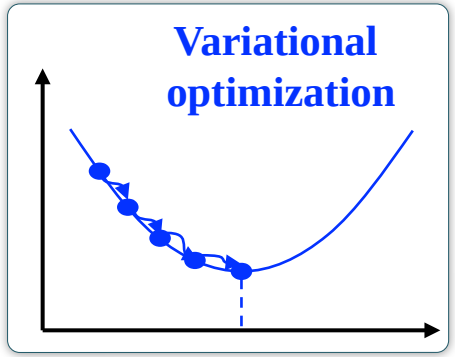
Variation retrieval of microphysics

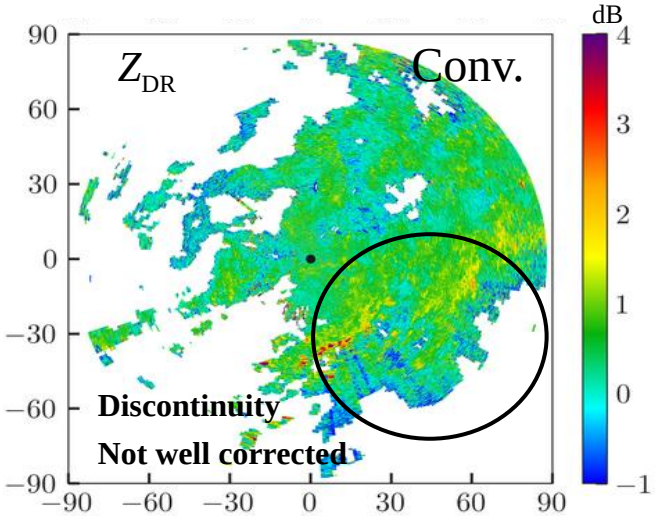
- The integrated variational optimization method for simultaneous retrieval of microphysical parameters and attenuation improves the physical consistency between parameters

Cost function example

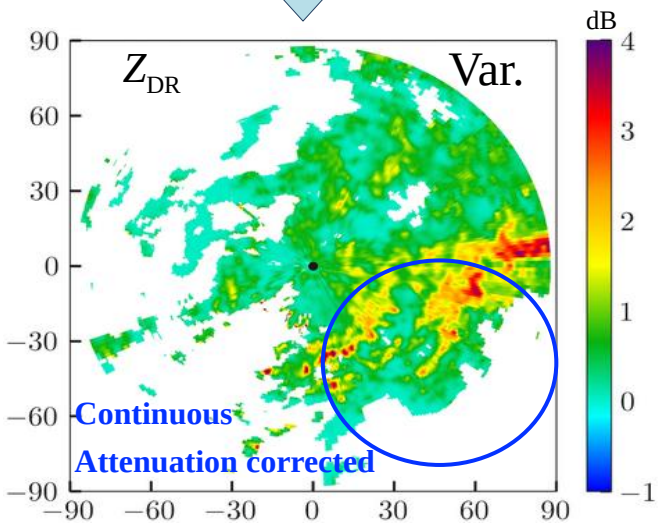
$$J = \left[Z_{\mathrm{DR}}\left[N_0, \Lambda, f_\mu(\Lambda)\right] - A_{\mathrm{DP}}\left[N_0, \Lambda, f_\mu(\Lambda)\right] - Z_{\mathrm{DR}}^m\right]^2$$

μ-Λ constraint attention relation obs.





VS.



Huang et al., 2019@JTECH; **Huang** et al., 2020a@JH; **Huang** et al., 2020b@JHM

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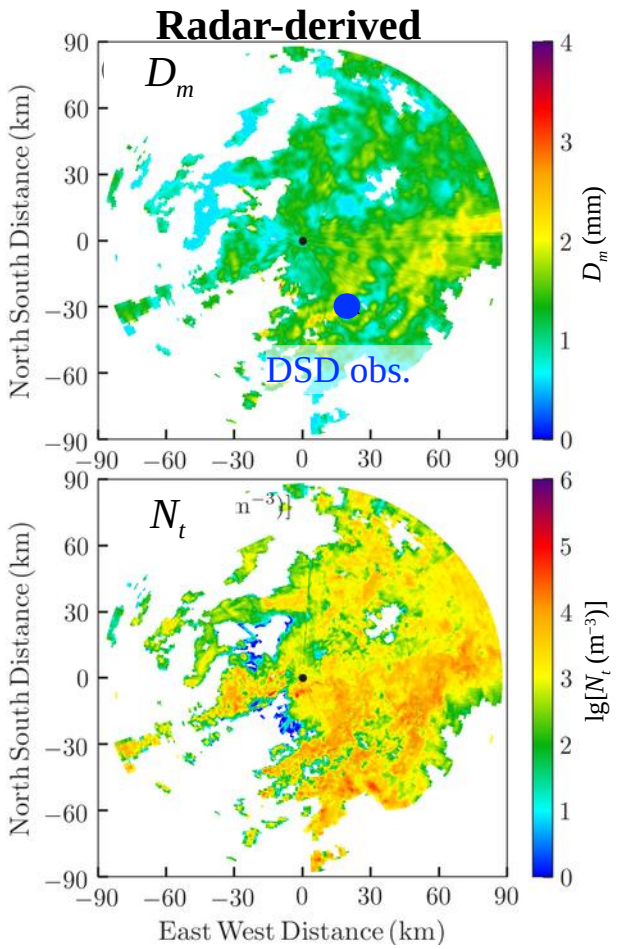

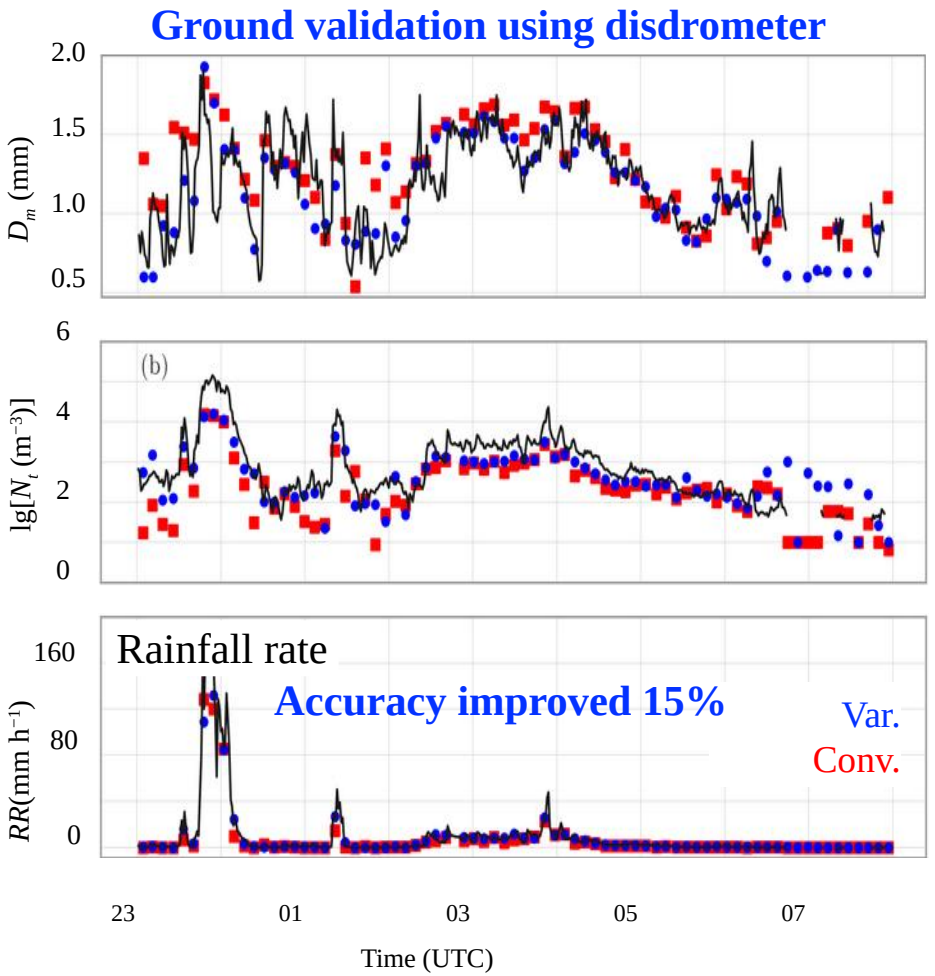

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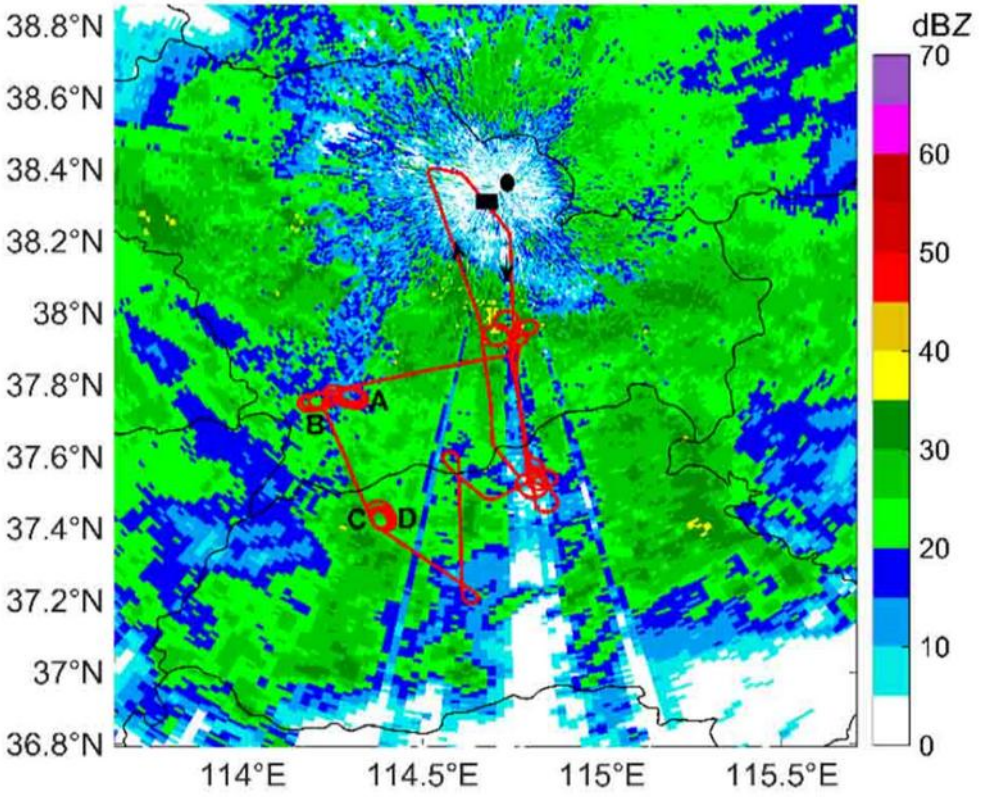
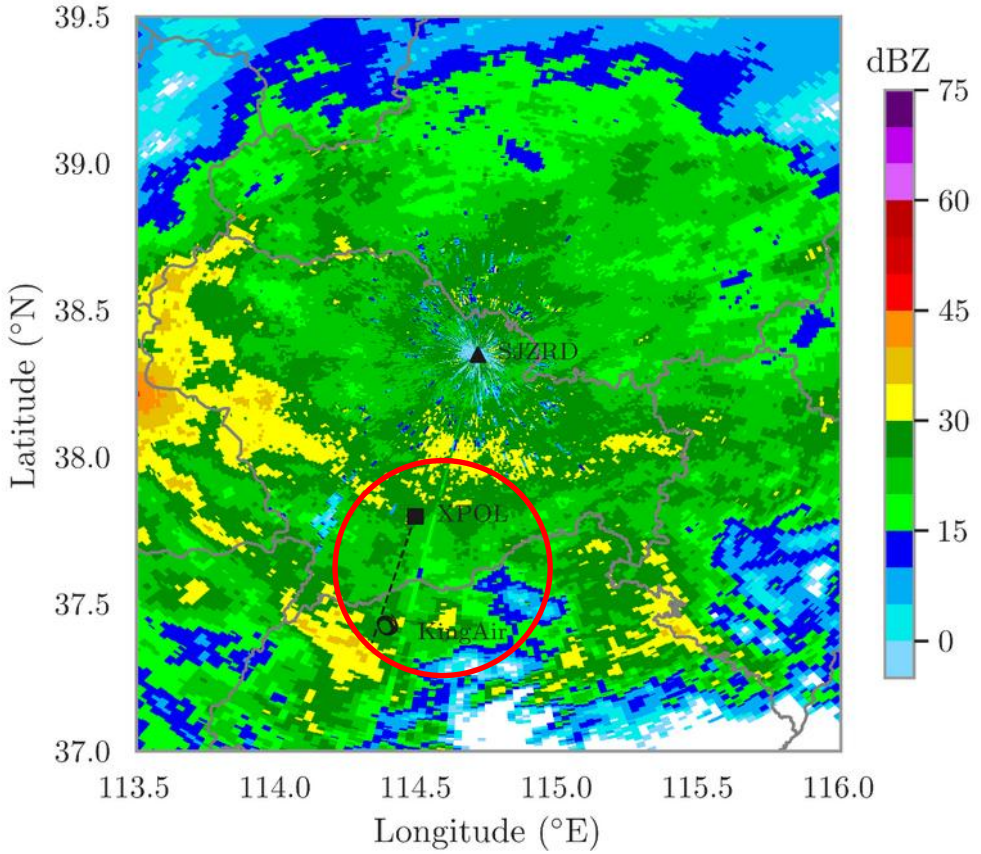
Radar observations and flight paths

2018 May 21 North China S-band radar
(flight path overlaid)



Location of XPOL and flight track

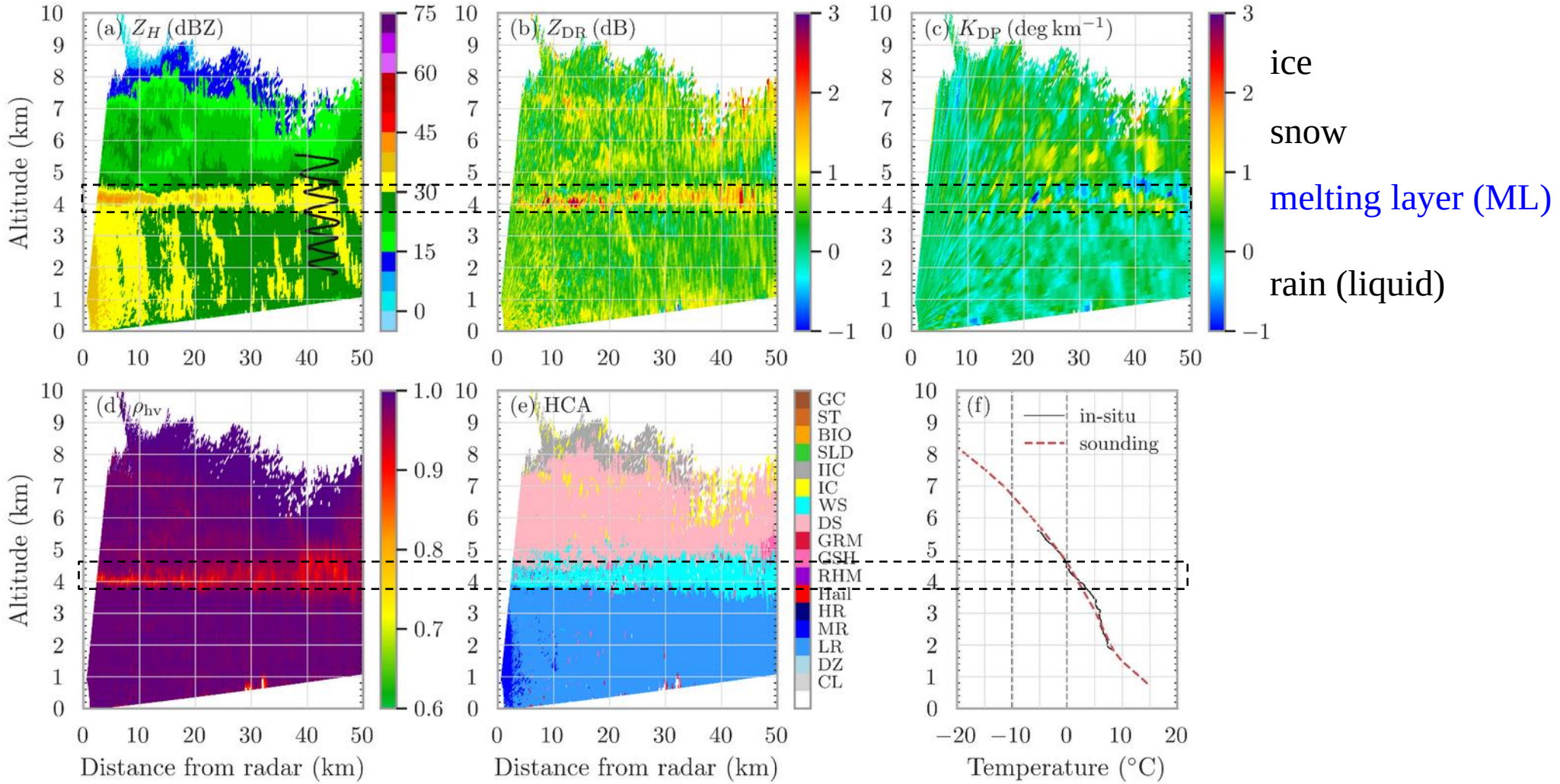


Data source: X-band polarimetric radar data for general structure

Airborne (King-Air Plane) 2DS, CPI, and HVPS for particles

Stratiform structure from radar observations

1313 UTC RHI observations from Shijiazhuang X-POL



ice

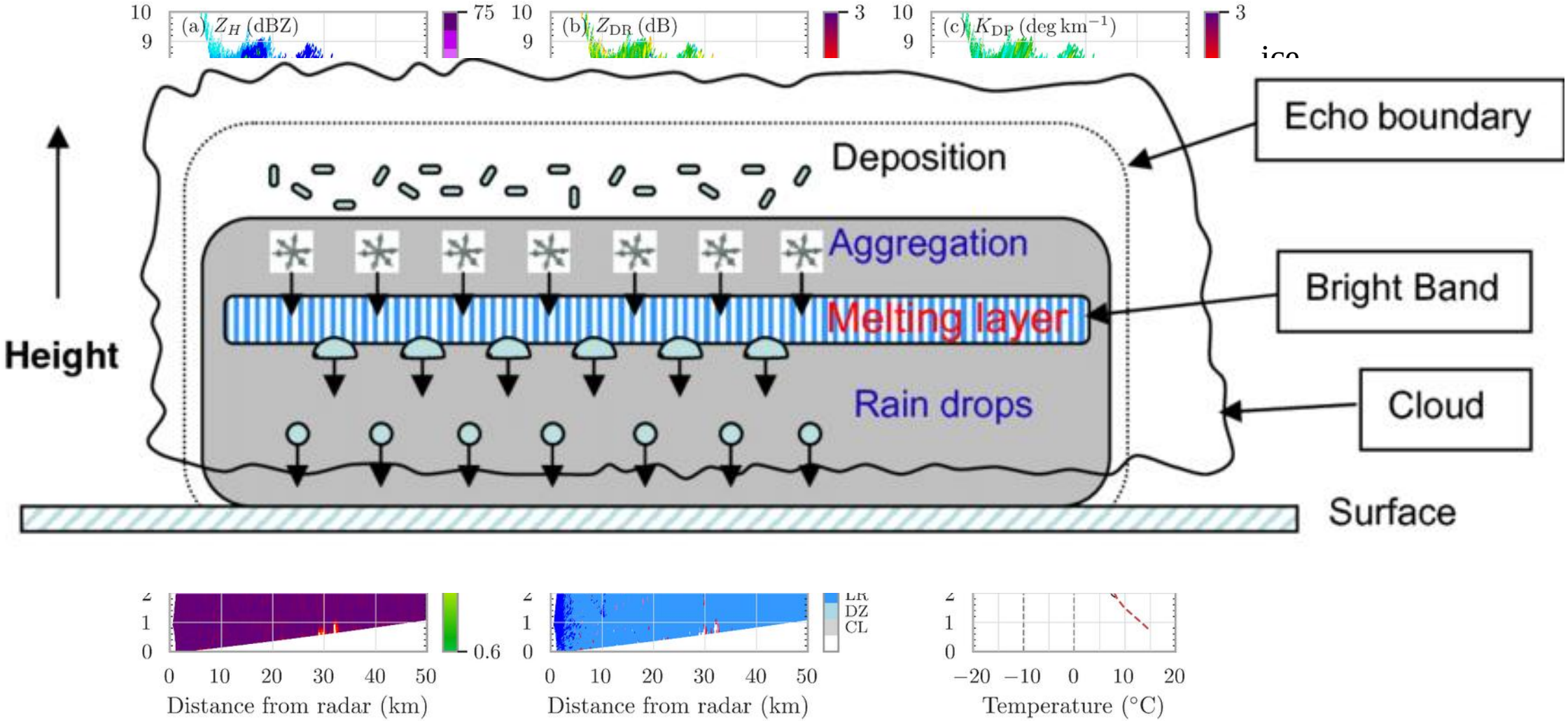
snow

melting layer (ML)

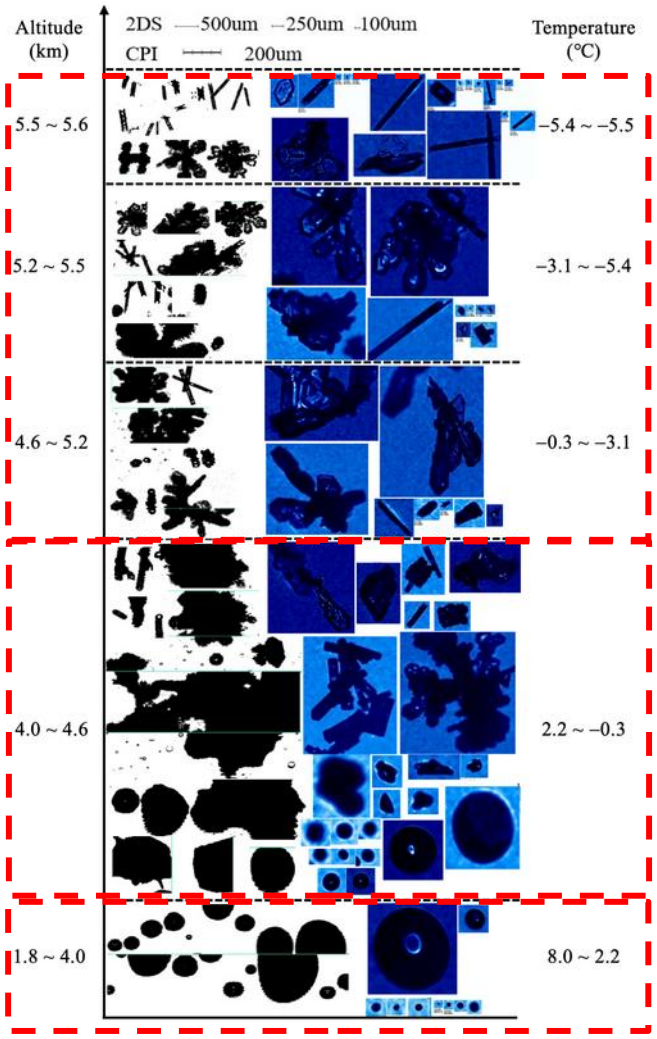
rain (liquid)

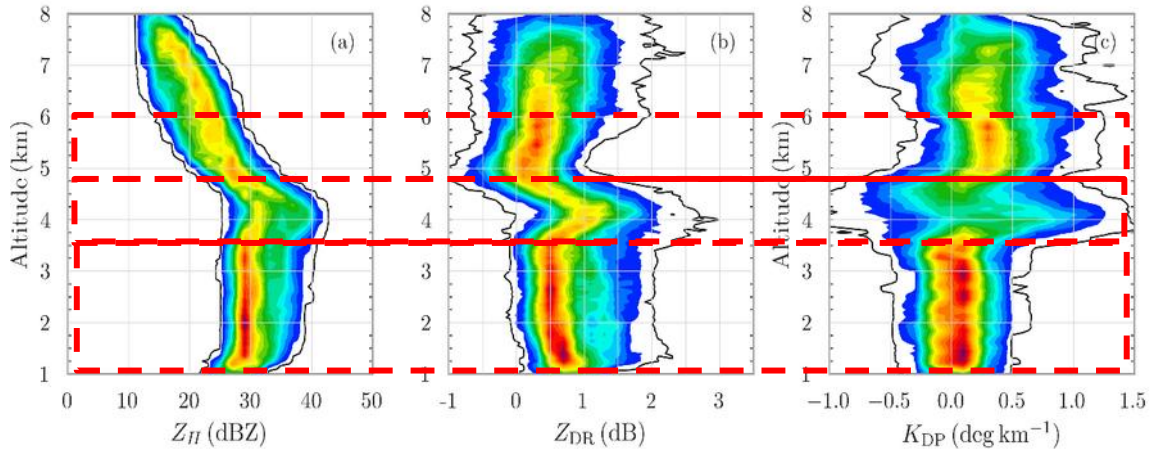
Stratiform structure from radar observations

1313 UTC RHI observations from Shijiazhuang X-POL



Ice habit and polarimetric signature





Ice layer:
- Above −5°C, needle/column crystals, Z_{DR} increases
- When altitude decreases, aggregation and riming dominate, Z_H increases, Z_{DR} decreases, K_{DP} increases

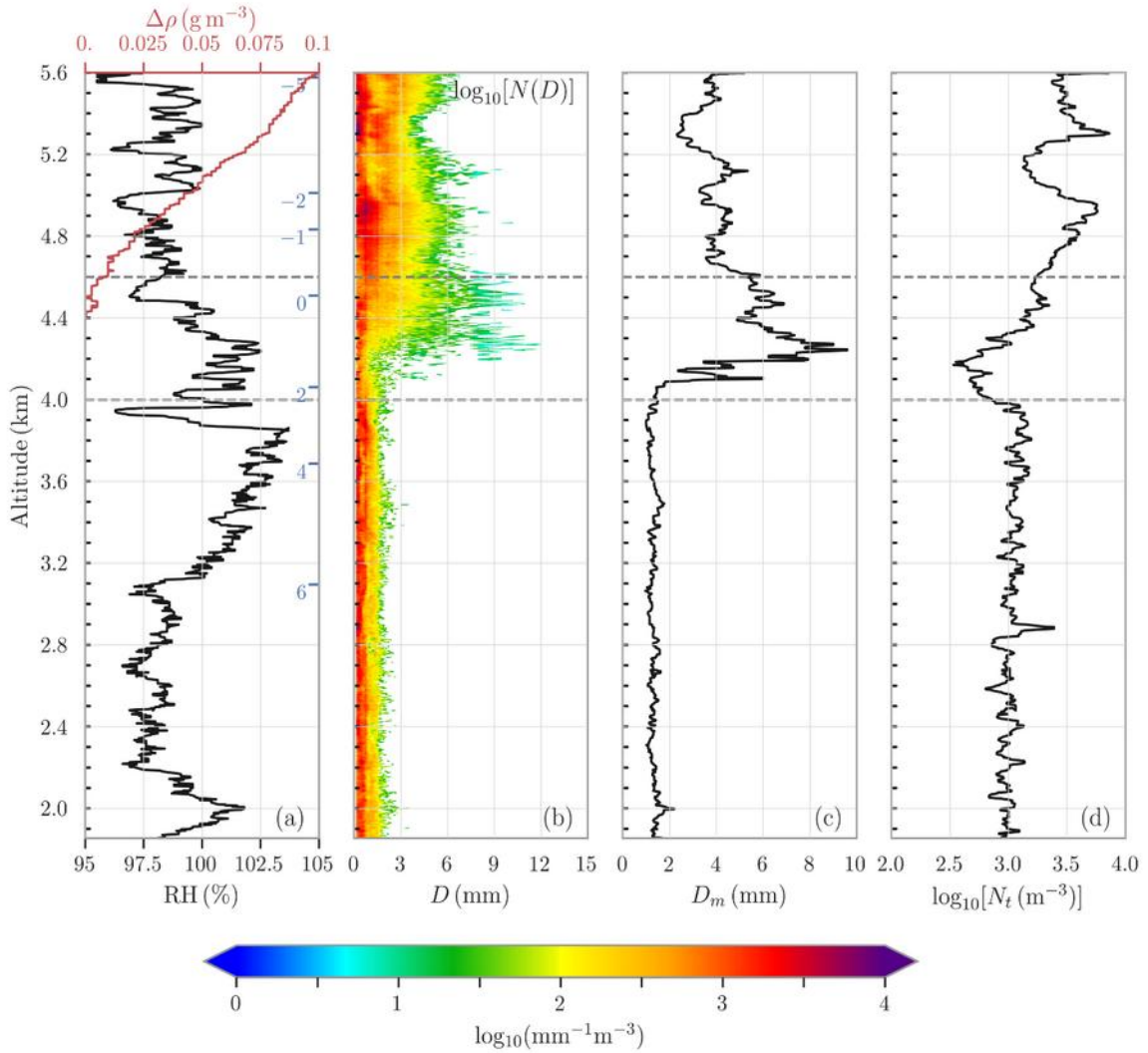
ML:
- Ice particles gradually melt forming a bright band, Z_H increases, Z_{DR} increases, and K_{DP} increases

Rain layer:
- Radar variables remain essentially unchanged across different altitudes

Profiles of microphysical parameters

HVPS (High Volume Precipitation Spectrometer)

RH PSD D_m N_t



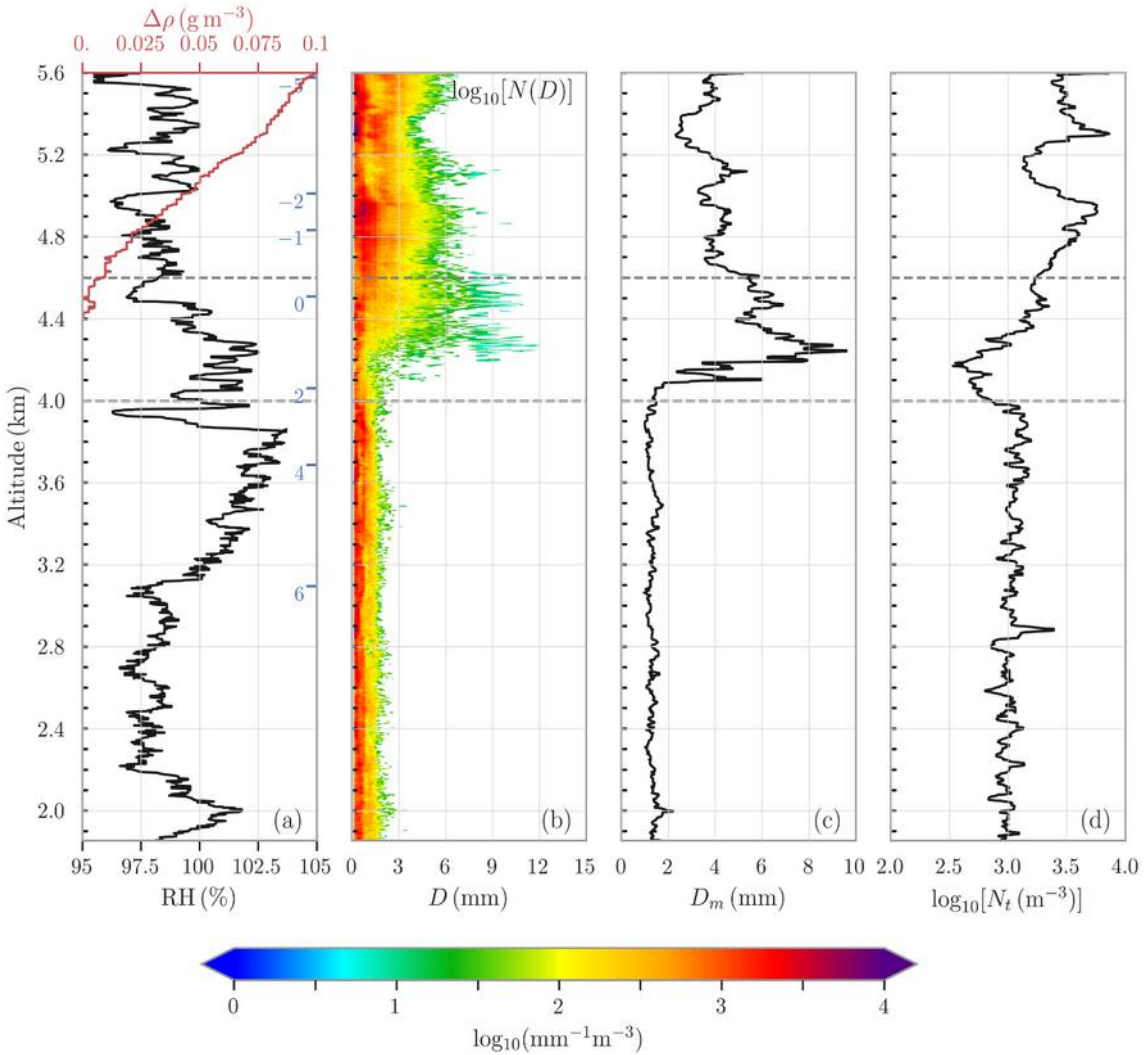
- **Ice crystals in high altitudes:** small size and relatively high concentration
- **With decreasing altitudes:** increase in size and decrease in concentration—aggregation and some riming
- **Particles in the melting layer:** D_m increases and then decreases
  - Increases due to aggregation of sticky melting particles
  - Decrease, melting or breakup?

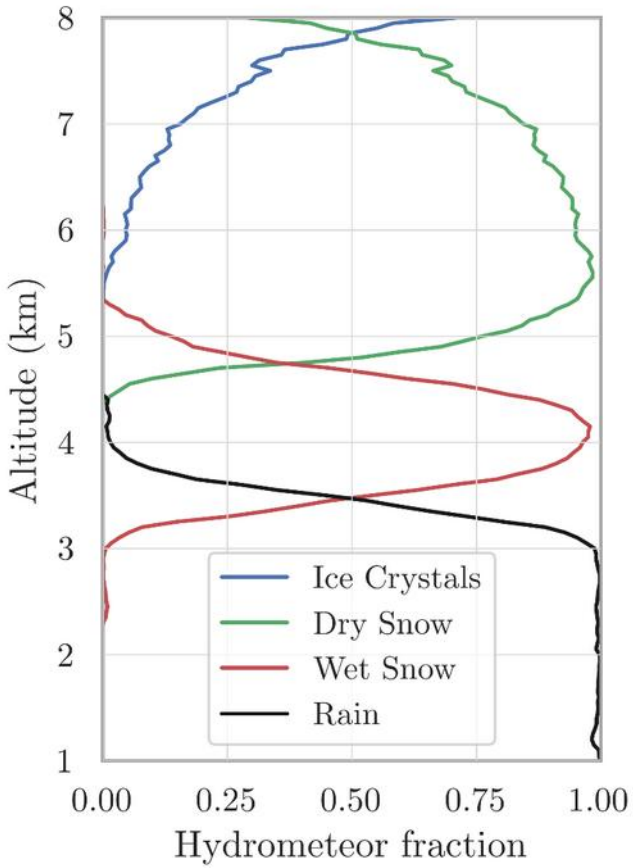
  —breakup due to increasing N_t

Profiles of microphysical parameters

HVPS (High Volume Precipitation Spectrometer)

RH PSD D_m N_t

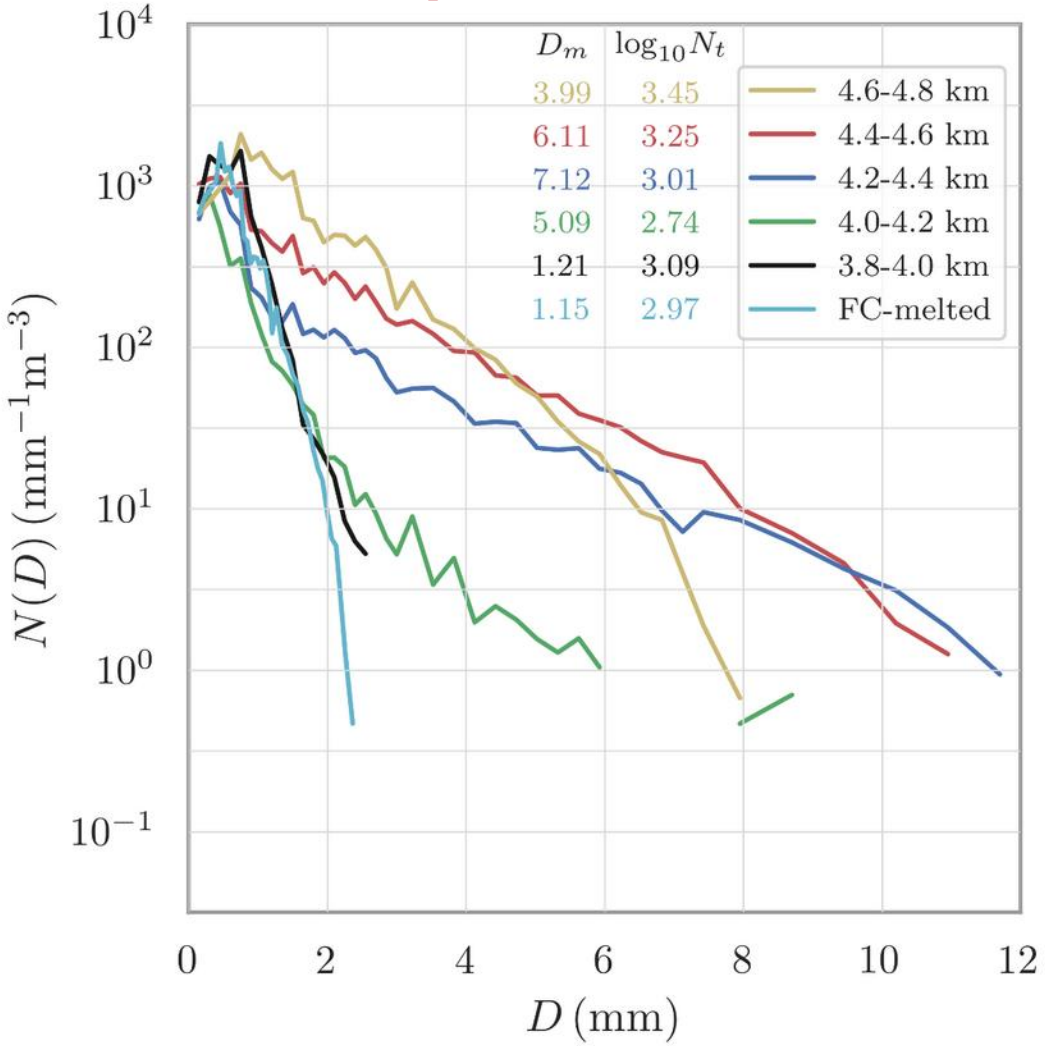




Melting layer microphysics and flux conservation

ML subsections (depth: 1/3 ML)

Above, Top, Median, Bottom, Below, FC



- Decrease in medium-size concentration :

  melting + aggregation

- Flux conservation (commonly used in models) correct in the case?

  $N(D)$ underestimated < 1 or > 1.8 mm

  finally, $D_m^{FC} < D_m^{obs}$ and $N_t^{FC} < N_t^{obs}$

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Conclusion and discussion

- A variational method for the retrieval of DSD parameters has been developed , simultaneously achieving optimized estimation of attenuation (short-wavelength radar) and DSD parameters

- Joint analysis of dual-polarization radar and aircraft observations reveals:
  - Ice crystal aggregation and riming above the melting layer, forming snowflakes
  - Contribution of coalescence and breakup of particles to radar bright bands
  - Particle concentration and diameter underestimated with flux conservation assumption

- **Outlook:** The flight levels are relatively low, and understanding of the ice crystal formation process remains incomplete. More observations are needed!

Thank you very much!

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- Huang, H., Zhao, K., Zhang, G., Hu, D., & Yang, Z. (2020). Optimized raindrop size distribution retrieval and quantitative rainfall estimation from polarimetric radar. *Journal of Hydrology, 580*, 124248.
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