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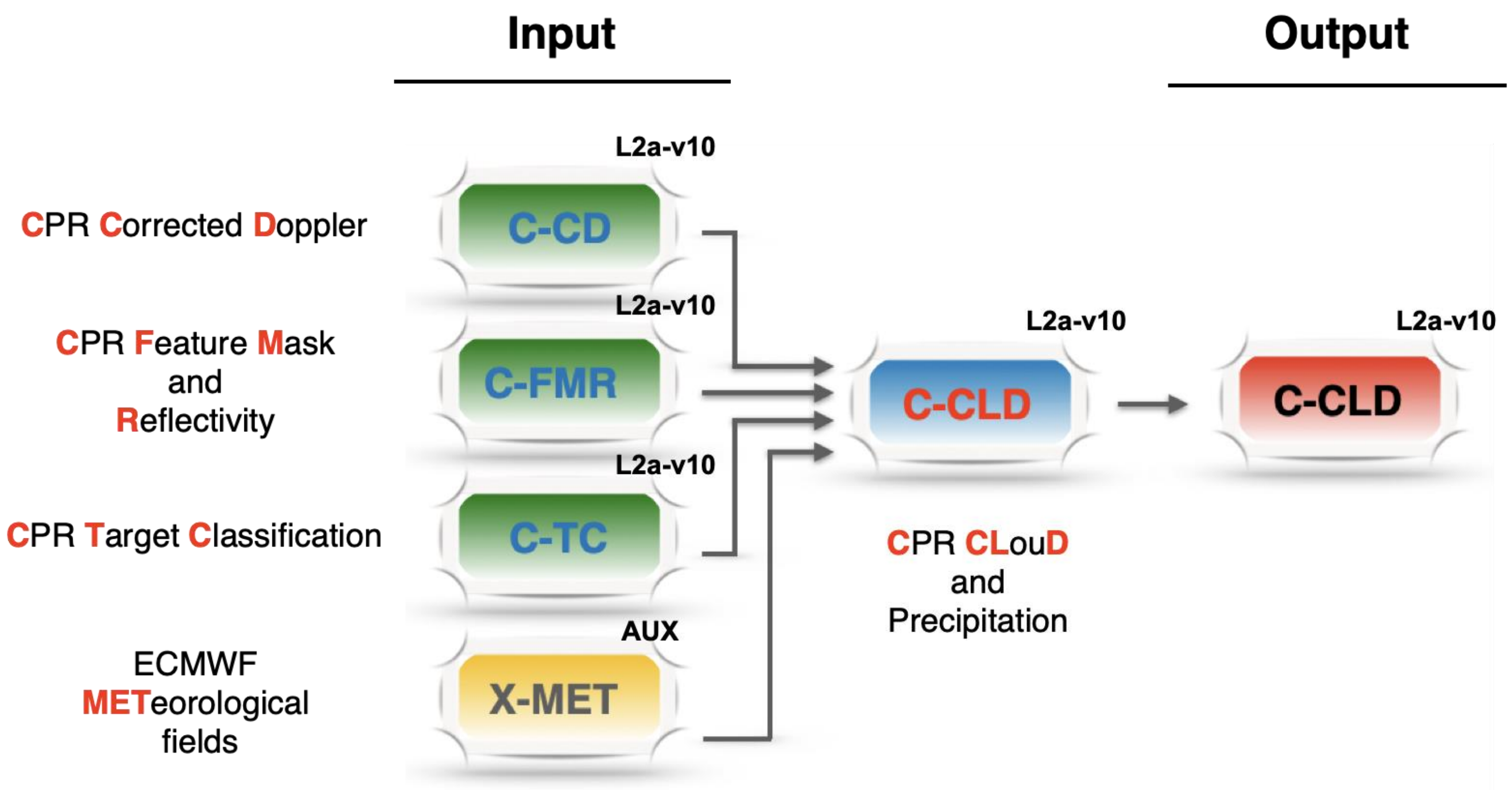
Cloud and Precipitation Microphysics Retrieval for EarthCARE's Doppler Cloud Profiling Radar Measurements

Kamil Mroz[1], *B. Puigdomènech Treserras*[2], *A. Battaglia*[1,4,5], *P. Kollias*[2,3], *A. Tatarevic*[2], *F. Tridon*[4]
[1]*National Centre for Earth Observation, UK;* [2]*McGill University, Canada; Stony* [3]*Brook University, USA;*
[4]*Politecnico of Turin, Italy;* [5]*University of Leicester, UK*

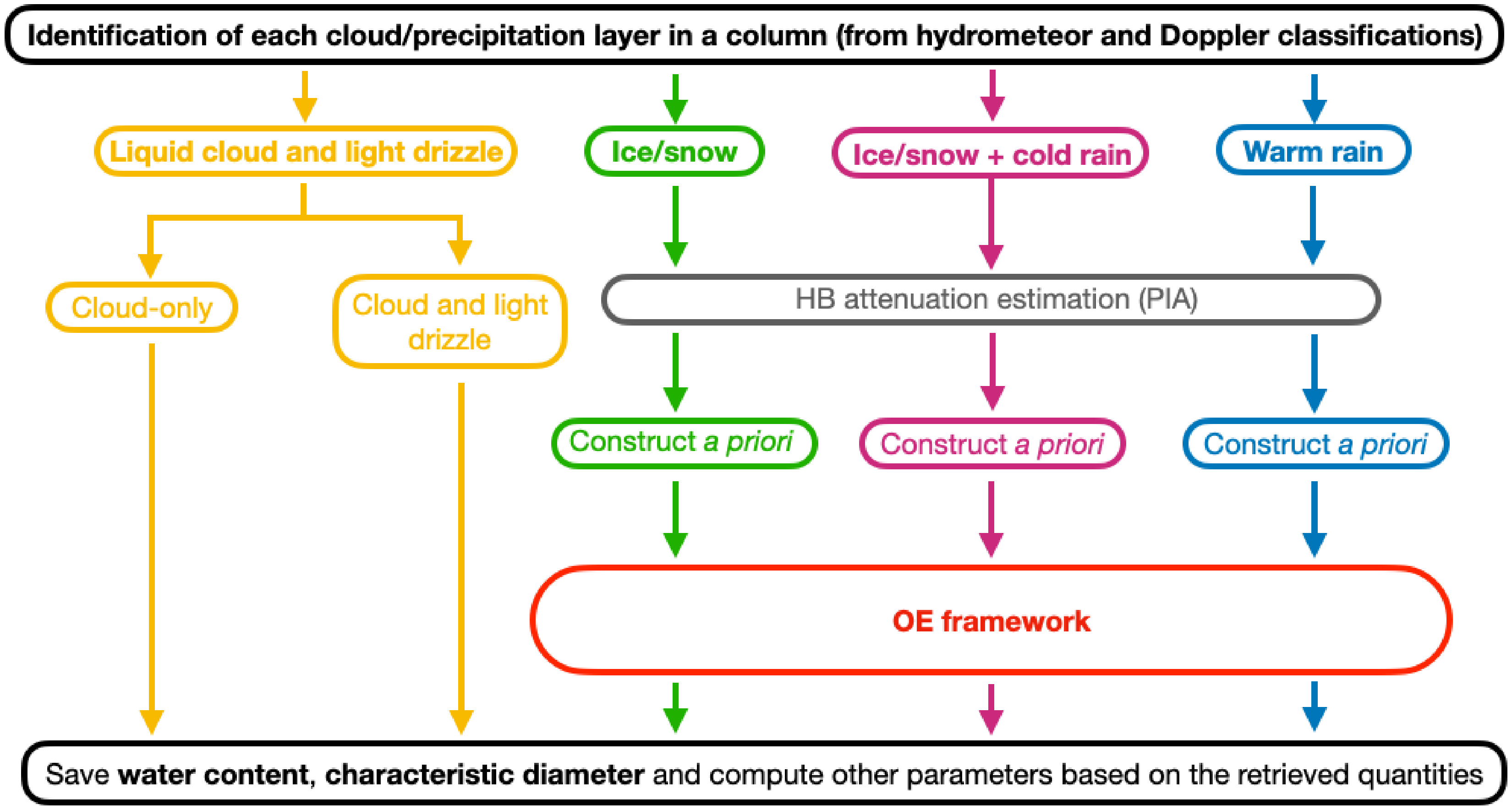
C-CLD overview

- Only the CPR data utilized:
  - C-FMR reflectivity
  - C-CD Doppler velocity
  - C-TC classification
- The algorithm is based on a profile-by-profile approach
- It is based on the Optimal Estimation framework
- Vertical distribution of 2 microphysical parameters is determined, i.e., water content and characteristic size



C-CLD overview

- C-CLD is composed of several modules
- C-TC classification is used to select the specific algorithm
- Liquid cloud and light drizzle algorithm based on the power law relationships
- Snow/cold &warm rain algorithms are based on the OE



OE concept

The OE framework aims at balancing the information provided by:

- The CPR measurements in the entire column
- The statistical information on ground-based precipitation rates and sizes
- Continuity of estimated quantities

$$2\phi = \underbrace{[y - F(x)]^T R_Y^{-1} [y - F(x)]}_{\text{Measurement component}} + \overbrace{[x - x_a]^T R_a^{-1} [x - x_a]}^{\text{A-priori term}} + \underbrace{x^T R_s^{-1} x}_{\text{Continuity}};$$

F - forward model

y – measured reflectivity and sedimentation velocity

x – state vector

x_a – a-priori estimate of the state vector,

R_y^{-1}, R_a^{-1}, R_x^{-1} - weights

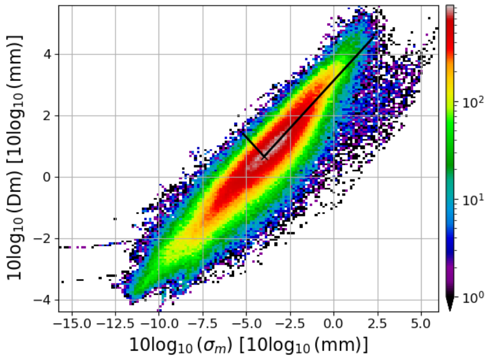
OE concept: measurement term

$$2\phi = \underbrace{[\boldsymbol{y} - \boldsymbol{F}(\boldsymbol{x})]^T \boldsymbol{R}_Y^{-1} [\boldsymbol{y} - \boldsymbol{F}(\boldsymbol{x})]}_{\text{Measurement component}} + \overbrace{[x - x_a]^T R_a^{-1} [x - x_a]}^{\text{A-priori term}} + \underbrace{x^T R_S^{-1} x}_{\text{Continuity}};$$

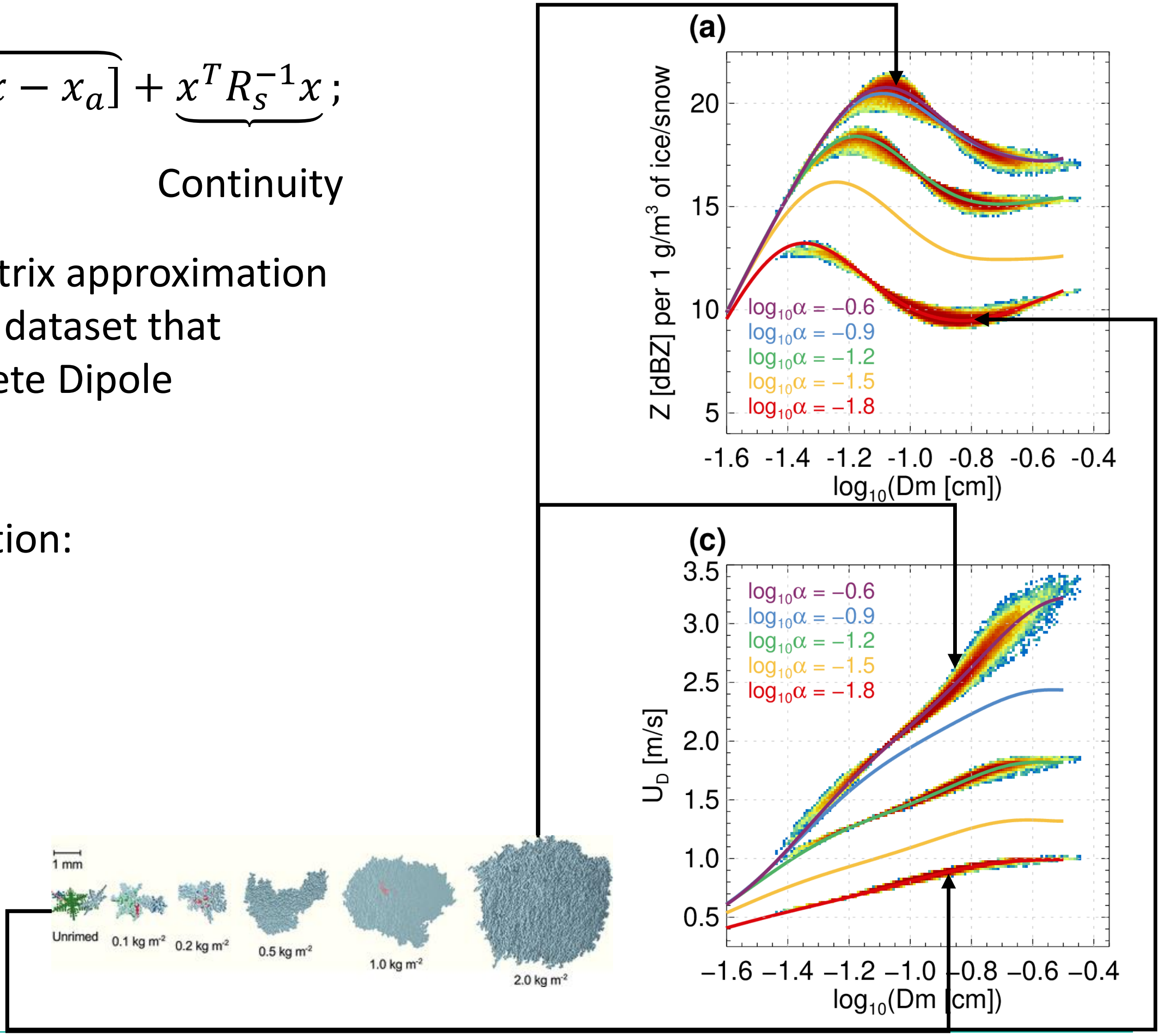
- Scattering properties of rain are simulated using T-matrix approximation
- Radar measurements are simulated using a scattering dataset that correspond to realistic snowflake shapes via the Discrete Dipole Approximation.
- Riming is parameterized, assuming the "fill-in" model
- Particle size distribution modeled as the Gamma function:

$$N(D) = \Gamma(D; D_m, WC, \mu)$$

where $\mu = \left(\frac{D_m}{\sigma_m}\right)^2 - 4 \approx 10D_m^{-0.8} - 4$



Leinonen & Szyrmer (2015)



C-CLD product

OE concept: a-priori term

A-priori term

$$2\phi = \underbrace{[y - F(x)]^T R_Y^{-1}[y - F(x)]}_{\text{Measurement component}} + \overbrace{[\boldsymbol{x} - \boldsymbol{x_a}]^T \boldsymbol{R_a^{-1}}[\boldsymbol{x} - \boldsymbol{x_a}]}^{\text{A-priori term}} + \underbrace{x^T R_S^{-1} x}_{\text{Continuity}} ;$$

Measurement component

Continuity

Ice/snow (Matrosov & Heymsfield 2008, 2017):

WC [g/m^3] = 0.086 (Z_e [mm^{6}m^{-3}])$^{0.92}$;

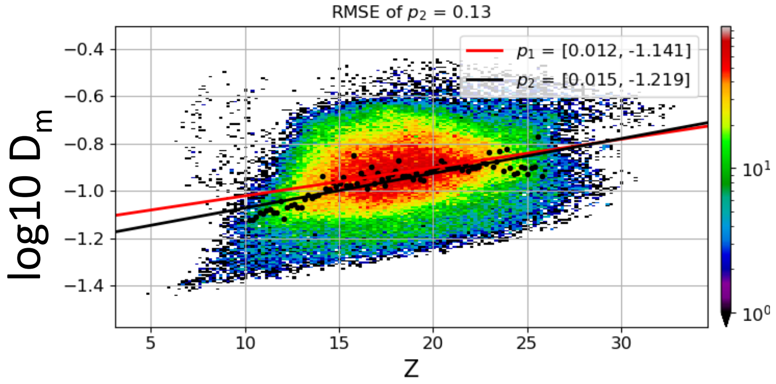
D_m [cm] = 0.052 (Z_e [dBZ])$^{0.280}$ for snow,
0.047 (Z_e [dBZ])$^{0.294}$ for cirrus

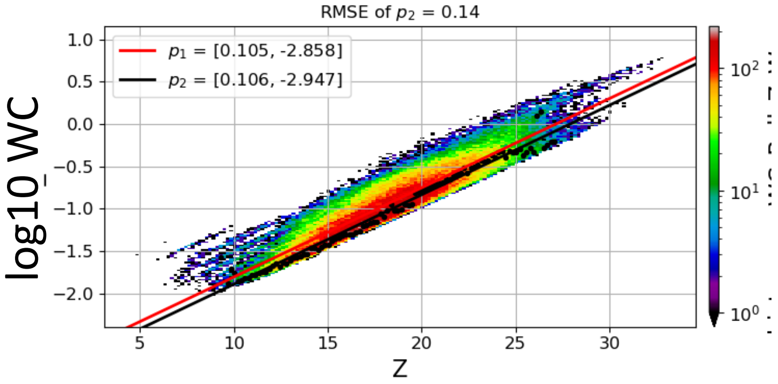
Uncertainty in $\log_{10}$WC of 0.9 B
Uncertainty in $\log_{10}D_m$ of 0.9 B

Rain (NASA DSD dataset):

$\log_{10}D_m$ [cm] = 0.01 Z_e [dBZ] – 1.55 ±0.15 for 10 dBZ< Z_e

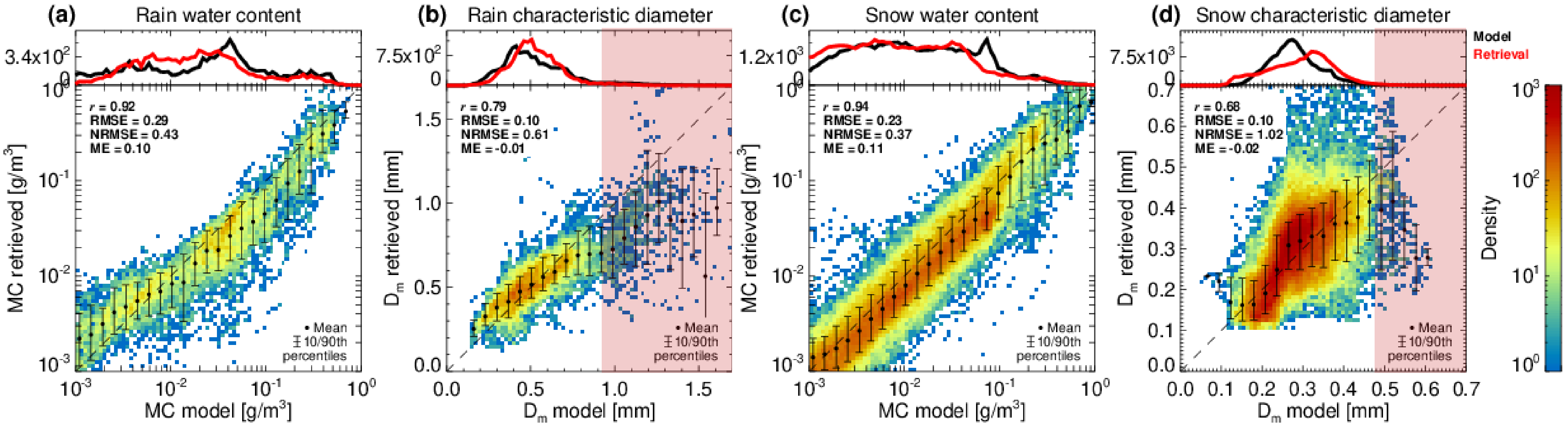
$\log_{10}$WC [g/m^3] = 0.109 Z_e [dBZ] – 2.93 ±0.2 for Z_e >12.5dBZ
= 0.038 Z_e [dBZ] – 2.04 ± 0.3
for Z_e <12.5dBZ





C-CLD product

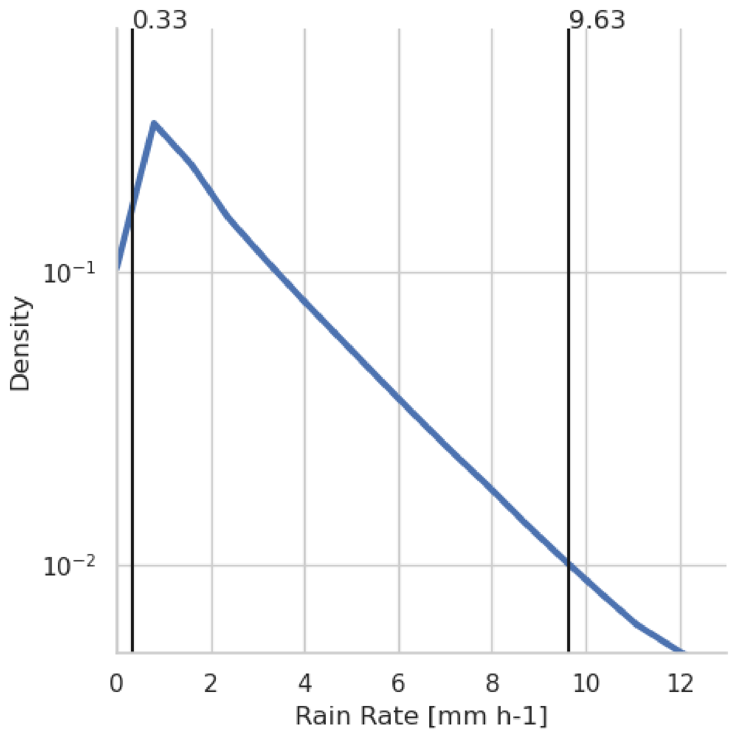
Validation: GEM simulations

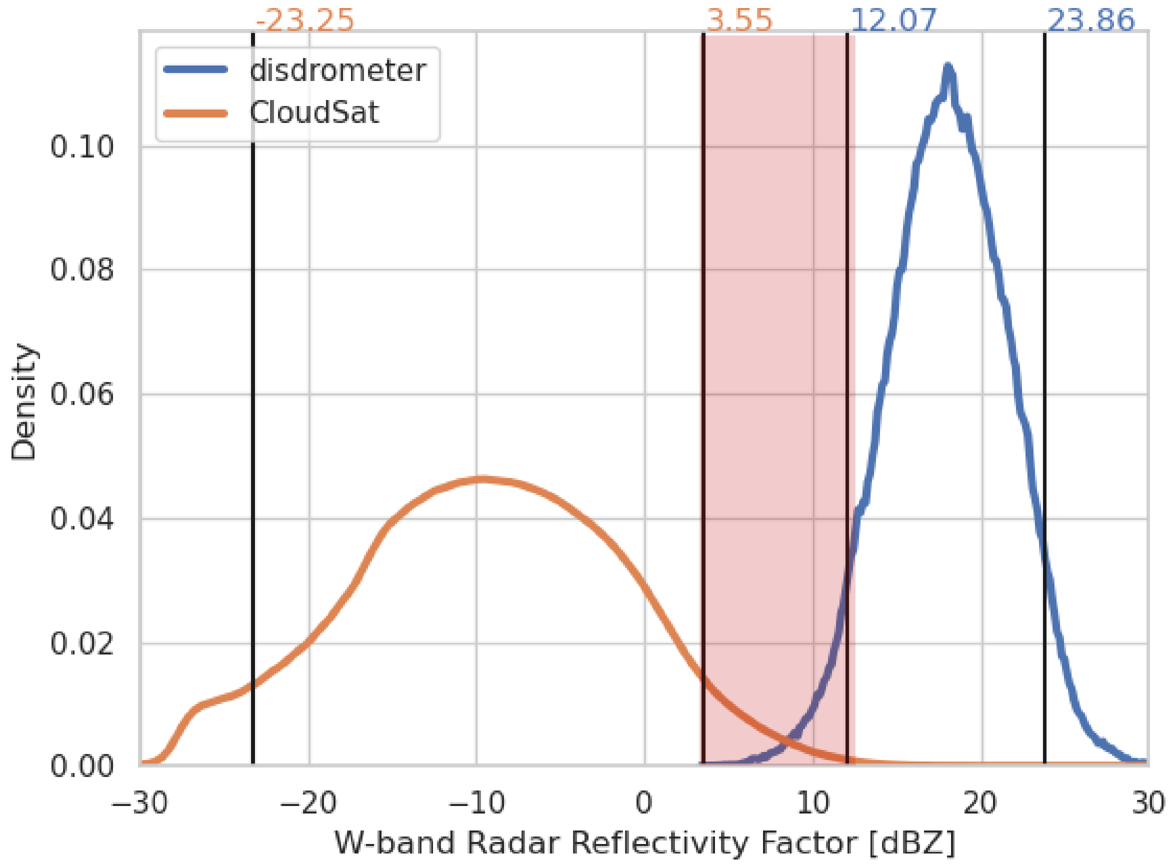


- Underestimate for large raindrop sizes
- Insufficient number of the validation points for large

Validation needed: rain module

PDF of
disdrometer data

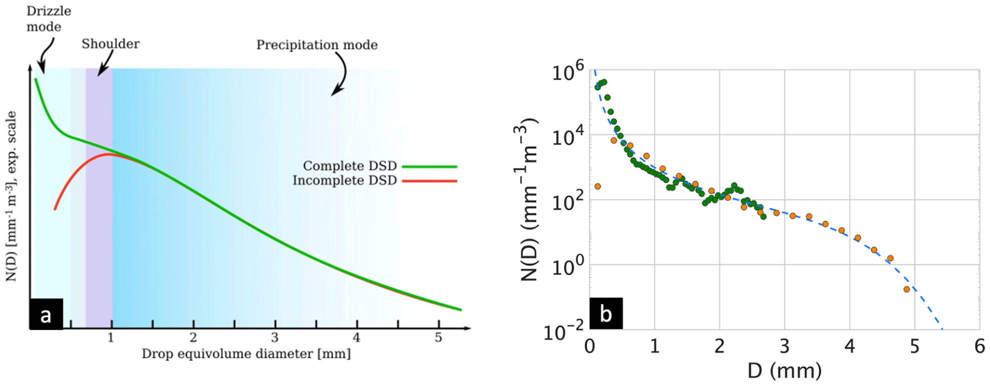




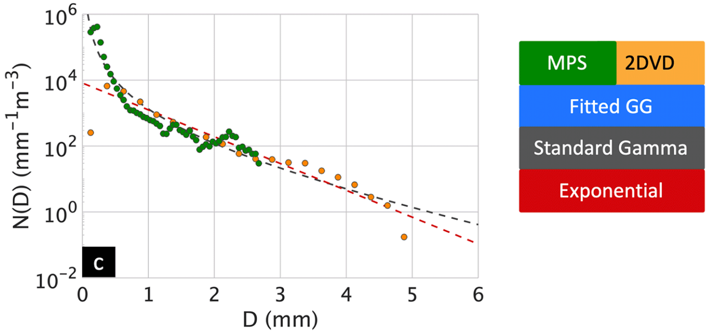
Only **0.2%** of CloudSat data in rain exceeds **12dBZ**

Validation needed: rain module

Disdrometer + cloud probe

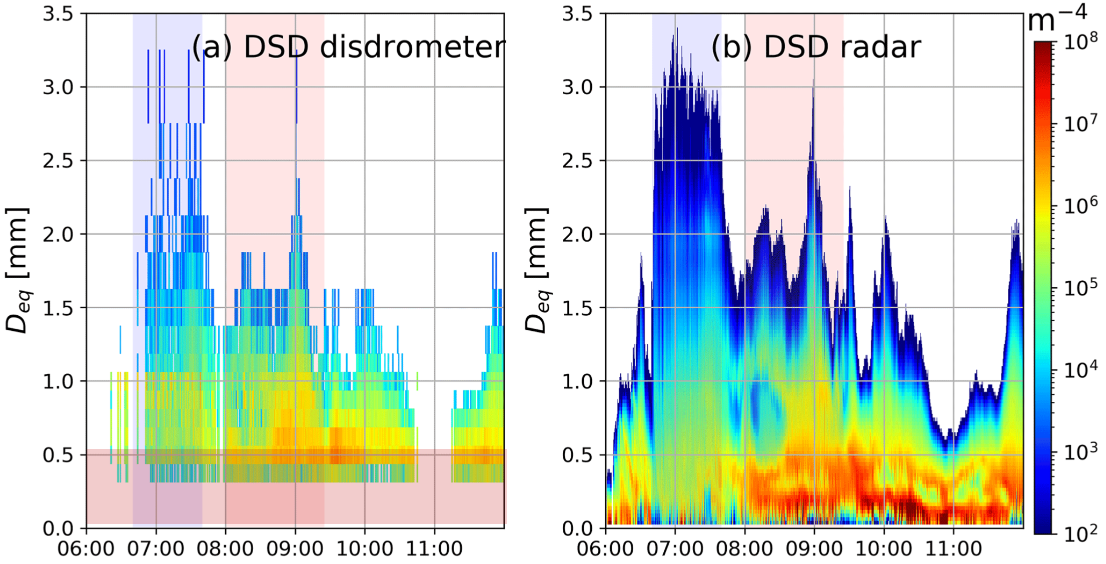


Bringi et al. (2020)



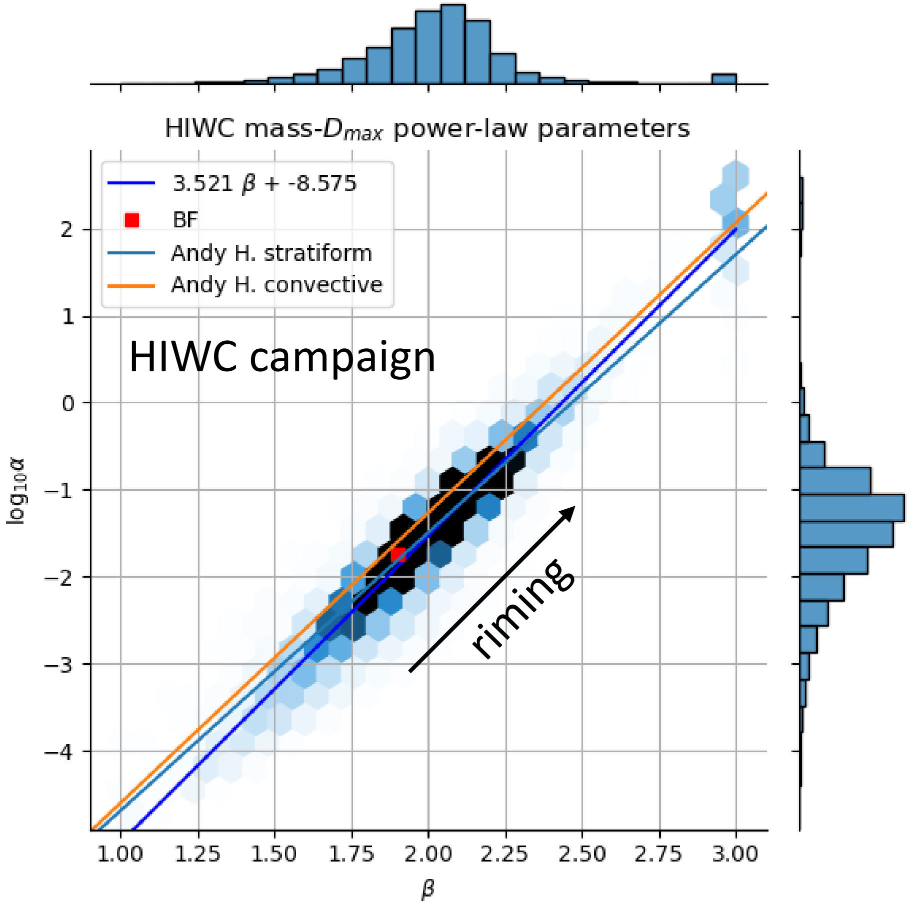
- Long integration time
- Small sampling volume
- Direct DSD measurements

Vertically pointing radar

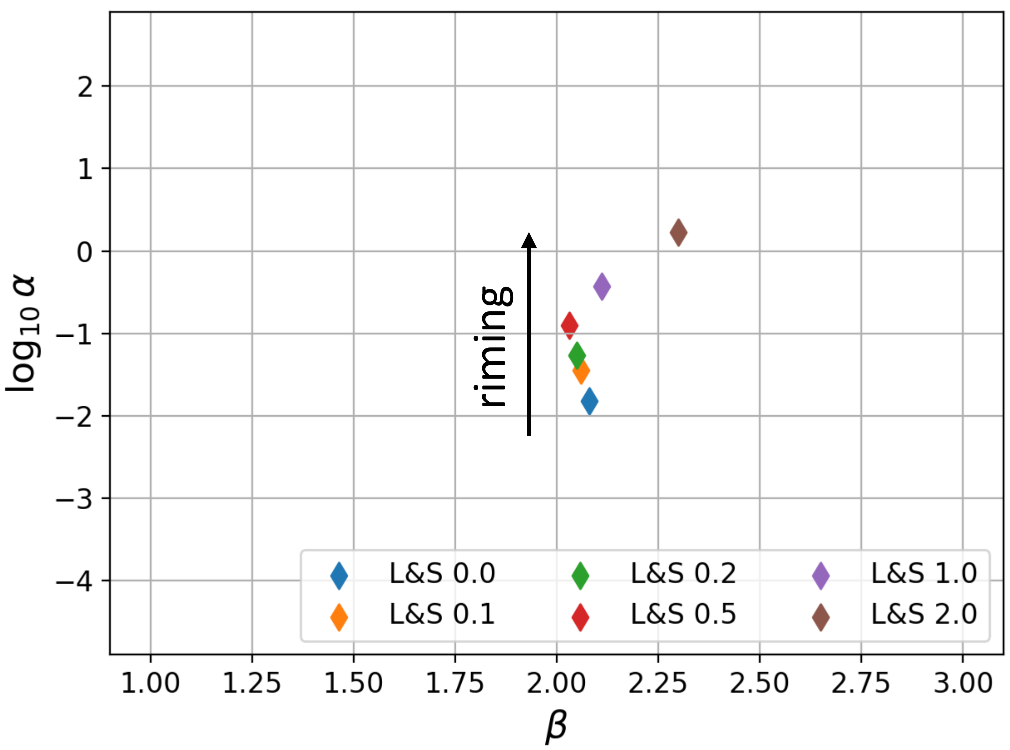


- Short integration time
- Large sampling volume
- Indirect DSD estimate:
- ➢ Vertical wind estimate is crucial for accuracy – W or G band system needed (Kollias et al. 2002)
- ➢ Lidar system needed to estimate #droplets below 200um

Mass-size relationship: m [kg] = α D[m]$^{\beta}$

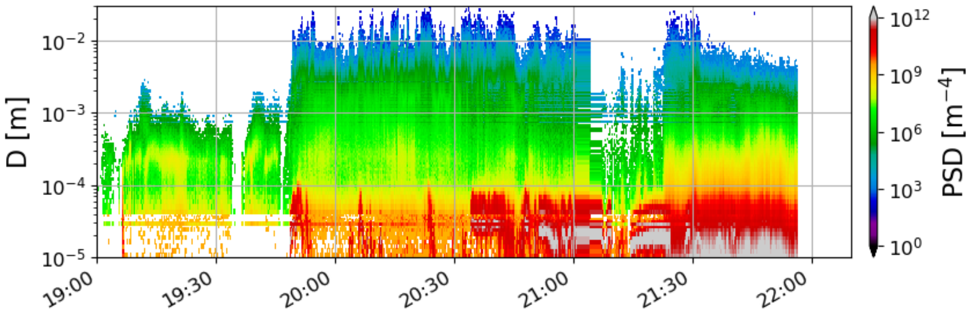


Simulations of aggregates

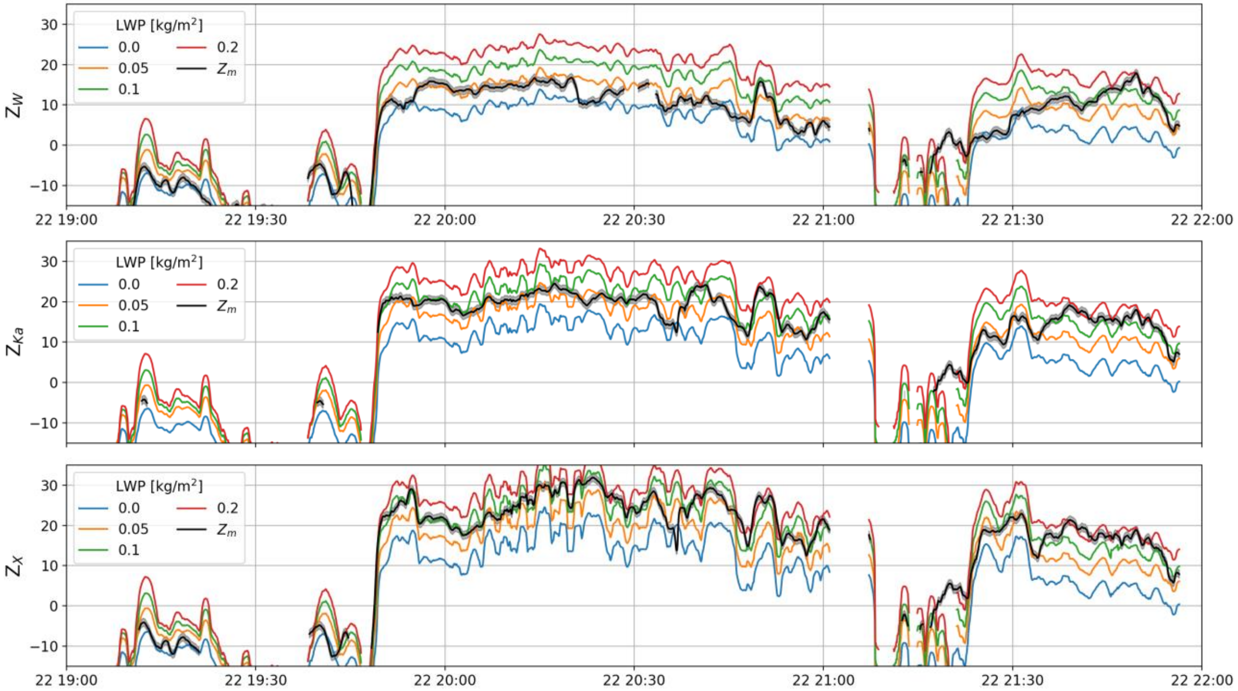


C-CLD product

Validation needed: snow/ice module

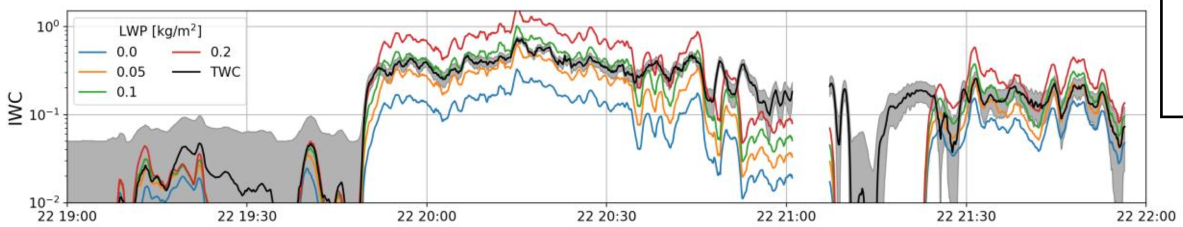


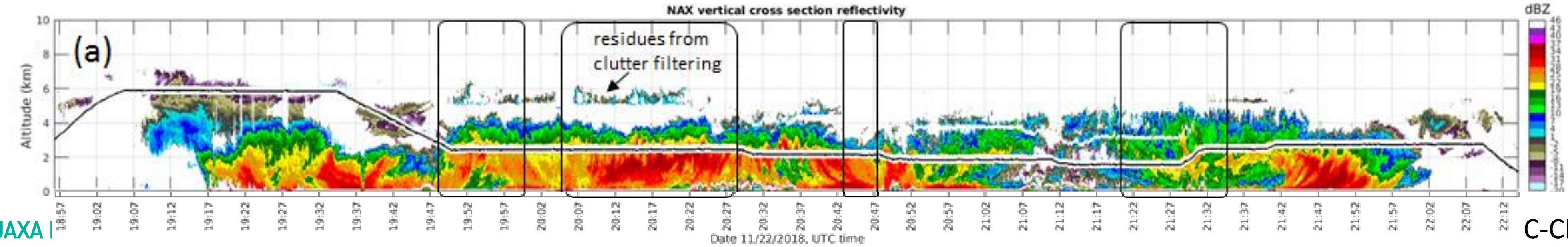
Radar



Ice density dependent simulations

Nevzorov





RadSnowExp

C-CLD product

Conclusions and Future work

- C-CLD is a precipitation retrieval based on the OE framework
- Information content of EC CPR measurements varies depending on hydrometeor size and type:
  - reflectivity is more informative for ice and snow
  - mean Doppler velocity more useful in rain
- Calibration and validation activities need to focus on weather conditions not included in GEM simulations:
  - Large particle sizes
  - Warm rain conditions
- C-CLD algorithm was applied to stratiform precipitation only; we can test it in convective profiles
- More studies on liquid cloud detection needed
- Explore potential for horizontal continuity, i.e., diverge from a profile-to-profile approach