An efficient volume scan polarimetric radar forward OPERAtor to improve the representaTION of HYDROMETEORS in the COSMO model
(Operation Hydrometeors)

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Objectives

1. **Exploitation of radar polarimetry for quantitative process detection in precipitating clouds and for model evaluation**
   & provides an efficient polarimetric forward operator
2. Improvement of cloud and precipitation schemes in atmospheric models based on process fingerprints detectable in polarimetric observations
3. Monitoring of the energy budget evolution due to phase changes in the cloudy, precipitating atmosphere for a better understanding of its dynamics
4. Generation of precipitation system analyses by assimilation of polarimetric radar observations into atmospheric models for weather forecasting
5. Radar-based detection of the initiation of convection for the improvement of thunderstorm prediction

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Major goals

1) Extend non-polarimetric forward operator EMVORADO to polarimetry assuming spheroids at precipiation radar wavelengths, non-spheroidal particles and cloud radar wavelengths in phase 2

2) Evaluate (and improve in phase 2) the representation of hydrometeor types and sizes in COSMO/ICON-LAM

3) Evaluate ML-signatures in COSMO/ICON-LAM and revise ML-model in EMVORADO
(mixed-phase model microphysics in phase 2)

Standard approach for hydrometeor classification (HMC)

To assign dominant hydrometeor types to radar resolution bins …

1) Definition of number and type of hydrometeors
2) Formulation of expected radar observations for each class (mostly through scattering simulations alone, sometimes modified to better reproduce observations)
3) Association of each radar bin with one class via comparison of observed radar variables with expected ranges

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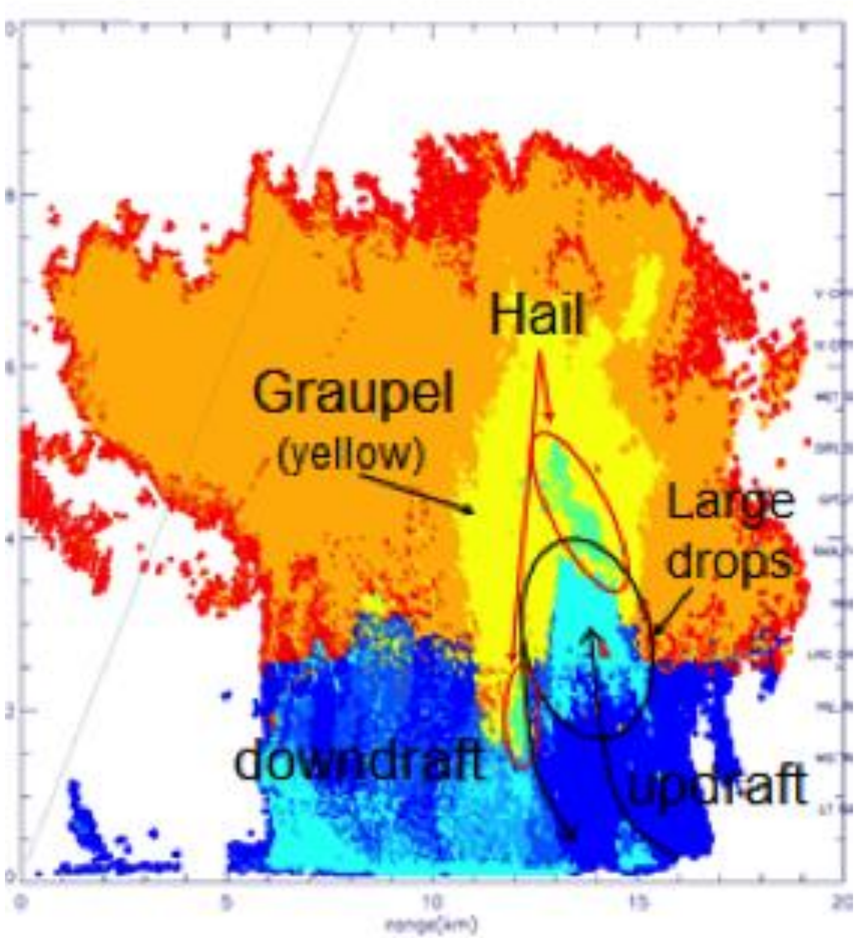
Overall research question: Does the model produce the right hydrometeor types with correct mean particle sizes?



- vert. ice crystals
- hor. ice crystals
- wet (melting) snow
- dry snow
- graupel/small hail
- mixture of rain & hail
- hail
- rain dominated by large drops
- heavy rain
- mod. rain
- light rain

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COSMO classes: cloud water, rain, cloud ice, snow, graupel, and hail

Resulting problems/ challenges for a direct comparison

1) HMCs have different class definitions and numbers
2) Scattering for ice hydrometeors are uncertain and the combination with observation errors (point 4) may lead to unphysical class attributions
3) A less represented hydrometeor class may be identified as dominant in hydrometeor mixtures due to disproportional impact
4) Quantification of the impact of the accuracy of radar measurements on HMC typing is challenging (Park et al. 2009 made an attempt)
5) A comparison between observed and modelled hydrometeor types can only be done statistically

Proposed dual strategy

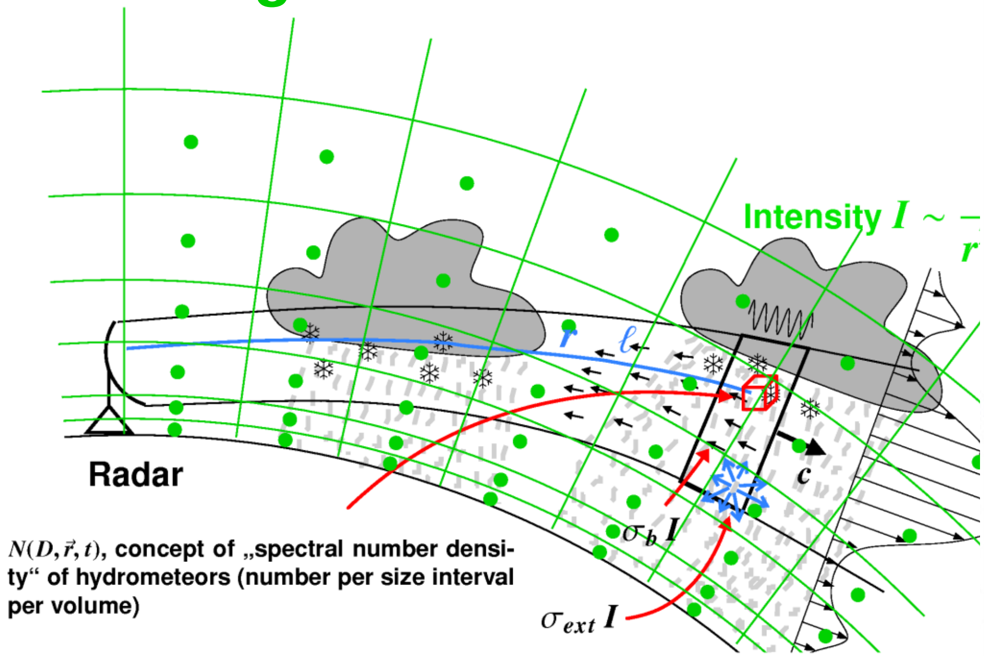
1. Comparison of modelled hydrometeor space-time distributions with a sophisticated polarimetry-based HMC (classification AFTER clustering)

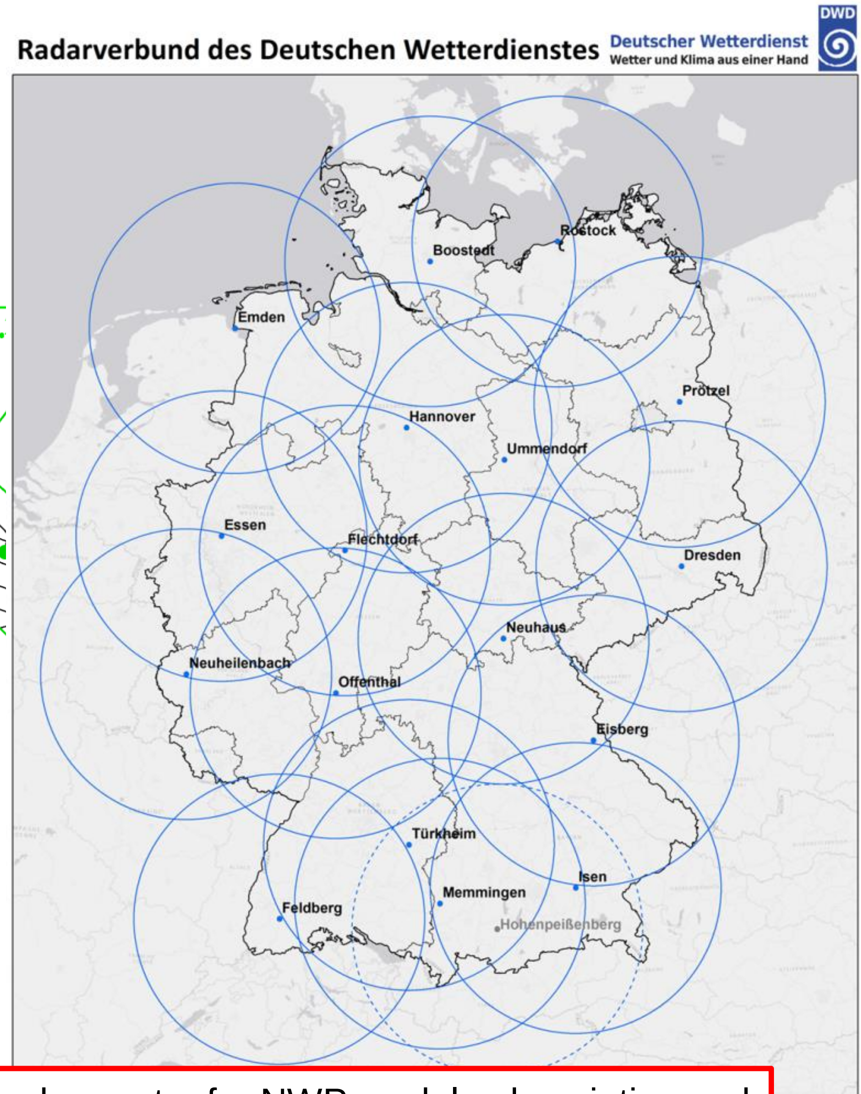
2. A direct comparison of simulated and observed distributions of polarimetric moments

The existing conventional radar forward operator EMVORADO

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

model grid and weather radar





Simulated moments on radar grid:

- ➔ **Z** (Mie, optionally including attenuation, partial melting, beam broadening)
- ➔ V_r (optionally Z-weighted beam broad.)

Zeng et al., 2016: An efficient volume-scanning radar forward operator for NWP models: description and coupling to the COSMO model, QJRMS, **142**, 3234-3256, doi:10.1002/qj.2904

Status of EMVORADO

- Efficient Modular VOlume scan RADar Operator
- Framework for efficient and yet accurate simulation of radar volume data of entire networks in a modular and highly configurable way
- Consistent to assumptions on particles in microphysics (PSDs, mass-size, vel-size), but no subgrid-scale clouds (e.g., parameterized cumulus or stratocumulus)
- Physics options for reflectivity and radial wind simulation:
  - Beam propagation, beam function smoothing, beam blockage
  - Mie- or Rayleigh scattering, attenuation
  - Partially melted particles
- Lookup tables for Mie-scattering for efficiency
- Parellel code, online coupled to COSMO–model (ICON in progress right now!), or applicable offline to archived model data
- Simulated volume scans (range, azimut, elevation)

Status of EMVORADO

➔ Melting layer: Choosable different EMA's for ice-water-air mixtures, size-dependent melted fraction

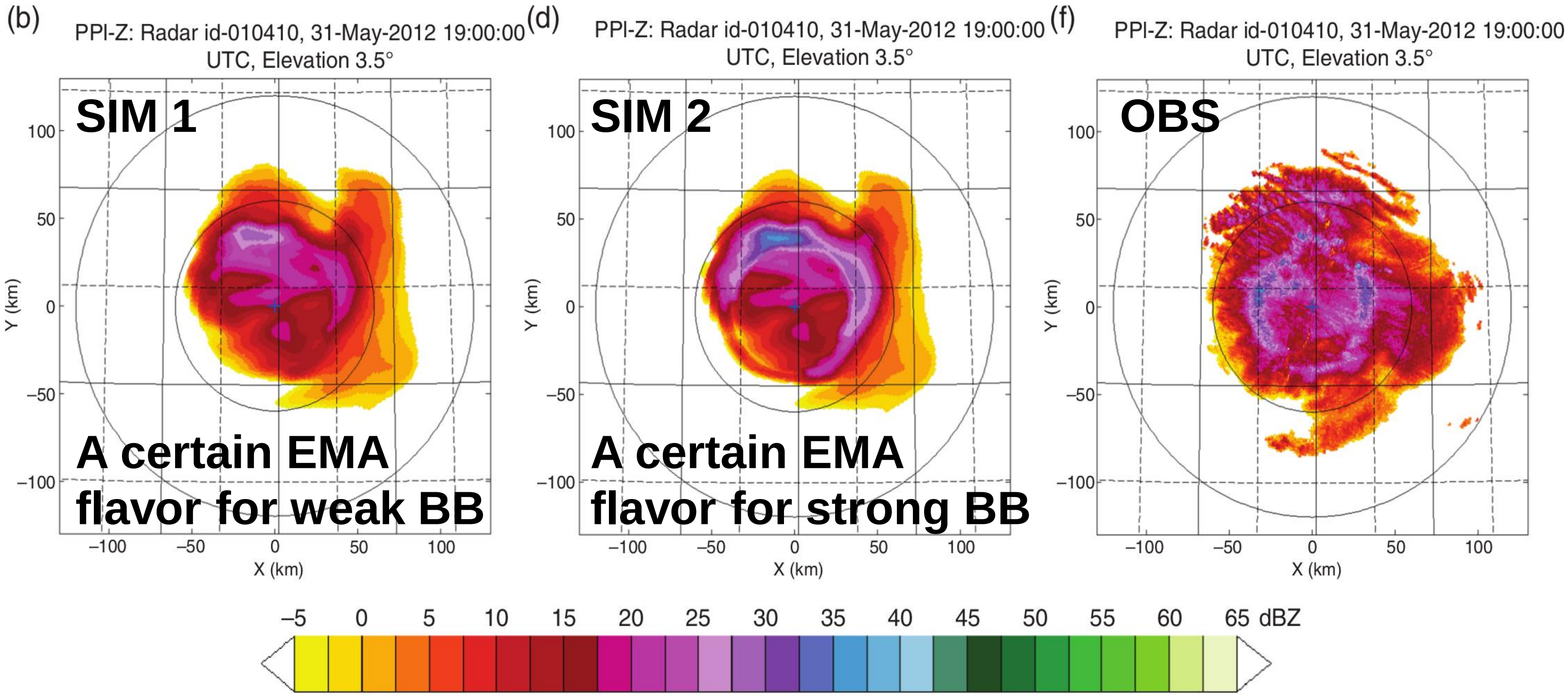


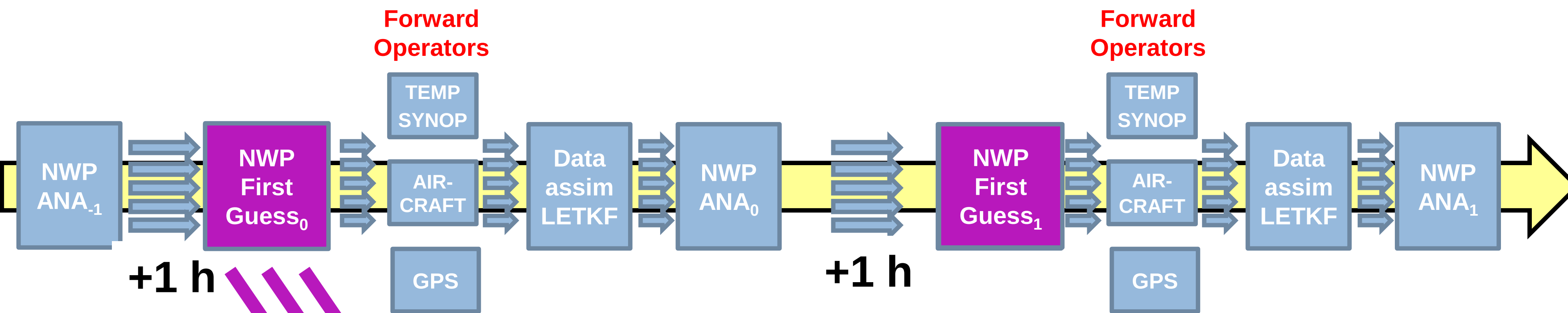
Fig 12 of Zeng et al. (2016): *Simulated PPIs of Z using two "extreme" EMAs for melting particles, for a bright-band case and in comparison to the observed PPI (right). Left: assumed Rayleigh-scattering with Oguchi (1983) EMA (weakest bright-band). Middle: assumed Mie-scattering with a flavor of Maxwell-Garnett (1904) EMA (strongest effect according to an extensive sensitivity study in Blahak, 2016).*

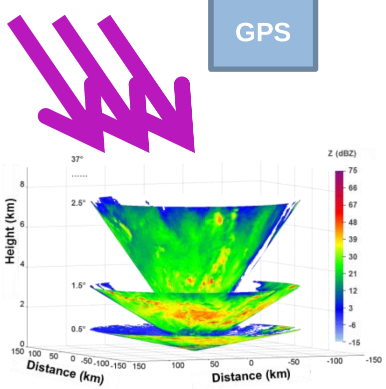
Plan: polarimetric upgrade to EMVORADO

- **EMVORADO-POL**
- We plan to add:
  - Z_H, ZDR, RHO_{HV}, K_{DP}, A_H, A_{DR} for oblate spheroids
  - Efficiency by lookup tables along the lines of existing Mie-scattering option
  - Building on polarimetric operators of Uni Bonn and NSSL Oklahoma (cooperation with Jeffrey Snyder) for lookup table generation and use
- Propagation effects and local elevation angle taken into account
- Non-model-constrained parameters (particle asymetry, canting angle distr.) taken from literature
- Available in ICON-LAM to other SPP-projects after about first year

Plan: Case studies for microphysics validation based on DA-cycle + 1-h forecasts

- ➔ Need model precip statistics as close to the observations as possible, and
- ➔ Need model state in physical balance.
- ➔ How to achieve this?
  - ➔ Look at **„first guess“ forecasts** (~1 h or less) of ensemble DA-cycle
  - ➔ **Here, imbalances caused by DA have just vanished**





Data from first guess runs for validation:

- **Model hydrometeor variables**
- **EMVORADO-POL**

Proposed dual strategy

1. Comparison of modelled hydrometeor space-time distributions with a sophisticated polarimetry-based HMC (classification AFTER clustering)

2. A direct comparison of simulated and observed distributions of polarimetric moments

Strategy 1)

I. Generate **3D grids of observed and synthetic polarimetric variables** for the defined 5 stratiform and 5 convective case study days, respectively

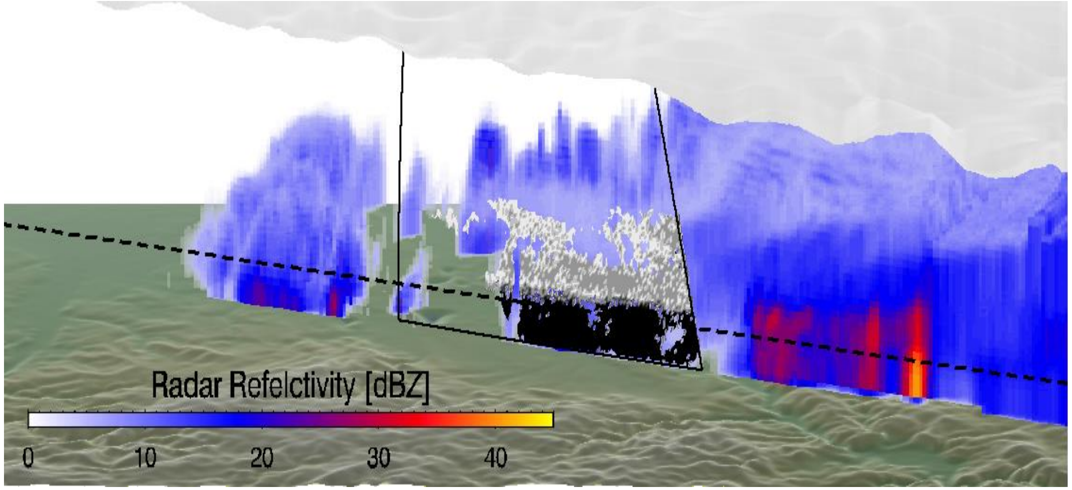


Illustration of 3D compositing a la Diederich et al. (2015) including results of HMC (Zrnic et al. 2000 adapted to X-band):
light rain in black, wet snow in dark grey, dry snow in light grey, and dendrites/plates in white.

Strategy 1)

II. Apply Agglomerative Hierarchical **Clustering** (AHC, similarity of variables and smoothness of boundaries) to both **observed and synthetic radar composites**

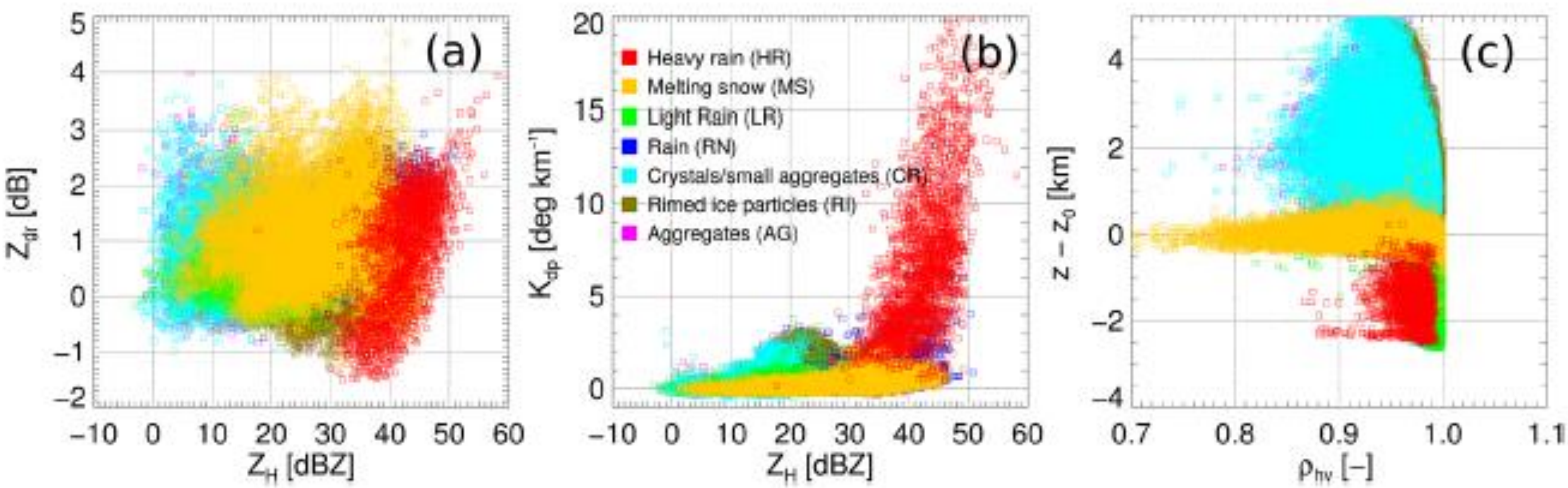


Illustration of cluster definition a la Grazioli et al. (2015)
we do it for COSMO classes: cloud water, rain, cloud ice, snow, graupel, and hail

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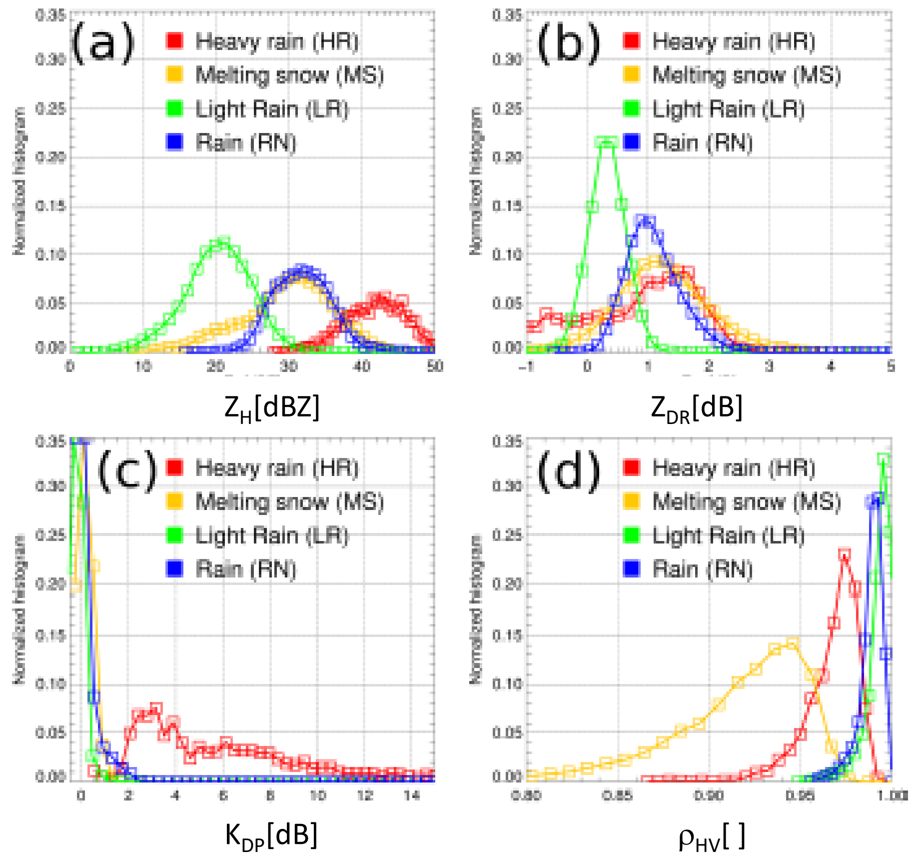
Strategy 1)

III. Generate **reference distributions of Z_H, Z_{DR}, ρ_{HV}, K_{DP} for the 6 hydrometeor types** included in COSMO/ICON-LAM (2-moment scheme) as a function of mixing ratios, number concentrations, environmental variables



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Strategy 1)

IV. **HMC of observed and synthetic clusters** via comparison with both published membership functions and our own generated reference distributions for the 6 classes.

V. **Comparison of observed and modelled hydrometeor types** Distributions of classified types as a function of height

VI. **Reliability of HMCs** (our advanced HMC and standard routines) **in mixtures of hydrometeors**

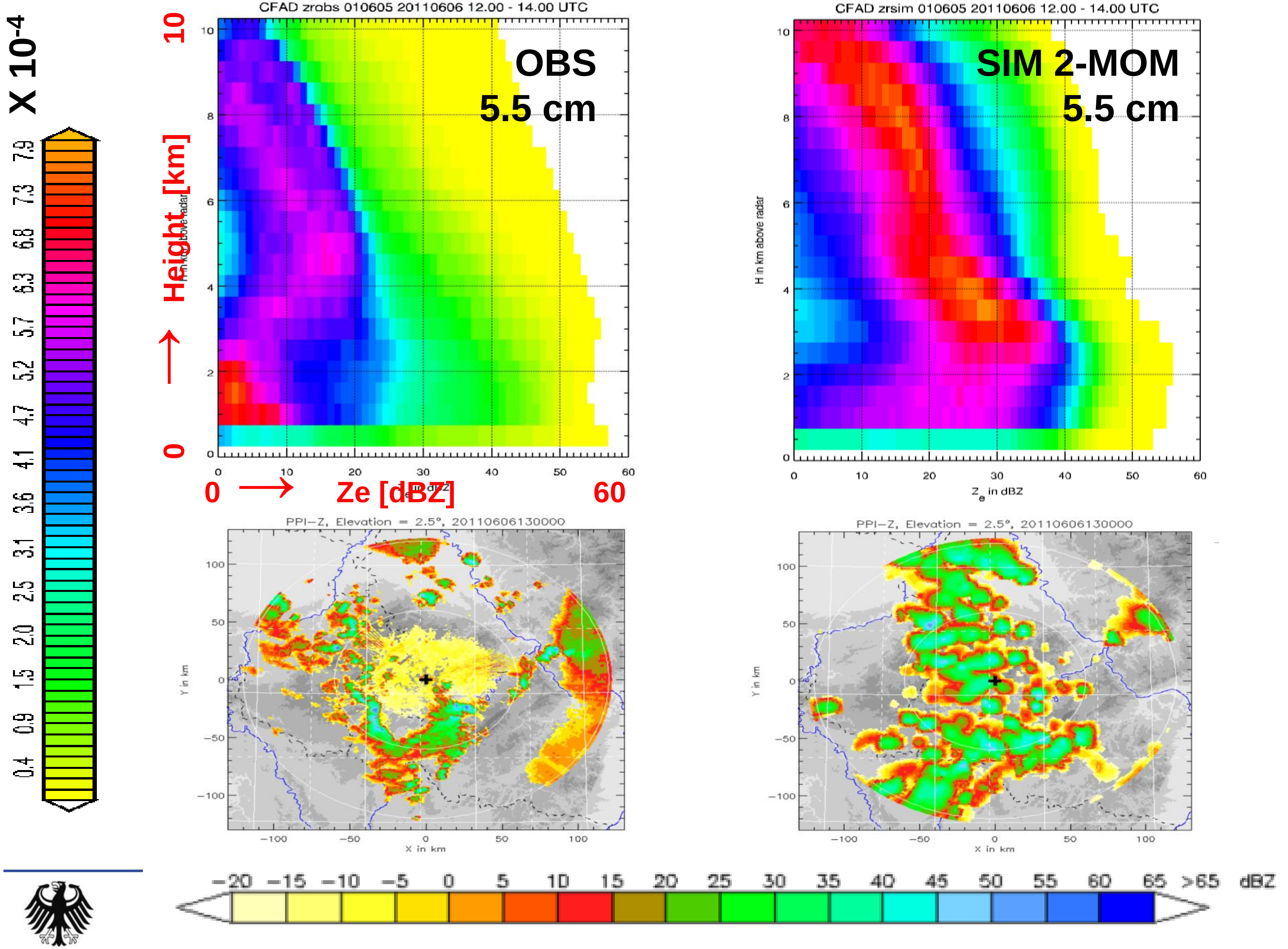
VII. **Validation of raindrop sizes in COSMO/ICON-LAM** using $D_m=1.53\ Z_{DR}^{0.4}$ or more recent retrievals developed in PARA

Strategy 2: Direct comparison of polarimetric moments

- → Z_H, ZDR, RHO_{HV}, K_{DP}, A_H, A_{DR}
- → **Data: DWD network, X-Band Uni Bonn / FZ Jülich**
- → Evaluation of melting layer signatures and revised melting model in EMVORADO-POL
- → (Conditional) histograms of polarimetric variables:
  - → CFADs, QVPs (→ overall model biases)
  - → Stratified according to hydrometeor types / clusters (→ typical differences for each hydrometeor type, independent from differences of spacial coverage)

Example for CFADs of reflectivity

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Perspectives for Phase 2

- ➔ Non-spheroidal frozen particle shapes, mm-wavelengths (coop. Kneifel/Seifert IMPRINT)
- ➔ Direct assimilation of polarimetric volume scan data into ICON-LAM
- ➔ Based on results of phase 1, improvements to 2-moment microphysics in ICON-LAM (coop. IMPRINT)

- ➔ Preparations already near end of Phase 1:
  - ➔ First steps for non-spheroidal frozen particle shapes (coop. IMPRINT)
  - ➔ Comparison of EMVORADO-POL to other forward operators in SPP-PROM

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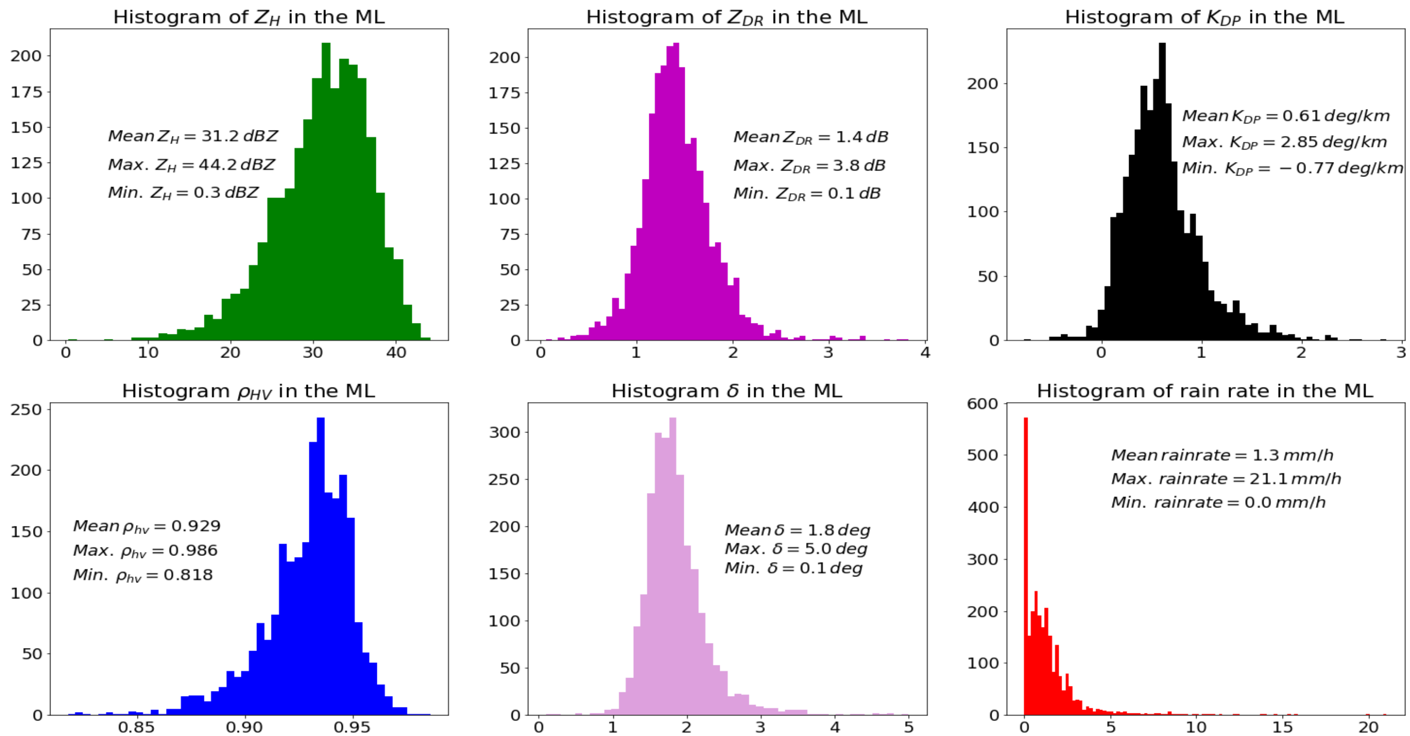
Histograms of pol. variables in the ML at X band



Work packages:

1. Generate a climatology of polarimetric variables in the ML at C- band