PRISTINE

–

Polarimetric Radar simulations with realistic Ice and Snow properties and mulTI-frequeNcy consistency Evaluation

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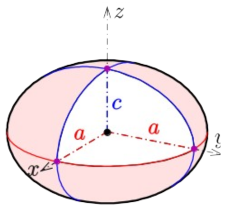
+ contribs by J. Steinheuer, … (Uni Bonn)

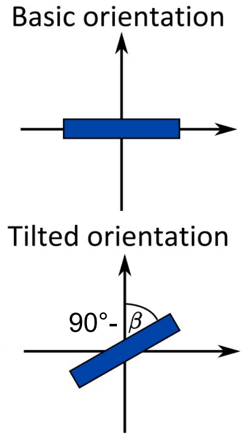
Polarimetric radar operator

- Approach: add polarimetry to EMVORADO, but **keep existing core features & characteristics**
  - consistent model coupling, sensor (network) modelling
  - hydrometeor property assumptions (e.g. hydrometeor morphology & melting state)
  - speed (→bulk scattering lookup-tables)
- Added scattering model option: **T-Matrix** + **angular moments**
  - **default:** shape (AR), orientation (s_b), melt fraction dependence from **Ryzhkov et al. (2011)**

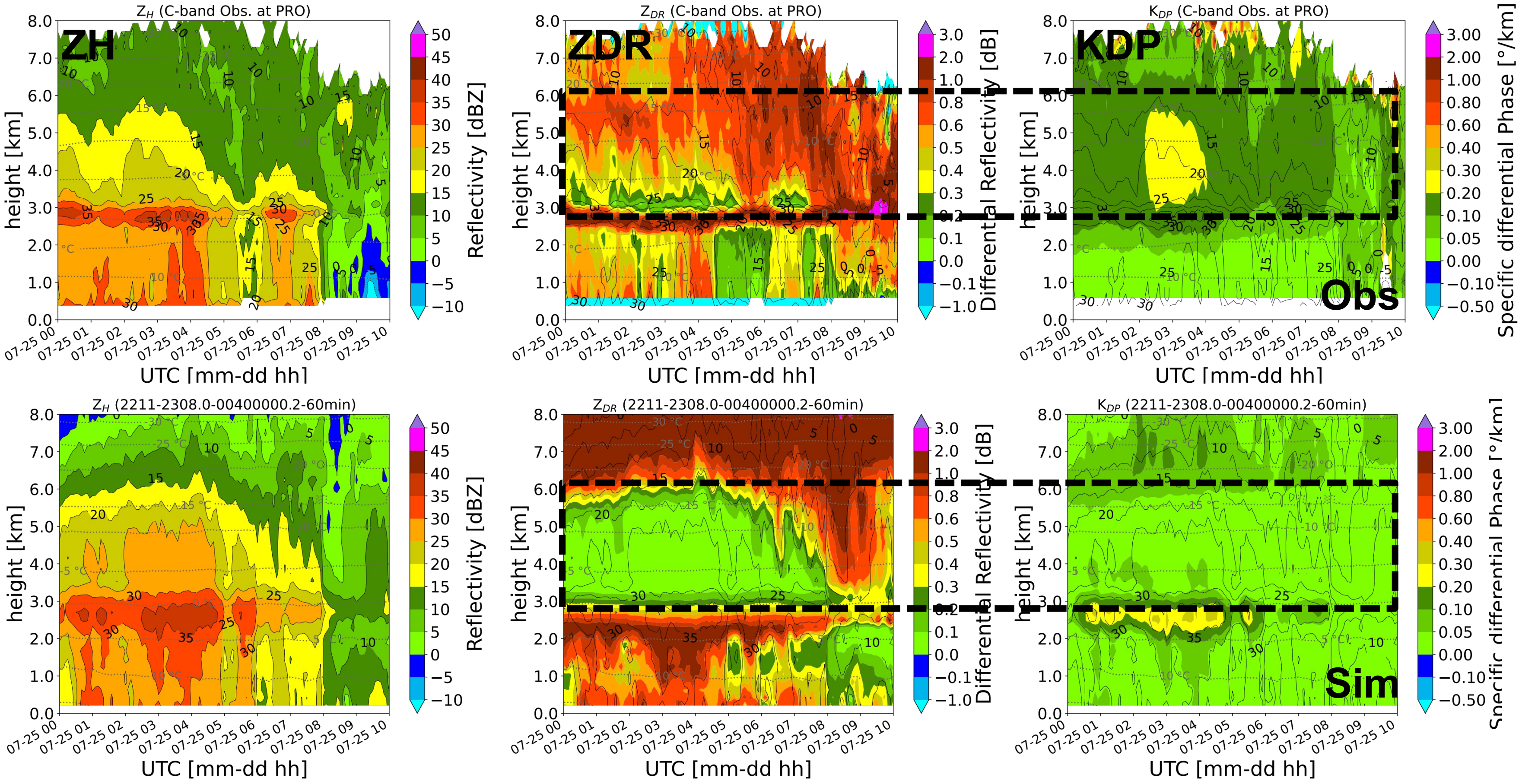
*state-of-the-art, but **has** its **issues***

liquid	rain	ice	snow	graupel, hail	
Rayleigh	oblate spheroids	oblate spheroids	oblate spheroids	oblate spheroids	shape
-	Brandes (2002) f(deg4-in-D)	Matrosov (1996) thick plates aD^b (→ 0.2)	**0.8**	1.0-0.02*D 0.8 (D>10mm)	AR
-	10°	~~10°~~ 25° (Bukovcic, p.c.)	**40°**	40°	$\mathbf{s_b}$
-	-	both: lin. in f_m to rain	both: lin in f_m to rain	AR: lin. in f_m between AR_{wet}=[AR_{dry},0.8,0.48,AR_{rain}] for f_m=[0,0.2,0.8,1] s: lin. in f_m to rain	melting behaviour (f_m=mass melt fraction)



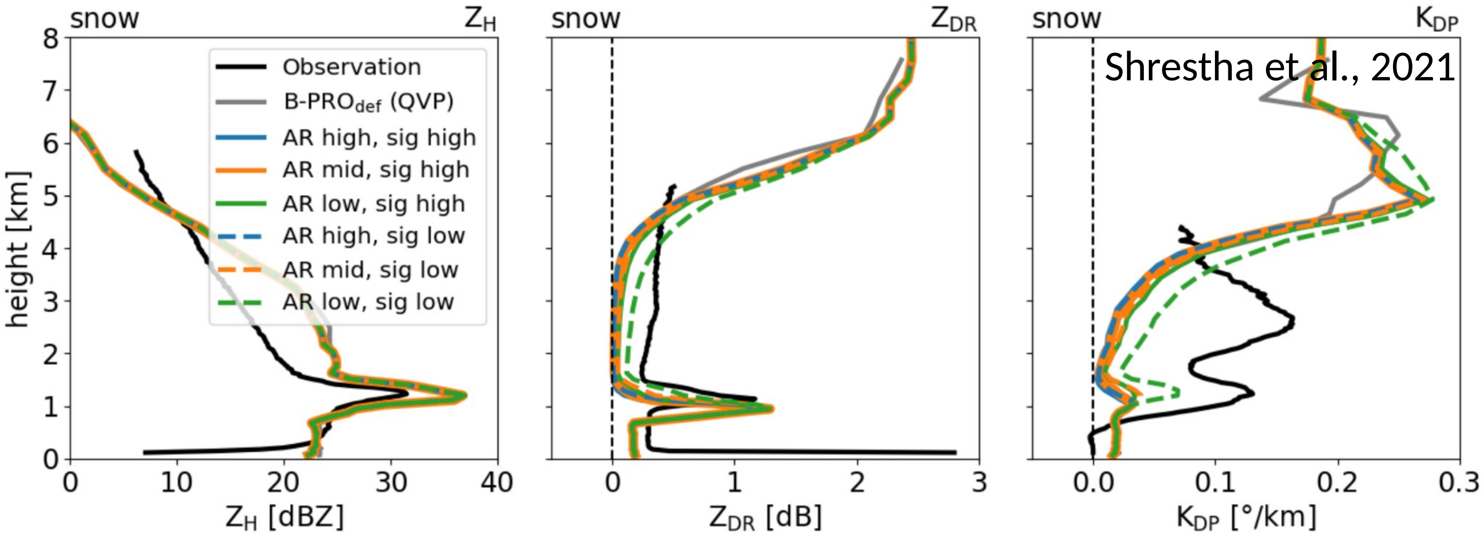


Motivation: lack of snow polarimetric signatures



- ➔ Polarimetric „void“ in dendritic growth layer

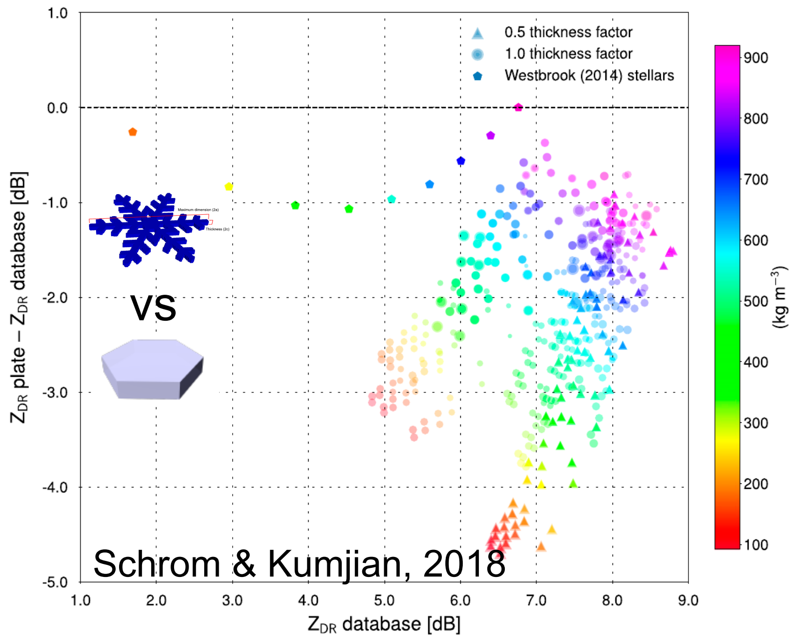
Motivation: lack of snow polarimetric signatures



	snow
AR_{high}	Ryzhkov et al. (2011) $max(1.0 - 20D, 0.8)$
AR_{mid}	**Xie et al. (2016)** $\boldsymbol{max(0.7 - 10D, 0.5)}$
AR_{low}	Dunnavan et al. (2019) 0.4
σ_{high}	**Ryzhkov et al. (2011)** **40°**
σ_{low}	Matsui et al. (2019) 20°

➔ Polarimetric „void“ in dendritic growth layer

- persists till quite extreme AR & σ_β
- characteristic to low-effective-density proxies (spheroids, hexagonal plates, ...)



DWD: Project aims

➔ **Improve DWD‘s radar operator EMVORADO**

- for (better) use in
  - **model evaluation:** O-B deviations due to NWP model or radar operator?
  - data assimilation: bias reduction (at the source, not post-proc)

- but keeping its capabilities
  - **model consistency (esp. PSD, m-D relation)**
  - calculation speed (eg. bulk scatt. lookup tables)
  - flexibility in instrument definition, e.g. frequency

➔ **Phase 1: Externally prepared model-consistent LUT**

- a) Quick & (very) dirty: re-use hash ID from TMat template
- b) make up own, simplified hash for SSDB: e.g. only consider PSD & m-D

➔ Phase 2ff: in-EMVORADO LUT preparation

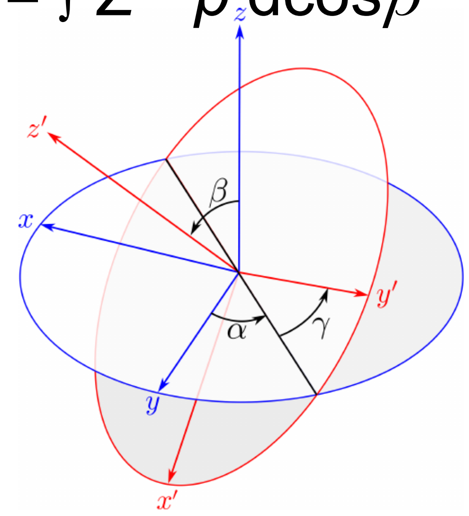
EMVORADO bulk LUT from SSDB ARO data

- Integration **canting angle *b* distribution**

$$\langle Z_b \rangle = \int Z * p * \sin\beta \, d\beta = \int Z * p \, d\cos\beta$$

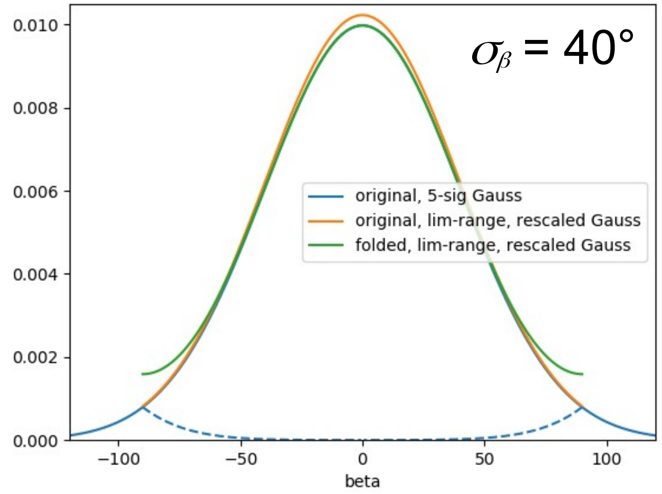
$$p = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

  - Gaussian distribution in β with σ_β around μ_β = 0°
  - trapezoidal quadrature in β
    - from $\Delta\beta$ = 1° → negligible impact of choice of quadrature & base variable
    - renormalized → relevant for large(r) σ_β



- (Construction of combined size grid from multi-habit data)

- Integration **particle size distribution**
  - modified Gamma distribution $n(x) = N_0 x^\mu \exp(-\Lambda x^\gamma)$
    - hydrometeor-class specific parameters, **governed by model**
  - trapezoidal quadrature
    - over non-equidistant size grids (TMat/Mie: Simpson)
    - no renormalization so far → to be analyzed



Before results: Some notes on SSP-governing microphysics

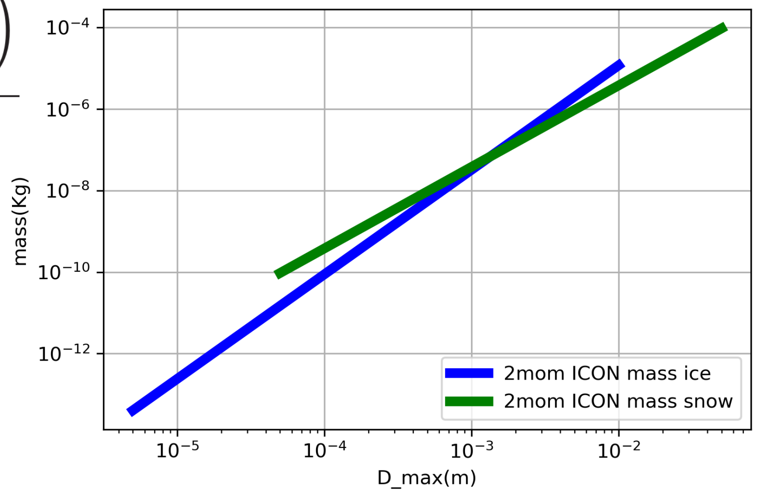
- PSD: modified Gamma distribution (MGD) for all hydrometeor classes $n(x) = N_0 x^\mu \exp(-\Lambda x^\gamma)$
  - reduces to
    - exponential PSD for $\mu = 0$ and $\gamma = 1$
    - power-law PSD for $\Lambda = 0$
  - depending on microphysics scheme, only 1 or 2 free parameters
    - ICON 2mom: μ & γ fixed, N_0 & Λ determined from prognostic *q*x and *N*x (ie mass and number conc.)

- EMVORADO LUT over
  - 2mom: bulk mean particle mass m_{mean} = *q*x / *N*x
  - 1mom: *q*x

$$Nx = N_{\text{tot}} = \frac{N_0}{\gamma} \frac{\Gamma\left(\frac{\mu+1}{\gamma}\right)}{\Lambda^{(\mu+1)/\gamma}}$$

- **$\text{Dmax}_{\text{mass-mean}}$** from m_{mean} by hydrometeor class specific *m-D* relation
  - cloud ice: *m* = 158.8e-2 * Dmax^2.56
  - snow: *m* = 3.800e-2 * Dmax^2.0

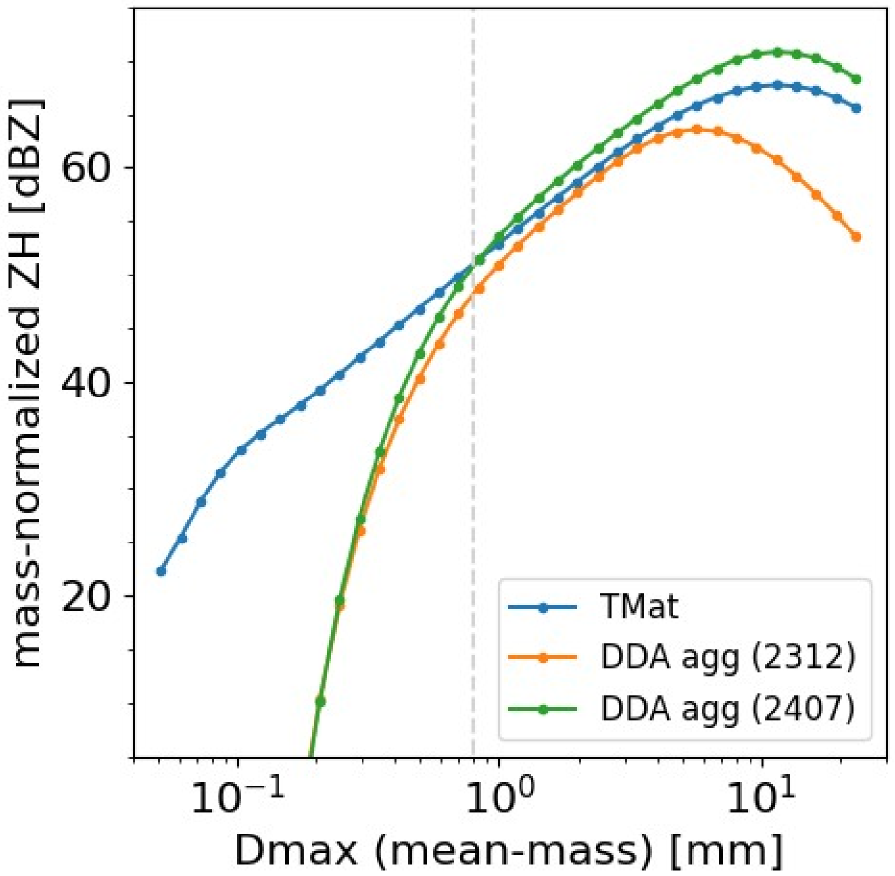
*m = a * D^b*



Results: Bulk scattering SSP – snow

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ **reflectivity** (sanity check)



➔ **1st instance**: still missing large aggregates

- DDA calc time
- particles with requested m-D from aggregation tool

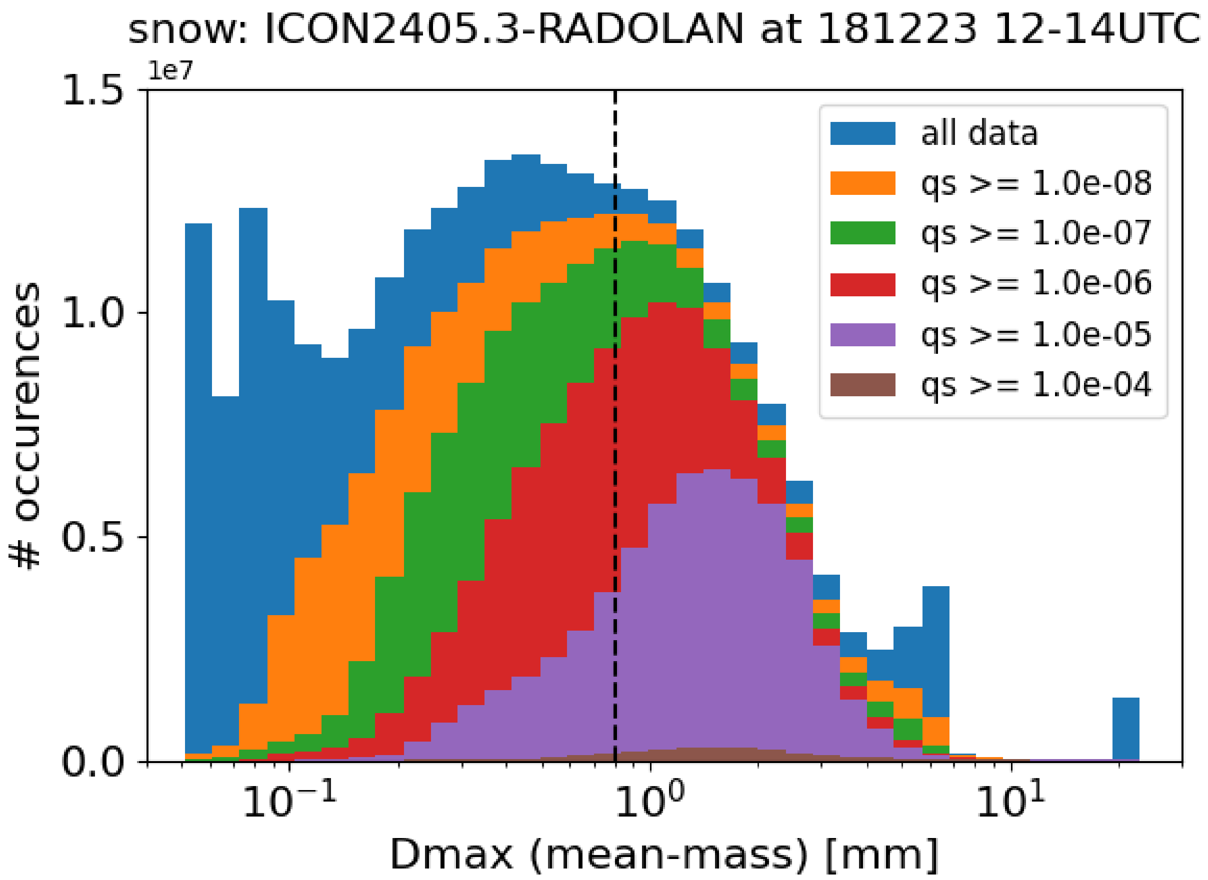
➔ **2nd instance**: missing small particles (min(Dmax) = 1.4mm)

- how small aggregates are realistic?
- how to handle small D in PSD convolution?
- how frequent, ie how relevant, are small $\text{Dmax}_{\text{mass-mean}}$?

Results: Bulk scattering SSP – snow

➔ **reflectivity** (sanity check)

- how frequent, ie how relevant, are small $Dmax_{mass\text{-}mean}$?



➔ stratiform winter day w/ low or no ML

➔ RADOLAN-section of ICON-D2

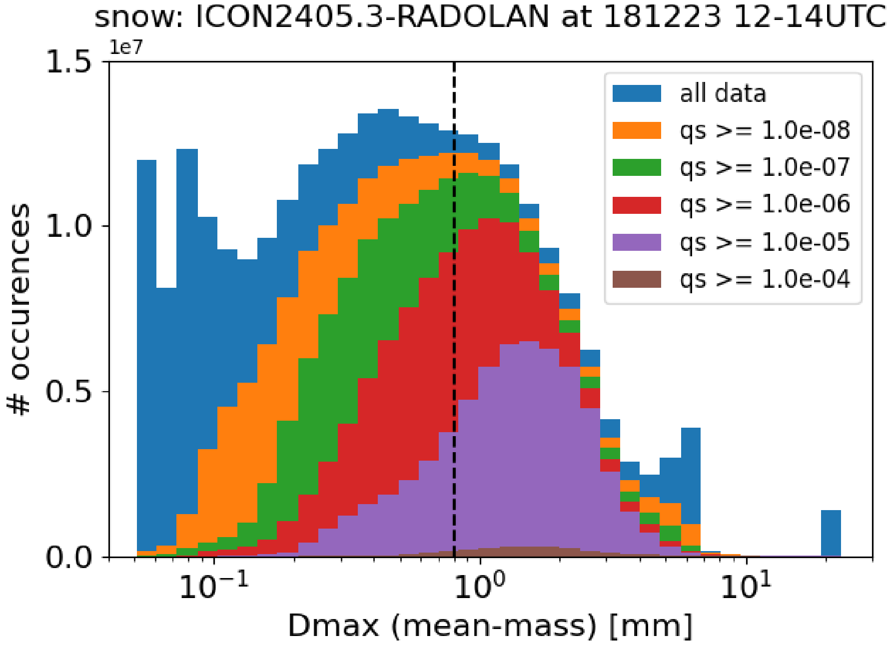
➔ 12 – 14 UTC (init @ 11 UTC)

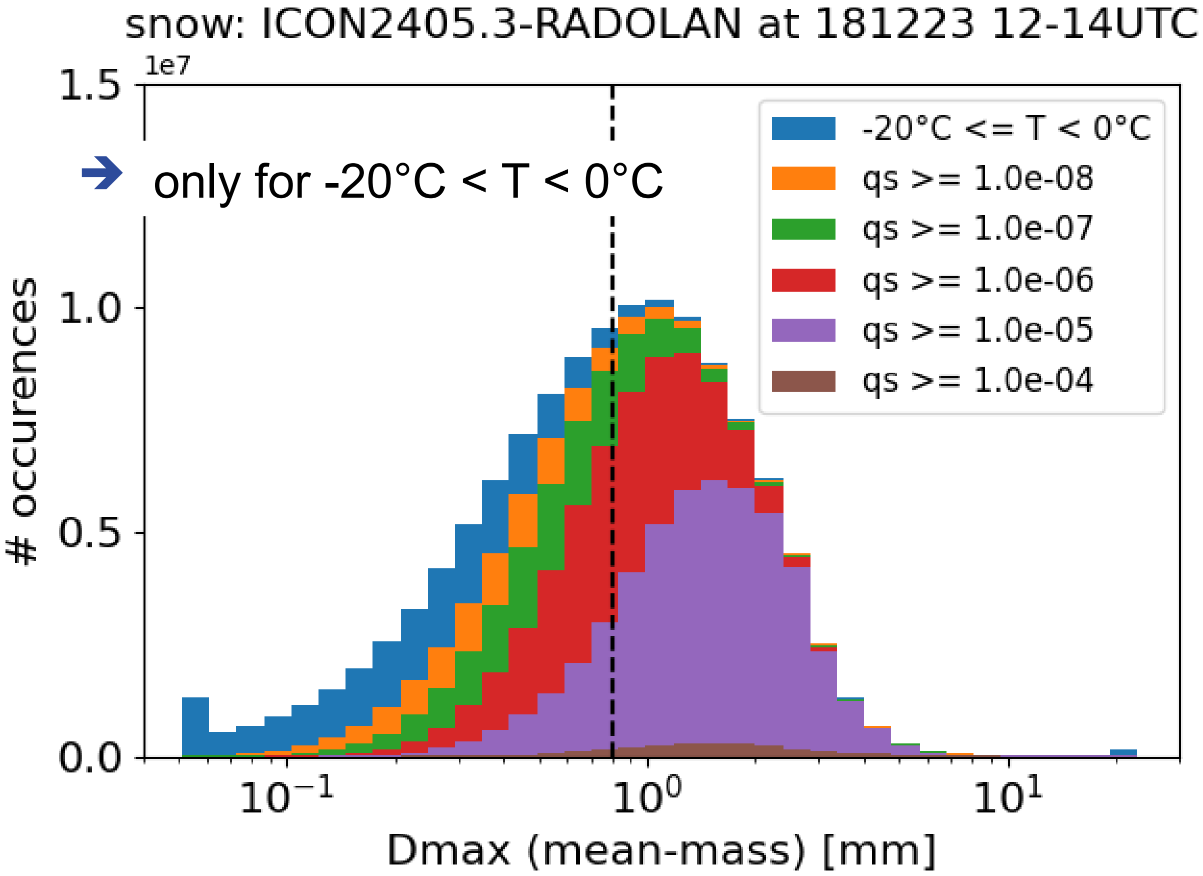
➔ ALL model levels

Results: Bulk scattering SSP – snow

➔ **reflectivity** (sanity check)

- how frequent, ie how relevant, are small $Dmax_{\text{mass-mean}}$?





➔ only for -20°C < T < 0°C

Results: Bulk scattering SSP – snow

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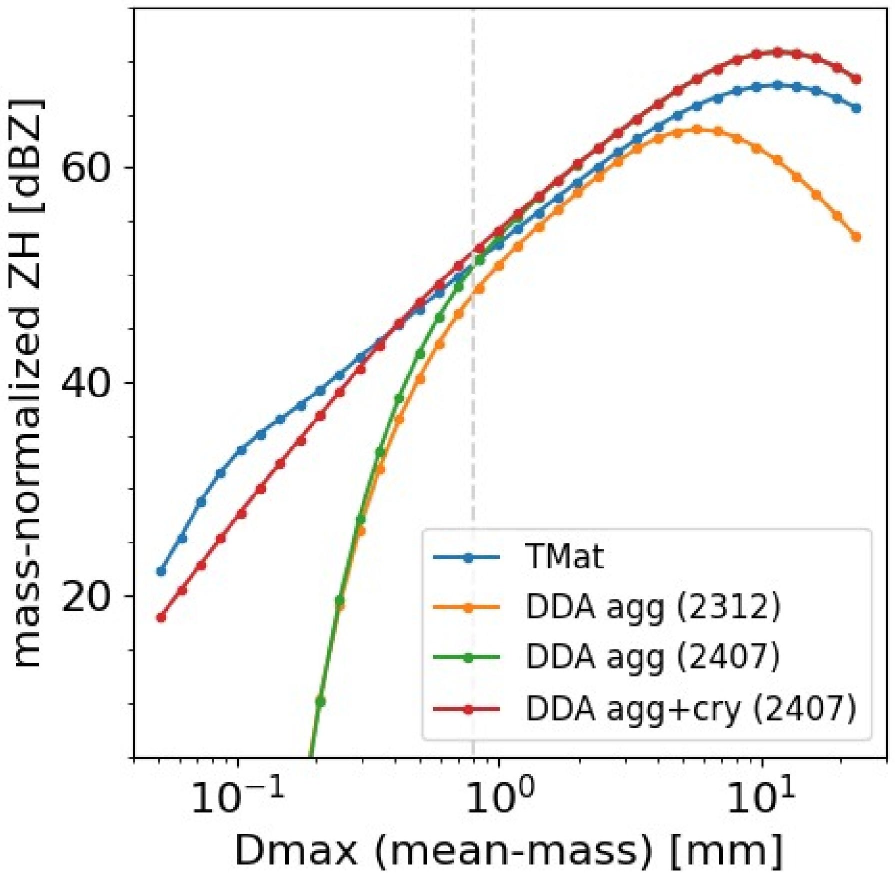


➔ **2nd instance**: missing small particles (min(Dmax) = 1.4mm)

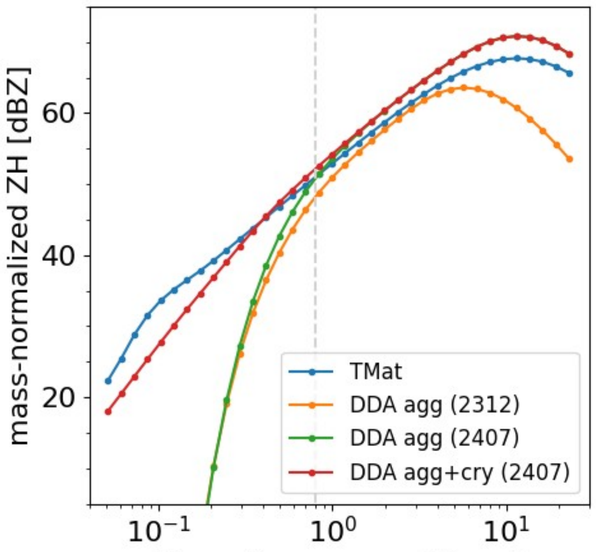
- how to handle small D in PSD convolution?

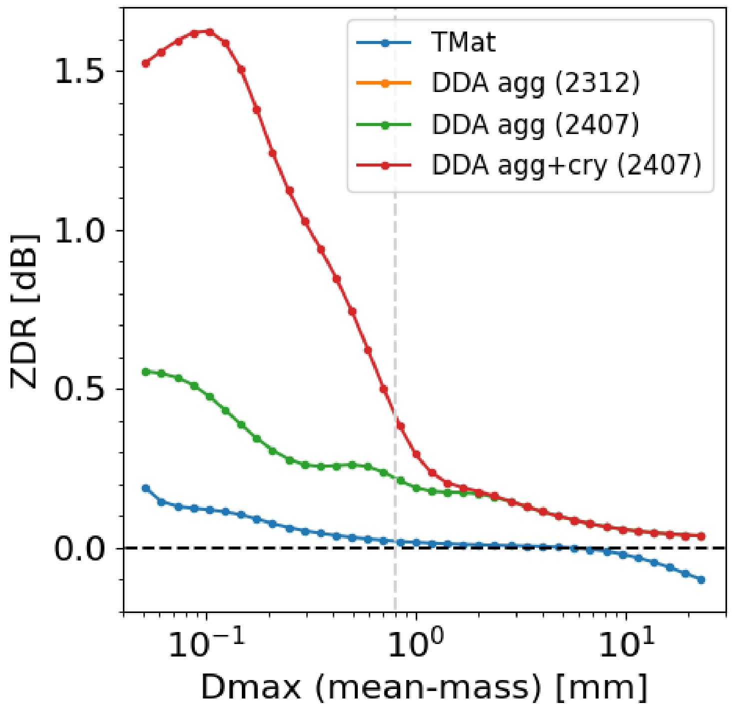
➔ **3rd instance**: supplemented with small-D crystals

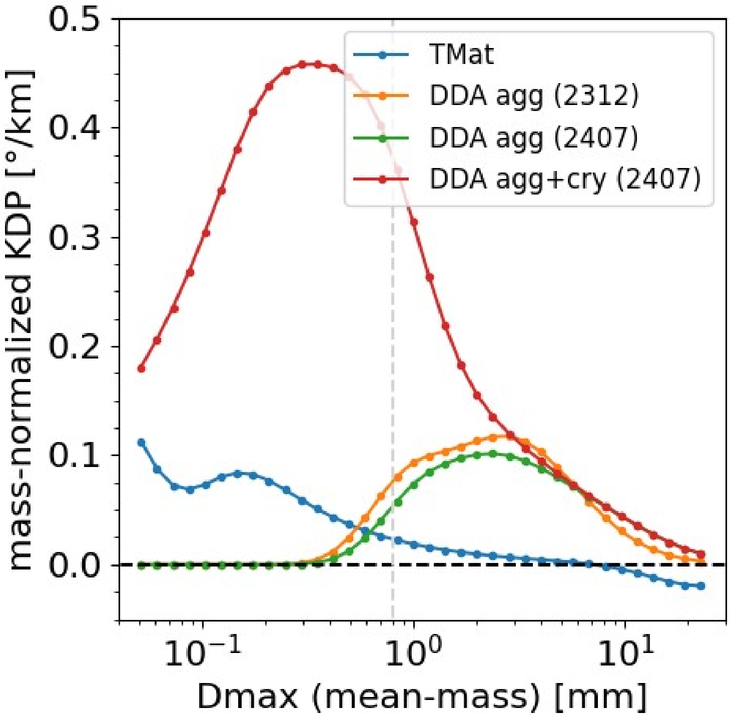
- does well here

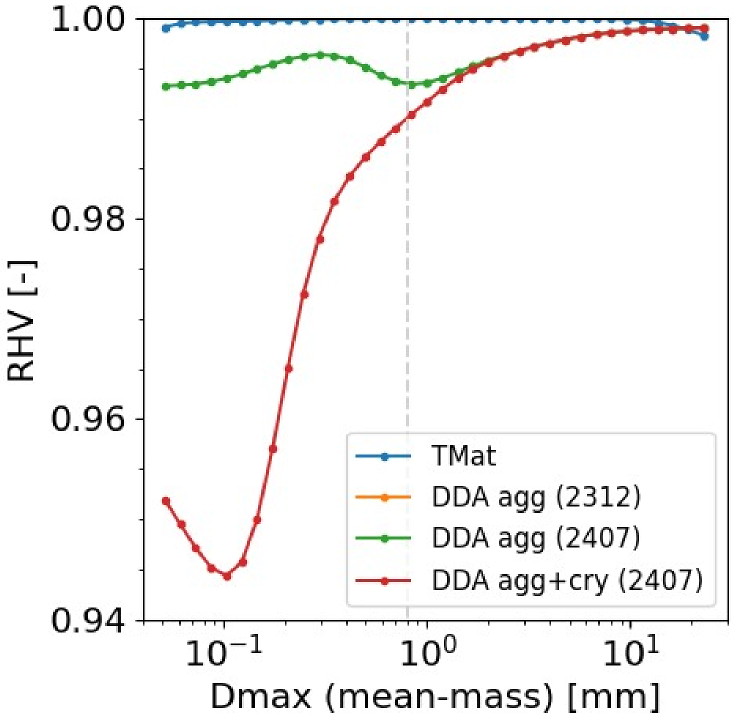
Results: Bulk scattering SSP – snow

➔ **polarimetric parameters**

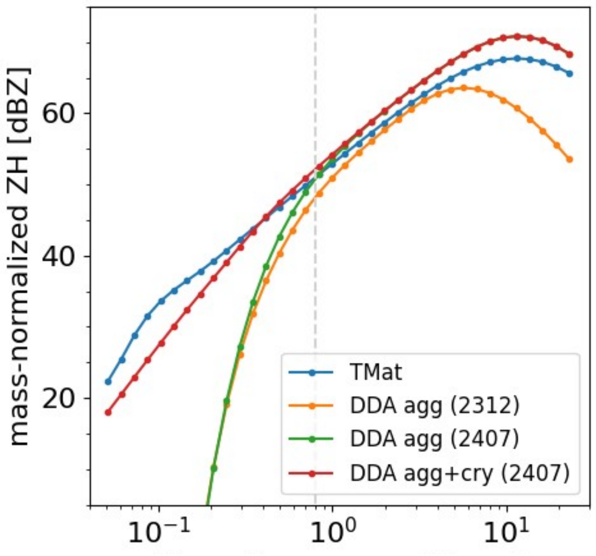






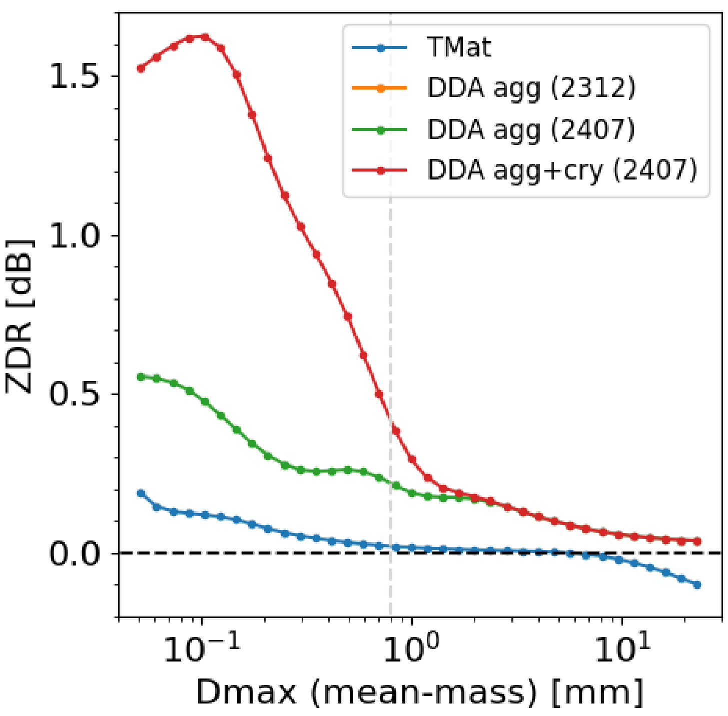


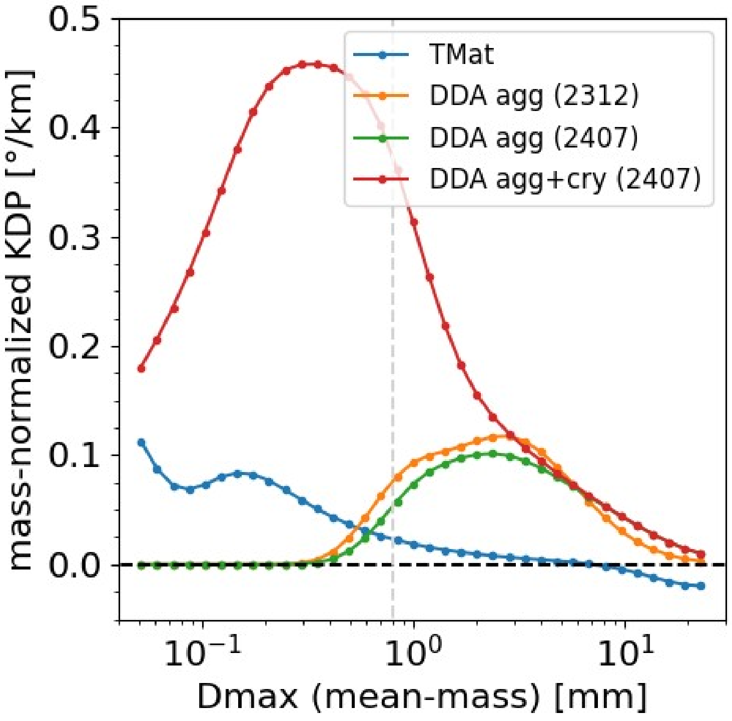
Results: Bulk scattering SSP – snow

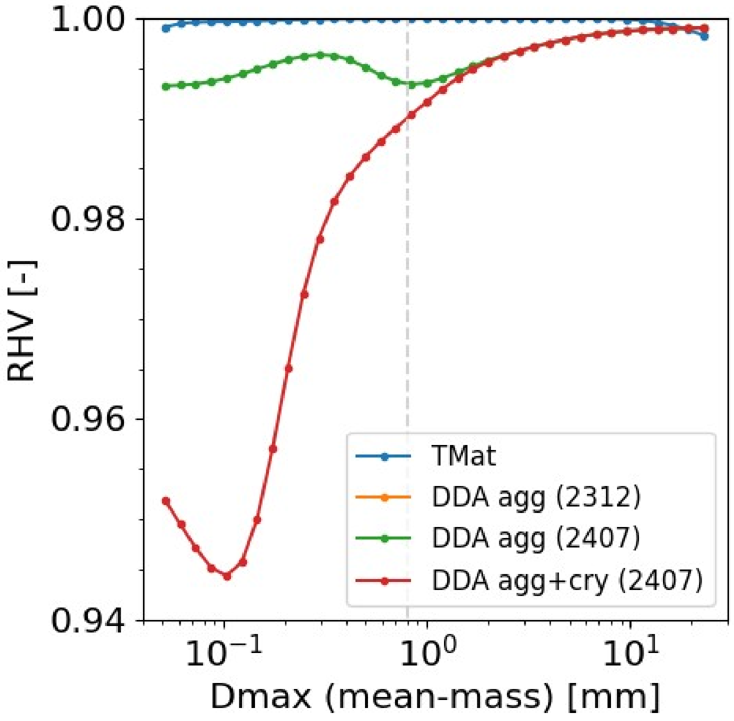


➔ **polarimetric parameters**

+ DDA-ZDR larger than TMat-ZDR (~0.2dB) over range of bulk mean sizes
+ DDA-RhoHV slightly smaller than TMat-RhoHV
- strong, seemingly unrealistic impact of small-D supplemental crystals







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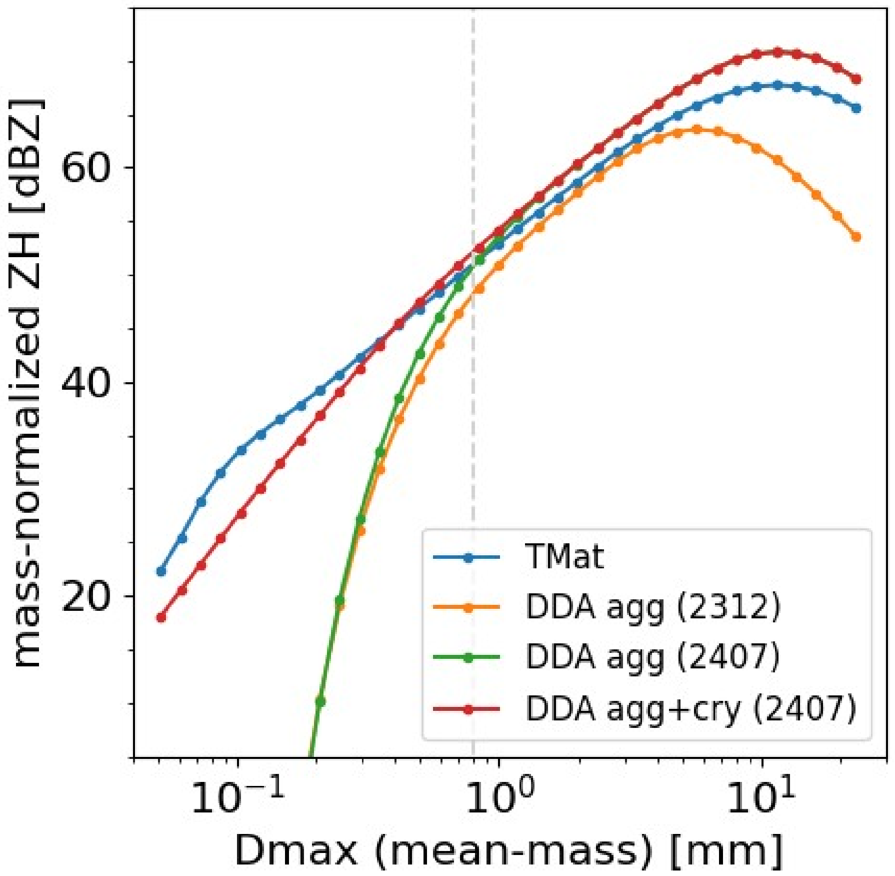
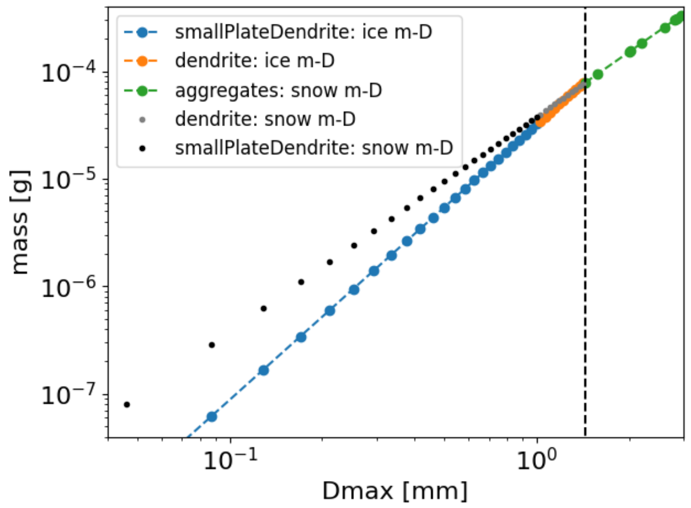


➔ **2nd instance**: missing small particles (min(Dmax) = 1.4mm)

- how to handle small D in PSD convolution?

➔ **3rd instance**: supplemented with small-D crystals

- does well here, **not that well in polarimetric parameters**
- (these) crystals follow cloud ice m-D



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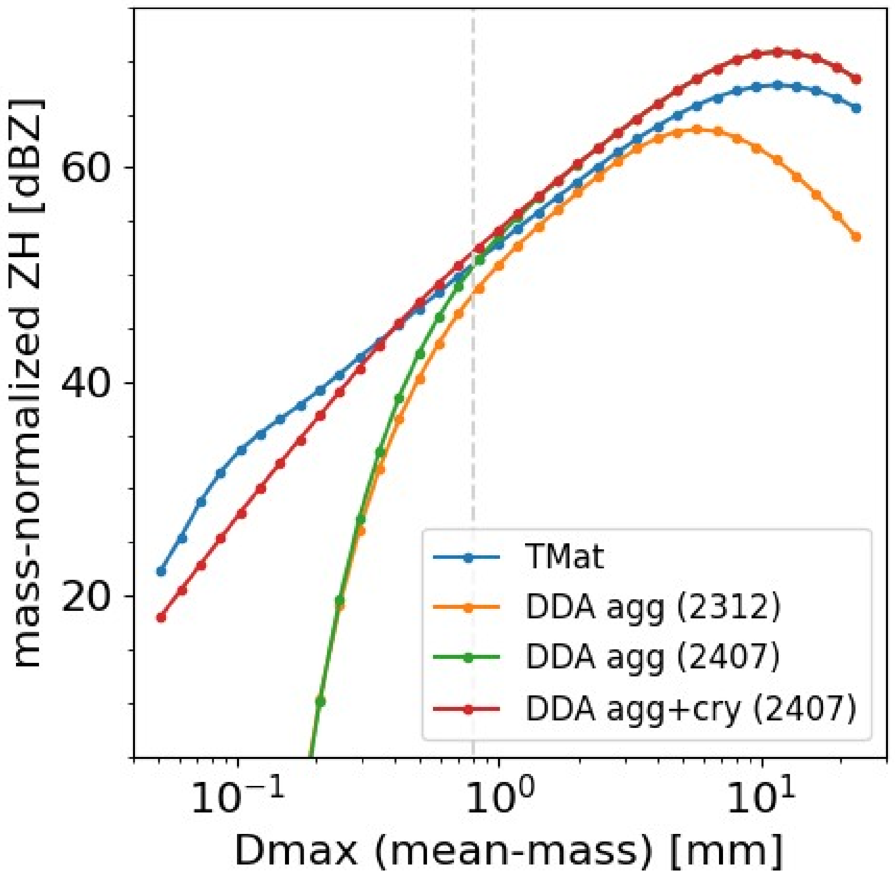

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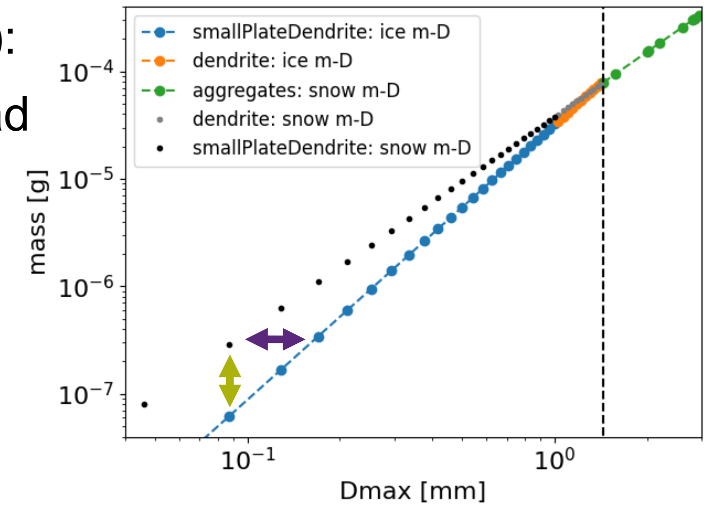
➔ supplementation alternatives(?):

- use **mass-equivalent** (instead of **Dmax-equiv**) crystals



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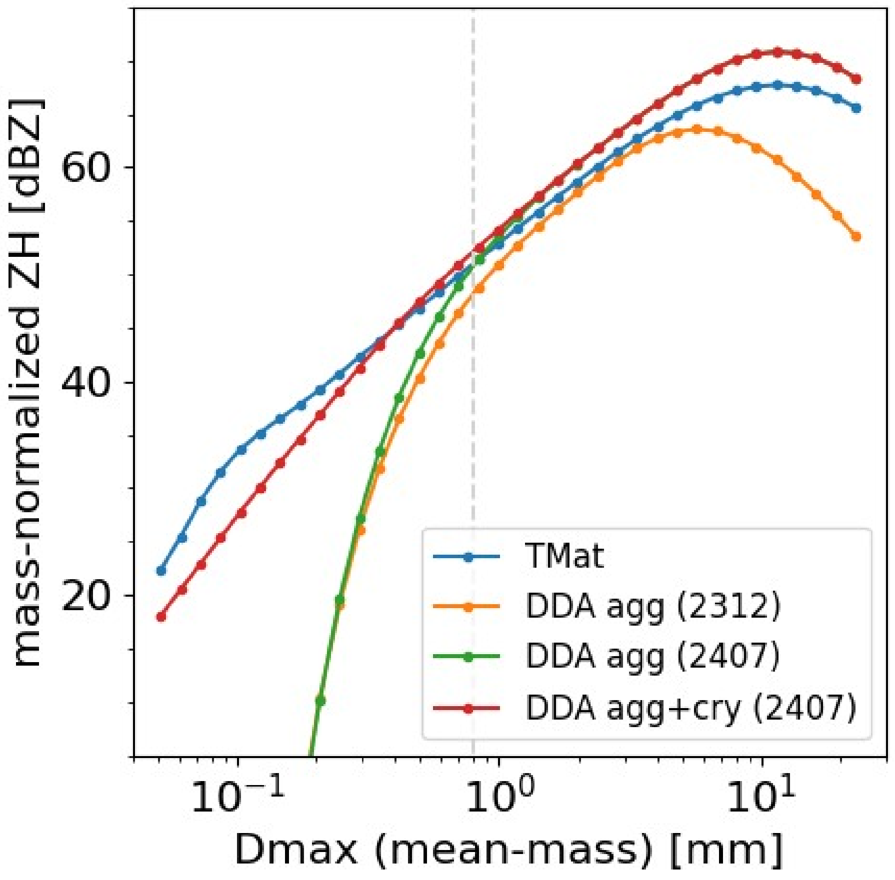

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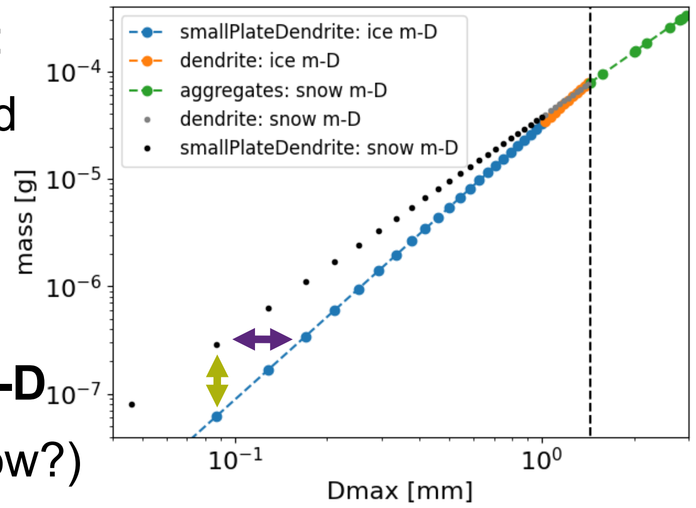
- how to handle small D in PSD convolution?

➔ **3rd instance**: supplemented with small-D crystals

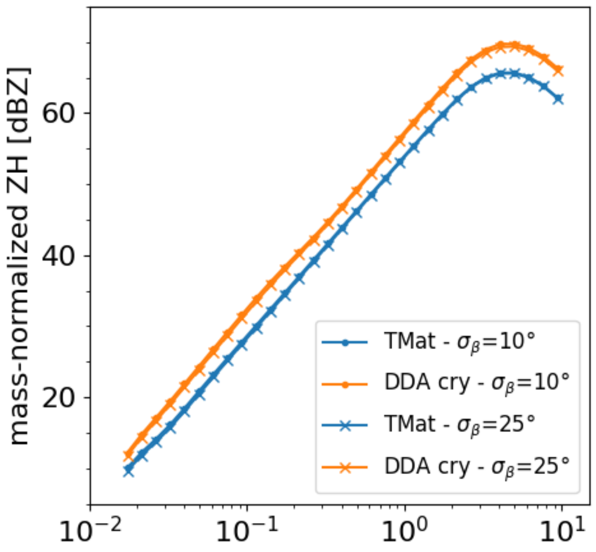
- does well here, **not that well in polarimetric parameters**
- (these) crystals follow cloud ice m-D

➔ supplementation alternatives(?):

- use **mass-equivalent** (instead of **Dmax-equiv**) crystals
- rescale agg-only-PSD to total mass
- create **crystals with snow m-D**
- create smaller aggregates (how?)

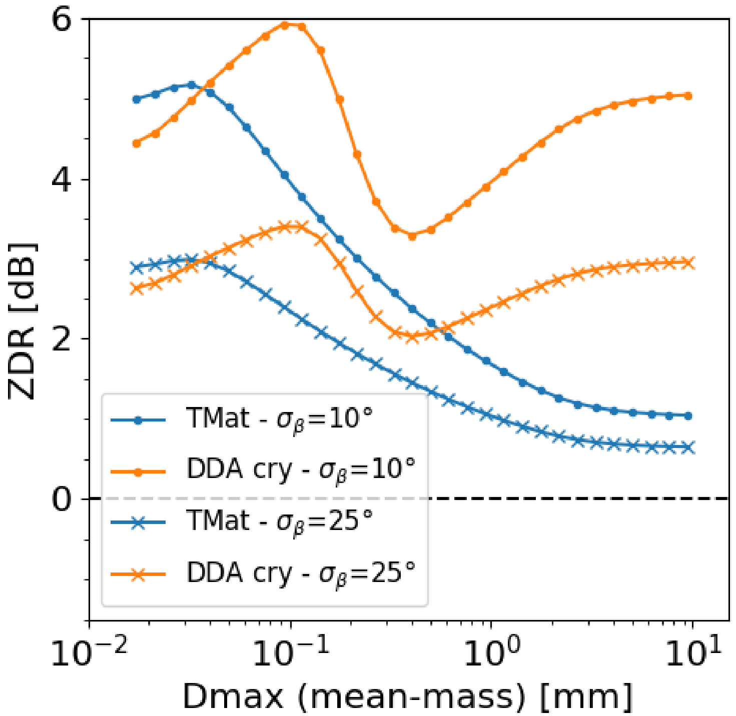


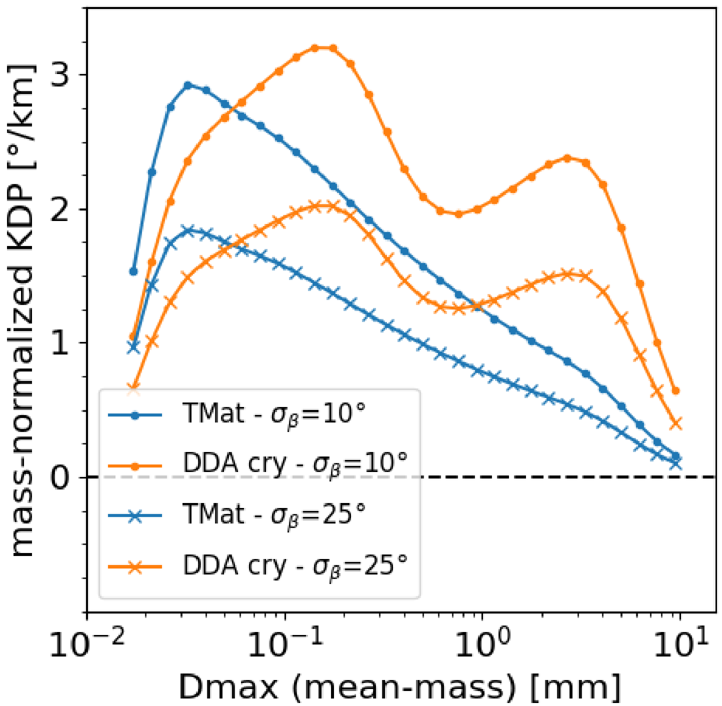
Results: Bulk scattering SSP – ice

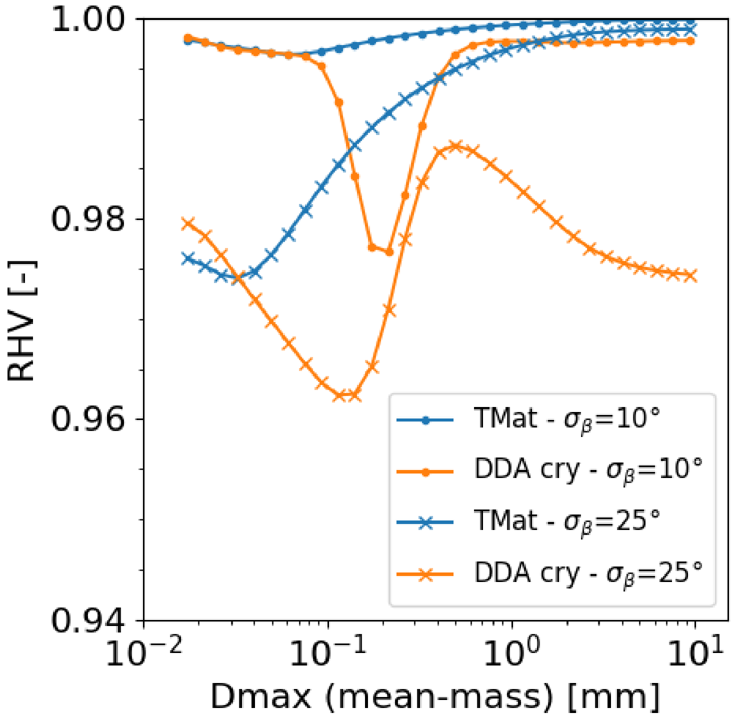


➔ **polarimetric parameters**

- tendency of DDA-ZDR to increase, DDA-RHV to decrease with size – opposite to TMat
- RHV smaller for stronger tumbling
- quite clear imprints of crystal habit change



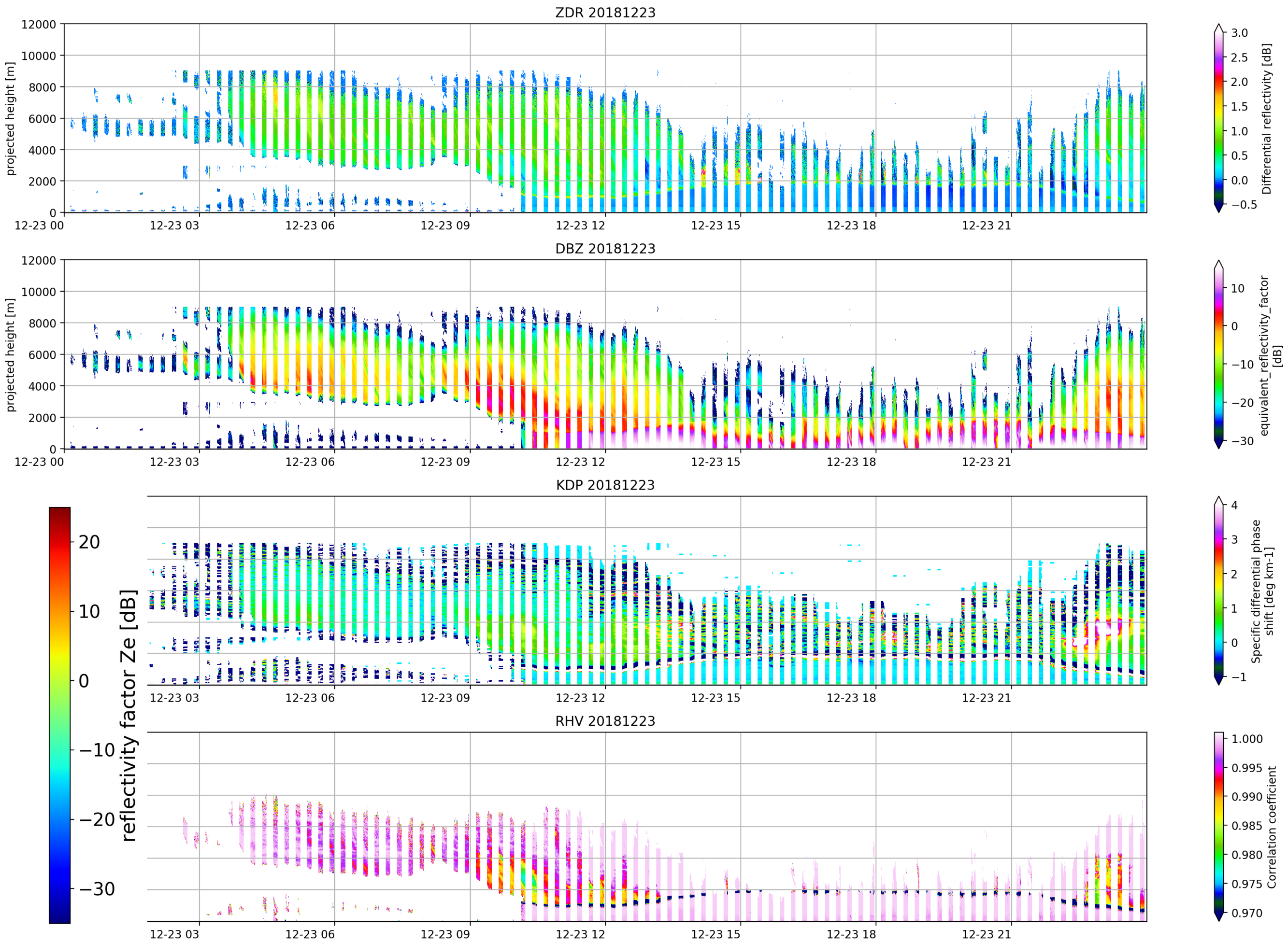


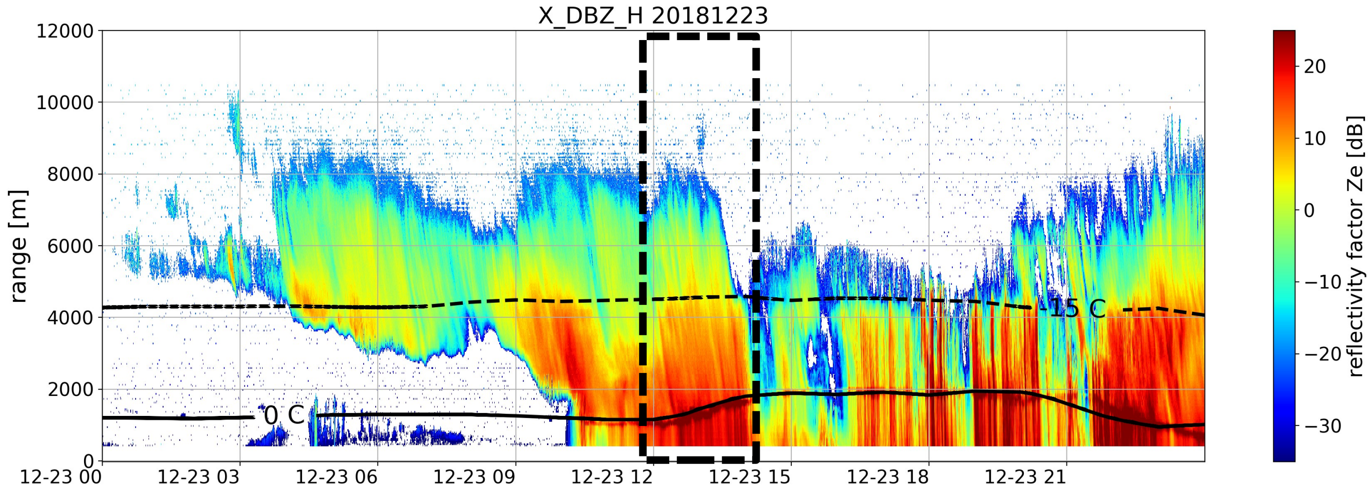


Results: Radar measurements – case intro

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- stratiform (longer-time homogeneous), dry-snow dominated day (little riming, low/no ML): 23 Dec 2018
- from TRIPEx-pol campaign at/around **Jülich**
  - multi-freq zenith-viewing radar suite
  - polarimetric W-band radar (elev=30°)





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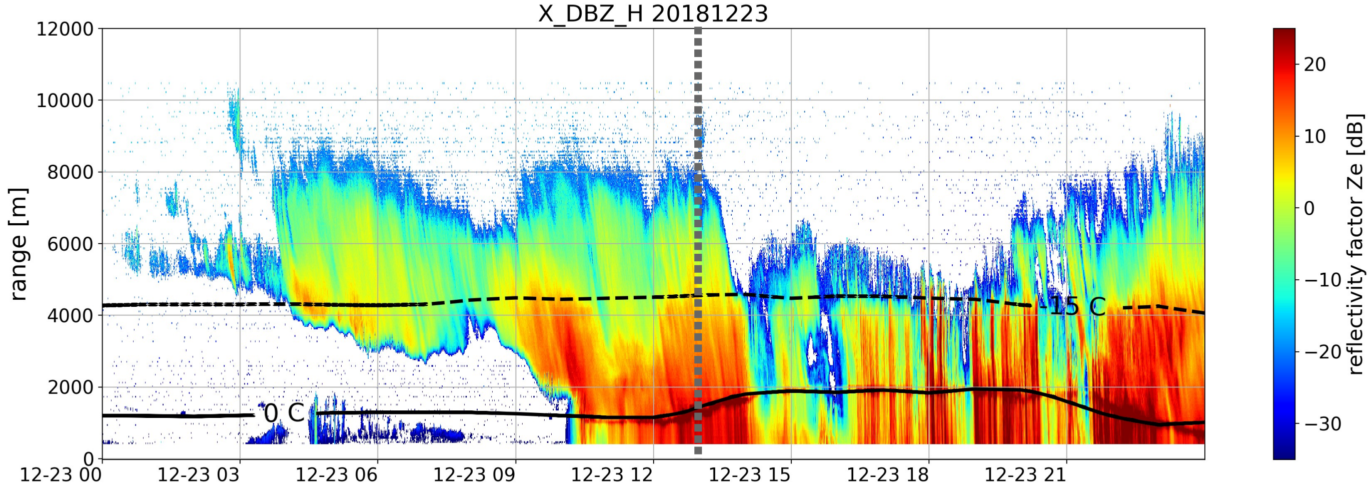
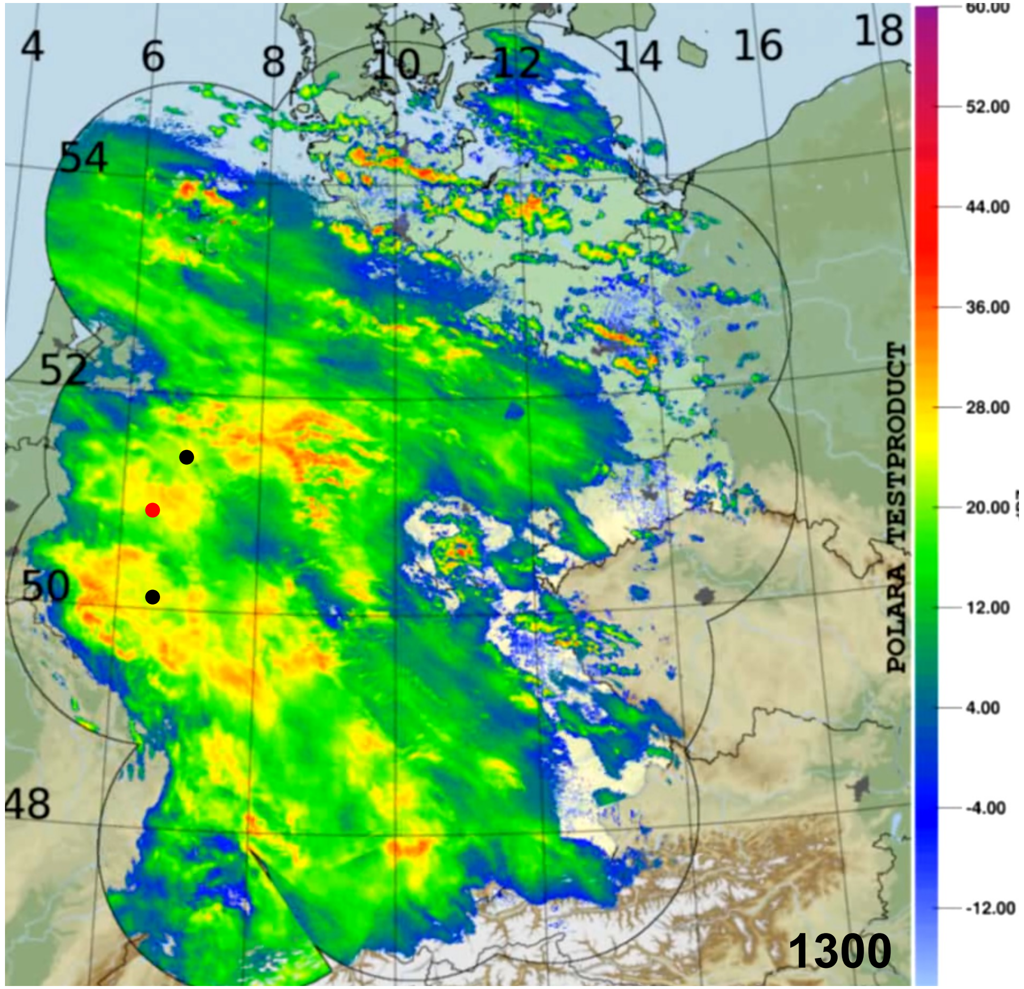
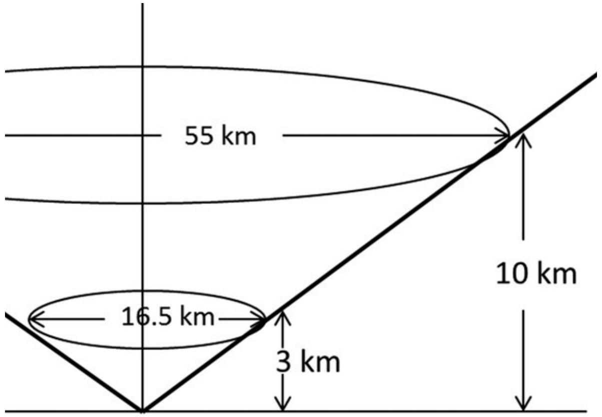
- from TRIPEx-pol campaign at/around **Jülich**
  - multi-freq zenith-viewing radar suite
  - polarimetric W-band radar (el=30°)
- from DWD operations
  - network of C-band polarimetric radar (el=0.5°-25°) (near-TRIPEx: **ESS**, **NHL**)

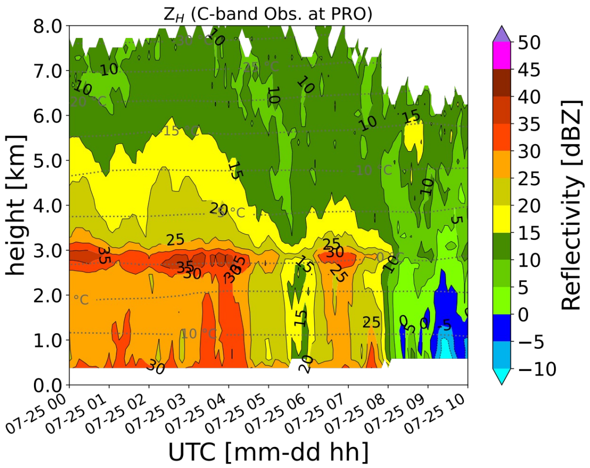




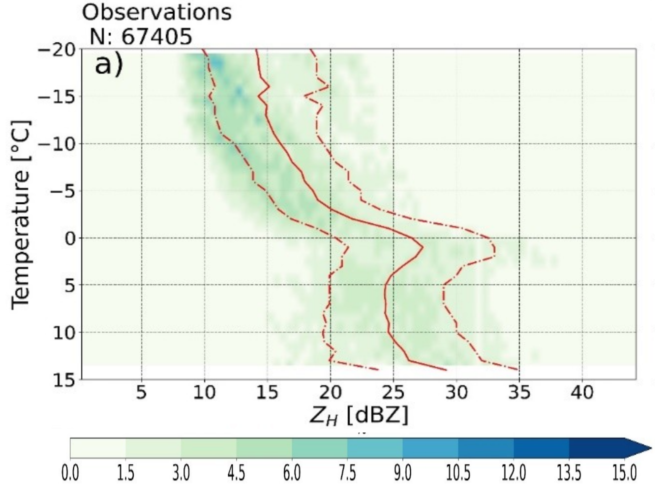
Results: Radar measurements – QVPs & CFTDs

- ➔ Quasi-Vertical Profile (**QVP**)
  - single elevation of a single station (distance & homogeneity ↔ vertical resolution & polarimetric signals)
  - single representative (e.g. mean, median) over all azimuths at each range distance bin
  - assigned to range-equivalent height
  - results in one vertical profile per time step



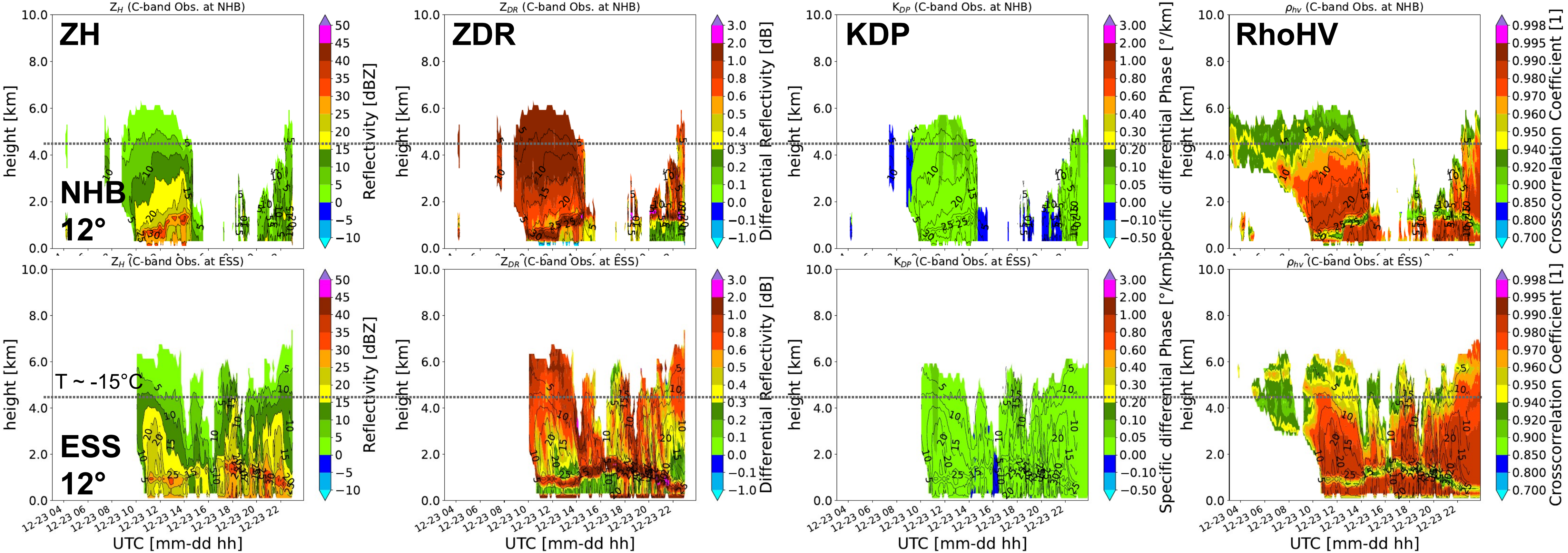


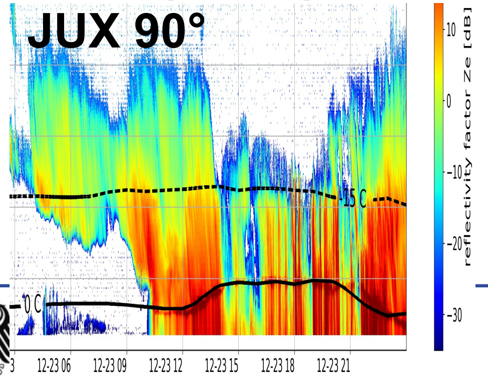
- ➔ Contoured Frequency by Temperature Diagram (**CFTD**)
  - 2D histogram
  - similar to contoured frequency by altitude diagrams (CFAD), but over temperature (requires addit. info), hence makes melting layer structure visible
  - multiple elevations & stations simultaneously possible



Results: Radar measurements – QVP (obs)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand





- ➔ early non-precip layer not present in C-band(?) QVP(?), except in RhoHV
- ➔ ML at ~1-2km visible in C-band ZH, ZDR, RhoHV
- ➔ ZDR in DGL up to 2dB (realistic? or calib/QA?), KDP hardly >0.05°/km

Results: Radar measurements – QVP (obs)

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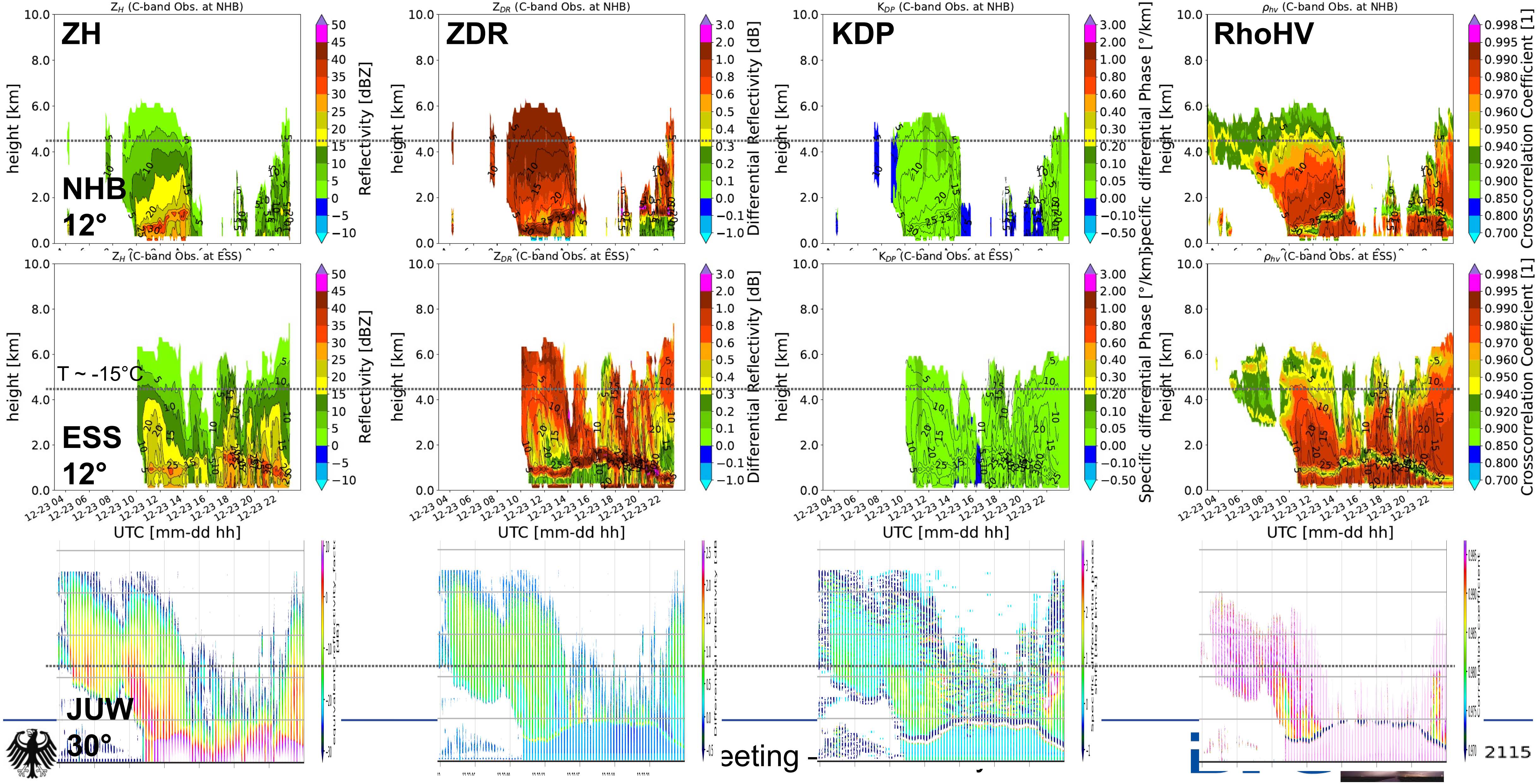
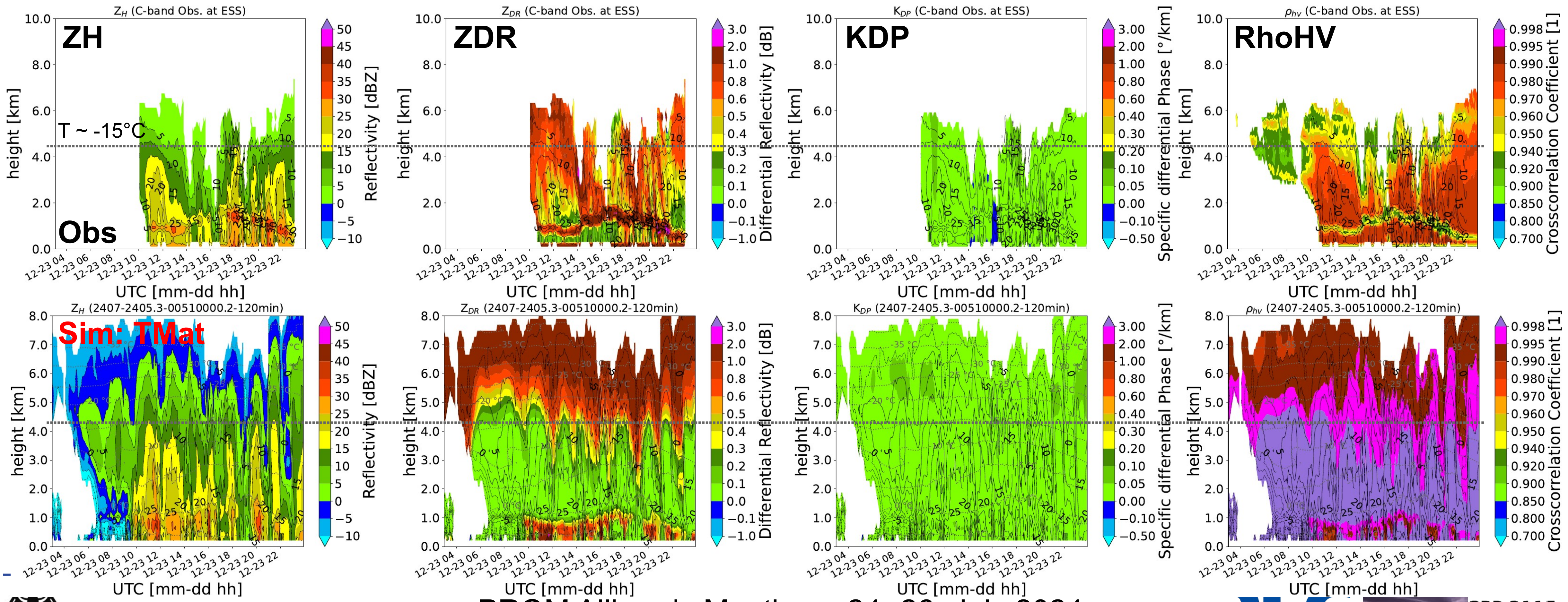


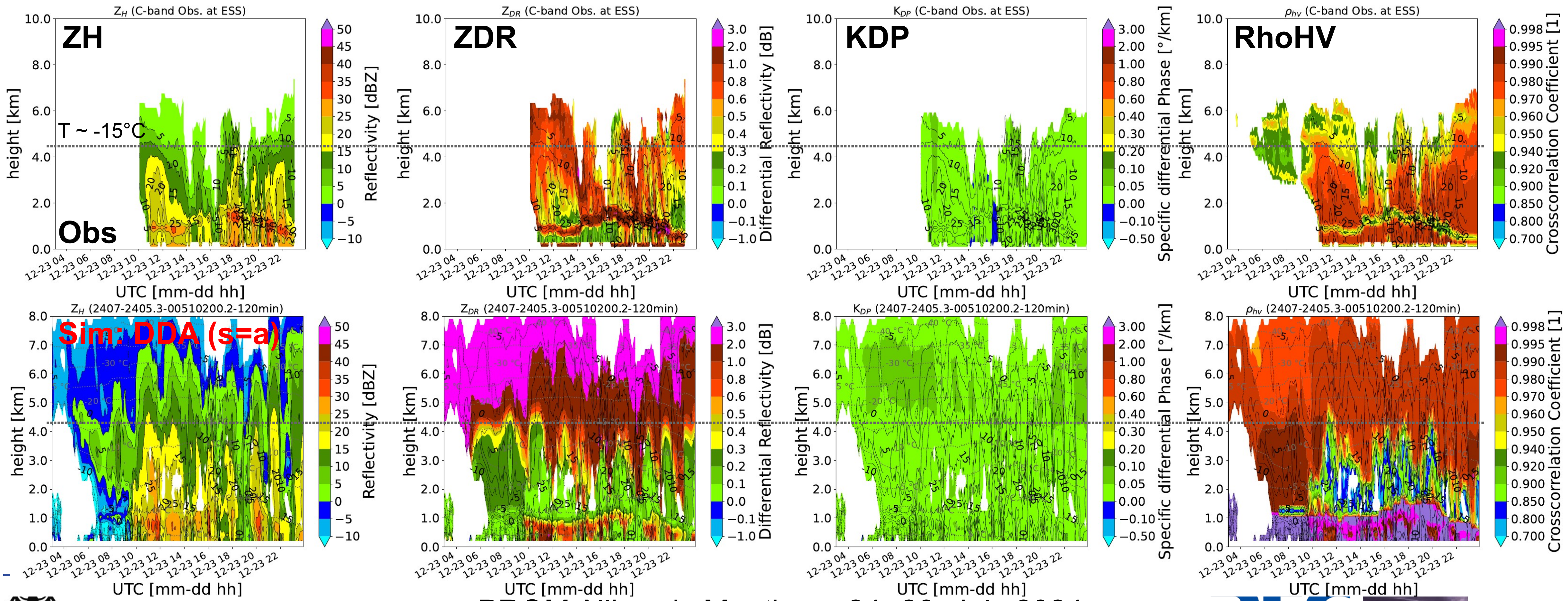
Results: Radar measurements – QVP (ESS 12°)

- ZH okay in amplitude and („wave“) structure, but „blurred” & too low brightband; with early non-precip layer
- again, the „polarimetric void“ in DGL
- sharp, but too low BB-top in ZDR



Results: Radar measurements – QVP (ESS 12°)

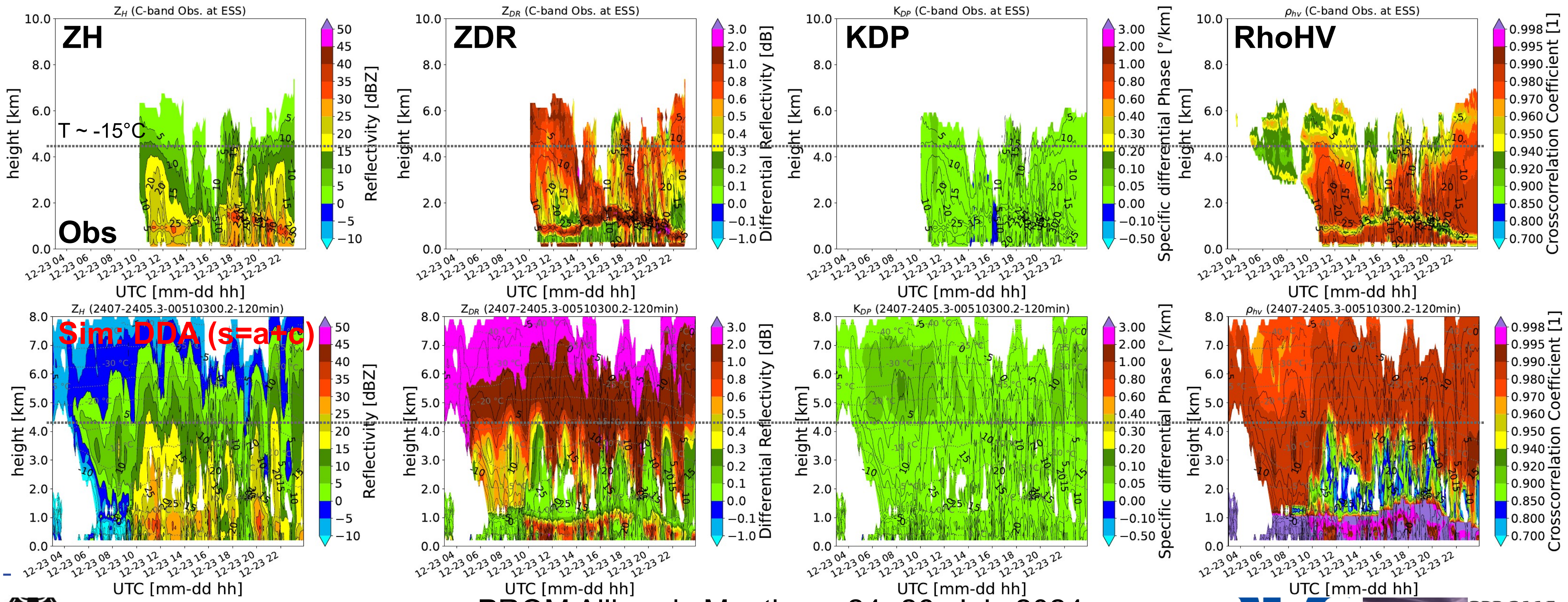
- slight increase in ZH above ML; clearer detachment of non-precip layer
- where cloud ice dominates, clear increase of polarimetric signals (above DGL and in ice [fall?] streaks)
- in DGL, some increase of ZDR (<0.1dB → <0.3dB) and significant decrease in RhoHV (part. in inhomog.)



Results: Radar measurements – QVP (ESS 12°)

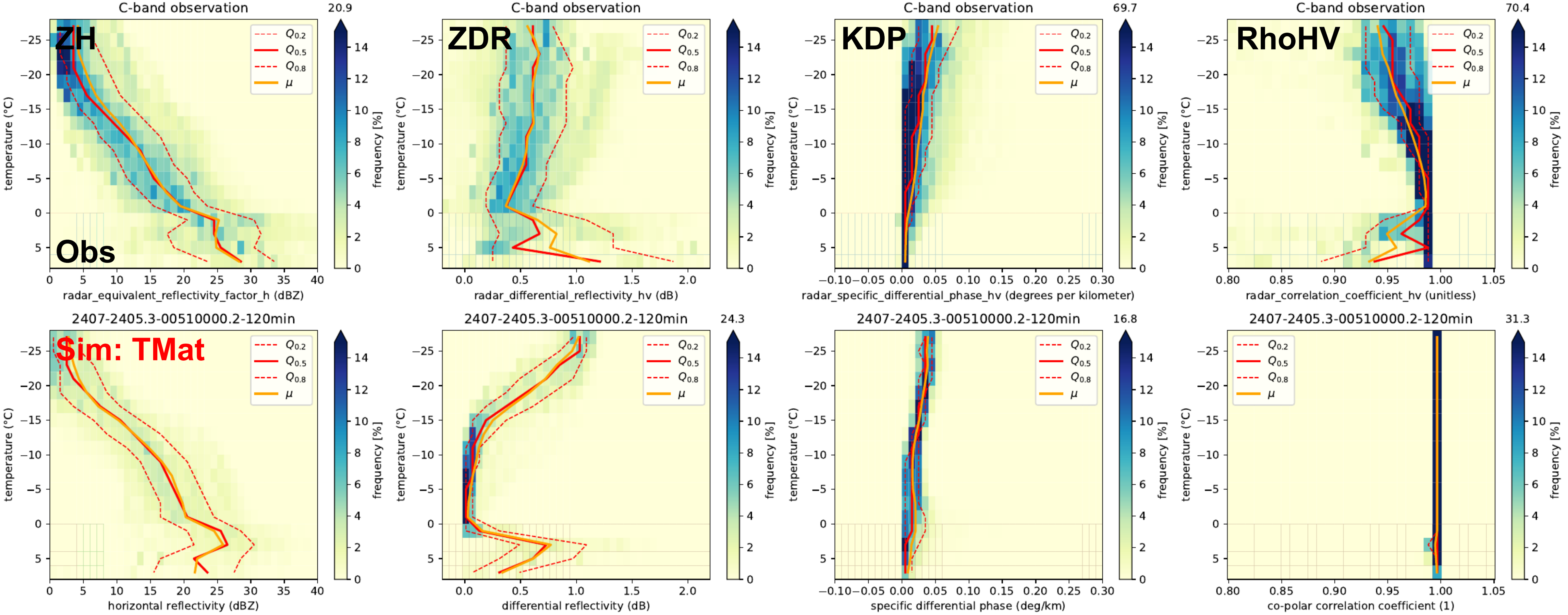
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- further increase in ZH above ML
- where cloud ice dominates, even stronger increase of polarimetric signals → there's snow, too, obv!
- in DGL (non-precip layer in part.), further increase of ZDR (→ <0.6dB) and further decrease in RhoHV



Results: Radar measurements – CFTD (12°)

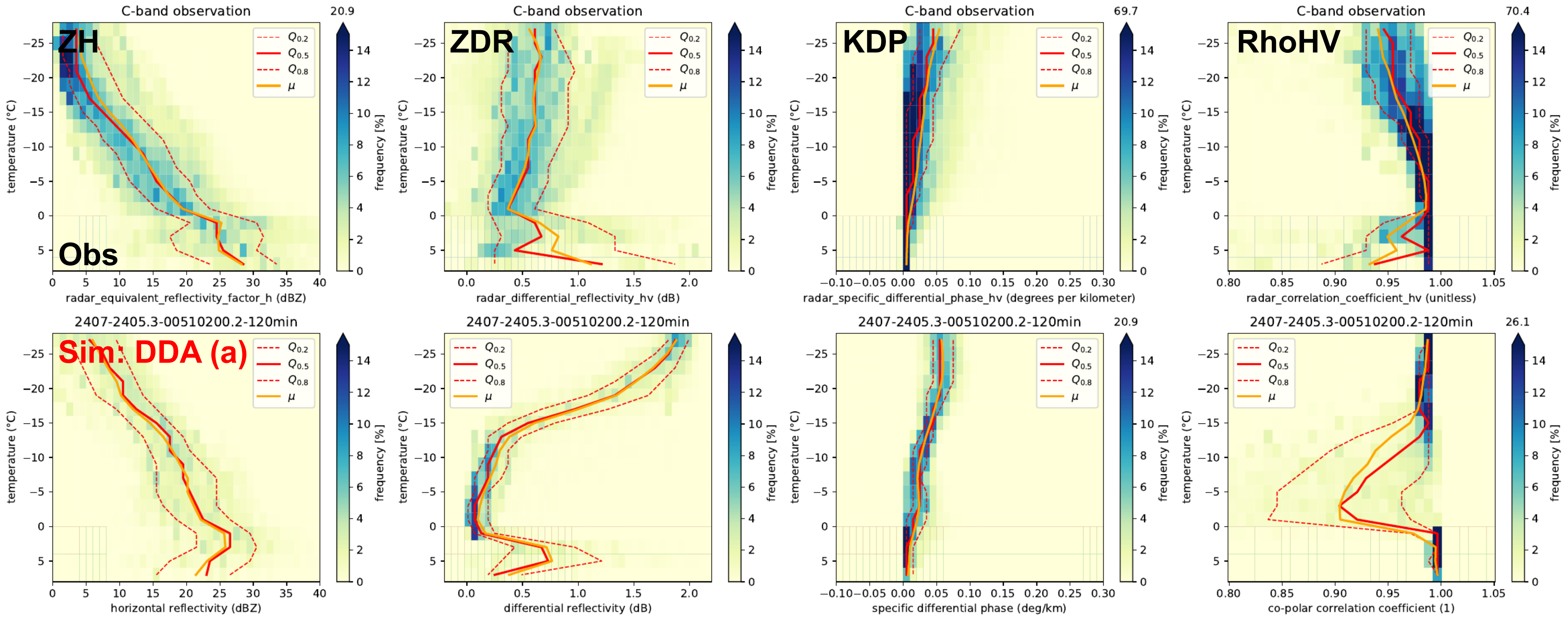
- similar ZH profile (but lower absolute occurence?), more pronounced BB
- very low spread in ZDR, part. in DGL; too low in DGL, too high above, pronounced ZDR-BB (unlike obs)
- low spread in KDP, too low values above ML, slight KDP-BB (unlike obs)
- no RhoHV signal at all anywhere (except a super-slight bump at ML-bottom(?))



Results: Radar measurements – CFTD (12°)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

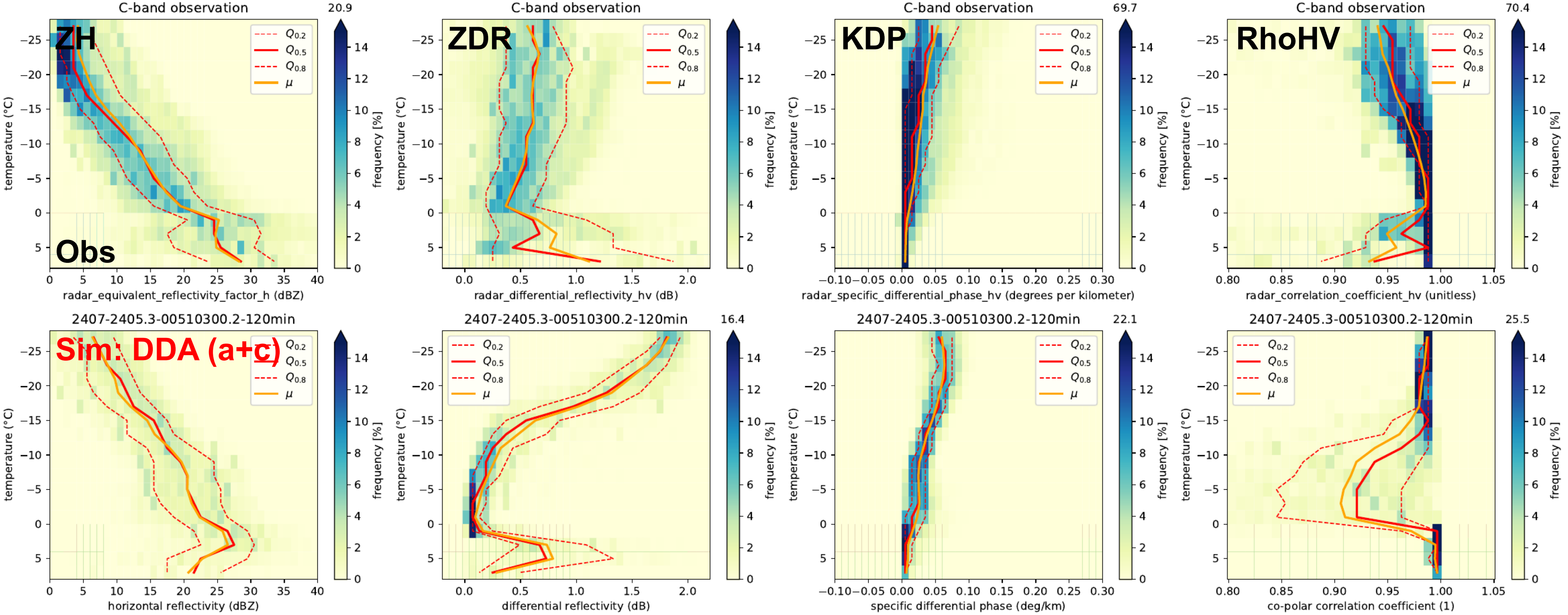
- ➔ slight increase in ZH, reduced slope above ML
- ➔ increase of ZDR and spread in DGL, strong increase (~1dB) on already too high ZDR above DGL
- ➔ increase in KDP and spread above ML, mean ok, spread still too low, low values missing
- ➔ (too) strong RhoHV decrease and increase of spread in DGL, above still too high w/o spread



Results: Radar measurements – CFTD (12°)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- ➔ more spread in above-ML ZH, mean as for DDA(a)
- ➔ slight further increase at top of DGL, slight decrease above
- ➔ slight further increase in above-ML KDP
- ➔ slight increase of RhoHV at DGL bottom, slight further derease at DGL top, but too low throughout DGL



Conclusions & Outlook

- → polarimetric signals in DGL improved, but
  - ZDR still too low
  - KDP slightly too high
  - RhoHV far too low

- → further work on some (important) details needed
  - abrupt habit transition leaves imprint on bulk properties
    - particularly critical for (hydrometeor-class combined) RhoHV
  - small snow-particle handling
- → deeper analysis of case, e.g.
  - diverging effects seen in non-precip vs. precip (or no & w/ ML?) parts of event: low ZDR, super-low RhoHV in precip parts while increased ZDR, moderately decreased RhoHV in detached non-precip part
- → review and refine analysis methods
  - missing non-precip layer in QVP; ML detection in winter cases
  - understand FO-modification inconsistent and seemingly different results in QVP and CFTD