Operation Hydrometeors

–

An **efficient** volume scan polarimetric radar forward OPERAtor to improve the representaTION of HYDROMETEORS in the COSMO/ICON model

J. Mendrok, U. Blahak (DWD)

SPP 2115

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What?

„An efficient volume scan polarimetric radar forward OPERAtor to improve the representaTION of HYDROMETEORS in the COSMO/ICON model“

➔ Forward operator

- synthetic observations from atmospheric state:
- what would an certain observation look like for a given atmospheric state?

What?

„An efficient volume scan polarimetric radar forward OPERAtor to improve the representaTION of HYDROMETEORS in the COSMO/ICON model"

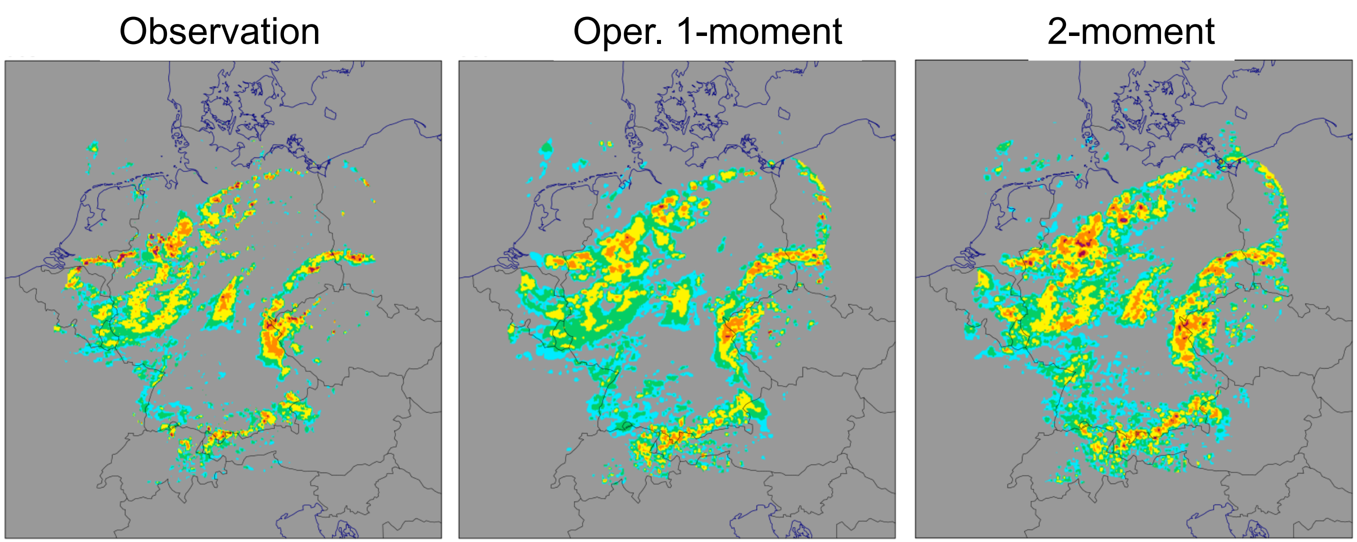
- Forward operator
  - synthetic observations from atmospheric state
- COSMO/ICON model
  - NWP atm. fields (qx, nx, T, …)
  - hydrometeor microphysics

Why?

„An efficient volume scan polarimetric radar forward OPERAtor to improve the representaTION of HYDROMETEORS in the COSMO/ICON model“

- „FO is a fundamental prerequisite for the fusion of radar polarimetry and atmospheric modelling“

- Model validation
  - Forecast/analysis-based FO-derived synthetic observations vs real observations



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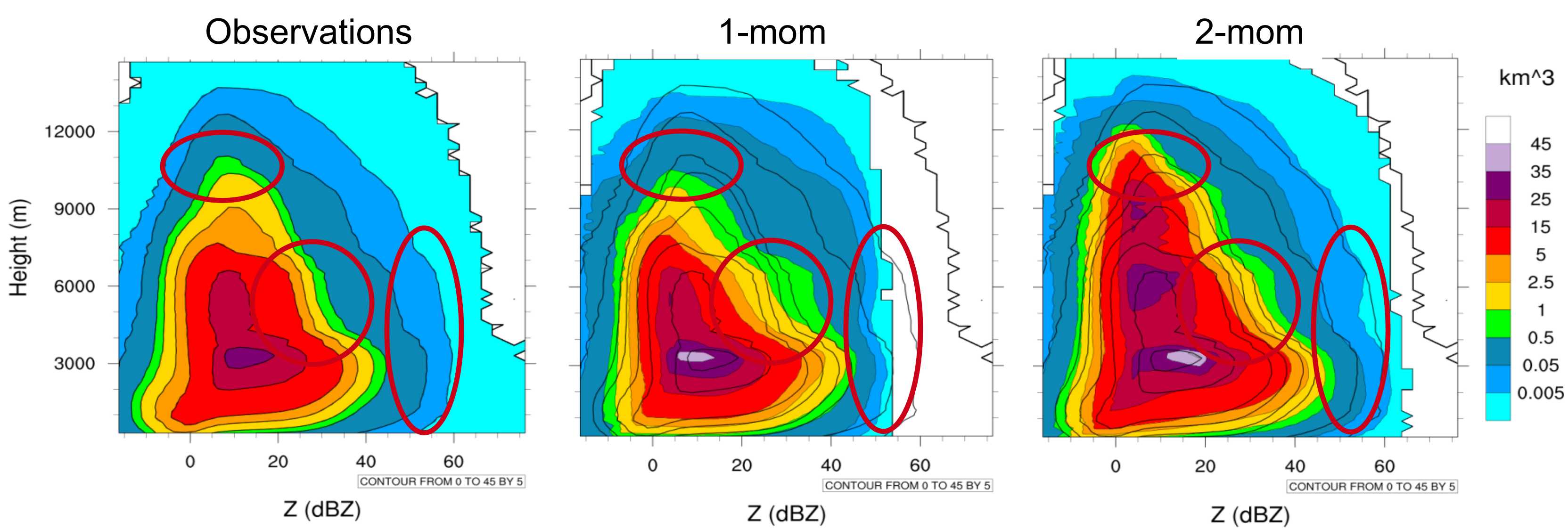

Why?

UNIVERSITÄT BONN DWD

„An efficient volume scan polarimetric radar forward OPERAtor to improve the representaTION of HYDROMETEORS in the COSMO/ICON model“

→ „FO is a fundamental prerequisite for the fusion of radar polarimetry and atmospheric modelling“

→ Model validation

- Forecast/analysis-based FO-derived synthetic measurements vs real measurements
- FO challenges:
  - Accuracy
  - Assumptions due to „incomplete“ NWP atm. state

Approach: Extend operational sing-pol FO

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- **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** (1- and 2-layer particles)
- **Lookup tables for Mie-scattering** for efficiency
- Parellel code, **online coupled to both COSMO– and ICON** models, or applicable offline to 3D model state data stored on disc
- Simulated volume scans (range, azimuth, elevation)

Approach: Polarimetry theory

EMVORADO

→ $Z = f(\beta_b)$, $A = f(\beta_e)$

2 real

→ „Mie"-LUTs

- Z, A
  per hydrometeor type
- $f(q_x$, T, [melt fraction])

i.e. **one value** each
per model grid point or radar bin

EMVORADO-POL

→ Z_h, Z_{DR}, L_{DR}, ρ_{hv}, K_{DP}, A_h, A_{DP}

$= f(\mathbf{s}^{f/b}_{hh}, \mathbf{s}^{f/b}_{vv})$ **at least 8 real**

$= f(\mathbf{Z,K})$ (additivity!)

→ „Mie"-LUTs

- 8 additive real-number parameters per hydrometeor type
- $f(q_x$, T, [melt fraction], **[elev ang, ...]**)

→ further „incomplete-NWP" assumptions

- shape: **aspect ratio** f(D)?
- orientation: **canting (distrib)** f(?)?

i.e. one value each per radar bin,
elev-dep. values at model grid points

Status

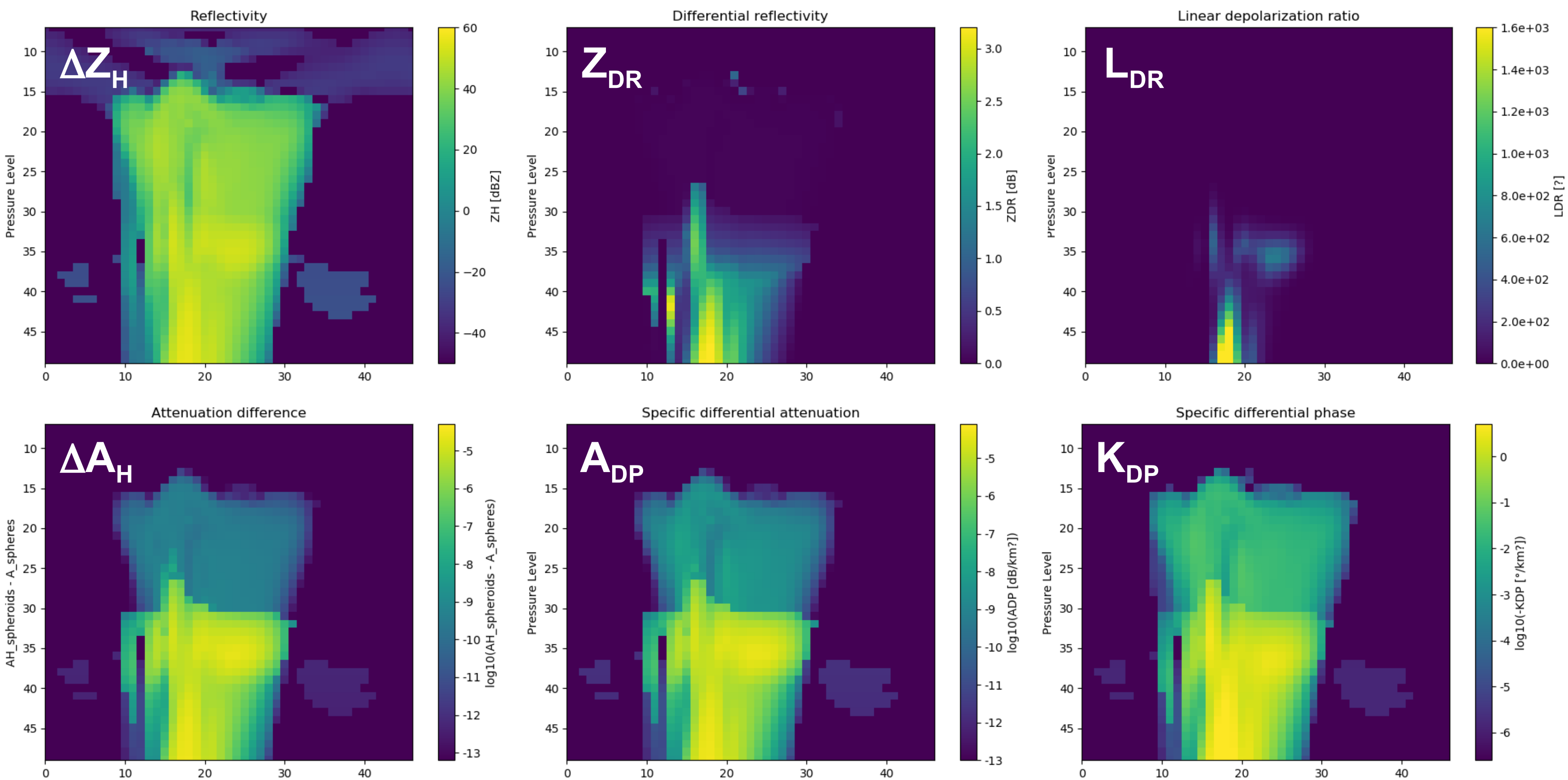
- „Quick start“ applying 3rd party pol-module:

Status

- → „Quick start“ applying 3rd party pol-module:
  - J.Snyder (NSSL) EMVORADO extention
    - T-matrix interface
    - β_x → $s^{f/b}_{a/b}$ (oblates only)
    - Z, A → Z_h, Z_{DR}, L_{DR}, (ρ_{hv}), K_{DP}, A_h, A_{DP} **(incl. use in LUTs :-/)**
    - orientation: [Ryzhkov11] angular moments and distribution parameters
  - Status:
    - Merged into current EMVORADO & running & **testing**

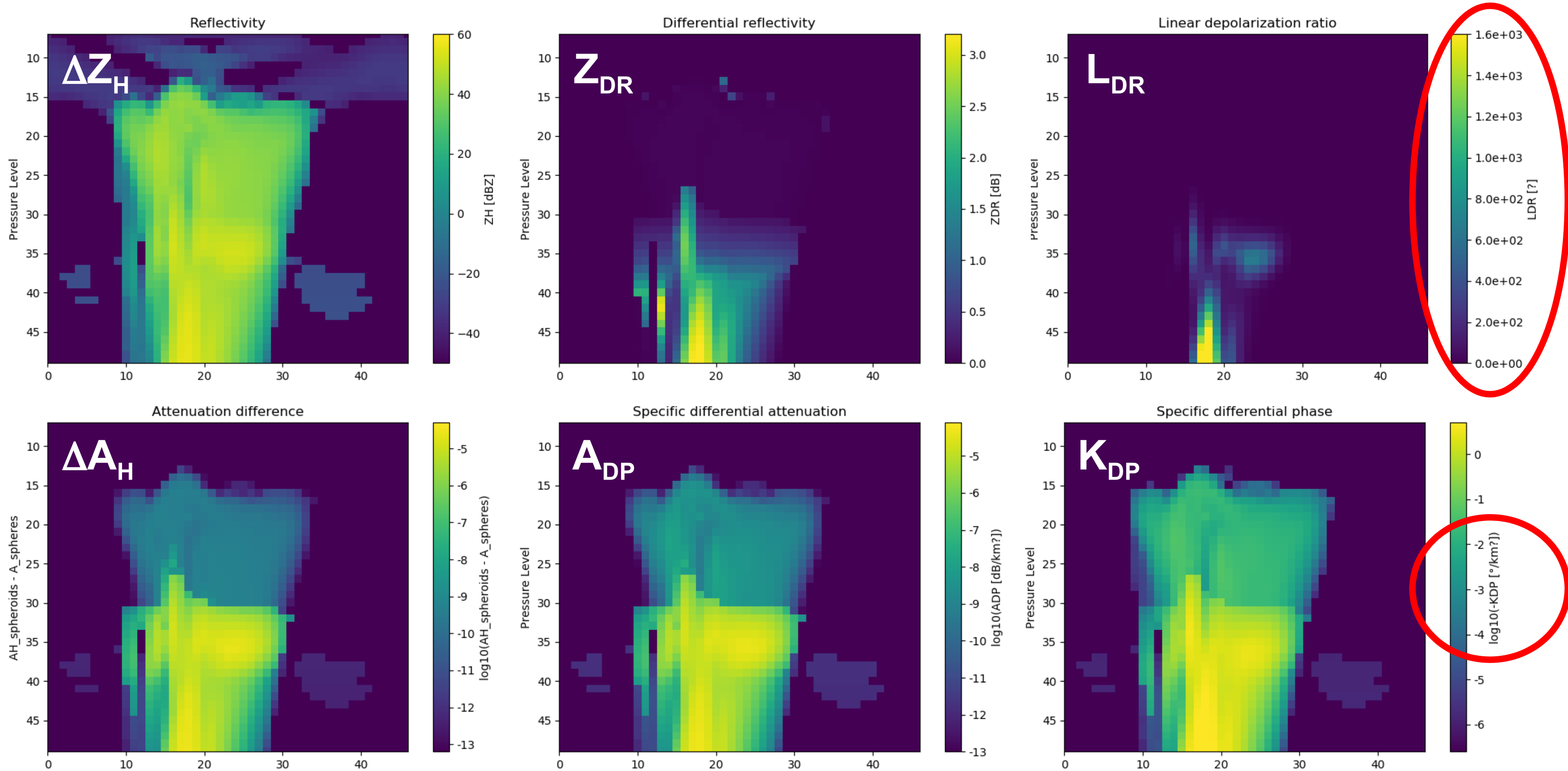
Status

- „Quick start“ applying 3rd party pol-module: Testing (! slightly outdated !)
  - Radar parameter curtains of a „warm bubble“ scene: **Reasonable patterns**



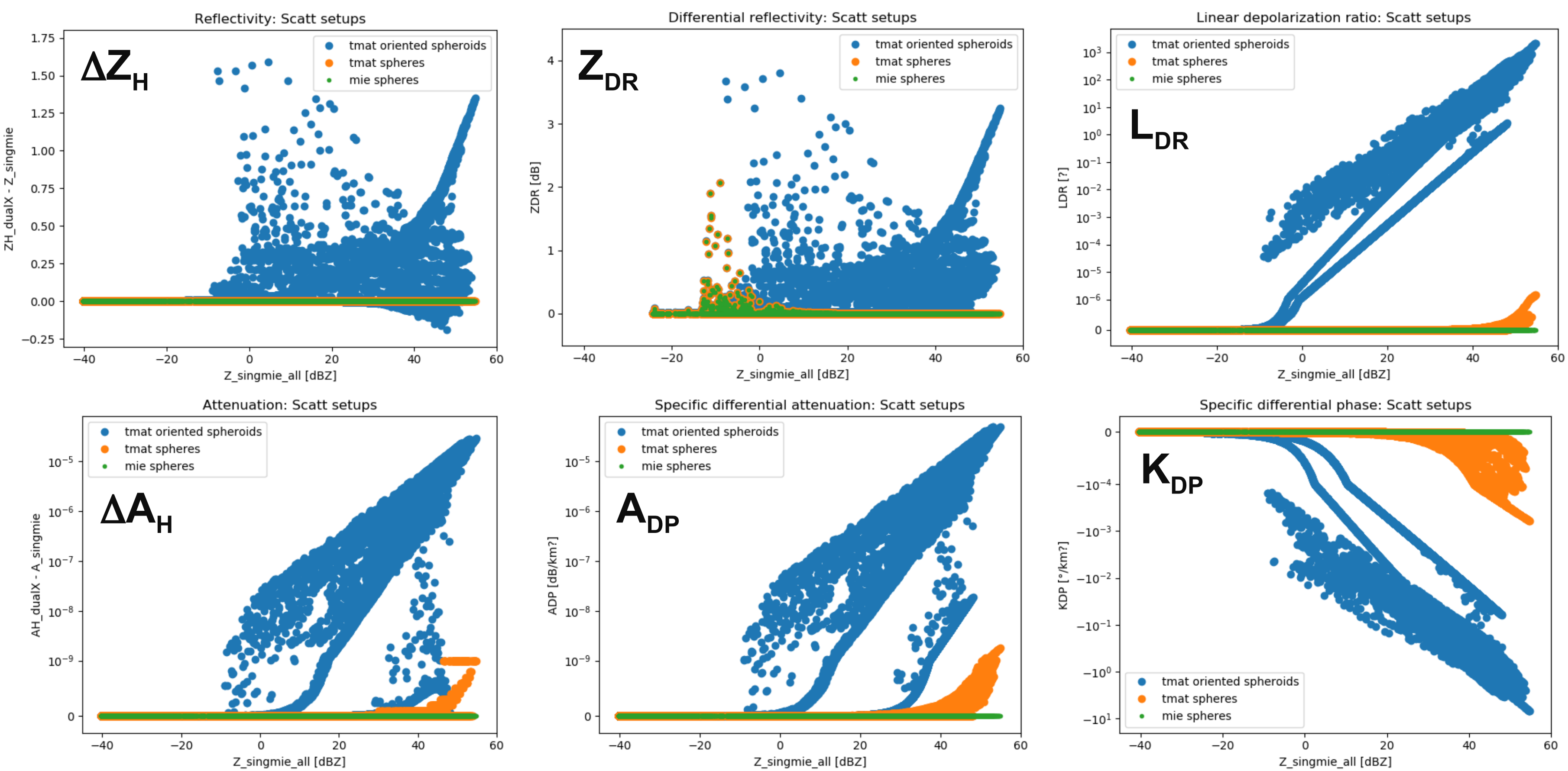
Status

- „Quick start“ applying 3rd party pol-module: Testing (! slightly outdated !)
  - Radar parameter curtains of a „warm bubble“ scene: Reasonable patterns, **but...**



Status

- ➔ „Quick start“ applying 3rd party pol-module: Testing (! slightly outdated !)
  - **polEMV (spheroid)** : **polEMV (tmat-spheres)** : **polEMV (mie)** : **opEMV (mie)**



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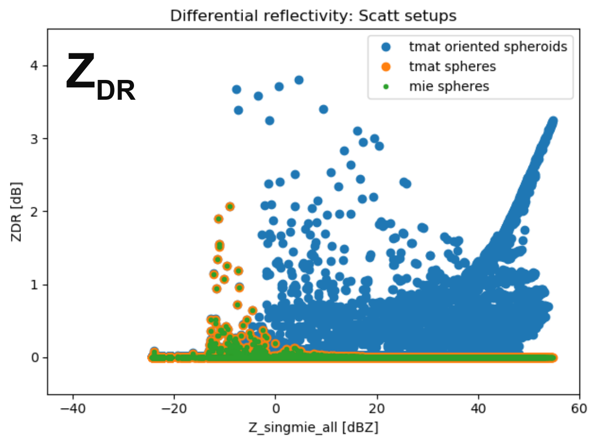
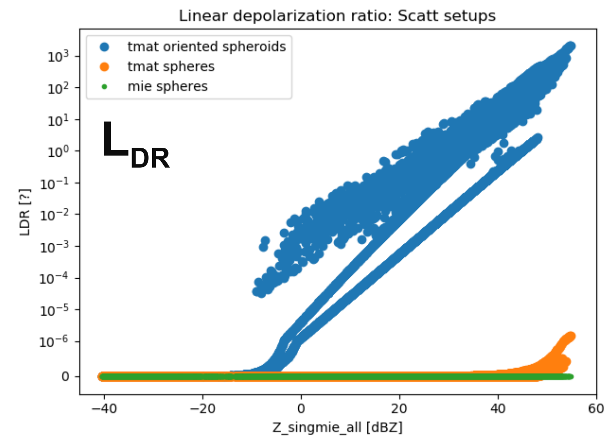
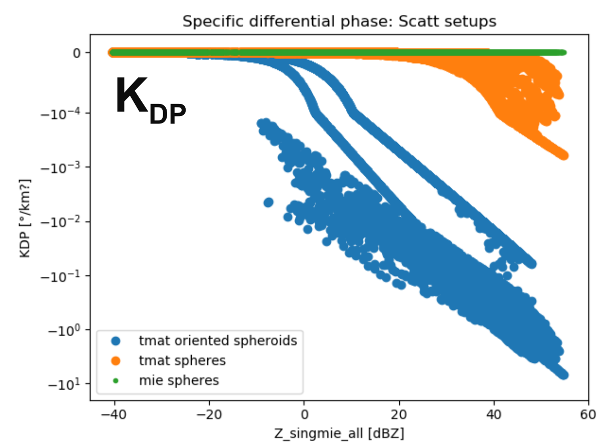




- tests vs opEMV & Mie ok:
  - polarimetric parameters ~0 (except Z_{DR} at low Z_H)
  - tmat-spheres ~ mie-spheres

- unit (?) issues in L_{DR} and K_{DP}
- empty ρ_{hv}

- known or expected issues (not tested or shown here):
  - additivity
  - elevation angle dependence



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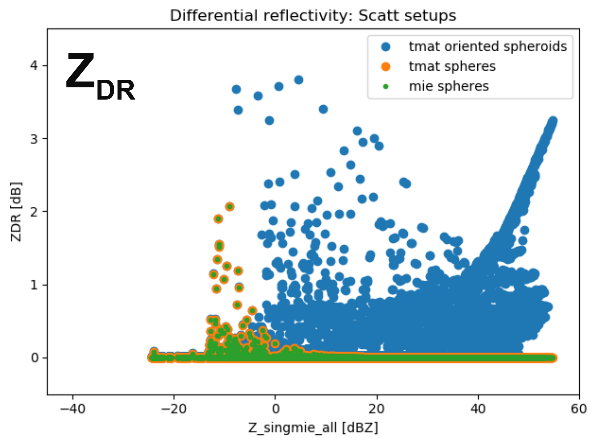
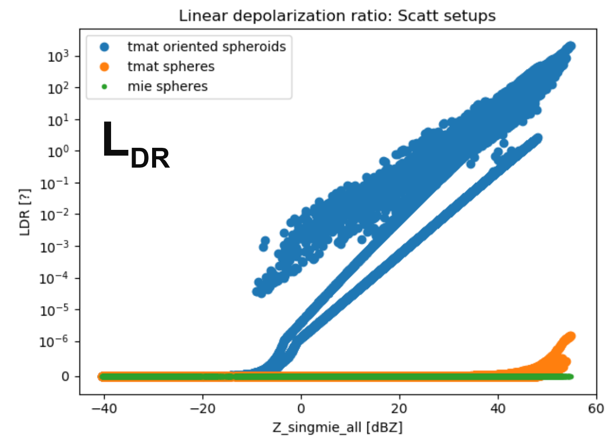
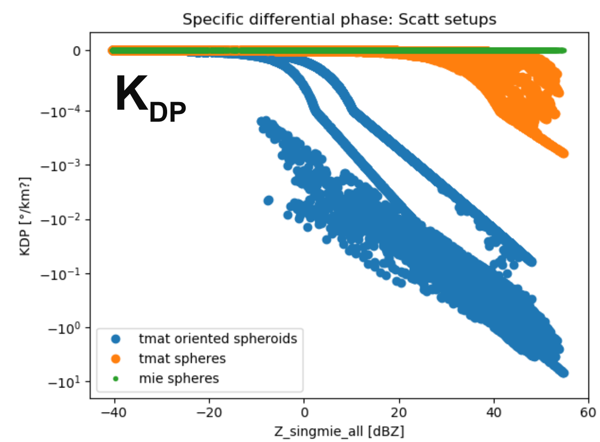




➔ Status update:

most of these fixed or fixing, but not yet re-tested



Status: Orientation & elevation effects

→ Q: How much does this affect the polarimetric parameters?

(And how good are some common approximations these?)

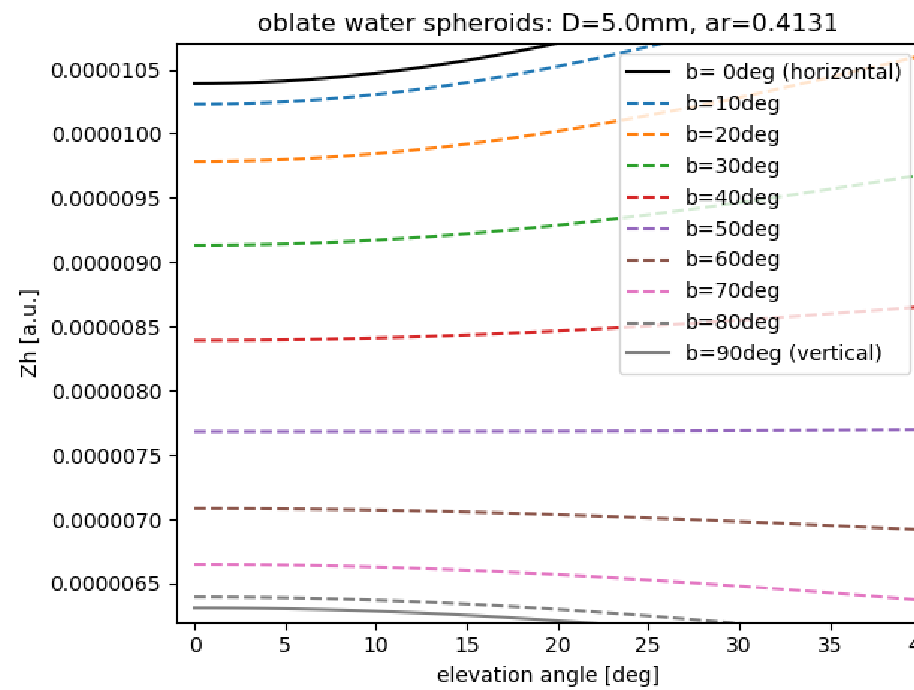
→ M: single-particle case study of a rain drop

- De = 5.0mm
- ar ~ 0.4 (oblate) (ar_pro = 1/ar_obl)
- m ~ (8.4, -2.2)

Status: Orientation & elevation effects

De = 5.0mm
ar ~ 0.4
m ~ (8.4, -2.2)

➔ Orientation effects (over elevation...): **Zh**



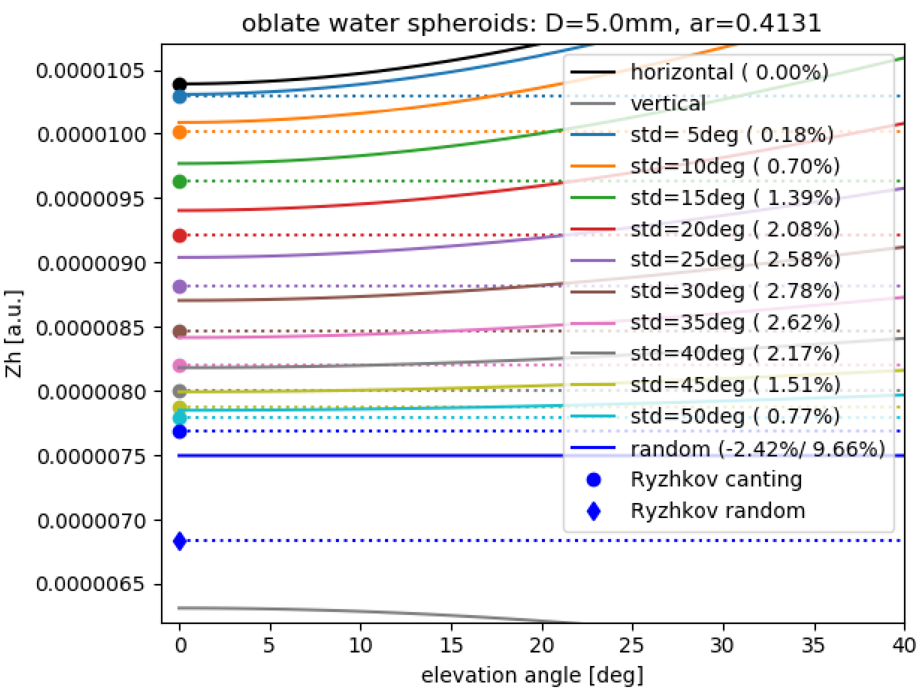
fixed tilts

Status: Orientation & elevation effects

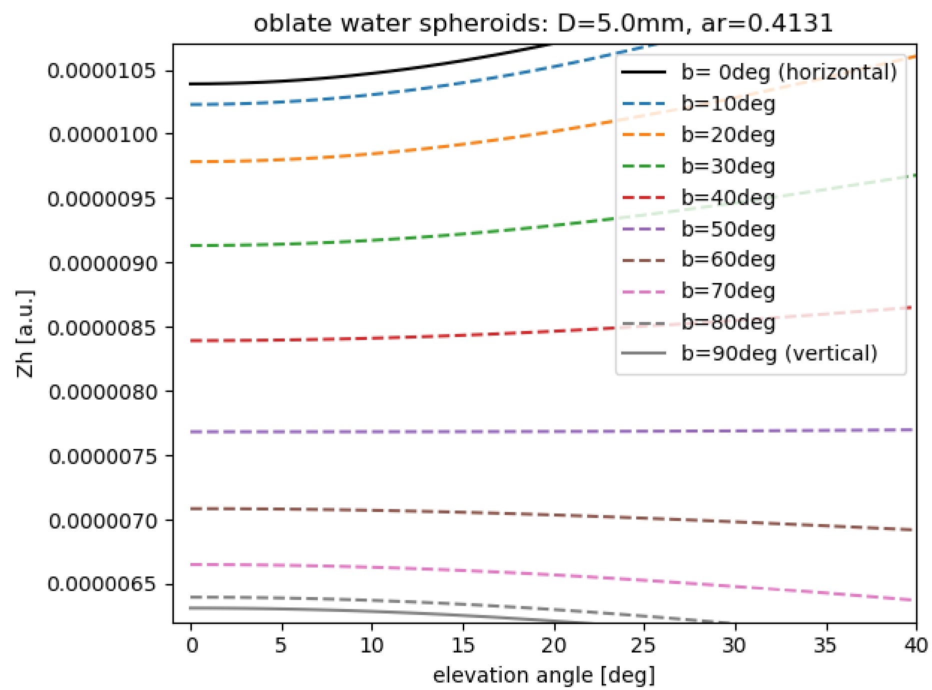
De = 5.0mm
ar ~ 0.4
m ~ (8.4, -2.2)

➔ Orientation effects (over elevation...): **Zh**

- explicit orientation averaging (–) vs. angular moment approach (o)
- explicit averaging (ea) verified vs. Mishchenko total-random Tmatrix and vs. „oriented" spheres



tilt distributions



fixed tilts

Status: Orientation & elevation effects

De = 5.0mm
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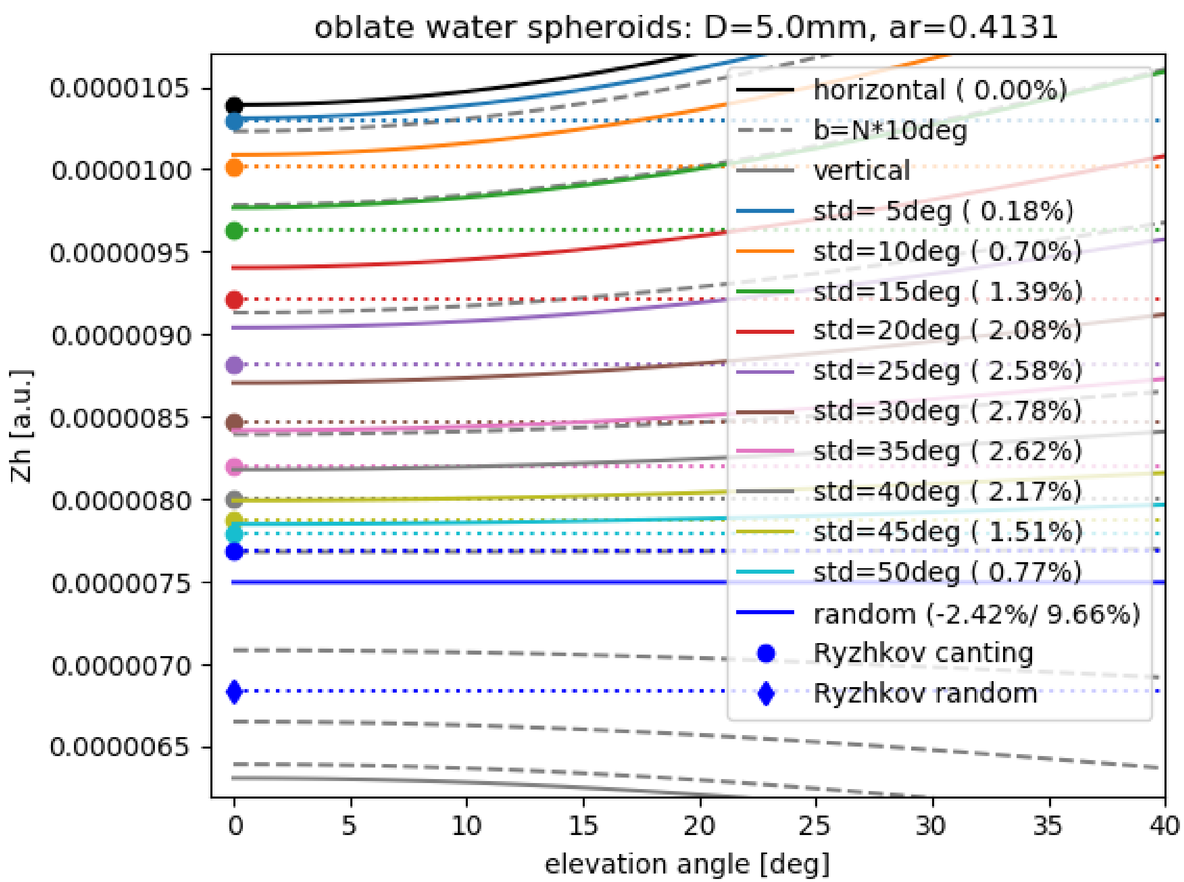
➔ Orientation effects (over elevation...): **Zh**

- explicit orientation averaging (–) vs. angular moment approx. (o)



- difference of Zh(β=0) and Zh(β-std=40°) ~25%

- [Ryzhkov11] angular moments (A) approximate orientation effects
- deviations in Zh(0) small, but equivalent-std offset up to 5°

- for std≤50°, Zh(A) < Zh(ea)
- using Zh(0) for all Zh(elev) amplifies the underestimation

- total-random A-approximation is worse than azimuthally-random with large std!?!

Outlook

→ Beyond the „Quick start“: **own/re-done PolEMVORADO module**

- improve code structure / modularisation (avoid Mie & Tmat entangling…)
- revised set of internal and LUT parameters (additivity!!!)
- opening up for other (less approximative) options / variants
  - user-controlable hydrometeor orientation (&shape?)
  - explicit orientation averaging (from efficient Tmat use)
  - consideration of elevation angle dependence
  - arbitrarily shaped particles
  - other scatt data sources (than Mie&Tmat → ScattDBs!)
  - …

→ **Focus on accuracy before focus on efficiency!**

The End...

Thank you for your attention!

Additional Slides...

Approach: Polarimetry theory

Name	Symbol [unit]	Formula(s)
reflectivity factor at horizontal polarization	Z_h [mm^6m^{-3}]	$\propto \sigma_{hh}$ $\propto \lvert S_{hh}\rvert^2$ $\propto Z_{11}-Z_{12}-Z_{21}+Z_{22}$
	$\mathbf{Z_H}$ [dBZ]	$= 10\log_{10}(Z_h)$
reflectivity factor at vertical polarization	Z_v [mm^6m^{-3}]	$\propto \sigma_{vv}$ $\propto \lvert S_{vv}\rvert^2$ $\propto Z_{11}+Z_{12}+Z_{21}+Z_{22}$
	Z_V [dBZ]	$= 10\log_{10}(Z_v)$
Difference reflectivity	Z_{DP} [mm^6m^{-3}]	$= \lvert Z_h-Z_v\rvert$ $\propto Z_{12}+Z_{21}$
Differential reflectivity	$\mathbf{Z_{DR}}$ [dB]	$= Z_h/Z_v = Z_H-Z_V = \sigma_{hh}/\sigma_{vv}$ $= \lvert S_{hh}\rvert^2 / \lvert S_{vv}\rvert^2$ $= (Z_{11}-Z_{12}-Z_{21}+Z_{22}) / (Z_{11}+Z_{12}+Z_{21}+Z_{22})$
Linear depolarization ratio	**LDR** [-]	$= \sigma_{hv}/\sigma_{vv}$ $= \lvert S_{hv}\rvert^2 / \lvert S_{hh}\rvert^2$ $= (Z_{11}-Z_{12}+Z_{21}-Z_{22}) / (Z_{11}-Z_{12}-Z_{21}+Z_{22})$
Co-polar (also: cross) **correlation coefficient**	$\boldsymbol{\rho_{hv}}$ [-]	$\propto \lvert S_{hh}S_{vv}^*\rvert / (\sigma_{hh}\sigma_{vv})^{1/2}$ $= ((Z_{33}+Z_{44})^2+(Z_{43}-Z_{34})^2)^{1/2} / (\sigma_{hh}\sigma_{vv})^{1/2}$
Backscatter differential phase	δ_{hv} [°]	$= \arg(S_{hh}S_{vv}^*)$ $= \arctan((Z_{43}-Z_{34})/(Z_{33}+Z_{44}))$
Specific differential phase	$\mathbf{K_{DP}}$ [°/km]	$\propto Re(S^0_{hh}-S^0_{vv})$ $\propto K_{34}$
Differential phase shift	Φ_{DP} [°]	Path integral of K_{DP}
Specific attenuation at horizontal polarization	$\mathbf{A_h}$ [dB/km]	$\propto Im(S^0_{hh})$ $\propto K_{11}-K_{12}$
Specific attenuation at vertical polarization	A_v [dB/km]	$\propto Im(S^0_{vv})$ $\propto K_{11}+K_{12}$
Specific differential attenuation	A_{DP} [dB/km]	$\propto Im(S^0_{hh}-S^0_{vv})$ $\propto K_{12}$

➔ Possible LUT parameter sets:

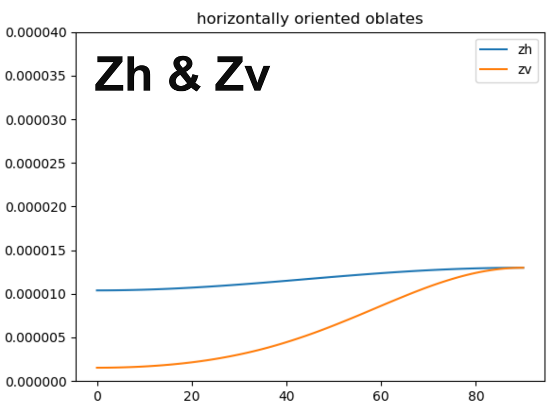
- σ_{hh}, σ_{vv}, σ_{hv}, $Re(S_{hh}S^*_{vv})$, $Im(S_{hh}S^*_{vv})$, $Re(S^0_{hh}-S^0_{vv})$, $Im(S^0_{hh})$, $Im(S^0_{vv})$
- Z_{11}, Z_{12}, Z_{22}, $Z_{33}+Z_{44}$, $Z_{43}-Z_{34}$, K_{11}, K_{12}, K_{34}

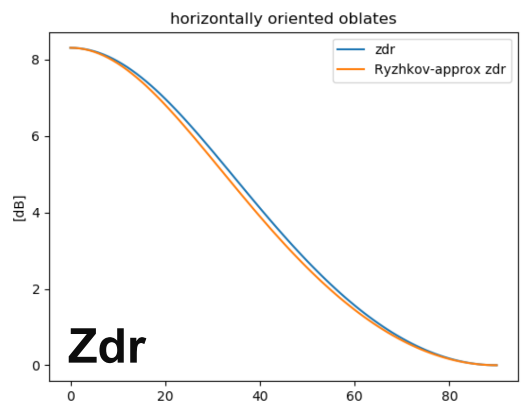
➔ select/design set (easily) derived from **S** and **Z**/**K** data

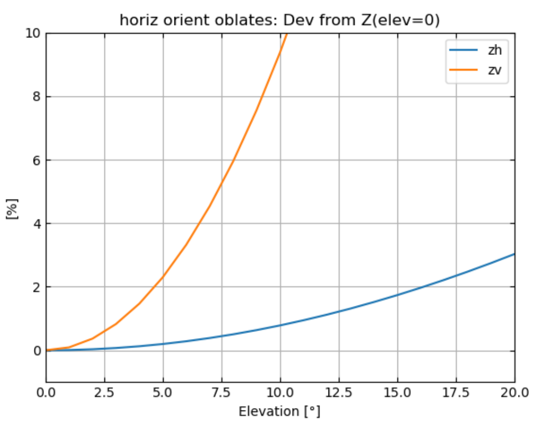
Status: Orientation & elevation effects

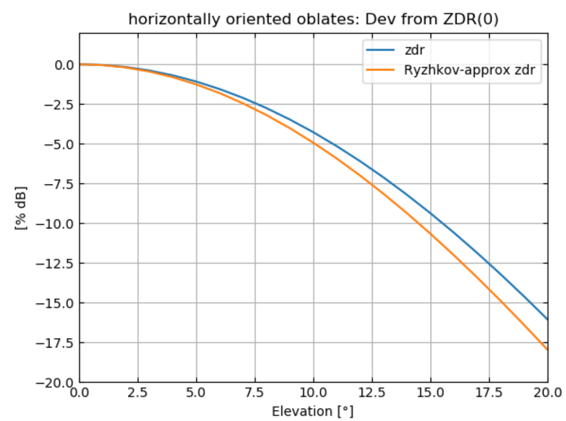
De = 5.0mm
ar ~ 0.4
m ~ (8.4, -2.2)

➔ Elevation effects perfectly **horizontally** (and vertically) oriented particles:





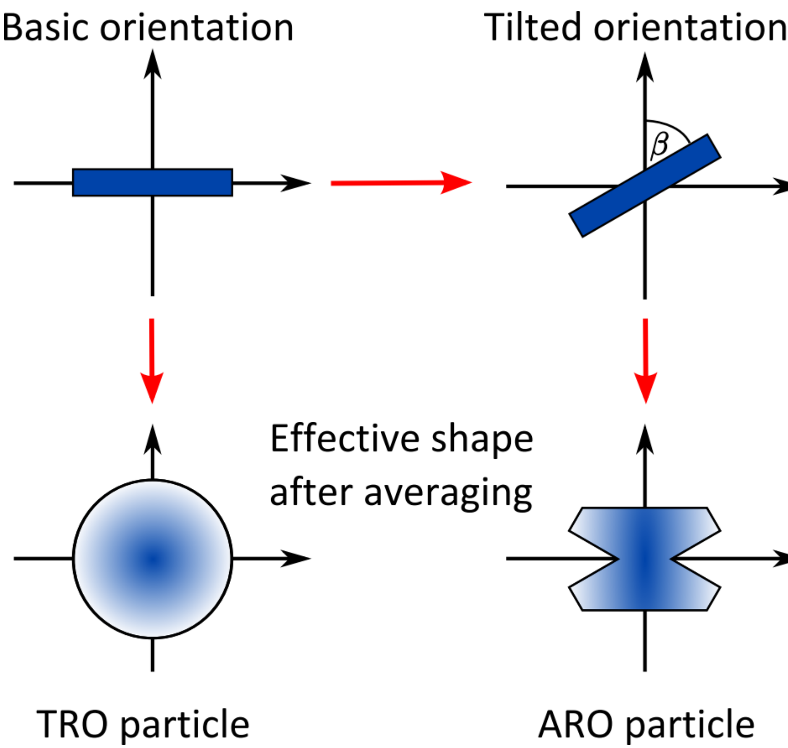




Status: Orientation & elevation effects

Non-spherical particles

➔ appear different when oriented differently or when observed from different direction



courtesy of Brath et al., 2019 (AMTD)

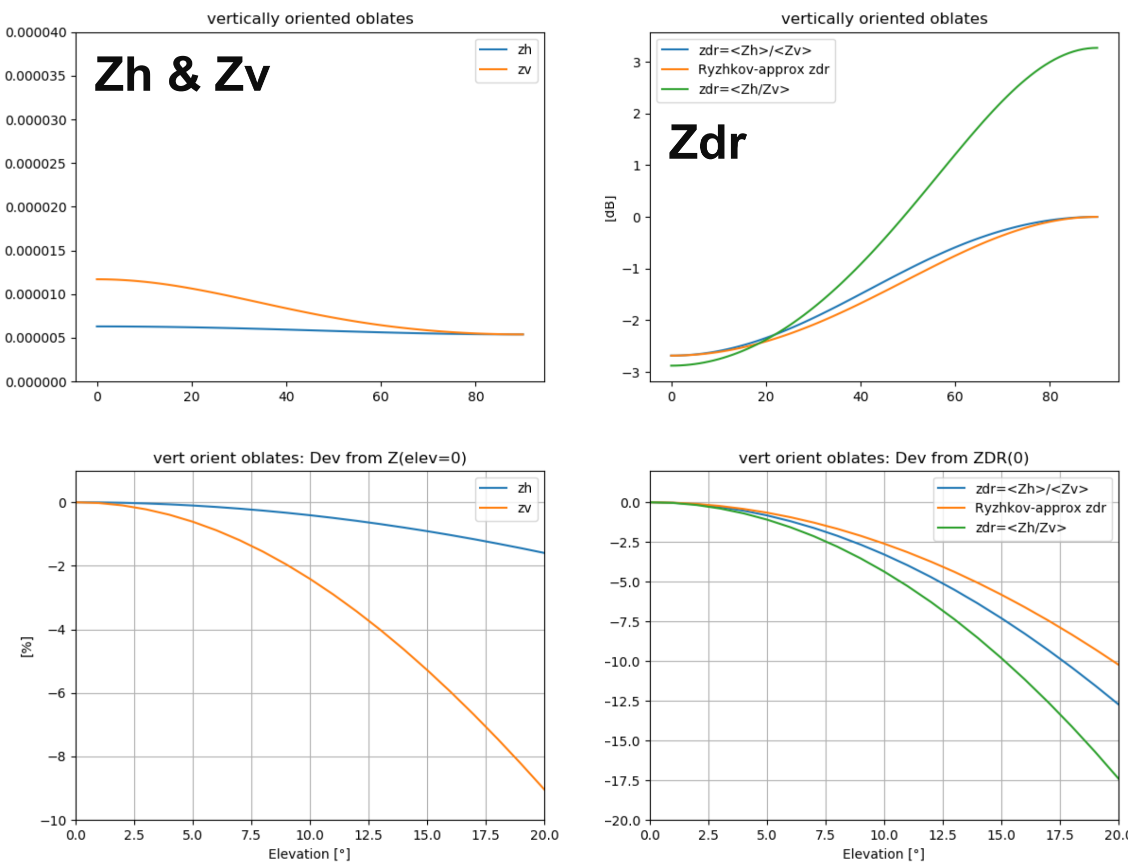
➔ are typically assumed to be oriented

- azimuthally randomly ($p_\alpha = p_\gamma = 1/2\pi$)
- with largest dimension
  - horizontally on average (mean canting = 0°)
  - with canting probability distribution ($p_\beta=f(\beta)$)

Status: Orientation & elevation effects

De = 5.0mm
ar ~ 0.4
m ~ (8.4, -2.2)

➔ Elevation effects perfectly horizontally (and **vertically**) oriented particles:



- low variation in Zh at elev<25°
- ≥10% variation in Zv, ~20% in Zdr

- Ryzhkov16-Zdr works well over all elevs
- even for vertically oriented oblates
- largest devs at medium elevs

Status: Orientation & elevation effects

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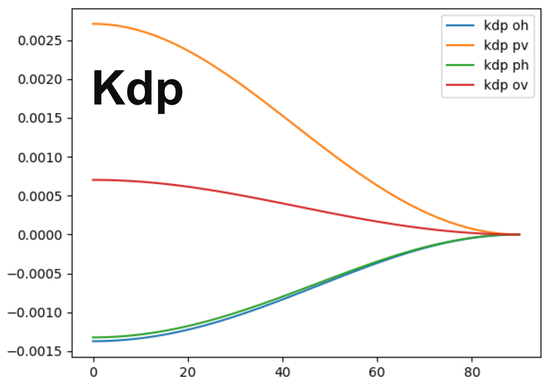
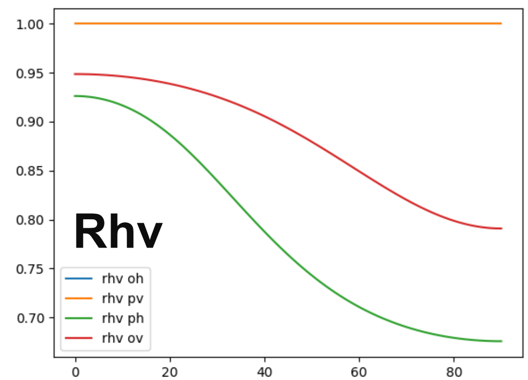
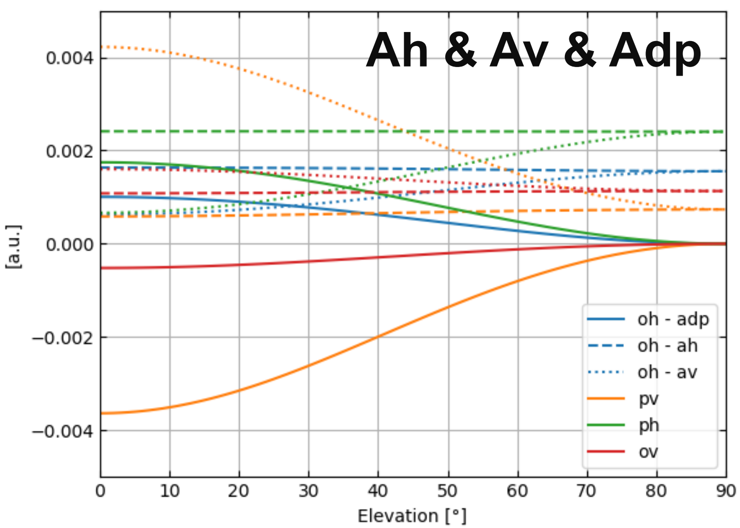
➔ Elevation effects perfectly **horizontally (and vertically)** oriented particles:







- Ryzhkov16 approx only for Zdr, but desireable for other parameters, too
- all params show some kind of „sin-like“ behaviour
- 2-pt sin-fit (not shown) works very well over (d)elevs <25°