Recent developments in the radar forward operator EMVORADO:

Polarimetric upgrade and technical changes

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DFG PROM SPP 2115 SINFONY

Outline

- General remarks on EMVORADO in COSMO (and ICON)

- Polarimetric extention
  - background & implementation
  - usage
  - application examples & challenges

- Other technical changes
  - change, **usage**, **performance & result impact**

General remarks

Code:

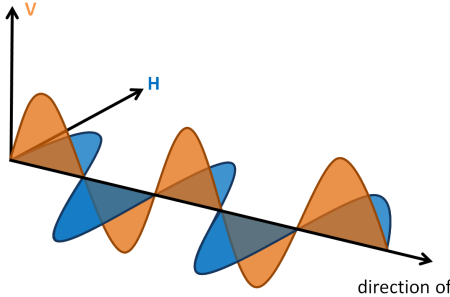
- Upgrades as shown here contained in COSMO master branch at CSCS (merged on 20.8.2021)
- Also part of the ICON master branch at gitlab.dkrz.de

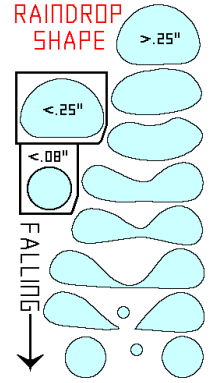
Documentation:

- DOCS/misc.global
- There is an **updated EMVORADO User's Guide** on the COSMO-webpage **(relevant also for ICON)**
  - http://www.cosmo-model.org/content/model/documentation/core/emvorado_userguide.pdf
- The **old User's Guide** for the previous version **is still available for reference:**
  - http://www.cosmo-model.org/content/model/documentation/core/emvorado_userguide_singlepol.pdf

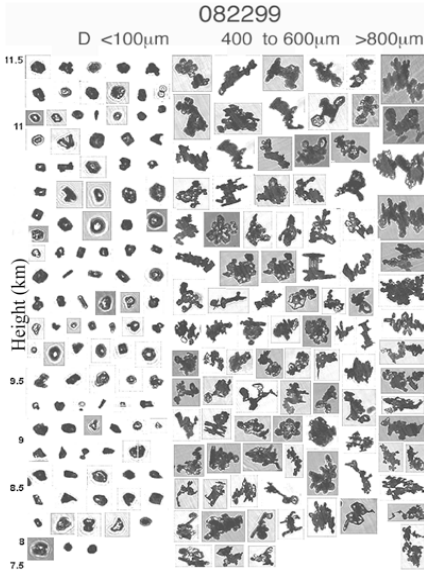
Polarimetric extention

- Background:
  - Non-spherical scatterers affect EM waves differently depending on their oscillation direction
  - Icy hydrometeors & rain are non-spherical





  - Information on size, shape, orientation
  - Modern weather radars measure polarimetric parameters, e.g. ZDR, KDP, rhoHV, …



- Potential:
  - Evaluate and constrain NWP models
  - Exploit in DA

- Requires ability to convert model fields to observation equivalents:
  - suitable, ie polarimetry-capable, forward operator

Polarimetric extention: Approach

Use Mie scattering implementation (itype_refl=1) as template

➔ Keep its capabilities

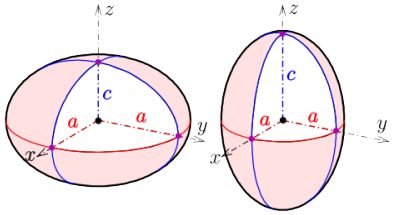
- bulk scatt. LUT (Z, A)
- melting scheme
- 1- and 2-layer particle morphologies
- choice of EMA
- beam pattern & propagation (bending & broadening)
- attenuation effects
- scan pattern
- composites; superobbing, feedback files for DA

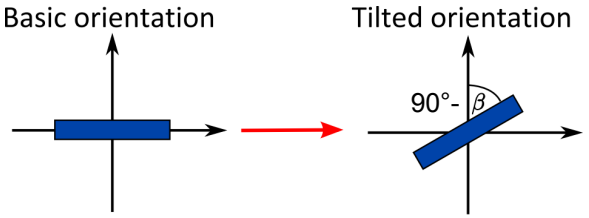
➔ Adapt / Extend where necessary

- non-sphericity capable scatt model:
  - T-Matrix (rotat. sym. scatterers)
- parameter set
  - additional output:
    - Differential reflectivity ZDR [dB]
    - Linear depolarization ratio LDR [-]
    - Cross-correllation coefficient RHOHV [-]
    - Total differential phase shift PHIDP [°]
    - Specific differential phase shift KDP [°/km]
    - Differential 2-way attenuation coefficient ADP [db/km]
  - internally & LUT: additive parameters (+6)

Polarimetric extention: Approach

- **Extend** where necessary: **shape & orientation model**
  - [oblate] spheroids
    - shape: aspect ratio AR=c/a
    - orientation: canting β of A_{max} vs. horizontal, resp. σ_β around β=0°





- AR and σ_β (+melt fraction dependence) from Ryzhkov et al. (2011) for all hydromet. classes (excl. liq.cloud)

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	1.0-0.02*D 0.8 (D>10mm)	1.0-0.02*D 0.8 (D>10mm)	AR
-	10°	10°	40°	40°	σ_β
-	-	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] σ: lin. in f_m to rain	melting behaviour (f_m=mass melt fraction)

Polarimetric extention: Usage

➔ Use Mie-reflectivity option as template:

```
&RADARSIM_PARAM
…
dbz_meta_glob%itype_refl = 5, ! 5=T-Matrix, 1=Mie, 2…4=Rayleigh
loutdbz = .true.,
loutpolstd = .true.,          ! standard set of polarimetric params
```

scattering model selection

lout* controls set of calc params, cf. loutdbz

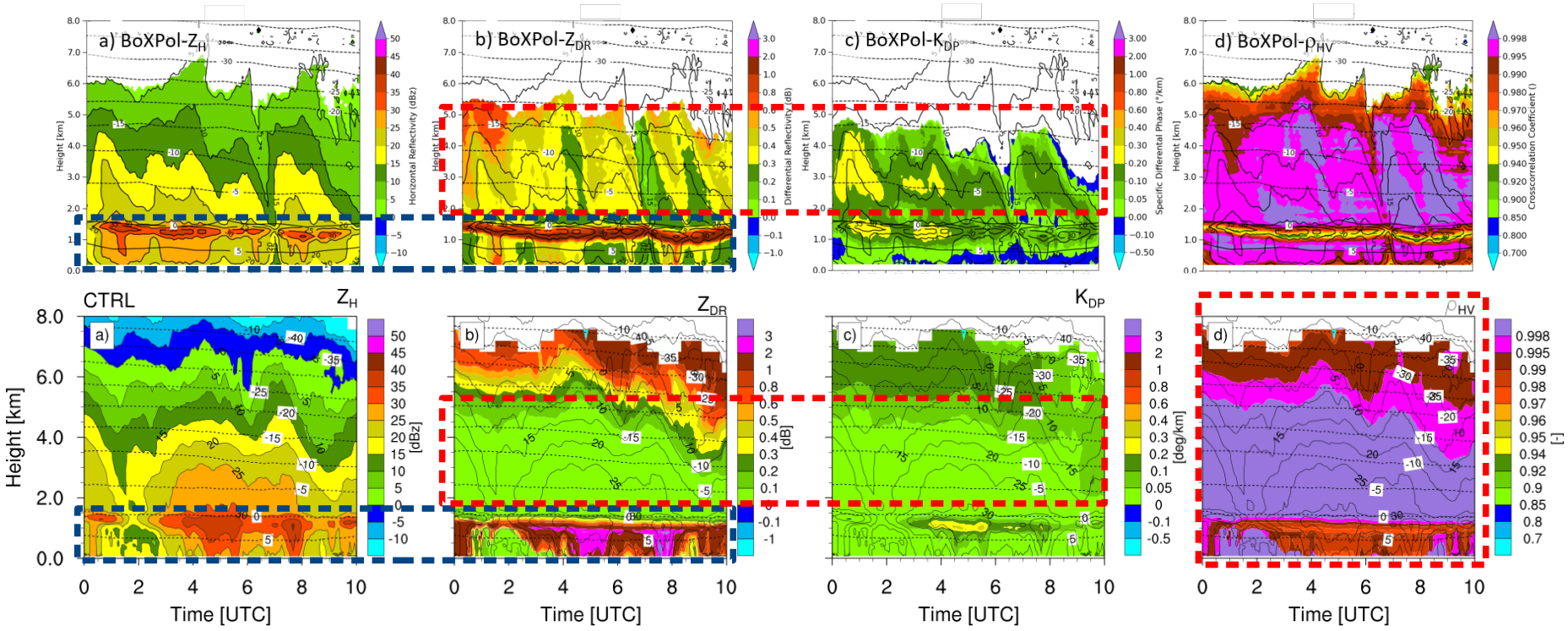
➔ further recommended settings (efficiency, consistency):

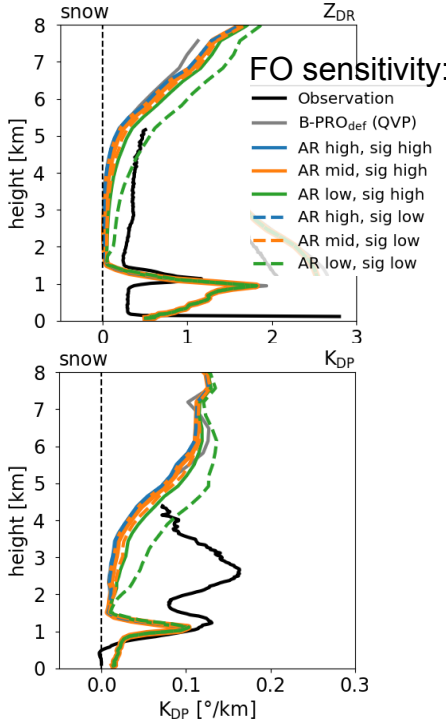
```
&RADARSIM_PARAM
…
dbz_meta_glob%llookup_mie = .true.,    ! use LUTs, TMat on-the-fly is VERY slow

dbz_meta_glob%itype_Dref_fmelt = 2,    ! const melt-Dref = much faster LUT calc

llookup_interp_mode_dualpol = .true., ! use identical interpol for all pol params
```

Polarimetric extention: Applications & Challenges

➔ Model evaluation (Shrestha et al., 2021):

- COSMO 2-mom of stratiform rain event, observed with X-band pol. radar at Bonn, Germany





➔ FO uncertainties & shortcomings:

- shape & orientation: choice of parametrizations, natural variability
- suitability of homogeneous models for fluffy, low effective density particles, eg snow aggregates

Polarimetric extention: (DA) Challenges

➔ FO uncertainties (non-**polarimetry** specific)

- **Particle model, shape & orientation**
- Effective medium approximation of refractive index
- Melting scheme

- Understanding of the measurement process: **beam smoothing of pol. parameters** (Z-weighted?)

➔ Technical

- LUT calc time consuming (but: calculated once & re-used; then as fast as Mie/Rayleigh!)
- Memory requirements (5-10 times Mie)

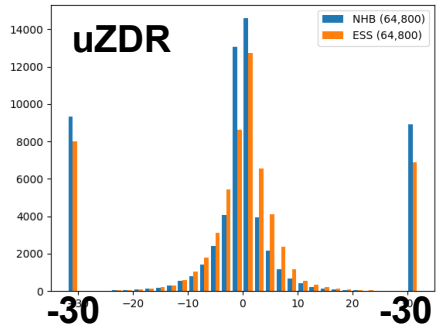
- Lacking implementation of superobbing & feedback files

Polarimetry: (DA) Challenges

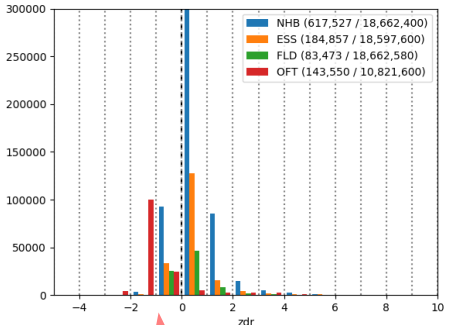
- FO uncertainties (non-**polarimetry** specific)
- Technical
- Observations
  - processing, quality & understanding (of DWD C-band network obs)

2016-06-04
elev = 5.5°

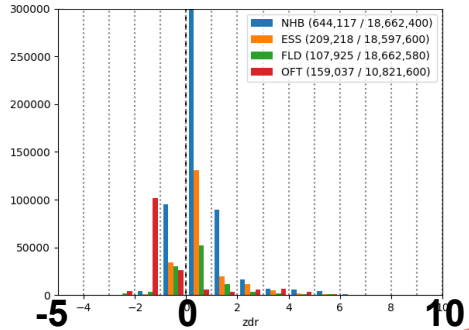
5min
all (ind. valid) data



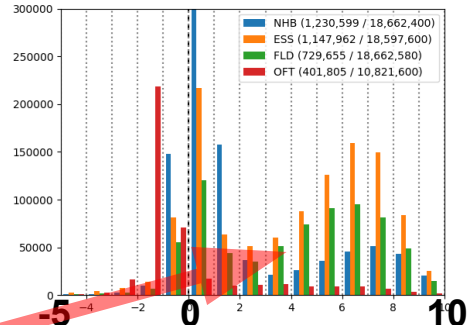
RHV > 0.8
Z >= 10dBZ



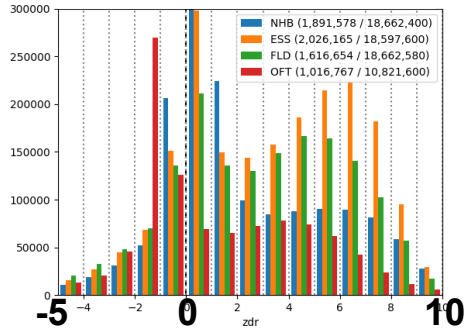
Z >= 10dBZ

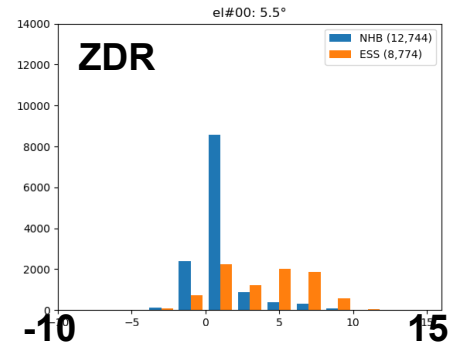


24h
Z >= -5dBZ

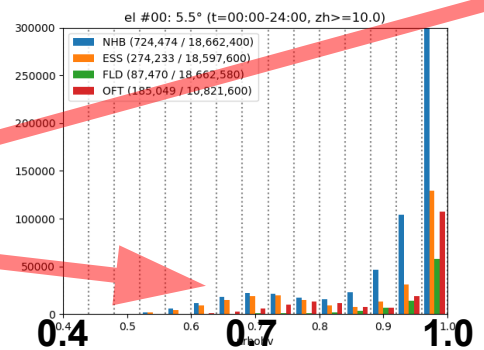


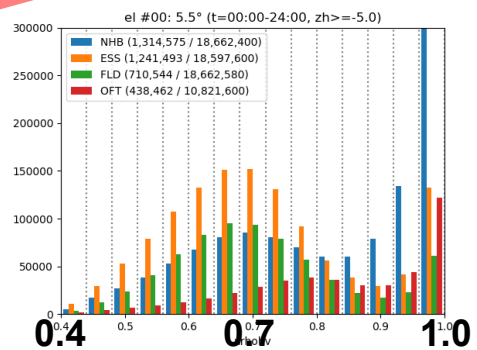
Z >= -99dBZ

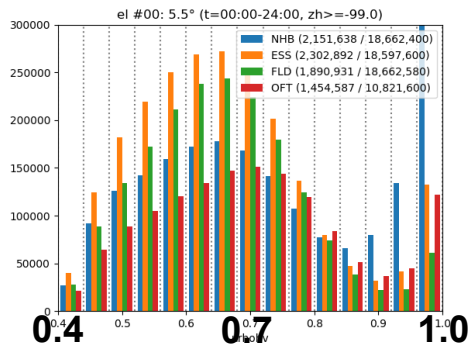


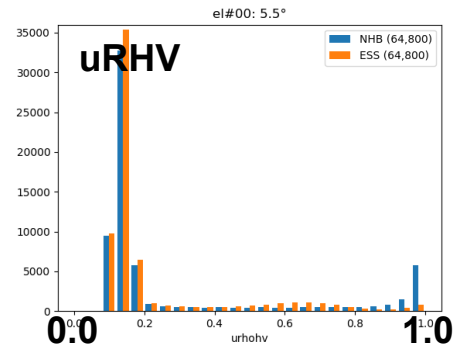


?









Other technical changes

- Pre-polarimetry features (Mie-scattering, radial wind) still available, mostly unchanged
  - Affects simulation results? → yes

- Due to
  - Triggered / along with polarimetry extention development
  - Bug fixes
  - User requests

- See also
  - Extra slides for more elaborate info
  - User Guide and DOCS/misc.global for exhaustive list

Other technical changes

➔ Consistency:

- code refactoring (incl. less code duplication)
- unified hydrometeor content thresholds in on-the-fly and LUT runs (small changes in on-the-fly low-Z cases)

➔ Computation speed:

- optional faster parallelization scheme for LUT generation (see: `itype_mpipar_lookupgen`, `pe_start_lookupgen`, `pe_end_lookupgen`)
- optional const. Dref in diagnostic melt fraction. Reduces necessary calculations in LUT generation. (changes the results in the melting layer; potentially significantly)

➔ Controling setups:

- new namelist parameter `dbz_meta_glob` to specify global background values for radar station `dbz_meta`
- melting scheme parameters user-accessible (incl. change of ice default, ie affects melting cloud ice results; rare)

Other technical changes

➔ Output:

- multiple output streams (formats, time intervals, file name patterns, output paths) for the same volume scans (see: `voldata_ostream, t_voldata_ostream`)
- multi-moment multi-volume output for simulated volume scans (`voldata_ostream(i)%format='cdfin-mulmom'`)
- grib2-format volume scan output (requires DWD's eccodes_2.21.0 definitions; so far **reflectivity** ("zrsim", "zrobs") **only** due to missing shortNames for other params)

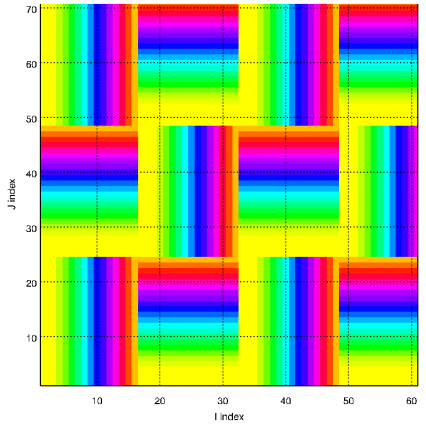
➔ Observation input:

- new reader for DWD's flavor of hdf5 radar observation files (incl. certain polarimetric data)
- optional aggregation in range (e.g., reduce 250-m-data to 1000 m range resolution) to save memory

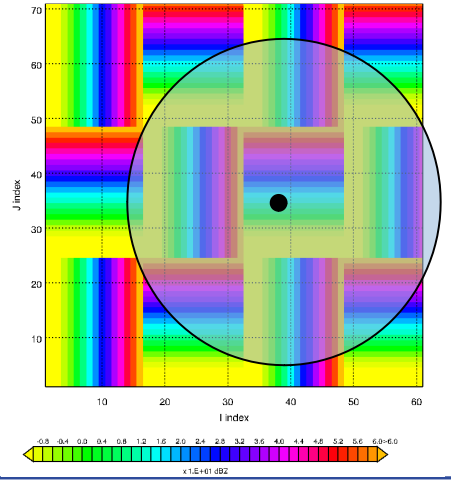
Other technical changes: Impact on reflectivity results

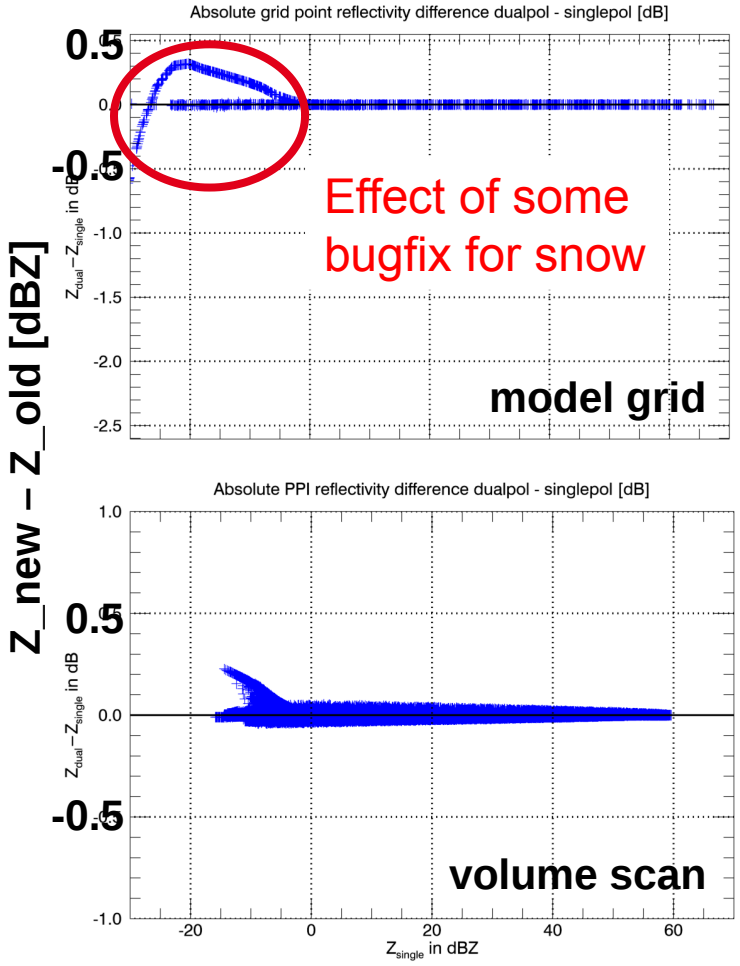
➔ **Mie**-reflectivity (itype_refl=1) compared between previous (Z_old) and new version (Z_new):

Hydrometeor test pattern

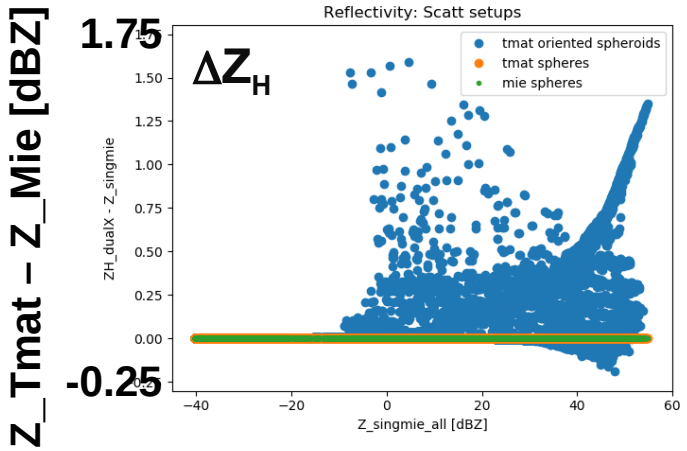


… observed by virtual PPI scan





➔ reflectivity ZH between T-Matrix and Mie solutions:



The end

(More) Questions?

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Extra slides (from UB)

Recent upgrade of EMVORADO in the COSMO master branch

- Within DFG SPP-PROM project „OperationHydrometeors“ and in cooperation with Jacob Carlin and Jeffrey Snyder, EMVORADO has been upgraded by a new option to simulate **reflectivity and polarimetric radar moments** assuming **non-spherical (oblate spheroidal)** particle shapes based on the **T-matrix** method:
  - Differential reflectivity ZDR [dB]
  - Cross-correllation coefficient RHOHV [-]
  - Total differential phase shift PHIDP [°]
  - Specific differential phase shift KDP [°/km]
  - Linear depolarization ratio LDR [-]
  - Differential 2-way attenuation coefficient ADP [db/km]

- All previous features (Mie-scattering, radial wind) still available (with minor bug fixes and technical updates)

- Polarization parameters integrated in other physical options: online beam propagation, beam smoothing, beam blockage

Other technical changes and improvements

- Split up the big module radar_mie_iface_cosmo.f90 to a number of smaller modules
- Split up the big module radar_process_output.f90 to a number of smaller modules
- Added new optional grib2-output for reflectivity volume scans ("zrsim", "zrobs"), requires DWD's eccodes_2.21.0 definitions.
- Added new possibility to have several (up to 5) output streams (formats, time intervals, file names with flexible file name patterns and output paths) for the same simulated and/or observed volume scans. For this, each stream is configured by an instance of the new derived type "t_voldata_ostream" in the new namelist parameter list "voldata_ostream(1:5)". Some old namelist parameters for volume scan output have been eliminated (see below).
- Added new option for multi-moment multi-volume output files for simulated volume scans (voldata_ostream(i)%format='cdfin-mulmom')
- Added new faster parallelization scheme for lookup table (LUT) generation as an option: optimized order of computations with re-cycling of Mie-results and better parallelization. New associated namelist parameters "itype_mpipar_lookupgen" (default is "2" which is the new scheme), "pe_start_lookupgen" and "pe_end_lookupgen" (gang of compute PEs which do the computations - only relevant for ICON on DWD's NEC). Speeds up the Mie-LUT computation from 30 s to about 3 s on DWD's NEC)

Other technical changes and improvements

- New lookup tables for T-matrix computations. The name of the files depends on the chosen scattering theory of the run:
  - radar_mietab_*.bin (Mie-theory, itype_refl=1)
  - radar_tmatrixtab_*.bin (T-matrix, itype_refl=5)
  - Version number for LUT increases from 002 to 012 and revised computation of the hash-value, which is part of the LUT file names“
- New reader for DWD's flavor of hdf5 radar observation files (includiung some polarimetric moments)
- Revised hydrometeor test pattern for development purposes
- New namelist parameter "dbz_meta_glob" of type "dbzcalc_params", replacing the previous "itype_refl_glob" and "llookup_mie_glob" and offering the possibility to specify global background values of all type components for all radars

Other technical changes and improvements

- Introduced the above polarimetric radar moments. New options "dbz_meta_glob%itype_refl=5" (T-matrix for spheroidal particles and "6" (T-matrix but assuming spherical particles; option for cross-comparison with classical Mie-scattering "dbz_meta_glob%itype_refl=1"). No composites and fof-files yet of these new variables. Also no grib2-ouput due to missing shortNames. Processing of polarimetric variables on top of reflectivity and attenuation coefficient is triggered by "loutdbz=.TRUE." and "loutpolstd=.TRUE." or "loutpolall=.TRUE.“
- Added new type components in "dbzcalc_params" of previously hardcoded parameters for EMVORADO’s melting scheme. The defaults are mostly equal to the previously hardcoded parameters, except for melting cloud ice. This changes the results for reflectivity slightly at grid points with melting cloud ice, which is not very often.
- Added new option for the diagnostic melt fraction as function of particle size and temperature and a new parameter "dbz_meta_glob%itype_Dref_fmelt" to select the option (``2") or use the default scheme (``1"). The new option is somewhat simplified and uses fixed reference diameters in the meltdegree formula instead of some mean PSD size. This greatly enhances the efficiency of polarimetric T-matrix LUT generation, but also changes the results in the melting layer.

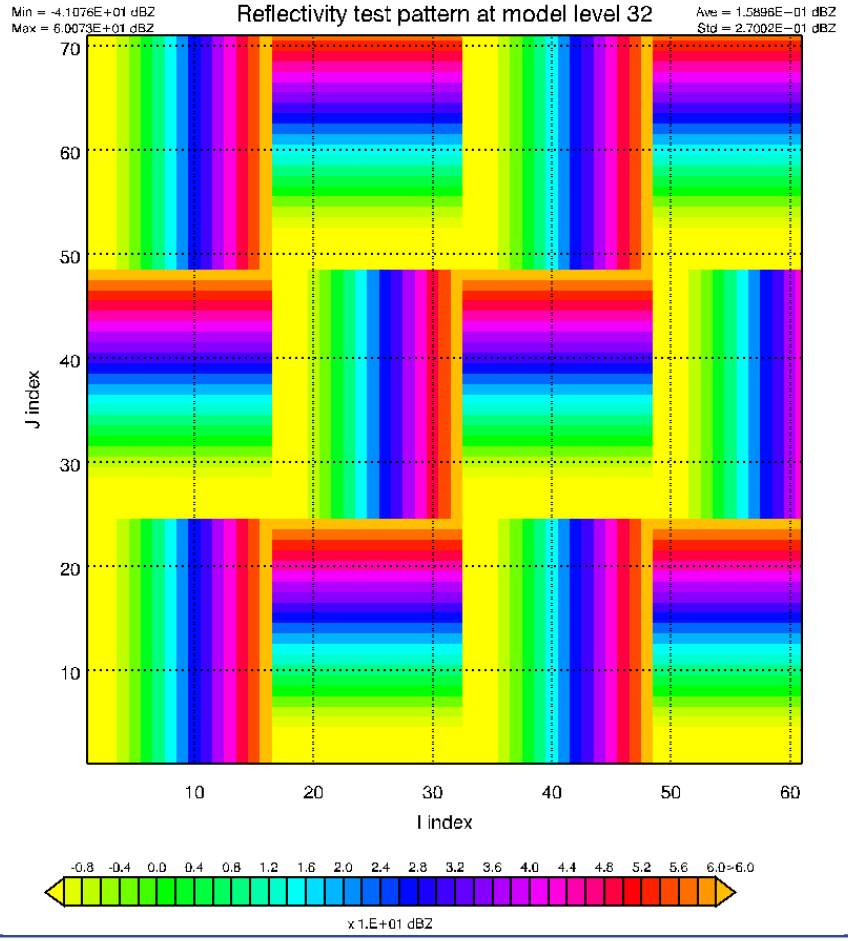
Other technical changes and improvements

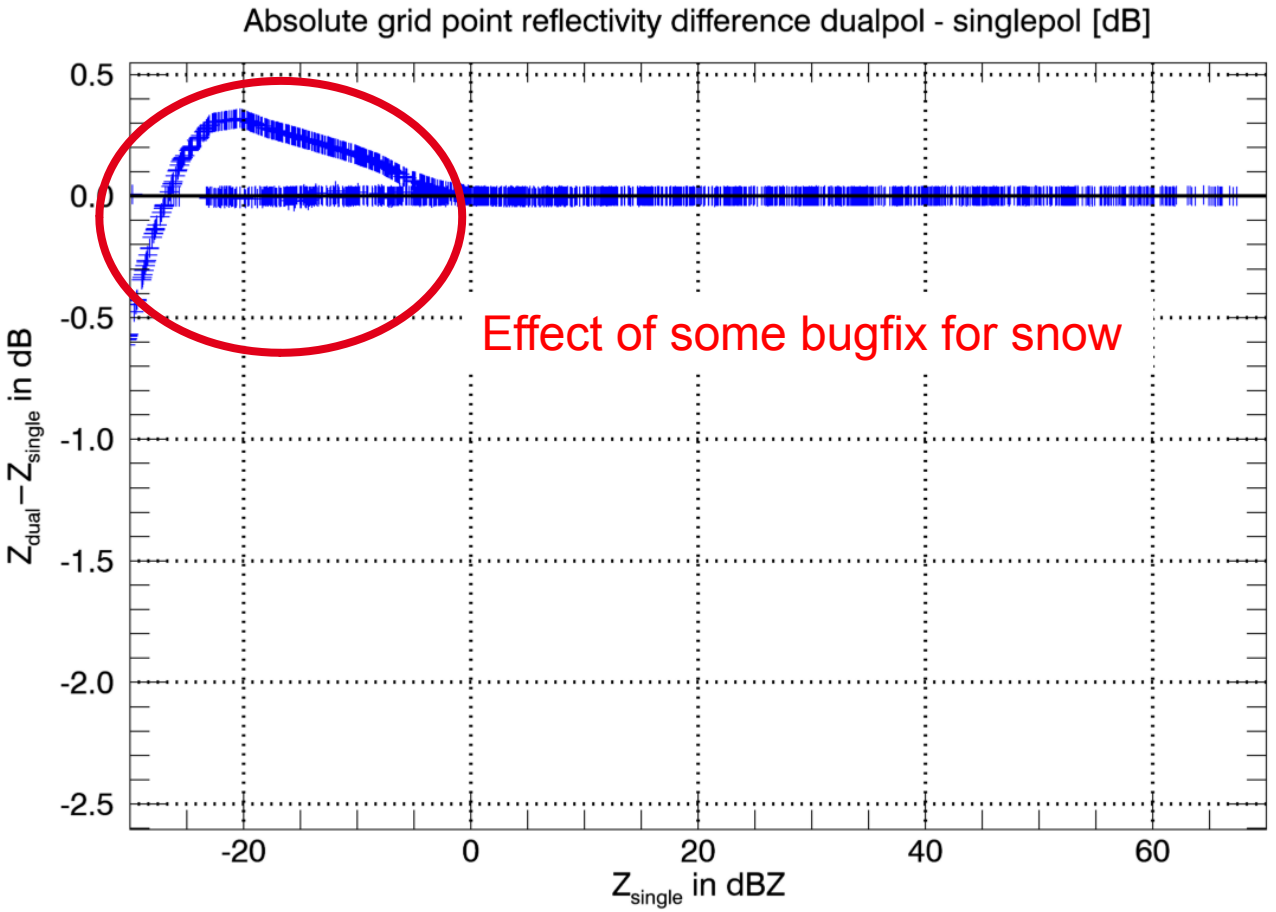
- Added new namelist parameter "llookup_interp_mode_dualpol" to switch to a consistent interpolation technique for table lookup among all polarimetric moments (cubic interpolation of linear values). Avoids interpolation artifacts, e.g., values of RHOHV > 1.
- New namelist parameter "lcalc_dbz_on_radarbins" for new option to reverse the order of interpolating model state variables to radarbins and computing polarimetric moments. If .TRUE., first interpolate the model state and then compute radar moments. Only implemented for 4/3-earth beam propagation ("lonline=.FALSE.")
- Added new option to aggregate observation data in range on input, e.g., reduce 250-m-data to 1000 m range resolution to save memory without much loss of representativity in the context of a numerical model

Changes of the results in existing applications

➔ Mie-reflectivity (itype_refl=1) compared between previous (Z_single) and new version (Z_dual):

Hydrometeor test pattern





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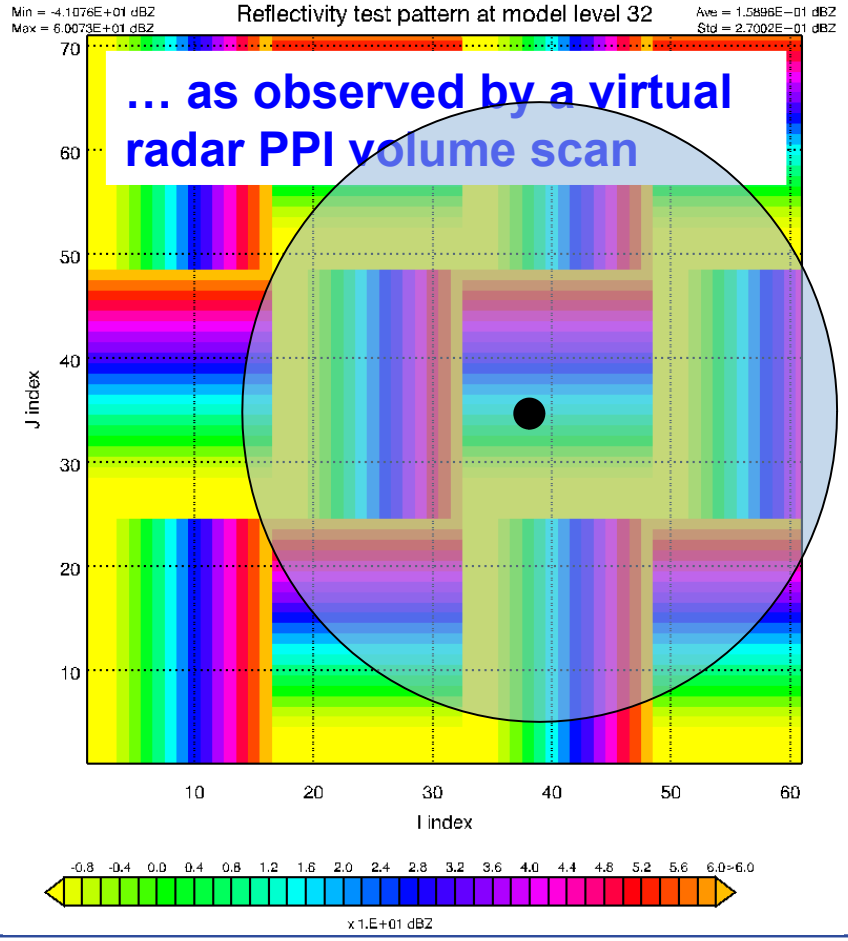
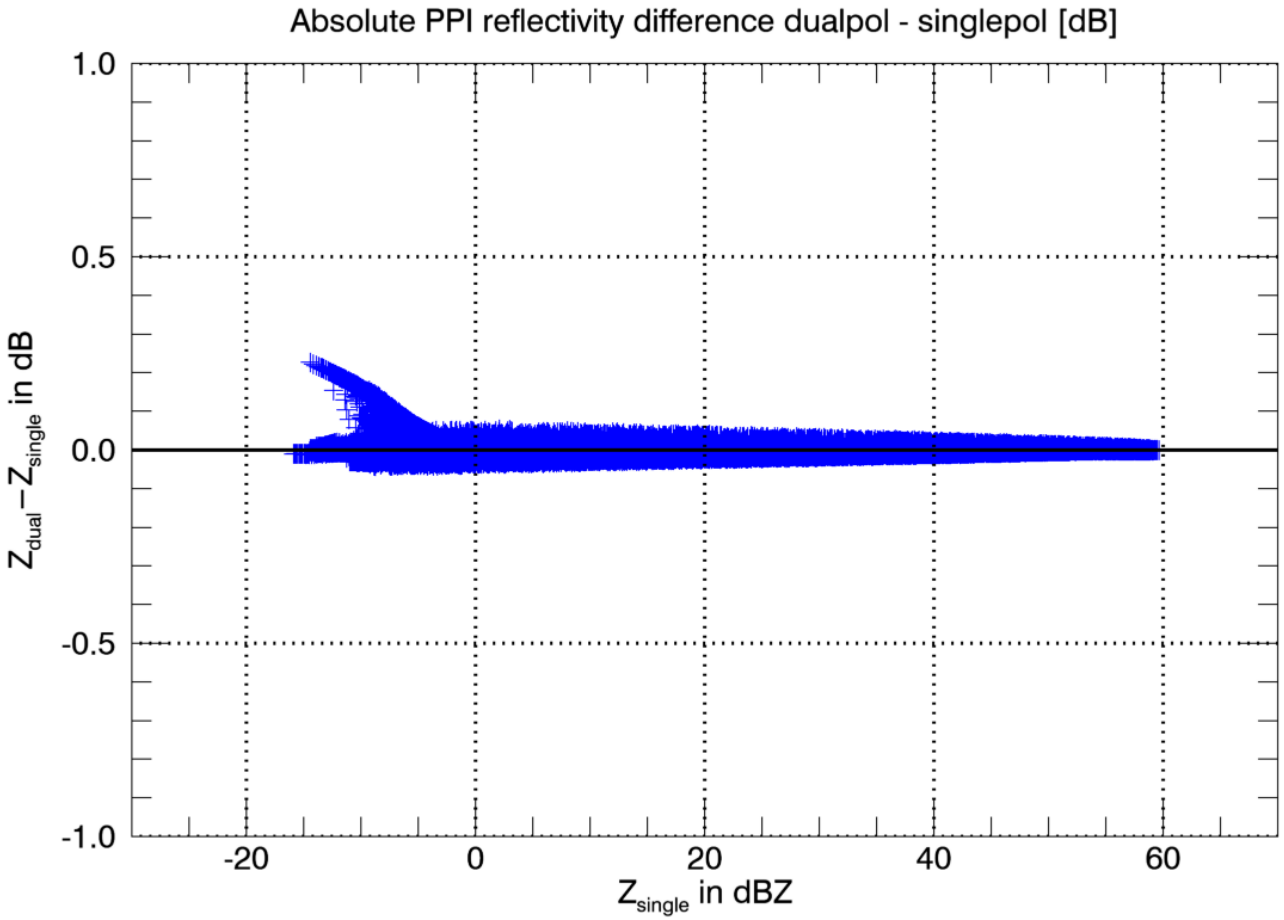
Hydrometeor test pattern





Changes in the RADARSIM_PARAMS namelist

- New parameter dbz_meta_glob of type dbzcalc_params
- Eliminated itype_refl_glob and llookup_mie_glob, because these can now be set by dbz_meta_glob %itype_refl and dbz_meta_glob%llookup_mie
- Additional type components of dbzcalc_params, which concerns the parameters dbz_meta_glob and dbz_meta(1:nradsta_max). The most important new parameters are (by example in dbz_meta_glob):
  - New option dbz_meta_glob%itype_refl = 5 for T-matrix scattering theory and non-spherical particles.
  - New option dbz_meta_glob%itype_refl = 6 for T-matrix scattering theory and spherical particles for cross-comparison with Mie-scattering (only relevant for developers).
  - New component dbz_meta_glob%itype_Dref_fmelt (= 1: previous dynamic melting scheme; = 2: new simplified melting scheme to reduce runtime for polarimetric computations).
  - The other new components are listed in the new User's Guide.
- New parameters loutpolstd and loutpolall
- New parameters itype_mpipar_lookupgen, pe_start_lookupgen and pe_end_lookupgen
- New parameter llookup_interp_mode_dualpol
- New parameter lcalc_dbz_on_radarbins

Changes in the RADARSIM_PARAMS namelist

- New parameter voldata_ostream(1:noutstreams_max) of type t_voldata_ostream
- Eliminated voldata_format, voldata_output_list, cdfin_dt and cdfin_tref, which can now be set via voldata_ostream(1:noutstreams_max)%format, voldata_ostream(1:noutstreams_max)%output_list, voldata_ostream(1:noutstreams_max)%content_dt and voldata_ostream(1:noutstreams_max) %content_tref
- New parameter ysubdircomp to explicitly specify the output subdirectory under ydirradarout of composites in grib2. If it starts with a „/“, it is taken as an absolute path.
- New parameter composite_file_pattern to explicitly specify the file pattern of composite files, with the help of (optional) keys.
- New parameter ysubdirfof to explicitly specify the output subdirectory under „ydirradarout“ of fof files. If it starts with a „/,“, it is taken as an absolute path.
- New parameter ydir_ready_write to explicitly specify the output directory for READY files.
- New parameter ready_file_pattern to explicitly specify the file pattern of READY files, with the help of (optional) keys

Changes of the results in existing applications

- No changes for radial wind
- Small insignificant changes of Mie reflectivity (itype_refl=1) on the order of 0.1 dB have been observed as a consequence of bug fixes and of adaptions of some lower hydrometeor thresholds for solid particles to trigger Mie-computations (1e-6 --> 1e-7)

Code and Dokumentation

Code:

- The EMVORADO dualpol upgrade has been merged into the COSMO master branch at CSCS on 20.8.2021
- It is also part of the ICON master branch at gitlab.dkrz.de

Documentation:

- DOCS/misc.global
- There is an **updated EMVORADO User's Guide** on the COSMO-webpage **(relevant also for ICON)**
  - http://www.cosmo-model.org/content/model/documentation/core/emvorado_userguide.pdf
- The **old User's Guide** for the previous version **is still available for reference:**
  - http://www.cosmo-model.org/content/model/documentation/core/emvorado_userguide_singlepol.pdf