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Atmospheric Measurement Techniques Discussions

Interactive comment on "From model to radar variables: a new forward polarimetric radar operator for COSMO" *by* Daniel Wolfensberger and Alexis Berne

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1 General Comments

This paper deals with the development of a new polarimetric forward operator for the COSMO-model (ZH, ZDR, KDP, AH, ADR, radial wind, Doppler spectrum). Although the forward operator employs state-of-the-art computation methods to simulate beam propagation- and beam broadening effects and to compute the polarimetric moments from model output (T-matrix for oblate spheroids, 2-component Maxwell-Garnett effective medium approximation for melting particles), it clearly has its merits and useful new developments:

- A particular emphasis is put to efficient and yet accurate numerical methods (quadrature schemes, lookup tables) which is important with respect to its practical applicability.
- Todays state-of-the-art NWP models do not contain any prognostic information about shape asymetry and tumbling behaviour of the hydrometeors (canting angle distribution), but these are important input parameters for the simulation of polarimetric moments. To this end, new parameterizations for graupel- and snow particles of the probability density functions of axis ratio and canting angle distribution as function of partice size have been developed. These new fits are based

on a large particle sample from in-situ observations of a multi-angle snow flake camera (MASC) and might be useful for the community.

- Special quadrature scheme for beam broadening effects at the edges of the melting layer.
- Simulation of the entire Doppler spectrum, not only mean value (radial wind) and standard deviation (spectral width).

This operator is then used to compare measured and simulated polarimetric moments of the Swiss C-Band radar network, an X-Band radar and a space-born Ka-Band cloud radar for different case studies and weather situations. The source code of the operator is freely available on the internet.

While the above merits make the paper well worth publishing, the presentation needs polishing and there seems to be an error in the attenuation simulation for the Doppler spectrum, see below. This error, however, should be possible to correct with a reasonable effort, and therefore I recommend to **accept this paper after major revisions.**

2 Specific comments

Page 14, line 11 ff:

The exact definition of the scattering matrix elements s which relate the incident and scattered $\vec{E}$ field as function of direction (which angles?) remains somewhat unclear, which is not uncommon in the literature. However, I would find it useful to see the exact equation and a sketch defining the scattering angles. Also, which sign convention for the imaginary part of the refractive index of the scatterers is applied?

These choices influence the exact equations for the radar observables in Appendix C. unclear

Page 20, line 1:

Maxwell-Garnett is only one of many known Effective Medium Approximations, and Eq. (13) is the special case of a 2-component mixture (n-component mixture see Bohren and Huffman (1983)) where small ice spheres are suspended in air ("matrix"). You could mention some alternative formulations from the literature (see Blahak (2016) for a summary) but stating that, if none of the components is a strong dielectric, all these formulas approximately agree to first order (Bohren and Huffman (1983)). This will become more important later in your section 3.7.2, Permittivity.

Page 21, line 9:

Your Eq. (10) is wrong, because the argument of $\log$ should be dimensionless. Did you mean something like

$$Z_H(r) = S(r_0) + G + SNR_{thr} + 20 \cdot \log_{10}\left(\frac{r}{r_0}\right) \tag{1}$$

where $S(r_0)$ is the sensitivity at a certain reference range r_0. Please review this Equation. Is this just a "typo" or are your results affected?

Page 22, line 19:

Please define D: melted diameter or actual diameter of a melting particle?

Page 23, line 15 ff:

The description of your applied EMA is too short and omits necessary detail: Please give the exact formula of ϵ_{eff} that you applied for partially melted particles. Describe the role of the air inclusions. Note that there is an $n-$component version of Maxwell-Garnett given in Bohren and Huffman (1983), as well as a variant that assumes spheroidal inclusions instead of spherical inclusions in the matrix medium. Note also that there are other EMA's "on the market", derived under different assumptions on the internal melting morphology and it is not clear which one is "best". This might also depend on the specific radar observable under consideration and is really hard to determine.

Definition of ρ_{total}?

Also, please illustrate in a new figure the typical dependence of the mass fraction of water $f_{water} = m_{water}/m_{ice}$ for single particles as function of D and f^m_{wet}, as derived from your Eq. (24) together with (21). This will shed more light on your implicit assumptions about the distribution of melt water among the particle sizes for given average degree of melting.

Page 24, line 1:

In contrast to your Eq. (28), in the original literature Szyrmer and Zawadzki (1999) the equation reads

$$N^r(D_r)v^r_t(D_r) = N^m(D)v^m_t(D) \tag{2}$$

with D_r equivalent melted diameter of the particle and D its "true" diameter, claiming that this will describe a one-to-one correspondence, i.e., one snow flake leads to one raindrop during the melting process (no shedding/aggregation) and in a steady state the spectral precipitation rate through the melting layer is conserved, While this is not entirely correct (the original formula neglects the functional determinant $dD(D_r)/dD_r$ of the size distribution transformation) your (28) is also not correct in the sense of a one-to-one correspondence.

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The correct transformation to achieve this would be

$$N^r(D_r)v_t^r(D_r)dD_r = N^m(D)v_t^m(D)dD \quad \Longrightarrow \quad N^m(D) = N^r(D_r(D))\frac{v_t^r(D_r(D))}{v_t^m(D)}\frac{dD_r}{dD} \quad (3)$$

$$with \quad D_r(D) = \left(\frac{\rho_{total}(D)}{\rho_{water}}\right)^{1/3} D \quad (4)$$

where $\rho_{total}(D)$ is the bulk density of the melting particle having diameter D.

While your (28) as a parameterization is entirely valid, there is no one-to-one-correspondence and therefore implicitly shedding/aggregation processes are parameterized across the melting layer in a possibly unrealistic way.

I see two possible ways forward: (a) change your computation of $N^m(D)$ using the “correct” transformation for the one-to-one-correspondence, or (b) keep your parameterization but discuss the implicitly contained shedding/aggregation parameterization somehow.

(a) would be a solution in line with other literature, but some of your data/plots may have to be recomputed,

(b) would be possible by, e.g., producing an exemplary plot based on a specific rain DSD $N^r(D_r)$, which compares $N^m(D)-$ spectra derived by your Eq. (28) and (29) and by the above “correct” one-to-one-correspondence-transformation for different values of f_{wet}^m at constant precipitation flux.

In your Eq. (29), the distribution in the denominator should be $N^m(D)$, not $N^r(D)$, right?

Because $N^m(D)$ through the melting layer is extrapolated from the rain DSD at the bottom, the transition to the dry snow PSD just above the melting layer is not continuous. How large is the "jump"?

Page 28, line 1:

The numeric representation of the convolution with a Gaussian kernel in Eq. (39) is wrong. To correct, do either:

- replace the wrong index i in $v_{r,bins}[i]$ by j, take the square of this velocity and let the sum over j run over a symmetric interval ($-N_{FFT}/2$ to $+N_{FFT}/2$ I guess),
- or change $S[i-j]$ to $S[j]$ and $v_{r,bins}[i]$ to $(v_{r,bins}[i] - v_{r,bins}[j])^2$.

Also, you have to divide by the sum of the Gaussian weights!

Page 28, line 3 ff:

This section should perhaps be better named "attenuation computation" instead of "correction", because the latter is usually used to denote the inverse procedure applied to observations.

Also, the attenuation computation given in Eqs. (40) to (42) is wrong. According to Lambert-Beers law, attenuation in the space of linear reflectivities (such as your spectral reflectivity S) is given by

$$Z_h^{att} = Z_h \, 10^{0.1 \int_0^{r_0} k_H(r)\, dr} = K \, Z_h \quad (5)$$

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k_H is already 2-way according to your definition in Appendix C (Factor 20/$\ln 10 = 8.686$). The attenuation factor K simply applies to all channels of S, so that

$$S^{att}[i] \;=\; K\,S[i] \tag{6}$$

Please correct also the text of this section accordingly and recompute the data of your figure 14.

Page 34, line 1:

While I agree with the findings of the DSD-comparison in this special case, the well-known general difficulties of such comparisons (vastly different sampling volumes, shapes of normalized spectra strongly depend on rain rate) should be discussed a bit more and why their influence is presumably small in this case.

Also, whether or not to use this “improved” shape parameter value in the forward operator instead of the microphysics-consistent value depends on the application (model verification vs. data assimilation).

Applying it in the model microphysics may be a good idea, but without re-tuning other parameters in the model, one might end up with a degradation of the surface precipitation, because one of the compensating errors has been taken away.

3 Technical Corrections

Page 4, line 16, 24:

Since COSMO 5.1, ice sedimentation is also taken into account in the 1-moment schemes.

Page 4, line 19:

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Add two more references for the 2-moment scheme, because the addition of the separate hail class came after Seifert (2006): Blahak (2008), Noppel et al. (2010)

Page 5, line 6 (Table 1):

N_0 Rain: missing "free" after "2529". Also check the value 2529 (which units???), because the $N0$-μ-relation of Ulbrich (1983) is applied, with a base value of 8000 m^{-3}mm^{-1} for $\mu = 0$ and increasing with increasing μ.

Specify the units of N_0 in the table caption.

Page 10, line 3:

$\frac{dn}{dh} = const$, not cst

Page 17, line 8 ff:

Change mathematical presentation of your formulas (10) and (11). To reflect that in your *ansatz* the parameters of the Normal- and generalized gamma distribution depend on diameter D, you don't have to use the awkward superscripts. In the second formula, I think a_r has to be replaced by $1/a_r$, if I look at your Figure 5 and if I'm not mistaken:

$$o: \qquad g_o(o, D) = \mathcal{N}\left(0, \sigma_o(D)\right) \tag{7}$$

$$1/a_r: \qquad g_{1/a_r}(1/a_r, D) = \frac{(1/a_r - 1)^{\Lambda_{a_r}(D)-1} \; \exp\left(-\frac{1/a_r - 1}{M(D)}\right)}{M(D)^{\Lambda_{a_r}(D)}\,\Gamma(\Lambda_{a_r}(D))} \tag{8}$$

where g_o and g_{1/a_r} are the distributions of o and $1/a_r$, respectively. You can eliminate the offset l from the formula and text. Just set it to 1.

Is it correct that $g_{a_r}(a_r, D) = g_{1/a_r}(1/a_r, D) \,/\, a_r^2$? If yes, you can mention this in the text, because $g_{a_r}(a_r, D)$ is the one you most likely used for computing the radar observables, right?

Page 17, line 11 ff:

Delete the sentence starting with "The superscript [D] . . . ". In the next sentence, correct ". . . constant factor $l = 1$, . . . " $\Longrightarrow$ "constant shift of 1, . . . ".
Replace also the next sentence "The relationship . . . " by
"These parameters depend on the diameter D. Technically, Λ_{a_r}, M and σ_o first have been fitted separately for each single diameter bin of MASC, then their dependence on D has been fitted by power laws for each parameter,"
At this point, you can insert the power laws from Figure 5 as equations in the text, they deserve it! When you do so, please indicate all units.
Then continue with "Note that these power laws allow to estimate the parameters for any arbitrary maximum diameter. This also allows integration over the canting angle . . . "

Page 20, line 23:

Homogenize notation of the probability density functions $p(\beta)$, $p(a_r)$ with Eq. (10) and (11)

Page 27, line 21:

Missing backslash in front of $sigma_\theta$.

Page 37, line 20:

Sentence is garbled, delete "will be performed".

Page 37, line 21:

"$(x^{rot}, y^{rot}, z^{rot})$" the same as "$(x_m, y_m, z_m)$"?

Page 41, line 1 and 2:

The factor 2 has to be removed from the equations because k_H and k_V are already two-way attenuation coefficients. And the "$+$" sign should be "$-$".

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