Radar Forward Operator for Data Assimilation and Model Verification for the COSMO Model

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Bundesministerium
für Verkehr, Bau
und Stadtentwicklung

Karlsruhe Institute of Technology

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INTRODUCTION

A new radar forward operator for simulating terrestrial weather radar measurements from NWP model output is currently developed. It is suitable for a broad range of applications like, e.g., radar data assimilation in the framework of Ensemble Kalman Filter systems (as such is currently developed at the German Weather service DWD) or verification of cloud microphysical parameterizations.

This operator calculates the radar observables reflectivity and radial wind (later also polarization parameters) from the prognostic model output. The rationale is to have a comprehensive radar simulator, which comprises all relevant physical aspects of radar cloud measurements in a quite accurate way, but at the same time to provide the possibility for simplifications in a modular fashion. This enables the user to configure and tailor the operator for his/her specific application, that is, to find the „best“ balance between physical accuracy and computational effort.

The operator is implemented currently as a sub-module into the non-hydrostatic compressible COSMO-model of DWD.

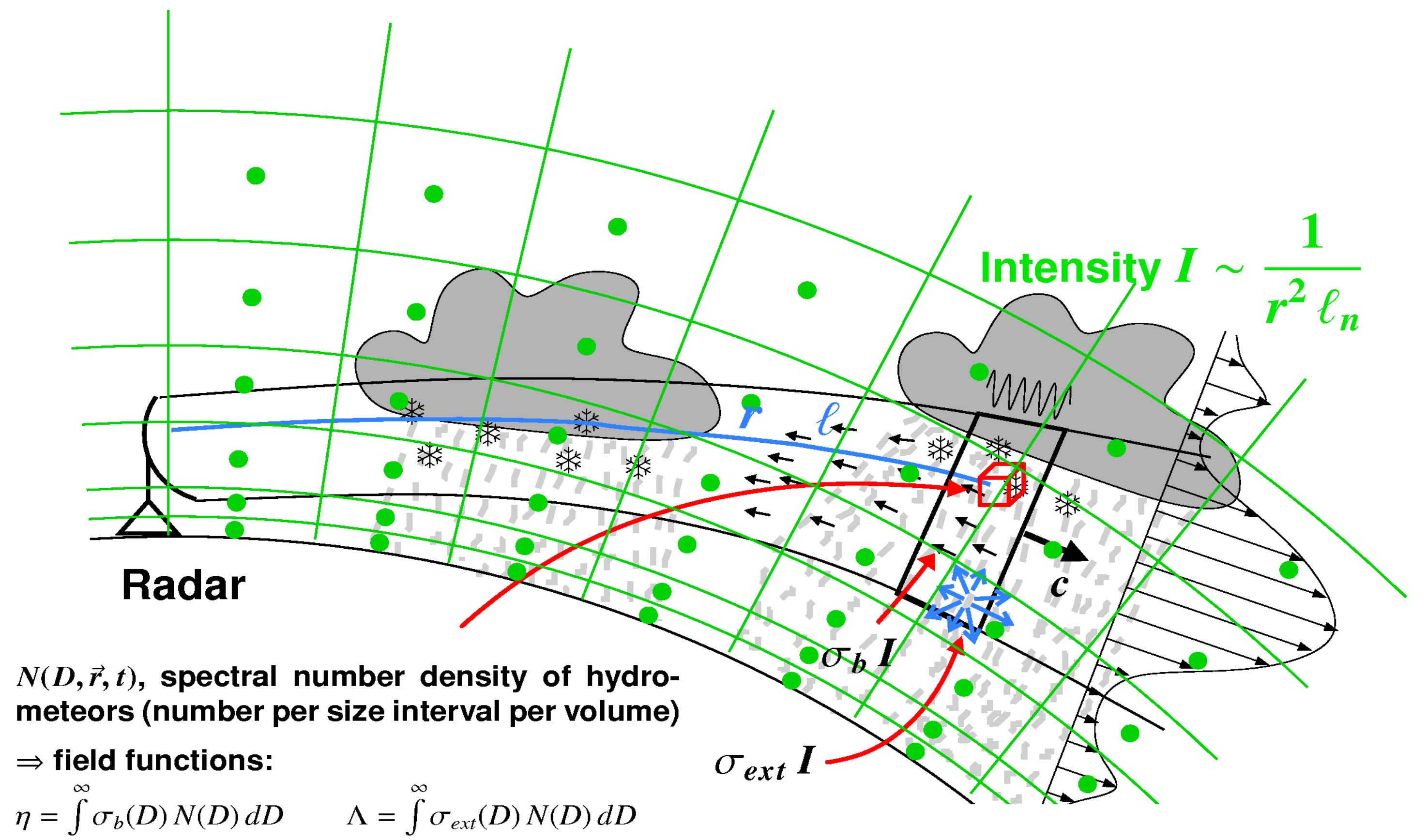
Main design criteria: efficiency, applicability on supercomputers, parallel and vectorizable code.

RADAR FORWARD OPERATOR AND NWP MODEL

Basic purpose of forward operator: simulate the measurement process of radar observables like radial wind v_r or equiv. reflect. factor Z_e within the „virtual reality“ of an NWP model.

Main ingredients (as depicted to the right):

- Green: model grid boxes = native grid for the modeled hydrometeor variables, u, v, w, T, p, e.
- Beam propag. depends on refractive index of air (function of T, p, e)
- Effective beam weighting function / pulse volume
- Backscattering / extinction: field functions η, Λ
- Compute η, Λ and v_r (from u, v, w, ...) on model grid **(Mie-scattering or Rayleigh)**, average according to radar forward operator equations below.

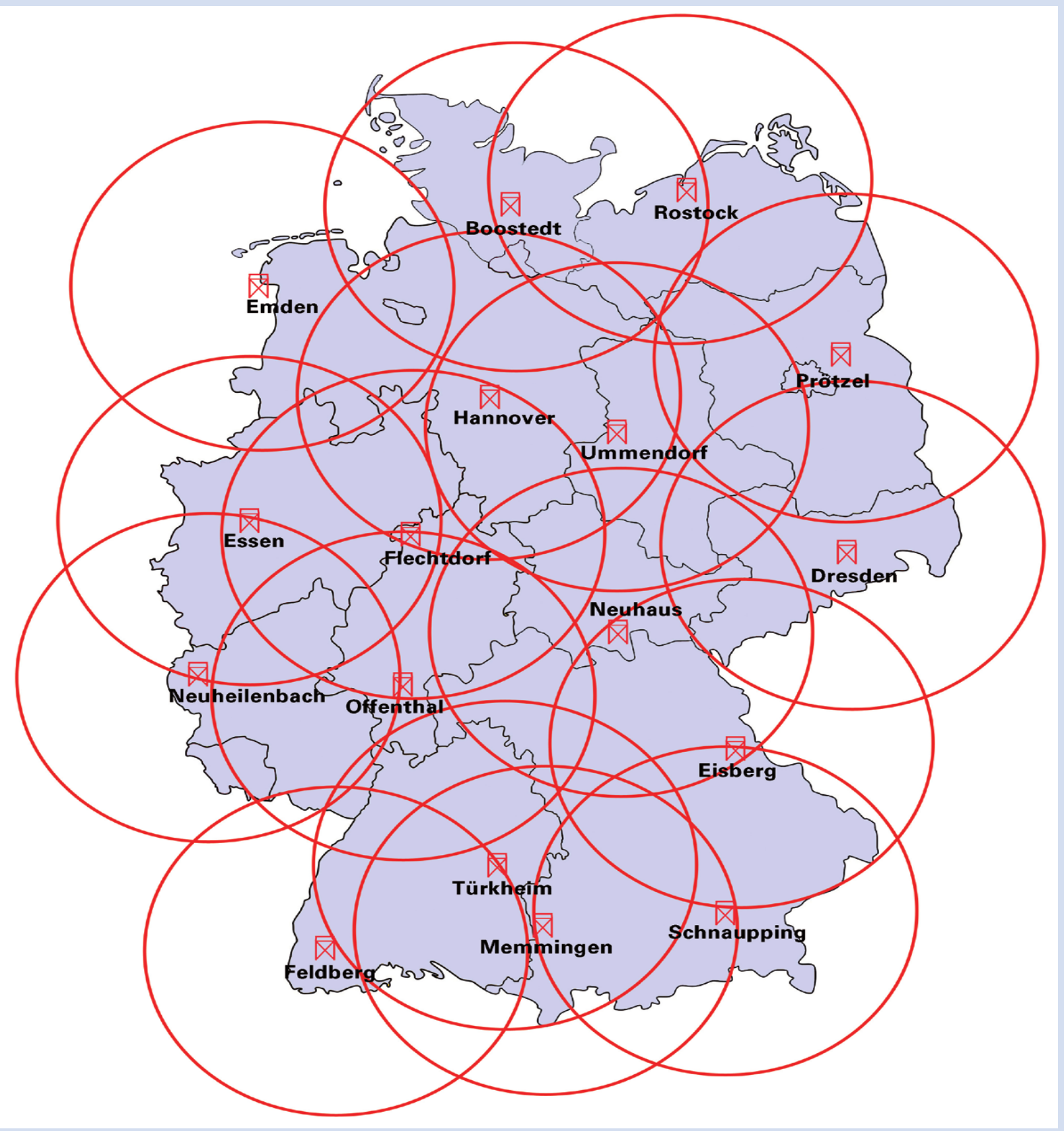


$N(D,\vec{r},t)$, spectral number density of hydrometeors (number per size interval per volume)

⇒ field functions:

$$\eta = \int_0^\infty \sigma_b(D)\,N(D)\,dD \qquad \Lambda = \int_0^\infty \sigma_{ext}(D)\,N(D)\,dD$$

$$\ell_n = \exp\left(\int_0^r \Lambda(r')\,dr'\right)$$



The new German radar network. 17 C-band dual polarization Dop-pler radars, evenly distributed.

- Complete coverage
- Volume scans every 5 min.

BASIC EQUATIONS FOR Z_e AND V_r (POLARISATION PARAMETERS OMITTED)

Radar operator for effective reflectivity factor Z_e in ”beam system”, single beam:

$$Z_e^{(R)}(r_0) = \frac{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{-\pi}^{\pi}\int\limits_{-\pi/2}^{\pi/2} Z_e(r,\phi,\theta)\,\overbrace{\exp\left(-2\int\limits_0^r \Lambda(r',\phi,\theta)\,dr'\right)}^{\ell_n^{-2}(r,\phi,\theta)}\,\frac{f^4(\phi,\theta)}{r^2}\cos\theta\,d\theta\,d\phi\,dr}{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{-\pi}^{\pi}\int\limits_{-\pi/2}^{\pi/2}\frac{f^4(\phi,\theta)}{r^2}\cos\theta\,d\theta\,d\phi\,dr}$$

with ℓ_n^{-2} = path integrated attenuation by precip from the radar to location (r,ϕ,θ)

Effective reflectivity factor:

$$Z_e(r,\phi,\theta) = \eta(r,\phi,\theta)\,\frac{\lambda^4}{\pi^5\left|K_{w,0}\right|^2}$$

Reflectivity weighted average fall speed of hydrometeors:

$$\overline{v}_T = \frac{\int\limits_0^\infty \sigma_b(D)\,N(D)\,v_T(D)\,dD}{\eta}$$

Radar operator for radial velocity in ”beam system”, single beam:

$$v_r^{(R)}(r_0) = \frac{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{-\pi}^{\pi}\int\limits_{-\pi/2}^{\pi/2}(\vec{v}\cdot\vec{e}_r)\,\frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr}{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{-\pi}^{\pi}\int\limits_{-\pi/2}^{\pi/2}\frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr} - \frac{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{-\pi}^{\pi}\int\limits_{-\pi/2}^{\pi/2}(\vec{e}_3\cdot\vec{e}_r)\,\overline{v}_T\,\frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr}{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{-\pi}^{\pi}\int\limits_{-\pi/2}^{\pi/2}\frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr}$$

Actually implemented: Radar operator for Z_e in ”radar system” taking into account azimutal averaging:

$$\langle Z_e^{(R)}\rangle(r_0,\alpha_*,\epsilon_0) = \frac{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{\alpha_*-\pi}^{\alpha_*+\pi}\int\limits_{\epsilon_0-\pi/2}^{\epsilon_0+\pi/2} Z_e(r,\alpha,\epsilon)\,\exp\left(-2\int\limits_0^r \Lambda(r',\alpha,\epsilon)\,dr'\right)\frac{f_e^4(\alpha,\epsilon)}{r^2}\cos\epsilon\,d\epsilon\,d\alpha\,dr}{\int\limits_{r_0-c\tau/4}^{r_0+c\tau/4}\int\limits_{\alpha_*-\pi}^{\alpha_*+\pi}\int\limits_{\epsilon_0-\pi/2}^{\epsilon_0+\pi/2}\frac{f_e^4(\alpha,\epsilon)}{r^2}\cos\epsilon\,d\epsilon\,d\alpha\,dr}$$

with the approximate effective beam weighting function of an azimutally scanning radar (Blahak, 2008):

$$f_e^4(\alpha,\epsilon) = \exp\left\{-8\,\ln 2\left(\left(\frac{(\alpha-\alpha_*)\,\cos\epsilon}{\alpha_{3,eff,0}+(\cos\epsilon_0-1)\,\Delta\alpha\,(1-\exp(-1.5\,\Delta\alpha/\theta_3))}\right)^2+\left(\frac{\epsilon-\epsilon_0}{\theta_3}\right)^2\right)\right\}$$

Neglections: „matched-filter“ range weighting; radar miscalibration; wet radome attenuation; gaseous attenuation; aliasing

Possible (modular) simplifications: disregard radial / horizontal / vertical smoothing; disregard reflectivity weighting / hydrometeor fallspeed for v_r ...

APPLICATIONS OF THE OPERATOR

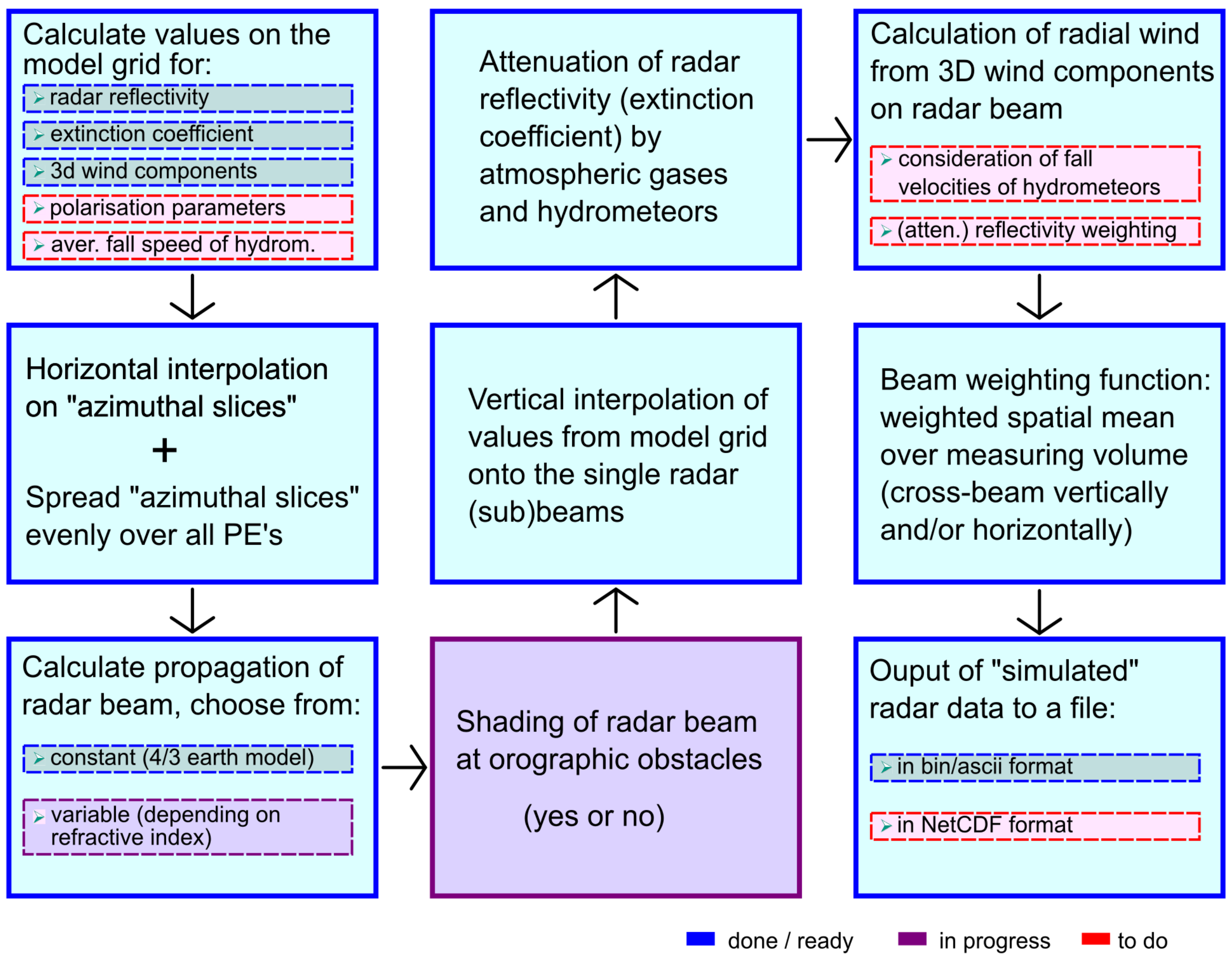
Data Assimilation:

- 17 C-Band dual polarisation Doppler radars over Germany, but full 3D information not used at the moment for assimilation into the operational COSMO NWP model.
- Already pre-operational: Ensemble-system, dx=2.8 km, 40 members
- Planned: Assimilate radial wind and reflectivity by Localized Ensemble Transform Kalman Filter approach (LETKF), based on the above ensemble, by means of the radar forward operator.

Model cloud microphysics verification:

- Comparison of (model physics consistent) simulated data with measured data (of particular interest: statistics of the vertical profile)

FLOW CHART AND CURRENT STATUS



Calculate values on the model grid for:
- radar reflectivity
- extinction coefficient
- 3d wind components
- polarisation parameters
- aver. fall speed of hydrom.

Horizontal interpolation on "azimuthal slices"
+
Spread "azimuthal slices" evenly over all PE's

Calculate propagation of radar beam, choose from:
- constant (4/3 earth model)
- variable (depending on refractive index)

Shading of radar beam at orographic obstacles

(yes or no)

Vertical interpolation of values from model grid onto the single radar (sub)beams

Attenuation of radar reflectivity (extinction coefficient) by atmospheric gases and hydrometeors

Calculation of radial wind from 3D wind components on radar beam
- consideration of fall velocities of hydrometeors
- (atten.) reflectivity weighting

Beam weighting function: weighted spatial mean over measuring volume (cross-beam vertically and/or horizontally)

Ouput of "simulated" radar data to a file:
- in bin/ascii format
- in NetCDF format

🟦 done / ready 🟪 in progress 🟥 to do

Literature: Blahak, 2008: An approximation of the effective beam weighting function for scanning meteorological radars, JAOTECH
Blahak, 2007: RADAR_MIE_LM and RADAR_MIELIB - calculation of radar reflectivity from model output, Internal Report
Caumont et al. 2008: What should be considered when simulating Doppler velocities measured by ground-based weather radars?, JAM

Department FE 1 Meteorological Analysis and Modelling