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 \( \eta, \Lambda \)
- Compute \( \eta, \Lambda \) and \( v_r \) (from \( u, v, w, ... \)) on model grid (Mie-scattering or Rayleigh), average according to radar forward operator equations below.

BASIC EQUATIONS FOR \( Z_e \) AND \( V_r \) (POLARISATION PARAMETERS OMITTED)

Rad. operator for effective reflectivity factor \( Z_e \) in „beam system“: single beam:

\[
Z_e = \int \frac{\eta \Lambda}{\sqrt{2 \pi \rho}} \frac{\cos \theta}{r^2} \exp \left( -\frac{\rho^2}{2 \sigma^2} \right) \, d\rho
data.
\]

with \( \rho \) = path integ. attenuation by prec. from the radar to location \( r \) = x, y, z.

Rad. operator for radial velocity in „beam system“: single beam:

\[
v_r = \int \frac{\eta \Lambda}{\sqrt{2 \pi \rho}} \frac{\cos \theta}{r^2} \exp \left( -\frac{\rho^2}{2 \sigma^2} \right) \, d\rho \quad \text{data}.
\]

Actually implemented: Rad. operator for \( Z_e \) in „radar system“ taking into account azimuthal averaging:

\[
\int \frac{\eta \Lambda}{\sqrt{2 \pi \rho}} \frac{\cos \theta}{r^2} \exp \left( -\frac{\rho^2}{2 \sigma^2} \right) \, d\rho \quad \text{data}.
\]

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:
- radial reflectivity
- extinction coefficient
- 3D wind components
- polarization parameters
- over-all fallspeed of hydrometers

Horizontal interpolation on “azimuthal slices”
- Spread “azimuthal slices” evenly over all PE’s

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

Shading of radar beam at orographic obstacles (yes or no)

Output of “simulated” radar data to a file: metabolic total
- NADIS format
- KITrad format
- in format

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

Data Assimilation:
- Attenuation of radar reflectivity (extinction coefficient) by atmospheric gases and hydrometers
- Calculation of radial wind from 3D wind components on radar beam
- Consideration of fall velocities of hydrometers
- Radar reflectivity weighting

Li: 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