News about the COSMO Radar Forward Operator

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Bundesministerium für Verkehr, Bau und Stadtentwicklung

Karlsruhe Institute of Technology

Ulrich Blahak[1], Yuefei Zeng[2], Dorit Epperlein[2]

[1]German Weather Service DWD, Offenbach, Germany

[2]Karlsruhe Institute of Technology (KIT), Germany

INTRODUCTION

A new radar forward operator for simulating terrestrial weather radar measurements (reflectivity Z_e, radial wind v_r) from NWP model output has been developed within an Extramural Research project. It is suitable for a broad range of applications like, e.g., *radar data assimilation in the framework of Ensemble Kalman Filter systems* (such as the KENDA system) or *verification of cloud microphysical parameterizations*.

The operator comprises all relevant physical aspects of radar cloud measurements in a quite accurate way, but at the same time providing the possibility for simplifications in a modular fashion to gain efficiency at the expense of accuracy.

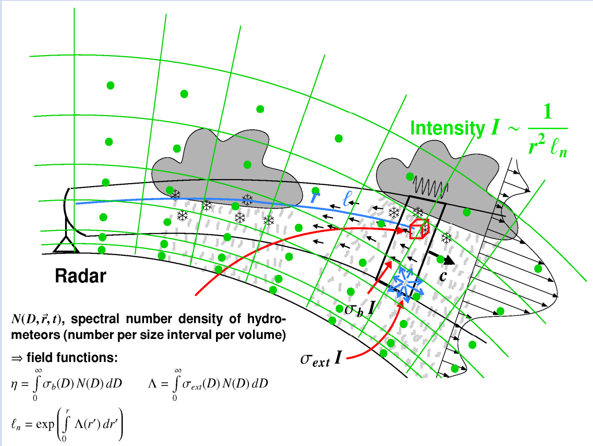
Main design criteria: efficiency, applicability on supercomputers, parallel and vectorizable code.

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 propagation, 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 model variables on model grid **(Mie-scattering or Rayleigh)**, then interpolate to (sub-)beams of the „radar" grid and apply radar forward operator equations below.



BASIC EQUATIONS FOR Z_e AND V_r (POLARISATION PARAMETERS OMITTED)

Radar operator for equivalent reflectivity factor Z_e in "beam system", single beam:

$$Z_e^{(R)}(r_0) = \frac{\int_{r_0-c\tau/4}^{r_0+c\tau/4}\int_{-\pi}^{\pi}\int_{-\pi/2}^{\pi/2} Z_e(r,\phi,\theta)\,\overbrace{\exp\left(-2\int_0^r \Lambda(r',\phi,\theta)\,dr'\right)}^{\ell_n^{-2}(r,\phi,\theta)}\,\frac{f^4(\phi,\theta)}{r^2}\cos\theta\,d\theta\,d\phi\,dr}{\int_{r_0-c\tau/4}^{r_0+c\tau/4}\int_{-\pi}^{\pi}\int_{-\pi/2}^{\pi/2} \frac{f^4(\phi,\theta)}{r^2}\cos\theta\,d\theta\,d\phi\,dr}$$

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

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

$$v_r^{(R)}(r_0) = \frac{\int_{r_0-c\tau/4}^{r_0+c\tau/4}\int_{-\pi}^{\pi}\int_{-\pi/2}^{\pi/2} (\vec v\cdot\vec e_r)\,\frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr}{\int_{r_0-c\tau/4}^{r_0+c\tau/4}\int_{-\pi}^{\pi}\int_{-\pi/2}^{\pi/2} \frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr} - \frac{\int_{r_0-c\tau/4}^{r_0+c\tau/4}\int_{-\pi}^{\pi}\int_{-\pi/2}^{\pi/2} (\vec e_3\cdot\vec e_r)\,\bar v_T\,\frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr}{\int_{r_0-c\tau/4}^{r_0+c\tau/4}\int_{-\pi}^{\pi}\int_{-\pi/2}^{\pi/2} \frac{\eta}{\ell_n^2}\,\frac{f^4}{r^2}\cos\theta\,d\theta\,d\phi\,dr}$$

Above, Z_e and the reflectivity weighted hydrometeor fallspeed $\bar v_T$ are defined as

$$Z_e(r,\phi,\theta) = \eta(r,\phi,\theta)\,\frac{\lambda^4}{\pi^5\,|K_{w,0}|^2} \qquad \bar v_T = \frac{1}{\eta}\int_0^\infty \sigma_b(D)\,N(D)\,v_T(D)\,dD$$

Actually implemented: Radar operator for Z_e in "radar system", assuming azimutal averaging of successive pulses, disregarding range weighting:

$$\langle Z_e^{(R)}\rangle(r_0,\alpha_*,\epsilon_0) = \frac{\int_{\alpha_*-\pi}^{\alpha_*+\pi}\int_{\epsilon_0-\pi/2}^{\epsilon_0+\pi/2} Z_e(r_0,\alpha,\epsilon)\,\exp\left(-2\int_0^{r_0}\Lambda(r',\alpha,\epsilon)\,dr'\right)\frac{f_e^4(\alpha,\epsilon)}{r_0^2}\cos\epsilon\,d\epsilon\,d\alpha}{\int_{\alpha_*-\pi}^{\alpha_*+\pi}\int_{\epsilon_0-\pi/2}^{\epsilon_0+\pi/2}\frac{f_e^4(\alpha,\epsilon)}{r_0^2}\cos\epsilon\,d\epsilon\,d\alpha}$$

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

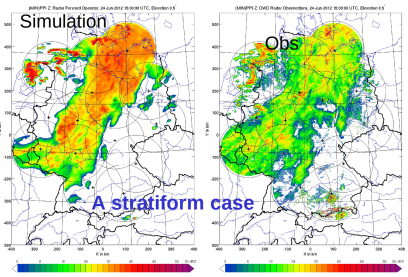
$$f_e^4(\alpha,\epsilon) = \exp\left\{-8\ln 2\left(\left(\frac{(\alpha-\alpha_*)\cos\epsilon}{\alpha_{3,eff,0}+(\cos\epsilon_0-1)\,\Delta\alpha\,(1-\exp(-1.5\,\Delta\alpha/\theta_3))}\right)^2+\left(\frac{\epsilon-\epsilon_0}{\theta_3}\right)^2\right)\right\}$$

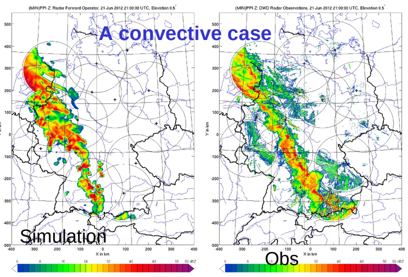
Neglections: range weighting; radar miscalibration; wet radome attenuation; gaseous attenuation; aliasing

Possible (modular) simplifications: disregard horizontal / vertical smoothing; disregard reflectivity weighting / hydrometeor fallspeed for v_r; Rayleigh instead of Mie; disregard hydrometeor attenuation; offline or online beam propagation (Zeng et al., 2013)

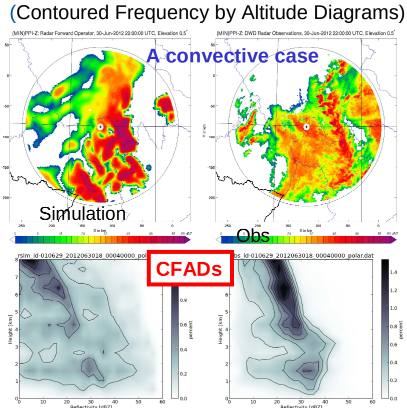
MODEL VERIFICATION

Examples of case studies: COSMO-DE with simulations and observations of 16 German radars every 15 min, shown as PPI-overlays:





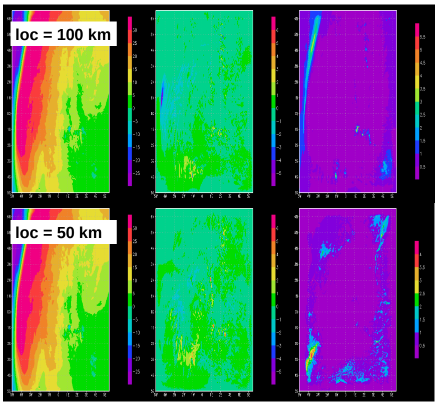
Good way to compare Sim and OBS: CFADs (Contoured Frequency by Altitude Diagrams)

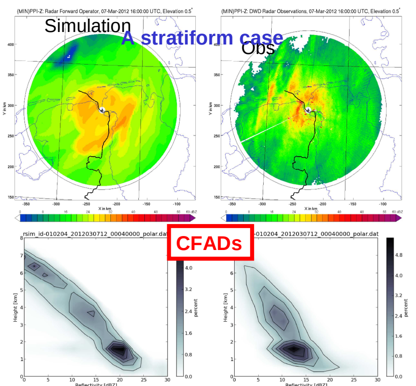


FIRST ASSIMILATION EXPERIMENTS

- 17 C-Band dual polarisation Doppler radars
- COSMO-DE Ensemble of 40 Members, driven by GME global test ensemble
- First experiment for mainly technical tests: 31.5.2011, 18 UTC + 03 h
- Assimilate radial wind every hour by LETKF using the KENDA Software
- **Results for v-component** after third assimilation cycle for different localization radii:

fg (mean) | assim. incr. (mean) | fg (spread)





Literature: Blahak, 2008: An approximation to 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

Zeng et al., 2013: Radar beam tracing methods based on atmospheric refractive index, JAOTECH, submitted