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A polarimetric radar forward operator

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Abstract. Quantitative forecast of precipitation is still a difficult task and several national and international programmes have the aim to solve the associated problems. The verification of precipitation forecasts is complicated, and only a weather radar is able to verify the forecasts of the four-dimensional distribution and structure of hydrometeors. In order to compare numerical simulations with radar observations a radar forward operator will be used to transform the modeled fields into parameters which are measured by a weather radar. This also requires to consider propagation and attenuation effects. A radar simulator (RSM) for the Lokal Modell (LM) of the Deutscher Wetterdienst (DWD) was developed by G. Haase at the University of Bonn. For the usage of RSM with the polarimetric diversity Doppler radar POLDIRAD at DLR Oberpfaffenhofen a polarimetric radar forward operator (SynPolRad) is under development. Polarimetric signatures of different hydrometeors are simulated using a T-Matrix procedure. Numerical simulations of convection with the high resolution version of the LM are used as input for SynPolRad. First results of SynPolRad are compared to POLDIRAD observations for a case study in July 2002.

1 Introduction

Forecasting precipitation is still one of the major problems in numerical weather prediction (NWP). This is due to the complex distribution of water in space and time in the atmosphere in all its three phases. Another major problem is the verification of the predicted variables. The operational verification of quantitative precipitation forecasts from mesoscale models is mostly based on comparisons of the model output averaged over a day and measurements from rain gauge networks that have varying station density. Because of the sparse temporal and local information of gauge data, this information may not be representative of model grid box values. Evaluating precipitation forecasts by radar is also difficult because of the mismatch between the spatial and temporal scales of models and observations and the assumptions that have to be made to change reflectivity into rain rates at the ground (Z-R relationship).

Radar systems and especially polarimetric radars provide multi-dimensional information which are not directly connected to the model variables. As radar systems do not directly measure atmospheric constituents represented by model variables two approaches coexist for the comparison of model and remote sensing data namely the model-to-observation and the observation-to-model approach (Chevallier and Bauer, 2003). Both possibilities are influenced by different spatial and temporal sampling as well as model resolutions. In this work we will focus on the model-to-observation approach.

The model-to-observation method uses a so called forward operator to transform the model output into the variables of the remote sensing instrument and perform comparisons in terms of observables. This approach avoids uncertainties related to the retrieval process because the model can be described much more accurately than the inversion process, which always involves certain assumptions. Another important advantage is the independence from training data sets needed for the retrieval process which are known to lack representativeness. Furthermore this method allows the full exploitation of the information content of the remote sensors and is an important step towards future data assimilation methods.

Radar simulation has been used in several studies to address problems of radar meteorology. Chandrasekar and Bringi (1987) studied the influence of varying rain drop-size distributions (DSD) on the relation between radar reflectivity and the surface rain rate. In later studies by Chandrasekar the work was extended to multi-parameter radar, particularly the error structure of differential reflectivity, X-band attenuation, and specific differential phase. To simulate radar reflectivities from forecasts of the mesoscale Lokal Modell (LM) of

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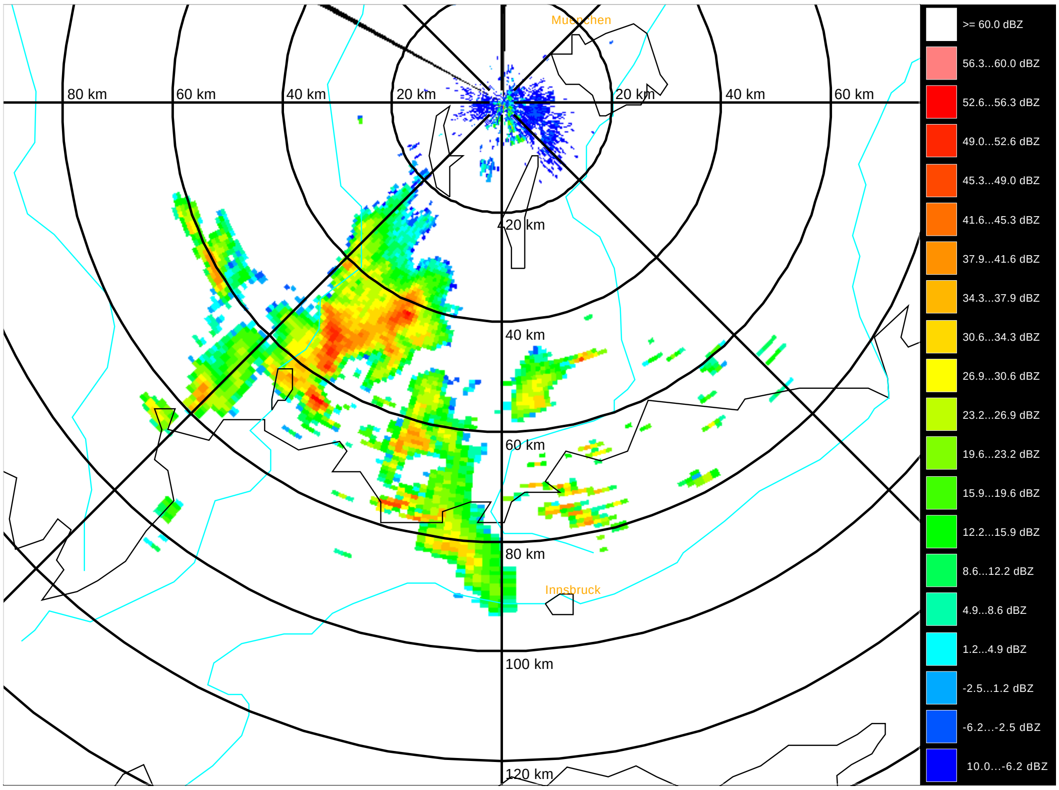

Fig. 1. POLDIRAD PPI scan of reflectivity [dBZ] at an elevation angle of 1° on 9 July 2002 at 15:35 UTC showing convective cells south west and south of the instrument location at Oberpfaffenhofen.

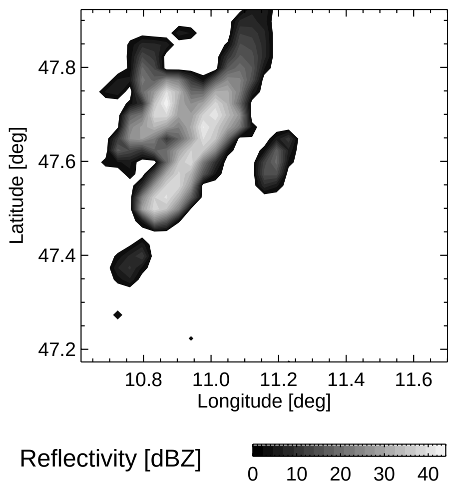

Fig. 2. The synthetic reflectivity [dBZ] CAPPI on 9 July 2002 at 16:00 UTC (fc +10 h) at model level 20 (approximately the 600 hPa level).

DWD, the RSM model was developed (Haase and Crewell, 2000), which currently is employed for operational validation at DWD and the Finnish Weather Service (FMI).

Since the shape and orientation of hydrometeors leads to polarimetric signatures, measurements by POLDIRAD provide information on the distribution of the different type of hydrometeors, including the degree of melting of ice particles, or identification of the size category of particles (Höller et al., 1994; Vivekanandan et al., 1999). For a better interpretation of polarimetric radar observations detailed scattering simulations of melting ice particles were performed by Dölling (1997) using the T-matrix approach. The calculations showed the sensitivity of the simulated polarimetric radar parameters on the mixing ratio and the falling behaviour of the hydrometeors.

2 Methods and Model

The polarimetric radar forward operator SynPolRad combines two already existing codes – the RSM and the T-Matrix code. In a first step SynPolRad calculates the electromagnetic interactions of the radar beam with the hydrometeors at the model grid points using the T-matrix code. In a second step the propagation and attenuation of the radar beam in the model domain is included following the RSM.

SynPolRad is developed using LM output, but can be used with other mesoscale models. The non-hydrostatic LM (Doms and Schättler, 1999) has been the operational short range weather forecasting tool at DWD since December 1999. The LM has a generalized terrain-following vertical coordinate, which divides the atmosphere in 35 layers from the bottom up to 20 hPa. The prognostic variables are

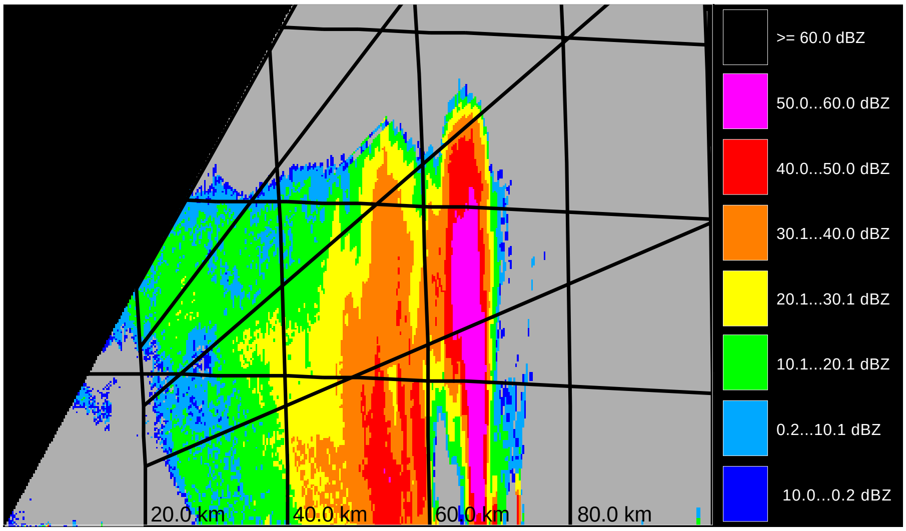

Fig. 3. POLDIRAD RHI scan of reflectivity [dBZ] on 9 July 2002 at 15:35 UTC.

the wind vector, temperature, pressure perturbation, specific humidity, cloud liquid water, and precipitation including the cloud ice. The model includes a grid-scale cloud and precipitation scheme as well as a parameterization of moist convection (Tiedtke, 1989), which is switched off at 2.8 km resolution. To parameterize the conversion terms, cloud water is treated as a bulk phase without spectral distribution, whereas size distribution functions are specified for rain and snow. In the present study hourly output fields of the operational LM configuration (mesh size of 7 km encompassing all of Central Europe), driven with fields of DWD's global model (GME), serve as input for the high resolution experiment (mesh size of 2.8 km, setup of the LM-K test suite version 3.8).

The T-Matrix-code calculates the effective reflectivity factor (Z), the differential reflectivity (ZDR), the differential attenuation, the specific propagation differential phase shift (KDP), and the linear depolarization ratio (LDR). It distinguishes cloud droplets, rain drops, pristine ice columns, pristine ice plates, snow flakes, aggregates, graupel, conical hail, and spheroidal hail. Polarimetric signatures depend on the size, shape, orientation, dielectric constant, and falling behaviour of the different hydrometeors. The present T-Matrix code needs explicitly the drop size distribution determining the shape and size of the hydrometeors. The canting angle distribution, the density, and the dielectric constant are parameterized. In order to apply the T-Matrix code on the LM output the particle size distributions for snow and rain have to be deduced using the Marshall Palmer distribution for rain (Marshall and Palmer, 1948) and the Gunn and Marshall distribution for snow (Gunn and Marshall, 1957) where the minimum and maximum effective radius are set to fixed values of 0.01 and 8 mm for rain and 0.01 and 10 mm for snow, respectively. At the moment snow is calculated using the pristine ice plate option of the T-Matrix code following the advice of DWD who also treats snow as ice plates. Further sensitivity studies will be performed on this issue in the future. The propagation of the radar beam is not yet included in SynPolRad at the moment, but will be included in the near future.

3 Results

During the VERTIKATOR (Lugauer and Coauthors, 2003) field campaign, deep convection was observed in the Alpine foreland on 9 July 2002. At 14:00 UTC first convective cells evolved in the western Alpine region moving under intensification northeastwards. A PPI scan measured by POLDIRAD shows the convective activity north of the Alps at 15:35 UTC (Fig. 1).

In a first attempt to calculate synthetic polarimetric radar images, high resolution LM forecasts (initialized at 06 UTC on 9 July 2002) were used. At 16 UTC, convection occures in the Alpine foreland with reflectivities of more than 40 dBZ (Fig. 2). Shown is a CAPPI at model level 20 which corresponds approximately to the 600 hPa level. The reason for chosing this level is that this event happened to produce only a small amount of precipitation at the ground and therefore the PPI scans in higher levels shows more features.
The vertical cross section at 10.85° E depicts a convective cells with rain rates up to 12 mm/h in 700 hPa (Fig. 4). Because of strong updraughts exceeding 3.8 m/s rain is present well above the 0° isotherme. The small area aloft (approximately 500 hPa) consists of snow with relatively weak precipitation fluxes not reaching the 0^o isotherme.

Figure 5 shows the synthetic RHI scan by SynPolRad which corresponds well with the precipitation fluxes in Fig. 4, especially under consideration of the 0.05 mm/h contour of rain. Comparing the RHI of POLDIRAD (Fig. 3) and the synthetic RHI (Fig. 5) it can be seen that the radar scan shows more structure with a stratiform region zone on the left featuring relatively weak reflectivities of 10 dBZ and two cores of strong precipitation related to graupel and hail

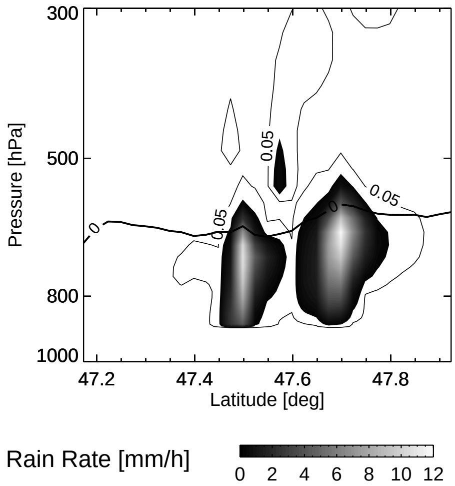

Fig. 4. The modeled snow and rain rate [mm/h] superimposed with the 0° isotherme on 9 July 2002. The 0.05 mm/h isoline of the precipitation fluxes is given as a contour line.

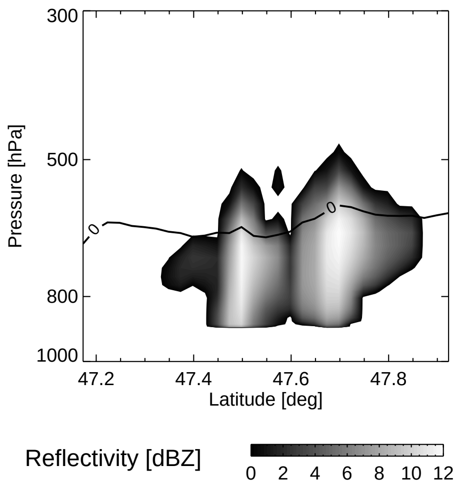

Fig. 5. The synthetic reflectivity RHI scan [dBZ] on 9 July 2002.

attaining maximal reflectivities of up to 60 dBZ on the right side of Fig. 3. In comparison, the maximum reflectivity of the synthetic reflectivity reaches smaller values of 38 dBz.

Figure 6 shows the hydrometeor classification after Höller et al. (1994) applied on the synthetic polarimetric variables. Light grey regions beneath the 0^o isotherme are related to small raindrops and the dark grey regions to snow and dry small graupel, respectively. Above the 0° isotherme the dark grey regions correspond to large graupel and the light grey regions to large hail. The Höller scheme uses the LDR, ZDR and temperature in order to determine the hydrometeor type. As shown in Fig. 4 most of the precipitation fields is related to rain and only a small fraction at about 500 hPa consists of snow. In the hydrometeor classification scheme, temperature is used to distinguish between the snow and ice phase. The failure of the hydrometeor classification scheme is due to missing information on the ice phase concerning the hydrometeor type and its falling behaviour in LM.

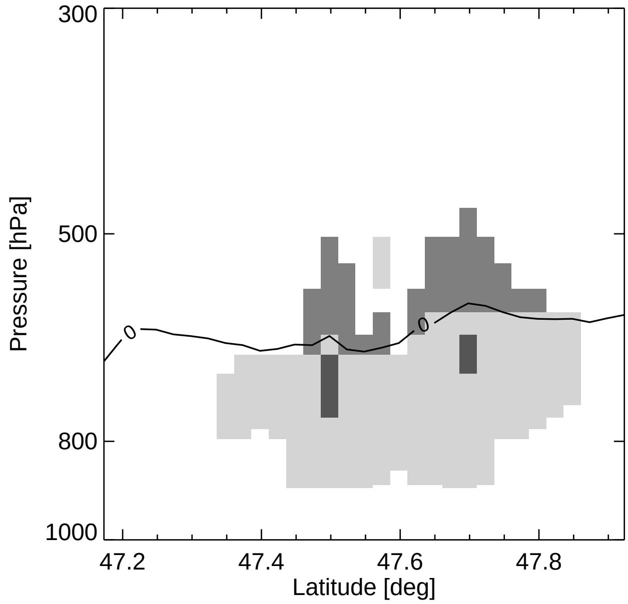

Fig. 6. The hydrometeor classification after Höller et al. (1994). Light grey regions beneath the 0° isotherme are related to small raindrops and the dark grey regions to snow and dry small graupel, respectively. Above the 0° isotherme the dark grey regions correspond to large graupel and the light grey regions to large hail.

4 Discussion and outlook

First results of SynPolRad for a case-study observed on 9 July 2002 are compared to POLDIRAD observation. It was shown that SynPolRad is able to simulate the polarimetric features of the hydrometeors in the LM model domain although further research is necessary with regards to the ice phase. The ice hydrometeors are treated in LM as ice plates regardless of the snow rate or other meteorological parameters. For the hydrometeor classification the LDR and ZDR are the important variables besides temperature. The ZDR depends mostly on the shape of the hydrometeor whereas the LDR is dominated by the falling behaviour and the tumbling of the hydrometeor. In order to determine the ZDR and LDR correctly and to create realistic synthetic polarimetric radar images further assumptions have to be done to differentiate the LM output in snow, hail, and graupel in dependence of other meteorological parameters as for instance the temperature or updraught velocities. Furthermore the propagation and attenuation of the radar beam will be included in SynPolRad although the attenuation in rain is of minor importance in the C-Band range. By comparing the model results for different case studies with observations of POLDIRAD it will be possible to identify weaknesses in the cloud parameterization scheme and the model initialization in the future.

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