SYNERGETIC USE OF POLARIMETRIC DOPPLER RADARS AT KA- AND C- BAND FOR RETRIEVAL OF WATER DROP AND ICE PARTICLE SIZE DISTRIBUTIONS

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1. ABSTRACT

A retrieval method to derive size distributions from synergetic use of vertical pointed Ka-band and polarimetric C-band radar is introduced. The method is based on using the full height-resolved Doppler spectra instead of mean values of reflectivity and radial velocity inside the radar bin volume. Within a Mie based radar forward operator, Doppler spectra were simulated from assumed size distributions, taking into account the attenuation at Ka-band. In an iterative way, the parameters of distributions were varied until differences between simulated and observed Doppler spectra could minimized. First results were achieved from a case study of 23 July 2007 during the Convection and Orographically Induced Precipitation Study (COPS).

1. INTRODUCTION

The verification of radar retrieval results like hydrometeor type, quantity, and dynamics of clouds is an essential requirement for assimilating observation data into Numerical Weather Prediction (NWP) models. Field campaigns were executed to enrich the observational data base. One of the aims of Convection and Orographically Induced Precipitation Study (COPS) in 2007 – took place in south-west Germany and eastern France - was to improve the Quantitative Precipitation Forecast (QPF) in mountainous areas (Wulfmeyer et al., 2007). For this purpose, a huge amount of different observation instruments were concentrated in the region around Black Forest, Vogues and Rhine valley, especially at so-called supersites. The current study focus on comparison between polarimetric C-band and vertically pointed Ka-band radar, to retrieve profiles of hydrometeor content and quantity.

2. DATA

A vertical pointing Doppler research radar, MIRA-36, was operated at supersite Achern during the COPS period. From measured spectra, the radar moments: reflectivity, mean Doppler velocity and depolarization ratio (LDR) were estimated every 10 seconds with altitude resolution of 30 m. The DLR C-band radar POLDIRAD was located during the COPS period 36 km away from Achern supersite. Every 10 min a profile was taken by scanning as range height indicator (RHI).

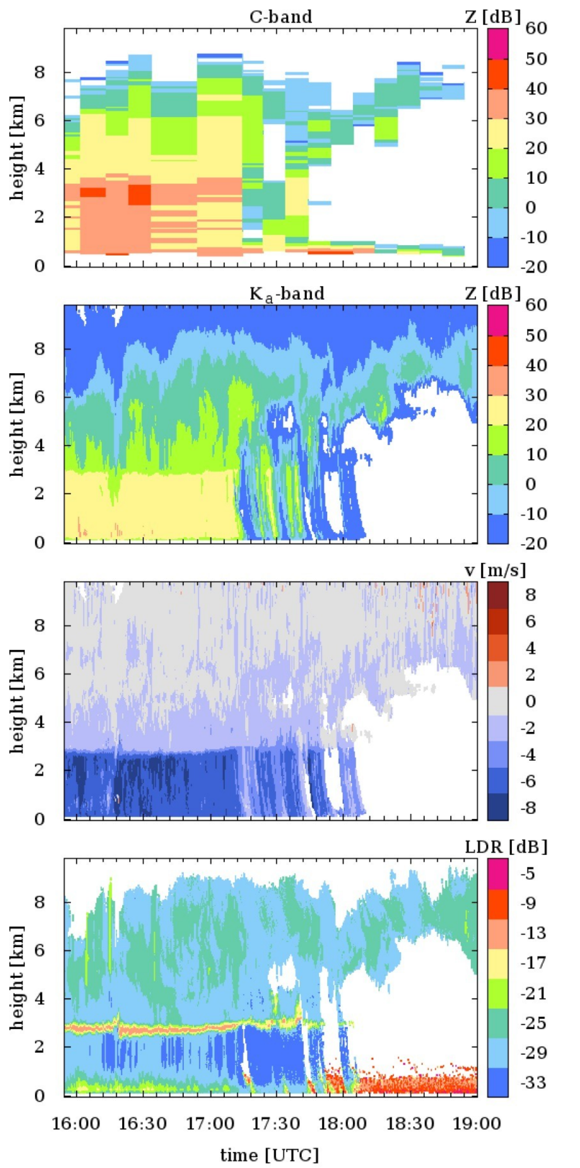

Figure 1: *Radar observations above Achern supersite at 23 July 2007 from 16 to 19 UTC. C-band reflectivity (top) taken from RHI scans every 10 min were compared with reflectivity, mean Doppler velocity and depolarization ratio (LDR) with 10 sec time resolution from vertically looking Ka-band radar.*

3. METHOD

As a first step, spatial and temporal correlated reflectivity profiles from Ka and C-band radar were compared. Generally, two different effects could be observed in the reflectivity profiles with raising altitude:

- an increasing of reflectivity differences below the melting layer in rainfall regions and
- a decreasing of reflectivity differences above the melting layer in regions dominated by small ice crystals and snow.

The first effect is caused by the rain drop attenuation which is stronger at the Ka- as at the C-band, the latter by the higher sensitivity of Ka-band for small particles.

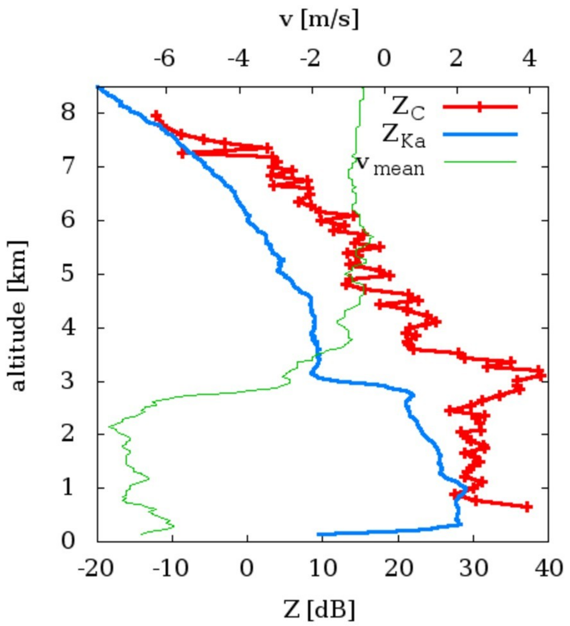

Figure 2: *Measured profile at 23 July 2007 16:38 UTC of C-band radar reflectivity from POLDIRAD with corresponding Ka-band cloud radar reflectivity and mean velocity.*

By evaluating the cloud radar Doppler spectra and comparing the profiles of reflectivity, water drop and ice particle size distributions could be quantified by executing the following steps:

1) scaling of measured cloud radar spectra by using retrieved reflectivity after Bauer (2007),

2) fitting of parameters of an exponential particle size distribution to measured spectra by using radar forward operator (Haynes et al, 2007),

3) recalculating of Ka-band reflectivity profile considering rain attenuation, and

4) simulating C-band reflectivity and comparing with measured profile.

For the rain drop size distribution (RDSD) an exponential size distribution *N(D)* with two independent parameters (N_0, D_0) is used.

$$N(D) = N_0 \; e^{-3.67 \; D/D_0}$$

4. FIRST RESULTS

4.1 Scaling of measured spectra

Cloud radar Doppler spectra are available for the co- and the cross (cx) channel. While for the co channel the reflected and transmitted waves are at the same plane, for the cx-channel the planes are rotated by 90°. The ratio between co- and cx- channel is called linear depolarization ratio (LDR) and useful for instance for estimating the melting layer height and extension.

From vertical upward looking point of view, water drops are predominantly spherical and in this case LDR has no import evidence. Therefore it was tested to taking into account co- as well as cx-channel for the scaling of measured spectra. Because of strong reflectance, for many cases the co-channel was frequently saturated and the uses of scaled cx-channel is suggested instead (Figure 3).

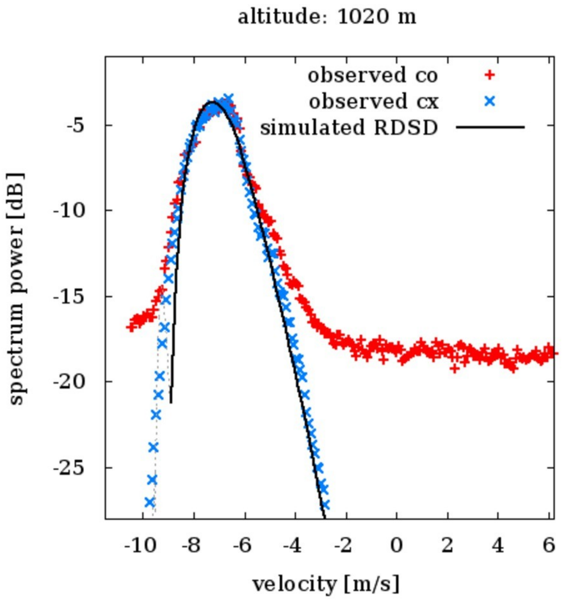

Figure 3*: Scaled Doppler spectra by using co- and cross- (cx) channel to reach the reflectivity of 29 dBZ from profile at 16:38 UTC at 1 km altitude. Because of saturation effects, noise level for co channel is higher as for cx-channel. Exponential size distribution parameters N_0, D_0 were fitted to linear scaled spectra power of co and cx-channel.*

Both channels were scaled until the reflectivity reached the same value calculated by using the radar moment procedure after Bauer (2007). The main errors are expected due to estimating of noise level.

4.2 Relationship between Doppler velocity and rain drop size

The drop sizes required for the simulation could be derived from measured cloud radar Doppler velocities by using relation between fall velocity *v* and drop diameter *D* after Atlas (1973).

$$v(D)[m/s] = 9.65 - 10.3\ e^{-0.6\ D[mm]}$$

Restrictions have to take into account for the reverse function *D(v),* first a maximum velocity of 9.65 m/s will be reached for increasing diameter and second the minimum velocity have to limited to -0.65 m/s to prevent negative drop sizes.

Because of water drop collapsing effects, in practice drop sizes are limited to 6-8 mm diameter, corresponding to fall velocities of 9.37 and 9.57 m/s, respectively. Higher Doppler velocities are supposed to related to additional vertical air motion and spectral broadening because of turbulence effects.

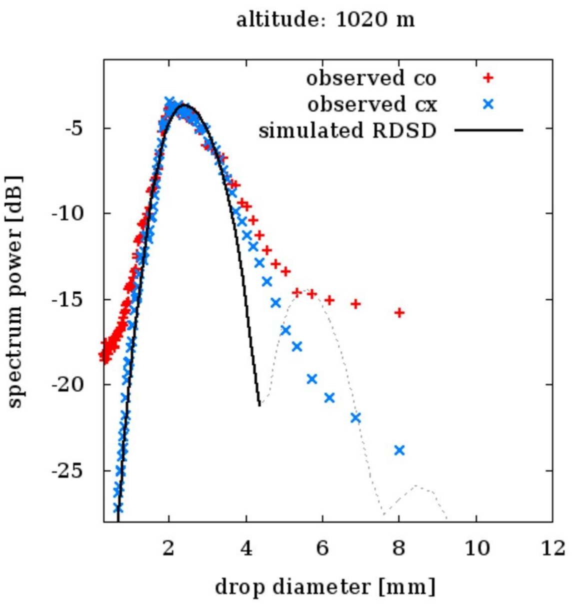

Figure 4*: Scaled measured and simulated Doppler spectra as in Figure 3 plotted with corresponding drop size diameter after Atlas (1973). The rain drop size distribution (dotted line) were limited to 4.2 mm (black line) for calculating corresponding Ka- and C-band reflectivity.*

For the current study, all drop size distributions were cut at 4.2 mm (8.8 m/s), related to the first minimum of mie backscattering (dotted line in Figure 4). An extended drop size range (up to 6 mm) with a small amount of larger drops does'nt effect the Ka-band reflectivity, but the corresponding C-band reflectivity would achieve unrealistic high values.

4.3 Fitting of size distribution parameters

A spectral bin radar forward operator was developed, based on routines from radar simulator Quick-Beam (Haynes, 2007). By using the forward operator, the spectrum power for each diameter range were calculated for an assumed drop size distribution. Further the reflectivity, attenuation and mean fall velocity were estimated from given size distribution.

For the liquid phase, the parameters of exponential size distribution (N_0, D_0) were fitted to the measured power spectra in a least square sense. To prevent the noise level effect, datasets were compared at linear instead of displayed logarithmic scale.

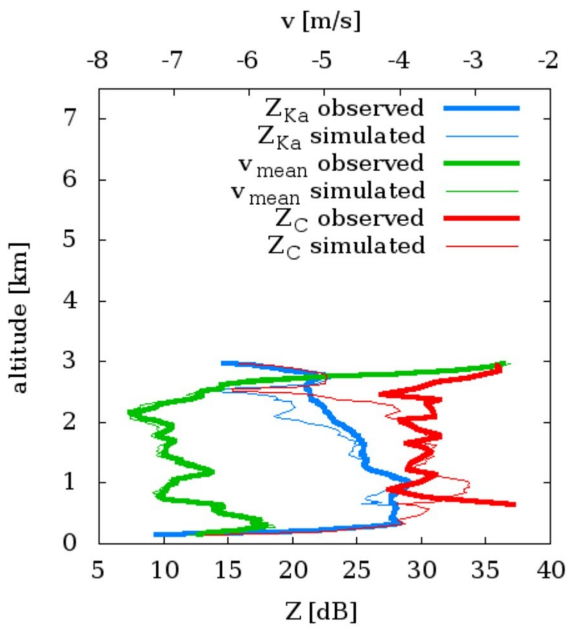

Figure 5: *Juxtaposing of measured and simulated reflectivity as well as mean fall velocity below the melting layer (3 km) by using exponential RDSD for 16:38 UTC.*

4.4 Simulated and observed reflectivity

The retrieval method was tested for a rainfall event at 23 July 2007 for the liquid water column below the melting height (< 3 km). While the simulated mean fall velocity matched well with measured values for the whole liquid phase profile, the simulated Ka-band and C-band reflectivity matched only below 1.8 km (Figure 5). In the upper part (above 1.8 km) reflectivity at both bands were underestimated by the simulation due to not considered part of Doppler spectra with velocities above 8.8 m/s (Figure 6). Further the shape of the spectrum contains multimodale peaks which is not consistent to the assumed exponential size distribution. The additional peak at -9.5 m/s could be explained by a strong downward wind (> 1 m/s) caused by embedded convection below the melting layer.

The retrieved Ka band attenuation (not shown) was used to adjust the cloud radar reflectivity profile. The attenuation reached maximum values around 0.4 dB/km and were be used for estimating the liquid water content (LWC).

A similar radar intercomparison C/Ka band study by Matrosov (2010) (there Figure 2) shows lower Ka-band reflectivity (0 to 10 dBZ) with similar C-band reflectivity (~30 dBZ) compared to our samples. The discrepancy to our study could be caused by a different size distribution in the liquid part.

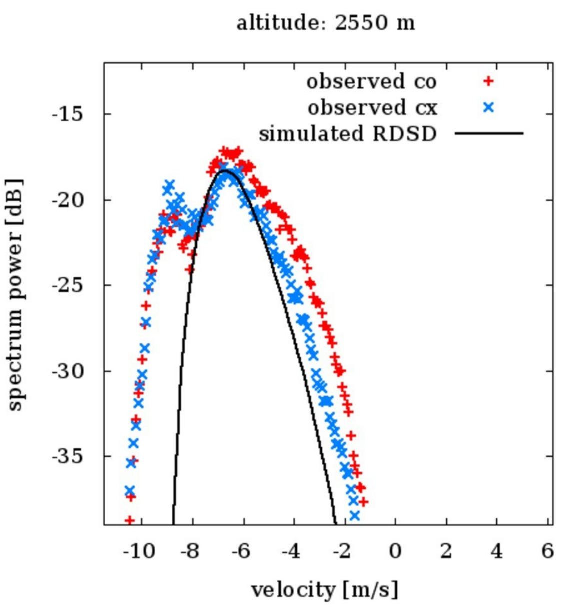

Figure 6: *Measured Doppler spectra and best fitted RDSD at 2.5 km altitude where the reflectivity is strongly underestimated by the simulation due to the limited spectrum at -8.8 m/s.*

5. SUMMARY AND OUTLOOK

Radar data from vertical pointed Ka-band and synchronized range height indicator scans (RHI) from C-band were compared during the COPS-field campaign. A new method was introduced for retrieving parameters of exponential size distribution from measured Doppler spectra. Derived Ka-band attenuation were used to adjust the profile. First results show good agreements between simulated and measured C- and Ka- band reflectivity in the lower part as well as mean fall velocity in the whole profile below the melting layer. The discrepancies were caused due to spectrum signal at Doppler velocities below -9.5 m/s which were suppressed by the evaluating procedure.

In a further step, the procedure will also tested above the melting layer in cases of ice and snow with adjusted relation between particle size and terminal velocities. Furthermore, additional data e.g. from sounding and SODAR wind profilers will be used to estimate and minimize the relevant error sources expected from vertical air motion and turbulence.

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