Cloud Profiles from C-Band Ground-Based Radar

J. Steinert and M. Chandra

Chair of Microwave Engineering and Photonics
Chemnitz University of Technology
D-09107 Chemnitz, Germany
joerg.steinert@etit.tu-chemnitz.de,madhu.chandra@etit.tu-chemnitz.de

ABSTRACT

Ground-based weather radars are designed to observe a wide area around their location. For research interests the RHI (range height indicator, changing elevation) mode is meaningful in contrast to the operationally used PPI (plane position indicator, changing azimuth) scan method. With the RHI mode the vertical profile at a chosen distance from the radar can be extracted from the complete scan. Using this approach, typical vertical profiles of key polarimetric observables (Z, ZDR and LDR) will be obtained. In this paper, the advantages and disadvantages of this method will be elucidated with reference to temporal and spatial non-uniformity inherent to the data. Examples, from both stratiform and convective clouds, will be given from archived data recorded with the C-Band radar POLDIRAD (radar site Oberpfaffenhofen (near Munich, Germany)).

1. INTRODUCTION

Since their first usage in the latter half of the last century, weather radars are a very common hardware tool to observe the precipitation and cloud behaviour. Apart from the usage of local oriented profilers, weather radars with elevation angles below 90° show a widespread area up to 100 km distance dependent on physical and local conditions.
Consisting of different particle types, the clouds are the significant targets in radar meteorology. With the vertical structure of clouds, important features to understand are the microphysical composition, height and expanse of the melting-layer and the particle motions. The estimation of this profiles is the main part of this study.
By starting with a short description of the radar hardware and the obtained parameters in section 2, the geometry of the scanned volume is introduced in section 3. The method for extracting the vertical profiles (VP) out of the radar scans is explained in section 4. Followed by examples of the profiles shown in section 5 and concluding remarks.

2. RADAR HARDWARE

POLDIRAD is a C-Band pulsed doppler weather radar, that was built in 1986. Detailed technical facts of the radar are given in [2]. The POLDIRAD operates in an alternating dual polarisation measurement mode. The determined backscattering matrix (Eqn. 1) has a time lag Δt between the measurement of the echo from the first transmitted polarisation and the echo from the second transmitted polarisation.

$$S = \begin{pmatrix} S_{vv}(t) & S_{vh}(t+\Delta t) \\ S_{hv}(t) & S_{hh}(t+\Delta t) \end{pmatrix} \tag{1}$$

The indices v and h are relating to the used polarisation state for receiving and transmitting, correspond respectively here to linear vertical and linear horizontal polarisations. The time lag Δt or also named as PRT is the repetition time of a pulse. The calculation is done by $PRT = \frac{1}{PRF}$ with PRF the pulse repetition frequency. For $PRF = 1200\,Hz$ (PRF of the analysed data) then implies $PRT = \frac{1}{1200}\,s = 0.83\,ms$. The complete measurement scheme is displayed in [2, Fig. 5].
The study was focused on the four reflectivities (Z_{vv}, Z_{hv}, Z_{vh} and Z_{hh}) in the different polarisation states with the reflectivities in the unit $[dBZ]$. Physically they are in $\left[\frac{mm^6}{m^3}\right]$ and named with ζ_{xy} but depending on their high range of values they are transformed in the logarithmic scale with $Z_{xy} = 10 \cdot log_{10}(\zeta_{xy})$. From the absolute reflectivities two other parameters can be derived. At first the differential reflectivity Z_{DR} with

$$Z_{DR} = Z_{hh} - Z_{vv} \tag{2}$$

and then the linear depolarisation ratios

$$LDR_{hv} = Z_{hv} - Z_{vv} \tag{3}$$

and

$$LDR_{vh} = Z_{vh} - Z_{hh} \tag{4}$$

wherein Z_{DR} and L_{DR} are in $[dB]$. The precalculated reflectivities are taken from the logarithmic receivers (POLDIRAD has linear receivers for time-series data, too). The dynamic range of the reflectivities is given with $80\,dB$ and the accuracy is $\pm 1\,dB$, [2]. The cross-polar isolation is $\approx 35\,dB$ and so the minimum value for LDR is $-35\,dB$ (negative because for meteorological echoes cross-polar signal is lower than co-polar value).

3. GEOMETRY OF THE SCANNED VOLUME

The parameters in this section are explained graphically in Fig. 1. For an RHI scan, the azimuth is fixed and the

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

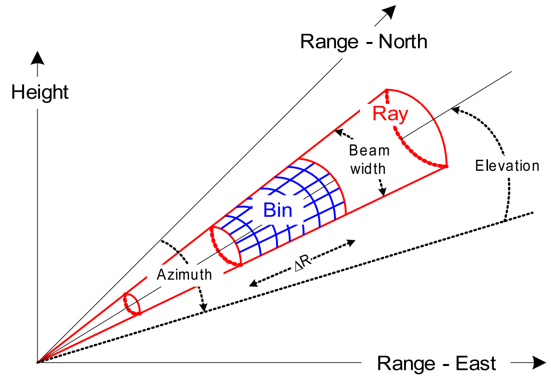

Figure 1. Representation and geometrical parameters for one ray.

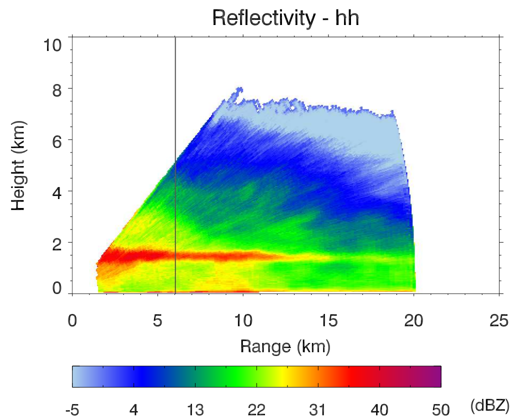

Figure 2. Z_{hh} of a stratiform event recorded on 16th November 1995 (grey line: position of VP shown in Fig. 3).

elevation is varied. The measured volume (ray, red in Fig. 1) is mathematically a cone described by the beam width of the radar antenna (POLDIRAD, 1°). This cone is separated in range in equal parts (bin, blue in Fig. 1) with the range increment $\Delta R = \frac{c \cdot \tau}{2}$, c the speed of light and τ the pulse width. With a common $\tau = 1\ \mu s$ is $\Delta R = 150 m$. The ray by ray measuring scheme has the disadvantage, that in one RHI the rays are measured consecutively in time.

4. EXTRACTING THE PROFILES

If the rays have the same azimuth (given for the RHI scan) the view on the scattering volumes (bins) can be simplified. Physically the rays are three-dimensional structures but according to the rotation symmetric structure a 2-D view shall sufficient by just looking at the range and height from the radar. The incrementation steps of the elevation are adjustable. So if the steps are lower as the beam width (remember 1°) overlapping areas exist with an augmentation of information in this regions. The comparison or hopefully additional and therefore verification of this new information is relating to ergodic measuring conditions. The main difference will be the different time labels of the measured data.
For the transformation of the polar information to a cartesian grid, the plotted rays were readin pixel by pixel. This image processing technique has the advantage that for every coordinate in the image the value of the specific parameter can be determined. The disadvantage is the accuracy that depends on the color depth of the system. In our case it is 8 bit and so we have $256 - 1 = 255$ possible steps (one color is reserved for unlighted area). By looking at the $80\ dB$ dynamic range for the reflectivities the reachable accuracy is $\frac{80}{255}\ dB \approx 0.31\ dB$. With respect to the reflectivity accuracy of $\pm 1\ dB$ this is an acceptable solution. If higher resolutions are needed, the expanding to multi-picture mode (splitting the parameter values in several parts and plotting separately) shall be a feasable method.
The spatial resolution depends, in this method, on the pixel resolution. For example we assume an RHI of $30\ km$ in range and $10\ km$ in height. The resolution of the image and therefore of the cartesian grid is fixed at 400 * 300 pixels and so the pixel resolution results in $75\ m$ in range and $33\ m$ in height. In the range direction this resolution is accurate enough due to a size of the bin of $150\ m$ ($1\ \mu s$ pulse width) thus a double oversampling is done at the bottom of the scan. Furthermore the considered range shall not transcend $60 km$ to prevent undersampling. The height accuracy depends on the distance from the radar R and the beam width (1°) with $height = tan(1^\circ) \cdot R$. At a distance of $2\ km$ the beam height at the ground is higher than $33\ m$ assuming a flat earth geometry. Since measurements nearer than $2\ km$ are not taken into acount in this study, the height resolution can be seen as feasable, too.
The more precise way is to calculate the values in the cartesian view numerically. The disadvantage here is the high increase of processing time, if a processing of the complete scan is desired.

5. EXAMPLE PROFILES

The distinction of clouds in stratiform and convective types is done by the microphysical processes inside. Seen is this for example by the height profiles of the reflectivities. Here the stratiform clouds are characterised by a peak in the profiles which is related to the melting layer. The convective clouds are more complicated in their structure and the analysis of the height profiles is challenging. The profiles are given, each with a case study for stratiform and convective type.

5.1. Stratiform case

A scan of a stratiform event was taken on the 16th of November 1995 and is displayed with the co-polar reflectivity Z_{hh} in Fig. 2. Based on the radar location in Oberpfaffenhofen the azimuth of the scan is 170° and so directed to the South (towards the Alps).
With the chosen distance for the vertical profile of $6\ km$, Z_{hh}, Z_{DR} and LDR (here LDR_{vh}) are shown in Fig. 3.

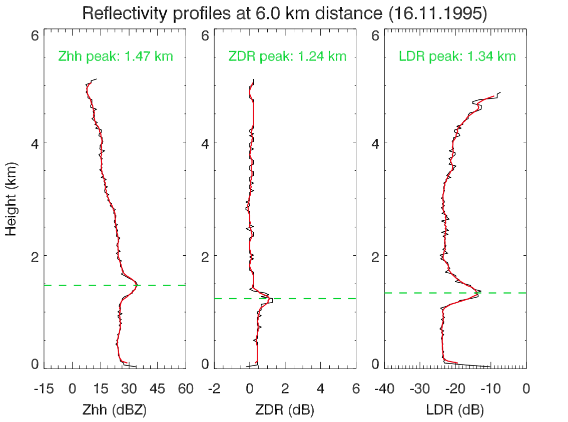

Figure 3. VP of Z_{hh}, Z_{DR} and LDR of the stratiform event (Fig. 2) at a distance of $6\ km$ (black: raw, red: smoothed, green: height of the max.).

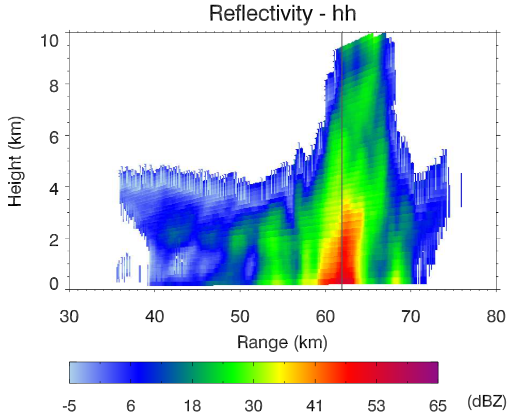

Figure 5. Z_{hh} of a convective event recorded on 13th August 1998 (grey line corresponds to the VP shown in Fig. 6).

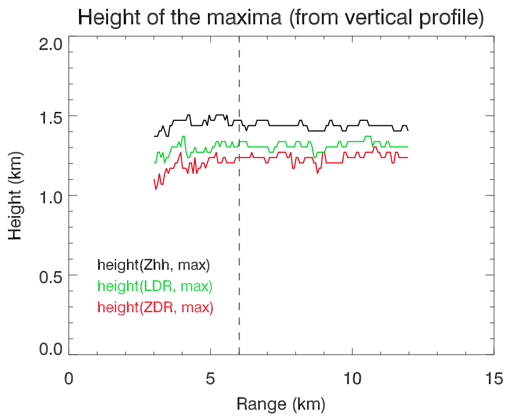

Figure 4. Height of $max(Z_{hh})$ (black), $max(Z_{DR})$ (red) and $max(LDR)$ (green) from the stratiform event (dashed line: position of the VP in Fig. 3).

At this distance the melting layer lies within the scanned area.

The black curve in the respective plots is the detailed profile and the red line is a smoothed version with a box car averaging of five height steps. Apart from the loss of height resolution this smoothing offers the opportunity to analyse the profiles exclusive of small variations due to systematic errors. The height estimation of the local maximum value is an example for the analysis. The heights of the peaks of the three variables are overplotted in green color in Fig. 3. Here the height of the maximum value of LDR lies between Z_{hh} and Z_{DR}. For further considerations on this effect the profiles, including melting layer, between $3\ km$ and $12\ km$ range were treated and resulted in Fig. 4.

The heights of the maximum values of the three parameters show a good constant relation to each other (Fig. 4). The difference between the maxima of Z_{hh} and LDR is

$$hmax_{(Z,LDR)} = h(Z_{hh,max}) - h(LDR_{max}) = 137 \pm 36m \quad (5)$$

and between the maxima of Z_{hh} and Z_{DR} we get

$$hmax_{(Z,ZDR)} = h(Z_{hh,max}) - h(Z_{DR,max}) = 223 \pm 50m. \quad (6)$$

For comparison to $hmax_{(Z,ZDR)}$ a value of about $200\,m$ is ascertained in [1]. So this height difference is assumed as realistic.

5.2. Convective case

Fig. 5 gives Z_{hh} of a convective event recorded on 13th of August 1998. Here the azimuth is $90°$ and so looking to the East.

The profile is taken through the convective cell (Fig. 6) at a distance of $62\,km$. Again the three parameters Z_{hh}, Z_{DR} and LDR (here LDR_{vh}) were observed.

Obvious is the decrease of the reflectivity and the differential reflectivity with height. As in Z_{hh} the depression is very steady there is a step at the Z_{DR} profile. Above the step the profile is very steady with nearly zero decrease. The profile of LDR just show a slightly decrease but a high increase at the top of the cloud. The assumption is that it is related to the structure of the anvil above the convective cell. Physically here reside ice crystals that, related to the updraft and downdraft motions in a convective cloud, can lead to increasing values of the cross-polar reflectivity. A more detailed analysis on the profiles of the convective case will be a topic for further research. Qualitatively and tentatively, the convective profiles are similar to the stratiform profiles above the melting zone.

6. CONCLUSIONS

The study delivered vertical reflectivity profiles for stratiform and convective types of precipitation. The differences are the magnitude of decrements and increments

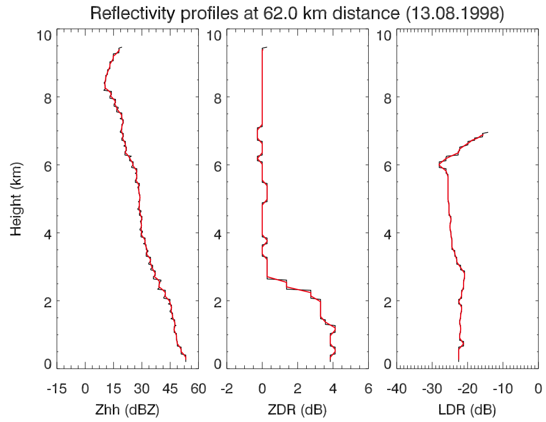

Figure 6. VPs of Z_{hh}, Z_{DR} and LDR of the convective scan (Fig. 5) at a distance of $62\,km$ (black: raw VP, red: smoothed VP).

of the values. Important is the discussion of the appearing peaks though in the stratiform profile which relates to the melting layer as a highly interesting area in cloud classification. For convective clouds the spontaneous change of deviation in Z_{DR} is a point of discussion that shall be addressed in future. The LDR profile as in stratiform precipitation is explainable for the detection of the melting layer show for the convective case a straight behaviour with exception of the values at the top of the cloud.

Apart from these results it has to be stated that this method of extracting the profiles have disadvantages that have to be kept in mind. At first the resolution is a compromise and is, in relation to the pulse width and the distance from the radar, more or less accurate. Another point is the estimation method with the limit of the 255 steps although it is just a software point and so expandable by recoding of the extracting algorithm. And last but not least, the estimation of pulse volumes in large distances (more than $60\,km$) from the radar there the size of the pulse volume is very large and so just a few measured 'points' exist. Additionally the nonuniform beam-filling is critical above these ranges for estimating correct reflectivity values, [3]. For a higher accuracy the 'oversampling' of the data is a good choice by choosing an elevation step that is lower than the beam width. The temporal relation of this method, as the measuring time of the scan rises as the number of measured rays, wasn't taken into account until yet.

Further discussion shall be made on the differences between the profiles of stratiform and convective scans. This is still a challenging task for the application of hydrometeor classifications.

REFERENCES

[1] Dissanayake, A. W., Chandra, M., and Watson, P. A., 1983: *Backscattering and Differential Backscattering Characteristics of the Melting Layer*, Proc. of URSI Commision F Symposium, pp. 363-370.

[2] Schroth, A. C., Chandra, M. S., and Meischner, P. F., 1988: *A C-Band Coherent Polarimetric Radar for Propagation and Cloud Physics Research*, J. Atmos. Oceanic Technol., 5, pp. 803-822.

[3] Marzano, F. S., Vulpiani, G., and Picciotti, E., 2004: *Rain Field and reflectivity Vertical Profile Reconstruction From C-Band Radar Volumetric Data*, IEEE Trans. Geosci. Remote Sens., 42, pp. 1033-1046.