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EXTRACTION OF CLOUD PARAMETERS USING MULTIPEAK ANALYSIS OF CLOUD RADAR DATA

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1. INTRODUCTION

The use of a vertically pointing 8.3 mm wavelength radar for studying mixed phase in clouds will be described.

The Ka-band radars are particularly suited for cloud droplets and small rain drop regime measurements, by their capability to penetrate through rain- and snow-falls and to detect small hydrometeors. Traditionally three moments of Doppler spectra are used as basis to retrieve microphysical cloud parameters, e. g. characteristic particle size (Gossard, 1997), liquid water content (Liao, 1994) and turbulence parameters (Kollias, 2001).

In this contribution additional features of the Doppler vertical velocity spectra are described, which permit to extract more detailed information on the microphysical structure of clouds and on the kinetics in clouds, particularly in cases of mixed-phase coexisting cloud- and drizzle-droplets. A peak detection algorithm has been developed, by which the Doppler spectra are decomposed into multiple peaks. When possible, also the peak-specific linear depolarization ratio is estimated for every mode of the spectra, to derive information on phase and type of the hydrometeor associated to it. Examples of Doppler spectra profiles will be shown to illustrate the retrieval technique.

The results here presented demonstrate that the multi-peak analysis of Doppler spectra can help to improve our knowledge of microphysical processes in clouds.

2. THE DATA PROCESSING

The measurements were obtained with the 36-GHz Doppler research cloud radar MIRA-36 (Metek GmbH, Germany) during 2006/2007 in Hamburg, Germany. The radar characteristics are summarized in table 1 (see also M. Bauer, this conference).

The noise is removed using the Hildebrand and Sekhon threshold method (see Hildebrand, 1974).

The spectra, devoid of the noise, were transformed into the logarithmic domain before applying the multiple peak detection algorithm, to find out if they showed a standard systematic behavior. Normally in clouds one narrow peak per sample volume is present, with center close to zero velocity [fig. 1a, black line]. Rain spectra are instead broader and shifted to higher falling velocities. In addition, they show some skewness [fig. 1c, black line].

CHARACTERISTIC	VALUE
frequency	36 GHz
peak power	30 kW
pulse length	200 ns
pulse repetition frequency	5 kHz
range resolution	30 m
diameter of the Antenna	1.2 m
beamwidth	0.52°
sensitivity	-44 dBZ at 5km
FFT length	256
integration time	10 s

Table 1. Radar operational parameters

These qualitative features are well known, and based on the Doppler velocity cloud droplets and snow crystals can be distinguished from raindrops. Doppler spectra however, show sometimes multiple peaks which indicate that different types of hydrometeors are coexisting in the sampling volume [fig. 1 b, d and e, black continuous lines].

The description of these spectra by just three global moments means to ignore significant information and would lead to erroneous retrievals.

In order to detect and to separate the peaks, it is assumed that multi-modal Doppler spectra can be represented by a linear superposition of Gaussian distributions, every distribution being produced by a different class of hydrometeors present in the sample volume. First, the hypothesis is tested that one class of meteorological targets in the sample volume produces a normal distributed spectrum.

For this purpose the spectrum is fitted with an unimodal Gaussian curve [fig. 1 a and c, red lines], and the $\hat{\chi}^2$ for the statistic is evaluated. After

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inspection of many spectra and of their mono-modal fits with the relative $\hat{\chi}^2$ values, it was decided that the fit with two normal superposed distributions is performed when the $\hat{\chi}^2$ exceeds unity [fig. 1 b and d]. For three-modal spectra well separated single distributions were instead not observed because of their spread, and to turn from two- to three-modal fit a $\hat{\chi}^2$ equal to five appeared to be a reasonable choice to obtain a physically meaningful fit [fig. 1 e]. The latter cases are usually present only in rain regime, and they will be matter of future investigations.

Known the parameters of the Gaussian curves that compose a spectrum, a separability criterion is applied: two contiguous peaks are discriminable when the distance between their centers is greater than the mean value of their standard deviations. Finally, a cluster analysis is performed in order to identify contiguous profiles of individual modes.

The peak detection algorithm is applied to both the radar channels (co- and cross-polar). Examples of spectra profile structure for raining clouds are shown in figure 2. For every range gate the Doppler spectrum is depicted by vertical velocity center value (vertical black thicks) and standard deviation (horizontal bars) of its component. In case of multi peaks, the cluster classification results are indicated by different colors of their standard deviation bars (blue in fig. 2 a, blue and red in fig. 2 b and blue, red and yellow in fig. 2 c).

3. RESULTS

3.1 *Mixed-Phase Structures*

The peak detection algorithm often reveals well separated double peaks above the melting layer. It is reasonable to consider this kind of signal due to cloud droplets and snow flakes coexisting in the same resolution volume.

The vertical extension of these structures reaches from the melting layer to 500 meters above it [fig. 3 a], or can also cover all the cloud range [fig. 3 b], and can persist for a time period from 10 minutes up to one hour.

A double structure present along the cloud above the melting layer can sometimes extend into the rain range (see for example fig. 2 b, co-channel), but no systematic correlation between double peaks in clouds and rain was until now observed.

Another occasionally observed double structure is the generation of a “branch”, hung on the left (higher falling velocity) with respect of the main velocity line [fig. 4].

This group of particles, no more than 500 meters in vertical range extension, falls fast, and disappears in the melting layer after some minutes.

Analogous events were observed occasionally in rain, with more branches present at the same time [fig. 5].

3.2 *Calculation of LDR*

A proper association of clusters in the two channels, permits to evaluate the peak-specific LDR. Anyway, hydrometeors can normally not be seen in the cross-channel, due to the low power level point. For the same reason a bi-modal distribution in the co-channel only rarely appears also in the cross-channel. Figure 6 shows one example of this favorable cases in which it is possible calculate the LDR for bi-modal spectra distribution.

The values for two modes at the same sample volumes, between 1 and 2 km in figure 6, are quite different: below -30 dB for the main cluster (in blue) and greater than -20 dB for the other (in red).

These values suggest the existence of mixed-phase layer, composed perhaps by liquid droplets and ice crystals, present near the cloud base in the considered event. This conclusion agrees with a study of Shupe (2004) in which a mixed-phase cloud was analyzed with different instruments.

3.3 *Vertical Mean Velocity*

An other interesting result, obtained by the individuation of peaks in Doppler spectra, regards the vertical evolution of clouds. In figure 7 one can see the Doppler falling velocity of hydrometeors linearly increasing while approaching the cloud base. This should correspond to a progressive increasing of the number of bigger particles present in the sample volumes. Looking into several data time series, it turned out that the mean velocity gradient seems to be fairly constant for a broad range of cloud types with a mean value of about $0.15 \cdot 10^{-3}\ s^{-1}$. In figure 8 a time series for the gradient is shown. Deviations from this behavior appear close to the cloud top (in fig. 7 at about 5.7 km), where turbulence is enhanced due to radiative cooling. Sometimes abrupt deviations are observed also in a narrow layer close to the cloud base.

4. CONCLUSIONS AND OUTLOOKS

The described multiple peak detection algorithm, including peak specific LDR, appears to be an advantageous tool to extract information particularly on mixed-phase clouds.

A prospect to better cloud kinetics understanding is outlined by the assessment of the vertical mean velocity gradient in clouds. Also the observation of coherent multiple peak structures in the spectra profile can be useful for this purpose.

Further steps towards unambiguous interpretation in term of microphysical parameters is to integrate this enhanced analysis in a multi-sensor system, including lidar and microwave radiometer measurements and a cloud resolving model.

Measurements are now being collected together with other remote sensing systems as well as in-situ aircraft measurements of cloud microphysics within the COPS experiment (Convective and Orographically-induced Precipitation Study) taking place presently in southern Germany (http://www.uni-hohenheim.de/spp-iop).

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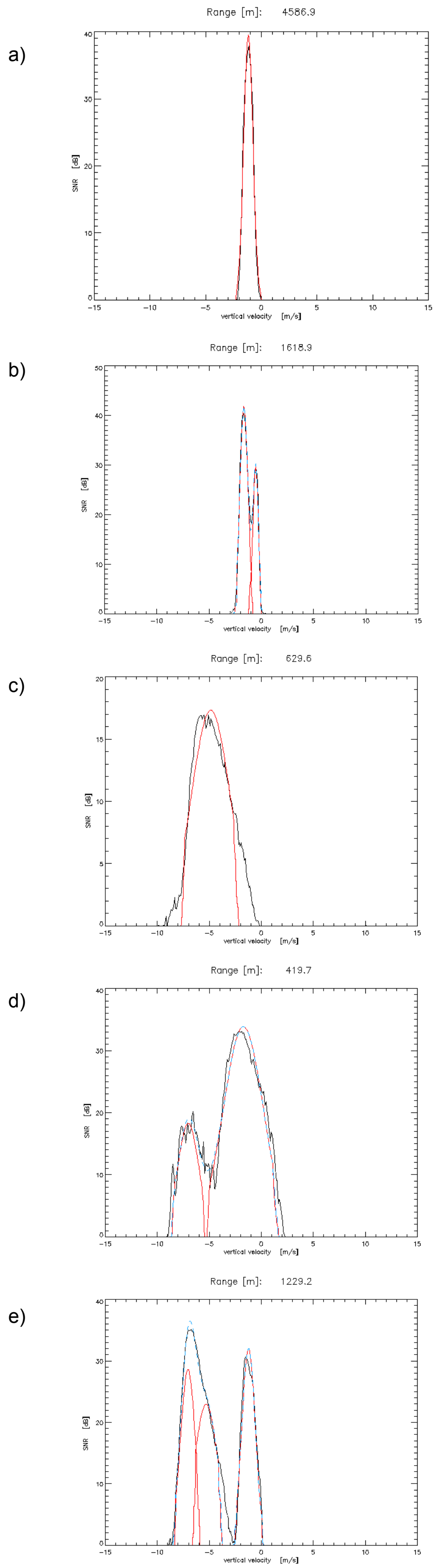

Figure 1. Examples of different modes Doppler spectra (velocity against SNR), as they are observed in clouds [a,b] and rain [d,e,f]. Negative velocities are downwards. These samples come from data collected during January 2007. In black the data in the logarithmic domain are plotted. Red lines individuate the component peaks. When more peaks are present, their sum is individuated by a blue dotted line.

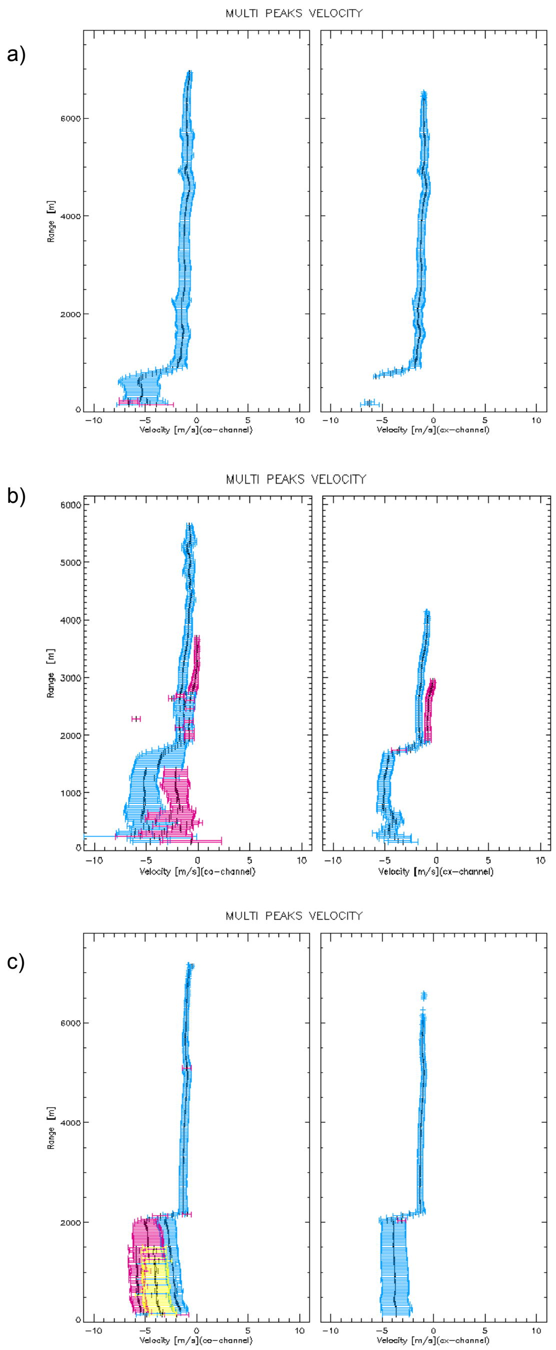

Figure 2. Examples of Doppler spectra profile from data collected on January [a, b] and March [c] 2007. The resolution is 30 m in range and 10 s in time. Co- and cross-channels are shown for every dwell . See text for details.

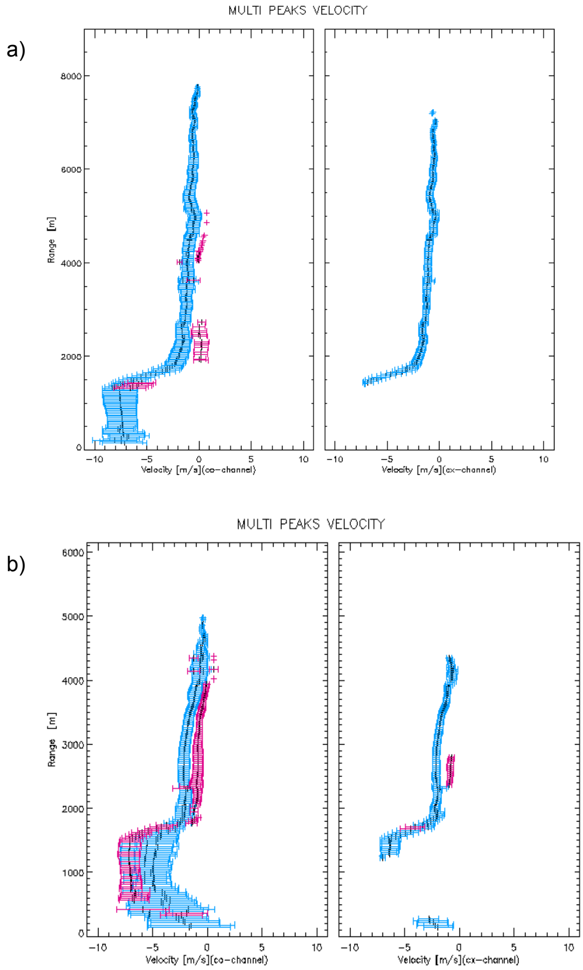

Figure 3. Examples of mixed-phase spectra profile from data collected on May [a] and March [b] 2007. See text for details.

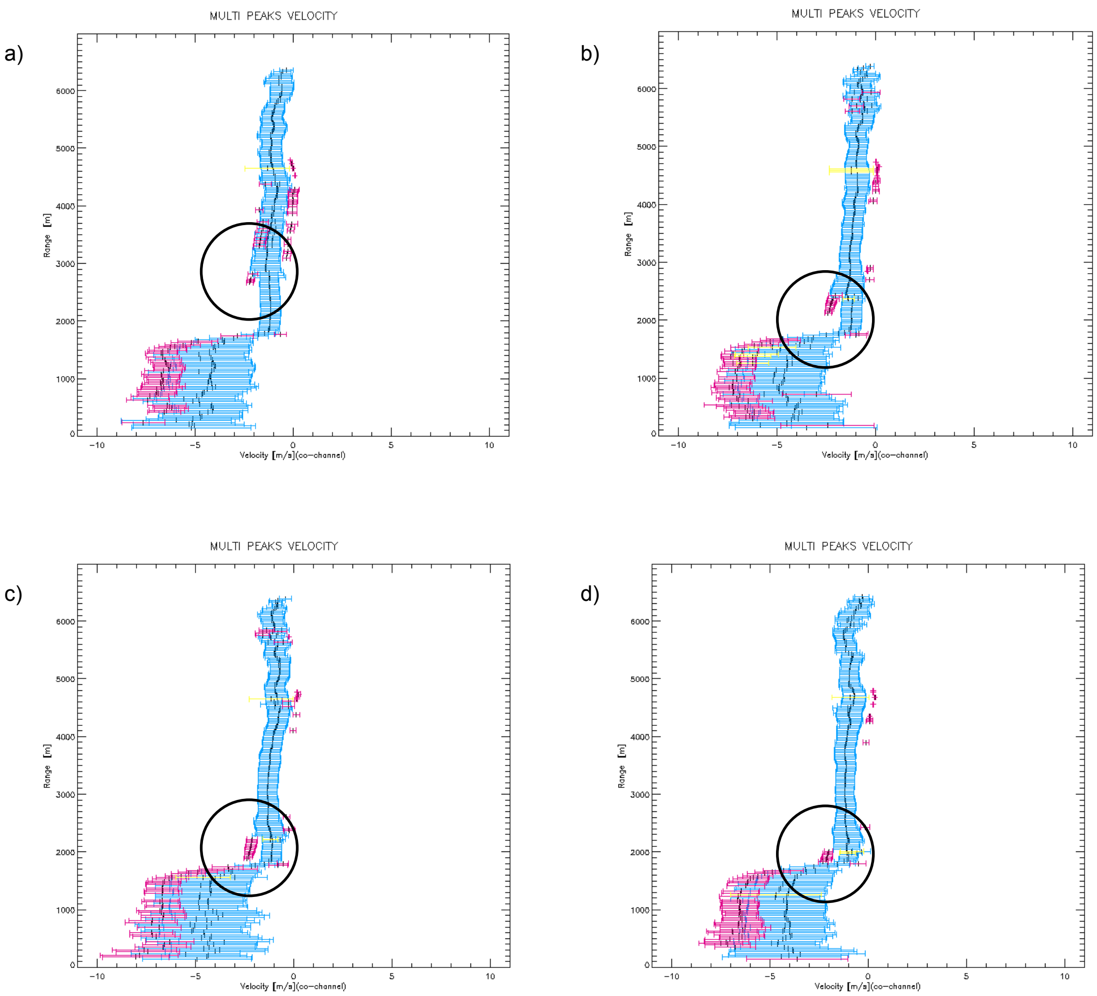

Figure 4. Sequence of a co-channel spectra profile, March 2007. A branch, emerged in the first plot at 3 km on the left side, is shifting downwards. Between the first plot and the last one there pass around 1 minute and half.

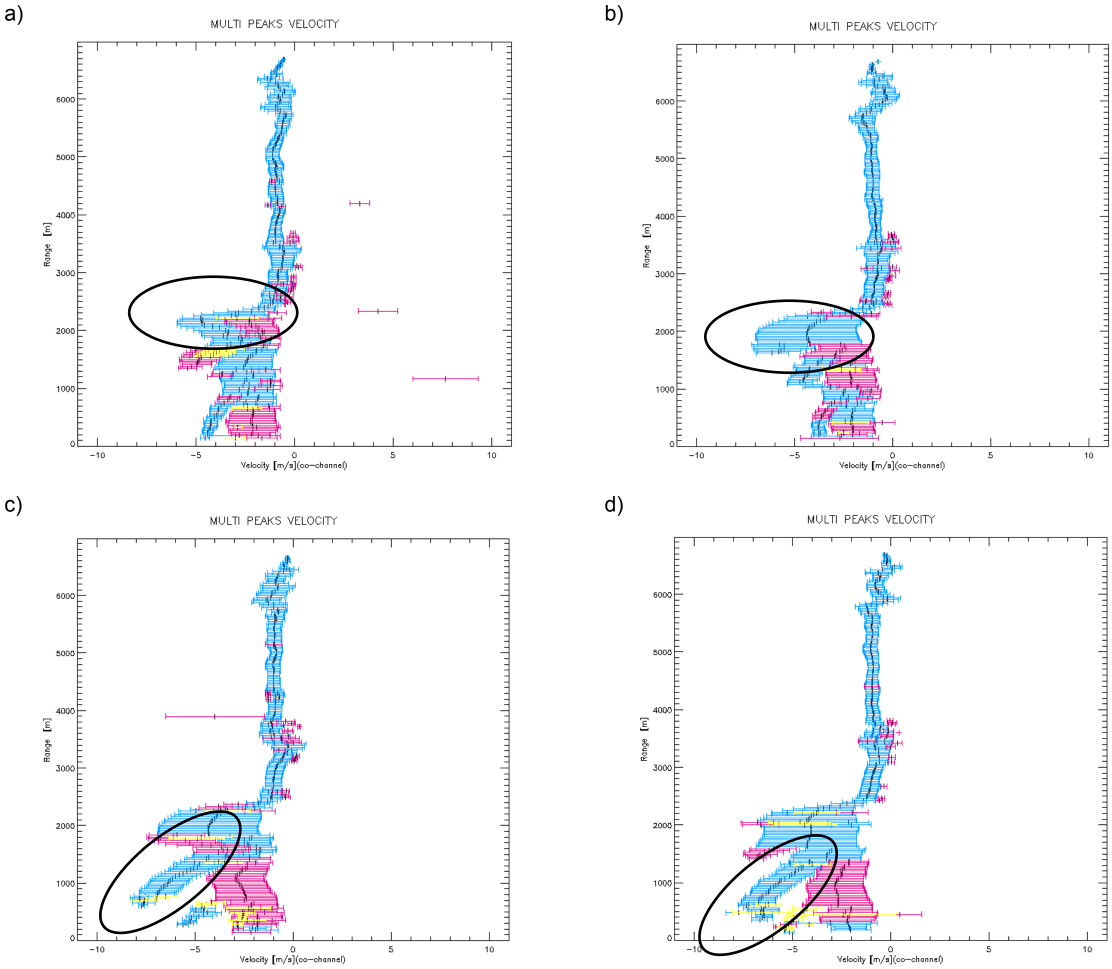

Figure 5. Sequence of a co-channel spectra profile, April 2007. Note the contemporaneous presence of 3 or 4 branches in the rain regime (below 2.5 km). Here the branch indicated by the arrow is followed. Between the first plot and the last one there pass around 3 minutes.

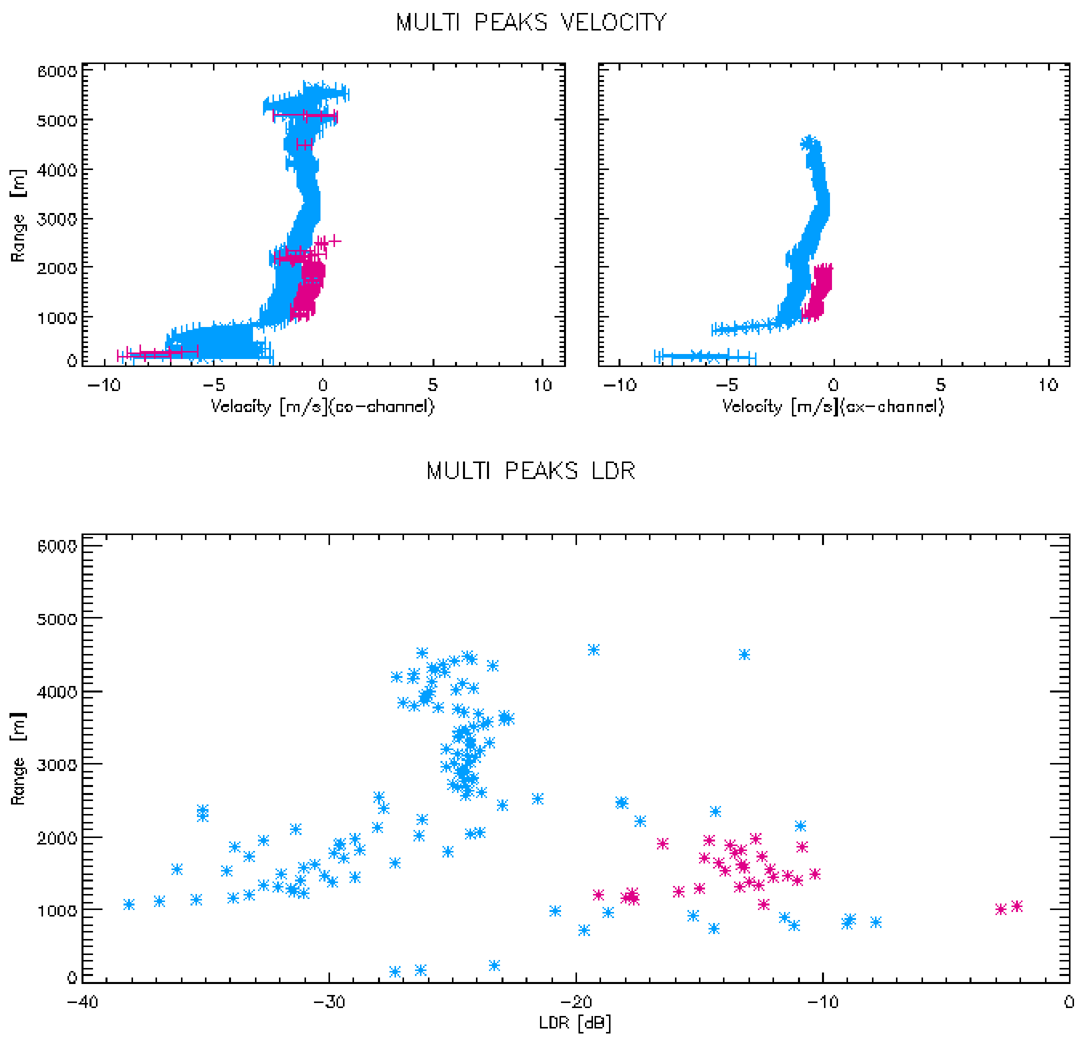

Figure 6. Example of LDR values for a bimodal spectra profile (February 2007). See text for details.

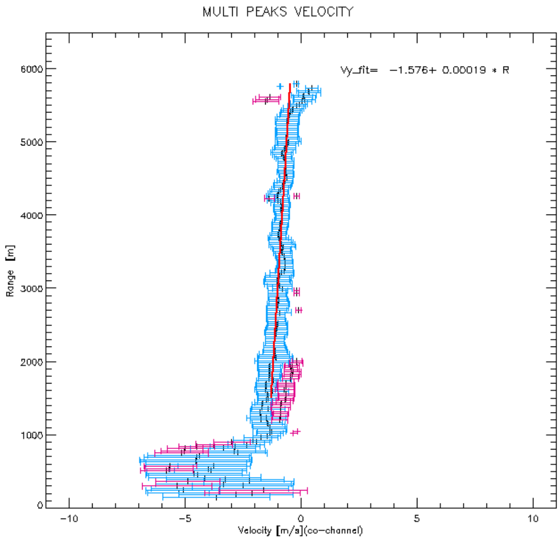

Figure 7. Examples of spectra profile (March 2007). The mean velocity values for the main cluster in cloud are linearly fitted (red line).

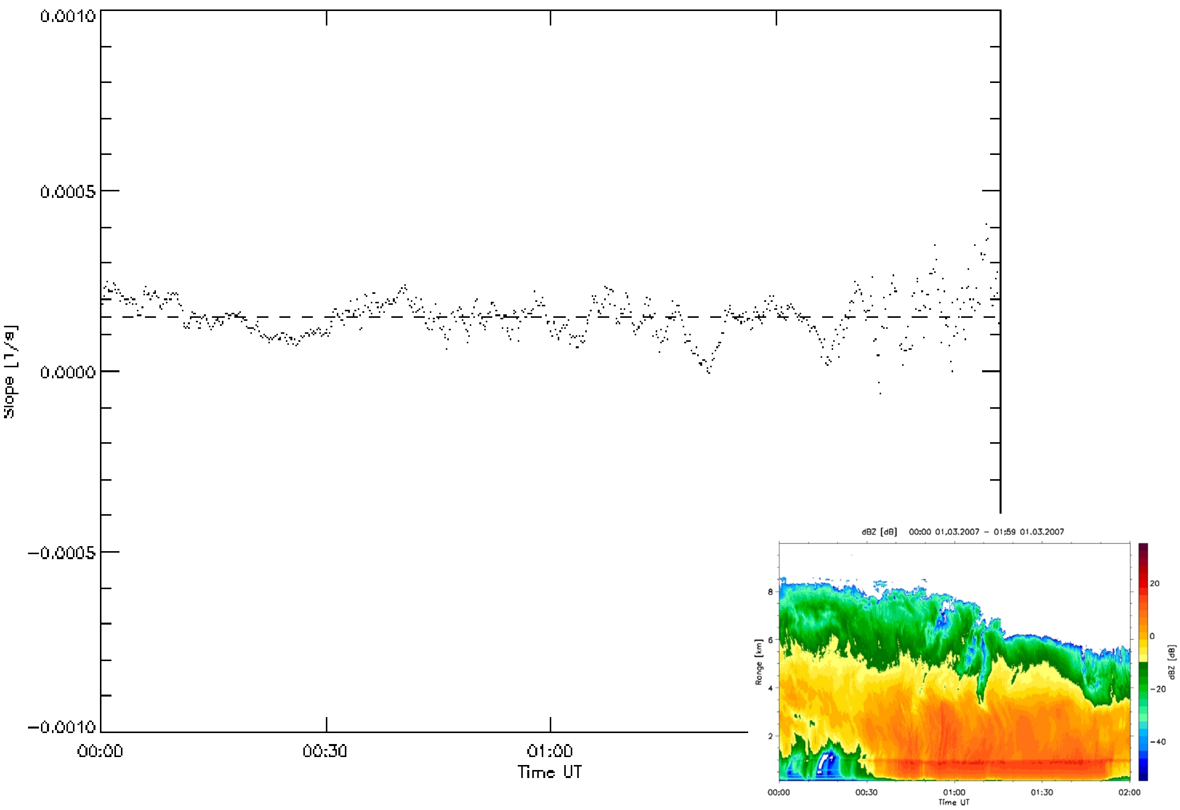

Figure 8. Time series for the vertical mean velocity gradient in a cloud (March 2007). The dots represent single estimates and the dashed line indicates the mean value along the observation period. The reflectivity of the same event is showed in the panel.