MICROPHYSICAL PROPERTIES OF STRATIFORM CLOUDS

BY CLOUD RADAR MEASUREMENTS

Sabrina Melchionna *
Max Planck Institute for Meteorology, Hamburg, Germany

1. ABSTRACT

In this contribution we derive microphysical properties of deep stratiform clouds, such as size, shape, and phase, by using measurements taken with a 35-GHz vertically pointing Doppler radar. Furthermore we infer a growing process for cloud particles by comparing the measurements with a non operational configuration of the COSMO-DE model.

2. BACKGROUND

In order to characterize clouds by Doppler radar measurements, radar meteorologists generally use the moments of the Doppler spectrum.

A Doppler spectrum is determined by the power backscattered by the hydrometeors in function of their Doppler velocity, and for cloud particles it has a Gaussian shape. The shaded area in fig. 1(A) depicts a typical Doppler spectrum for ice particles within a cloud. This spectrum, as well as all the measurements considered in this work, was taken in Hamburg by the 35-GHz vertically pointing Doppler radar MIRA-36.

The moments of the Doppler spectrum are evaluated as the total backscattered power (reflectivity Z, measured in dBZ), the mean Doppler velocity, and the spectral width. With polarized radars it is also possible to measure the Linear Depolarization Ratio (LDR) as the ratio of the power backscattered on two orthogonal polarized channels (named co- and cross-channel). For vertically pointing radars the moments are plotted on Range-Time Indicators (RTI) which can be regarded as representing a vertical section of the cloud as it passes over the radar. From the moments we derive general properties of clouds, such as cloud extent and rough classification of cloud particles. Moreover, LDR tells us how much asymmetric the particles are. Combining the moments of the Doppler spectrum with Lidar and microwave radiometer measurements, Illingworth and coauthors (2007) were able to classify hydrometeors on a continuous basis.

Corresponding author address: Sabrina Melchionna, MPI Meteorology, Bundesstraße 53, D-20146 Hamburg, Germany. E-mail: sabrina.melchionna@zmaw.de

In mixed-phase clouds, constituted by snow crystals, supercooled droplets, and ice crystals, every group (read "mode") of particles contributes to the spectrum with a Gaussian distribution having slightly different parameters. Radar systems are more sensible to the bigger particles present in a resolution volume, because the reflectivity is proportional to the sixth power of the diameter.

Nowadays radar techniques are advanced enough to provide fine resolved measurements of spectra. For instance MIRA-36 has a resolution for the Doppler velocity of 8.3 cm/s. Spectra measured by such radar systems often show a bimodality, that means double peaked power distributions, as shown for example in fig. 1(B). These kinds of spectra are indicative of mixed-phase layers. We should specify that also particles moving not uniformly in one radar resolution volume, as can happen to ice crystals because of turbulent motion on cooling cloud tops, could produce a double peaked spectrum.

Traditionally the moments of the Doppler spectrum are evaluated considering the spectra due to only one mode of particles. Thus, in case of mixed-phase clouds, the extraction of cloud microphysical parameters by using the global moments leads to incomplete, when not erroneous, retrievals.

In Melchionna et al. (2008), we described a method to decompose spectra in up to two modes so that we could calculate the mode-specific moments and LDR. We also evaluated the increase of Doppler velocity on the fall path, interpreting it as the consequence of particle growth. This method is now upgraded and takes into account the vertical air motion. In order to reduce its influence, we average radar measurements as formulated by Matrosov et al. (2002). The limit of this method as well as of all these sort of averaging approaches - see for example Delanoë et al. (2007) - is that they are applicable only to non-convective clouds.

In this contribution we show a case of study for which we compare some microphysical parameters obtained from the mode-specific moments with the results of a non-operational configuration of the COSMO-DE model. The COSMO model (Consortium for Small-Scale

Modeling) is a limited-area atmospheric prediction model. The configuration here used includes an explicit cloud microphysical parametrization. It predicts the mixing ratio of cloud droplets, raindrops, cloud ice, graupel, and snowflakes. For details about this model configuration see Seifert and Beheng (2006).

3. DESCRIPTION OF THE CASE OF STUDY

We show here the case of study of the 07 December 2006. A warm front associated to a low pressure system passed over Hamburg. During the day a moderate precipitation rate and temperatures at the ground ranging from 4°C to 8°C were registered.

3.1 Size, shape, and phase

Figure 2 shows the RTI for the first mode of reflectivity and figure 3 shows the RTI for the first mode of LDR; figures 4, 5, and 6 show the RTIs for the first (A) and second (B) mode of falling velocity, diameter of the particles, and Ice Water Content (IWC). As first moment we mean always the mode with higher falling velocity. These cloud particle properties are evaluated as in Matrosov et al. (2002). The reduction of the vertical air motion (fig. 4-6) is obtained by a 15 minutes average. Note that for the rain, below the melting layer at circa 1.5 km, the shown values are unrealistic, because the decomposition method is intended for cloud particles only. Echoes from raindrops do not have in fact a Gaussian power density distribution, which is instead the rationale for the application of our decomposition method.

From the first mode results we learn that this is an ice cloud, with ice crystals of some hundreds micron growing along the vertical downwards to snow crystals of 3 mm. Second modes are present on the cloud top boundary, in a layer of one kilometer above the melting layer between 11:00 and 14:00 UTC, and at 4 km between 14:30 and 15:30 UTC. Turbulence produces the two modes at the cloud top as consequence of radiation induced instability. At 15:00 UTC the two modes are likely due to air motions within the cloud; the visible change in the melting layer height supports this hypothesis. A mixed-phase area produces the two modes above the melting layer, as explained in the following.

Behind the couples of fall velocity values, the LDR values are coherently structured along the vertical (see the time sequence of spectra profiles in fig. 7), suggesting that we deal with two different groups of particles. Let us recall that mixed-phase layers are connected with secondary production of ice – the so called splintering process, or Hallett and Mossop effect, see Cantrell and Heymsfield (2005). This process needs temperatures around -7°C and the presence of both snow crystals and supercooled droplets: snow crystals, rimed by the droplets, splinter out pristine ice crystals. The physical reasons of the splintering are still unknown. Above the melting layer right conditions of temperature exist that allow this secondary production of ice to occur, because here the temperature decreases from 0°C with increasing height. Unfortunately, at the time this measurement was taken, the site was not equipped with an independent sensor for the profiling of temperature. Among the constituents of a mixed-phase area, that are snow crystals, ice crystals, and supercooled droplets, we can detect with cloud radar only snow crystals (first mode), and supercooled droplets or ice crystals (second mode). Following Zawadzki et al. (2001), we deduce that here the radar detects pristine ice crystals: in the spectra profile the second mode seems to disappear in the melting layer (see again fig. 7), meaning that the particles are melting.

3.2 Growing process of cloud particles

To analyze the growing process of the particles, we consider just the main mode. For every spectra profile, we fit the mean fall velocity of the particles in function of the height range. The value of the slope gives us an indication on the increase of fall velocity of the particles. We repeat the fit after reducing the vertical air motions. In the case here presented, this value is stabilized at 15 cm/s for every km of fall path (fig. 8). We explain this result as the consequence of a consistent growing process of the particles.

3.3 Comparing with the model

In a layer between 1 and 4 km from 12:00 to 18:00 UTC the model predicts presence of cloud liquid water along with production of a little amount of graupel (fig. 9). This result further supports our hypothesis about the occurrence of secondary ice production by splintering.

We also calculate the increasing of the fall velocity for the fall velocity predicted by the model (fig. 8). Note that the measured velocities are reflectivity weighted, that means with the 6th power of the diameter, whereas the model velocities are weighted with the mass, that means with the 3rd power of the diameter. Although the velocities are weighted differently, the increase of vertical velocity with descending motion is surprisingly similar, especially in the deeper part of the cloud. By switching on one growing process at the time in the model, such as growth by water vapor deposition, by collection processes, or by freezing of water drops, we shall understand which one is critical in the evolution of the bigger particles in the cloud.

4. CONCLUSIONS

In this contribution we considered Doppler spectra received with a cloud radar to retrieve information on microphysical structure of clouds and on dynamics of cloud systems. By decomposition of the Doppler spectra, we retrieved information on mixed-phase areas and on turbulent motions in the cloud.

In the case presented, we found that the fall velocity of cloud particles increases with an average of about 15 cm/s per kilometer fall path, a value consistent with the result of the cloud resolving model COSMO-DE.

The method, here presented in its application to one case of study, is being applied to several deep stratiform clouds and cirrus, chosen among a data set ranging from August 2006 to May 2007. The use of radar for cloud studies should be considered for the validation of numerical models. A first comparison show already good agreement.

5. ACKNOWLEDGEMENTS

6. REFERENCES

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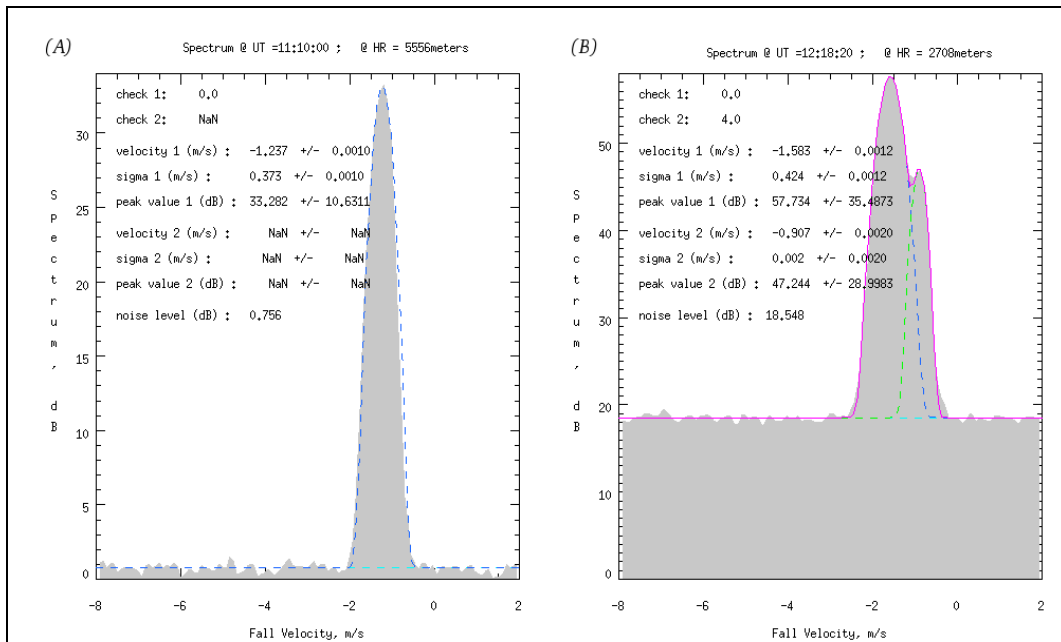
Figure 1: *Example of Doppler spectra. (A) Unimodal spectrum, due to ice cloud particles; 2006.12.07 11:10:00 UTC, 5.56 km AGL. (B) Bimodal spectrum, due to mixed-phase cloud particles; 2006.12.07 12:18:20 UTC, 2.7 km AGL. Shaded area: radar measurements; blue dashed line: Gaussian fit, first mode; green dashed line: Gaussian fit, second mode; pink solid line: linear superposition of the two modes, if present; cyan blue dashed line: noise level. On the left side of the panel the numeric results for Gaussian fits are shown. Negative velocities are downwards. Note the different y-axis range between panel (A) and (B).*
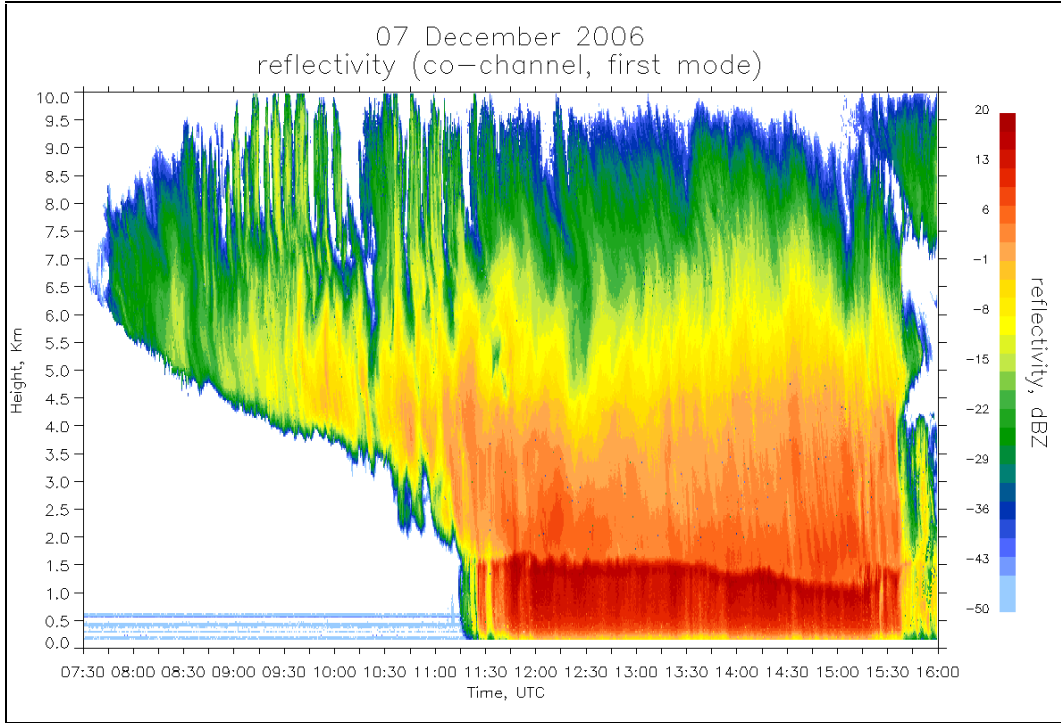
Figure 2: *Reflectivity of the first mode in the co-channel for the 2006.12.07 . Height ranges from 0 to 10 km AGL; time ranges from 7:30 to 16:00 UTC; reflectivity ranges from -50 dBZ in light blue to 20 dBZ in red.*
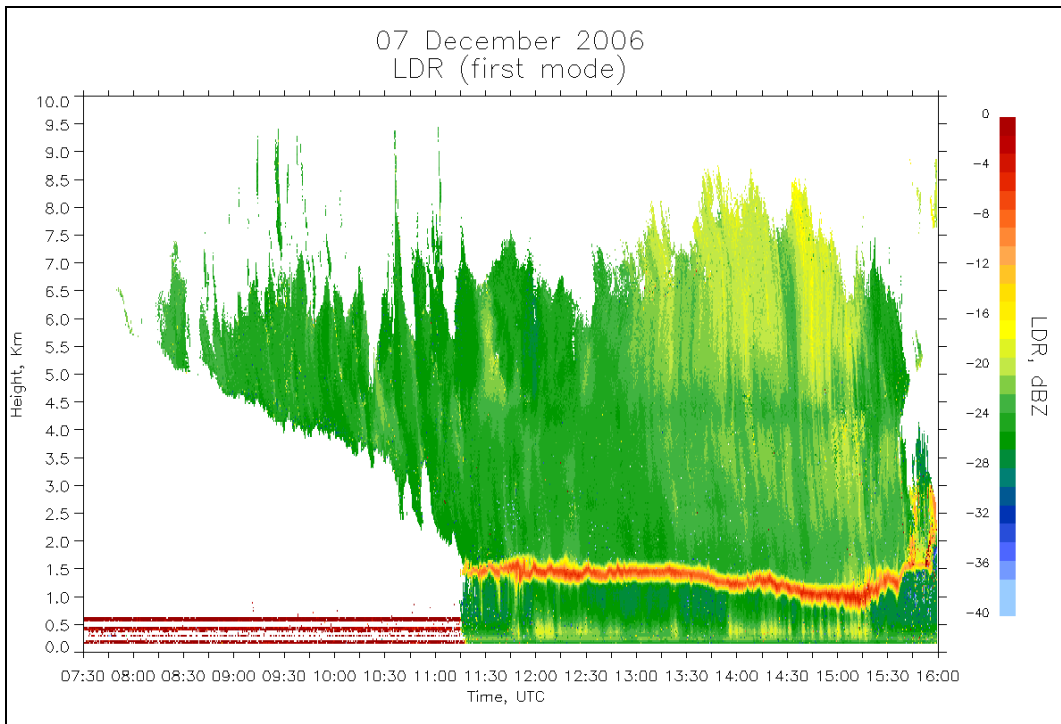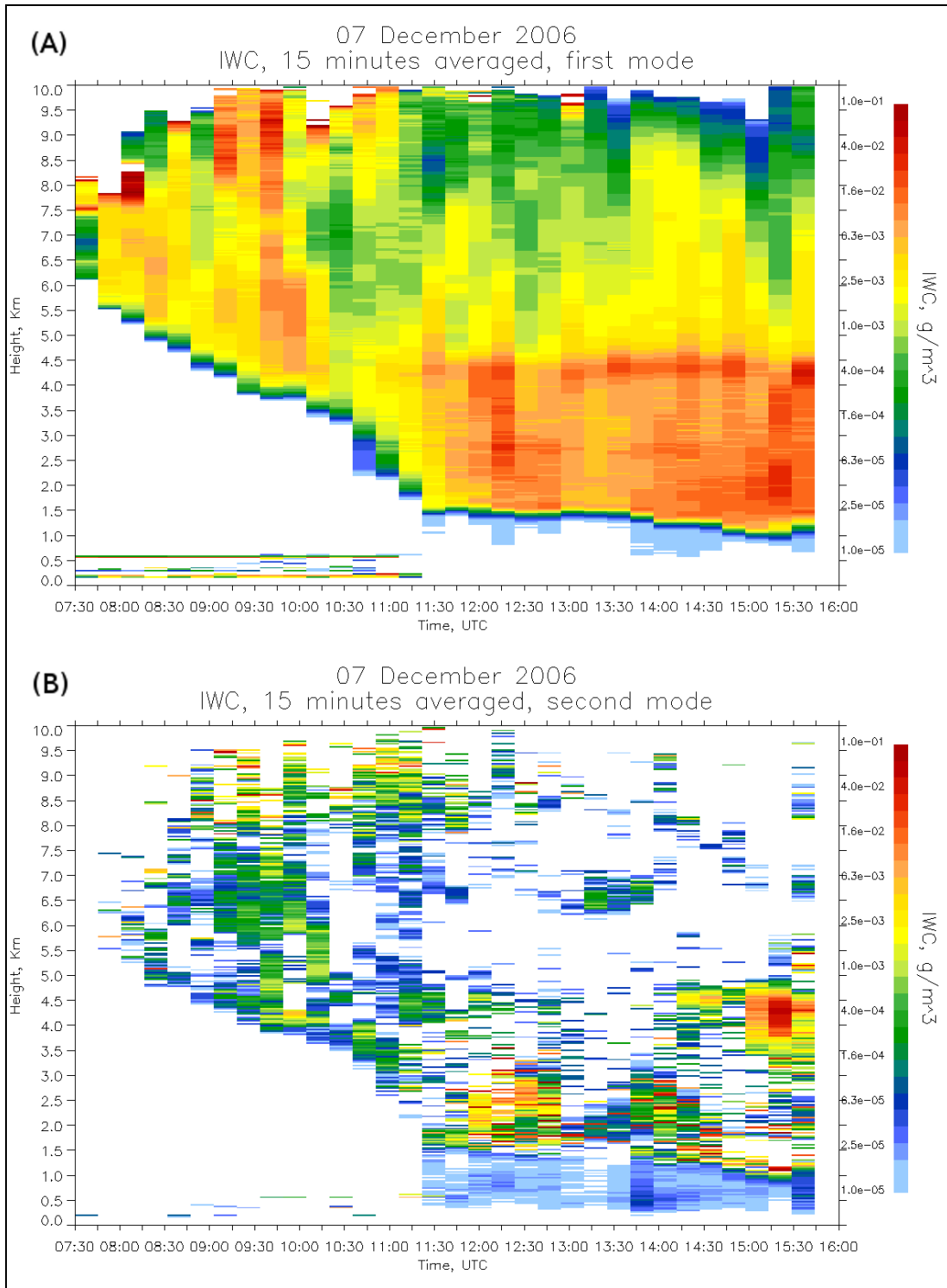

Figure 3: *LDR of the first mode for the 2006.12.07 . Note the melting layer at about 1.5 km in red. Height ranges from 0 to 10 km AGL; time ranges from 7:30 to 16:00 UTC; values of the LDR range from -40 dB in light blue to 0 dB in red .*
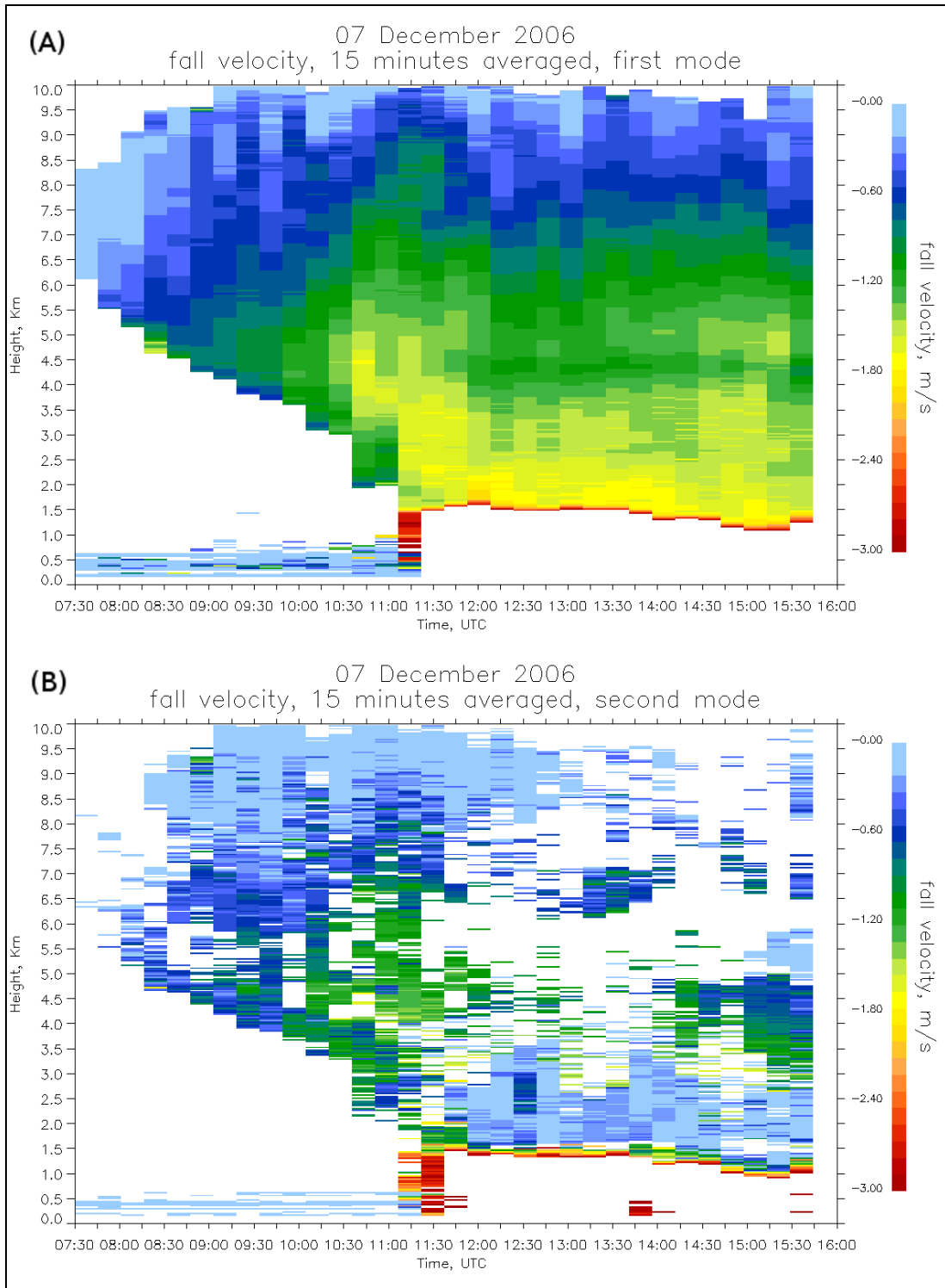
Figure 4: *Terminal fall velocity of the first (A) and second (B) mode for the 2006.12.07 . Height ranges from 0 to 10 km AGL; time ranges from 7:30 to 16:00 UTC; velocity ranges from 0 m/s in light blue to -3 m/s in red. Negative velocities are downwards.*
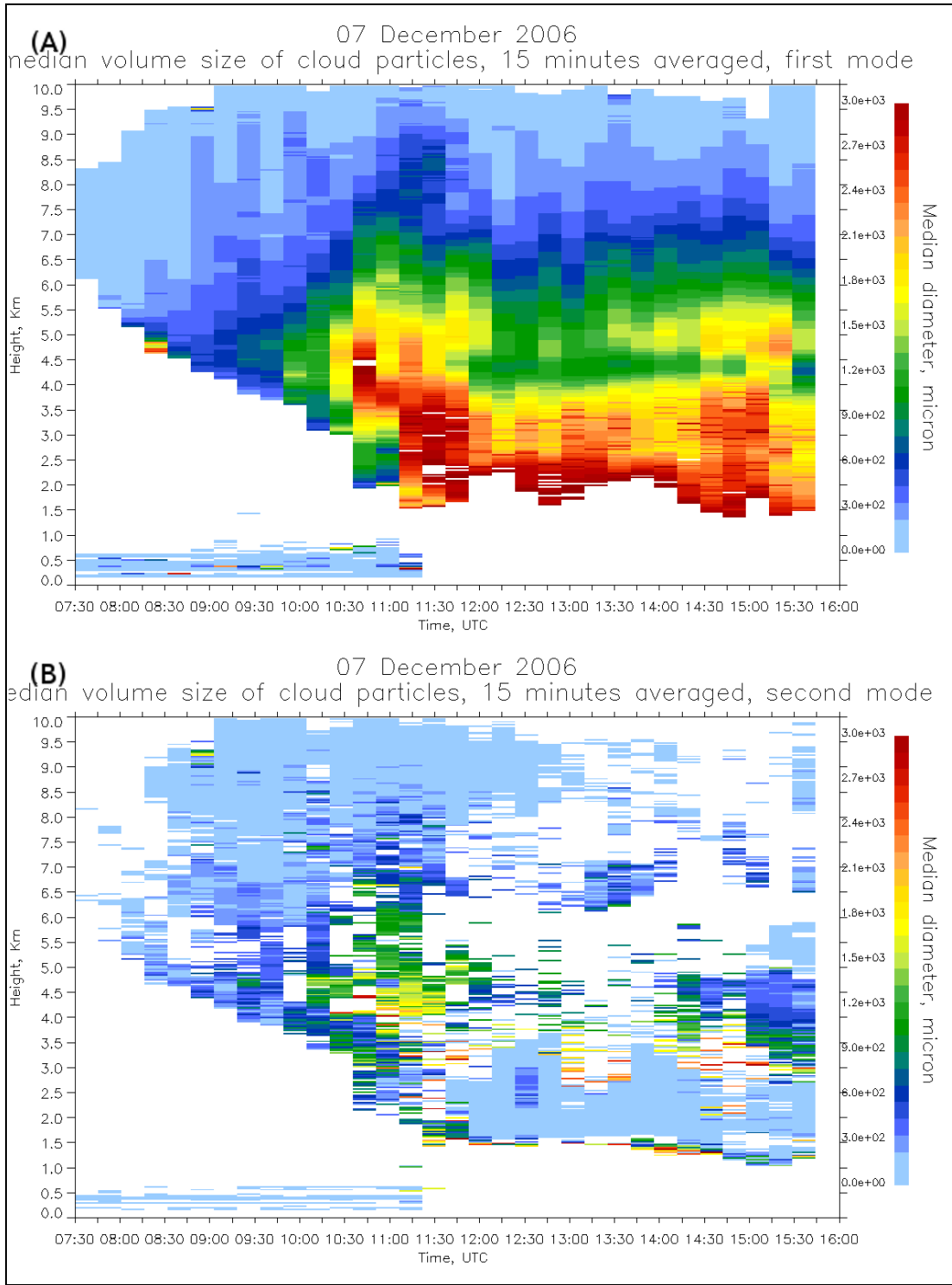
Figure 5: *Median volume size diameter of cloud particles of the first (A) and second (B) mode for the 2006.12.07 . Height range from 0 to 10 km AGL; time range from 7:30 to 16:00 UTC; dimension from 0 mm in light blue to 3 mm in red.*

Figure 6: *IWC of the first (A) and second (B) mode for the 2006.12.07 . Height range from 0 to 10 km AGL; time range from 7:30 to 16:00 UTC; IWC from 1·10⁻⁵ g/m³ in light blue to 0.1 g/m³ in red.*
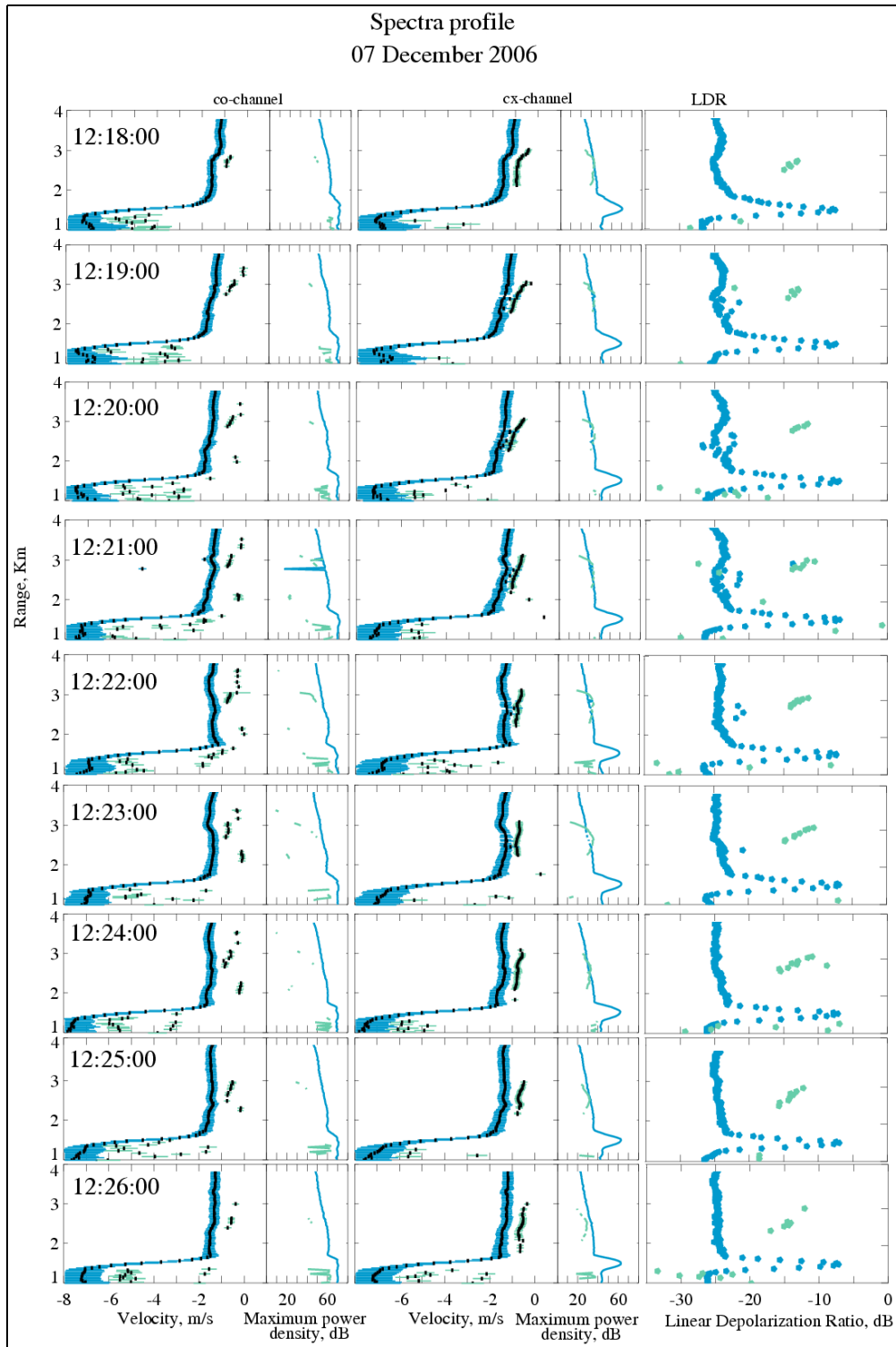
Figure 7: *Spectra profiles for the 2006.12.07 from 12:18 to 12:26 UTC, one every minute. The averaging time for every profile is 10 seconds. Height ranges from 1 to 4 km AGL. Left and middle panels: results of the decomposition for co- and cross- channel. On the left side of every panel the mode-specific velocity (with negative velocities downwards) is depicted by black ticks, and the mode-specific standard deviation by colored horizontal bars; the colors indicate the mode order number: pale blue for the primary mode, pale green for the secondary mode; on the right side the mode-specific peak value profiles are depicted by correspondingly colored lines. Right panel: mode-specific LDR; the colors match the relative mode.*
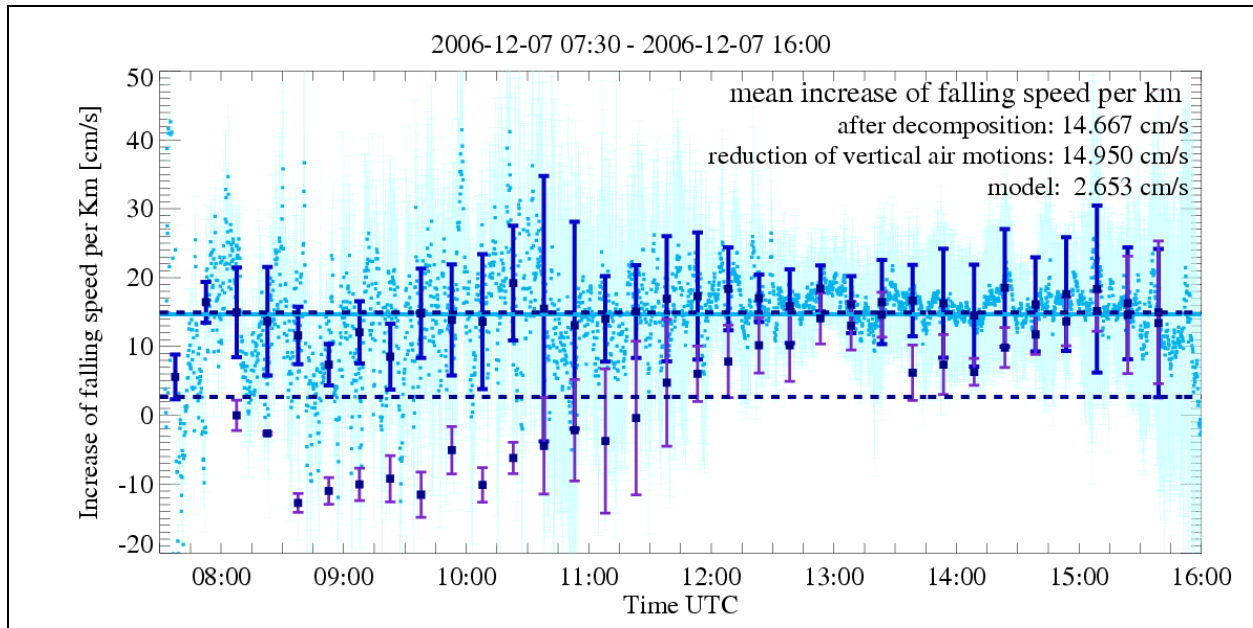
Figure 8: *Time series for the vertical mean velocity gradient for the 2006.12.07 between 07:30 and 16:00 UTC. The dots represent single estimates of the gradient and the corresponding vertical bars the goodness of every single estimate. Pale blue: data after decomposition. Dark blue: data after reduction of vertical air motions. Purple: results of the model. The dashed line indicates the mean value along the corresponding observation period.*
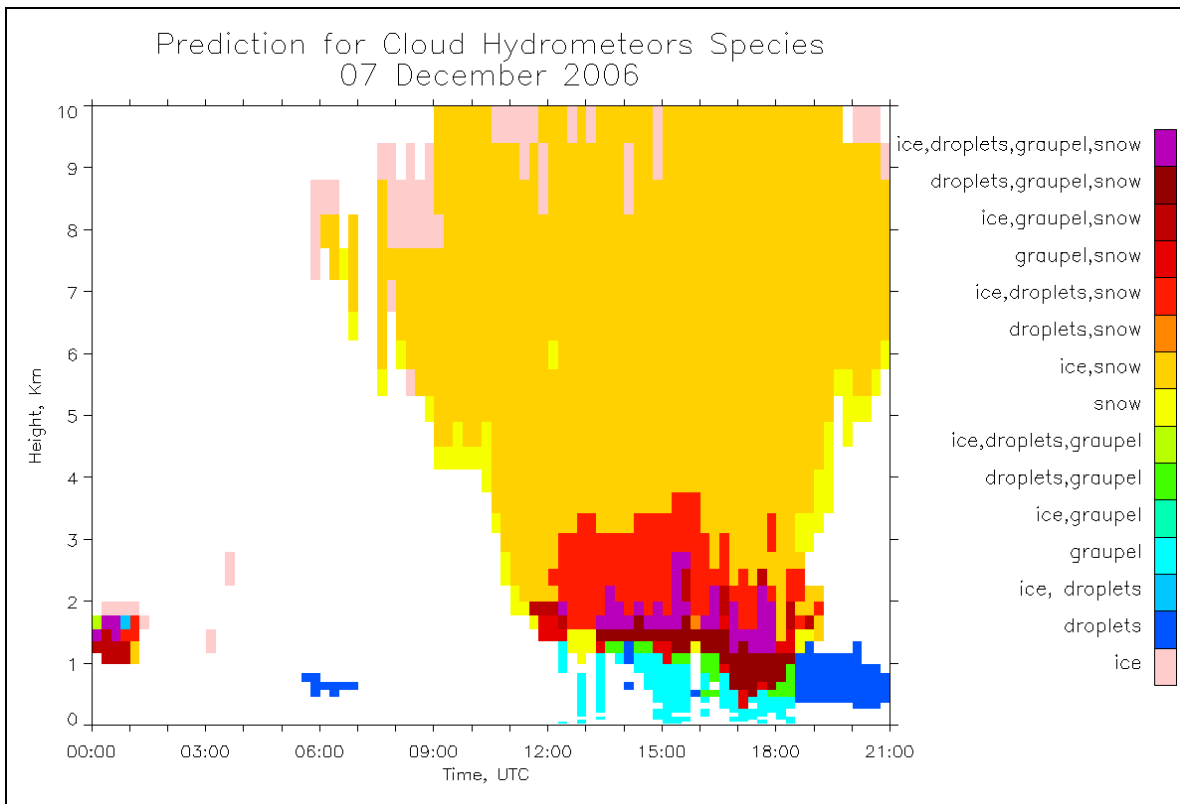
Figure 9: *Model prediction for ice particles, droplets, graupel and snow for the 2006.12.07 . See legend on the left for colors meaning. Note the mixed-phase area between 1 and 3 km. Height ranges from 0 to 10 km AGL. Time scale ranges from 00:00 to 21:00 UTC.*