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Radar observations of snow above the melting layer

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Abstract. In melting layer modeling commonly assumed that one snowflake above a melting layer produces one raindrop below it. This assumption, however, is not always valid. In this paper we study different regimes of the melting layer. Observations of the melting at 45 degrees elevation angle were used for this study. A unique measurement setup was provided by the Transportable Atmospheric Radar (TARA), operated by the Delft University of Technology. The TARA not only allows for fully polarimetric measurements, but a dual offset beam configuration permits retrieval of 3D wind velocity fields. Combining dual offset beam observations with polarimetric measurements, we were able to observe both dynamical and microphysical properties of the melting layer. By studying particle fluxes above and below a melting layer we can differentiate between aggregations of snowflakes that result in less raindrops relative to a number of snowflakes, breakup and one-to-one regimes. Polarimetric measurements, on the other hand, give us insight into different particle populations present.

1 Introduction

The melting layer, also known as a bright band, is a layer where snowflakes melt to raindrops. The melting layer is a characteristic feature of a stratiform precipitation. Investigations of the melting process are mainly motivated by the interest in the formation of the stratiform precipitation and by its influence on satellite communications. The future NASA Global Precipitation Mission (GPM) will cover northern hemisphere where stratiform rain events are abounded. Therefore, it is important to develop a thorough understanding of the statiform rain formation.

One of the major assumptions of the melting layer modeling is that one snowflake above the zero isotherm creates one raindrop below (Russchenberg and Ligthart, 1996; Skaropoulos and Russchenberg, 2003). This assumption allows one to create a rather simple and relatively accurate model of the melting layer. It, however, commonly believed not to be valid (Drummond et al., 1996).

In this study we have used a combination of polarimetric radar measurements of a stratiform precipitation and 3 beam radar measurements. This combination allows us to study the microphysical properties of the precipitation event together with the dynamical properties provided by 3 beam measurement configuration. The measurements presented in this paper were carried out by TARA, that is an S-band polarimetric radar. The measurements took place on Spetember 19, 2001 at Cabauw, The Netherlands.

2 Data processing

The TARA antenna system include two offset feeds that produces two beams at 15 degrees angles to the main beam (Heijnen et al., 2000). This configuration allows for estimation of 3D velocity fields. During the measurements carried out on September 19, 2001 TARA was taking observations using both offset beams and by alternating polarization states in the main beam. By combining velocity measurements from the three beams one can retrieve a 3D velocity field. The result of this processing is shown in Fig. 1. We can see that the retrieved vertical velocity closely resembles a typical fall velocity profile in a stratiform rain. The main beam elevation angle for this measurement was 45 degrees.

From the main beam measurements co-polar and cross-polar power spectra were calculated. Than the retrieved vertical velocities were used to scale spectra such way that *hh* power spectra mean velocities became equal to the retrieved vertical velocities. Examples of the resulting spectra can be seen in Figs. 3–5.

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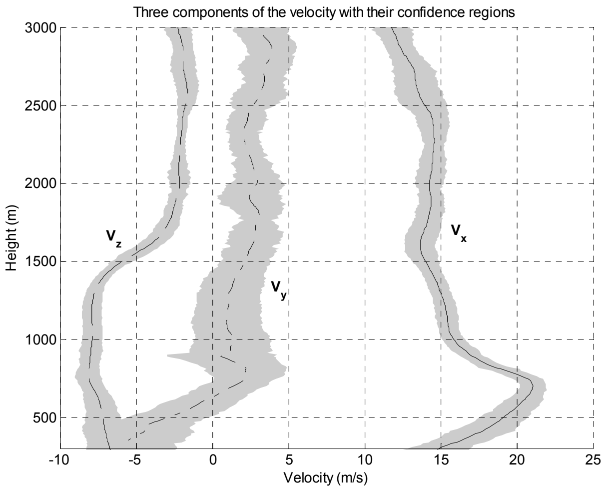

Fig. 1. Mean components of the retrieved wind velocities. The grey shaded areas represent confidence regions of the wind velocity retrieval. Here V_z is the retrieved vertical velocity component.

3 Observations

In Fig. 2 the range profile of the precipitation is shown. From this measurement boundaries of the melting layer were estimated, by finding points close to the melting layer that have maximum curvature (Drummond et al., 1996). Drummond et al. (1996) has shown that by calculating dimensionless quantity γ given as

$$\gamma = \frac{Z_{es} v_s}{Z_{er} v_r}$$

one can detect region where one snowflake one raindrop assumption fails. Here Z_{es}represents reflectivity at the point of the maximum curvature above the melting layer. The Z_{er} represents reflectivity at the point of the maximum curvature below the melting layer. And v_s and v_r are corresponding mean fall velocities. The above given parameter is related to the ratio of particle fluxes above and below the melting layer, given that one snowflake one raindrop assumption is valid. Moreover, in this case γ is equal to 0.23.

An accurate observation of this quantity is difficult since it requires knowledge of the mean fall velocities. Since we have no way of knowing the exact fall velocities we only can estimate values of γ to a certain degree of accuracy. In Fig. 2 time profile of the calculated parameter γ is shown. The two dashed lines represent boundaries of the trust region . These boundaries were estimated by taking into account expected ambient air velocity variations. We can see from this figure that if γ values would lie between 0.15 and 0.6 one would expect that assumption of one snowflake one drop is valid. If the value exceeds 0.6 one can treat it as an indicator that snowflakes break-up while melting. If the γ values are less than 0.15 one should expect to observe aggregation of snowflakes.

Let us have a closer look at different melting regimes. In Figs. 3–5 power spectra for region I (1-to-1), II (aggregation) and V (possible break-up?) are shown. From the first glance one can observe that spectrum width above the melting layer for region II is larger than for the other two measurements. This observation complies with the theory that predicts that for aggregation to start a wide distribution of particle sizes is needed, that would allow large, faster falling particles to collect small ones. We can find even more confirmation in Fig. 6 where *hh* power spectra and spectral Zdr are shown for these three regions. The top figure corresponds to the first region, the middle one to the third and the bottom one to the fifth. Since, smaller particles, such as columns and needles, are oblate and larger aggregates, such as graupel, are more spherical one can use spectral Zdr values to differentiate between populations of particles.

In the Fig. 6 one can see that in the one-to-one region there are more of smaller, oblate, particles present. The aggregation regime is characterized by presence of both graupel like particle and oblate crystals, as shown in the Fig. 6. The third region is characterized by presence of mainly aggregates. This region is therefore more likely shows break-up of showflakes. We should note that γ is very high for this region, but due to the uncertainty in the fall velocity we can't make conclusions just based on the value of this parameter.

4 Conclusions

In this study we have shown that the use of spectral polarimetric measurements is advantageous for describing microphysical properties of snow. We have shown that commonly used assumption of one snowflake one raindrop is not always valid. Moreover, using spectral polarimetric analysis we have observed different populations of particles for different melting regimes. Nonetheless, a further study is needed to quantify presented observations.

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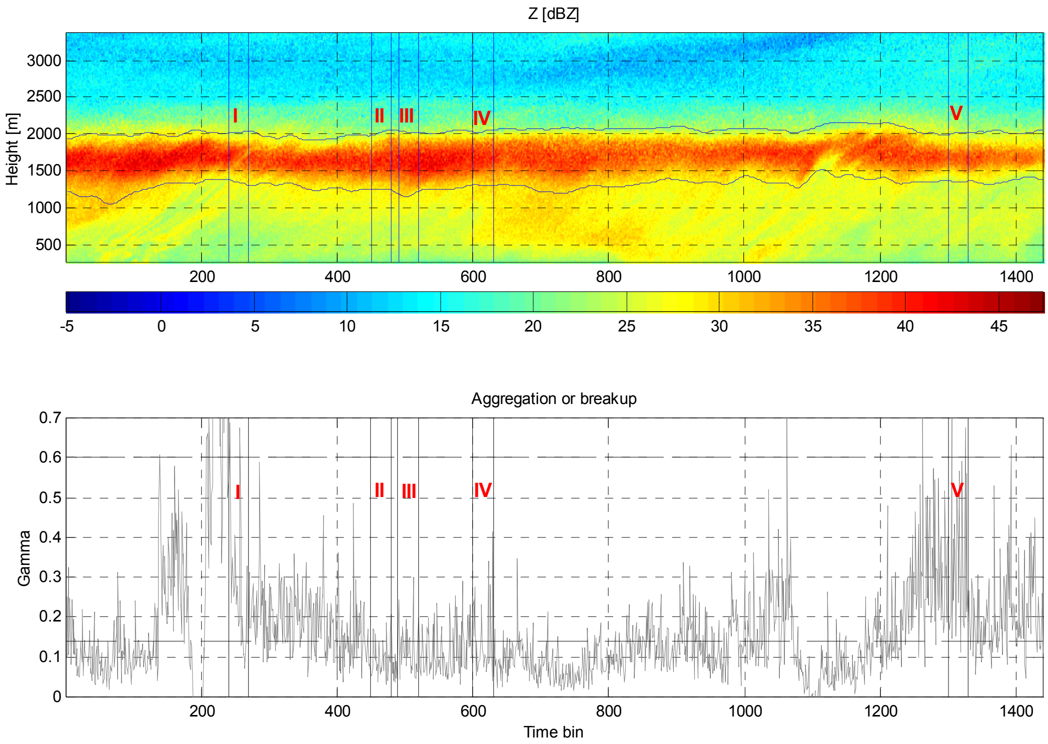

Fig. 2. Range profiles of the precipitation. The measurements were taken at 45 degree elevation angle. The boundaries of the melting layer were detected by finding maximum curvature points of the reflectivity profiles in the neighborhood of the melting layer. The bottom figure shows time behavior of the parameter γ, which is used to detect different melting regimes.

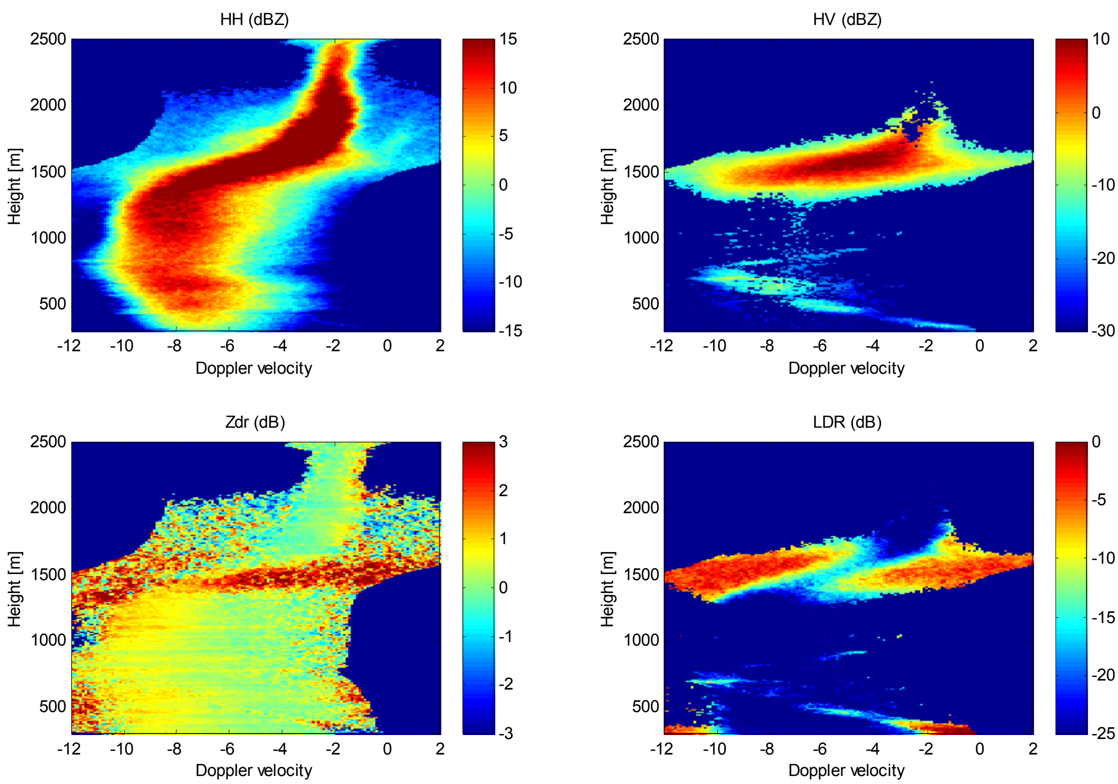

Fig. 3. Doppler power co-polar and cross-polar spectra (above) and spectral Zdr and Ldr (below) of the precipitation. This figure corresponds to the measurements taken in the region I (shown in Fig. 2). This region was classified as one snowflake one drop melting regime.

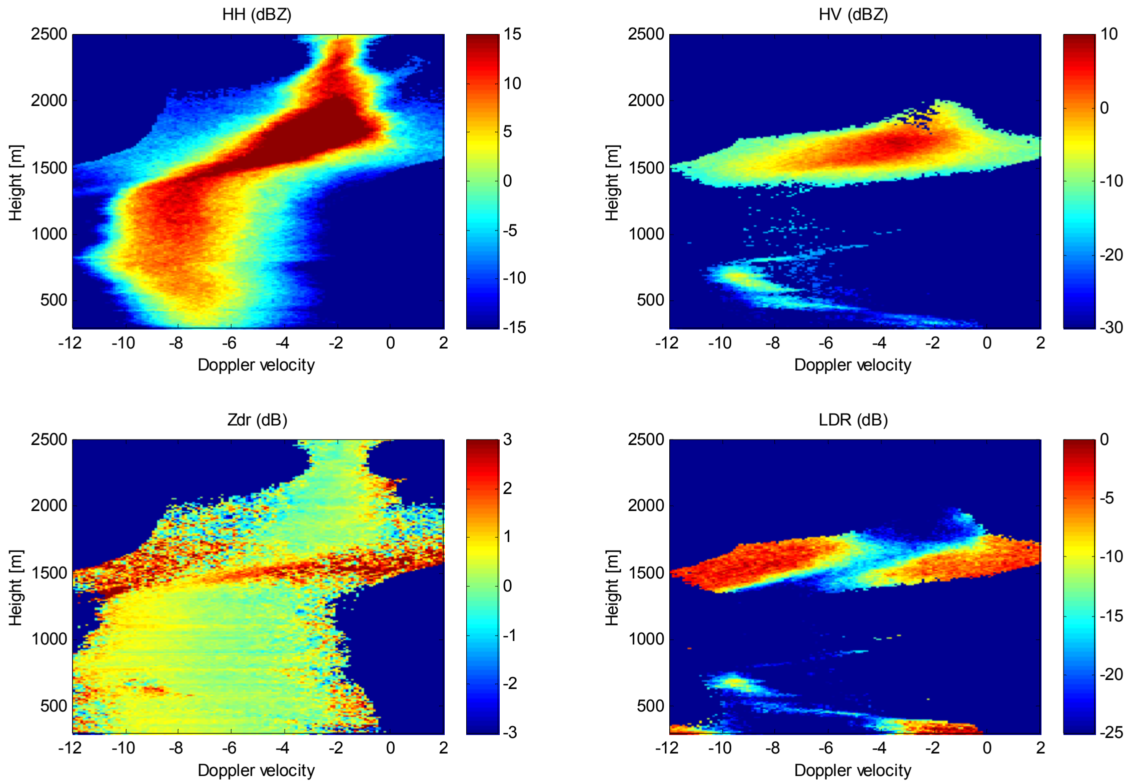

Fig. 4. The aggregation regime, note widened spectrum above the melting layer. The measurements were taken in the region II.

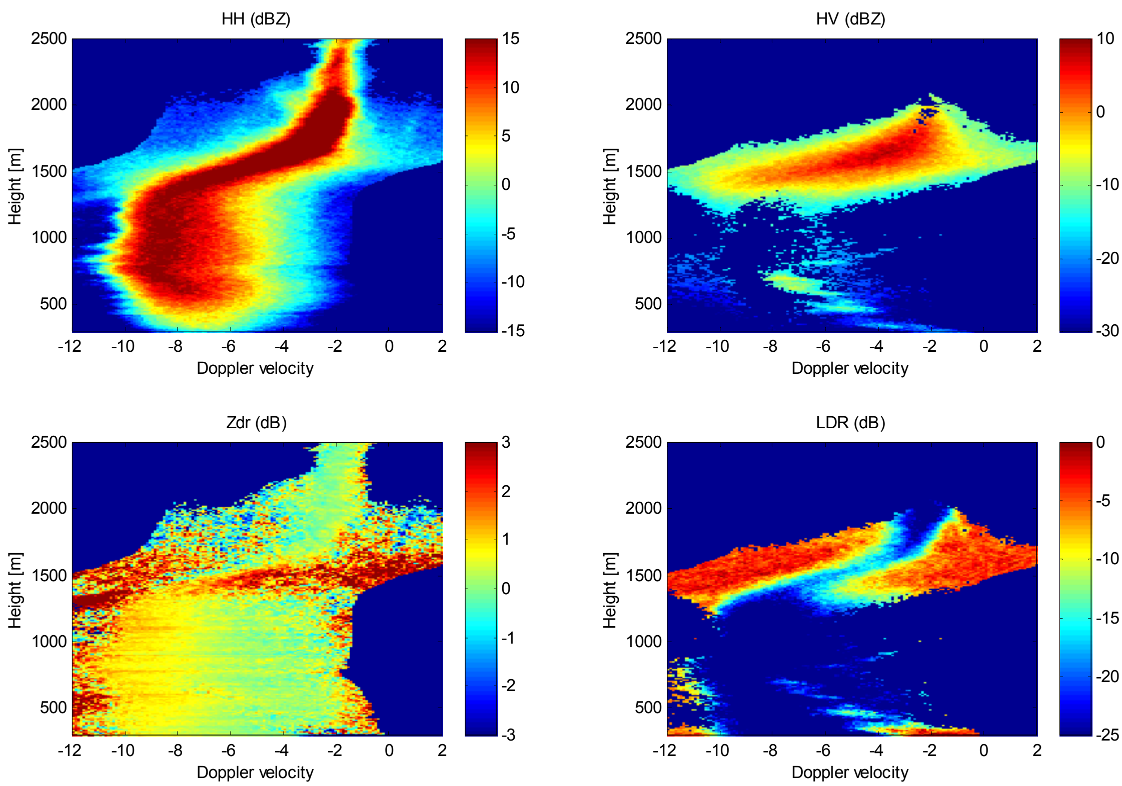

Fig. 5. This measurement was classified as 1-to-1 regime. However, a more thorough analysis shows that it more likely corresponds to the breakup regime. The measurements were taken in the region V.

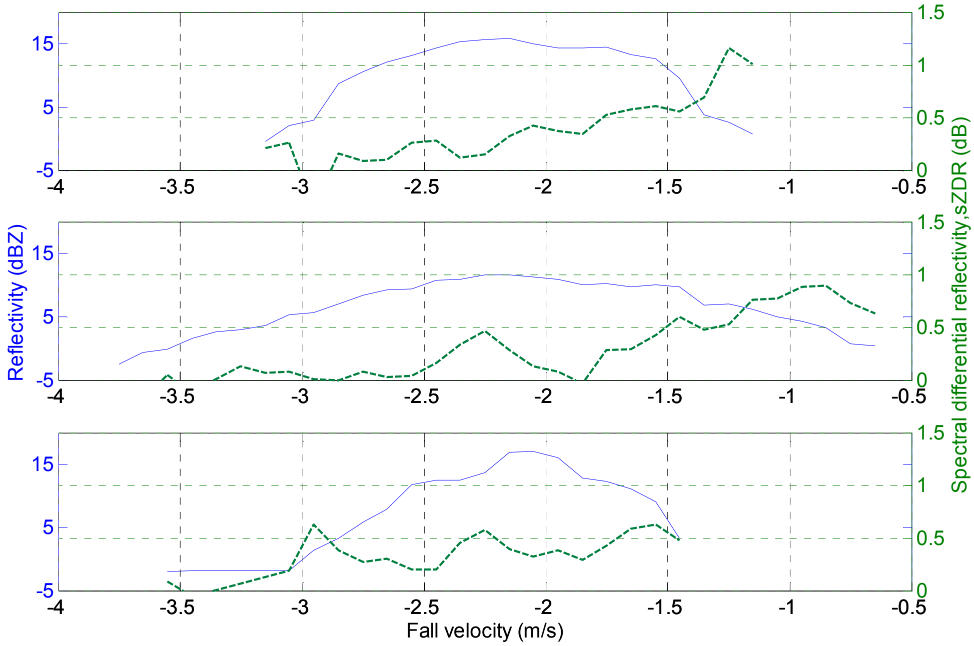

Fig. 6. Power spectra and the sZdr values of snow for the three melting regimes. The figure at the top shows the region I from the Fig. 1. The middle figure shows the region II, and the bottom one represents region V. It should be noted that the region V was identified as 1-to-1 region. Most probably this was a misidentification caused by the velocity uncertainty. The bottom figure shows that Doppler power spectrum is skewed towards larger particles and sZdr values are relatively low. Therefore, most probably region V corresponds to the break-up regime.