THE EFFECT OF THE ORIENTATION OF ICE CRYSTALS IN THE MELTING LAYER AND ICE CLOUDS ON MEASUREMENTS USING RADAR AND LIDAR

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1. ABSTRACT

This paper presents measurements with lidar and radar of the melting layer of precipitation and of ice clouds. The particle shape and orientation have to be accounted for to explain some of the remarkable features of the measurements.

Lidar reflections from ice clouds are known to be very dependent on the direction of the lidar beam. Our measurements indicate that they are also strongly dependent on the orientation of the ice particles. In the layer which the radar and a radiosonde indicate to be turbulent, the lidar reflects on average 10 times less power than in the other parts of the ice cloud.

A similar effect is seen in the melting layer. This layer in which ice melts into raindrops is known in the radar community as 'the bright band', for the high radar reflections. The opposite goes for the lidar reflections from the melting layer which are up to a factor 100 less than that of the rain beneath the layer.

2. INTRODUCTION

In this paper the measurements will be discussed in detail and some mechanisms will be discussed, with emphasis on mechanisms for which non-spherical particles are necessary. As it is hard to understand these mechanisms with information from just one instrument, these measurements show the power of sensory synergy for gaining a better understanding of microphysical processes.

The measurements are part of the Clara project, an extensive multi-sensor field campaign of clouds in the Netherlands. More information on Clara can be found on http://irctr.et.tudelft.nl/projects/clara/

The instrumentation is described in section 3. Then the case of the ice cloud is presented and discussed in section 4. Section 5 is about the dark band in light rain.

3. INSTRUMENTATION

The TU-Delft S-band radar (Darr) has a wavelength of 9 cm and is pointed to the zenith. Two lidars were collocated with Darr during the measurements of light rain. One commercial system: the Vaisala CT75K (KNMI, wavelength 906 nm). RIVM operated the other lidar system, which uses a 1064 nm laser and stores single shots every 0.6 seconds. Both lidar systems show the same trend in their observations.

Figure 1. Lidar reflection of ice cloud, with dark band at 4.2 km. Colour version of all pictures are available at: http://irctr.et.tudelft.nl/reports/1998/conlight/
4. DARK BAND IN AN ICE CLOUD

Specular reflections from horizontal aligned ice crystals are important for lidar measurements in ice clouds. Thomas et al. (1990) e.g. measured a angular dependence of just 0.3° around the zenith by tilting the lidar. In the same way a tilting of the crystals could also reduce the lidar reflection.

4.1 Measurements of ice cloud

A lidar measurement of an ice cloud shows a dark band during almost 4 hours at 4.3 km (fig. 1). For the last part of this measurement there is also radar data available, (fig. 2). The radar also has a small decrease in reflection at this height. The width of the velocity spectrum is much bigger in the dark band. The falling streaks from radar and lidar fit onto each other and the streak seen by lidar at the top and bottom also fit together.

After 9.25 hrs the radar doesn’t get refractions anymore from the top and bottom of the cloud, probably as the particles become smaller at the edge of the vanishing cloud.

Data from a radiosonde revealed a strong change in wind direction. At 4 and 4.6 km the wind direction was North but in the dark band it was East; In the dark band itself it is constant over 200 m. The radiosonde recorded a relative humidity from 75 % at 4 km to 90 % at 4.5 km.

4.2 Discussion

The dark band in this case could be caused by a change in the orientation of the ice crystals. Above and below the dark band the ice crystals are horizontally aligned and thus reflect more power than in the dark band where the particles are disaligned.

This disalignment can be caused by turbulence or wind shear. The radiosonde indicates that the wind shear in the dark band itself is less than in the rest of the cloud, so it’s probably turbulence.

With only lidar information one might be tempted to wrongly assume that there are two cloud layers, although the falling streaks already hinted that this in not the case. The radar provides the extra information needed to fully understand the lidar height profiles.

5. DARK BAND IN THE MELTING LAYER

The bright band is usually explained by an increase of the refractive index of the melting particle at the top of the melting layer and a decrease of particle size and number density at the bottom of the melting layer (Russchenberg et al; 1996). The melting layer for lidar is sometimes seen to give low reflections. For this dark band there is not yet a conclusive explanation. The dark band in the melting layer is described in more detail in Venema et al. (1998).
5.1 Measurements of melting layer

The radar reflection for the 23rd April 1996 is shown in figure 3a, the lidar backscatter of the same period in figure 3b. From this time period the height profiles of radar reflection, radar velocity and lidar backscatter were calculated, see figure 3c.

Remarkable is that the dark band can be very deep. 28 percent of the observations it was more than 10 dB and 11 percent of the cases it was bigger than 20 dB compared to the rain.

The radar reflection in the rain varied between 0 and 20 dBZ (which is typical for all measured dark bands). A dark band of more than 15 dB deep only occurs when the radar reflection in the rain was less than about 15 dBZ (rain rate about 0.2 mm/h).

The rain droplets have diameters between 0.5 and 2 mm. The number density in the rain is in most cases less than 10 m⁻³. There is almost no correlation between this number density and the depth of the dark band. Only for the few points with number density of more than 100 m⁻³ the dark band tends to be less deep.

Measurements made on the 1st of April 1998 show that the lidar reflections in the rain are very dependent on the pointing-angle. If the lidar is pointed to the zenith the reflections are up to four times as high as the measurement under a small angle with the zenith, see figure 4. In the beginning of this measurement the cloud is seen to precipitate ice crystals which melt a few hundred meters lower. This is seen more often.

Measurements made by Sassen (1995) of the dark band show that the optical depolarisation is high above the minimum of the dark band and close to zero below. The radar depolarisation peaks at the height of lidar minimum reflection and is still high in the lower part of the melting layer.

5.2 Discussion

A significant number of measurements show a difference in lidar backscatter of more than 20 dB. So the explaining mechanisms have to be able to give a such a large difference. Furthermore the mechanisms should explain an increase in lidar return at the bottom of the melting layer as well as a decrease at the top of the melting layer, as the decrease is probably not always caused by a cloud bottom, see e.g. the beginning of the measurement on the 1st of April 1998.

The polarisation measurements of Sassen show a low optical depolarisation ratio in the lower part of the dark band, so the optical reflection has to come from a symmetrical particle.

Five mechanisms are proposed: (1) A change in refractive index during melting, (2) aggregation and breakup, (3) collapse of the particle, (4) the orientation and shape of the melting particles and (5) enhanced vertical
backscatter by water droplet shape.

For various reasons the first three mechanisms are thought to give at its best a minor contribution to the dark band [Venema et al]. The last two will be given more attention as they probably give a significant contribution and involve non-spherical particles.

Orientation and shape of the melting particle

For very light rain it may be more useful to think of flat crystals instead of aggregated snowflakes. Symmetrical crystals fall with their biggest dimension horizontally aligned, and reflect mostly in the vertical direction.

In the upper part of the dark band the reflections are dominated by the crystal part of the particle and the reflected power could decrease as the crystals will no longer be falling horizontally. Melting can cause the particle to be no longer symmetrical e.g. if the water droplet is not exactly in the middle.

In the lower part of the dark band the power will come mostly from the liquid part of the particle and will increase as the water fraction will become bigger by the melting of the crystal and reflect more and more power.

With this mechanism a very deep dark band is possible. Furthermore it can explain why the optical depolarisation is almost zero in the lower dark band. It also explains why the dark band begins directly at the top of the melting layer. Aggregation may broaden the scattering peak and thus reduce the depth of the dark band, as found. And it explains the depolarisation results found for lidar and radar.

Enhanced backscatter by water droplet

The case study of the 1st of April 1998 shows that the lidar backscatter of rain is much higher if the lidar is pointed vertically than if the lidar is pointed under a small angle. This may be due to the shape of the droplet. The frictional forces on the droplet may flatten the base of the droplet a little bit; this would increase the lidar backscatter in the vertical direction. This effect can cause part of the increase of the optical backscatter in the lower part of the dark band, as the water fraction of the melting crystal may experience a similar flattening as the amount of water becomes larger and the velocity increases. Further research in this area is needed.

6. CONCLUSIONS

In the melting layer during very light rain a dark band is seen with lidar. The shape of the water droplet can explain (part of) the difference in backscatter between the dark band and the rain. Taking into account the shape and orientation of a melting crystal, can complete the picture; Though it explains the measurements well, there is no direct evidence for this last mechanism.

An experiment with a doppler radar and doppler lidar would be helpful. Velocity information can help to be sure both instruments see the same particles and thus makes the combination of instruments more valuable.

REFERENCES


