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Lidar and Radar Measurements of the melting layer in the frame of the Convective and Orographically-induced Precipitation Study

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ABSTRACT. During the Convective and Orographically-induced Precipitation Study (COPS), lidar dark/ bright bands were observed by the Univ. of BASILicata Raman lidar system (*BASIL)* on several IOPs and SOPs (among others, 23 July, 15 August, 17 August). Dark/bright band signatures appear in the lidar measurements of the particle backscattering at 355, 532 and 1064 nm performed in the melting layer and particle extinction at 355 and 532 nm. Lidar data are supported by measurements from the University of Hamburg cloud radar *MIRA 36* (36 GHz), the University of Hamburg dual-polarization micro rain radars (24.1 GHz) and the University of Manchester Radio UHF clear air wind profiler (1.29 GHz). Results from *BASIL* and the radars are illustrated and discussed to support in the comprehension of the microphysical and scattering processes responsible for the appearance of the lidar dark band and radar bright band.

INTRODUCTION

Changes in scattering properties of precipitating particles are found to take place during the snowflake-to-raindrop transition in the proximity of the freezing level. A maximum in radar reflectivity, known as the radar bright band, is observed in the microwave domain, while a minimum in lidar echoes appears at optical wavelengths, this phenomenon being referred as lidar dark band (Sassen and Chen, 1995). The radar bright band has been known and studied for more than three decades and it is presently a well understood phenomenon (Battan, 1973; Meneghini and Liao, 2000). On the contrary, the lidar dark band has been poorly investigated and, to date, no systematic and coordinated observation are available.

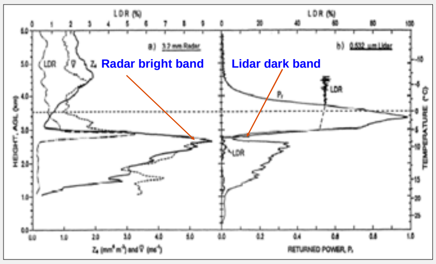


Fig 1: Maximum in radar reflectivity at microwave wavelengths (Radar bright band). **Minimum in particle backscatter in the optical domain** (Lidar dark band, Sassen and Chen, 1995) **Changes in hydrometeor scattering properties take place during the** snowflake-to-raindrop transition, near the 0^0C isotherm

RADARS

During COPS, lidar data were supported by measurements from the University of Hamburg cloud radar MIRA 36 (36 GHz, 0.83 cm, Ka-band), the University of Hamburg dual-polarization micro rain radars (24.1 GHz, 1.24 cm, K-band) and the University of Manchester Radio UHF clear air wind profiler (1.29 GHz, 23.24 cm, UHF band). Additional ancillary information on the state of the atmosphere was provided by radiosondes, launched every three hours during each measurement session, as well as by a sodar and a microwave radiometer. This large "ensemble" of instruments makes the used instrumental setup for the study of precipitating hydrometeors in the melting layer.

BASIL

Lidar measurements were performed by the DIFA-Univ. of BASILicata Raman lidar system (*BASIL*, figs. 2-3*)*. The major feature of *BASIL* is represented by its capability to perform high-resolution and accurate measurements of atmospheric temperature and water vapour, both in daytime and night-time, based on the application of the rotational Raman lidar technique in the UV. Besides temperature and water vapour, *BASIL* is capable to provide measurements of particle backscatter at 355, 532 and 1064 nm, particle extinction coefficient at 355 and 532 nm and particle depolarization at 355 and 532 nm. Lidar systems for precipitation studies need to be shielded from precipitation, which is not the case of *BASIL*. However, a careful operation of the system till the time precipitation reached surface allowed to capture several precipitation episodes involving melting hydrometeors.

Fig.2: BASIL - Interior of the sea-tainer with the laser in the foreground and the receiver in the background.

Fig.3: BASIL - External part of the sea-tainer.

RESULTS

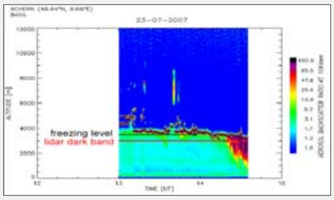


Fig 4. Time evolution of particle backscatter ratio ao 1064 nm

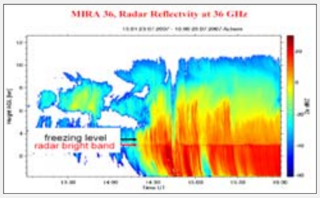


Fig 6. Time evolution of radar reflectivity at 36GHz

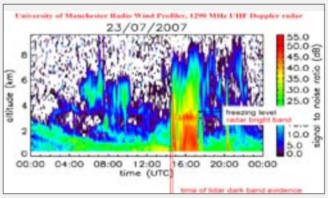


Fig 5. Time evolution of radar reflectivity at 1.29GHz.

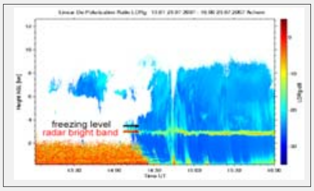


Fig 7. Time evolution of the linear depolarization ratio at 1.29 GHz

Figure 4 illustrates the time evolution of the particle backscatter ratio at 1064 nm over a period of approx. 1.5 hours from 13:00 UTC to 14:35 UTC on 23 July 2007 as measured by *BASIL*. Stratiform clouds persist throughout the measurement record, with a cloud base of 3.4-3.8 km. Around 14:15 UTC melting hydrometeors start precipitating from clouds. Freezing level, identified through the radiosonde launched at 14:00 UTC, is located at 3.5 km (black arrow in figure). The dark band appears a horizontal line of lower particle backscatter values at 2.8-2.9 km between 14:15 and 14:35 UTC (red arrow in figure).

Figure 5** and **Figure 6 shows the evolution with time from 00:00 UTC to 24:00 UTC on 23 July 2007 of the radar reflectivity at 1.29 GHz and 36 GHz respectively, measured by the University of Manchester clear air wind profiler. The radar bright band peak (red arrow in figure) occurs in the melting region at 3.0-3.1 km, just above (100-200 m) the lidar dark-band minimum. Vertical lines in the figure identify the period of lidar dark band observation.

Figure 7 illustrates the time evolution of the linear depolarization ratio at 1.29 GHz from 13:00 UTC to 16:00 UTC on 23 July 2007 as measured by *MIRA 36*. The figure reveals the presence of enhanced depolarization values in the bright band layer, where linear depolarization ratio values reach -10 dB. Lidar depolarization, on the contrary, is found to be absent at the height of the lidar dark band and to be maximum near the bottom of the melting layer, where severely melted snowflakes collapse into raindrops (not shown here). ***Figure 8*** shows again the particle backscatter ratio at 1064 as in figure 4. However, a different colour scale is used in order to highlight precipitation streams.

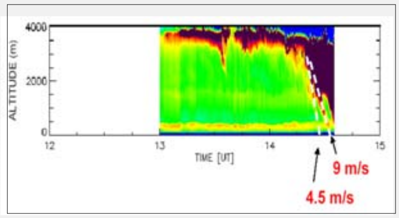


Fig 8. Time evolution of the particle backscatter ratio at 1064 nm

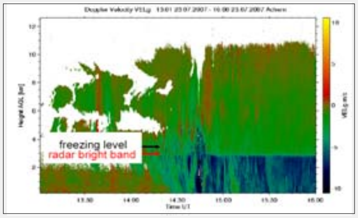
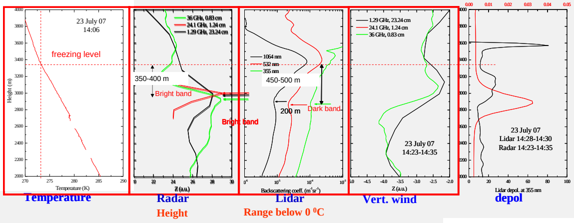


Fig 9. Time evolution of hydrometeors vertical velocity

The slope of the precipitation streams in the time-height map allows to roughly quantify the fall speed of precipitating hydrometeors. This approach assume that there is no horizontal advection of the precipitating particles. Fall speed estimates are in the range 4.5-9 m/s. These values are in agreement with those measured by *MIRA 36* (***figure 9***). Values of Doppler vertical velocity are not exceeding 4 m/s above the melting layer, with an abrupt transition to much larger values (5-10 m/s) in the lower portion of the melting layer.



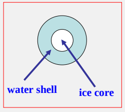
Freezing level	~ 3350 m a.g.l.	-		
Radar bright band	2950-3000 m a.g.l.	350-400 m	3.4 - 3.9 ^{0}C	276.5-277.0 K
Lidar dark band	2850-2900 m a.g.l.	450-500 m	4.4 - 4.9 ^{0}C	277.5-278.0 K
Lidar bright band	2700-2750 m a.g.l.	600-650 m		

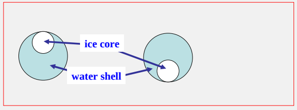
Lidar depol 25-30 % @ 3200 m, ~ 10 % @ 2850 m a.g.l.
Radar depol peak @ 2900 m a.g.l.
Radar Doppler velocity (@) reaches its plateau @ 2600-2700 m

Unexpected low values of lidar depolarization at the height of the lidar dark and bright bands, which may imply that precipitating particles are almost spherical.

Simulation approach:
We combine:
- a Mie scattering code
- melting layer model

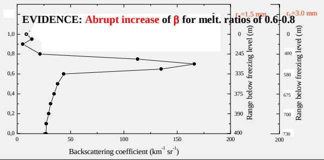
Mie computations based on a concentric/eccentric sphere code





Melting hydrometeor model:
water shell + ice core
(Yokoyama and Tanaka, 1984; Olson et al., 2001)

Backs. Coeff. at 0.35 µm versus core/shell radius ratio r_c/r_s



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