J.P.1.22 SIMULATIONS AND MEASUREMENTS OF RADAR REFLECTIONS FROM THE MELTING LAYER OF PRECIPITATION AT MM WAVELENGTHS

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1. Introduction

The melting layer of precipitation is the layer below the 0ºC isotherm where snowflakes melt and turn into raindrops. This layer is commonly known as the 'radar bright band' because it often appears as a band of enhanced reflectivity when viewed through radar operating at cm or mm wavelengths. The microphysics of the melting layer of precipitation as well as its interaction with electromagnetic waves are important both in climate studies and in telecommunications: on the one hand, the melting layer is a characteristic feature of stratiform precipitation; on the other hand, this layer has a degrading effect on satellite communication links.

In this study we present simulations and measurements of radar reflections from the melting layer of precipitation. Our objective is the validation of a theoretical model of backscattering of EM waves from the melting layer of precipitation. The theoretical model is briefly described in Section 2; it combines a simple microphysical model of the melting layer of precipitation [1] with a T-matrix technique for calculating the scattering of EM waves by partially aligned axially symmetric particles [2,3]. The radar observations are presented in Section 3; they were made during the Baltex/Bridge Cloud campaign [4] by use of an atmospheric radar with Doppler and polarimetric capabilities [5]. Comparisons between simulations and measurements are presented and discussed in Section 4. Finally, concluding remarks and suggestions for future work are made in Section 5.

2. Theoretical model of radar reflections from the melting layer of precipitation

a. Microphysical model

A simple model is used to describe the complex microphysical processes in the melting layer of precipitation. This model is outlined below; it is described in more detail in Ref. 1.

Main assumptions and input parameters: It is assumed that particles neither aggregate nor break up while melting, that is, that each snowflake yields a single raindrop. Furthermore, the mass flux is assumed to remain constant throughout the melting layer. Hence, the size distribution and the number concentration of the particles at all heights in the melting layer can be determined by use of only two input parameters: the rain intensity, R, below the melting layer and the density of the snow particles, ρ_s, above the melting layer.

Melting rate: The melted mass fraction increases monotonously with the depth that the particle has descended into the melting layer. The depth of the melting layer is empirically related to the rain intensity.

Particle size: Raindrops below the melting layer are assumed to follow a Marshall-Palmer drop size distribution. The polydisperse size distribution is approximated by a monodisperse one with equal mean volume.

Particle fall speed: Raindrops are assumed to fall with terminal velocity (Gunn and Kinzer law). The fall velocity of melting particles depends on their drag coefficient, which decreases linearly with their diameter.

Particle shape: Melting particles are assumed to be oblate spheroids with axial ratios depending on the size and on the stage of melting of the particles. In particular, at the top of the melting layer small ice particles are assumed to be more oblate than large ones whereas at the bottom of the melting layer small raindrops are assumed to be less oblate than large ones.

Particle orientation: The orientation of the melting particles is described by a probability density function over orientations that is symmetric about the vertical direction. The width of this probability density function depends on the stage of melting: it decreases from the top to the bottom of the melting layer.

b. Scattering model

Melting particles are inhomogeneous mixtures of air, snow, and water, the relative fraction of each constituent depending on the stage of melting. For the purposes of this study, melting particles are treated as homogeneous and an effective dielectric constant is assumed. The latter is obtained as the average of the Maxwell-Garnett mixing formula for two different topologies: snow inclusions in a water matrix and water inclusions in a snow matrix.

Scattering calculations assume single and incoherent scattering. Furthermore, the attenuation of the radar signals in their propagation path is neglected. The radar polarimetric signature of a collection of partially aligned melting particles is described in terms of the ensemble-averaged backscattering covariance matrix. The latter is calculated by use of the T-matrix approach and of a technique for averaging over particle orientations analytically [2,3]. The time-consuming computation of the T-matrix is done for only one orientation of the scattering particle, namely for the case where the symmetry axis of the particle is directed along the direction of the incident EM wave. The average over all possible orientations is then calculated analytically through use of the quantum theory of angular momentum. This technique is described in detail in Refs. [2,3]; it is an extension to the T-matrix method for randomly oriented axisymmetric particles [6], which has been reported [7] to speed up calculations by a factor of several tens.

c. Simulated profiles of radar observables

Simulated profiles of radar observables (at S, Ka, and W band) are shown in Fig.1. Plotted are the horizontal equivalent reflectivity factor, Z_{HH}, the linear depolarization ratio, $L_{DR}=10\log(Z_{HV}/Z_{VV})$ and the differential reflectivity, $Z_{DR}=10\log(Z_{HH}/Z_{VV})$.

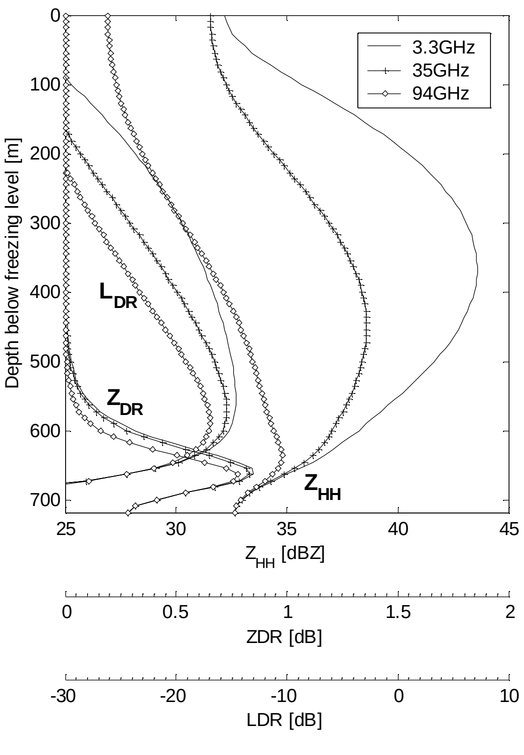


Fig.1 Simulated profiles of radar observables

The values of the various model parameters are given in Table 1. At S band, all radar observables exhibit peaks that appear in the following order from the top to the bottom of the melting layer: Z_{HH}, L_{DR}, and Z_{DR}. The values as well as the location of the peaks of the radar observables are in agreement with reported measurements [1,8]; this issue is further discussed in Section 4. At higher frequencies, the strength of the bright band peak can be seen to decrease significantly (35 GHz) or to almost vanish (94 GHz). In contrast, the profiles of the polarimetric observables L_{DR} and Z_{DR} are less affected, which is in agreement with intuition since these observables are primarily dependent on the shape and not on the size of the particles. The results indicate that the melting layer might still be identified at 35 and at 94GHz by means of its polarimetric signature.

Frequency	3.3GHz
Elevation angle	60º
Rain intensity	4 mm/h
Snow density	0.12 gr/cm^3
Orientation width (snow)	90º
Orientation width (rain)	3º
Minimum axial ratio	0.3
Maximum axial ratio	0.9

Table 1. Model parameters for Figs. 1

3. Measurements of radar reflections from the melting layer of precipitation

a. Measurement event and instrumentation

Radar observations of the melting layer of precipitation were made on the 19th of September, 2001, in the framework of the Baltex/Bridge Cloud Campaign. During the measurement period (from 09:00 to 12:00 UTC) there was stratiform rain of moderate to hard intensity. The 0° isotherm was recorded by radio soundings to be at a height of approximately 2Km.

Two collocated radar systems were used, operating at the S band and the Ka band, respectively. However, the Ka band radar signal was severely attenuated by water droplets forming on the antenna shroud; the Ka band measurements are, therefore, not discussed in what follows. The S band system is the TARA atmospheric radar [7], developed and operated by the Delft University of Technology. It is a 3.3GHz FM-CW Doppler-polarimetric radar, capable of recording the time series of the beat signal. The settings of the radar system during the measurement period are summarized in Table 2.

Transmit power	0.34Watt
Range resolution	15m
Time resolution	1.536sec or 2.560 sec
Polarization states	VV,HV, HH
Elevation (from horizontal)	90º, 75º, 60º, 45º

Table 2. Settings of TARA atmospheric radar

b. S band measurements

Figs.2 depict time-height images of the radar observables during a 15-minute measurement periods. The radar elevation angle is 60º. A band of enhanced reflectivity (from 2000m up to approximately 1500m) is clearly identifiable in the Z_{HH} image. Cross-polar returns, as evidenced in the L_{DR} image, only become significant at the lower part of the melting layer while the Z_{DR} peak appears slightly below. Note that the polarimetric observables seem to follow the variation of the Z_{HH} peak, despite the horizontal variability.

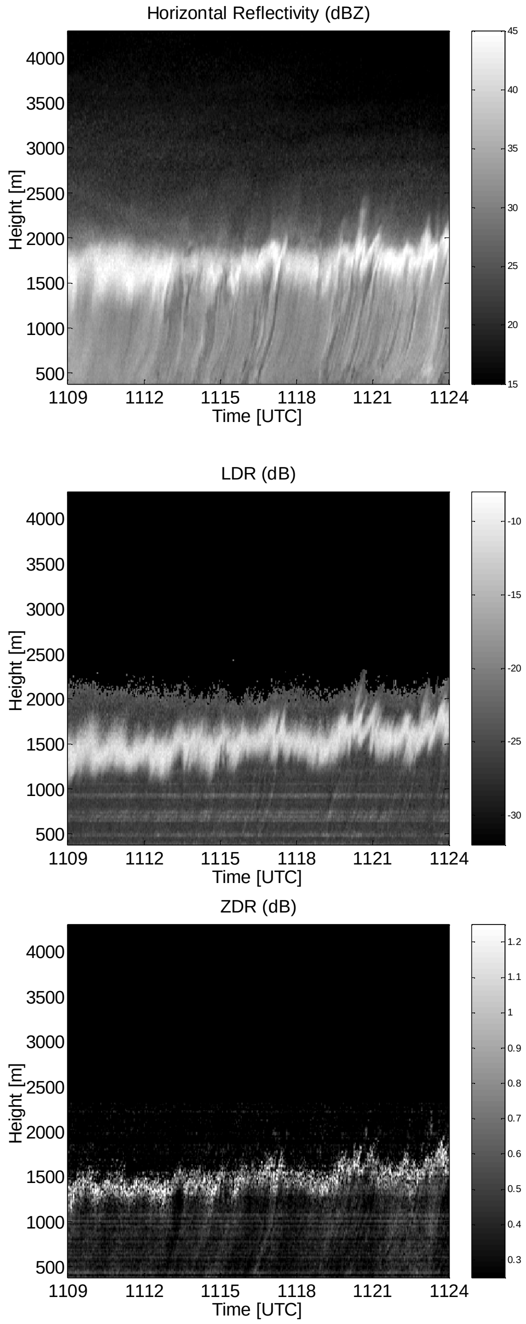


Fig.2 Z_{HH}, LDR and ZDR at 60º elevation

More insight can be gained by means of the measured Doppler spectra. The spectrograph of Fig.3 represents a 2-minute period of vertically pointing measurements. Each horizontal line corresponds to a Doppler spectrum of horizontal reflectivity at a particular height. Above the freezing level (~2000m) the Doppler spectra are narrow (within the range from 1m/sec to 2m/sec) whereas below the freezing level the Doppler spectra become wider and the mean velocity increases significantly (negative velocities are approaching the radar). Note that the spectra below the freezing level have been unfolded.

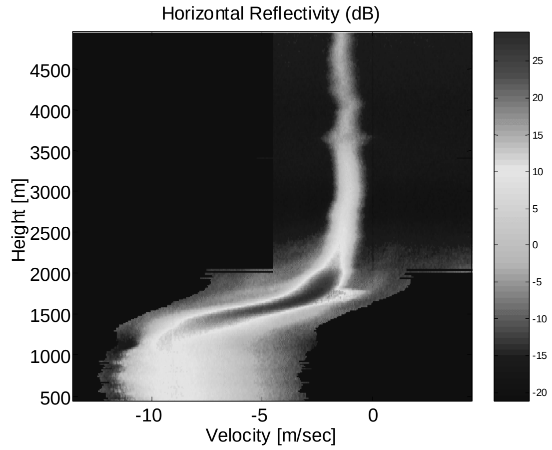


Fig.3 Spectrograph of copolar reflectivity

4. Comparisons between measurements and simulations

Figs. 4 depict simulated height profiles alongside of measured ones for three different illumination angles. The frequency is 3.3GHz and the parameters of the theoretical model (apart from the elevation angle) are those of Table 1.

The simulated profiles can be seen to agree fairly well with the measured ones: the values of the peaks of the radar observables as well as their relative location are close to the observed ones. None the less, the peak L_{DR} value is underestimated by about 3dB in all cases, the L_{DR} peak is shifted upward, and the simulated Z_{DR} peak is narrower than the observed one.

5. Conclusions and future work

A theoretical model which combines microphysics of the melting layer of precipitation with a T-matrix method for the backscattering of EM waves by partially aligned particles is shown to agree fairly well with observations at 3.3GHz. Simulations at higher frequencies indicate the presence of Z_{DR} and L_{DR} peaks in the melting layer of precipitation even when there is no bright band.

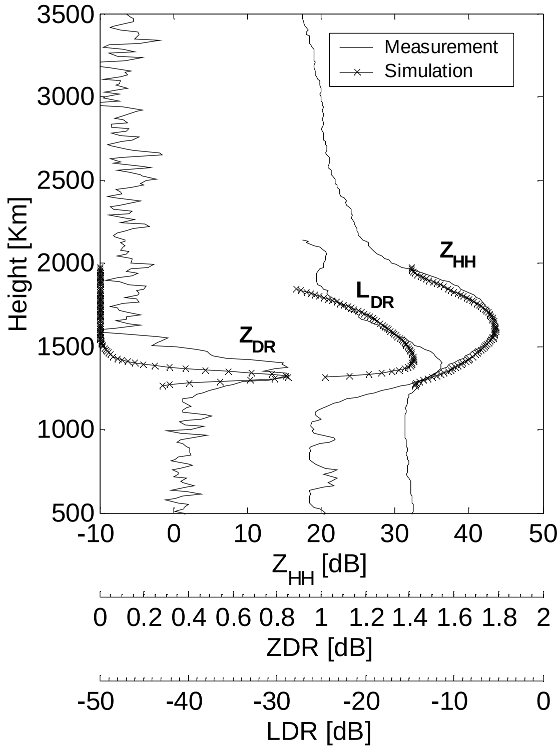
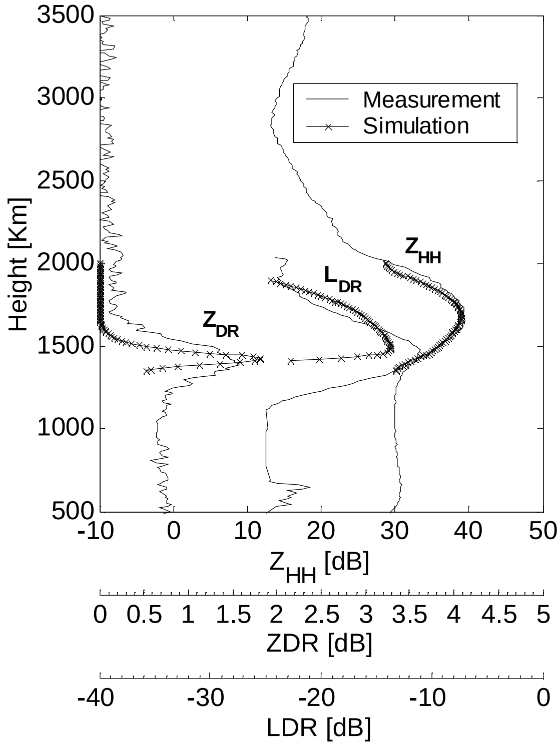


Fig.7 Simulations against observations at 3.3GHz (a) Elevation=60º



(b) Elevation=45º

Future plans include a more comprehensive assessment of the theoretical model via comparisons with observations at 35 and at 94GHz. In addition, comparison of simulated Doppler spectra with measured ones can indicate how the microphysical model should be refined. Finally, other factors that should be taken into account are (a) the attenuation of the radar waves in their propagation path, and (b) effects from the radiation pattern of the radar antennas.

Acknowledgements

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