5B.3 RADAR DOPPLER POLARIMETRY APPLIED TO PRECIPITATION MEASUREMENTS: INTRODUCTION OF THE SPECTRAL DIFFERENTIAL REFLECTIVITY

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1. INTRODUCTION

The differential reflectivity *Zdr* which is the ratio of horizontally and vertically polarized radar signals, is sensitive to the shape and orientation of the hydrometeors. It indicates the presence of particles with different shapes and orientations in the different meteorological layers of precipitation: rain, melting layer and precipitating cloud. The value of this parameter is related to a mean shape, which is not always representative of the measured particles.

A major improvement for understanding the microstructure of precipitation can be achieved by combining simultaneous Doppler and polarimetric information. Two power Doppler spectra, *hh* and *vv* must be measured simultaneously in order to obtain the Doppler velocity spectrum of *Zdr*. The spectral differential reflectivity *sZdr* is thus defined for each Doppler velocity and provides detailed measures of the microstructure of precipitation.

The Doppler velocity spectrum gives the distribution of the drop fall velocity. In case of rain, the Doppler velocity can be related to the size of the hydrometeors. Because *sZdr* is a function of the Doppler velocity and sensitive to the shape of hydrometeors, this enables the study of the shape-size relationship. When turbulence occurs, the relation *sZdr* versus Doppler velocity changes. From the study of this change, a second application of this new parameter can be investigated: remote observation of the eddy dissipation rate of turbulence in rain storms.

In the paper the principle of the spectral differential reflectivity is discussed. Measurements, done with the Delft Atmospheric Research Radar (S-band, wavelength = 9 cm), are used to demonstrate the potential of *sZdr*.

2. DOPPLER POLARIMETRY AND DEFINITION OF THE SPECTRAL DIFFERENTIAL REFLECTIVITY

For atmospheric measurements, the time behavior of one element of the scattering matrices can be described as a random process. Therefore a second moment analysis of the time series of scattering matrices is performed using a covariance matrix, Ryzhkov (2001). The covariance matrix elements are the correlation and cross correlation functions of the random processes *Shh*, *Shv* and *Svv*. The differential reflectivity *Zdr* (1) is defined from the correlation functions at the time lag 0, *Rhh* and *Rvv* (2) and is expressed in dB. The integer *n* represents the range bin considered, *t* is time and < > indicates time average. The subscript *xx* represents *hh* or *vv*.

$$Z_{dr}(n) = 10\log\left(\frac{R_{hh}(0,n)}{R_{vv}(0,n)}\right) \qquad (1)$$

where

$$R_{xx}(0,n) = \left\langle S_{xx}(t,n)\,S_{xx}^{*}(t,n)\right\rangle \qquad (2)$$

The covariance matrix elements and the differential reflectivity derived from two of these elements, show averaged polarimetric properties of the range bin considered. In this case, the differential reflectivity describes a mean particle shape. The value 0 dB indicates for example a mean spherical shape (*Rhh=Rvv*).

When the random processes are stationary, a second moment spectral analysis can be performed. The dynamic properties of the targets are then also considered. Using the time series of scattering matrices, the Fourier transform of the correlation and cross correlation functions leads to the power spectra *hh*, *hv* and *vv* and the cross spectra (*hv*, *hh*), (*vv*, *hh*) and (*vv*, *hv*). They form the elements of the spectral covariance matrix, which is then defined for each range bin *n* and each Doppler frequency *l*. This results in a complete target description, combining polarimetric and dynamic properties of the radar target. We call this description radar Doppler polarimetry and the spectral covariance matrix is a Doppler polarimetric result.

In particular, the spectral differential reflectivity (3) can be defined from two elements of the spectral covariance matrix: the Doppler power spectra *Fhh* and *Fvv* (4). The expression $l\,w_D$ is the Doppler angular frequency and *Tm* is the time between two successive measurements involving the same polarization and range.

$$sZ_{dr}(l,n) = 10\log\left(\frac{F_{hh}(l,n)}{F_{vv}(l,n)}\right) \qquad (3)$$

where $F_{xx}(l,n) = \sum_{m} R_{xx}(m,n)\,e^{-jlw_D mT_m}$ (4)

and $R_{xx}(m,n) = \left\langle S_{xx}(t,n)\,S_{xx}^{*}(t+mT_m,n)\right\rangle$ (5)

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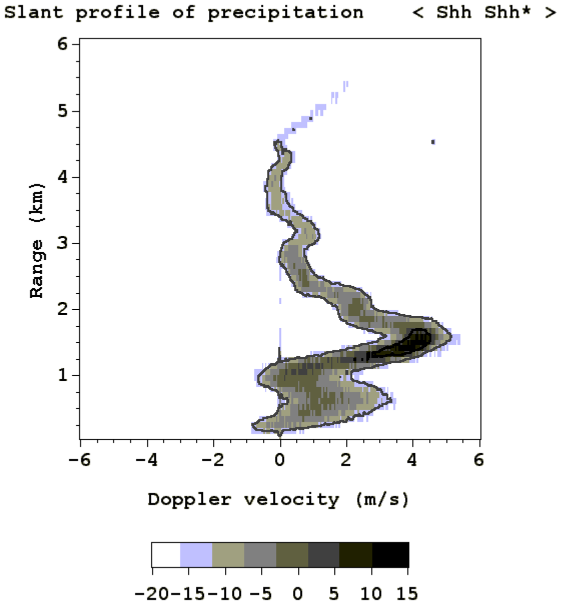

FIGURE 1. SPECTRAL REFLECTIVITY (dBZ)

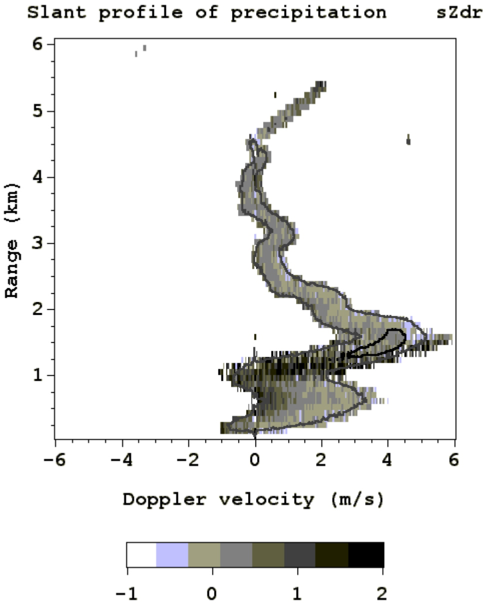

FIGURE 2. SPECTRAL DIFFERENTIAL REFLECTIVITY (dB)

The spectral differential reflectivity *sZdr* has the meaning of *Zdr* for each Doppler frequency resolution bin.

3. MEASUREMENTS

The scattering matrix, expressed in the linear basis (*h*,*v*), is obtained each 3.75 ms. A cycle of 3 measurements of 1.25 ms each (*hh*, *hv*, *vv*) is repeated in time to acquire time series of scattering matrices. Then, selecting a specific range and polarization, a Doppler FFT is carried out. The result consists of 3 Doppler spectra per range and is obtained each 1 s.

The spectral reflectivity and the spectral differential reflectivity for a slant profile of precipitation are given in Figs. 1 and 2, respectively. The slant profile is measured with an elevation of 30 degrees. The maximum range of 6 km corresponds to a maximum height of 3 km. The range resolution is 89 meters. This event represents light rain. The reflectivity of rain is 13 dBZ. The reflectivity is the summation of the spectral reflectivity values. The rain intensity is less than 1 mm/h. The averaging time is 20 s. Though the measurement is carried out with a radar azimuth orthogonal to the horizontal wind direction, the Doppler velocity contains a wind Doppler velocity component in both figures. There are large variations of the horizontal wind direction as a function of height, which leads to zigzag slant profiles.

Two contours, which are related to the spectral reflectivity, are drawn. The first one is an envelope contour of the precipitation at –15 dBZ, which leads to a minimum signal-to-noise ratio of 28 dB. The second contour at 5 dBZ indicates the peak of the melting layer. This spectral reflectivity peak is located between the ranges 1.3 and 1.75 km (upper part of the melting layer). Above the melting layer, there is the precipitating cloud. The whole melting layer is comprised between the ranges 1 and 1.75 km. The peak of the spectral differential reflectivity (Fig. 2) is located between 1 and 1.3 km (lower part of the melting layer). Under 1 km, there is rain.

The lower part of the melting layer shows inhomogeneities in Fig. 2. There is a rather large variability of the spectral differential reflectivity without clear trend. It is different for rain where *sZdr* shows a clear dependency with the Doppler velocity. An example is given in Fig. 4. The corresponding Doppler spectrum of the reflectivity is plotted in Fig. 3.

4. THE SPECTRAL DIFFERENTIAL REFLECTIVITY AS TURBULENCE INTENSITY PARAMETER ?

Research is being carried out to investigate theoretically and experimentally the use of *sZdr* to characterise turbulence intensity. For this purpose, a model is developed (Yanovsky) and leads to the spectral differential reflectivity in dB versus the Doppler velocity in m/s for several eddy dissipation rates. This is illustrated in Fig. 5 where four theoretical curves (black), that characterize negligible turbulence until severe turbulence, are plotted. The fifth curve (grey) is a fitted curve using *sZdr* data in rain of the presented slant profile. The *sZdr* data are also plotted in Fig. 5. For this slant profile measurement, the turbulence intensity is expected to be negligible.

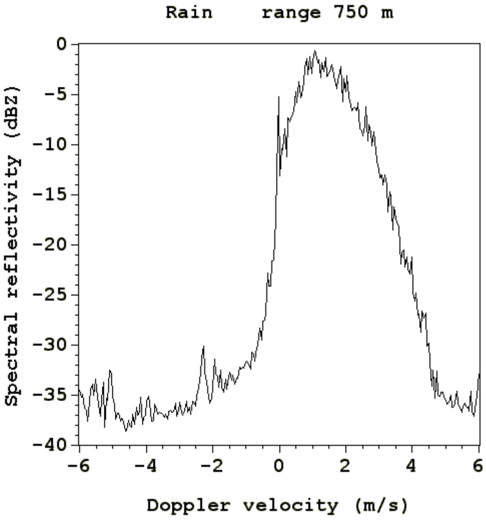

FIGURE 3. REFLECTIVITY DOPPLER SPECTRUM

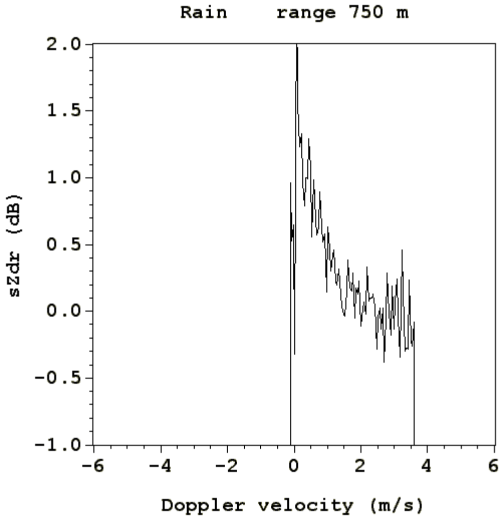

FIGURE 4. SZDR VS. DOPPLER VELOCITY

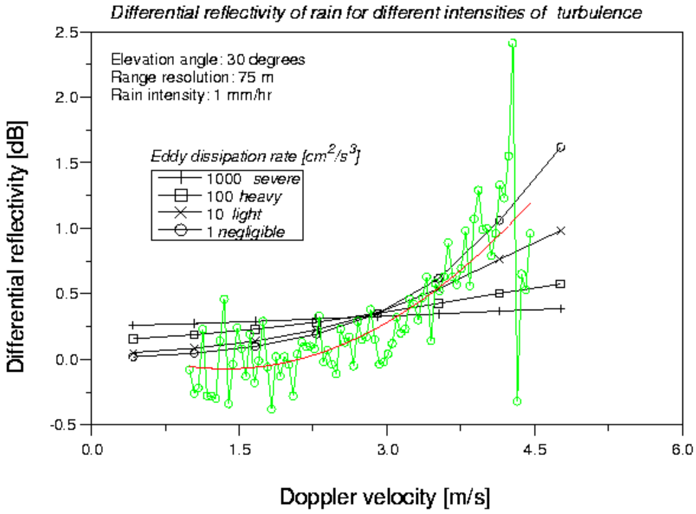

FIGURE 5. MODEL DEVELOPMENT ILLUSTRATION

In absence of turbulence, the Doppler velocity spectrum results in a distribution of the drop fall velocity. Therefore the hydrometeors are classified from small to large in size, which is equivalent in rain from spherical shape (*sZdr* = 0 dB) to spheroidal shape (*sZdr* equals a few dB's). When there is turbulence, this classification is perturbated and there is mixing of small hydrometeors with large hydrometeors in a Doppler velocity resolution bin. Therefore the large positive correlation between *sZdr* and Doppler velocity becomes less until disappearance in case of strong turbulence where all the sizes of hydrometeors are present for each Doppler velocity resolution bin.

REFERENCES

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