SOME RELATIONSHIPS BETWEEN OBSERVABLES OF DOPPLER-POLARIMETRIC RADAR AND RAIN PARAMETERS

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ABSTRACT

In this study on the basis of the system of physical and mathematical models, which were developed in the framework of joint Delft-Kiev project, the relationship between microstructure & dynamics of rain and Doppler-polarimetric parameters of reflected radar signal is derived. Rain rate and turbulence in rain can be retrieved on this basis.

I. INTRODUCTION

Determination of the relationships between radar echo-signal characteristics and intensity of rain is the oldest problem of radar meteorology. Later more sophisticated parameters of rain microstructure and turbulence in rain became available for the deriving from radar returns. The implementation of Doppler-polarimetric radars opens new possibilities to improve the quality of radar measuring intensity and other parameters of rain.

This paper describes some results of the joint research project "Study on new techniques for atmospheric radar remote sensing", which was fulfilled by the International Research Centre for Telecommunications-transmission and Radar (IRCTR) at the Delft University of Technology (The Netherlands) and the Kiev National Aviation University (Ukraine). The complex of mathematical models is developed in the framework of this project to describe features of manifestations of rain microstructure and turbulence in rain during their interaction with radar signal [1]. Computer simulation of Doppler-polarimetric spectra of radar signal from rain is done on the basis of these models. General model uses rain microstructure and turbulence parameters as initial data. The model gives Doppler spectra at different combinations of linear polarization of transmitting and receiving waves. During the investigation of the developed model some new relationships between radar observables and the reflecting weather object were discovered.

In this paper we consider three Doppler-polarimetric parameters: mean Doppler velocity at orthogonal polarizations, Doppler spectrum width at different polarizations, and the slope of the regression line of a specific differential reflectivity. We will show that these parameters can be related with microstructure and turbulence in rain. Finally, eddy dissipation rate and rain rate will be retrieved.

II. MODELS OF RAIN MICROSTRUCTURE AND DYNAMICS

The microstructure of rain is described by statistical distributions of the size, shape, fall speed, orientation, and concentration of raindrops. The fall speed of raindrops in stagnant air is related to their size. The shape of a falling raindrop is not exactly spherical: it is flattened at the base. In quiet air the horizontal axis of a spheroid droplet is horizontal. Local disturbances of the air density and wind variations may force the raindrop to cant. The canting angle of drop is a random value assumed to be subjected to Gaussian distribution. The gamma-distribution is used as a model of dropsize distribution:

$$N(D) = N_0 D^{\mu} e^{-\frac{3.67+\mu}{D_0}D} \qquad (1)$$

with μ as spread parameter, and D_0 as median drop diameter. The dropsize distribution plays an important role in the development of the model because it effects on both Doppler and polarization characteristics. The inertia of raindrops in a turbulent environment is taken into account in accordance with [2].

The turbulence energetic spectrum $S(\Omega)$ is a decomposition of the kinetic energy of turbulence in Fourier series on the wave numbers $\Omega = 2\pi / L$ (spatial frequency). In the inertial subrange, if the conditions of homogeneity and local isotropy of turbulence are valid, the analytical expression of turbulence spectrum is:

$$S(\Omega) = C\ \varepsilon^{2/3}\Omega^{-5/3} \tag{2}$$

where C is a dimensionless constant, and ε is the eddy dissipation rate. Ω is defined as $\Omega = |\vec{\Omega}| = 2\pi/L$ with $\vec{\Omega}$ as three-dimensional turbulence wave-vector. The kinetic energy of turbulence passes on consecutively from large scales to small ones, and then it is dissipated at the scale $l \le l_{min}$. The latter process is quantified by the eddy dissipation rate ε, which is a fundamental parameter of turbulence that characterizes the turbulence intensity. It does not depend on scale of turbulence within the inertial subrange, which makes ε convenient as an initial parameter for the modeling.

III. DOPPLER-POLARIMETRIC SPECTRA

The Doppler measurements give the information about the dynamic properties of the process (for example, wind, speed of drops falling), and the polarimetry is connected to the shape and orientation of the hydrometeors. For researching the relationship between the intensity of precipitation and radar echo the model [1] was used. It takes into consideration the polarization properties of radar signal, reflected from the ensemble of raindrops as a function of their speed. The model is based on several previous ones. There are the two main basic models: the model of radar signal from precipitation [3], which takes into account the polarization features caused by the shape and spatial orientation of drops and the model of influence of turbulence on radar scatteres [2]. The model allows calculating the power spectra of radar signals from rain $S_{mn}(v)$, where v – is the radial component of Doppler speed, at different combinations of polarization on transmitting (first index) and receiving (second index). The indexes may have the following meanings: m=*x; y*, *n=x; y*, *x-y* - linear orthogonal polarization base. If the basis is "horizontal - vertical" (*x=h; y=v*), the model provides spectra $S_{hh}(v)$, $S_{vv}(v)$, which correspond to the two main polarization components on orthogonal polarizations. The model takes into account parameters of atmospheric turbulence - eddy dissipation rate ε and the range of turbulence scales L_{max}, parameters of radar and the characteristic of a microstructure of rain - dropsize distribution, which allows to calculate the rain intensity.
Doppler spectra calculated for one radar volume of rain at horizontal *hh* and at vertical *vv* polarizations are shown in figure 1.

IV. RATE RAIN RETRIEVAL

First we will consider the difference between mean Doppler velocity at orthogonal polarizations. Such parameter was first introduced by [4] and named Differential Doppler Velocity (DDV).

The purpose of this section is to show that DDV is related not only with rain intensity but also is depended on turbulence in rain.

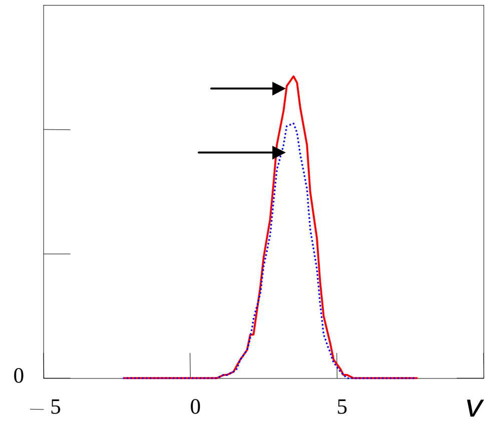

Fig. 1. Co- polar Doppler spectra

The normalized Doppler spectra can be written as

$$S_{Nmn}(v) = S_{mn}(v) \Big/ \int S_{mn}(v)dv. \tag{3}$$

So, the mean speeds of droplets can be calculated as the first ordinary moment:

$$\bar{v}_{mn} = \int v\, S_{Nmn}(v)dv. \tag{4}$$

Measured parameter, which can be metered with the help of Doppler-polarimetric radar, is the difference between the mean speeds, which are retrieved at orthogonal polarizations: $\Delta V = \bar{V}_{hh} - \bar{V}_{vv}$. Parameter ΔV is DDV.
Parameter ΔV was calculated at different initial data (μ, D_0, ε, etc.) One of the results, which displays the relation between parameter ΔV and median diameter D_0 of the raindrops at constant μ and different ε is shown in a figure 2.
Median drop diameter D_0 is connected with rain intensity:

$$R(D_0) = \int_0^\infty N(D, D_0)v(D)V(D)dD, \tag{5}$$

where $N(D, D_0)$ is given by formula (1), $v(D)$ is a fall speed of the drop of size D, $V(D)$ is the volume of drop with equivalent diameter D.

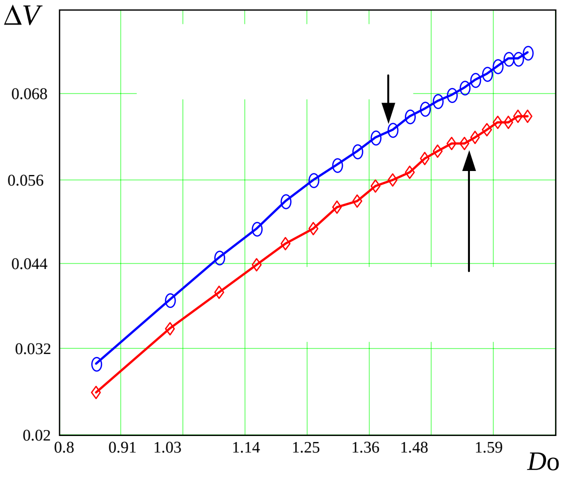

Fig.2. Parameter ΔV versus median drop diameter D_0 at two values of eddy dissipation rate ε in rain

It is seen that DDV is more if the rain rate is more. It is clear because the big drops are more oblate and fall faster; having big axis horizontal they give more signal at *hh* polarization in comparison with *vv* polarization. Turbulence disturbs the normal orientation of drops and decreases the degree of the connection between ΔV and D_0 that is also displayed in figure 2.

V. TURBULENCE INTENSITY RETRIEVAL

On the basis of Doppler-polaimetric spectra the polarization characteristics - specific differential reflectivity *Zdr(v)* and specific linear depolarization ratio *Ldr(v)* are calculated. These functions are in essence the characteristics, which can be measured with Dopple-polarimetric radar. They are described as follows:

$$Zdr(v) = 10lg[S_{hh}(v)/S_{vv}(v)], \qquad (6)$$

$$Ldr(v) = 10lg[S_{hv}(v)/S_{vv}(v)]. \qquad (7)$$

The functions (6) and (7) are monotone increasing functions in the real range of argument *v*. They can be approximated by linear regression lines. In this case one of the parameters considered in this paper is the slope of the regression line $SlpZd$. The other parameter is Doppler spectrum width at different polarizations ΔV_{hh}, ΔV_{vv} and ΔV_{hv}.

The relationship in logarithmic scale between the parameter of intensity of turbulence ε [cm^2/s^3] and the Doppler spectrum width ΔV_{hh} [m\s], appointed on -3dB level, shown in figure 3 at three values of spread μ of dropsize gamma-distribution (1).

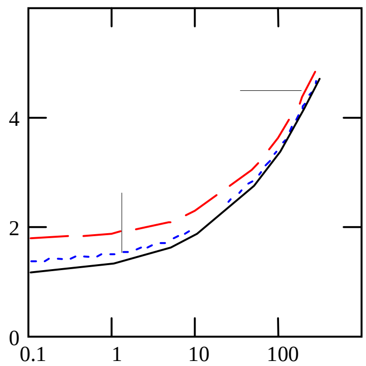

Fig.3. The relationship between the intensity of turbulence and Doppler spectrum width at different dropsize distributions.

Similar dependencies are shown in figure 4 at the same designations but for two values of turbulence spatial scale L_{max} and in linear scale.

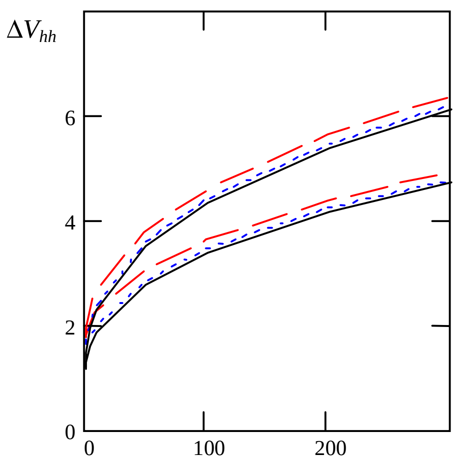

Fig.4. The relationship between the intensity of turbulence and Doppler spectrum width at different range of turbulence spatial scale.

It is seen that an increasing spatial scale of turbulence leads to the increasing of the Doppler spectrum width.
Relation between the slope of the regression line $SlpZd$ and turbulence intensity parameter ε are shown in a figure 5 at Do=0,866 (R=1mm/hour), Lmax=1000 m and with the two values of dropsize distribution

spread: μ =5 and μ = 1. The chart in figure 6 illustrates the close relation between the width of a the spectrum and inverse value of the slope $1/SlpZd$. Turbulence increases a Doppler spectrum width at any combinations of polarization of the transmitting and the receiving signal. It is natural and well-known result.

On the other hand, turbulence leads to flatter curves of $Zdr(v)$, or to the decreasing of the values of slope $SlpZd$. The last result can be explained by the following. The more drop size the more drop fall velocity and the oblate the drop is and normally the rain drops are oriented with horizontal bigger diameter. That is why the curve $Zdr(v)$ given by formula (6) goes upwards. Turbulence disturbs the normal positions of raindrops. This results in flat curve $Zdr(v)$.

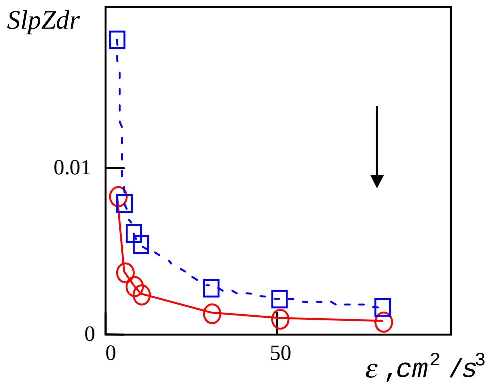

Fig.5. Slope of the linear regression of the curve *Zdr*(*v*) versus eddy dissipation rate ε.

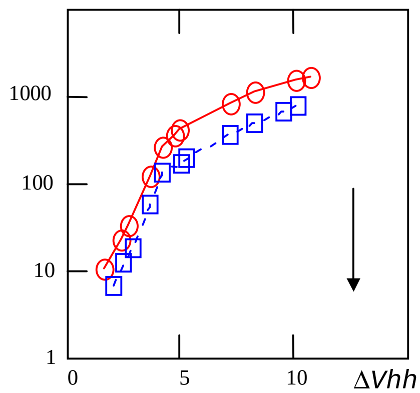

Fig.6. The relations between inverse $SlpZdr^{-1}$ and Doppler spectrum width ΔV_{hh} .

VI. CONCLUSION

The simulated study shows that as Doppler as polarization parameters of radar signal from rain contain information on rain microstructure and turbulence intensity in weather object.

The differential Doppler velocity of raindrops carries the important information on microstructure of rain and can be used in order to measure the rain intensity. However turbulence decreases this effect and should be taken into consideration as well. The results of the calculations should be checked using experimental data, which can be obtained with Doppler-polarimetric radar [5].

The research has shown the connection between the parameters of a signal of the Dopple-polarimetric radar and the intensity of turbulence.

All the data and results where received on the computer, using approved model, which was previously validated using the comparison with the real experimental data [2]. However the quantitative results need for more extensive experimental confirmation.

The method based on these researches can be practically used for study turbulence in precipitation, detection turbulent zones dangerous for flight, as well as for measuring rate rain, and other applications.

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