Refined Models and Numerical Simulation of Polarimetric Radar Signals Scatterred by Various Types of Hydrometeors

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***Abstract*— In this paper the mathematical models are presented to describe scattering electromagnetic waves by hydrometeors of various types such as: raindrops, cloud droplets, flat and elongated ice crystals etc. These models are developed based on the practical implementation of requirements to the algorithm for detection of zones of possible icing of aircrafts, using the data of the avionic weather radar. Various scenarios of the appearance of such zones are analyzed. Polarymetric radar data, which can be obtained by remote sensing of one or more types of hydrometeors are modeled and analyzed.**

Keywords—polarimetric radar, hydrometeors, Rayleigh scattering

I. INTRODUCTION

Parameters of signals that are backscattered from meteorological objects depend on the physical and statistical characteristics of hydrometeors. Consequently, we can identify the type of hydrometeors in the complex meteorological object using some parameters of the backscattered radar signals. The main goal of this article is to develope the advanced models which confirm qualitatively and quantitively that the values of some polarymetric parameters are different after the backscattering from the different types of hydrometeors, such as supercooled droplets in the cloud, rain drops, ice crystals of various types.

II. THE RADAR CROSS SECTION

If the diameter D of the irradiated particles is much smaller than the radar wavelength λ, the particle can be considered as the Rayleigh scatterer, and its radar cross section (RCS) σ can be estimated as $\sigma \approx (\pi^5 / \lambda^4)|K|^2 D^6$ with K as the complex refractive index of particles [1]. For nonspherical particles as usually we use the concept of equivalent diameter. Since there are many of reflecting Rayleigh particles of different size in the complex meteorological target, the specific RCS per unit volume defined as function of radar reflectivity factor Z.

III. THE PROBLEM OF ICING-IN-FLIGHT ZONE DETECTION

To prevent an accident, the pilot of the aircraft should avoid a contact of the aircraft with supercooled water droplets. There is a theoretical possibility of detecting the presence of liquid droplets using data from airborne weather radar [3, 4]. The basic idea of this method is that the water droplets and ice crystals scatters of the incident electromagnetic waves in different ways. The polarimetric algorithm [3, 5] of detecting supercooled water drops is based on the measurement of two polarimetric variables: differential reflectivity (DR), which depend on the received power of the principal polarization components (Phh and *Pvv*), and linear depolarization ratio (LDR), which depends on the ratio of cross-polarized component *Phv* to a principally polarized component [3].

Liquid-drop cloud without rain consists of small droplets having almost spherical shape. That is why the polarization does not play a significant role in the scattering in such clouds. Reflected power signal obtained in the horizontal and vertical planes are almost identical. Therefore, the cross-polarization component is close to zero, and LDR tends to minus infinity. Mathematical modeling of the backscattered signal in case of small cloud droplets gives the calculated values about 0 dB for ZDR, and up to -75 dB LDR [3, 9]. And these values do not depend on the scan angle (relative to the radar antenna).

Rain (without the turbulence) is characterized by drops of ordered orientation in the vertical plane. ZDR maximum value observed in a horizontal (or nearly horizontal), scanning angle. This is because the projection of the drops into a plane perpendicular to the scanning beam gives an ellipse with the largest difference between the horizontal and vertical axes. DR can be equal to 0.5 dB (in the case of a small rain) up to 3…45 dB in the case of strong rain. LDR in case of rain may be in the range of -35 to -25 dB [3, 9]. Influence of turbulence was considered in [6].

In the case of ice crystals, there is no clear relationship between size and shape of the backscatterer, as is observed for raindrops. An important feature of the crystals compared with rain clouds is more chaotic orientation of the particles in space.

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IV. MODELS AND NUMERICAL SIMULATION

Mathematical modeling and measurements give the values from 9 dB in the case of strong vertically oriented ice crystals to -9 dB in the case of a horizontal arrangement of space. Usually this value lies in a more limited range from -3 to 3 dB [7, 9]. LDR value for crystals may be in the range of -14 ... -16 dB (for uniform distribution of crystal axis orientation) or -25 ... -30 dB (when ordered orientation in a vertical or horizontal plane occurs) [3, 7].

Then compare the values of the power of two components of the reflected signal Phh and Pvv; using results of this comparison, the values of the orthogonal components Phv, Pvh and the known value of temperature one make a decision on the presence or absence potentially dangerous zone in the volume of space, which is defined by the radiation direction, the delay time of reflected signals and duration of radar pulses. If the temperature of the object is below the freezing point of water and at the same time the conditions Phh = Pvv and Phv = Pvh = 0 are true, then one makes a decision on the availability icing zone, and in the opposite case a decision about absence of the dangerous zone is done.

The algorithm described above assumes a clear distinction between types of hydrometeors and does not imply the simultaneous presence in the volume of liquid droplets and ice crystals.

V. ADVANCED MODELS OF SCATTERING ON DIFFERENT TYPES OF HYDROMETEORS

The developed advanced models are based on the approach [10, 11] which was corrected and developed in particular in the aspect of accurate taking into account the orientation of particles and statistical view onto the distribution of angles that characterize positions of particles. As an example in Fig.1 the improved factors Φ_{hh} , Φ_{vv} and Φ_{hv} , that characterize orientation of scatterer are shown as functions of angles of particle azimuth α and canting δ. The mixture of different types of scatterers is consider. The details of the models are discussed during the presentation.

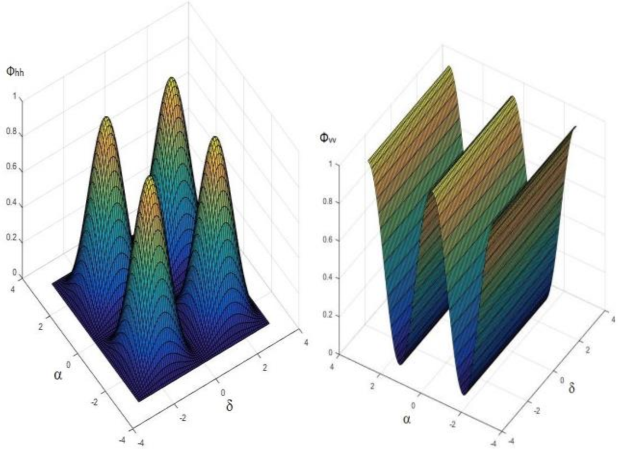

Fig. 1. Calculated factors Φ_{hh} and Φ_{vv} for hh (left) and vv cases.

VI. CONCLUSION

The mathematical models have been developed to describe scattering electromagnetic waves by hydrometeors of various types such as: raindrops, cloud droplets, flat and elongated ice crystals etc. The models are based on the practical implementation of requirements to the algorithm for detection of zones of possible icing of aircrafts, using the data of the avionic weather radar. Various scenarios of the appearance of such zones have been analyzed and discussed during the presentation.

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