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ANALYTICAL METHOD OF POLARIMETRIC VARIABLES PREDICTION IN THE CASE OF REMOTE SENSING OF ICE CRYSTALS CLOUDS

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Abstract**—***In this paper an analytical method of prediction some parameters of radar backscattered signal in case of remote sensing of clouds and precipitation have been introduced. This method finally has been used to the create of the mathematical model of radar signal backscattering on ice particles. In the article have been presented range of corrected formulas to calculate several polarimetric parameters like Differential Reflectivity, Linear Depolarization Ratio, and Correlation Coefficient as output parameter set of the described model. These formulas gave more accurate result of calculation than original variant, published in sources [3]. Some physical parameters of the ice crystals like length, diameter for elongated particles and width, a thickness for oblated ones have taken as input parameters of the model. Described mathematical model could be useful to weather radar designers, in order to have the ability to recognize dangerous meteorological phenomena basing on information of backscattered signal.*

Index Terms—Polarimetric radar; remote sensing; ice crystals; hydrometeors.

I. INTRODUCTION

The problem of detection and recognition of different types of hydrometeors with the help of airborne weather radar arise in front of aviation engineers, who work on increasing safety of the civilian aircraft flights. The possibility to reconstruct the inner structure of the complex meteorological object (cloud) basing on the information, that contains into backscattered signal of weather radar could significantly increase awareness of pilots about fly conditions on the route. The continuous improvement of radar surveillance techniques for meteorological phenomena, including for the provision of aviation, has led to a significant improvement in the quality of meteorological information and flight safety in difficult meteorological conditions. From the very beginning of the application of radar for the study of precipitation and clouds, there is a complex problem of obtaining indirect information (qualitative and quantitative) about the characteristics of objects by the results of processing reflected radio signals.

II. PROBLEM STATEMENT

While the theory of backscattering for some types of hydrometeors like rain drops, hail particles etc. are well developed, for other types of scatterers like ice crystals there are some spaces in the scientific approach. The introduction of multiparametric polarimetric methods in onboard and terrestrial meteorological radars is constrained by the lack of development and investigation of appropriate signal processing techniques and the interpretation of remote sensing data. A significant increase in the number of parameters complicates the processing and interpretation of information, resulting in multi-criteria processing and decision-making procedures, which are very difficult to optimize and implement. In this paper described an analytical method of prediction polarimetric measurable from the ice crystals of different types. This method is based on the assumption that for sounding wave with length in several times bigger than usual size of the scatterer, the shape of any particle could be approximated by the ellipsoid with appropriate relations between axes. Calculation of backscattering on ellipsoids is much easier than calculation for complex shapes of real crystals and could be done using modified Rayleigh formulas with acceptable accuracy [1], [2], [3].

III. BACKSCATTERING ON THE SINGLE PARTICLE

The polarization characteristics of individual hydrometeor could be described using inverse scattering matrix [**S**], which connects the electric field backscatter $[\mathbf{E}]^b$ in the antenna with the incident electric field $[\mathbf{E}]^i$ as follows [1] and [2]:

$$\begin{bmatrix} \mathbf{E}_1 \\ \mathbf{E}_2 \end{bmatrix}^b = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{E}_1 \\ \mathbf{E}_2 \end{bmatrix}^i \frac{\exp(-jkr)}{r}, \qquad (1)$$

with $j = (-1)^{1/2}$. The subscripts 1 and 2 denote the two orthogonal polarizations, e.g., linear vertical and linear horizontal or circular right rotation and left rotation circular, $k = 2\pi/\lambda$ where k is the wave number. The first index of the scattering matrix elements relates to a backscattered polarization, and the second index – to the polarization of the incident electric field. In the reciprocal of the environment, which is an ensemble of hydrometeors, $s_{12} = s_{21}$ the orthogonal field with circular polarization can be expressed in terms of orthogonal linearly polarized fields via transformation [1]:

$$\begin{bmatrix}\mathbf{E}_r\\ \mathbf{E}_l\end{bmatrix}^i = [\mathbf{G}]\cdot\begin{bmatrix}\mathbf{E}_h\\ \mathbf{E}_v\end{bmatrix}^i, \qquad (2)$$

wherein the matrix

$$[\mathbf{G}] = \frac{1}{\sqrt{2}}\begin{bmatrix} j & 1\\ -j & 1\end{bmatrix}, \qquad (3)$$

and the subscripts *r, l* denote the right and left circular polarization; *h, v* is the horizontal and vertical linear polarization. Similar relationships may be written to and backscattering fields, but then it is necessary to use a matrix conjugated with respect to [G], since the reflection from the hydrometeor circularly polarized wave changes the direction of rotation on reversed of transmitter wave [1]. Consequently,

$$[\mathbf{E}_c]^b = [\mathbf{G}^*]\cdot[\mathbf{E}_+]^b. \qquad (4)$$

where the subscripts *c* and + denote orthogonal pairs with circular and linear polarization, respectively. There [1], the following relation between the scattering matrices for the linear and circular polarizations:

$$[\mathbf{S}_c] = [\mathbf{G}^*]\cdot[\mathbf{S}]\cdot[\mathbf{G}^*]^{-1}. \qquad (5)$$

Therefore, the individual elements are interconnected by obvious relations [1]:

$$\begin{aligned} s_{rr} &= (s_{vv} - s_{hh} - j2s_{vh})/2,\\ s_{ll} &= (s_{vv} - s_{hh} + j2s_{vh})/2, \qquad (6)\\ s_{lr} &= s_{rl} = (s_{vv} + s_{hh})/2. \end{aligned}$$

Thus, it is possible to switch from one polarization orthogonal basis to another.

To simplify the analysis of propagation effects in the atmosphere is not taken into account. According to [2] consider a linearly polarized electric field of a backscattering hydrometeor at a distance r_n [1]:

$$E_{ij} = \frac{P_j^{1/2} G_A^{1/2} F(\theta,\psi)\eta_0^{1/2} s_{ij}(n)}{2\sqrt{\pi}\cdot r_n}\exp(-j2kr_n), \qquad (7)$$

where s_{ij} is the backscattering matrix element of (1) for the n-th hydrometeor; k is the wavenumber; P_j is the transmitter power; G_A is the antenna gain (as the wave propagates in the same direction); $F(\theta, \psi)$ is the normalized form of antenna pattern; η_0 = 377 Ohm impedance of free space, and E_{ij} is the received field. The magnitude of the field incident on the separate particle is given by $P_j^{1/2} G_A^{1/2} F(\theta,\psi)\eta_0^{1/2} / 2\sqrt{\pi} r_n$, so as to satisfy the conditions of the relation between scattering coefficients s_{ij} in (7) with an effective area backscattering σ_t in accordance with equation [1]:

$$|s_{hh}|^2 = \frac{\sigma_t}{4\pi}. \qquad (8)$$

The signal voltage on u_{ij} the receiver of weather radar will be processed to determine the properties of hydrometeors. Voltage u_{ij} to nth of hydrometeor is proportional to the scattering coefficient and can be written as [1]:

$$u_{ij}(r_n) = s_{ij}(n) F(r_n) \exp(-j2kr_n), \qquad (9)$$

$F(r_n)$ comprises a proportionality factor dependent on the distance, attenuation weighting function and other parameters of the selected mathematical model [1]. U_{ij} voltage for an ensemble of scattering particles is the superposition of voltages from each individual scatterer:

$$U_{ij} = \sum_{\mathbf{n}} s_{ij}(n)\cdot\exp(-j2kr_n)\cdot F(\mathbf{r}_\mathbf{n}). \qquad (10)$$

Average value U_{ij} is zero due to the contribution of the phase terms in the summation result. Therefore, as the characteristics of the polarized signals is generally used various moments of the second order $\langle U_{ij} U_{kl}^* \rangle$ and associate them with the properties of scatterers (triangular brackets indicate the mean of the distribution and the asterisk – complex conjugate). Starting from (10) [1], [3], we obtain:

$$\begin{aligned} \langle U_{ij} U_{kl}^* \rangle &= \sum_n \langle [s_{ij}(n) s_{kl}^*(n)] \rangle |F(\mathbf{r}_\mathbf{n})|^2 \\ &= \langle s_{ij} s_{kl}^* \rangle \int |F(\mathbf{r}_\mathbf{n})|^2\, dV. \end{aligned} \qquad (11)$$

In the last equation summation over n is replaced by an integral of the weighting function on the reflecting volume and it is assumed that the particles are distributed homogeneously in the volume. In the most general case, the moments of the second order (11) may be arranged in a covariance matrix 4x4, but due to the reciprocity, a member of $\langle U_{ij} = U_{ji} \rangle$, thus, the covariance matrix is reduced to a dimension of 3x3. From equation (11) it is clear that the covariance matrix of the voltages is multiplied by a scalar covariance matrix of backscattering, which can be written as follows [1] and [3]:

$$\begin{matrix} \left\langle \left|s_{hh}\right|^2 \right\rangle & \left\langle s_{hv} s_{hh}^* \right\rangle & \left\langle s_{vv} s_{hh}^* \right\rangle \\ \left\langle s_{hh}\, s_{hv}^* \right\rangle & \left\langle \left|s_{hv}\right|^2 \right\rangle & \left\langle s_{vv} s_{hv}^* \right\rangle \\ \left\langle s_{hh} s_{vv}^* \right\rangle & \left\langle s_{hv} s_{vv}^* \right\rangle & \left\langle \left|s_{vv}\right|^2 \right\rangle \end{matrix} \qquad (12)$$

Using this covariance matrix, we can introduce a set of parameters of the polarization for the radar signal, that could be measured and to associate these parameters to the observed values and the properties of backscatters.

IV. POLARIMETRIC MEASURABLE PARAMETERS

Polarimetric measurable parameters or variables - are non-redundant characteristics of backscatters, which depend on polarization. Polarimetric values of parameters of the reflected signal can be calculated from the measured values of reflected signal power at different polarizations for a given power and polarization of the emitted signal. To determine the power of the received signal in the horizontal and vertical polarizations at the given characteristics of the target (meteorological object), it is obviously necessary to be able to determine the effective scattering surface at different polarizations for individual hydrometeor and for certain region of cloud that is filled by the array of such hydrometeors. That is, it is necessary to link the physical parameters of hydrometeors and the power of the reflected signal.

Then equations (12) can be expressed in terms of distributions of hydrometeors properties such as the equivalent diameter, shape, angle of inclination etc. It can, therefore, be written in the general form [1], [3]

$$\left\langle s_{ij} s_{kl}^* \right\rangle = \int N(\mathbf{X}) s_{ij} s_{kl}^* \, d\mathbf{X}, \qquad (13)$$

wherein $N(X)$ is the probability density function (*PDF*) properties of the lens, s_{ij} is the backscattering matrix elements (1) which are represented by the vector **X**.

The symmetric off-diagonal elements of the covariance matrix (12) are connected. In fact, there are nine actual values (three – on the main diagonal and six remaining off-diagonal elements), which can be measured with the help of polarimetric radar.

Most of the elements of the covariance matrix could be used alone or in combination with other elements, to obtain information about the properties of hydrometeors. It seems that a lot of parameters characterizing the properties of hydrometeors can be estimated from nine measurable quantities. This is true in some special cases, such as when sensing pure rain. But often hydrometeors represents a diverse mixture, do not always have a well-defined shape, and polarimetric signatures can be quite uncertain. Moreover, relationship between the particles and the parameters these are measured are nonlinear, and, moreover, are hidden under the integrals of expectation (as in formula (13)). Therefore, researchers [1] – [4] use a combination of measured values is used to eliminate some of the characteristics and properties of hydrometeors highlight others.

Basic polarimetric measurement variables which are derived from the observed parameters backscatter covariance matrix are given below [1] and [3].

Radar reflectivity with horizontal polarization

$$Z_H = \frac{4\lambda^4}{\pi^4 |K|^2} \left\langle \left|s_{hh}\right|^2 \right\rangle, \qquad (14)$$

where K – is the complex refractive index of the substance particles [38]. Value of $|K|^2$ for water is about 0.93, and for ice – 0.19 [2], [3].
Then vertical polarization is:

$$Z_V = \frac{4\lambda^4}{\pi^4 |K|^2} \left\langle \left|s_{vv}\right|^2 \right\rangle, \qquad (15)$$

and differential reflectivity is:

$$Z_{DR} = 10\log \frac{\left|s_{hh}\right|^2}{\left|s_{vv}\right|^2}. \qquad (16)$$

Linear depolarization ratio will be:

$$LDR_{hv} = 10\log \frac{\left|s_{hv}\right|^2}{\left|s_{vv}\right|^2}, \qquad (17)$$

or

$$LDR_{vh} = 10\log \frac{\left|s_{vh}\right|^2}{\left|s_{vv}\right|^2}. \qquad (18)$$

The correlation coefficient with zero shift is:

$$\rho_{hv}(0) = \frac{\left\langle s_{vv} s_{hh}^* \right\rangle}{\left\langle \left|s_{hh}\right|^2 \right\rangle^{\frac{1}{2}} \left\langle \left|s_{vv}\right|^2 \right\rangle^{\frac{1}{2}}}. \qquad (19)$$

Apart from these five measured variables can be used in other polarization characteristics, e.g., differential phase, which is a phase difference of reflected signals at orthogonal polarizations

$$\phi_{DP} = \phi_H - \phi_V,. \qquad (20)$$

where ϕ_H is the phase of the reflected signal in the horizontal and ϕ_V is the vertical polarization. Since the phase difference depends on the distance at which the particles are placed then usually use specific differential phase as information parameter:

$$K_{DP} = \frac{\phi_{DP}(R_1) - \phi_{DP}(R_2)}{2(R_2 - R_1)}, \tag{21}$$

where R_1 and R_2 are ranges up to the two resolved volumes ($R_1 > R_2$) [1], [4].

Let us consider such polarimetric parameters as differential reflectivity linear depolarization ratio (*DR*), linear depolarization ratio (*LDR*) and the correlation coefficient is the zero shift (*CF* or correlation factor). These parameters are conveniently calculated in the mathematical simulation of the radar signal reflected from meteorological objects since they represent the relationship or fractions (equations (16) – (19)). When calculating the absolute values, such as radar reflectivity, phase shifting, etc. There is a possibility of the divergence of one or several parameters calculated from actual values. A relative value when calculating admitted divergence of calculated parameters to the real characteristics of meteorological objects in the numerator and the denominator can be mutually compensated for and does not have a significant effect on the result.

In this paper we use an approach to calculating the RCS (radar cross-section) of hydrometeors according to Rayleigh formulas. This approach is applicable (i.e., provides a satisfactory accuracy of the calculation) only in the case where the wavelength is much larger target size. According to the experimental data [2], [3], [5], the largest size of raindrops is about 7 ... 8 mm, the size of the ice crystals does not normally exceed [5] – [7] 10 ... 12 mm. Consequently, the calculated length of radar waves to scan hydrometeors array must be of the order of a few centimeters to conditions of Rayleigh scattering were satisfied.

V. BACKSCATTERING FROM THE ELLIPSOID

Parameters of the reflected signal from the object meteorological depend on the physical and statistical characteristics of the plurality of hydrometeors comprising the meteorological objects. Therefore, it is possible to identify the type of hydrometeors in the composition of the complex meteorological object by using some of the parameters of the reflected radar signal from him. The main objective of this chapter of the thesis – to show that the values of some polarimetric values (equations (14) – (19)) will be different from different types of hydrometeors.

In order to account for non-sphericity of hydrometeors, in a model form their use oblate or prolate ellipsoids with a certain ratio between semi-axes *a*1, *a*2, *a*3 (Fig. 1) [1], [3].

We now consider the general case with a tilted relative to the observer particle (Fig. 1). Calculation of the echo polarimetric components, in this case, became much more complicated than in the case of the vertical or horizontal particle.

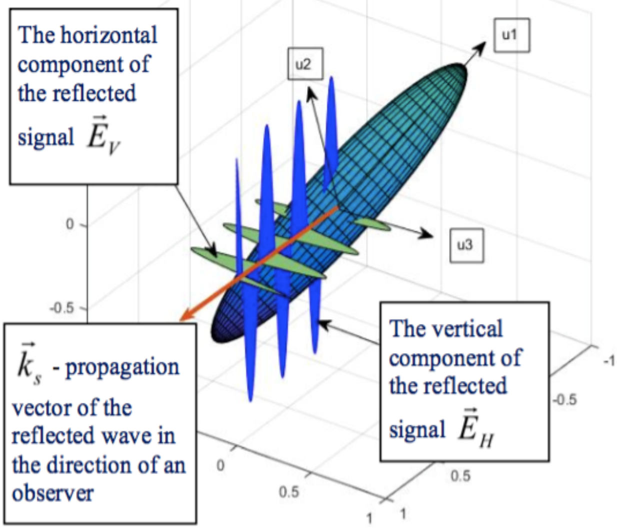

Fig. 1. The reflected signal is at an inclined position relative to the ellipsoid bystander

Let's define a set of parameters of a radar target, which will be used to construct mathematical models of signals reflected from the object of weather. These parameters include the coordinates of a single particle in a spherical coordinate system with respect to the initial position:

– α is the angle of rotation of a particle in a horizontal plane;

– δ is the angle of rotation of a particle in a vertical plane;

– φ is the angle of rotation of a particle in a frontal plane or a polarization angle;

– θ is the angle of inclination to the plane of the horizon radar.

The coordinate system, in this case, is linked to the particle, rather than an observer.

So, we can write:

$$q_{hh} = \left[\Lambda_1 + \left(\Lambda_3 - \Lambda_1\right) \cdot \Phi_{hh}\right]^2, \tag{22}$$

$$q_{vv} = \left[\Lambda_1 + \left(\Lambda_3 - \Lambda_1\right) \cdot \Phi_{vv}\right]^2, \tag{23}$$

$$q_{hv} = \left[\left(\Lambda_3 - \Lambda_1\right) \cdot \Phi_{hv}\right]^2. \tag{24}$$

The coefficients Φ_{hh}, Φ_{vv} and Φ_{hv} are responsible for trigonometric transformations may be calculated by equations [3]:

$$\Phi_{hh}=\sin^2\delta\cos^2\alpha\sin^2\varphi\sin^2\theta+\sin^2\delta\sin^2\alpha\cos^2\varphi+\cos^2\delta\sin^2\varphi\cos^2\theta-\frac{1}{2}\sin 2\delta\cos\alpha\sin^2\varphi\sin 2\theta$$
$$-\frac{1}{2}\sin 2\delta\sin\alpha\sin 2\varphi\cos\theta+\frac{1}{2}\sin^2\delta\sin 2\alpha\sin 2\varphi\sin\theta, \quad (25)$$

$$\Phi_{vv}=\sin^2\delta\cos^2\alpha\cos^2\varphi\sin^2\theta+\sin^2\delta\sin^2\alpha\sin^2\varphi+\cos^2\delta\cos^2\varphi\cos^2\theta$$
$$-\frac{1}{2}\sin 2\delta\cos\alpha\cos^2\varphi\sin 2\theta+\frac{1}{2}\sin 2\delta\sin\alpha\sin 2\varphi\cos\theta-\frac{1}{2}\sin^2\delta\sin 2\alpha\sin 2\varphi\sin\theta, \quad (26)$$

$$\Phi_{hv}=\frac{1}{2}\sin 2\varphi(\sin^2\delta\sin^2\alpha-\sin^2\delta\cos^2\alpha\sin^2\theta-\cos^2\delta-\sin 2\delta\cos\alpha\sin 2\theta)$$
$$-\frac{1}{2}\cos 2\varphi(\sin 2\alpha\sin^2\delta\sin\theta-\sin 2\delta\sin\alpha\cos\theta). \quad (27)$$

coefficients Φ_{hh} and Φ_{vv} assume values from 0 to 1, and the coefficient Φ_{hv} is from -0.5 to 0.5 when changing angles α, β, φ and θ from -π to π (Figs 2, 3, and 4).

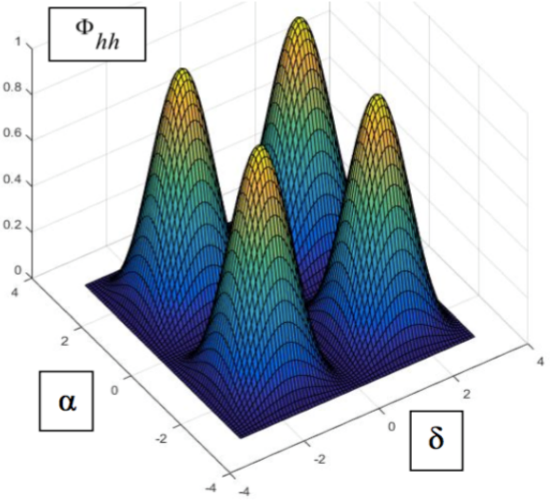

Fig. 2. Meaning factor Φ_{hh} for angles α and δ at range from -π to π when φ and θ = 0

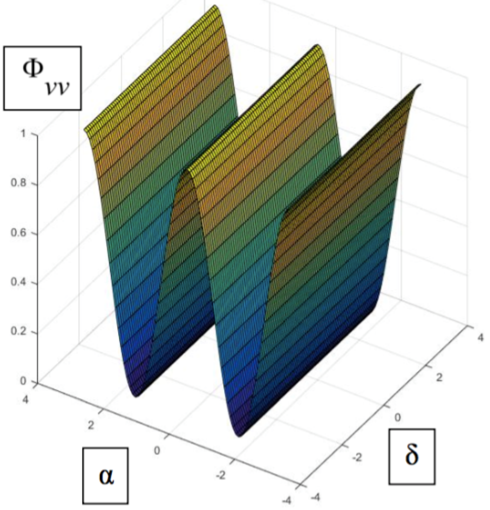

Fig. 3. Meaningfactor Φ_{vv} for angles α and δ at range from -π to π when φ and θ = 0

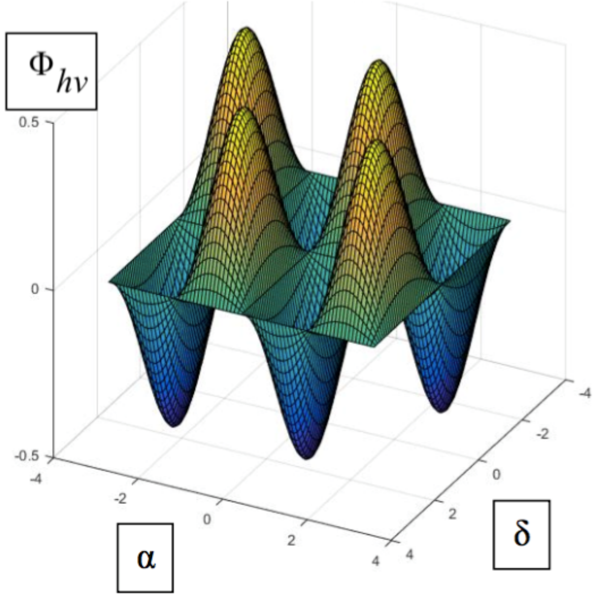

Fig. 4. Meaning factor Φ_{hv} for angles α and δ at range from -π to π when φ and θ = 0

Equation (27) is given in corrected form and differs from the one published in [3].

Let's consider a specific ellipsoid with the known relations between the axle shafts a_1 and $a_2 = a_3$. And predetermined rotational angles α, δ, the angle of the polarization plane φ, and the angle of rotation of the radar antenna relative to the horizontal plane θ. For such an ellipsoid in equation (16) is the ratio of squares of the elements covariance matrix backscatter $\frac{|s_{hh}|^2}{|s_{vv}|^2}$. It can be replaced by the ratio RCS at different polarizations $\frac{\sigma_{hh}}{\sigma_{vv}}$. Therefore, for a single particle differential reflectivity can be calculated as:

$$Z_{DR}=10\log\frac{\sigma_{hh}}{\sigma_{vv}}=10\log\frac{q_{hh}}{q_{vv}}.$$

Similarly to (17) and (18) the expression of linear depolarization ratio for one of the ellipsoid can be written:

$$LDR_{hv} = 10\log\frac{\sigma_{hv}}{\sigma_{vv}} = 10\log\frac{q_{hv}}{q_{vv}},$$

$$LDR_{vh} = 10\log\frac{\sigma_{vh}}{\sigma_{vv}} = 10\log\frac{q_{vh}}{q_{vv}}.$$

VI. CONCLUSIONS

The paper discusses and analyzes the mechanism of polarimetric parameters of radar backscattering signal calculation in the case of remote sensing of meteorological objects. The formulas allowing to calculate the polarimetric parameters of the radar signal reflected from elliptic particles such as ice crystals are given. These formulas can be used to create mathematical models for the reflection of radar signals from more complex meteorological targets.

REFERENCES

[1] F. J. Yanovsky, "Millimeter Wave Radar: Principles and Applications." In Millimeter Wave Technology in Wireless PAN, LAN, and MAN, Editors: Shao-Qiu Xiao, Ming-Tuo Zhou, Yan Zhang, Chapter 10, pp. 305–376, ISBN: 9780849382277, Auerbach Publications CRC Press, 2008, 464 pp.

[2] V. N. Bringi, V. Chandrasekar, "Polarimetric Doppler weather radar. Principles and applications", *Cambridge University Press*, 2001, pp. 45-88.

[3] H. W. J. Russchenberg, "Ground-based remote sensing of precipitation using a multi-polarized FM-CW Doppler radar." *Deft University Press*, 1992, pp. 46–55.

[4] A. A. Pitertsev and F. J. Yanovsky, "Polarimetric Method for Remote Predicting a Zone of Icing-in-Flight in Clouds and Precipitation." *Proc. Microwaves, Radar and Remote Sensing Symposium*, August 25 – 27, 2011, Kiev, Ukraine, pp. 220–223.

[5] A. Pitertsev and F. Yanovsky. "Radar Determination of Probable Icing-in-Flight." *Proceedings Microwaves, Radar and Remote Sensing Symposium (MRRS-2008)*, Kiev, 2008, pp. 293–295.

[6] A. Pitertsev and F. Yanovsky. "Advanced Algorithm for Radar Detection of Icing. Calculation of Polarimetric Observables." *Proceedings International Workshop on Microwaves, Radar and Remote Sensing MRRS 2005*, September 19-21, Kiev, Ukraine, pp. 87–90.

[7] F. Yanovsky, A. Pitertsev, and T. Sidorenko. "Aircraft Icing Prevention Radar System: Models and Software for Calculation of Information Parameters." *Proc. International Radar Symposium IRS-2005*, Berlin, Germany, 2005, pp. 489–492.

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О. А. Пітерцев. Аналітичний метод прогнозування поляриметричних змінних у випадку дистанційного зондування хмар із кристалів льоду

Представлено аналітичний метод прогнозування деяких параметрів радіолокаційного зворотного розсіяного сигналу в випадку дистанційного зондування хмар і опадів. Згодом цей метод було використано для створення математичної моделі зворотного розсіювання радіолокаційного сигналу на частинках льоду. Представлено низку скоригованих формул для розрахунку декількох поляриметричних параметрів, таких як диференційна відбиваність, лінійне деполяризаційне відношення і коефіцієнт кореляції в якості набору вихідних параметрів описаної моделі. Ці формули дають більш точний результат розрахунку, ніж оригінальний варіант, опублікований в першоджерелах. В якості вхідних параметрів моделі взяті деякі фізичні параметри кристалів льоду, такі як довжина, діаметр видовжених частинок і ширина, товщина для сплюснутих. Описана математична модель може бути корисна для інженерів, що створюють метеорологічні радари, щоб мати можливість розпізнавати небезпечні метеорологічні явища на основі параметрів відбитого сигналу.

Ключові слова: поляриметричний радіолокатор; дистанційне зондування; кристали льоду; гідрометеори.

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Кількість публікацій: 28.
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А. А. Питерцев Аналитический метод прогнозирования поляриметрических переменных в случае дистанционного зондирования облаков из кристаллов льда

Введен аналитический метод прогнозирования некоторых параметров радиолокационного обратного рассеянного сигнала в случае дистанционного зондирования облаков и осадков. Впоследствии этот метод был использован для создания математической модели обратного рассеяния радиолокационного сигнала на частицах льда. Представлен ряд скорректированных формул для расчета нескольких поляриметрических параметров, таких как дифференциальная отражаемость, линейное деполяризационное отношение и коэффициент корреляции в качестве набора выходных параметров описанной модели. Эти формулы дают более точный результат расчета, чем оригинальный вариант, опубликованный в первоисточниках. В качестве входных параметров модели взяты некоторые физические параметры кристаллов льда, такие как длина, диаметр удлиненных частиц и ширина, толщина для сплющенных. Описанная математическая модель может быть полезна для метеорологических дизайнеров радаров, чтобы иметь возможность распознавать опасные метеорологические явления на основе параметров отраженного сигнала.

Ключевые слова: поляриметрический радиолокатор; дистанционное зондирование; кристаллы льда; гидрометеоры.

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