# An approach to discrimination of hydrometeors with similar polarization properties within the resolution volume

Yuliya Averyanova
Air Navigation Systems Department
National Aviation University
Kyiv, Ukraine
ayua@nau.edu.ua

Felix J. Yanovsky
Electronics Department
National Aviation University
Kyiv, Ukraine
yanovsky@nau.edu.ua

*Abstract*—In this paper the possibility to distinguish hydrometeors with similar polarization properties inside the reflecting volume and estimating their differential impact onto polarization properties of reflected signal is made. The results are important for different practical application of radar meteorology including drop size distribution estimate, rainfall intensity estimate, wind speed measurement, turbulence and strong wind shear detection.

*Index Terms*—**Radar meteorology; polarimetry; scattering; scattering volume; liquid hydrometeor.**

## I. Introduction

Dangerous meteorological phenomena detection as well as obtaining information about meteorological conditions is a question of high importance for many fields of human activity including aviation, meteorology, agriculture and others. Since the middle of 20th century meteorological radars prove their important role as the powerful tools for many meteorological applications. Non-coherent radars that were the first instruments for indirect radar measurements allow evaluating the rate of meteorological phenomena danger by measuring the radar reflectivity. Of course, operation with only one informative parameter of the reflected signal is insufficient for solving different practical tasks and even leads to the appearance of many contradictions in data interpretation. This fact assisted to develop new methods and systems for information obtaining about dangerous meteorological phenomena. Thus, coherent meteorological radars or Doppler meteorological radars were developed and used nowadays for meteorological purposes. They allow obtaining information about dynamics of meteorological formation. Some methods and algorithm for wind measurements as well as turbulence or wind shear detection with Doppler radar can be found in [1, 2]. Further development of meteorological radars results in the development of Doppler-Polarimetric radar systems that have additional possibility of polarimetry to identify different types of hydrometeors. The possibilities and benefits of polarization measurements are presented in [3]. The advantages and possibilities of Doppler–Polarimetric methods and systems are shown in [4, 5, 6, 7, 8]. The polarimetric algorithms for hail detection can be found in [9, 10]. Some methods and algorithms of dangerous icing-in-flight detection using polarimetry are presented in [11, 12].

Modern polarimetry is used for hydrometeor identification mostly. But the fact that radar signal reflectors change their shape and orientation under the wind related phenomena influence is promising for operation with polarimetry for wind related phenomena detection and estimation. Some approaches that illustrate this possibility are presented in [13, 14, 15, 16]. These approaches are based on the behavior peculiarities of different liquid hydrometeors under the wind related phenomena influence that change their shape and orientation [17, 18]. Thus, it is interesting to evaluate the external influence character and its intensity through the change of drop orientation, shape variations and vibration of drops that, in turn, impact onto the polarimetric features of the reflected radar signal.

Modern radar polarimetry provides the most promising tools for measuring and estimating these polarization signatures for wide range of applications including dropsize distribution estimate, rain intensity measurement as well as dangerous dynamic phenomena detection and estimation.

In real situation peculiarities of drop behavior caused by wind related phenomena can be veiled beyond the averaged estimates of reflections from hydrometeors assemble. Therefore distinguishing hydrometeors with similar polarization properties inside the reflecting volume and estimating their differential impact into the polarization properties of reflected signal are important tasks for practical implementation of polarimetric methods for wind related phenomena detection and estimate.

## II. Relationship of Relected Signal Polarimetric Features with Scatterers Properties

Let us to use the principle depicted in [19] to find amount or volume of the particles with similar polarization properties inside the reflecting volume. In case of medium that consists of small particles that scatter and absorb electromagnetic waves, the complex refraction index can be written as

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$$m = n - i\tilde{n} \quad (1)$$

$\tilde{n}$ is an imaginary component that represents the absorption;

$n$ is a real component that represents scattering;

$n$ is equal to $m$ in case of non-absorptive particles.

Refraction index in [19] is proposed to find if combine the formula of Lorentz-Lorenz (2) for scattering under the condition when interparticle distances are small with respect to the wavelenth λ

$$4\pi\alpha N = 3(m^2-1)/m^2+2, \quad (2)$$

with formula from [19] for $m$ calculation under the condition when interparticle distances are large with respect to the wavelenth λ:

$$m = 1-i2\pi Nk^{-3}S(0), \quad (3)$$

$S(0)$ is function that depict forward scattering;

$\alpha$ is tenzor that in common case can be represented as scattering matrix;

$k^{-}=2\pi/\lambda$.

Value of $m$ obtained with formula (3) always is close to 1 [19].

Formula (2) considers scattering in all directions and formula (3) considers forward scattering, but some researches neglect this difference [19]. Backscattering under the conditions of formula (3) represents sum of backscattering produced by different particles.

It is shown in [19] that when $m$ is close to 1 in formula [2] the right part becomes equal to $m^2$-1. For the case of small particles

$$S(0) = i\,k^{-3}\,\alpha.$$

As a result of combination (2) with (3) it is obtained in [19]:

$$m - 1 = 2\pi\alpha N \quad (4)$$

N is the number of particles.

Under the conditions:

1) particles are homogenious;
2) particles have volume V;
3) refraction indexof particles $m^{/}$ is close to 1;

Hulst [19] uses ratio:

$$m - 1 = (m^{/} - 1)NV. \quad (5)$$

Formula (5) shows that $m - 1$ is proportional to the part of the volume $NV$ that is occupied by particles.

Supposing that $\alpha$ is real, refraction index can be written as

$$n = 1+2\pi\alpha N \quad (6)$$

It is important to note that scattering pattern is equal for any particles with sizes less than λ. Therefore it is impossible to define the particles size using the scattering pattern because of the intensity of electromagnetic oscillation is proportional to the number of particles in 1 $cm^{3.}$ The number of particles usually is unknown that makes it impossible to define drops size using the intensity of backscattering only.

Combining two effects and make radar measurements at different polarization angles it is possible to measure backscattering at different polarization angles. The measured backscattering gives the value $(Na^2)_i$ . Index $i$ represents polarization for which the measurements were done. Measuring refraction index at different polarization angle it is possible to obtain the value $(N\alpha)_i$. Index $i$ again represents polarization of reflected electromagnetic oscillation. Now it is possible to obtain $N_i$ and $\alpha_{i\ that}$ were obtained at different polarization angles. Having information about $N$ and medium density the information about mass of single particles can be obtained [19]. Information about mass and structure of the particle allows to obtain the volume of particle that is also related to $\alpha$.

It is known that the best reception of polarized signals is achieved when vectors of antenna polarization and signal polarization are coinciding. In other cases the energy level is defined as the projection of the electric field strength vector on the main axis of corresponding antenna pattern. The stronger the change of polarization, the weaker the energy of oscillations in the antenna tuned to receive oscillations with principal polarization; at the same time the higher energetic level of oscillations is received by the antenna tuned to polarization that is different from polarization of the sounding waveform. Taking into account fact mentioned above as well as the nature of liquid hydrometeors to change the polarization of reflected electromagnetic wave under the atmospheric dynamic phenomena influence it is possible to say that maximum contribution into intensity of backscattering with some definite polarization is given by particles of correspondent size, shape and orientation. Following the presented principle it is possible to estimate the number of particles and their dimensions that contribute into backscattering at some definite polarization. The estimation can be realized by measuring backscattering at different polarization angles. For this purpose it is reasonable to use the radar system with numbers of receiving antennas that is larger than two (two antennas are commonly used nowadays in modern polarimetric radars: one receiving antenna can receive signals with main polarization – polarization of sounding waveform and another receiving antenna can receive signals with orthogonal polarization). Such measurements allow to avoid averaging when polarization characteristics estimation and further loss of information about weight of contribution of separate liquid particle into final change of reflected electromagnetic wave polarization. Having this information it is possible to distinguish number and dimensions of hydrometeors with similar polarization properties inside the reflecting volume. Then, having obtained information about liquid hydrometeors with similar polarization properties that was obtained by radar antennas it is possible to calculate the numbers of particles and their dimensions. This information can be useful not only for dropsize distribution estimate and rainfall measurements but also for wind related phenomena detection and estimate with polarization methods.

## III. Features of the Radar System

The presented approach can be realized with radar system that was proposed in [20, 21]. The system primarily was developed for determination of dangerous weather phenomena connected with wind and for increasing the informativity of weather radar systems relatively to the obtaining information about factors that are the origin of changing polarization of reflected signal.

The system [20] operates the following way:

*1)* transmitting into the atmosphere the sounding signal with the fixed polarization

*2)* receiving reflected signal by the set of the antennas. Each antenna in the antenna set is tuned to receive signals of certain polarization. Then measuring the power of the signal with different polarization is made and if necessary the polarimetric parameters are calculated.

The operation of the system [20] for simplicity can be represented with the consequence of procedures for energy estimates at different antennas of polarimetric radar. It corresponds to the *n*-channel system that is shown in Fig.1. First number in blocks numbering in Fig.1 corresponds to channel and the second number designates the position of the block in the channel. Each channel corresponds to the definite polarization component of the received electromagnetic wave.

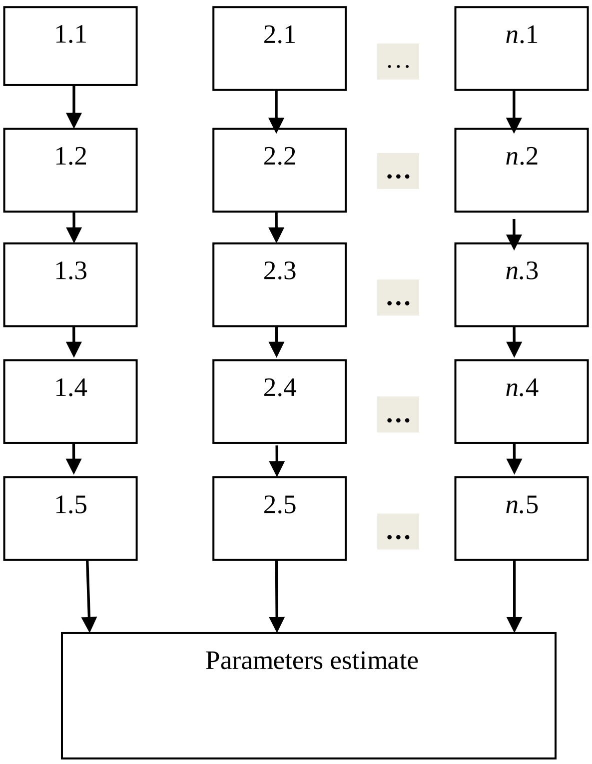


Fig.1. Principle of system operation for obtaining information about number and dimensions of hydrometeors with similar polarization properties inside the reflecting volume.

Block 1.1 represents receiving the signal with polarization that corresponds to the sounding waveform polarization (principle polarization);

block 1.2 represents the process of signal parameters measurement in the antenna that tuned to receive oscillations with principal polarization;

block 1.3 represents the process of estimating instantaneous power of received signal using the current variation in the antenna tuned to receive oscillations with principal polarization;

block 1.4 represents determination of weight coefficients for power redistribution at the antenna tuned to receive oscillations with principal polarization and determination of number and dimensions of hydrometeors that do not change polarization of the sounding waveform when backscattering;

block 1.5 represents instantaneous power separation over the polarization spectrum components taking into account their lifetime at the antenna that tuned to receive signals with principal polarization [22].

Blocks 2.1 - 2.5 represent the similar procedures for the antennas tuned to receive signals with polarization that is different from the polarization of sounding waveform and polarization that is orthogonal to the principle. The difference can be found only in block 2.4 in determination of number and dimensions of a portion of hydrometeors that change polarization of reflected electromagnetic wave by some specific angle. In this case the polarization of the reflected signal almost coincides with polarization properties of receiving antenna.

Blocks *n*.1 - *n*.5 demonstrate the similar procedures for the antenna that tuned to receive signals with orthogonal polarization taking into account peculiarities of procedure *n*.4.

After procedures .1-.5 it is possible to extract information about extent of different drops deformation taking into account the difference in their sizes and shapes inside the reflecting volume. This can help to estimate more precisely the intensity of influencing phenomena as well as to make a conclusion about its physical nature and thus better evaluate the danger of atmospheric phenomena connected with wind. Also, it helps to avoid the range of contradictions in information interpretation, for example, when increase of reflected energy at antenna with some definite polarization is caused by the big number of smaller drops or a few large drops.

## CONCLUSIONS

Presented principle of estimation of reflected signal properties with polarization features using the radar systemwith n receiving antennas allows to obtain information about number and dimensions of hydrometeors with similar polarization properties inside the reflecting volume. The presented approach is based on simultaneous measurement and estimation of backscattering from hydrometeor assemble with n antennas adjusted to receive electromagnetic waves with different polarization. Then calculation of particle volume and their number can be made. The realization of presented approach can improve estimates of dynamic phenomena according algorithm [13, 14, 15, 16, 21] as well as to improve measurements for other tasks of radar meteorology including drop size distribution estimate, rainfall intensity estimate, wind speed measurement, strong wind shear detection.

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