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TURBULENCE INTENSITY CLASSIFICATION BASED ON ESTIMATING STATISTICAL POLARIMETRIC PARAMETERS OF RADAR REFLECTIONS FROM RAIN

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In this paper the polarimetric approach for wind phenomena detection and study is proposed and analyzed. The polarimetric estimation of turbulence intensity is made with single unipolarized antenna radar system. The turbulence intensity classification based on statistical parameters of radar reflections from rain is made.

KEY WORDS: *radar polarimetry; hydrometeors; turbulence; statistical estimates*

1. INTRODUCTION

Operative obtaining information about hazardous weather phenomena is the question of great interest for many branches of human activity and of great importance for aviation. Since the development of radars the aviation services succeeded noticeably. Nowadays the non-coherent radar systems as well as coherent Doppler radars are in wide use throughout the world. The coherent Doppler radars in contrast to non-coherent systems allow to get information about dynamic processes in the atmosphere. However, as it was indicated in [1], modern radar systems cannot define the total wind vector, they are not successful enough just near the ground where their operation is characterized with rather high level of false alarm.

During the last period, the researches to improve detection algorithm and data processing for Doppler systems as well as in the field of combined Doppler-polarimetric meteorological radars were made [2,3,4]. They have proved that Doppler-polarimetric approach has much better possibilities in comparison with "conventional" and coherent Doppler radar alone [5,6]. However the operation of these systems is connected with complication of signal processing and data interpretation. Among the experts it was the opinion that polarimetric methods are effective for hydrometeor type recognition but not effective for turbulence detection. In [7] the principle possibility to use polarimetry for detection of turbulent zones in rain was shown.

In [8] polarimetric system that receives reflected waves with main polarization (polarization of sounding waveform) and polarization that differs from main and orthogonal to the main polarization is proposed and considered. This system gives possibility to obtain and analyze polarization spectra of electromagnetic waves reflected from hydrometeors [9]. In such system the reflected power of signal with changed polarization has higher energetic level compare to the signal in the antenna with orthogonal polarization [10]. This fact simplifies the polarization parameters calculation including parameters for atmospheric dynamics study and estimation.

In [8] the method for estimation of polarization variation of reflected from hydrometeor electromagnetic wave with unipolarized system is presented. The method is of interest for additional use in modern weather radars for deeper studding and better detecting hazardous weather phenomena including wind related phenomena.

Given paper is aimed to show possibility to make a detection dangerous turbulence detection and its intensity classification taking into account polarization characteristics of reflected from weather object signals.

2. TURBULENCE INTENSITY ESTIMATE WITH POLARIMETRIC RADAR

It was shown in [11] that degree of polarization angle change of reflected signal as informative parameter is changed according to the directional cosines and leads to the receiving energy fluctuation in the antenna. The fluctuations appear because the maximum value of receiving antenna energy corresponds to the reception of the reflected from weather target wave with polarization that coincides with sounding wave polarization. In case of changing polarization of the reflected from weather target wave, the receiving antenna current is defined as the projection on its beam width main axis. Taking into account the fact that fluctuation of antenna current can be caused by many factors we need to decide how to discern the useful fluctuation. For this purpose the physics of atmospheric phenomena are studied and frequency characteristics of amplitude fluctuations due to different factors are taken into account. According to [11] the polarization angle variations in reflected signal are provided by the frequency characteristics of signal reflectors under the wind phenomena influence and they are revealed as variations of low frequency (LF) component of received signal. In Figs.1-4 the examples of modeled LF envelope of reflected from weather object signal for different value of turbulence intensity are shown. The LF envelope is extracted with Hilbert Transform. The turbulence intensity is given as aircraft acceleration expressed in g units.

Comparing Figs. 1-4 it is possible to see that turbulence intensity increase leads to the rise of envelope level, changing the character of the reflected signal envelope and appearance of additional curvature of the reflected signal envelope. Therefore it is possible to say that behavior of LF components of reflected from hydrometeors signal contains information about presence of turbulence and indicates its intensity.

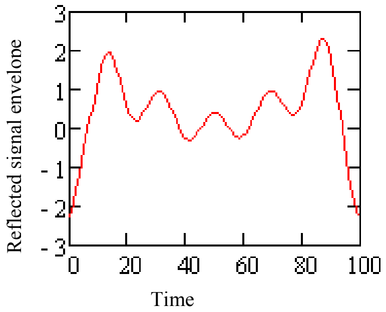

FIG. 1: LF envelope shape for light turbulence. Aircraft acceleration equals 0.2g

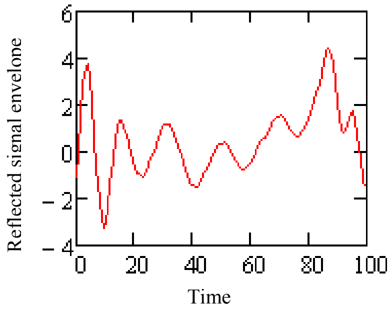

FIG. 2: LF envelope shape for moderate turbulence. Aircraft acceleration equals 0.5g

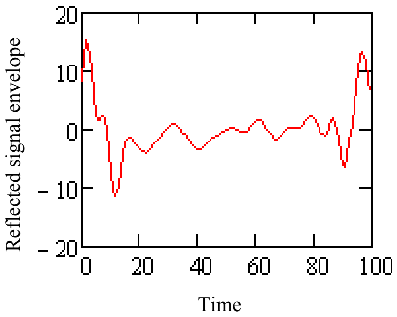

FIG. 3: LF envelope shape for strong turbulence. Aircraft acceleration equals 1g

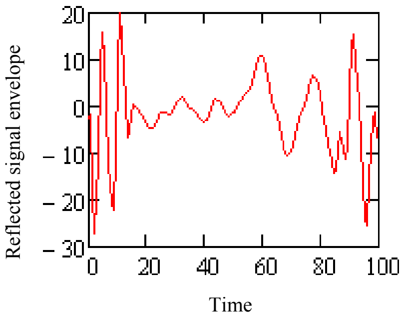

FIG. 4: LF envelope shape for severe turbulence. Aircraft acceleration equals 2g

3. ESTIMATING STATISTICAL POLARIMETRIC PARAMETERS AND TURBULENCE INTENSITY CLASSIFICATION

In this paper the turbulence intensity classification is made using the statistical data about variance of random process of LF component change as information parameter. After collecting statistical data about information parameter for 4 cases – light, moderate, strong turbulence we form the distribution of these parameters. Figure 5 shows the informative parameter distribution when light turbulence, moderate, strong and severe turbulence presence. Turbulence intensity are chosen to indicate the degree of aircraft acceleration (Δ*n)* during the flight according [12] Table 1.

TABLE 1: Turbulence intensity during the flight

Moderate turbulence	Δ*n* = ±0.5g…±1g	During route flight
Severe turbulence	Δ*n* is more than ±1g	During route flight

It is possible to see from Fig. 5 that the probability density concentrated strongly near the unity for light turbulence. The probability density is dispersed over wide interval in case of severe turbulence. For these two cases the distributions are superimposed on a short interval. This fact is promising for possibility to use polarimetry for turbulence detection.

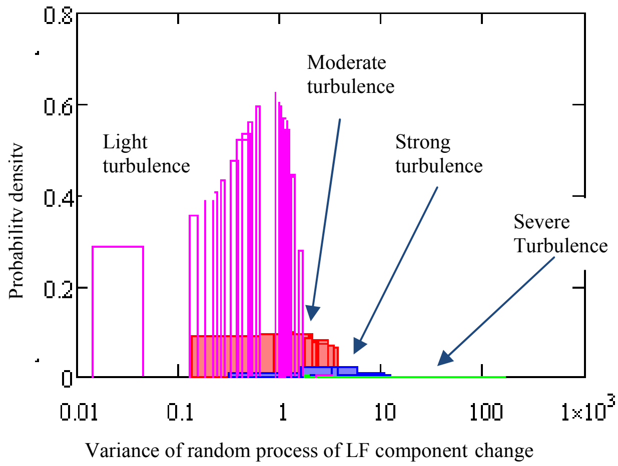

FIG. 5: Modeling results of informative parameter distribution for light, moderate, strong and severe turbulence in Log scale

To turbulence intensity classification we calculated the probability of right decision and false alarm when detection of turbulence with different intensity. For this purpose we choose the value of threshold to provide the minimum error when turbulence of wanted intensity detection. Then we calculate the probability of right decision and false alarm for all cases as a threshold function. The probability of false alarm and integrated probability of error as a threshold function are shown in Figs. 6-8.

From the Fig. 6 it is possible to see that the minimum of integrated probability of error is achieved at the threshold value equals about 2 when detection of moderate turbulence. In case of detecting strong turbulence (Fig. 7) the minimum of integrated probability of error can be found near the threshold value of about 6 and has the order of 0.1. The integrated probability of error decreases with threshold increasing constantly when detecting severe turbulence. To separate severe turbulence (more than 2g) from strong (more then 1g) the threshold can be taken of about 20. Though it is necessary to stress that, according Table 1, the turbulence that causes aircraft acceleration higher than 1g during the flight rout is considered as dangerous. Taking into consideration this fact the threshold indicating the strong turbulence can be taken of about 6.

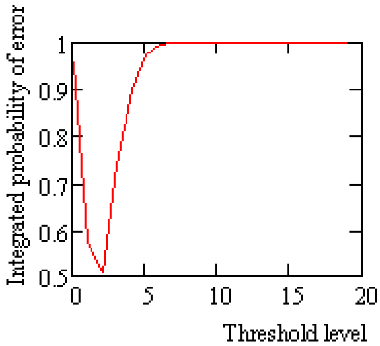

FIG. 6: Integrated probability of error as a threshold function when detecting moderate turbulence

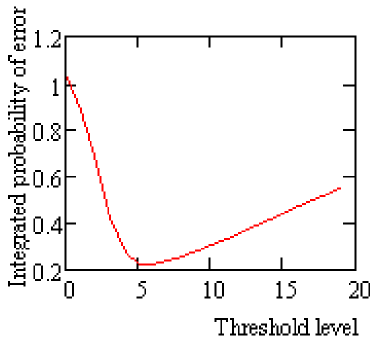

FIG. 7: Integrated probability of error as a threshold function when detecting strong turbulence

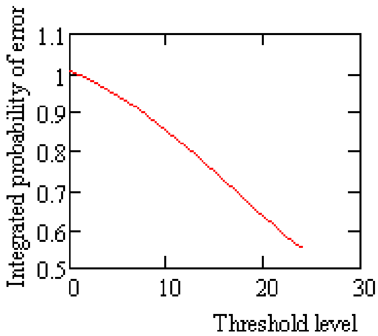

FIG. 8: Integrated probability of error as a threshold function when detecting severe turbulence

The classification of turbulence intensity according accepted ICAO criterion into light, moderate and strong is shown in Fig. 9. The ordinate axis indicates the level of integrated probability of errors for turbulence of different intensity. Solid line shows the integrated probability of error as a threshold function when detecting strong turbulence. Dotted line shows the integrated probability of error as a threshold function when detecting moderate turbulence. Dashed line shows the integrated probability of error as a threshold function when detecting severe turbulence. The absciss axis shows the value of variance of random process of LF component change due to change of polarization angle of reflected from weather object wave (informative parameter).

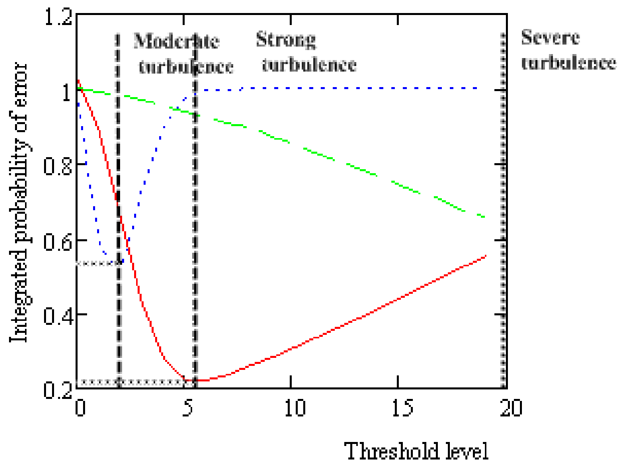

FIG. 9: Turbulence intensity classification

The vertical dotted line separates the regions for informative parameter values that correspond to different intensity of turbulence taking into consideration the minimum values of integrated probability of error for relevant turbulence intensity. The separation of strong turbulence from moderate is possible to make at higher level of probability than separation of moderate from light. The minimum integrated probability of error is achieved when detection of strong turbulence. It has the order of about 0.1 that corresponds the results obtained with some other methods for turbulence detection and classification.

4. CONCLUSIONS

1. The turbulence intensity classification proposed in this paper is based on untraditional estimate of polarization parameters of reflected from weather objects waves.
2. The integrated probability of error when turbulence detection using proposed method has the same order as the results obtained using other methods [13], for example when Doppler spectrum width is used for turbulence intensity estimate.
3. The proposed polarimetric method for turbulence detection and its intensity classification is untraditional but it can be implemented in both non-coherent and coherent radars.

4. The combined use of the proposed polarimetric method for wind related phenomena estimate, detection and intensity classification with other methods is the most interesting for deeper studding and better detecting hazardous weather phenomena.

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