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RADAR CHARACTERISTICS OF PRECIPITATION AFFECTING THE TRACKING OF SHIP'S RADAR OBJECTS

РАДІОЛОКАЦІЙНІ ХАРАКТЕРИСТИКИ ОПАДІВ, ЩО ВПЛИВАЮТЬ НА СУПРОВОДЖЕННЯ ОБ'ЄКТІВ СУДНОВОЮ РЛС

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ABSTRACT

In this paper, we consider the possibility of using the radar characteristics under precipitation conditions in order to reduce the echo signal's negative impact on the object tracking performed by the ship's radar. Precipitation particles' size, state (solid or liquid phase), shape, and the factors that determine their combined action play an important role in echo signal formation. The rain particles' size in comparison with the wavelength of the ship's radar may contribute to the creation of a larger or smaller noise echo signal on the ship's radar display. This signal's power in the Rayleigh scattering area towards the radar is characterized by the effective scattering area. Raindrops represent a combination of randomly located reflectors. Their scattering properties depend on spatial distribution and movement regularity.

At the same time, the radar characteristics of clouds with precipitation generated by them can be used in ship radars to determine the intensity of the atmospheric process along the ship's route. The uncertainty in determining the power attenuation of an electromagnetic wave emitted by a ship's radar antenna and passing through the precipitation zone can be reduced by the simultaneous use of two wavelengths on which a ship's radars operate.

The presented uncertainty function characterizes a narrow-band polarized scattered signal in regard to radar information about the distance to the sea object and the scatterer's speed. It characterizes the matched multidimensional coherent filter's properties. This filter provides optimal echo reception against the background of an uncorrelated precipitation echo signal. The matched filter belongs to the class of optimal linear filters according to the criterion of the maximum signal-to-noise ratio and is the main element for radar detection devices in the ship radar, which is optimal according to the Neyman-Pearson criteria.

Keywords: radar characteristics of precipitation, precipitation intensity, effective scattering area, precipitation particle diameter, dielectric constant, energy attenuation, radio waves, wavelength.

Statement of the problem in general terms and its relationship to scientific and practical tasks

The peculiarity of tracking objects with a ship's radar in the presence of precipitation of varying intensity, which complicates the process of navigation, is the necessity of considering their radar characteristics. This information is particularly important during the echo determination in the background of the precipitation echo on the ship's radar display. Methods for processing radar data on precipitation, considering their radar characteristics, allow the operator of a ship's radar to make the right decision about the echo signal presence or absence of an object, which generally increases the safety of navigation in difficult atmospheric conditions.

Analysis of recent advances and publications that have begun to address this problem and highlight unresolved issues.

A method for researching the radar characteristics of clouds and precipitation was proposed in [1], and in [2], as well as the influence of meteorological factors and the underlying surface on the operation of the radar were also considered.

In [3], an electrodynamic model of interference from hydrometeors is considered. In [4], models of interfering reflections from the earth's surface are considered for the analysis and design of radars.

Problem statement

The purpose of the paper is to analyze some features of the radar characteristics under precipitation conditions that affect the objects tracking by the ship's radar.

Statement of the material of the study with the justification of the obtained scientific results

The electromagnetic wave attenuation of the 3-cm range emitted by the ship's radar antenna significantly affects the objects' radar tracking. The weakening of electromagnetic energy is a function of the precipitation intensity. It depends on radar characteristics and is determined by the water content in a unit of the radar volume in the liquid phase. The vertical distribution of rain intensity is determined by its structure. Thus, in long continuous rains, this distribution is described by an exponential dependence. Convective rains are characterized by a diverse structure with the presence of separate bands raised above the water surface, due to the focal nature of shower clouds.

A thunderstorm area includes one or more storm zones centered at a height of one kilometer from the water surface. Powerful thunderstorm formations are associated with high-intensity precipitation, which degrades the objects' radar surveillance on the ship's path by illuminating large sections of the ship's radar indicator and completely masking the echo signals of an oncoming ship.

Even the use of circularly polarized waves does not solve the radio objects' visibility problem during precipitation with an intensity of one hundred to two hundred mm / h. The reason is that each particle of such precipitation is significantly different from the sphere and the decrease in the echo signal from precipitation is negligible.

When analyzing the echo signals of an object, we may compare two photographs where the first one illustrates the radar indicator in the presence of an echo signal from a powerful thundercloud with high-intensity heavy rainfall (radius from the center of the image is 75 km) with the emission and reception of linearly polarized waves (Fig. 1). And photograph 2 demonstrates the same indicator under the same conditions as in Fig. 1 when receiving a circular polarization echo (at a distance of 75 km from the center of the echo circle, objects are in the area of the rain shower echoes) (Fig. 2). There are still unsolved issues related to the assessment systematization of the electromagnetic radio waves attenuation of three and ten-centimeter ranges in rain within various climatic regions along the ship's route.

Since 1960 and up to the present time, the quantitative radar echoes interpretation and the search for their dependence on the falling rain intensity, the drops' size, and the speed of their fall, has not been completed. It is associated with the fact that research is carried out within the troposphere, therefore data recording is significantly complicated by the conditions.

The precipitation zone is characterized by the following parameters: shape, size, speed of movement, lifetime, phase of development, and structure.

According to synoptic information, precipitation is characterized by frontal and air-mass origin. Air-mass precipitations are subdivided into thunderstorms, showers, and widespread precipitation [5, 6]. According to the structure, the precipitation is subdivided into cellular, multicellular, and strip-like [7].

The intensity of precipitation at a given level depends on the concentration of raindrops, the spectrum of their sizes, and the rate of fall relative to the underlying surface and depends on the time and place of precipitation [8]

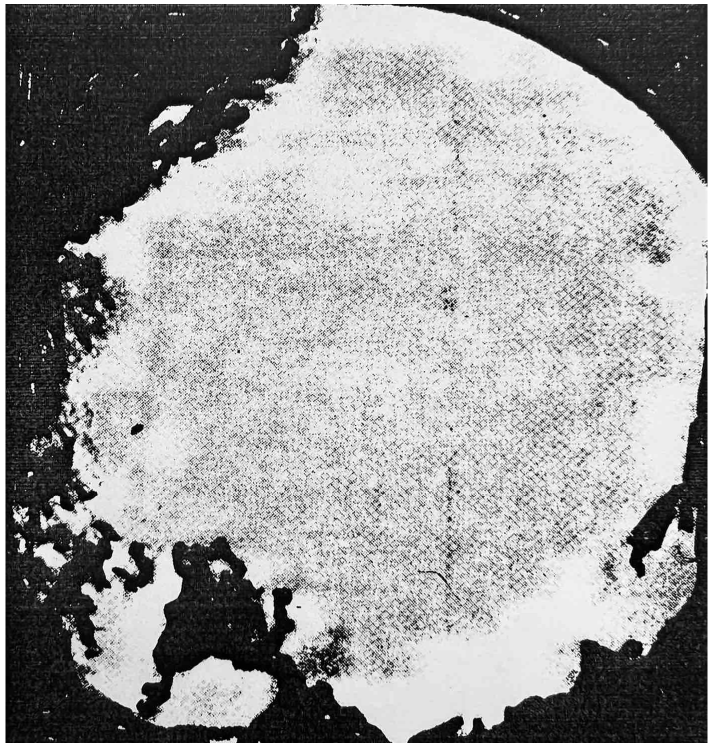

Fig. 1. Photograph of the radar indicator

Fig. 2. Photograph of the same indicator when receiving a circular polarization echo

$$I(x,y,t)=\frac{\pi}{6}\int_{d_{\min}}^{d_{\max}} d^3 N(x,y,t,D)\left[v(d)-u(x,y,z,t)\right]dD, \qquad (1)$$

where $v(d)$ is the rate of balanced fall of drops, m/s;

$u(x,y,z,t)$ is the vertical speed of air flows, m/s;

$d_{\max}$ and $d_{\min}$ are the maximum and minimum diameters of droplets in precipitation, mm;

$N(x,y,t,D)$ is the distribution function of precipitation particles per unit volume of air by diameters D.

The amount of precipitation Q is determined by the condition:

$$Q=\int_{t_1}^{t_2} I(t)\,dt. \quad (2)$$

The total lifetime $t_{\text{tot}}=50I_{\max}^{0,22}$ of the precipitation zone:

$$t_{\text{tot}}=50I_{\max}^{0,22}. \quad (3)$$

The sum η of the backscattering cross-sections of all particles in a cloud volume unit is determined by the equation:

$$\eta=\int_{D_{\min}}^{D_{\max}} N(D)\sigma(D,x)\,dD, \quad (4)$$

where $N(D)$ is the number of particles with a diameter D in the radar space of precipitation;

$\sigma(D,x)$ is the effective scattering area of particles with a diameter D at a wavelength λ.

The dependence η_λ of hail precipitation on their intensity and size on $\lambda=3,2$ cm and $\lambda=10$ cm is described by the following expressions:

$$\eta_{3,2}=6,7\cdot10^{-7}Nd_3^{2,1}, \quad (5)$$

$$\eta_{10}=3,8\cdot10^{-8}Nd_3^{5,4}, \quad (6)$$

$$\eta_{3,2}=2,3\cdot10^{-7}I^{0,6}, \quad (7)$$

$$\eta_{10}=6,3\cdot10^{-10}I^{1,54}. \quad (8)$$

The precipitation area S is estimated by the formula:

$$S=\frac{\pi}{4a_b b_s}, \quad (9)$$

where a_b is the major and b_s is the minor axis of the precipitation source, km.

Cell parameters for different regions of the globe have different values. Thus, for the North Atlantic, the median area for 1141 cells was 22 km^2; for the eastern Atlantic off the coast of Africa (Dakar), the maximum areas were 80 and 200 km^2.

The radar characteristics of rain cells near Montreal are given in Table 1.

Table 1. Characteristics of rain cells near Montreal

Radar characteristics	I, mm/h								
	5	**10**	**20**	**30**	**60**	**90**	**125**	**175**	**250**
N_{cell}	**906**	**1451**	**1643**	**1216**	**784**	**504**	**349**	**204**	**38**
D'_{cell}, km	**13,6**	**9,2**	**6**	—	**4,2**	**3**	**2**	—	—

Note. $D'_{\text{cell}} = \sqrt{S'}$, S' is the area of the radio echo, on the outer contour of which the threshold $I = I'$ of precipitation is set, which is determined by the formula $z = 200I^{1,6}$ – radar reflectivity of precipitation.

The dielectric constant ε of liquid precipitation particles is determined by the wavelength λ and temperature and has real and imaginary parts, which are calculated using the Debye formulas

$$\operatorname{Re}\varepsilon = \varepsilon_0 + \frac{\varepsilon_s - \varepsilon_0}{1 + \left(\lambda_s/\lambda\right)^2}, \quad (10)$$

where $\varepsilon_0 = 5,5,$ $\lambda_s = 1,4662e^{-0,0634t} + 0,000136t^2 - 0,02729t + 1,8735,$ $\varepsilon_s = 0,00081t^2 - 0,4088t + 88,2,$ here t is the temperature in °C.

Conclusions and prospects for further work in this area

The main radar characteristics of precipitation zones, which may occur along the ship's trajectory, are considered. Accounting for radar characteristics in the operation of a ship's radar to track an object, increases the safety of navigation in a certain region of the vessel's location.

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