

Radar Characteristics of Precipitation Affecting the Tracking of Ship's Radar Objects

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ABSTRACT: In this paper, we consider the possibility of using the radar characteristics of precipitation in order to reduce the negative impact of the echo signal generated by them on the radar tracking of objects performed by the ship's radar. In the formation of an echo signal by precipitation, both the precipitation particles themselves: their size, state (solid or liquid phase), shape, and the factors that determine their combined action (concentration, relative position, preferred orientation), are important. The size of rain particles when compared to the wavelength emitted by the ship's radar antenna contributes to the creation of a larger or smaller noise echo on the display of the ship's radar, the power of which in the Rayleigh scattering region toward the radar is characterized by the effective scattering area. Falling raindrops are a collection of randomly located reflectors and their scattering properties depend on the spatial distribution and regularity of movement. 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, and the uncertainty in determining the attenuation of the power of an electromagnetic wave emitted by a ship's radar antenna and passing through the precipitation zone can be reduced by simultaneous use of two wavelengths on which ship's radars operate.

1 INTRODUCTION

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 need to take into account their radar characteristics, which are especially important when they are used while the ship is moving through the precipitation zone. The value of such information is greatly increased when the echo is recognized in the background of the precipitation echo on the display screen of a ship's radar. Methods for processing radar data on precipitation, taking into account their radar characteristics, allow the operator of a ship's radar to make the right decision about the presence or absence of an echo signal of an object, which generally

increases the safety of navigation in difficult atmospheric conditions.

2 ANALYSIS OF RECENT RESULTS AND PUBLICATIONS IN WHICH THE SOLUTION TO THIS PROBLEM HAS BEEN STARTED AND THE ALLOCATION OF PREVIOUSLY UNSOLVED PARTS OF THE GENERAL PROBLEM

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.

3 PURPOSE STATEMENT

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

4 PRESENTATION OF THE MATERIAL OF THE RESEARCH WITH THE SUBSTANTIATION OF THE RESULTS OBTAINED

The weakening of the electromagnetic wave of the 3-cm range emitted by the ship's radar antenna significantly affects the radar tracking of the ship's radar objects. The weakening of electromagnetic energy is a function of the intensity of precipitation, which depends on radar characteristics and is determined by the content of water in the liquid phase in a unit of the radar space. The vertical distribution of rain intensity is determined by its structure. Thus, in long continuous rains, this distribution is described by an exponential dependence, rains of conventional origin 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 consists of 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 radar surveillance of objects on the ship's path by illuminating large sections of the ship's radar indicator and completely masks the echo signals of an oncoming ship.

Even the use of circular polarized waves does not solve the problem of radio visibility of objects during precipitation with an intensity of one hundred to two hundred mm / h, because 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 (Fig. 1, 2), there are still unsolved issues related to the systematization of the assessment of the attenuation of electromagnetic radio waves of three and ten-centimeter ranges in rain in various climatic regions of the globe, where the trajectories of sea vessels pass. Since 1960 and up to the present time, the quantitative interpretation of radar echoes and the search for their dependence on the intensity of the falling rain, the size of its drops, and the speed of their fall, has not been completed. This is largely due to the fact that the laboratory for research is the troposphere, in which laboratory conditions are beyond the possibility of recording them.

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

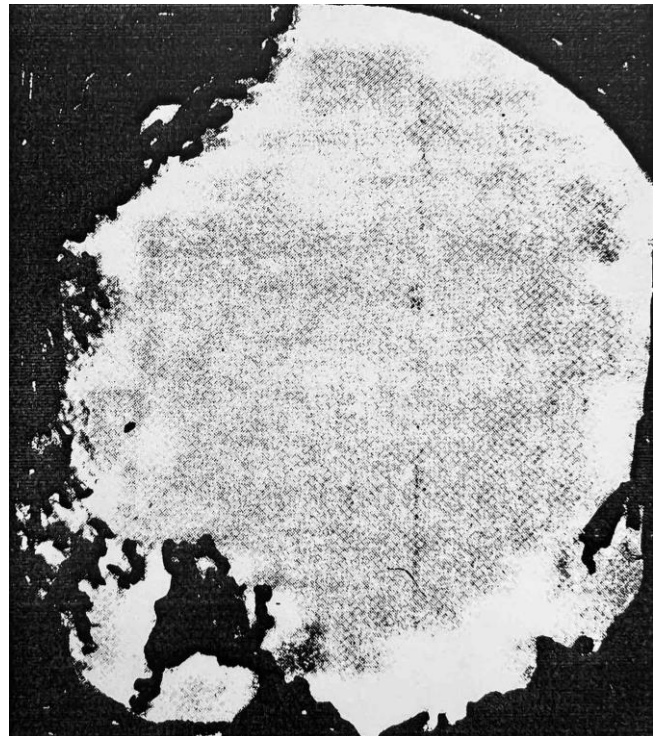


Figure 1. Photograph of the radar indicator in the presence of an echo signal from a powerful thundercloud with high-intensity heavy rainfall (radius from the center of the image is 75 km) with the emission and reception of linearly polarized waves



Figure 2. Photograph of 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)

From the point of view of 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 striplike [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]

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

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 from the condition:

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

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 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:

$$\eta_{3,2} = 6,7 \cdot 10^{-7} N d_3^{2,1} \quad (5)$$

$$\eta_{10} = 3,8 \cdot 10^{-8} N d_3^{5,4} \quad (6)$$

$$\eta_{3,2} = 2,3 \cdot 10^{-7} I^{0,6} \quad (7)$$

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

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 km²; for the eastern Atlantic off the coast of Africa (Dakar), the maximum areas were 80 and 200 km².

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

Table 1. Characteristics of rain cells near Montreal

Radar charact.	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	9,26	—	4,23	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

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

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.

5 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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