THE FEATURES OF THE SCATTERING OF ELECTROMAGNETIC AND ACOUSTIC WAVES IN THE WATER BOUNDARY LAYER OF THE ATMOSPHERE

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On the basis of exploration of the processes of small-scale dependence of the sea and atmosphere conducted in the Caspian Sea [6-9] were examined some features of the scattering of electromagnetic and acoustic waves in the water boundary layer of the atmosphere.

INTRODUCTION

The solution of the problems of radiophysics and hydrophysics demands to study the influence of the turbulent structure of the atmospheres water boundary layer on the scattering of electromagnetic and acoustic waves in it. The regime of the turbulence in the atmosphere's water boundary layer practically depends on the extent of the windy waves development defining by the attitude c/u_*, where *c*-phase velocity of the main energycarrying surface wave, u_*-dynamic velocity of wind. The vast scientific literature [1-3] is dedicated to the methods of theoretical calculation of the fluctuation phenomena's in the water boundary layer and their experimental research. A few of works are dedicated to the research of features of the scattering of electromagnetic and acoustic waves although the remote probe of the ocean and the sea has a big meaning. So our work is dedicated to the revealing of the influence of the turbulence's regime in the water boundary layer of the atmosphere on the scattering electromagnetic and acoustic waves in it.

TEORETICAL FOUNDATIONS

Some features of the scattering of electromagnetic and acoustic waves in the water boundary layer of the atmosphere are examined in the dependence on the phase of development of the windy waves on the basis of the exploration conducted in the Caspian Sea [7; 8] with following suppositions:

a) The thermal stratification in the water layer of the atmosphere is close to neutral that is the Richardson number reaches to zero (Ri→0).

b) Electromagnetic and acoustic waves are spread at the altitude $Z>Z^o$, where Z^o-height; vertical profiles of meteorological parameters are declined from the logarithmic law higher than the height.

The scattering of the electromagneting and acoustic waves passing through the turbulent medium (it is an atmosphere and sea) is a main cause of fluctuations of the refractive coefficient. The refractive coefficient of the atmosphere [1; 3; 4] is a function of the temperature, wind velocity and humidity.

For the description of the scattering of electromagnetic and acoustic waves flows in the volume *V* containing the turbulence we must determine the average value $\overline{d\sigma}$ - effective section of the dispersion in this volume in any directions $\vec{q}$.

This value is determined by the following formulas mentioned in [3,4].

In the case with electromagnetic waves:

$$\frac{\overline{d\sigma}}{V\cdot d\Omega_e}=2^{-\frac{14}{3}}\cdot K^{\frac{1}{3}}\cdot \sin^2\alpha\cdot\left[A^2\cdot\left(B^{(T)}\cdot\overline{N_T}+B^{(e)}\cdot\overline{N}_E\cdot B^2\right)\cdot\bar{\varepsilon}^{-\frac{1}{3}}\right]\cdot\left|\sin\frac{V}{2}\right|^{-\frac{14}{3}} \quad (1)$$

and in the case with acoustic waves:

$$\frac{\overline{d\sigma}}{V\cdot d\Omega_a}=2^{-\frac{14}{3}}\cdot K^{\frac{1}{3}}\cdot \cos^2 v\left[\frac{c_1\cdot\cos^2\frac{v}{2}\cdot\bar{\varepsilon}^{-\frac{2}{3}}}{c^2_0}+\frac{B^{(T)}\cdot\overline{N}_T\cdot\bar{\varepsilon}^{-\frac{1}{3}}}{4\cdot\overline{T}^2}\right]\cdot\left|\sin\frac{v}{2}\right|^{-\frac{11}{3}} \quad (2)$$

Here $K=\frac{2\pi}{\lambda}$ - wave number, α - angle between vectors $\vec{p}$ (whose the unit vector is perpendicular to the direction of the spreading of waves and describes its polarization) and $\vec{q}$; c_1- constant , equal 1,5 ; c_0- average speed of the spreading of acoustic waves in the air ; $\overline{N}_T$ and $\overline{N}_E$ -parameters characterizing the velocities of inhomogeneties alignment of temperature and specific density at the expense of the molecular effects , *v* - angle of waves' scattering , $\overline{T}$ - absolute average temperature , $\overline{E}$ - average specific humidity , Ω - spatial angle , $\bar{\varepsilon}$ - average velocity of dissipation of the turbulent energy , $B^{(T)}$ and $B^{(E)}$- constant values about unity ;

$$A=10^{-6}\cdot\left(79\frac{\overline{P}}{\overline{T}^2}\right)\cdot\left(1+\frac{15600}{\overline{T}}\cdot\overline{E}\right);$$

$$B=7800\Big/\left(1+\frac{15600}{\overline{T}}\cdot\overline{E}\right) \quad (3)$$

where $\overline{P}$ - average atmosphere's pressure.

According to the theory by Monin - Obukhov [2] in the case of thermal stratification, close to neutral, is used the following formulas:

$$\bar{\varepsilon} \approx \frac{u_*^3}{k \cdot z},$$

$$\overline{N}_T \approx \frac{k \cdot u_* \cdot T_*^2}{z}, \qquad (4)$$

$$\overline{N}_E \approx \frac{k \cdot u_* \cdot E_*^2}{z},$$

where u_* , T_* , E_* - accordingly gauges of the velocity of wind, temperature and humidity.

These values we can determine through flows of quantity of the momentum τ, the heat q_T and the humidity W_E in the following way:

$$u_* = \sqrt{\frac{\tau}{\rho}},$$

$$T_* = -\frac{q_T}{k \cdot u_* \cdot c_p \cdot \rho_a}, \qquad (5)$$

$$E_* = -\frac{W_E}{k \cdot \rho_a \cdot u_*},$$

where c_p and ρ_a - specific heat capacity and density of the air, k - constant of Carmana.

The direct natural measuring of the vertical flows of quantity of τ , q_T and W_E demand to use high-sensitive and expensive devices. So by solution of the problem of small-scale interaction of the atmosphere and the sea we must pay attention to the definition of the mentioned flows through easy-measurable exterior parameters [2]

:

$$\delta u = \overline{u}_a - \overline{u}_w \cong u_a;$$

$$\delta\overline{T} = \overline{T}_w - \overline{T}_a \qquad (6)$$

$$\delta\overline{E} = \overline{E}_w - \overline{E}_a$$

where $\overline{u}$; $\overline{T}$; $\overline{E}$ -average velocity of wind , temperature , density of air and indices "a" and "w" refer to the standard height their measuring and marine surface .

So vertical flows we can express in the following way:

$$\tau = \rho_a \cdot c_a \cdot \overline{u}_a^{\,2},$$

$$q_T = \rho_a \cdot c_T \cdot \overline{u}_a \cdot \delta\overline{T}, \qquad (7)$$

$$W_E = \rho_a \cdot \overline{u}_a \cdot \delta\overline{E},$$

where c_a ; c_T ; c_e - coefficients of the marine surface resistance, the transfer of heat and evaporation.

Then with help of the equations (5) we can receive:

$$T_* = \left(\frac{c_T}{\sqrt{c_a}}\right) \cdot \left(\overline{T}_a - \overline{T}_w\right),$$

$$E_* = \left(\frac{c_E}{\sqrt{c_a} \cdot k}\right) \cdot \left(\overline{E}_a - \overline{E}_w\right) \qquad (8)$$

If to use the received scales the formulas (4) will have a following form:

$$\varepsilon = \frac{u_*^{\,3}}{k \cdot z},$$

$$\overline{N}_T = \left(\frac{u_*}{k \cdot z}\right) \cdot S_1 \cdot \left(\overline{T}_a - \overline{T}_w\right), \qquad (9)$$

$$\overline{N}_E = \left(\frac{u_*}{k \cdot z}\right) \cdot S_2 \cdot \left(\overline{E}_a - \overline{E}_w\right)$$

where $S_1 = \dfrac{c_T^{\,2}}{c_a}$; $S_2 = \dfrac{c_E^{\,2}}{c_a}$ (10)

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Having defined a wave number as $2\pi/\lambda$ and having inserted the formulas (9) in (1) and (2) we can receive the following formulas:

$$\frac{\overline{d\sigma}}{V \cdot d\Omega_e} = \frac{2^{-\frac{14}{3}} (2\pi)^{1/3} \cdot \lambda^{-\frac{1}{3}}}{(k \cdot z)^{2/3}} \cdot \sin^2\alpha \left[A \cdot \left(B^{(T)}\right) \cdot S_1 \cdot \left(\overline{T}_a - \overline{T}_w\right) + B^{(E)} \cdot S_2 \cdot \left(\overline{E}_a - \overline{E}_w\right)^2 \cdot B^2\right] \cdot \left|\sin\frac{v}{2}\right|^{-\frac{11}{3}} \qquad (11)$$

$$\frac{\overline{d\sigma}}{V \cdot d\Omega_w} = \frac{2^{-\frac{14}{3}} (2\pi)^{\frac{1}{3}} \cdot \lambda^{-\frac{1}{3}}}{(k \cdot z)^{2/3}} \cdot \cos^2 v \cdot \left[\frac{c_1 \cdot \cos^2 \frac{v}{2} \cdot \varepsilon^{-\frac{2}{3}}}{c_o^{\,2}} + \frac{B^{(T)} \cdot \overline{N}_T \cdot \varepsilon^{-\frac{1}{3}}}{4\overline{T}^{\,2}}\right] \cdot \left|\sin\frac{v}{2}\right|^{-\frac{11}{3}} \qquad (12)$$

As it is seen from the formulas (11) and (12) parameters S_1 and S_2 enter the number of parameters determining the diffusion of waves. The last are determined with help of the coefficients c_a , c_T and c_e . As it is shown in the articles [5,7] one of the main parameters determining the dynamic processes in the water boundary layer is "waves' age "(which characterize the extent of the development of windy waves) expressed c/u_* . According to [5] the values $c/u_* \le 25-30$ correspond to the regime of the developing waving, $c/u_* \approx 30-40$ - the developed waving and $c/u_* \ge 40$ - the decadent waving.

RESULTS

For the definition of the dependence of the scattering of electromagnetic and sound waves on the extent of development of windy waves as it seen from (11) and (12) we must explore the variability of parameters S_1 and S_2 defined by the coefficients c_a , c_T and c_E . However up to now we have not a lot of experimental works which are dedicated to the study of the connections these coefficients with characteristics of the interaction wind are fields and surface waves. But we have a lot of experimental data which allow defining the variability of the parameter of roughness z_0 or c_a in a dependence on the characteristics of interaction of the sea and atmosphere.

So the task of the definition of the vertical flows of heat and moisture is tried to solve with help of the calculation of unit parameter z_0.

In the article [5] on the basis of the natural measuring of characteristics of the interaction of the sea and atmosphere in the wide range of the variability of exterior hydrometeorological conditions of the coefficients c_a , c_T and c_E were approximated by the following formulas :

$$c_a \approx 1{,}2 \cdot 10^{-3} \cdot \left(\frac{z^0 \cdot u_*}{V} \right) \tag{13}$$

$$c_T \approx c_E \approx 10^{-3} \cdot \left(\frac{z^0 \cdot u_*}{\nu} \right) \tag{14}$$

where $V \approx 0{,}15\ cm^2/sec$ is a coefficient of the kinematic viscosity of the air.

These formulas were received by the data of the direct measurement of τ , q_T and w_E. The conducting of the measuring in the different hydrometeorological conditions permitted authors to define the dependence z_0 and u_* on the parameter c/u_* , so far as u_* is stimulatingly determined by direct and indirect methods.

It is known that the development of the surface waves is escorted by the formation of the unstationary boundary layer of atmosphere. The connection between characteristics of the water boundary layer of atmosphere and the surface waves according to the data of the natural measuring is detail described in the work [6]. On the basis of the mathematical models of the atmosphere's boundary layer [7,8] we can receive the following formulas for its characteristics:

$$z^0 = \frac{u_\infty{}^2 \cdot \rho_w \cdot \beta}{\rho_a \cdot g^3} \cdot \left[\frac{4}{3} \cdot \left(\frac{c}{u_\infty} - \gamma \right) \right]^3 \cdot \frac{\xi \cdot e^{-\xi}}{1 - e^{-\xi}} \tag{15}$$

$$\frac{c}{u_\infty} = \left(1 - e^{-\xi}\right)^{-1} - \frac{1}{\xi} \quad ; \quad \frac{c}{u_*} = \frac{10}{3} \cdot \left(\frac{c}{u_\infty} - \gamma \right) \tag{16}$$

where u_∞ - wind velocity on an upper bound of the wave's boundary layer, g - speeding up of free fall (acceleration due to gravity); β -constant, equal 10^{-2} ; γ -constant coefficient; $\xi = \frac{u_\infty \cdot k}{u_*}$.

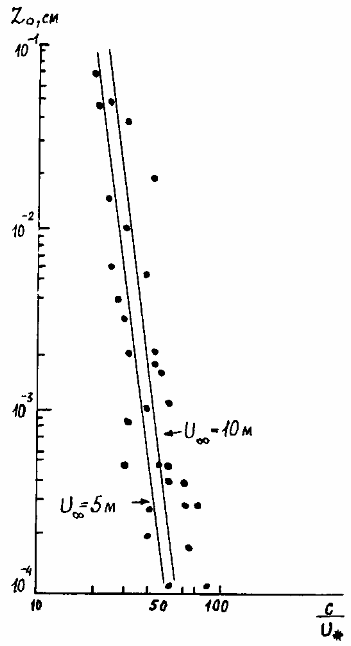

Fig.1. The dependence of the parameter of roughness on c/u_* .

The comparisons (15) and (16) with the experimental data has shown that its better conformity is achieved by γ =0,25.

The dependence of the parameter of roughness z_0 on the stage of the development of windy waves c/u_* according to the data of natural measuring in the Caspian Sea [7, 9] is shown on the fig.1. As it seen from the figure 1 the calculating and experimental points are coordinated quite satisfactorily.

Inserting the formula (15) in (13) and (14) and using (10) we can receive:

$$S = S_1 \approx S_2 = 8{,}4\cdot 10^{-4}\left\{\frac{u_\infty{}^3\cdot k\cdot\rho_w\cdot\beta}{g\cdot\gamma\cdot\rho_a}\cdot\left[\left(\frac{c}{u_\infty}-\gamma\right)\cdot\frac{u}{3}\right]^3\right\}\cdot\frac{e^{-\xi}}{1-e^{-\xi}} \quad (17)$$

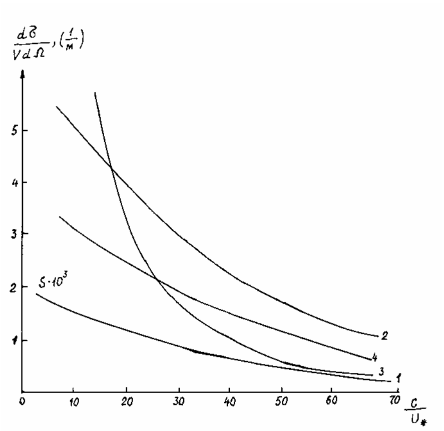

Fig.2. The dependence of characteristics of the scattering of electromagnetic and acoustic waves on c/u_* .

Such method simplifies to make calculation of the scattering according to the formulas (11) and (12), in which S enters.

The dependence of the parameter S on the stage of the development of windy waving (curve 1) is shown on the fig.2.

By constructing the figure $u_{10} = 10\, m/s$.

As it is seen from the figure when the parameter c/u_* increases from 10 to 70 the value S decreased up to1,5 times.

If to use $S = S_1 = S_2$ in the formulas of calculation of the scattering of electromagnetic and acoustic waves in the water layer of the atmosphere (11) and (12) after the foolproof transformations we are receiving:

$$\frac{\overline{d\sigma}}{V\cdot d\Omega_e} = \frac{2^{-\frac{14}{3}}\cdot(2\pi)^{1/3}\cdot\lambda^{-\frac{1}{3}}\cdot S}{(k\cdot z)^{2/3}}\cdot\sin^2\alpha\left[B^{(T)}\left(\overline{T}_a-\overline{T}_w\right)^2 + B^{(E)}\cdot\left(\overline{E}_a-\overline{E}_w\right)^2\cdot B^2\cdot A^2\right]\cdot\left|\sin\frac{v}{2}\right|^{-\frac{11}{3}} \quad (18)$$

$$\frac{\overline{d\sigma}}{V\cdot d\Omega_a} = \frac{2^{-\frac{14}{3}}\cdot(2\pi)^{1/3}\cdot\lambda^{-1/3}}{(k\cdot z)^{2/3}}\cdot\cos^2 v\cdot\left[\frac{c_1\cdot k^2\cdot\overline{u}_\infty{}^2}{\xi^2\cdot c_0}+\frac{B^{(T)}}{4}\cdot S\cdot\left(1-\frac{\overline{T}_w}{\overline{T}_a}\right)^2\right]\cdot\left|\sin\frac{v}{2}\right|^{-\frac{11}{3}} \quad (19)$$

Then inserting the formula (17) in (18) and (19) and taking into consideration (15) and (16) we can construct graphs of the dependence of characteristics of the scattering on the extent of development of windy waving. We have constructed the dependences of the scattering on parameter c/u_* for several cases.

The curve 2 (fig. 2) shows the dependence of the parameter $\frac{\overline{d\sigma}}{V\cdot d\Omega_e}$ on c/u_* by $\lambda = 0{,}081$;

$|\delta E| = 0{,}001^{2/2}$; $\gamma = 0{,}25$; $\overline{P} = 1000mb$;

$u_\infty = 10\, m/s$; $v = 48^0$ and $z = z_a = 10_m$.

But a reverse scattering by such methods is shown on the curve 4. Analogous dependence corresponds to the curve 3.

CONCLUSION

On the basis of analysis of the results of theoretical and experimental explorations of the turbulent water layer of the atmosphere and its interaction with windy waves is shown that the characteristics of the mentioned interaction have an influence on the scattering of electromagnetic and acoustic waves in it.

So the scattering of the waves rather quickly decreases by the increasing of the parameter c/u_* , characterizing the extent of the development of windy waves.

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ATMOSFERİN SUYANI QATINDA ELEKTROMAQNİT VƏ SƏS DALĞALARININ SƏPİLMƏSİNİN XÜSUSİYYƏTLƏRİ

Xəzərdə kiçik miqyaslı «dəniz-atmosfer» qarşılıqlı təsirinin eksperimental tədqiqatları nəticələri əsasında suyanı atmosfer qatında elektromaqnit və akustik dalğaların səpilməsi qanuna uyğunluqları araşdırılmışdır. Müəyyən edilmişdir ki, göstərilən atmosfer qatında elektromaqnit və akustik dalğaların səpilmə xarakteristikaları dalğa rejiminin inkişaf mərhələsini xarakterizə edən c/u_* parametrindən ciddi asılıdır.

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ОСОБЕННОСТИ РАССЕЯНИЯ ЭЛЕКТРОМАГНИТНЫХ И ЗВУКОВЫХ ВОЛН В ПРИВОДНОМ СЛОЕ АТМОСФЕРЫ

На основе результатов экспериментальных исследований мелкомасштабного взаимодействия «море-атмосфера» на Каспии проанализированы закономерности рассеяния электромагнитных и акустических волн в приводном слое атмосферы. Установлено, что характеристики рассеяния электромагнитных и акустических волн в указанном слое атмосферы существенно зависят от параметра c/u_* ,характеризующего стадию развития ветровых волн.

Received:24.06.04