The effect of dynamic properties of a vertically stratified sea and biogenic factors on concentration of phytoplankton *

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Mathematical model
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Turbulent diffusion
Passive suspension

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Abstract

The paper presents considerations on the methodology and results of theoretical investigations of the effect of a stratified sea dynamics and biogenic factors on concentration of chlorophyll. The investigations were carried out using a Crank-Nicholson's indirect numerical method and basing on a one-dimensional mathematical model of turbulent diffusion of a passive suspension, as well as a Platt's model describing the efficiency of a source. The algorithm of numerical model has been discussed and the results of investigations obtained using this algorithm have been presented in figures.

1. Objective and aim of research

The results of investigations on turbulent diffusion of marine suspensions, carried out during recent years in the world, Poland included, indicate that these processes are especially effectively affected by space-time mechanisms of 'tuning' of the stratified structure of density and flow velocity fields, manifesting itself by small-scale stratification (laminar-turbulent interlayering) recorded at vertical distribution profiles of hydrophysical features (Druet, Siwecki, 1983), (Fig. 1). This small-scale stratification of hydrophysical fields is characteristic of the entire sea basin volume, the upper sea layer (usually considered

* The presented research constitutes a part of investigations carried out within the CPBP-03.10 project on recognition of a small-scale structure of sea stratified with respect to density, the dynamics of this structure as well as their association with the mechanism forming the time-space 'maculation' of hydrophysical fields.

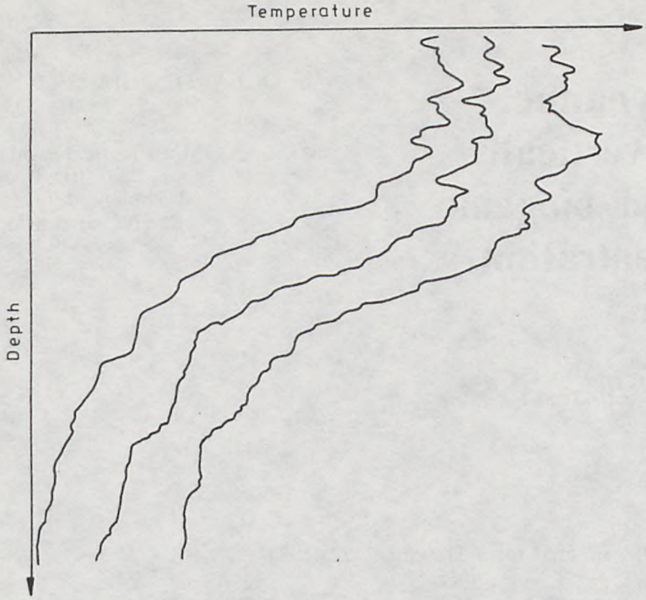

Fig. 1. Vertical distributions of instantaneous values of temperature (examples)

to be uniform) included (Fedorov, 1976). The mechanisms inducing such a stratified 'tuning' of hydrophysical fields in a sea, as well as the principles governing the time-space variability of their structure, constitute the subject of a relatively young field of knowledge and a topic of intensive investigations. An experiment on this topic carried out in the Baltic in 1980 during a multi-task, complex scientific expedition of the COMECON countries on the 'Profesor Siedlecki' research vessel (Sea Fisheries Institute, Gdynia) revealed some regularities (Druet, Siwecki, 1985), due to which investigations have been started on mathematical modelling of the effect of small-scale interlayering on the plankton concentration field in a stratified sea. It is well known that vertical stratification of the flow rate, temperature, and salinity fields manifests itself through occurrence of uniform, slightly turbulent layers of various thickness (from several cm to several m), separated by thinner laminar or quasi-laminar layers characterized by larger gradients of these hydrophysical features. Both uniform turbulent layers and laminar interlayers can undergo the structural reconstruction under suitable conditions, *ie* they can divide into smaller layers or change their thickness. Due to this stratification of a sea basin most often appears in the form of more complex vertical non-uniformities. The intensity of vertical streams of mass and energy exchange under such conditions changes with depth and depends on density distribution and dynamic properties. Such conditions force non-uniform distribution of both inanimate suspension and plankton concentration (Riley *et al*, 1949; Jerlov, 1959). Figure 2 presents an example of three

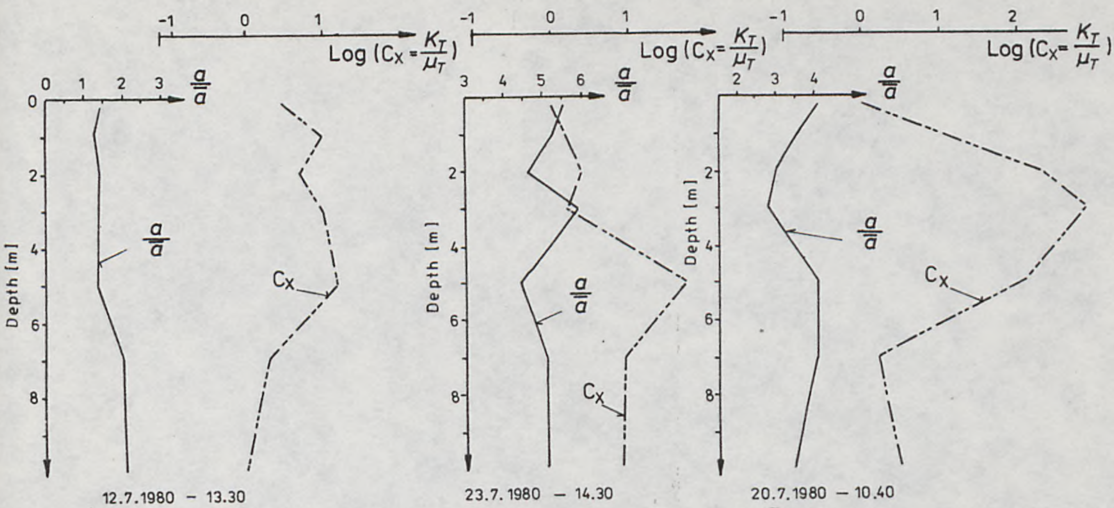

Fig. 2. Vertical distributions of chlorophyll *a* concentration and Cox number in a surface layer of the sea (examples)

various distributions of the Cox number (Cx) and related distributions of chlorophyll *a* concentration in the upper layer. It can be readily noticed that the characteristics of the Cx distributions are opposite to those of chlorophyll concentration, *ie* a relative minimum of the concentration distribution is related to a relative maximum of the Cx distribution and *vice versa*. Hence, functional relationships should exist between the turbulent diffusion coefficient and dimensionless chlorophyll concentration $\frac{a}{\bar{a}}$ where $\bar{a}$ is the average value at a section $z = 10$ m. An empirical regression function presented in Figure 3 confirms this thesis. The higher the value of the Cox number the smaller the chlorophyll concentration and *vice versa*. Consequently, the more intensive are the processes of microturbulent momentum exchange in a layer the smaller is the amount of suspensions in a unit volume of water.

In the light of principles of hydrodynamics the revealed regularity can appear only when the majority of discrete suspended matter is not characterized by neutral buoyancy, *ie* it is influenced either by gravity or by hydrostatic lift. In the former case suspended matter tends to settle while in the latter – to move upwards. In both cases turbulent layers (characterized by intensive momentum exchange) amplify while laminar layers weaken these tendencies. As a result in laminar layers ($Cx < 1$) a decrease of the mean rate of vertical motion of suspensions, transported advectively in the average water flow, and an increase of concentration occur, the phenomena being the opposite in turbulent layers. Obviously, this regularity appears to a larger or smaller extent also in quasi-turbulent or quasi-laminar layers (weak microturbulence).

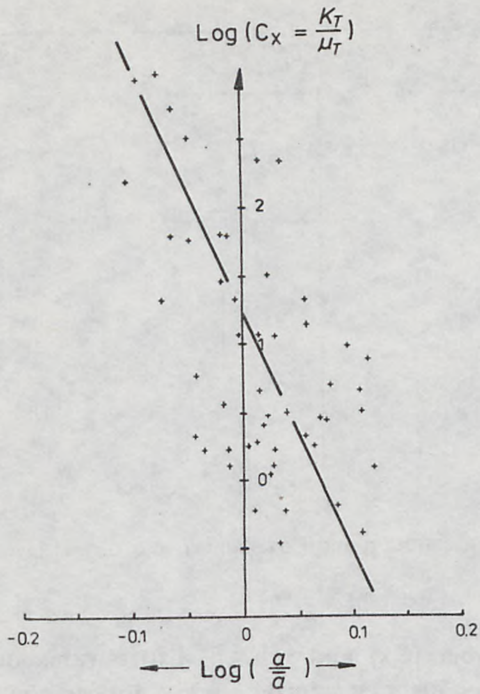

Fig. 3. The dependence of relative concentration of chlorophyll *a* on Cox number in a surface layer of the sea

In order to describe these regularities and to create the deterministic base for their interpretation the authors of this paper took up the mathematical model investigations, the preliminary results of which are described in this paper.

2. Fundamental equations and assumptions of investigations under conditions of uniform horizontal advection

Model investigations were based on the following differential equation of turbulent diffusion of a passive substance:

$$\frac{\partial \bar{v}}{\partial t}+\frac{\partial}{\partial x_i}(\bar{u}_i \cdot \bar{v}) = \frac{\partial}{\partial x_i}\left(K_v \frac{\partial \bar{v}}{\partial x_i}\right)+c\bar{v}, \tag{1}$$

where:

$\bar{v}$ – a mean chlorophyll concentration at a point localized by generalized co-ordinate vector x_i,
$\bar{u}_i$ – mean velocity vector of advective water flow,
K_v – suspension turbulent diffusion coefficient,
c – source efficiency coefficient (chlorophyll production rate).

At small distances (on the order of a few hundred meters) in a real sea basin horizontal uniformity of advective processes and constancy of hydrophysical parameters determining concentration of suspensions can be assumed. In such a case the equation (1) can be reduced to the following one-dimensional form in a cartesian co-ordinate system (z axis pointing downwards accordingly to the direction of earthpull action):

$$\frac{\partial \bar{v}}{\partial t}+\bar{v}\frac{\partial w}{\partial z}+\bar{w}\frac{\partial \bar{v}}{\partial z} = K\frac{\partial^2 v}{\partial z^2}+\frac{\partial \bar{v}}{\partial z}\frac{\partial K}{\partial z}+c\bar{v}, \tag{2}$$

where $\bar{w}$ is the vertical component of the mean suspension transport velocity and K is a coefficient of vertical turbulent diffusion of suspension. Velocity $\bar{w}$ can be described in the following manner:

$$\bar{w} = \bar{w}_0-\bar{w}_s \tag{3}$$

where $\bar{w}_0$ is the mean velocity of water masses vertical motion and $\bar{w}_s$ is the mean velocity of settlement of suspension in stagnant water, which can be approximately described in the following way for a substance with no self-movability:

$$\bar{w}_s = \frac{g(\varrho_s-\varrho_0)D_s^2}{18\mu}, \tag{4}$$

where:
ϱ_0 – water density ranging from $0.99 \leqslant \varrho_0 \leqslant 1.04$ kg/m^3,
ϱ_s – mean suspension density on the order of $\varrho_s \simeq 1.1\cdot 10^3$ kg/m^3,
D_s – a mean linear size of suspension $D \simeq 10^{-6}$ m,
μ – the coefficient of dynamic viscosity of water equal to 0.14 kg/m·s.
The following boundary condition has been assumed for a free surface:

$$K\frac{\partial \bar{v}}{\partial z}-(\bar{w}_0-\bar{w}_s)\,\bar{v} = 0|_{z=0}. \tag{5}$$

Equation (2) describes the process of changes in time of the suspension concentration along the z axis caused by changes in chemical and physical parameters of aqueous medium. This equation has been solved numerically using a direct method. The convergence condition for this method has the following form (Fig. 5):

$$T \leqslant \frac{4\sqrt{2}\,\Delta^2 K_i}{8\sqrt{2}K_i^2+\Delta^2\left[\frac{1}{2\Delta}(K_{i+1}-K_{i-1})+\bar{w}_{0i}-\bar{w}_{si}\right]^2}. \tag{6}$$

The condition (6) describes the relationship between the spatial step $\Delta = Z_{i+1}-Z_i$ and time step T as a function of physical parameters of water depth. It follows from (6) that for $\bar{w}_{0i}-\bar{w}_{si} \geqslant 0$, constant $K \leqslant 0.5$ cm^2/s, and spatial step equal to $\Delta = 1$ cm, the value of the time step will be $T < 1$ s.

Such a small discretization step causes that the time of calculations of a single case extends to several hours assuming the changes of parameters on the order of 1 h. Therefore, this method is not suitable for investigations on fast physical processes (small-scale turbulent exchange being one of them). It follows from the literature studies on numerical solving of diffusion-type differential equations that only an absolutely convergent method of a second order accuracy, with respect to time and spatial discretization step, can meet the requirements of our model. The indirect Crank-Nicholson's method (Potter, 1982), characterized by a relatively simple algorithm of calculations, fulfills these needs. A schematic diagram illustrating the time-space net used for integration of equation (2) with this method is presented in Figure 4.

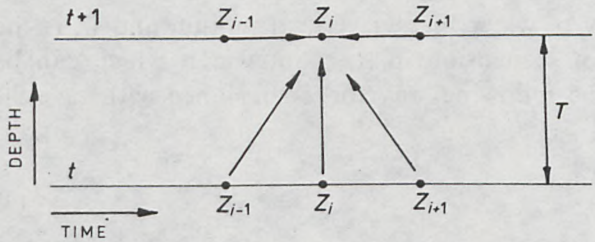

Fig. 4. Schematic diagram of a calculation net for the indirect Crank-Nicholson's method

Equation (2) can be rewritten in this scheme in the following way:

$$
\begin{aligned}
v_i^{t+1}&\left\{1+T\left[\frac{1}{\Delta^2}K_i+\frac{1}{2}\left(\frac{B_{i+1}-B_{i-1}}{2\Delta}\right)-\frac{1}{2}c_i\right]\right\}= \\
&= v_{i+1}^{t+1}\,T\left[\frac{1}{4\Delta}\left(\frac{K_{i+1}-K_{i-1}}{2\Delta}\right)+\frac{1}{2\Delta^2}K_i-\frac{1}{4\Delta}B_i\right]+ \\
&\quad v_{i-1}^{t+1}\,T\left[-\frac{1}{4\Delta}\left(\frac{K_{i+1}-K_{i-1}}{2\Delta}\right)+\frac{1}{2\Delta^2}K_i+\frac{1}{4\Delta}B_i\right]+ \\
&\quad v_{i+1}^{t}\,T\left[\frac{1}{4\Delta}\left(\frac{K_{i+1}-K_{i-1}}{2\Delta}\right)+\frac{1}{2\Delta^2}K_i-\frac{1}{4\Delta}B_i\right]+ \\
&\quad v_{i-1}^{t}\,T\left[-\frac{1}{4\Delta}\left(\frac{K_{i+1}-K_{i-1}}{2\Delta}\right)+\frac{1}{2\Delta^2}K_i+\frac{1}{4\Delta}B_i\right]+ \\
&\quad v_i^{t}\left\{1+T\left[\frac{-K}{\Delta^2}-\frac{1}{2}\left(\frac{B_{i+1}-B_{i-1}}{2\Delta}\right)+\frac{1}{2}c_i\right]\right\}.
\end{aligned}
\tag{7}
$$

The following properties of the net were utilized:

$$B_i = \bar{w}_{0i} - \bar{w}_{si}\,; \qquad \Delta = Z_{i+1} - Z_i,$$

$$\frac{\partial v}{\partial t} = \frac{v_i^{t+1} - v_i^t}{T},$$

$$\frac{\partial v}{\partial z} = \frac{1}{4}\left(\frac{v_{i+1}^{t+1} - v_{i-1}^{t+1}}{\Delta} + \frac{v_{i+1}^t - v_{i-1}^t}{\Delta}\right),$$

$$\frac{\partial^2 v}{\partial z^2} = \frac{1}{2}\left(\frac{v_{i+1}^{t+1} - 2v_i^{t+1} + v_{i-1}^{t+1}}{\Delta^2} + \frac{v_{i+1}^t - 2v_i^t + v_{i-1}^t}{\Delta^2}\right),$$

$$\frac{\partial K}{\partial z} = \frac{K_{i+1} - K_{i-1}}{2\Delta},$$

$$\frac{\partial B}{\partial z} = \frac{B_{i+1} - B_{i-1}}{2\Delta}.$$

The results of analysis carried out for the Fourier component $v = v(t) \cdot \exp(jkz)$ proved that equation (7) is characterized by the following amplification factor:

$$G = \frac{1 - TA}{1 + TA}, \tag{9}$$

where:

$$A = \frac{B_{i+1} - B_{i-1}}{4\Delta} - \frac{1}{2}c_i + \frac{K_i}{\Delta^2}(1 - \cos k\,\Delta) - j \sin k\,\Delta\left(\frac{K_{i+1} - K_{i-1}}{4\Delta^2} - \frac{B_i}{2\Delta}\right).$$

On a complex plane the amplification factor G is always smaller than unity. It follows from this statement that the von Neumann's criteria of stability are always fulfilled. The accuracy and stability of the scheme, however, were obtained at the cost of solving a more complex system of equations of the v^t variables for all the values of i. In the algorithm described by the equation (7) new values of dependent variables are not determined explicitly. Determination of these values requires solving a matrix equation at every time step. A matrix equation is characterized by a unique solution only when boundary conditions are determined explicitly. The conditions at the free sea surface and at a particular depth must be known in such a case. The following conditions have been assumed:

– at a free surface:

$$\bar{v}(0, t)(\bar{w}_{0z} - \bar{w}_{s2}) = K_0 \frac{\partial \bar{v}(0, t)}{\partial z}, \tag{10}$$

$$\bar{w}_{0z}(0, t) = \bar{w}_{s2}(0, t) = 0; \tag{11}$$

– at a depth $z = h$:

$$\bar{v}(h, t)(\bar{w}_{0z} - \bar{w}_{s2}) = K_h \frac{\partial \bar{v}(h, t)}{\partial z}. \tag{12}$$

In case when $h \to \infty$ or $h \gg h_l$, where h_l is the depth of the euphotic zone, the condition (12) can be replaced by the following ones:

$$\bar{v}(h, t) = 0 \quad \text{or} \quad \frac{\partial \bar{v}(h, t)}{\partial z} = 0. \tag{13}$$

The condition (10) exemplifies a state in which the processes of mass exchange through the free sea surface can be separated from the processes of phytoplankton transport through this surface.

The Platt's model, determining the rate of primary production depending on the dose of solar energy reaching an arbitrary depth z, has been accepted for determination of source efficiency in equation (2). According to this model the assimilation number $F\left[\frac{\text{mg of C}}{\text{mg of chlorophyll} \cdot s}\right]$ can be expressed in the following way:

$$F(\Pi, \eta, \alpha, \beta) = \Pi\{1 - \exp[-\alpha\eta(z)/\Pi]\} \exp[-\beta\eta(z)/\Pi], \tag{14}$$

where α, β, Π are dimensionless quantities characterizing the primary production in a basin. They are determined experimentally.

The $\eta(z)$ function $\left[\frac{\text{J}}{\text{m}^2\,\text{s}}\right]$ representing the dose of solar energy reaching the depth z is described by the following relationship:

$$\eta(\text{z}) = \eta_0 \tau_0 \tau_2 \exp[-k_d(z) z], \tag{15}$$

where τ_0 is the transmission of solar energy through a free sea surface, and τ_z is a similar transmission at a depth z (Dera, 1971). These parameters are determined from the following relationships:

$$\tau_0 = \frac{L_a}{L_0}, \quad \tau_z = \frac{L_z}{L_0}$$

where:

L_a – the intensity of light above the free surface,

L_0 – the intensity of light under the free surface,

L_z – the intensity of light at the depth z.

The $k_d(z)$ is the coefficient of diffusive attenuation of light at the depth z, while η_0 is the dose of solar energy reaching the free sea surface. This dose is determined from the solar constant assuming that the condition of atmosphere above the basin is well known.

Changes in time of the dose of solar energy reaching an arbitrary depth z are described by the following relationship:

$$\frac{\partial \eta(z, t)}{\partial t} = q(\sin\theta)^{\gamma}, \tag{16}$$

where:

q, γ – experimentally determined coefficients characterizing a sea basin,

$\sin\theta = \sin\delta_0 \sin\Psi + \cos\delta_0 \cos\Psi \cos LHA$,
$LHA = x \cdot 15° - 180°$.
x – GMT expressed in hours,
δ_0 – Sun declination angle,
Ψ – latitude angle.

According to the Platt's model and relationships (14–16) the rate of production is described by the following relationship:

$$c(z, t) = (3600)^{-1} \lambda t_d \Pi [1 - \exp(-\alpha\eta(z)/\Pi] \exp[-\beta\eta(z)/\Pi] \sin\theta, \tag{17}$$

where: λ – 0.046 for the Baltic Sea, t_d is the time between sunrise and sunset.

Equation (17), constituting a part of the differential equation (7), allows quantification of the effect of solar energy on the distribution function of phytoplankton in a water column of various optical and dynamic properties. Basing on this model numerical investigations were carried out on the time-

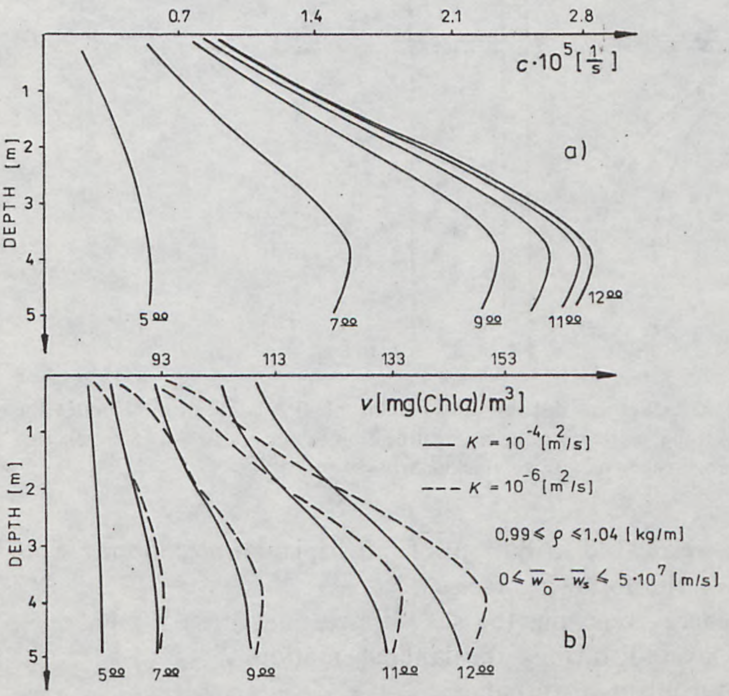

Fig. 5. Evolution in time (t) of vertical distribution of production rate (c) and chlorophyll a concentration in a sea homogeneous with respect to density

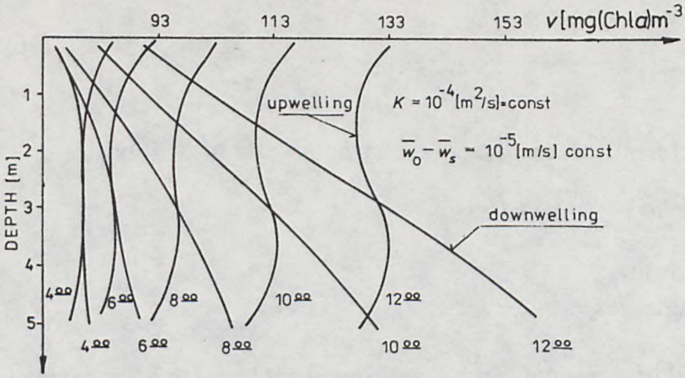

Fig. 6. Evolution in time (t) of vertical distribution of chlorophyll a concentration under the conditions of anisotropic vertical transport of suspensions in a sea homogeneous with respect to density

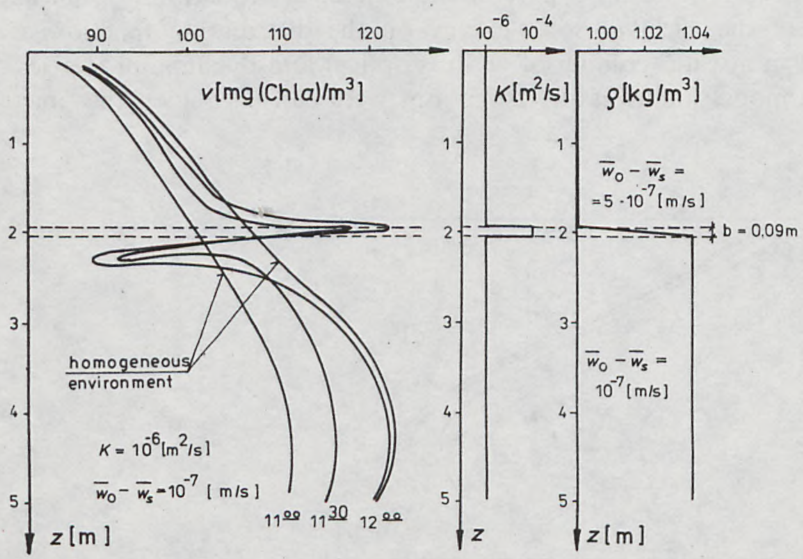

Fig. 7. Evolution in time (t) of vertical distribution of chlorophyll a concentration under the conditions of suspension settling, existence of a fine stratification in density field and presence of a turbulent layer in a stable fine structure of thickness $\delta = 9$ cm

-space variations in vertical distribution of phytoplankton concentration under the influence of the following factors:

- dose of solar energy reaching the sea surface,
- thickness of a layer disturbing the laminar motion,
- duration of a turbulent disturbance,
- rate of phytoplankton settling,
- rate of rising and falling of water masses,

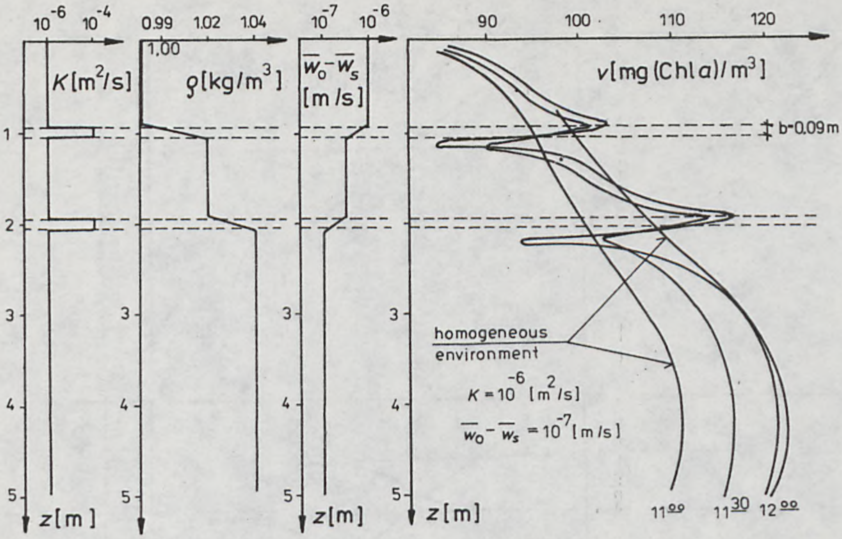

Fig. 8. Evolution in time (t) of vertical distribution of chlorophyll a concentration under the conditions of suspension settling, existence of a fine stratification in density field and presence of two turbulent layers in stable structures of thickness $\delta = 9$ cm

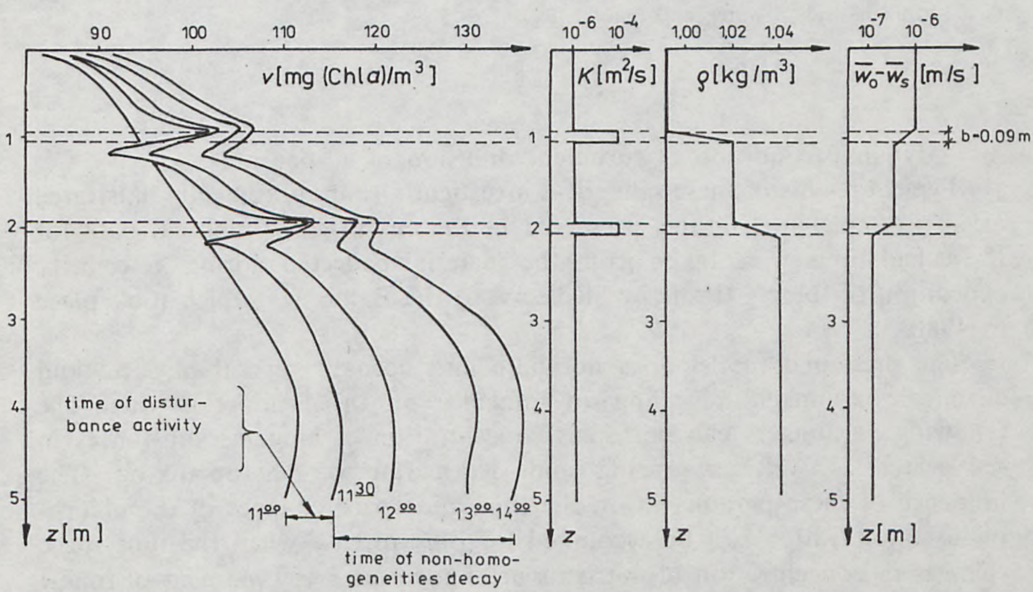

Fig. 9. The process of decay in time (t) of structural non-uniformities in vertical distribution of chlorophyll a concentration under conditions of suspension settling

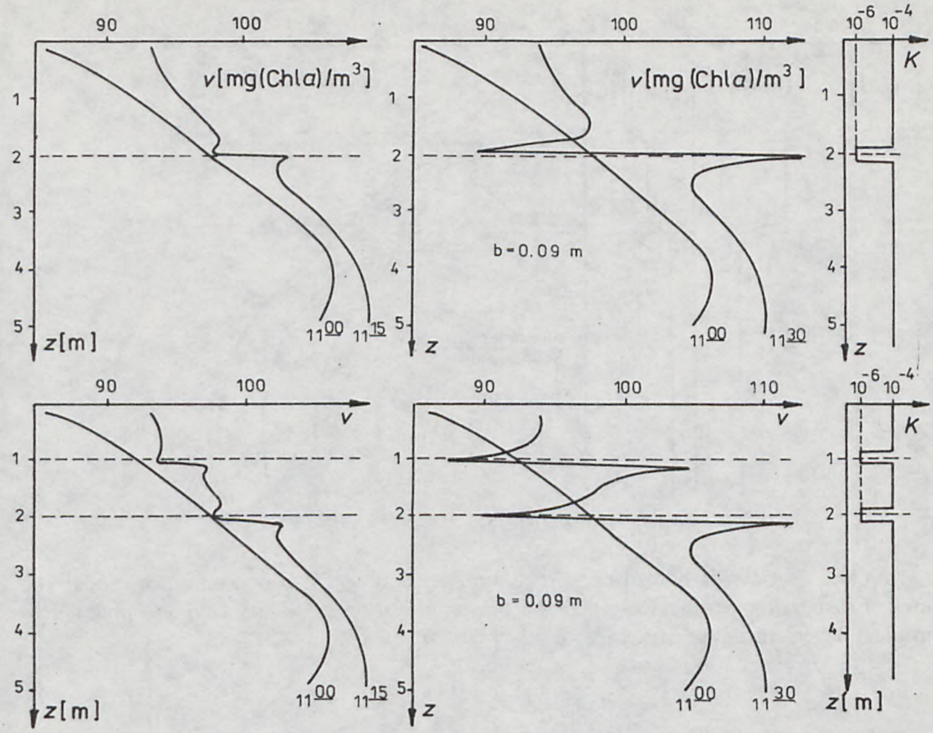

Fig. 10. Evolution in time (t) of vertical distribution of chlorophyll a concentration under conditions of suspension settling and existence of fine laminar interlayers of thickness $\delta = 9$ cm in a turbulent field of water horizontal flow

– dynamic condition of turbulent diffusion of suspensions.

Typical results of these numerical investigations are graphically illustrated as an example in diagrams presented in Figures 5 – 13. Empirical data for the calculations were taken from the material collected during a scientific expedition of the r/v 'Profesor Siedlecki' to the Baltic Sea which took place in 1980.

The presented model does not take into account several physical and chemical parameters revealing an influence on the production rate. The following parameters can be listed: concentration of biogenic substances in sea water as well as grazing and death rate of phytoplankton. The influence of these parameters on the time and space changes of the chlorophyll concentration can be accounted for only in case when the time-space changes in concentration of nutrients are known at every moment of time t and at an arbitrary depth z. A general formula of such a process can be written in the following way (Radach, 1983):

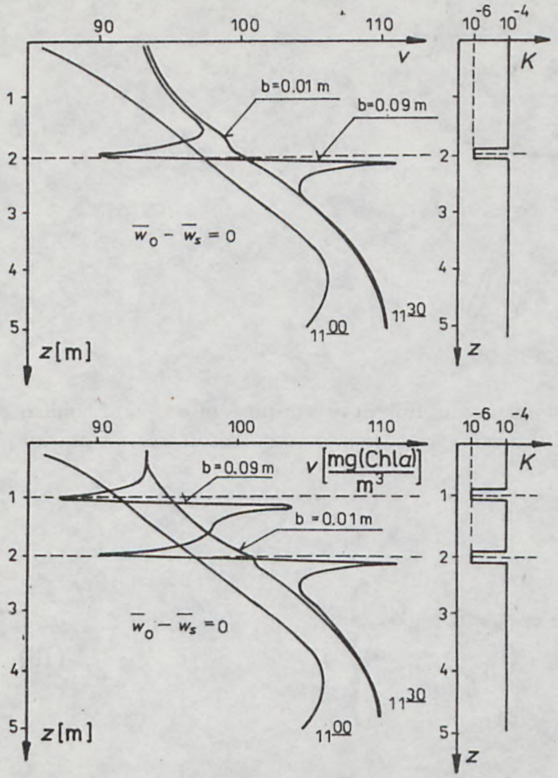

Fig. 11. The effect of the thickness of laminar interlayers on the intensity of formation of non--uniformities in vertical distribution of chlorophyll *a* concentration under conditions of suspension settling

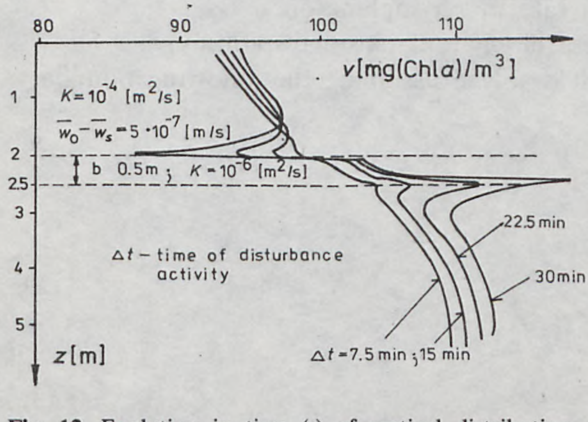

Fig. 12. Evolution in time (t) of vertical distribution of chlorophyll a concentration under conditions of suspension settling and existence of a laminar interlayer of thickness $\delta = 50$ cm in a turbulent velocity field

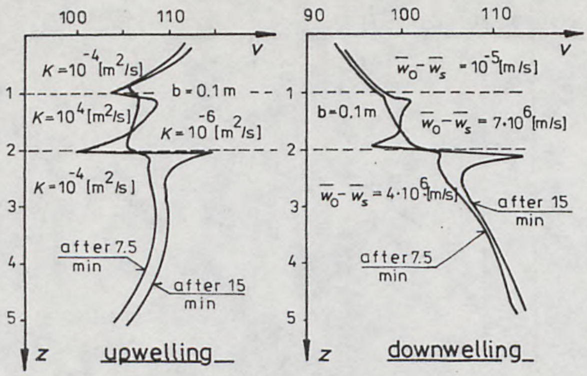

Fig. 13. Vertical distributions of chlorophyll *a* concentration in two instants of action of laminar interlayers of thickness $\delta = 10$ cm in a turbulent velocity field and anisotropic suspension transport

$$\left.\begin{aligned} \frac{\partial \bar{v}}{\partial t} &= \frac{\partial}{\partial z}\left(K\frac{\partial \bar{v}}{\partial z}\right) - \frac{\partial}{\partial z}(\bar{w}\cdot\bar{v}) + c(z,\, t)\,\bar{v} - R - M - W_r, \\ \frac{\partial N}{\partial t} &= \frac{\partial}{\partial z}\left(K_N\frac{\partial N}{\partial z}\right) + R_N - R_w. \end{aligned}\right\} \tag{18}$$

where:

N – concentration of biogenic substances,
K_N – biogenic substances diffusion coefficient,
W_r – term describing grazing of phytoplankton,
R_N – term describing the process of regeneration of biogenic substances,
R_w – term describing the rate of rising or falling of biogenic substances,
M – term describing the death rate of phytoplankton,
R – term describing the process of phytoplankton respiration.

The system of equations (18) is solved assuming the following boundary and initial conditions:

– at a free surface:

for $t = 0$:

$$N(z,\, t) = N_0(z),$$

$$\bar{v}(z,\, t) = \bar{v}_0(z); \tag{19}$$

for $z = 0$:

$$\frac{\partial N(0,\, t)}{\partial z} = 0,$$

$$\bar{w}\cdot\bar{v}(0,\, t) = K\frac{\partial \bar{v}(0,\, t)}{\partial z};$$

– at a depth $z = h$:

$$N(h, t) = N_0(h) = \text{const},$$

$$\bar{w} \cdot \bar{v}(h, t) = K \frac{\partial \bar{v}(h, t)}{\partial z}, \tag{20}$$

or

$$\frac{\partial \bar{v}(h, t)}{\partial z} = 0.$$

The system of equations (18) with the conditions (19) and (20) can be numerically solved provided that the terms R, M, W_r, R_N, and R_w are known in an analytical form. Analytical description of these terms is difficult and requires knowledge of physical and chemical characteristics of the investigated basin. Basing on the literature data these terms can be determined only using a trial-and-error method, because the process of plankton grazing, characteristic of a given basin, depends on the composition of phytoplankton and has different course during blooming. The described algorithm of investigations on time-space evolution of the chlorophyll *a* distribution in the Baltic Sea allows the analysis of the effect of environmental processes on the primary production. The program of numerical calculations has been prepared in such a manner that at any moment t and at an arbitrary depth z it allows:

– changing time step,
– assigning non-stationary conditions,
– changing the duration of non-stationarity.

Therefore, this program allows rapid simulation of physico-chemical conditions prevailing in the investigated basin.

3. Results of the first stage of model investigations

The investigations carried out using the one-dimensional model of transport and diffusion of suspensions revealed a number of very significant regularities ruling the formation of the vertical structure of chlorophyll *a* concentration. Figure 5a presents the vertical distributions of the rate of chlorophyll *a* production illustrating the evolution of the source intensity in the entire development cycle, *ie* from 5 am to 12 am. This evolution depends only on sunlight and can be considered independent of the variations of hydrophysical density, velocity, and turbulence fields in the investigated basin. Let us assume that the basin is uniform with respect to density and dynamics (constant K), and that the suspension settles with a constant rate $\bar{w}_0 - \bar{w}_s$. It has been revealed during the investigations on such a case under various conditions that within the possible in nature range of variability of water density, *ie* $0.99 \leqslant \varrho \leqslant 1.04$ kg/dm^3, and of the absolute value of mean velocity of vertical settlement of suspensions, *ie* $0 \leqslant |\bar{w}_0 - \bar{w}_s| \leqslant 5 \cdot 10^{-7}$ m/s, the above quantities do not significantly influence the vertical distribution of suspension concentration. On the other hand concentration distributions illustrated in Figure 5b reveal a distinct effect of changes of the turbulent diffusion coefficient within the range $10^{-6} \leqslant K \leqslant 10^{-4}$ m^2/s. Similarly, Figure 6 reveals a substantial effect of the direction of suspensions transport, changing significantly the distribution of chlorophyll *a* concentration.

Taking into account the above considerations let us introduce a stable structural change in the vertical distribution of water density and assume that a loss of stability of laminar flow, resulting in an appearance of an intensive wavy-vertical turbulence, occurs in a laminar layer of density jump of the thickness $\delta = 9$ cm. Vertical distributions of chlorophyll *a* concentration illustrated in Figure 8 reveal very significant structural changes due to small-scale stratification of the density and flow rate fields. Concentration increases strongly above the density jump layer and decreases significantly under this layer. An opposite regularity occurs when a laminar interlayer appears in the turbulent flow field (Fig. 10). This increase or decrease of concentration can reach $\pm 20^0/_0$ of the value characteristic of a vertically uniform basin. It is, therefore, significant for such phenomena as time-space variations in the distribution of nutritive suspensions or stability of spawning layers. Figure 8 reflects similar regularities but through a comparison of stratified distributions with distributions for a uniform basin it reveals the interaction of neighbouring structures, the stronger the influence the closer to each other are the interlayers. Taking into account the characteristics of medium-scale stratification of hydrophysical fields (Fig. 1) it can be anticipated that real distributions of suspension concentration in sea are certainly formed under conditions of interaction of structural interlayers.

Distributions shown in Figure 9 illustrate vanishing of the influence of structural anomaly on suspension concentration after subsiding of the distortion. This vanishing proceeds steadily in time and after a few hours the vertical distribution of concentration does not reveal a step non-uniformity in its structure.

Figures 11 and 12 reveal the effect of thickness of a layer in which the structural change of vertical distribution of suspension turbulent diffusion coefficient occurs on the intensity of structural change in a parallel distribution of suspensions concentration. It can be clearly seen that layers of the thickness $\delta < 1$ cm do not reveal a significant influence. On the other hand the increase of thickness $\delta > 1$ cm exerts the stronger influence the thicker is the layer characteristic of the anomaly. Further investigations on the effect of this parameter should allow determination of the relationship between δ and selected geometrical parameters defining the structural anomaly in vertical distribution of suspension concentration.

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