Patchiness of hydrophysical fields in the light of data from the PEX-86 experiment obtained at anchored stations

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Patchiness
Small scale stratification

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Abstract

Variable in time characteristics of hydrophysical fields of temperature, salinity, and density of sea water, recorded at anchored stations during the PEX-86 international experiment of Baltic countries, constitute the object of the presented study. Identification of forms of patchiness of marine environment hydrophysical fields and of hydrodynamic sources of their formation and development constitute the aim of these analysis. The scope of the study includes:
– discussion of the hydrodynamic sources forming the patchy structures of sea water temperature, salinity, and density fields,
– identification of the structures which could be recognized as forms of patchiness at the anchored stations of the PEX-86 experiment.

1. Object, aim, and scope of study

In the presented study the term 'patch' designates a layer of water masses of limited dimensions, characterized by a certain conventional range of slight variation of a given hydrophysical feature (temperature, salinity, water density, *etc.*), the horizontal dimension of which (a) is incomparably greater than its vertical dimension, constituting the thickness of a layer (b). Hence, the following relationship must be fulfilled between these dimensions:

$$\frac{a}{b} \gg 1. \qquad (1)$$

In the light of the above definition patchiness of hydrophysical fields is manifested in the sea in the form of horizontal interlayers framed by closed isolines of values of a given feature within which a homogeneous physical fields is conventionally assumed. Both turbulent mixing mechanisms and intrusive processes stratificating the uniform characteristics of hydrophysical fields into interlayers of smaller thickness meeting the condition (1) can be sources forming such structures. A typical source of generation can be attributed to each of these structures depending on the kind of a hydrophysical feature (see Figs. 15–16). This statement concerns mainly hydrophysical fields of temperature, salinity and density of sea water, which constitute together with the field of water masses velocity the basic hydrodynamic background, being a requisite of the processes of formation and development of patchiness of other environmental fields, such as the fields of concentration of chemical constituents (*eg* nutrients), concentration of passive suspensions, of phytoplankton, *etc*. Owing to the above reasons the authors of this study are of the opinion that internal hydrodynamic sources of turbulent mixing, as well as intrusion phenomena resulting in local stratification of the fields of temperature, salinity, and density of sea water at various depth play a fundamental role in formation of a phenomenon of various scale patchiness of numerous hydrological fields in the marine environment.

2. Sources and formation of patchy structures

According to the definition of patchiness presented in the former paragraph, formation of quasi-uniform regions in stratified fields of temperature, salinity and density of sea water can result from two reasons, *viz*:

– intrusive (advective) affluence of strongly mixed water masses characterized by features distinctly different than those of the surrounding environment,

– existence of internal sources inducing the mechanisms of local turbulent mixing of water masses in the stratified environment.

Both the mentioned sources generate mechanisms changing in time and space the local characteristics of hydrophysical fields of temperature, salinity, and density of sea water. Identification of these sources can be accomplished on the basis of variability of vertical distributions of temperature (T) and salinity (S) of sea water using the Hesselberg's equation of water masses stability for non-adiabatic state:

$$\frac{1}{\varrho_0}\frac{\overline{\Delta\varrho}}{\Delta z} = -\alpha\frac{\overline{\Delta T}}{\Delta z}+\beta\frac{\overline{\Delta S}}{\Delta z}, \tag{2}$$

where: $\alpha = -(1/\varrho_0)(\delta\varrho/\delta T)|_{\varrho,S}$, $\beta = (1/\varrho_0)(\delta\varrho/\delta S)|_{\varrho,T}$, $\overline{\Delta}/\Delta z$ is the difference between the mean values of a physical feature at the borders of the examined layer of thickness Δz, and ϱ_0 is the mean density of water in the Δz layer.

Vertical distribution of density ϱ can stabilize water masses in a Δz layer ($\overline{\Delta\varrho}/\Delta z > 0$) or destabilize them ($\overline{\Delta\varrho}/\Delta z < 0$) causing vertical convective mixing.

There are no physical premises in the latter case to think that patchy structures generated by hydrodynamical sources can occur in the Δz layer. Hence, the mechanisms that generate and form the patchiness phenomena of hydrophysical fields of temperature, salinity, and density of water masses in the Δz layer must meet the following condition:

$$\frac{\overline{\Delta\varrho}}{\Delta z} \geqslant 0|_{for\ \ non\text{-}adiabatic\ \ state} \tag{3}$$

Let us introduce to our considerations the stability parameter $R_\varrho = (\alpha/\beta) \times (\overline{\Delta T}/\overline{\Delta S})$. The following possible cases meeting the condition (3) can be distinguished using this parameter:

(i) stable vertical density distribution is formed under the conditions of inversive temperature distribution $(\overline{\Delta T}/\Delta z > 0)$ stabilized by salinity distribution $(\overline{\Delta S}/\Delta z > 0)$. Sources of local convective instability (Fiodorov, 1972; Schmitt, 1981) due to the processes of 'double diffusion' in the places of occurrence of stronger local inversive temperature gradient can be formed in such a case. It follows from the equation (2) and the criterion (3) that $\alpha(\overline{\Delta T}/\Delta z) < \beta(\overline{\Delta S}/\Delta z)$. Hence, the mechanisms of convective turbulent mixing which can form the patchy structure of hydrophysical fields of temperature, salinity, and density of aqueous medium in the Δz layer can arise under conditions of thermal inversion provided that:

$$0 < R_\varrho < 1; \tag{4}$$

(ii) stable vertical density distribution is formed under conditions of salinity inversion $(\overline{\Delta S}/\Delta z < 0)$ stabilized by temperature distribution $(\overline{\Delta T}/\Delta z < 0)$. Sources of local convective instability due to the processes of 'double diffusion' related to the phenomenon of 'salty fingers' (Fiodorov, 1972; Pingree, 1972; Schmitt, 1981) can be formed in such a case in the places of occurrence of strong local salinity inversions. The following dependence is obtained in such a case from the equation (2) and the criterion (3): $\alpha(\overline{\Delta T}/\Delta z) > \beta(\overline{\Delta S}/\Delta z)$. Hence, local convective mixing capable of formation of patchy structures of hydrophysical fields in a Δz layer can take place under conditions of occurrence of 'salty fingers' provided that:

$$R_\varrho > 1. \tag{5}$$

Results of investigations published in a series of papers (Fiodorov, 1972; Schmitt, 1981) demonstrated that when stratification of the 'salty fingers' type is formed as a result of a strong compensative temperature effect, the criterion (5) has the following form:

$$1 < R_\varrho \leqslant 2; \tag{6}$$

(iii) stable vertical density distribution is formed under conditions of stable salinity distribution $(\overline{\Delta S}/\Delta z > 0)$ and stable temperature distribution

($\overline{\Delta T}/\Delta z < 0$). Absolutely stable density field is dealt with in such a case. It follows from the criterion (3) for such a case that:

$$-1 < R_{\varrho} < 0. \tag{7}$$

Criterion 7 defines the conditions of absolute stability of hydrophysical fields of temperature, salinity, and density in the Δz layer. Local patchy structures can occur in such a case only when mechanisms generating Kelvin – Helmholtz hydrodynamic gradient instability come into being. Such conditions are most often fulfilled in laminar layers of strong density gradient in the presence of inner waves (Fiodorov, 1972; Linden, 1975; Pingree, 1972). Strongly mixed quasi-uniform layers ($\Delta V/b \simeq 0$), separated with layers of large gradients of a feature $V = (T, S, \varrho)$ of a given hydrophysical field are formed in such cases in the vertical stratified structure of a hydrophysical field. The results of a series of investigations demonstrated that in such layers the Richardson's number $Ri < 0.25$, and the ratios of mean gradients $\Delta V/b$ of quasi-uniform layers to the $\Delta V/\Delta z$ gradient of the Δz layer are considerably smaller than unity $[(\Delta V/b)(\Delta V/\Delta z) \ll 1]$, the values of these ratios for T and S not necessarily being equal to each other (Linden, 1975; Pingree, 1972; Zurbas and Ozmidov, 1987). Under the described conditions the Pingree's criterion (Pingree, 1972) basing on a half-empirical Prandtl's hypothesis on turbulent mixing path $[T' = \xi(\overline{\Delta T}/b)$; $S' = \xi(\overline{\Delta S}/b)]$ (where ξ is a small vertical shift) should be fulfilled in the Δz layer. This criterion can be written in the following way for the Δz layer:

$$\frac{\sigma_T}{\sigma_S} = \left|\frac{\overline{\Delta T}}{\overline{\Delta S}}\right|_{\Delta z}, \tag{8}$$

where σ is standard deviation.

Since fluctuations of T' and S' can also be due to kinematic effect of internal waves in laminar interlayers, also fulfilling the criterion (8) differentiation of the processes of turbulent mixing and kinematic effect of internal waves must be carried out on the basis of additional criteria. Such criteria have been formulated basing on geometrical parameters of fine structure of temperature field (Linden, 1975; Zurbas and Ozmidov, 1984) in the form of a ratio of thickness of a layer of larger temperature gradient (l) to thickness of a successive quasi-turbulent layer (b). Using the parameter $\lambda = l/b$, the additional criteria have the following form:

– for kinematic effect of internal waves:

$$\lambda \simeq 1, \tag{9}$$

– for Kelvin-Helmholtz gradient instability:

$$\lambda \geqslant 0.25, \tag{10}$$

– for convective instability:

$$\lambda \simeq 0.2 \div 0.1. \tag{11}$$

(**iv**) vertical density distribution is a neutral distribution ($\Delta\varrho/\Delta z = 0$). Uniform advection can occur in such a case. It follows from criterion (3) for this case that $\alpha\overline{\Delta T} \simeq \beta\overline{\Delta S}$ and:

$$R_\varrho = 1. \tag{12}$$

Pingree's criterion (Zurbas and Lips, 1987) for such a case has the following form:

$$\frac{\sigma_T}{\sigma_S} = \frac{\beta}{\alpha}\bigg|_{\Delta z}. \tag{13}$$

(**v**) Intrusive affluent of waters results in stratification of the Δz layer through convective mixing caused by double diffusion at the borders of inversive interlayers. Fluctuations of all physical parameters of water are characterized in such a case by the so-called 'relative intrusion amplitude' expressed by Zurbas (Zurbas and Ozmidov, 1987) in the following form:

$$A_T = 2\sqrt{2}\pi \frac{\sigma_T}{\dfrac{\overline{\Delta T}}{\Delta z} H} \tag{14}$$

where: $H = l + b$.

Intrusive advection can result in processes of stratification and mixing in cases when:

– convective mixing is due to processes of double diffusion under conditions of thermal inversion. The following criteria should be fulfilled:

$$\left.\begin{array}{l} 0 < R_\varrho < 1 \\ 1 < A_T < (|R_\varrho|)^{-1} \end{array}\right\}, \tag{15}$$

– double diffusion processes due to the effect of 'salty fingers' are generated. The above criteria have the following form:

$$\left.\begin{array}{l} R_\varrho > 1 \\ (|R_\varrho|)^{-1} < A_T < 1 \end{array}\right\}, \tag{16}$$

intrusive process takes place under the conditions of absolutely stable stratification of hydrophysical fields. The criteria have the following form:

$$\left.\begin{array}{l} -1 < R_\varrho < 0 \\ 0 < A_T < \min\left[1, (|R_\varrho|)^{-1}\right] \end{array}\right\}. \tag{17}$$

Answering the question whether the processes of stratification of hydrophysical fields take place under conditions of absolute stability of water masses or under intrusive conditions is often inexplicit in cases when it is based on the Pingree's criterion, which most often yields approximate results, requiring additional information, under real conditions. Due to these reasons, Zurbas and Lips formulated a new criterion, basing on the correlative evaluation. This criterion is based on evaluation of a certain parameter δ calculated from the following formula (Zurbas and Lips, 1987):

$$\delta = (\Phi - \Phi_n)(\Phi_s - \Phi_n)^{-1}, \tag{18}$$

where:

$$\Phi = \arctan\,[p + \operatorname{sign}(K_{TS})(p^2+1)^{1/2}],$$

$$\Phi_n = \arctan(1) = 45°,$$

$$\Phi_s = \arctan(R_p),$$

$$p = (r^2-1)(2K_{TSr})^{-1}, \quad r = \frac{\sigma^*_T}{\sigma^*_s}, \quad K_{TS} = \frac{\overline{T^* S^*}}{\sigma^*_s \sigma^*_T},$$

$$T^* = \alpha T', \quad S^* = \beta S', \quad \sigma^*_T = [\overline{(T^*)^2}]^{1/2}, \quad \sigma^*_S = [\overline{(S^*)^2}]^{172}.$$

Evaluation of the kind of a process forming the steplike or intrusive structure of hydrophysical fields based on the δ parameter is carried out on the basis of the following conditions:

– steplike structure is formed either under conditions of absolutely stable stratification, or as a result of local convective instability:

$$\delta > 0.5, \tag{19}$$

– intrusive structure:

$$\delta < 0.5. \tag{20}$$

The above mentioned five cases (**i**–**v**) describing the sources of processes capable of formation of patchy structures of hydrophysical fields of temperature, salinity, and density of sea water cover in principle all the possibilities of nature in this field.

Variability of solar radiation, variability of conditions in the near-water layer of atmosphere (pressure, air temperature, wind), as well as density gradients of sea waters due to the barocline phenomena or other mechanisms constitute major external sources of these processes. The discussed processes can overlap with various non-linear effects, identification of which is very difficult or even impossible in numerous significant cases. Due to this, the identification criteria described by equations (4)–(20) give only approximate evaluation. This evaluation, however, aided by series of other empirical characteristics like: correlation characteristics, T–S diagrams, fields of isolines of T, S and ϱ, variability of the Vaisala-Brunt parameter and Richardson's number, variability of Cox' number *etc*, enables identification of sources and mechanisms forming patchy structures and conditioning evolution of their forms in time and space.

3. Patchy structures in experiment regions

Momentary profiles representing vertical distributions of temperature and electrical conductivity were recorded using the method of vertical sounding at two fixed stations, *viz* AN-1 of the 56°25′N; 18°36′E co-ordinates and sea depth equal to $h_1 \simeq 60$ m, and AN-2 of the 56°22′N; 18°45′E co-ordinates and the depth $h_2 \simeq 90$ m. The measurements were carried out using standard STD probes, with time quantization step $t = 1.5$ h during the periods: 25th of April, 1986 to 30th of April, 1986 and from 2nd of May, 1986 to 8th of May, 1986. 198 momentary distributions of temperature and electrical conductivity were recorded at each of these stations during this period, 91 of them being recorded in April and 107 in May. These series of data $T(z)$ and $S(z)$, characterizing the layer of water masses $\Delta z \simeq 60$ m, were subjected to statistical and correlation analysis, as well as to evaluation according to the criteria described in paragraph 2. The series of standard hydrologic characteristics, facilitating diagnosis of the dynamic condition of water masses, was also estimated. On the basis of such data a quite explicit evaluation of both sources and mechanisms governing formation and dimensions of patchy structures in the temperature, salinity, and density fields of sea water within the regions of anchored stations of the PEX-86 experiment can be carried out.

3.1 Hydrological characteristics of the investigated regions

Figure 1 illustrates momentary data characterizing water masses at the AN-2 station according to the $T-S$ diagram criteria. Similar diagrams for mean values at particular depths are shown in Figure 2. It follows from these diagrams that hydrological conditions within the AN-2 region are typical of Baltic, *ie* two different water masses occur: Baltic water of nearly constant salinity equal to *ca* 7.7 promille and temperature changing largely with depth, occurring from the free surface to the depth of *ca* 60 m, and water of largely variable salinity changing from 7.7 promille to 10 promille, occurring in the layer from 60 m to the bottom. The layer of Baltic water distinctly warms up during the period from 25th of April to 8th of May while the characteristics of near-bottom water only slightly change during this time. These observations are fully confirmed by data collected at the AN-1 station, where only Baltic water occurs from the free surface to the bottom. This seasonal trend of warming up of water with time is also distinct in the empirical diagrams of the $T(t)$ function, illustrating variability of temperature in time at standard horizonts (Fig. 3). Courses of these functions also reveal a distinct daily variability decreasing with depth. This general hydrological information is supplemented by statistical histograms shown in Figures 4, 5, 6, and 7. They reveal a great diversity of temperature in upper layers, decreasing with depth. Salinity fields is nearly uniform down to 60 m. Distinct differentiation occurs

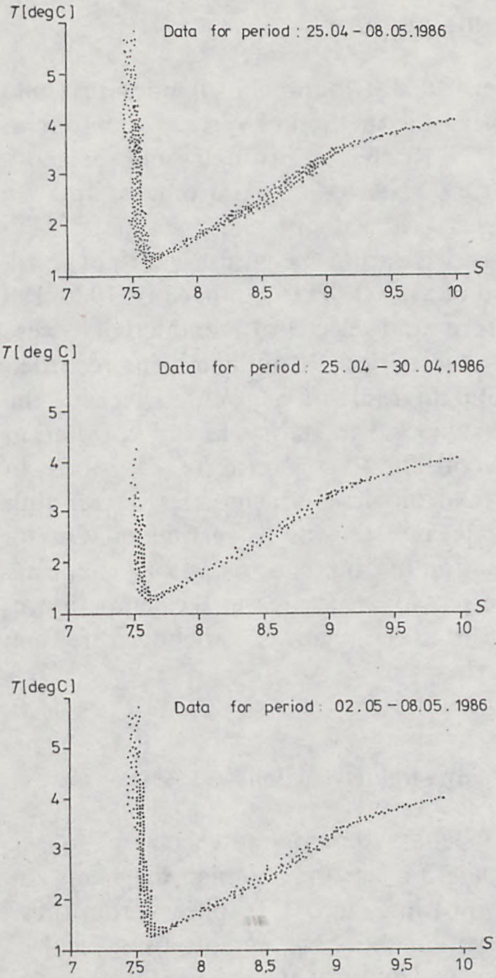


Fig. 1. Water masses T–S diagrams. Anchor station AN-2

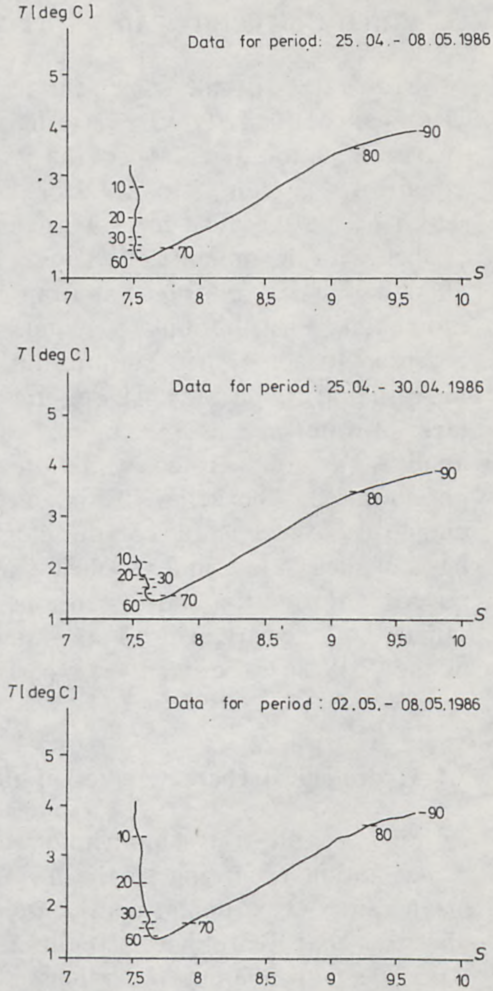


Fig. 2. Water masses T–S diagrams, data averaged on horizonts. Anchor station AN-2

only in the layer of North Sea origin waters. Differences in frequency (probability) distribution between the April and May measurement period do not reveal an explicit trend.

Figures 8, 9, 10, and 11 illustrate the results of all vertical probings carried out at the AN-1 and AN-2 stations in the layer down to 70 m within the period from 25th of April to 8th of May, 1986. Distributions of momentary temperatures (Figs. 8 and 9) reveal generally poor stability during the April period; this stability improves distinctly during the May period in the upper sea layer, where a seasonal thermocline is formed at the depth of *ca* 10–15 m. Momentary distributions reveal a large number of local thermal inversions within the regions of both the stations during the entire investigation period.

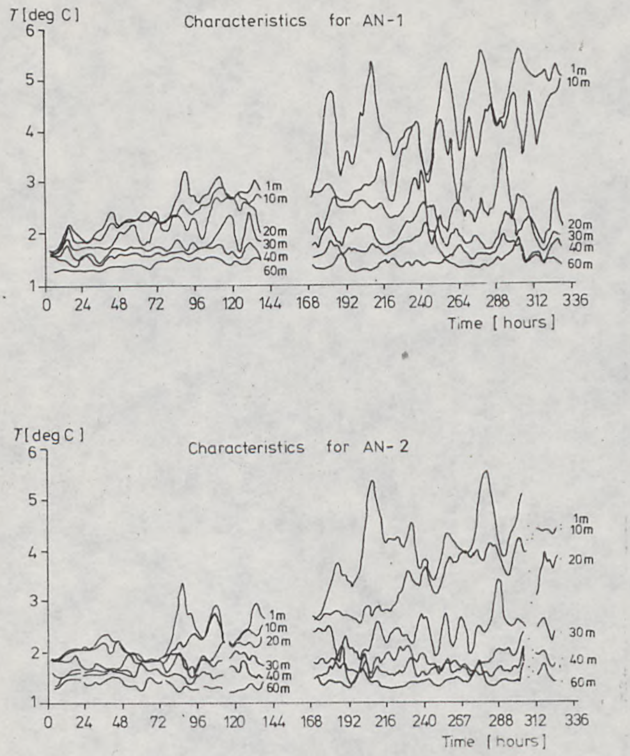


Fig. 3. Temperature changeability in time on standard horizonts

Momentary salinity distributions (Fig. 10 and 11) reveal poor stability down to 60 m during both the measurement periods. Their small-scale structure is distinctly steplike and reveal in numerous places local inversions. Hence, it can be anticipated that the thermohaline structure of water masses would promote formation of local instability sources resulting from the double diffusion effects within the region of both the stations.

The distance between the AN-1 and AN-2 measurement stations was equal to *ca* 4 nautical miles. Examinations of the correlation dependences between momentary and mean daily distributions of temperature and salinity reveal thermal connection between the momentary profiles at the −5 m horizon and lack of connection at the depth of −50 m. Correlation between momentary salinity profiles practically does not exist. Correlation coefficients between mean daily profiles reveal already significant dependence between temperatures and weaker between salinity at the −5 m ordinate. On the other hand, at the depth of −50 m correlation is very poor in both the hydrophysical fields. This characteristics testifies lack of dependence between the source of the examined processes at the AN-1 and AN-2 stations, which should be treated as independent proving grounds.

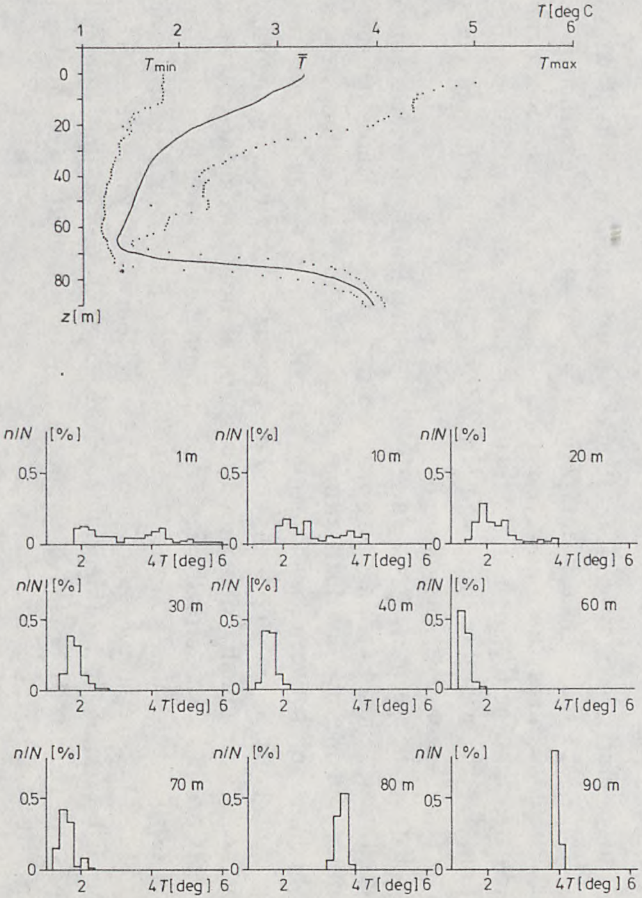


Fig. 4. Statistical characteristics of temperature variability for period 25.04–08.05.1986. Anchor station AN-2

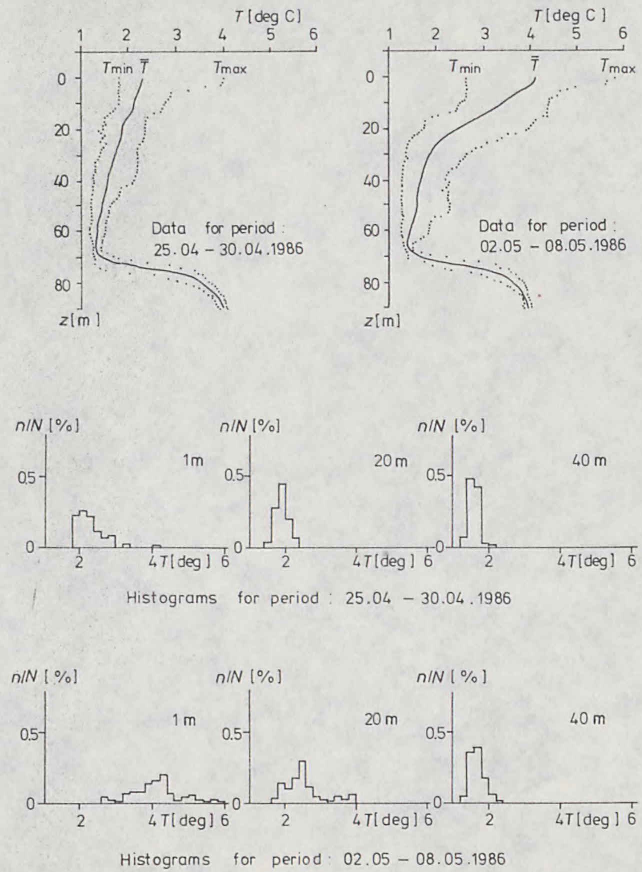


Fig. 5. Statistical characteristics of temperature variability for two measurement periods. Anchor station AN-2

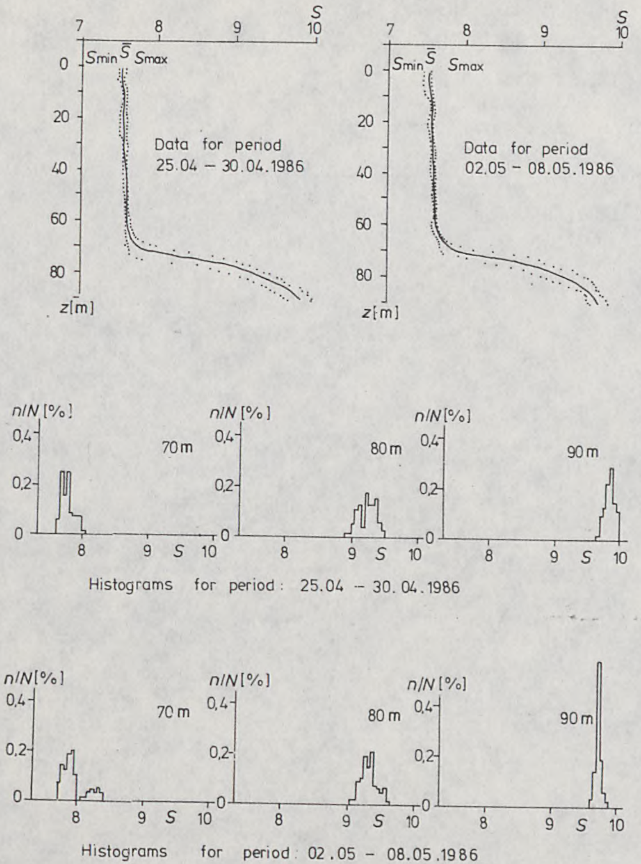


Fig. 6. Statistical characteristics of salinity variability for period 25.04–08.05.1986. Anchor station AN-2

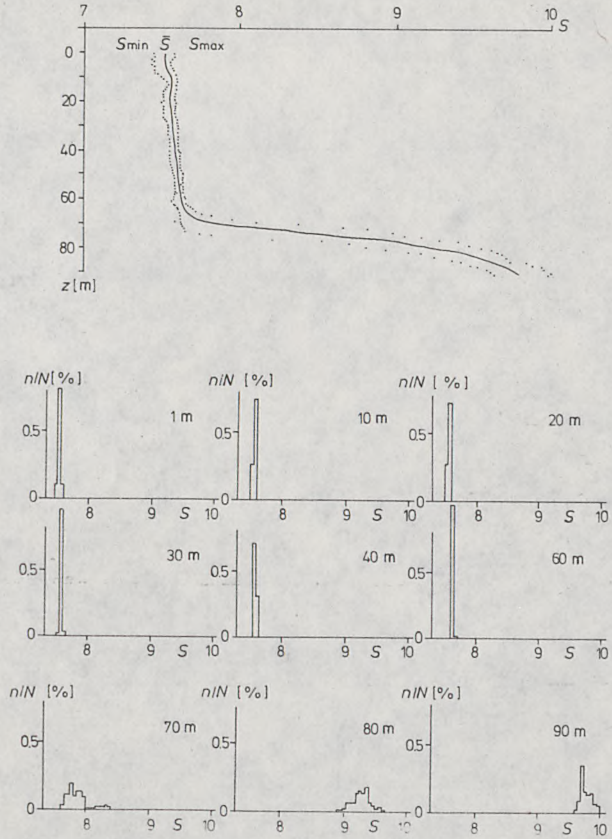


Fig. 7. Statistical characteristics of salinity variability for two measurement periods. Anchor station AN-2

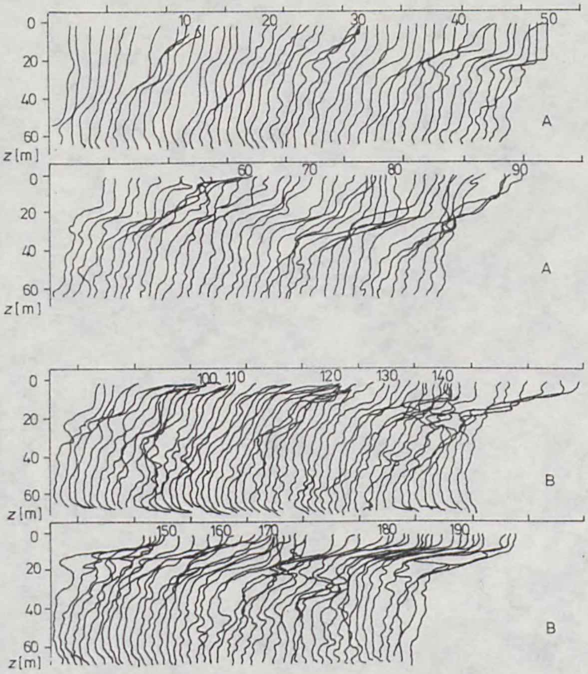


Fig. 8. Momentary vertical profiles of temperature measured at anchor station AN-1
Data for period: 25.04–30.04.1986–A and 02.05-08.05.1986–B. Numbers above profiles denote alternate number of sounding

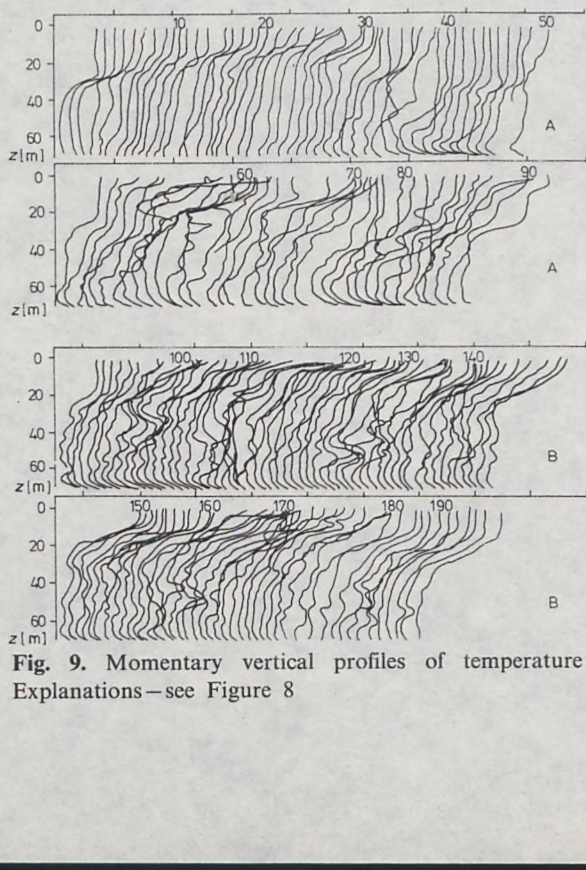


Fig. 9. Momentary vertical profiles of temperature measured at anchor station AN-2
Explanations–see Figure 8

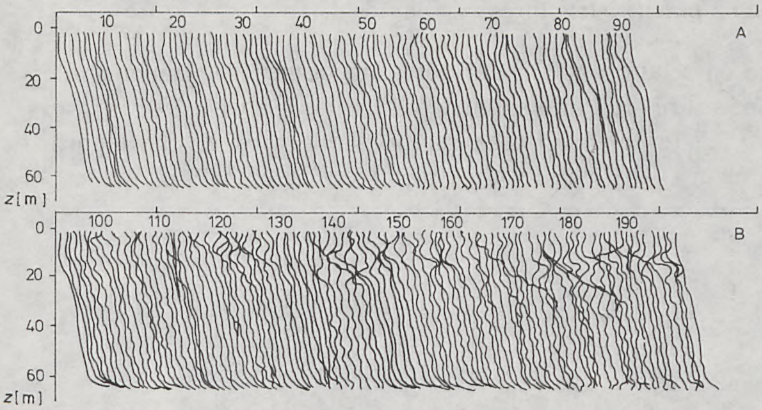


Fig. 10. Momentary vertical profiles of salinity measured at anchor station AN-1 Explanations – see Figure 8

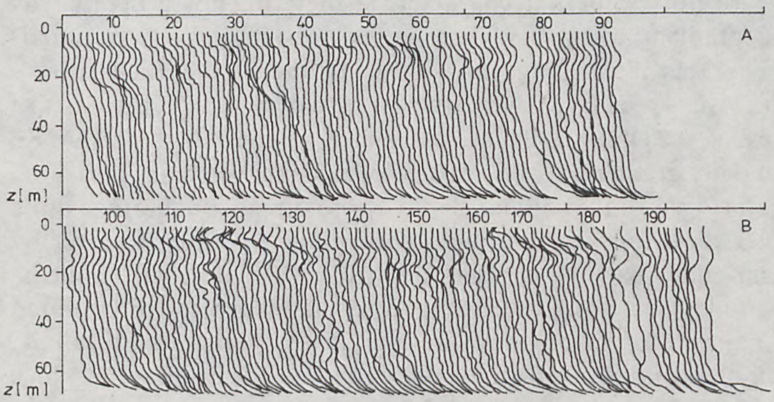


Fig. 11. Momentary vertical profiles of salinity measured at anchor station AN-2 Explanations – see Figure 8

3.2 Sources, size, and patchy structures

Diagrams of the correlation coefficient between momentary dimensionless fluctuations of temperature ($\alpha T'$) and salinity ($\beta S'$) recorded with STD sensors, illustrated in Figure 12, reveal very weak relationships between the recorded quantities, which means that within the examined layer the processes of

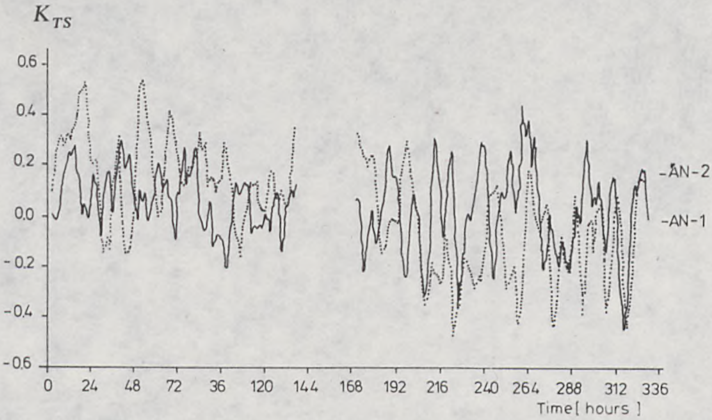


Fig. 12. Internal correlation between αT and $\beta S'$ data
K_{Ts}—correlation coefficient

turbulent mixing are not of inertial character, *ie* they are not generated by Kelvin-Helmholtz gradient instability. The correctness of this evaluation is testified by the diagrams illustrating variability in time of the Richardson's number (Ri) in the layer spreading from 10 to 40 m, calculated on the basis of momentary values of the Vaisala-Brunt parameter at the AN-1 and AN-2 stations and mean daily gradients of the module of currents velocities measured at the AN-1 station (Fig. 13). It is obviously an approximate, qualitative, quite erroneous characteristic. However, absolute momentary Ri values, greater by two orders of magnitude than the critical value $Ri = 0.25$, distinctly indicate lack of small-scale turbulence from the inertial interval. Hence, it can be stated that in a vast majority of cases they are the local thermal and salinity inversions fulfilling the conditions (i), (ii) or (iii) described in paragraph 2 which are the sources of local hydrodynamic instabilities of water masses within the regions of both the measurement stations, capable of formation of patchy structures in temperature, salinity, and density fields. Let us verify this diagnosis using the Pingree's criterion (8) and (13). Figure 14A shows diagrams illustrating variability in time of the $|\overline{\Delta T}/\overline{\Delta S}|$, σ_T/σ_S and α/β parameters. These characteristics distinctly indicate that during the April period, when $\beta/\alpha \ll \sigma_T/\sigma_S$, the criterion (13) is not fulfilled within the regions of both the measurement stations. Hence, temperature inversions observed in the momentary distributions are not generated by thermohaline intrusion process in the

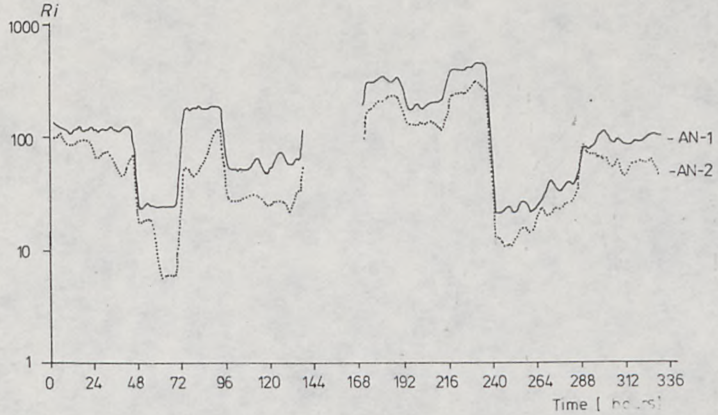


Fig. 13. Changeability of Richardson's number. $\Delta z = z_2 - z_1 = 40\ \text{m} - 10\ \text{m} = 30\ \text{m}$

density field, but are most probably due to anisotropic circulation of water masses of similar salinity and different temperature. Hodographs of sea currents within the region of AN-1 station indicate the possibility of existence of such a mechanism. A similar situation takes place within the region of the AN-2 station. Characteristics recorded at AN-1 station reveal strong similarity of the values of the $|\overline{\Delta T}/\overline{\Delta S}|$ and β/α parameters on 5th of May, 1986, indicating the possibility of fulfilling the criterion (13) during this period. It follows from vertical temperature and salinity distributions recorded on 5th of May that this diagnosis is valid. Criterion (8) is also fulfilled in a number of short periods which indicates that in both the examined regions short-term conditions of generation of locally isotropic turbulence caused by the Kelvin-Helmholtz gradient instability can occur, which does not follow from approximate evaluations based on the Richardson's number. The diagrams of the δ, R_ϱ and A_T parameters shown in Figure 14B disclose the most important information on the discussed problem, supplementing and generalizing the above diagnosis. Especially the R_ϱ parameter of water masses stability constitutes an important characteristic. A reliable diagnosis of the hydrodynamic condition of water masses governing formation and dimensions of patchy structures occurring within the regions of the AN-1 and AN-2 anchored stations down to -60 m can be made on the basis of data illustrated in Figure 14B and the characteristics discussed above. This diagnosis can be summarized in the following manner:

– during the April investigation period a vertical stratification of water masses density field is not absolutely hydrodynamically stable and weak anisotropic advective processes of waters of similar salinity often result in formation of local thermal inversions at various depth, generating convective instability. This instability constitutes a source of processes of mixing determining the dimensions of the resulting quasi-uniform patchy structures in all

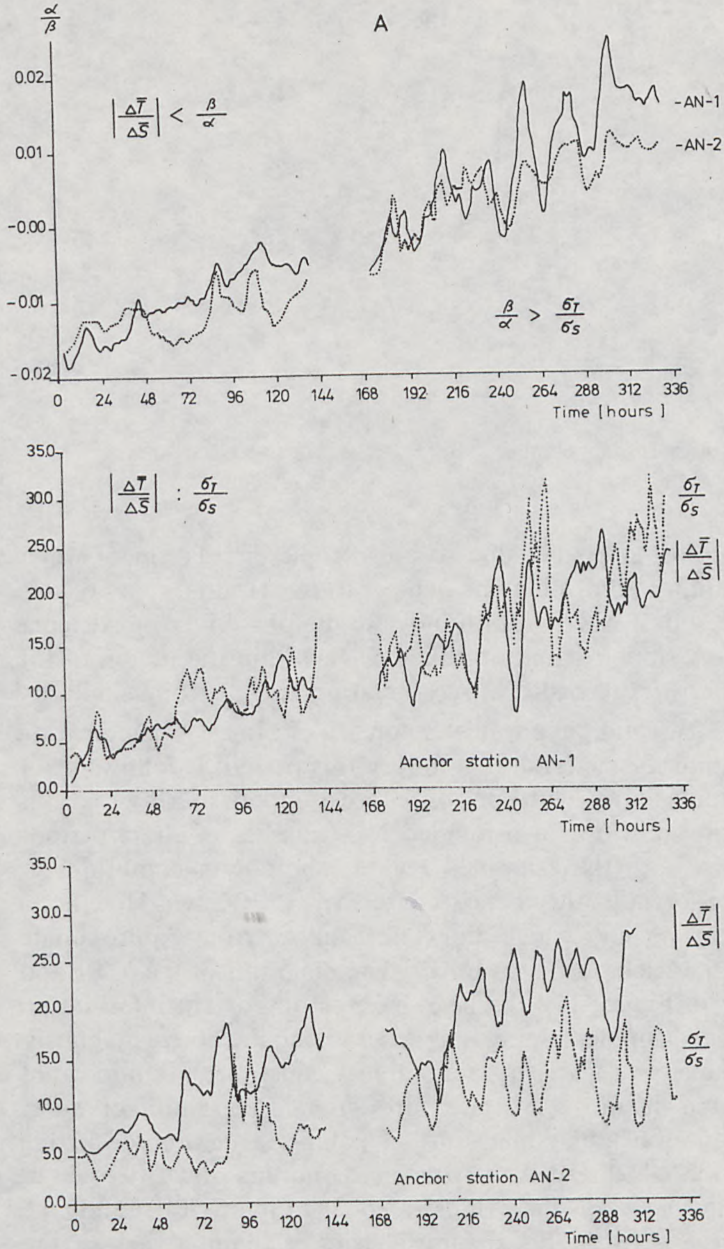
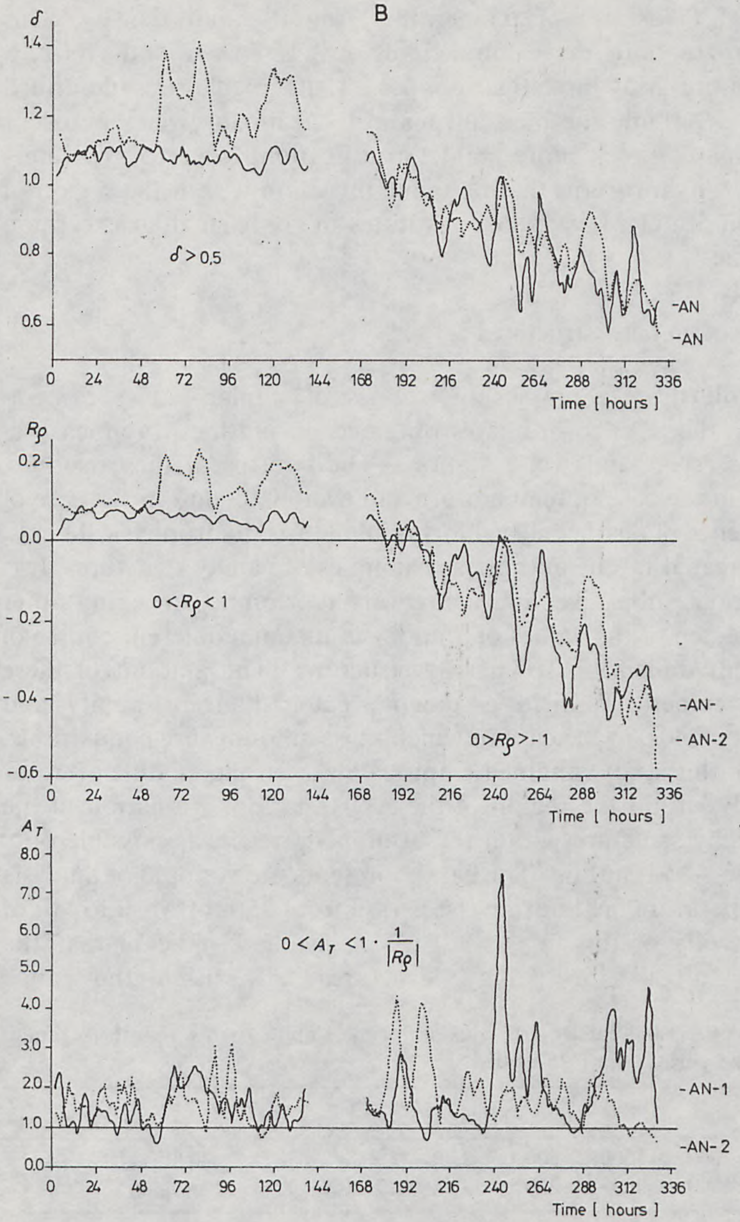


Fig. 14. Changeability of some parameters in time. A – of Pingree's parameter, B – of δ, $R\varrho$, A_T



B
δ
1.4
1.2
1.0
0.8
0.6
δ > 0.5
-AN
-AN
0 24 48 72 96 120 144 168 192 216 240 264 288 312 336
Time [hours]
Rρ
0.2
0.0
- 0.2
- 0.4
- 0.6
0 < Rρ < 1
0 > Rρ > - 1
-AN-
- AN-2
0 24 48 72 96 120 144 168 192 216 240 264 288 312 336
Time [hours]
A_T
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
$0 < A_T < 1 \cdot \frac{1}{|R\rho|}$
-AN-1
-AN- 2
0 24 48 72 96 120 144 168 192 216 240 264 288 312 336
Time [hours]

three hydrophysical fields, *viz* of temperature, salinity, and density. This regularity characterizes both the examined regions, *viz* AN-1 and AN-2,

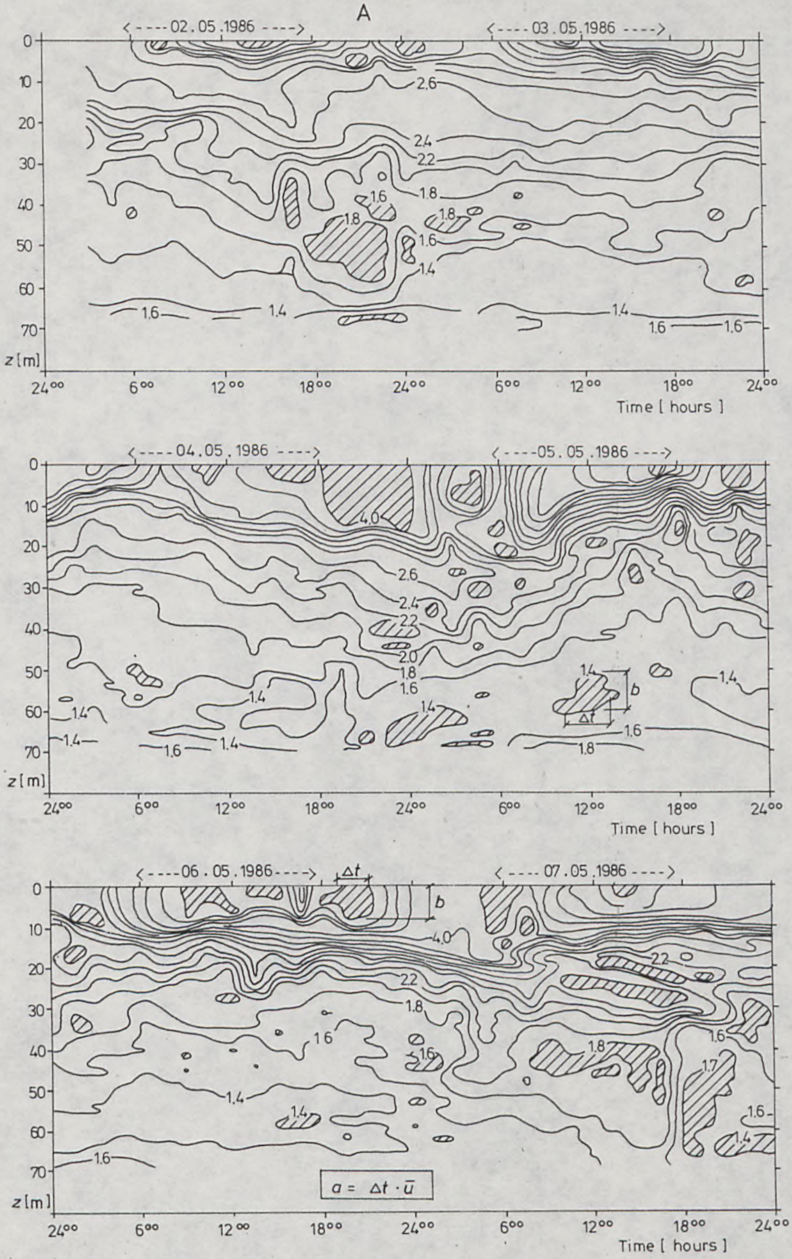
– during the entire May investigation period the regularities described above continue to determine the mechanisms of local mixing, yet they occur under the conditions of much more stable stratification, close to absolutely stable stratification. A short-term thermohaline inversion within the region of the AN-1 station on 5th of May, 1986, constitutes the only singular exception in this characteristic.

3.3 Characteristics of patchy structures

Figures 5–16 illustrate examples of isolines of similar values of temperature, salinity in the (z, t) co-ordinates obtained during the May measurement period at the AN-1 and AN-2 stations. The courses of these isolines, drawn every 0.2°C in the case of temperature and every 0.05 unit in the case of salinity reveal existence of distinct closed forms in all three hydrophysical fields. These forms were treated by the authors as examples of patchy structures. It is obviously an arbitrary, subjective, and controversial example, since any other size of quantization step of the values of T and S results in a different course of isolines and different dimensions of patchy structures. The amount of these structures in the temperature field is much greater than in salinity and conventional density fields, in the case of which these amounts are comparable. Since the authors of this study obtained empirical data on the module of water masses velocity only within the region of the AN-1 station, evaluation of the dimension of a patchy structure within the examined areas was possible only for the region of the AN-1 station. This study presents an example of analysis of evolution of temperature field during the period from 25th of April to 8th of May, 1986. The results of this analysis listed in Table 1 indicate that the thickness of 80% of all the patchy structures fall within the range

Table 1. Characteristics of thermal patchy structures of thickness up to 10 m within the region of AN-1 station during the period April 25–May 8

b [m]	a [m]										
	≥100 <500	≥500 <1000	≥1000 <1500	≥1500 <2000	≥2000 <2500	≥2500 <3000	≥3000 <3500	≥3500 <4000	≥4000 <4500	≥5000 <5500	Σ
2–2.9	12	8	5	3	2	1	–	1	1	–	33
3–3.9	–	5	–	2	2	1	1	–	–	1	12
4–4.9	–	2	2	–	–	1	1	–	1	–	7
5–5.9	–	–	–	–	–	–	–	–	–	–	–
6–6.9	–	–	1	1	–	–	–	1	–	1	4
7–7.9	–	–	–	–	–	–	–	–	–	–	–
8–8.9	–	–	–	–	–	–	–	–	–	–	–
9–10	–	–	–	1	–	–	–	1	–	–	2
Σ	12	15	8	7	4	3	2	3	2	2	58


A
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z [m]
Time [hours]
Δt
b
a = Δt · ū

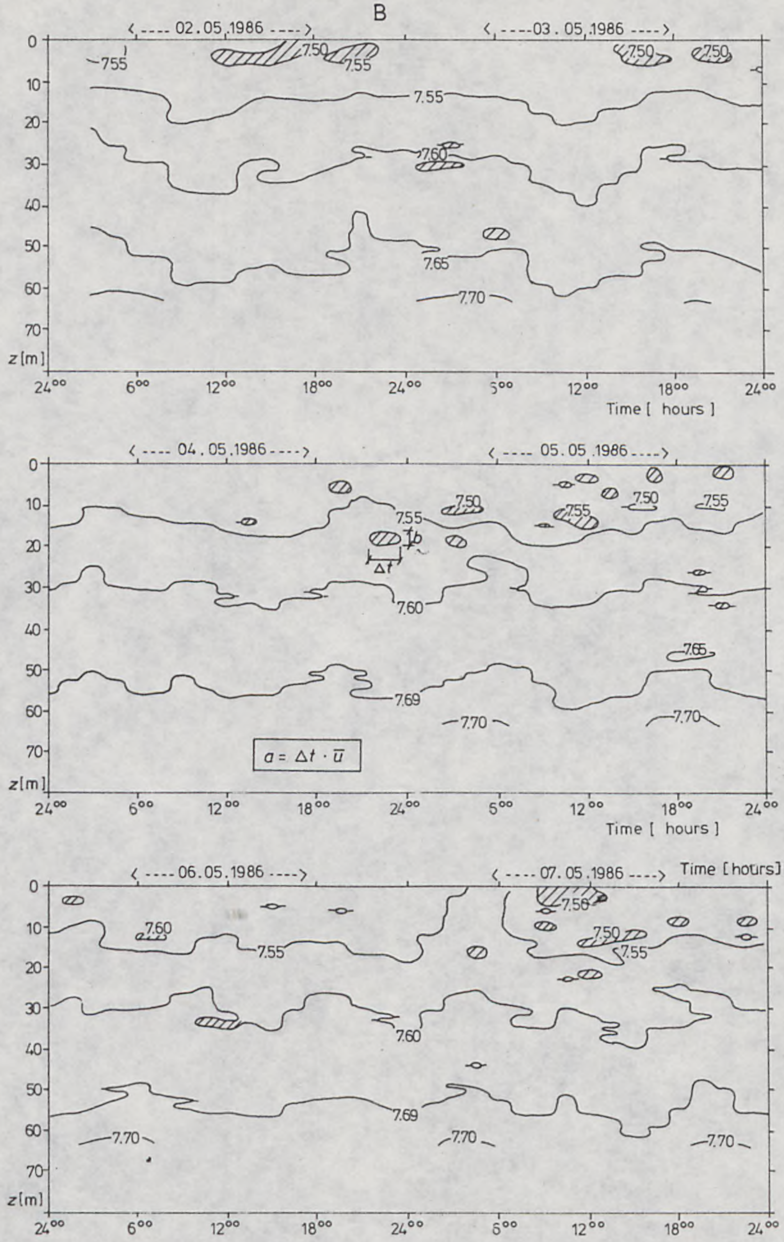
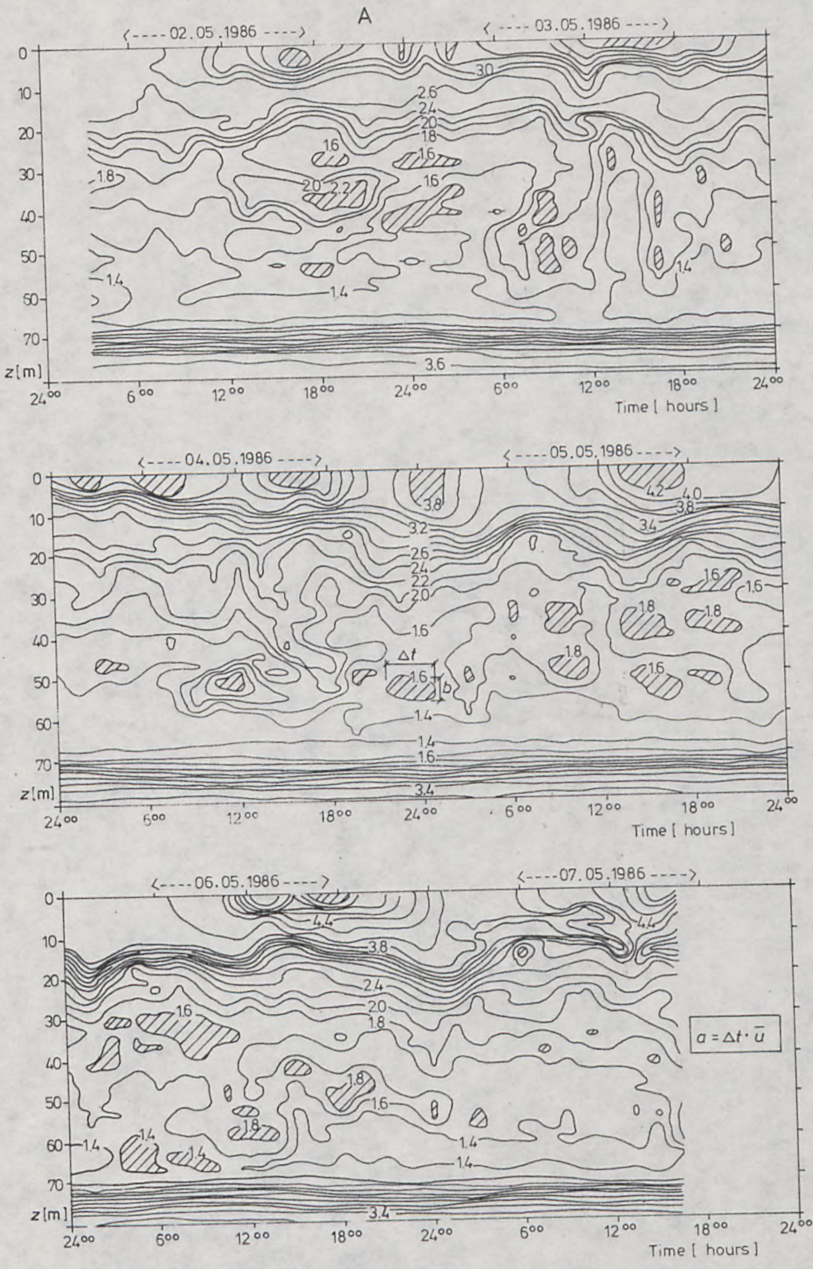


Fig. 15. Changeability in time of temperature (A) and salinity (B) isolines. Vertical section. Anchor station AN-1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z[m]
Time [hours]
Δt
b
a = Δt · ū

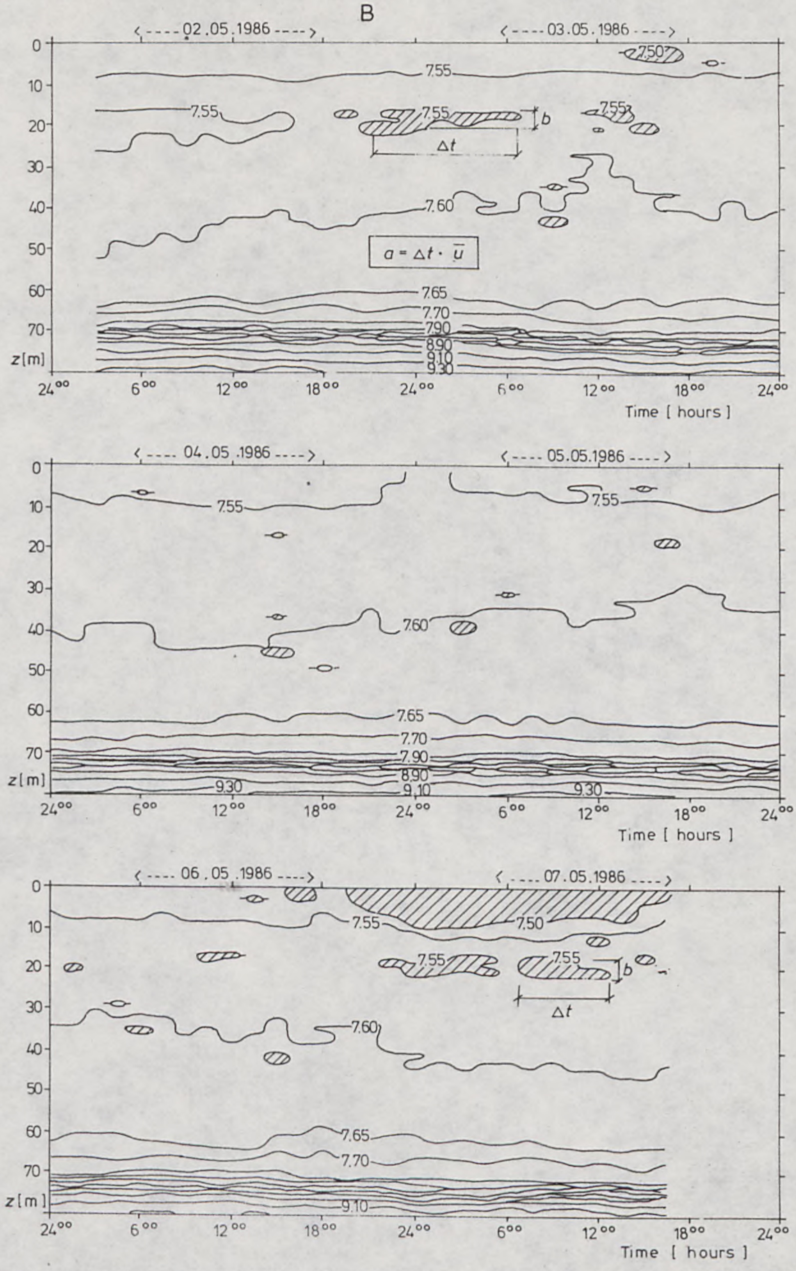

Fig. 16. Changeability in time of temperature (A) and salinity (B) isolines. Vertical section. Anchor station AN-2

$2 \text{ m} \leqslant b \leqslant 4$ m, 50% of which is characterized by horizontal dimensions contained in the interval $100 \text{ m} \leqslant a \leqslant 1000$ m. The analysis also revealed the existence in marine environment of patches of dimensions largely exceeding those of the most often occurring ones. This includes two patches of a horizontal dimension $a \simeq 7000$ m and thicknesses equal to $b_1 \simeq 4$ m and $b_2 \simeq 8$ m, three patches of a horizontal dimension $a \simeq 9000$ m and thicknesses equal to $b_1 \simeq 10$ m, $b_2 \simeq 7$ m, and $b_3 \simeq 4$ m, one patch of dimensions $a \simeq 11{,}000$ m and $b \simeq 4$ m, one patch of dimensions $a \simeq 13{,}000$ m and $b \simeq 10$ m, as well as one patch of dimensions $a \simeq 16{,}000$ m and $b \simeq 4$ m. The evaluation of the horizontal dimension a is obviously erroneous to some extent, particularly in the case of layers situated below 20 m, which results from the errors accompanying empirical data on the current velocity module ($\bar{u}$), used in the formula: $a = \Delta t|\bar{u}|$, and from the error of graphical evaluation of the Δt time interval. All patchy structures in the temperature, salinity, and density fields at the AN-1 and AN-2 stations were estimated with respect to the b parameter. These data are listed in Table 2. It is characteristic that all the thicknesses of patchy structures fall within the range $2 \text{ m} \leqslant b \leqslant 10$ m, *ie* in the range characteristic of quasi-uniform layers revealed in field investigations of the fine structure of hydrophysical fields in seas. This fact confirms indirectly correctness of the diagnosis made in this study. It also follows from data listed in Table 2 that patches in the density field are formed mainly under the influence of changes in the salinity field.

Table 2. Number of patchy structures of thickness (b) in temperature (T), salinity (S), and water density (ϱ) fields

b	AN-1 station			AN-2 station		
[m]	T	S	ϱ	T	S	ϱ
2–2.9	33	27	29	29	19	17
3–3.9	12	6	3	16	6	10
4–4.9	7	3	2	9	4	2
5–5.9	–	1	2	3	2	1
6–6.9	4	1	1	2	1	1
7–7.9	–	–	–	–	–	–
8–8.9	–	1	1	–	–	–
9–10	2	–	–	2	1	1
$\sum$	58	39	38	61	33	32

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