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SOME DYNAMIC CHARACTERISTICS OF THE EAST ADRIATIC COASTAL AREA

NEKE DINAMIČKE KARAKTERISTIKE ISTOČNOJADRANSKOG OBALNOG PODRUČJA

MIRA ZORE-ARMANDA, MARIO BONE and MIRO GAČIĆ

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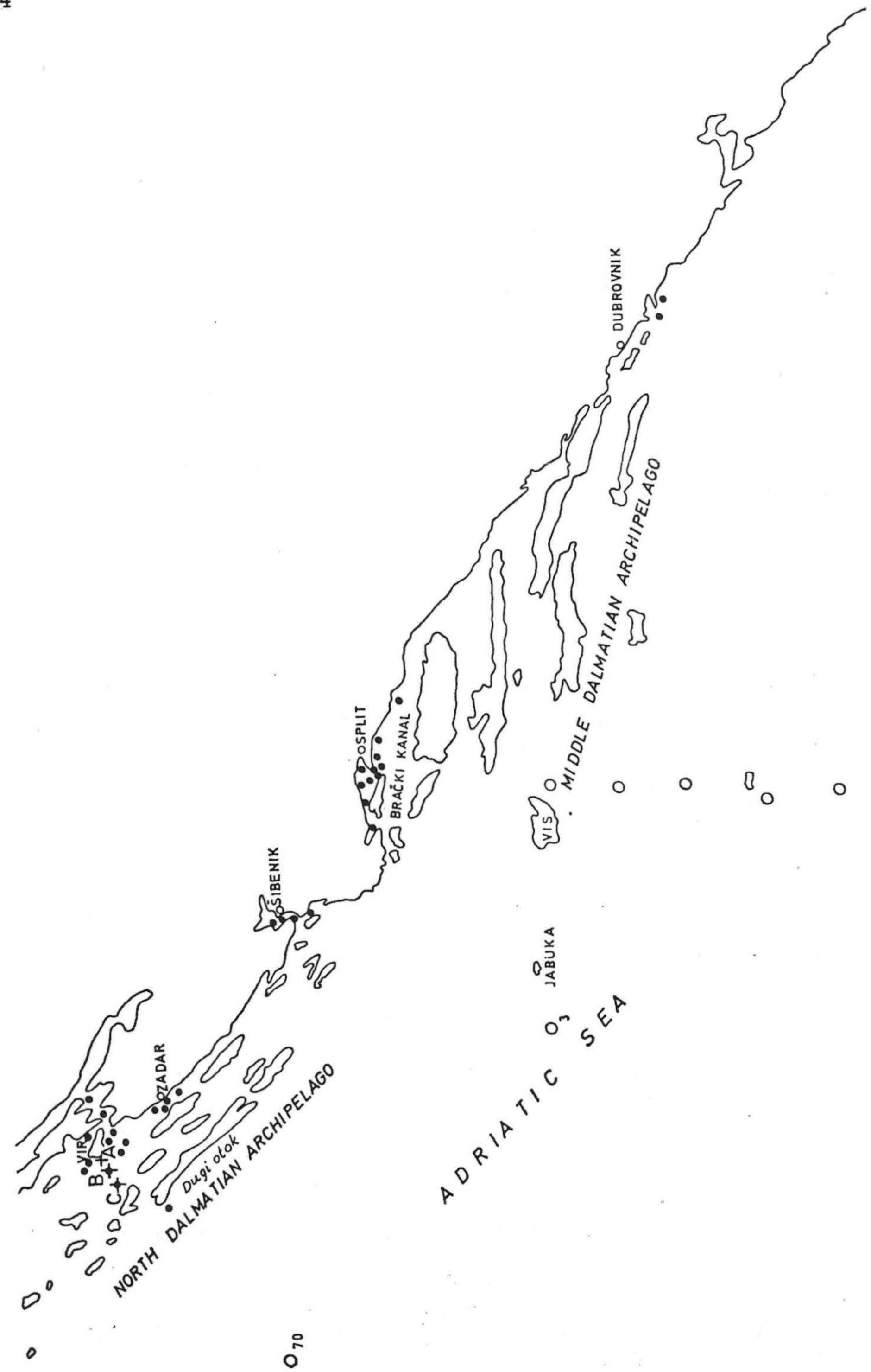
Due to growing concern about the pollution the Laboratory for the Physics of the Sea of the Oceanographic Institute has recently been active in coastal oceanography. Numerous measurements of basic hydrographic parameters and currents (about 100.000 data) have been carried out in collaboration with the Navy Hydrographic Institute. Measurements were taken in the coastal area off Dubrovnik, Split, Šibenik, Zadar, as well as in the north and middle Dalmatian archipelago. All the data refer to stations not deeper than 60 m and not more than 3 miles offshore (Fig. 1). In data processing standard statistical methods were employed (Zore-Armanda et al., 1971, 1974, 1977a, 1977b), while for nine monthly series of current data spectral analysis, after Gonella (1972) and Mooers (1973), has been conducted. It includes oscillations in the frequency domain from 0 to 0,1 cph, which are tidal, inertial and long-period (several days) oscillations.

The necessity of controlling the outflow into the sea of polluting water from city sewers, factories and nuclear plants, has made wider study of the diffusion processes necessary. The basis for the application of the multidimensional Kolmogoroff diffusion equation has been developed and investigations of the analytical solutions of the diffusion processes, under some specific conditions, have been carried out. The theoretical considerations were followed by the development of the experimental tehniques of dye diffusion of Rhodamin B in the sea as well as by the numerical treatment of the process.

The basic dynamic characteristics of the open Adriatic are rather well known due to the fact that in earlier periods more attention was paid to its investigation (Zore-Armanda, 1963; 1968). Owing to the quantity of data, it has been possible to understand better dynamic characteristics of the Dalmatian coastal area and to compare them with the open sea characteristics, as well as with the results obtained from previous studies (Gačić, 1975, Gačić and Smirčić, 1971).


DUBROVNIK
SPLIT
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VIR
A
B
C
Dugi otok
NORTH DALMATIAN ARCHIPELAGO
MIDDLE DALMATIAN ARCHIPELAGO
VIS
JABUKA
3
70
ADRIATIC SEA

CURRENT FIELD

Vertical Distribution of Relevant Characteristics

Three layers are typical for the open Adriatic during the warm period: surface, intermediate and bottom. In winter the surface and intermediate layers have similar characteristics and could not be well distinguished. The vertical circulation always includes all the layers so that currents of one layer get compensated by the currents of the other ones. These layers are clearly visible on T-S diagram of the Jabuka and southern Adriatic pits (Fig. 2).

The dispersion of the current directions is generally greater near the shore, while current directions on various depths differ only slightly. Yet, we can basically distinguish two layers in the coastal area. In the warm period the thermocline (having depth from 10 to 20 m separates the surface layer from the bottom one, which can be seen on T-S diagram (Fig. 2). This layer shows some specific dynamic properties. The oscillations of periods smaller than tidal are very frequently damped in that layer (Fig. 3). On the other hand we observe from spectral analysis that this very layer has the highest noise level with respect to tidal oscillations. The energy of oscillations of several day period is also decreased, possibly due to energy losses.

It has been observed in the surface layer, at the station near the Vir island that the part of the spectrum in the vicinity of the zero frequency is characterized by the energy increase. Such increase, has not been observed at 20 and 45 m depths (Fig. 5). In winter, though, when thermocline is not present the energy increase towards the lowest frequencies has been observed on both surface and deeper layers (Fig. 6). All this indicating that in summer-time the thermocline has the effect of preventing a close dynamic connection between the layers under and above it.

The vertical distribution of directions is shown on the Table 1; their frequencies, for three layers and five coastal regions, are given in percent. The calculations were carried out from all the diurnal current resultants available, including all the seasons, as well as several stations for each region.

The data from the Table 1 show the presence of only two layers, meaning that currents of one layer are, at least partly, compensated by currents of the other layer. While in some places, such as Dubrovnik, we find the bottom layer starting at considerable depth, in some others (the Kaštelanski zaljev) develops at 10 m depth. Only in the region of Vir sea (Virsko more) three layers could be seen, though not very clearly (Fig. 2).

The surface layer is characterized in the first place by the predominance of current in the NW direction. That is the direction of the current entering the Adriatic and circulating along its eastern coast. We find that such a circulation is also predominant near the coast as well as in the rather closed bays (the Kaštelanski zaljev), although not so frequently. In addition to NW direction the western and northern directions occur very frequently. Due to changing coastal orientation, both directions can represent inflowing cur-

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Fig. 1 — Stations in the coastal region (solid circle) and in the open sea (open circle). Diffusion experiments were carried out at stations marked by a cross.

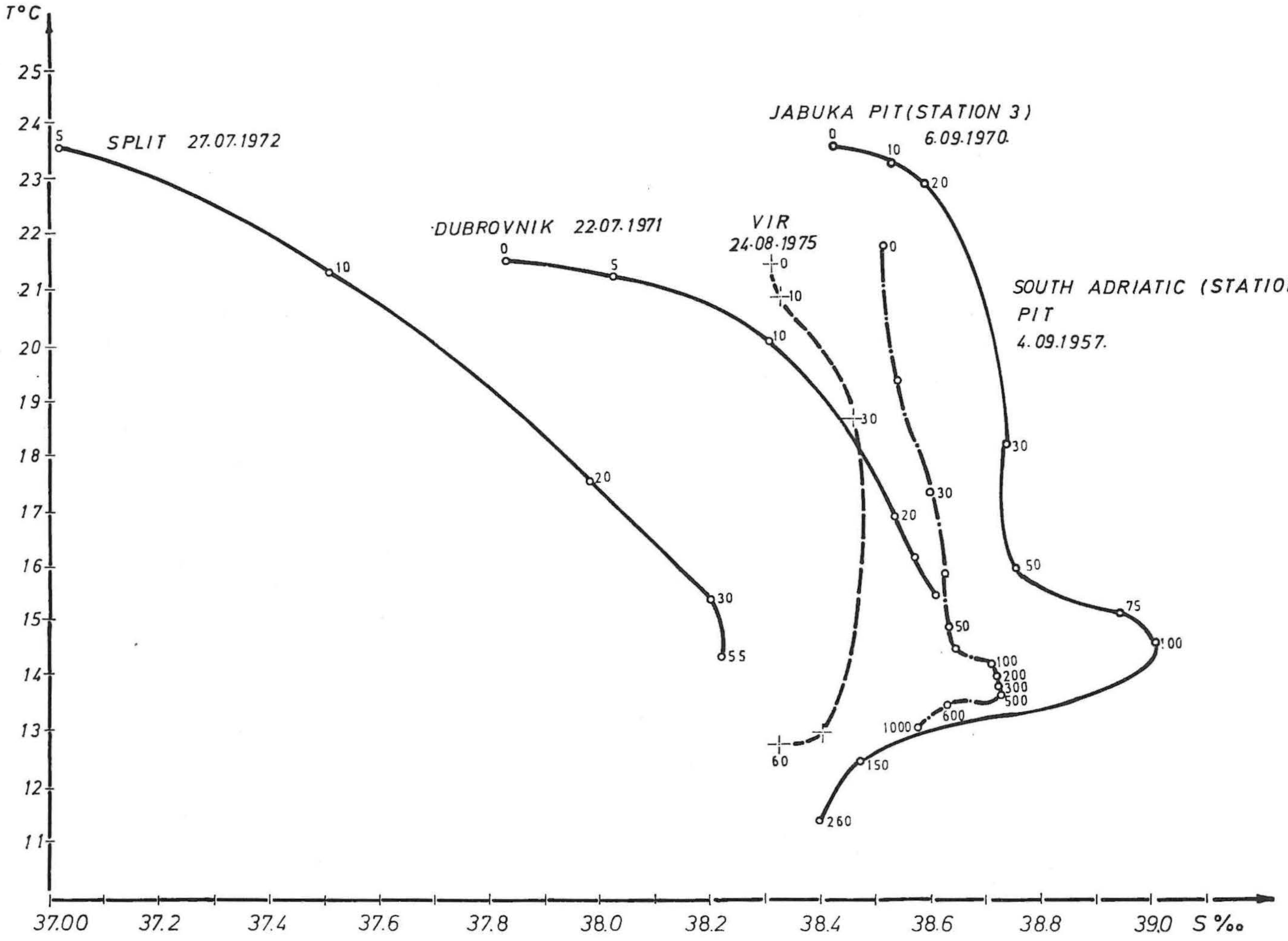

Fig. 2 — T-S diagrams for the stations of the coastal region and the open sea. Figures denote the depth in meters.

Table 1. Direction frequencies of diurnal resultant currents in %. (Significant directions are printed in bold type)

Region	Depth	N	NE	E	SE	S	SW	W	NW
	3 m	4	10	—	6	4	6	**39**	**31**
DUBROVNIK	10—30 m	6	12	6	**12**	—	8	**19**	**37**
	60 m	5	**18**	**39**	5	3	6	12	12
	3 m	11	5	8	5	2	5	**32**	**32**
BRAČKI	10—20 m	2	2	10	**21**	9	16	**31**	9
KANAL	25—50 m	3	9	16	**20**	3	13	**20**	16
	3 m	16	12	10	12	6	6	**19**	**19**
KAŠTELANSKI	10—20 m	15	5	**25**	15	5	5	**20**	**10**
ZALJEV (Split)	20—40 m	5	13	**17**	9	17	13	13	13
	3 m	**22**	2	7	4	4	3	**24**	**36**
ZADAR	15 m	8	4	8	8	18	1	**21**	**32**
	35 m	**23**	**17**	**6**	14	6	3	**18**	13
	3 m	**17**	**17**	11	9	8	6	13	**19**
VIRSKO MORE	10—25 m	11	11	15	13	7	8	13	**22**
	40—55 m	**17**	15	8	8	3	7	8	**35**

rents. It looks, however, that the W direction could also represent the offshore current for the most part of the coast. It occurs more frequently during the cold period (Table 3), and therefore can be connected with the typical winter NE wind, bora (Table 2). The deviation of the current direction to the right corresponds to the current induced by that wind, the most frequent and the strongest wind on the coast.

Table 2. Frequency (in %) and average force of the NE wind (bora) for 3 localities of the eastern coast.

	Zadar		Split		Dubrovnik	
month	frequency %	force B number	frequency %	force B number	frequency %	force B number
1	22	2.2	41	3.0	24	4.2
4	10	2.2	19	3.0	11	2.9
7	5	1.8	20	2.5	16	3.2
10	16	1.0	26	2.2	23	3.2

In Zadar and even more in the region of Vir both force and frequency of bora are the lowest and the W circulation is consequently less significant.

One of evidences that the wind influences the current is that the energy maximum occurs at the inertial frequency of the clockwise spectrum. Although the inertial frequency maximum is lower than the maximum of long period and tidal oscillation frequencies, it is still significant. The local maximum occurs only in the surface layer which indicates that the wind effect can only be observed in the first 10 meters. In winter it occurs more or less regularly (Fig. 4).

The bottom layer of the open sea is characterized by a current in the SE direction (outgoing). It could be understood as compensatory to the ingoing flow in the surface and intermediate layers. In the coastal area the current in the SE direction also occurs quite frequently, but not so often as in the

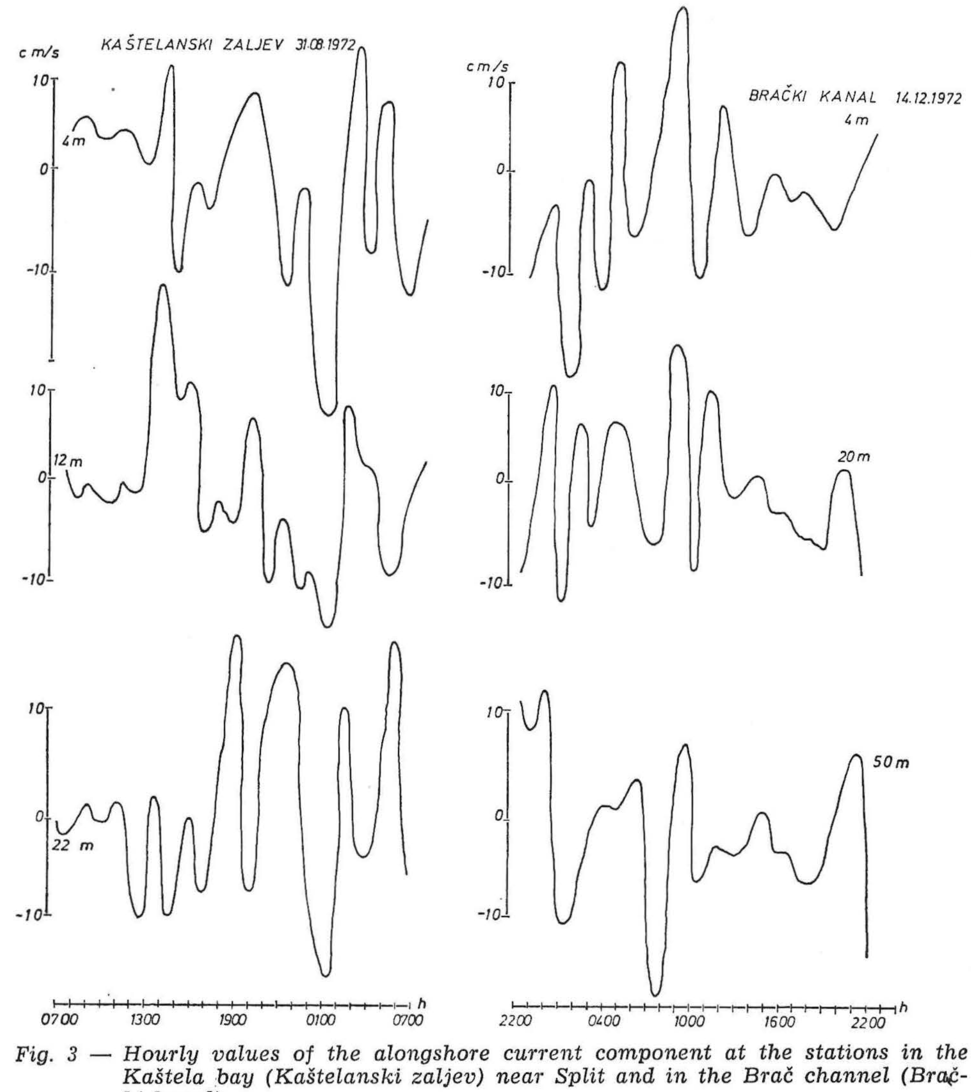

Fig. 3 — Hourly values of the alongshore current component at the stations in the Kaštela bay (Kaštelanski zaljev) near Split and in the Brač channel (Brački kanal).

open sea. Other compensatory directions occuring are the NE and E direction i.e. the current flowing shoreward. Therefore two types of circulation occur in the coastal area, one corresponding to the open sea circulation, and the other taking place between the coastal area and the open sea in the way that in the surface layer the water flows offshore, and in the bottom layer shoreward. It is hard to say how far offshore this circulation occurs. An excellent set of data, relating to an area in vicinity of the Vis island, also indicates the predominance of the N direction in the bottom layer. It shows that, up to 100 m depth, that type of circulation still occurs. On that location the upwelling, up to some 20 m depth in warm period, has also been observed on temperature data (B u l j a n, 1965).

T-S diagrams also show the existence of a bottom current in the onshore direction (Fig. 2). At 50 m depth water has properties of the open sea deep water , meaning that the bottom layer of the coast is being permanently

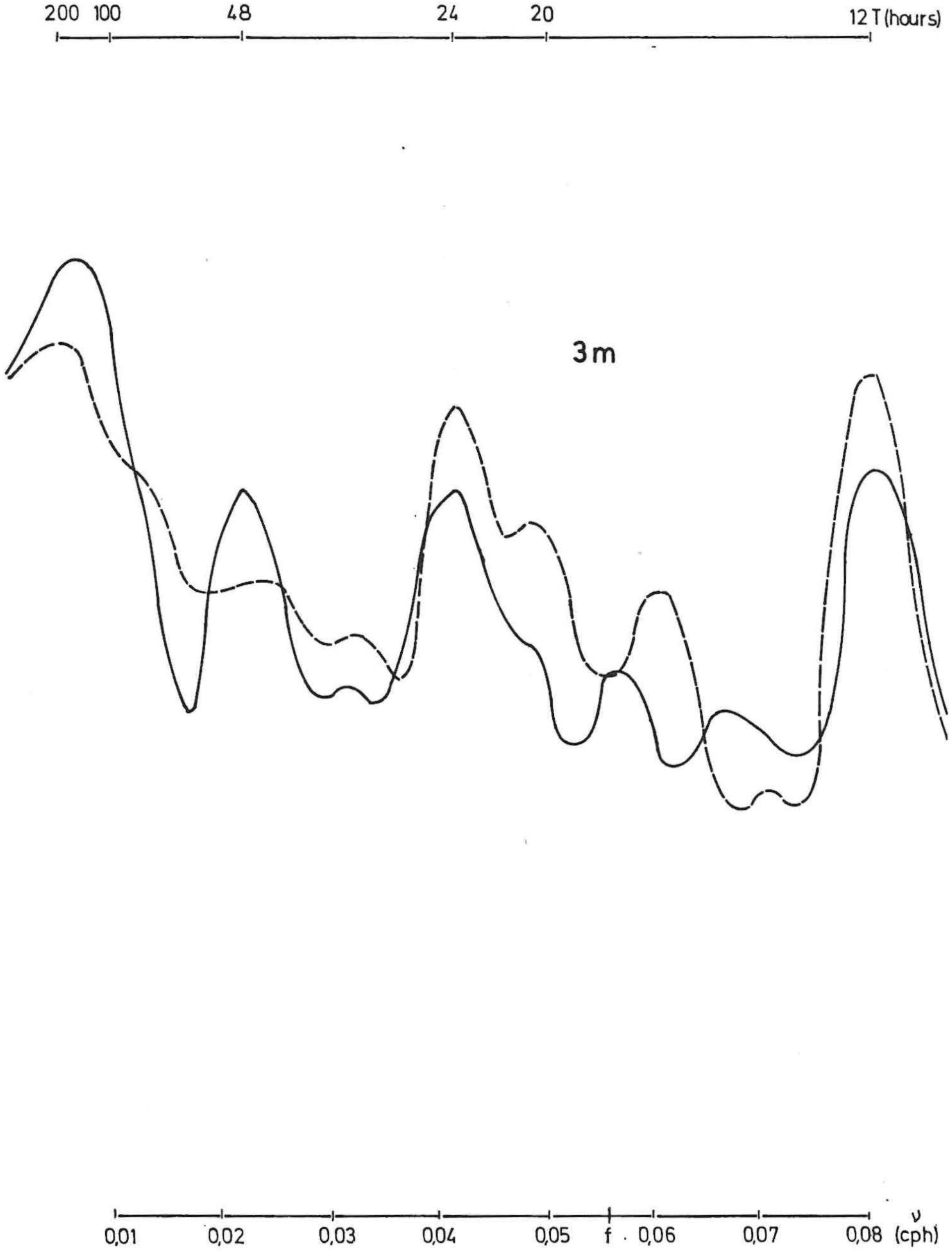

Fig. 4 — Spectral density functions for the coastal station near Dugi otok for January 1972 (- - - anticlockwise part; ——— clockwise part).

influenced by the open sea waters. It can be assumed that this water is upwelled very slowly towards the upper layers. The upwelling, besides the above mentioned station near the Vis island, has also been observed on the temperature data near the coast of some islands (Buljan and Špan, 1976).

Long-period Oscillations

Strong seasonal oscillations in the current field, due to differences in the field of mass, are very typical for the open Adriatic. The monthly series spectral analysis of the open sea shows the energy increase towards the zero-frequency, which indicates high energy of long-period, mostly seasonal fluctuations. In the coastal area (Table 3) direction frequencies are generally equally distributed and seasonal differences are less significant.

Table 3. Direction frequencies of the diurnal resultants in %/o relating to coastline from Dubrovnik to the region of Vir, as well as open Middle Adriatic, for all available depths (more frequent directions are printed in bold type)

Region	Season	N	NE	E	SE	S	SW	W	NW
Coastline	spring	10	12	13	16	8	8	13	**20**
	summer	10	16	11	4	4	10	16	**29**
	autumn	15	10	14	7	15	4	15	**20**
	winter	11	10	9	12	2	5	**25**	**26**
MEAN		11	12	12	10	7	7	17	24
Open Middle Adriatic	spring	14	16	5	4	5	3	**27**	**26**
	summer	**19**	13	11	9	6	10	10	**22**
	autumn	**18**	**20**	7	7	6	8	**18**	16
	winter	**20**	13	4	3	4	4	16	**36**
MEAN		18	16	7	6	5	6	17	25

In winter-time the NW direction is very significant in the open sea, prevailing with nearly 40%/o, while those prevailing in spring and autumn are W and NE directions i.e. transversal currents between the shores. In summer all those directions are less significant, besides, the SE direction is the most frequent in that season, due to the outgoing current from the Adriatic in the surface lawer, prevailing in that season.

In the coastal area the NW direction is predominant in all the seasons.

The W direction occurs almost all the time with high frequencies, while in winter its higher frequency may indicate its connection to bora. This wind being the most frequent and the most permanent one in winter, makes this assumption quite real (Table 2). Spectral analysis of the coastal current series also shows that the oscillation energy in the vicinity of zero-frequency is lower than at open sea stations (Fig. 4, 5 and 6). Seasonal fluctuations in the inshore current field are generally smaller than those on the open sea.

In the Adriatic, significant oscillations of the several day period (5—10 days) occur as well (Zore-Armanda et al. 1975). Spectral analysis shows that in both coastal and open sea areas the energy maximum occurs at frequency of 0.01 or 0.005 cph. On the open sea stations the maximum occurs at frequency of about 0.01 cph and has the magnitude of the tidal wave

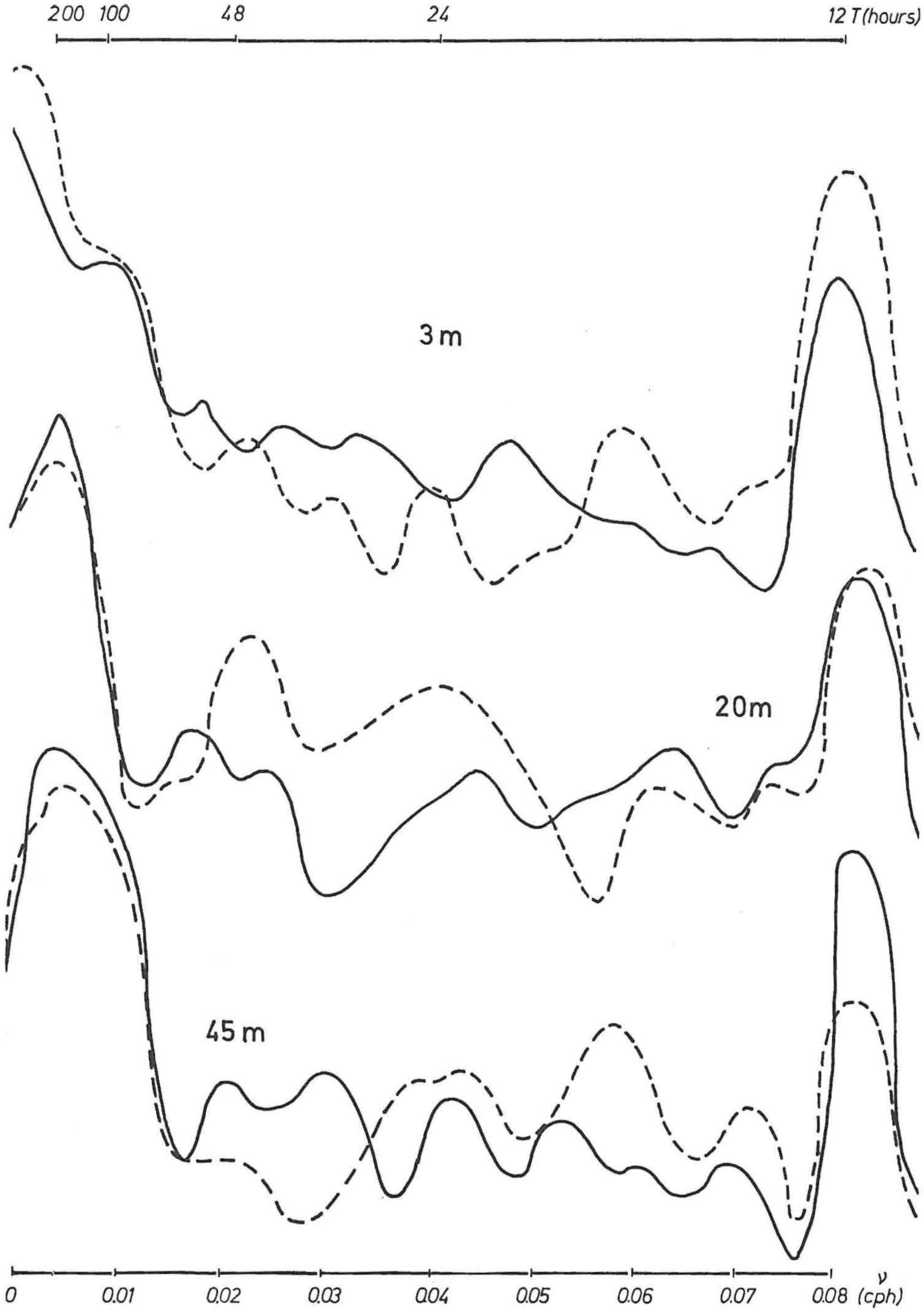

Fig. 5 — Spectral density functions for the station in the Vir region for three levels in the August 1975 (- - - anticlockwise part; —— clockwise part).

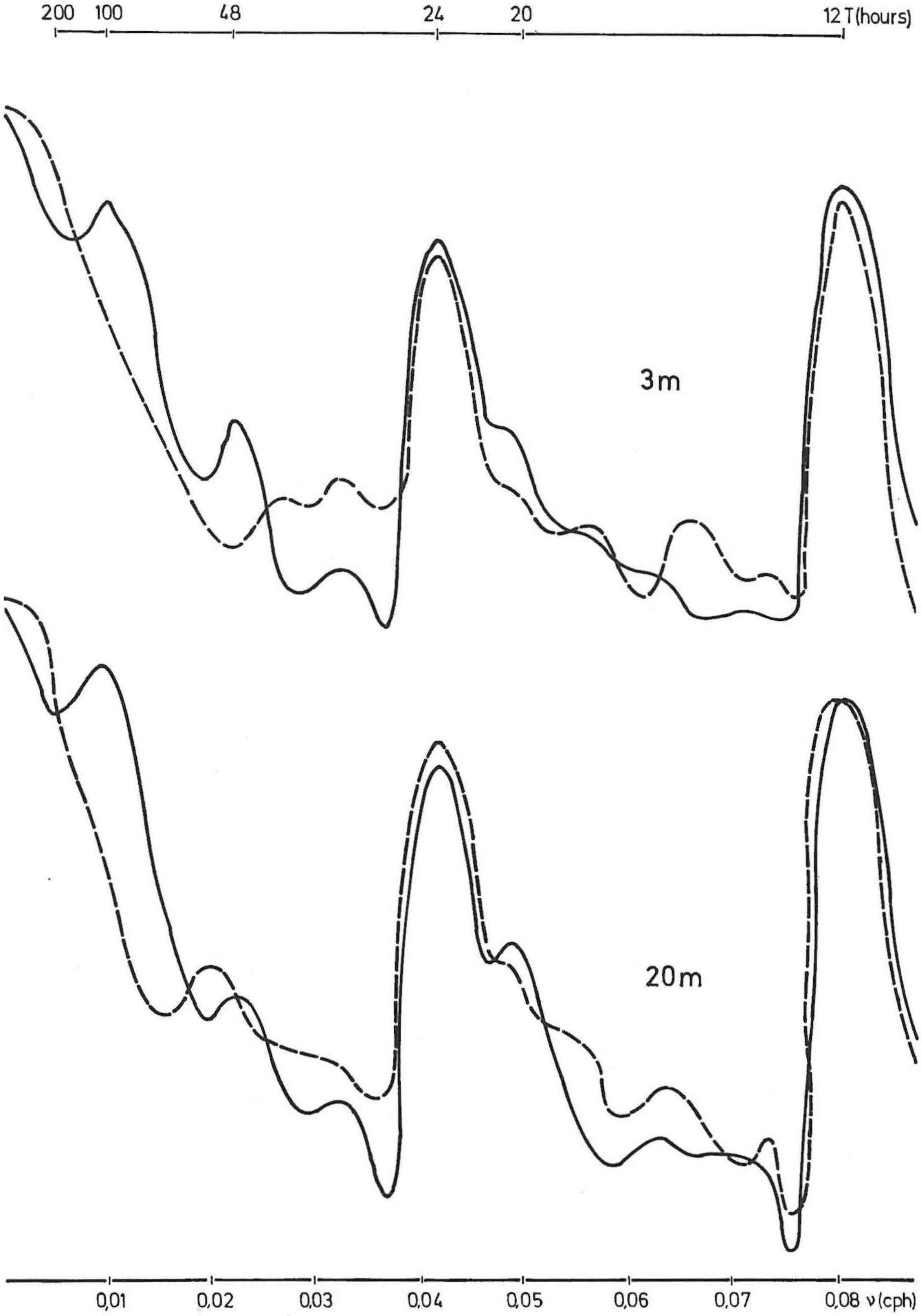

Fig. 6 — Spectral density functions for the station in the open sea (70) for the depths of 3 and 20 metres in December 1970 (- - - anticlockwise part; ——— clockwise part).

maximum, while in the coastal area that maximum is appreciably higher than the maximum at the tidal frequency. We could conclude therefore that in the coastal area the seasonal oscillations are less significant, while those of 5—10 day period are more significant than such oscillations on the open sea. They are pronounced in the temperature and salinity fields as well. For the time being the character of these oscillations is not clear.

One characteristics of these oscillations is the variability of its energy with depth. In summer it is the intermediate layer that can have the lowest oscillation energy, while in winter the energy in general decreases with depth.

Furthermore, the energy maximum in the open sea is higher in the counterclockwise part of the spectrum. The eccentricity of the rotation ellipses, being relatively small, indicates the presence of significant transversal current vector oscillations normal to the coast. On the coastal station the energy maximum is the same in both counterclockwise and clockwise part of the spectrum meaning that the oscillations are mostly linear.

This shows that low frequency oscillations on the open sea perform ellipses of small eccentricity, while the same oscillations in the coastal area are generally linear and parallel to the coastline. We shall see that tidal oscillations show completely opposite behaviour.

Table 4. Orientation of the major axis of the ellipse, of current vector rotation and stability coefficient of ellipse for low-frequency oscillations.

Station	Date	Frequency cph	Depth m	Orientation of the major axis of the ellipse (°)	Stability of the major axis of the ellipse
VIR	Aug./Sept. 1975.	0.005	3	25.9	0.65
			20	—34.9	0.56
			45	18.0	0.91
DUGI OTOK	Jan. 1971.	0.0073	3	24.7	0.07
			20	—1.9	0.005
OPEN SEA (70)	Nov. 1970.	0.01	3	—20.0	0.45
			20	—9.5	0.36
OPEN SEA (70)	Dec. 1970.	0.01	3	31.0	0.73
			65	38.6	0.89

Orientation of the major axis is defined in the coordinate system whose axis are obtained by rotating the system on the earth 35° in counterclockwise direction: x — velocity component is positive in NE direction, y — component is positive in SW direction. Stability coefficient of the major axis goes from 0 to 1 and is low for nearly circular motion, or, in case the orientation of the major axis varies appreciably.

Tidal Currents

As some earlier diurnal measurements, carried out at various locations over a long period, show, in the most part of the Adriatic, the tidal current oscillations perform ellipses. This refers to both coastal and open sea areas of the middle Adriatic. Between Ancona and Zadar, though, tidal oscillations are mostly rectilinear, occuring along the N-S direction i.e. are parallel to the coastline. The ellipse stability coefficient exceeds 0.9. The absence of transversal oscillations is rather unexpected due to assumed existence of amphidromic point of semidiurnal component in the vicinity of that locality.

In the coastal area of the Vir island the semidiurnal oscillations have different character. On the surface their energy is higher in the counterclockwise spectrum, while at 45 m depth it is higher in the clockwise spectrum. These two energies are equal at 20 m depth (Fig. 5).

It means that the surface current is in the shoreward direction, while the bottom current is in the opposite direction and viceversa. We can therefore deduce the existence of vortices with horizontal axes parallel to direction of progression of the tidal wave. It is evidently the matter of specific influence of friction and energy trasfer between the layers due to configuration of the coast. The stability coefficient of the ellipse is smaller than on the open sea.

The absence of diurnal oscillations in the region of Vir is particularly interesting (Fig. 5). As on that frequency the counterclockwise spectrum has a weak minimum and the clockwise one the weak maximum, damping of that oscillation is possible in one sense only (courterclockwise) causing imaginary increase of its period so that it occurs as low-frequency oscillation.

That very explanation of such low-frequency oscillations (0.005—0.01 cph) is possible. Some circumstances comfirm it, such as: relationship between the stability coefficient for tidal oscillations and 0.005 cph oscillation, the former decreasing with depth, the latter increasing with it, while the major axes orientation of the ellipse varies with depth in similar way so that those oscillations are evidently not indipendent.

Table 5. Orientation and stability coefficient of the major axes of the ellipse of the current vector rotation

Depth	Region of Vir Semidiurnal oscillation		Frequency 0.005 cph	
m	Orientation of the ellipse	Stability of the ellipse	Orientation of the ellipse	Stability of the ellipse
3	8.5	0.81	25.9	0.65
20	—42.7	0.63	—34.9	0.56
45	6.5	0.68	18.0	0.91

Current Speeds

Speeds in the coastal area are somewhat lower than on the open sea. The average speed in the open middle Adriatic is 20 cm/sec; it is somewhat higher along the western than along the eastern coast, in the southern Adriatic higher than in the middle Adriatic. We give speeds for some coastal localities.

Table 6. Characteristic speeds of the surface currents for some localities along the eastern coast in cm/sec

	Average speed	Maximum speeds	Diurnal resultants	Most frequent speeds	Average summer resultants	Average winter resultants
Dugi otok	16	38	6—16	9	13	13
The region of Vir (13 stations)	13	61	2—24	11	9	8
Zadar (4 stations)	8	49	2—8	6		
Kaštelanski zaljev (15 stations)	11	44	2—25	9	4	5
Brački kanal (4 stations)	15	75	2—47	10	4	8
Dubrovnik (2 stations)	11	43	3—20	9	5	5

Current speeds inside the insular system are therefore in average 50% slower than outside it. The tidal currents speeds are about 3—10 cm/sec.

DIFFUSION

As investigating and predicting of the inshore pollution could not be carried out neglecting transport processes connected with diffusion it was necessary to develop techniques of experimental and theoretical methods in order to understand, measure and predict diffusion processes.

Thus the diffusion process from an instantaneous point source (IPS) in the surface layer has been experimentally investigated in various dynamic situations.

The »IPS« method has been chosen for following reasons:

— any diffusion process could be obtained from IPS by the integration over time and space

— relative simplicity of experiments

— known theoretical methods for the interpretation of the obtained results

The surface layer has been chosen being experimentally most adequate, although it imposes doubtful theoretical simplifications.

Theoretically, diffusion in plane from »IPS« has been treated as stohastic radially symmetric process.

The experiment gives more or less significant aberrations from this model and mechanisms causing them are not clear.

The theoretical interpretation of experimental results is rather complicated, the vorticity being very significant in the coastal region. In order to investigate qualitatively in which way the vorticity modifies the radially symmetric processes of diffusion a numerical experiment has been conducted.

The experiment will be briefly described. The vorticity effect has been investigated by the following model

$$1)\qquad \frac{\partial S}{\partial x} + \left.\frac{\partial U}{\partial y}\right|_{\substack{x=0\\y=0}} y\, \frac{\partial S}{\partial x} = K \left(\frac{\partial^2 S}{\partial x^2} + \frac{\partial^2 S}{\partial y^2} \right)$$

S is concentration, with $$1a)\qquad \frac{\partial U}{\partial y} = \text{const.} = \left.\frac{\partial U}{\partial y}\right|_{\substack{x=0\\y=0}}$$

vorticity is given, so that $$1b)\qquad U = \left.\frac{\partial U}{\partial y}\right|_{\substack{x=0\\y=0}} y$$

and the whole process was considered in coordinate system moving at translational velocity of the current field, K is Fickyan isotropic diffusion coefficient.
The initial condition is $S(x, y\ t = 0) = \delta(x, y)$, where $\delta(x, y)$ is Dirac delta function.
Calculations were carried out by forward time difference and central space difference:

$$2)\qquad \tau^{-1}(S^{t+\tau}_{i,j} - S^{t}_{i,j}) + (\left.\frac{\partial U}{\partial y}\right|_{\substack{x=0\\y=0}} \lambda j)(2\lambda)^{-1}(S^{t}_{i+1,j} - S^{t}_{i-1,j}) =$$

$$K\lambda^{-2}(S^{t}_{i,j+1} + S^{t}_{i-1,j} + S^{t}_{i,j-1} + S^{t}_{i+1,j} - 4S^{t}_{i,j})$$

τ being time step and λ being spatial step.
The obtained numerical solution would be stable if the following inequalities are satisfied.

$$3)\qquad 1-4K\lambda^{-2} > 0 \quad , \quad K\lambda^{-2} - \left.\frac{\partial U}{\partial y}\right|_{\substack{x=0\\y=0}} \frac{1}{2} j_{max} > 0$$

then for $$3a)\qquad K=1m^2s^{-1} \, , \, \left.\frac{\partial U}{\partial y}\right|_{\substack{x=0\\y=0}} = 10^{-4}s^{-1} \, , \, j_{max} = 100$$

it can be obtained $\lambda < \sqrt{2}\ 10$ m, $\tau < 25$ s
In Fig. 7 the state of the spot alter 1 hour is shown for cases

$$4)\qquad \left.\frac{\partial U}{\partial y}\right|_{\substack{x=0\\y=0}} = 0 \; , \; 10^{-4}s^{-1}$$

From the Fig. 7 it can be seen that for $$4a)\qquad \left.\frac{\partial U}{\partial y}\right| \neq 0$$

-the diffusion process is not radially symmetric, (the isoconcentration lines have elliptical form).
-the intensity of diffusion process does not change basically and the surface included by isoconcentration line being approximetly equal in both cases.

From the numerical development of the process it can be also concluded that the spot apparently rotates. The characteristic alongation of the spot, occuring very frequently at experiments, can also be theoretically dealt with presuming that diffusion is not isotropic, which leads to the similar results as above in numerical experiment. In interpreting experimental results, however, we dealt, only with a developed radially summetric diffusion models. Only in the case of Fickyan process diffusion was not examined as isotropical one. It was separately examined along streamlines, and separately normal to them in cases where results of experiment obviously require it. This is, up to some extent, in agreement with the results of the numerical experiment, because although great shear is presumed (10^{-4} sec^{-1}) the deformation of the spot is not as great as it could be expected indicating that the spot deformation could be probably explained as the consequence of anisotropic diffusion. It remains as an open question whether discontinuities are present in the current field in which shear would be even greater and sufficient to cause adequatly great deformations of the dye spot.

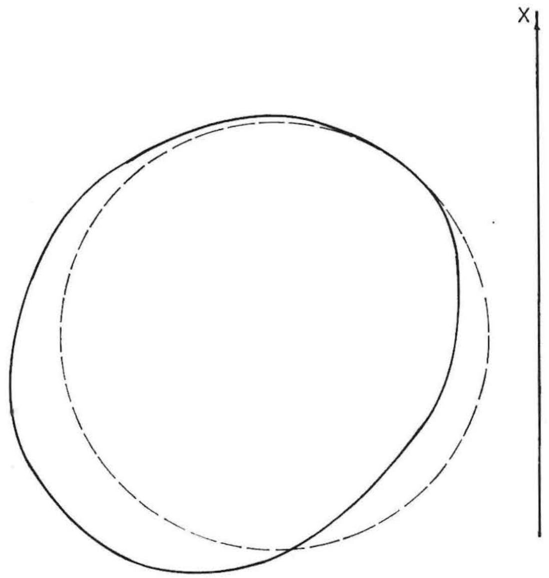

Fig. 7 — Results of the numerical experiment with the Fickyan istropic diffusion from IPS after one hour in the current field having non zero corticity (———) and zero vorticity (— — —)

Experiments with IPS have been carried out as follows:

On the chosen place 100 litres of Rhodamin B dye was thrown into the sea and the time registered. After half an hour we started to register the distribution of the dye concentration in the spot which was visible since the minimum level of detection was slightly higher than the minimum concentration which can be visually observed. The dye distribution in the spot was followed with a flourometer and was continually registered. The vessel moved through the dye at speed of about 2 m/sec, which was measured in order to determine the relationship between the length on the tape and the length in the spot. The experiment lasted until the concentration dropped the level of detection.

The results were processed by introducing the experimental results into the theoretical radially simetric diffusion models.

Results of such experiments aim to determine in which way the specific properties of localities in various dynamic situations are influencing the intensity of diffusion processes. Together with other results of experimental work these results could be basis for setting adequate numerical model by which the problem of transport and spreading of polluting substance is comprised in its complexity.

In the vicinity of the Vir island (as part of investigations carried out in order to predict the thermal pollution of the future nuclear power plant near Zadar) several IPS diffusion experiments have been carried out and some specific results have been obtained. In this case transport processes have been investigated as diffusion processes, being related to the component of the current field in the part of the spectrum exceeding 1 cph.

The Fig. 1 shows the region of the experiment. In Table 7 the most general outline of results obtained by experiment are given.

Table 7. Diffusion coefficient (order of magnitude) obtained by experiment in summer 1976 (Vir region)

Station	K m^2/sec alongshore	K m^2/sec normally to the shore
A	0.1	0.01
B	0.1	0.1
C	0.1	0.01

The result at the station A, situated near the coast, was to be expected. Diffusion along streamlines parallel with the coast is significant, but it is very low perpendicularly to the coast.

The result obtained at the point C is rather unusual and is probably caused by specific orographic characteristics of the locality influencing the current field geometry.

The dye loss from surface layer due to vertical displacement occurs as well and experimentally not sufficiently studied here. For that purpose we give some results of the experiment carried out in the summer under good weather conditions.

The maximum concentration at 10.00 h immediately after throwing the dye was 82 ppb, at 10.30 h in the maximum the dye was distributed along the vertical as it can be seen on the Table 8.

Table 8. Verticale distribution of dye concentration (Summer 1976)

Depth in cm	0	20	40
Concentration in ppb	15	37	18

Due to described observations, confirming the above assumptions, it has also been necessary, during the experiment of horizontal diffusion, to develop a system of controlling the mass loss in the observed layer.

SUMMARY

The results of the dynamic investigations of the coastal area are compared with the known characteristics of the open sea.

While in the open Adriatic three distinct layers could be distinguished, in the coastal area only two layers are usually present. During the warm period the two layers are separated by the thermocline and the transitory layer has some specific characteristics. In the surface layer the NW, W and N directions prevail. The first direction represents the current entering the Adriatic and going along its eastern coast. Due to configuration of the coastline the same meaning can be given, at least partly, to the N and W directions. But the W direction seems to have another meaning being connected with upwelling and offshore current, all influenced by (NE wind).

In the bottom layer the directions of the second quadrant (NE, E and SE) prevail. That is the compensatory current with respect to the surface current. The shoreward current (NE and E) brings the water from deeper layers into the coastal area and thus the circulation between the coastal area and open sea is established.

In the coastal area the dispersion of direction is larger, while the seasonal oscillations in the current field are not so pronounced there as on the open sea. In all the seasons the NW current prevails. In the coastal area, however, the oscillations of several days period are more pronounced, and the energy maximum on these frequencies is greater than the maximum on the frequency of tidal oscillations.

On the open sea between Ancona and Zadar the tidal oscillations are linear, while in the coastal area they perform ellipses. The low-frequency oscillations, however, show completely opposite characteristics. The absence of the 24 hour oscillation in the region of Vir can be explained by its appearing as the oscillation of lower frequency, due to specific conditions of configuration and friction.

The current speeds in the surface layer of the coastal area are roughly 50% lower than those on the open sea.

The diffusion was experimentally observed on the instantaneous point source in the surface layer in the different dynamic situations. Some problems encountered are discussed.

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NEKE DINAMIČKE KARAKTERISTIKE ISTOČNOJADRANSKOG OBALNOG PODRUČJA

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KRATAK SADRŽAJ

Posljednjih godina se je Laboratorij za fiziku mora Oceanografskog instituta orijentirao na obalnu oceanografiju zbog niza praktičnih potreba. U okviru raznih programa izvršena su u suradnji s Hidrografskim institutom JRM na nizu obalnih postaja u području Dubrovnika, Splita, Šibenika, Zadra, te sjeverno i srednjedalmatinskog arhipelaga brojna mjerenja oceanografskih karakteristika, strujanja (cca 100000 podataka) i difuzije. Taj je materijal obrađen standardnim metodama, a za mjesečne nizove strujomjernih podataka izvršena je spektralna analiza prema Gonelli (1972) i Mooers-u (1973). Difuzija je tretirana teoretski i razvojem eksperimentalnih tehnika difuzije Rhodamina B i numeričkog tretiranja procesa. Taj veliki materijal je omogućio da se uoče neke dinamičke karakteristike dalmatinske obalne regije, u usporedbi s otvorenim morem.

Dok se u otvorenom Jadranu pojavljuju tri jasno razgraničena sloja, u obalnom području su obično prisutna samo dva sloja u smislu da je strujanje u jednom sloju barem djelomično kompenzacijsko strujanju u drugom sloju. Površinski sloj je od pridnenog sloja u toplom razdoblju odijeljen termoklinom. Na tom se prelaznom nivou primjećuje najveći nivo buke u odnosu na plimne oscilacije, a oscilacije manjih perioda su u tom sloju često prigušene. Energija oscilacija većih perioda od nekoliko dana je također smanjena ukazujući na gubitke.

U površinskom sloju prevladava NW, W i N strujanje, tj. smjerovi četvrtog kvadranta. Prvi smjer predstavlja ulaznu struju uz istočnu obalu Jadrana, a zbog konfiguracije obale može se isto značenje donekle pridati i smjerovima W i N. Međutim čini se da smjer W ima i drugo značenje. Na većem dijelu obale on predstavlja strujanje u smjeru od obale. Obzirom da je češći u hladnom razdoblju, povezan je s burom, tj. NE vjetrom, koji tjera vodu površinskog sloja prema otvorenom moru. U pridnenom sloju prevladavaju smjerovi drugog kvadranta (NE, E i SE), a to je kompenzacijsko strujanje prema površinskom sloju. Osobito je zanimljivo strujanje prema obali (NE i E) jer ono donosi vodu dubljih slojeva u obalno područje, pa je tako uspostavljena cirkulacija između obalnog područja i otvorenog mora.

Otvoreni Jadran je karakteriziran vrlo izraženim sezonskim oscilacijama u strujnom polju uslovljenim razlikama u polju masa. U obalnom području je općenito veća raspršenost smjerova, i sezonske promjene su manje izražene. Tu u svim sezonama prevladava NW strujanje. Međutim, pojavljuju se istaknutije nego na otvorenom moru oscilacije perioda od nekoliko dana. Spektralna analiza mjesečnih nizova je na otvorenom moru pokazala porast energije oscilacija prema frekvenciji nula, što ukazuje da postoje oscilacije dužih perioda (sezonske) veoma visoke energije. Na obalnoj postaji maksimum energije se pojavljuje na frekvencijama od 0.01 cph ili 0,005 cph (oscilacije od 10 dana) a znatno je veći od maksimuma na frekvenciji plimnih oscilacija. Na postaji otvorenog mora maksimum energije na frekvencije od oko 0.01 cph je veličine maksimuma energije plimnog vala ili manji.

Plimne struje imaju brzine od cca 3—10 cm/sec. Oscilacije vektora struje se odvijaju po elipsama što pokazuje da se javljaju longitudinalne i transverzalne oscilacije, dok su na otvorenom moru između Ancone i Zadra plimne oscilacije linearne i paralelne s obalom. Niskofrekventne oscilacije pokazuju suprotne karakteristike. One se na otvorenom moru odvijaju po elipsama malog ekscentriciteta, dok su u priobalnom području gotovo linearne i odvijaju se po pravcima koji su uglavnom paralelni s obalnom linijom. Odsustvo 24-satne oscilacije u Virskom moru je povezano s mogućnosti da je ta oscilacija zbog posebnih uslova konfiguracije i trenja prešla u oscilaciju niže frekvencije.

Brzine struja su u obalnom području nešto manje nego na otvorenom moru. Srednja brzina u otvorenom srednjem Jadranu iznosi 20 cm/sek, a bliže zapadnoj obali je nešto veća nego bliže istočnoj obali, a veća je i u južnom Jadranu. U obalnom području je u površinskom sloju srednja brzina gotovo u pola sporija.

Vidjeli smo već da je u obalnom području velika raspršenost smjerova, odnosno vrlo izražena vrložnost strujnog polja. Da bi se dobio uvid u kom smislu vrložnost strujnog polja modificira kružno simetrične procese difuzije izvršen je numerički eksperiment. Djelovanje vrtložnosti u strujnom polju je razmatrano na modelu u kojem se proces kreće translacionom brzinom strujnog polja uzevši izotropan koeficijent Fickovog procesa difuzije. Stanje mrlje iza jednog sata pokazuje da proces difuzije nije kružno simetričan, već su linije izokoncentracije eliptičnog oblika, da mrlja rotira, te da se intenzitet procesa difuzije ne mijenja, jer je površina obuhvaćena linijom izokoncentracija ista. Eksperimentalno je proces difuzije razmatran na točkastom izvoru u površinskom sloju za različite dinamičke situacije.