Some aspects of the response of the coastal region in South Adriatic to the atmospheric forcing

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Introduction

During the summer 1979 intensive current measurements were conducted in the region off Dubrovnik as part of the studies on coastal transport of pollutants.

Three moorings were deployed on the profile normal to the local orientation of isobaths (Fig. 1). The mooring A was 1.5 Nm from the coast, the mooring C 4.5 Nm and the mooring B was in the middle of the two. On each mooring two "Aanderaa" current meters were attached; one at 10 and the other at 70 m depth. The interval of measurements was from August 16 through September 26 1979. During this period vertical STD profiles were done six times at the same stations and additionally at the station O. Sea level data, atmospheric pressure, wind and sea surface temperature (SST) data were also available from the coastal station in Dubrovnik. As the moorings were deployed very close to the coast during the summer, only baroclinic part of the current field was studied. Due to the malfunction and loses of instruments, only three current vector

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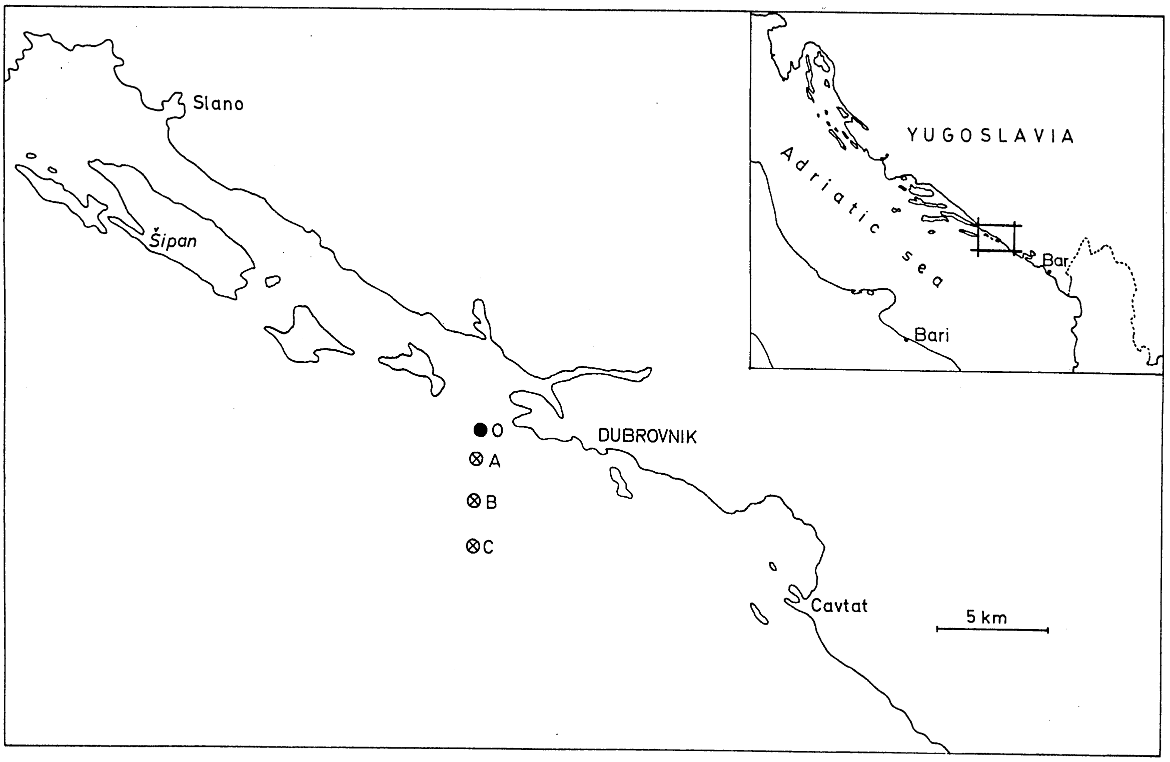

Fig. 1. — Locations of current meters and STD stations.

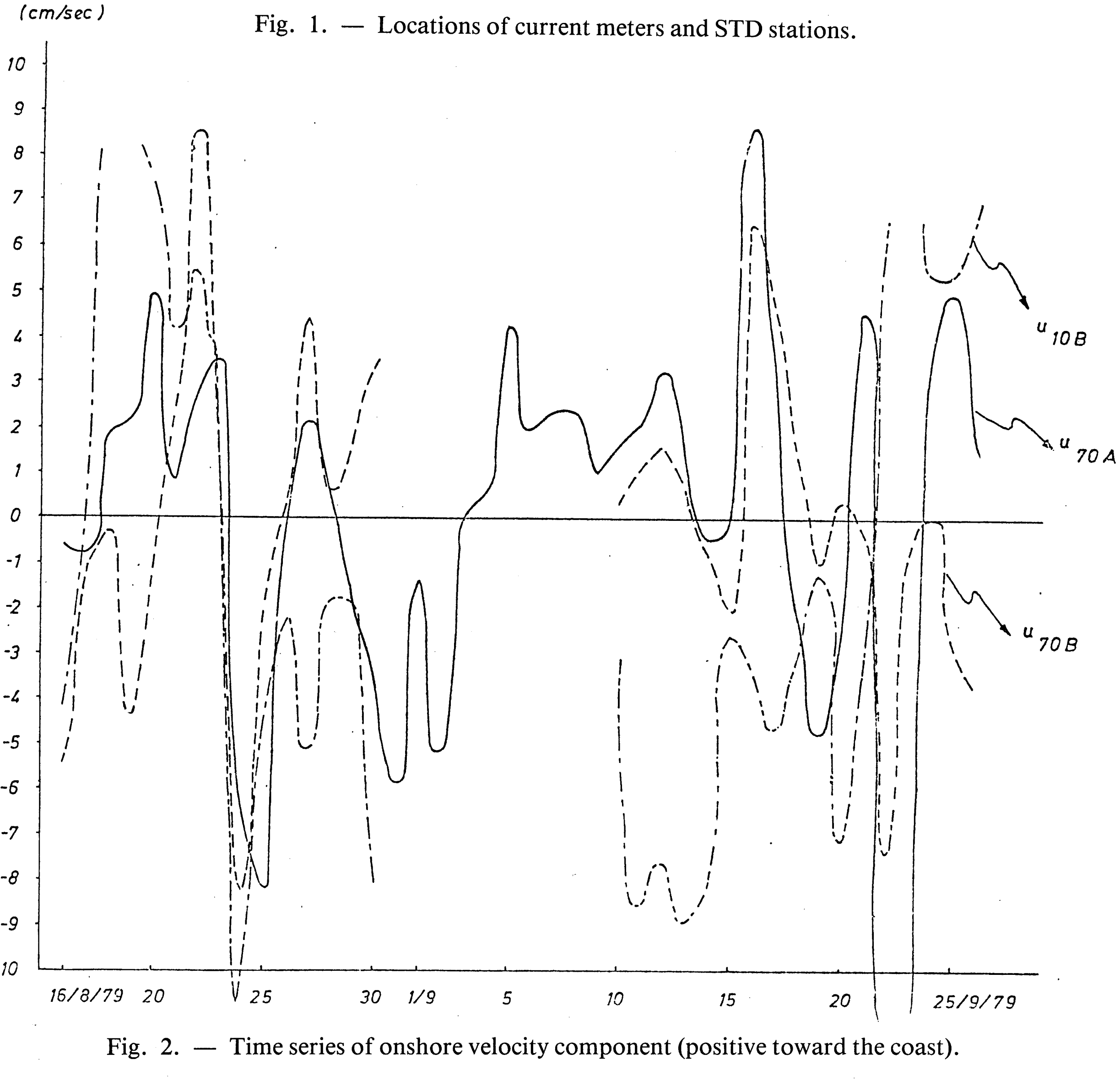

Fig. 2. — Time series of onshore velocity component (positive toward the coast).

time series were available and only limited conclusions about the current oscillations could be drawn analysing the data.

The objective of this paper is to describe the characteristics of current field and to define the way the coastal region responds to the atmospheric forcing.

Data analysis and discussion

Period of measurements was characterized by a relatively moderate winds and two events with a strong SE wind; one at about August 20 and the other at about September 23.

The analysis was done in the time domain, the alongshore and onshore velocity components being analysed separately. Only time series of the 24-hour mean current vectors were analysed as the energy contained in oscillations with a period longer than a day is several times larger than the energy of oscillations with a period less than a day.

This was shown comparing the variance of hourly mean vectors for 24 hours and the variance of daily mean vectors.

The orientation of the coast was taken to be parallel with the local orientation of isobaths (E-W direction).

On Figs. 2 and 3, time series of onshore and alongshore velocity components respectively are displayed (onshore velocity component positive toward the coast and alongshore one positive toward E).

During the first several days of the record, both alongshore and onshore velocity components were generally inphase at both depths while in the second part of the record both velocity components at

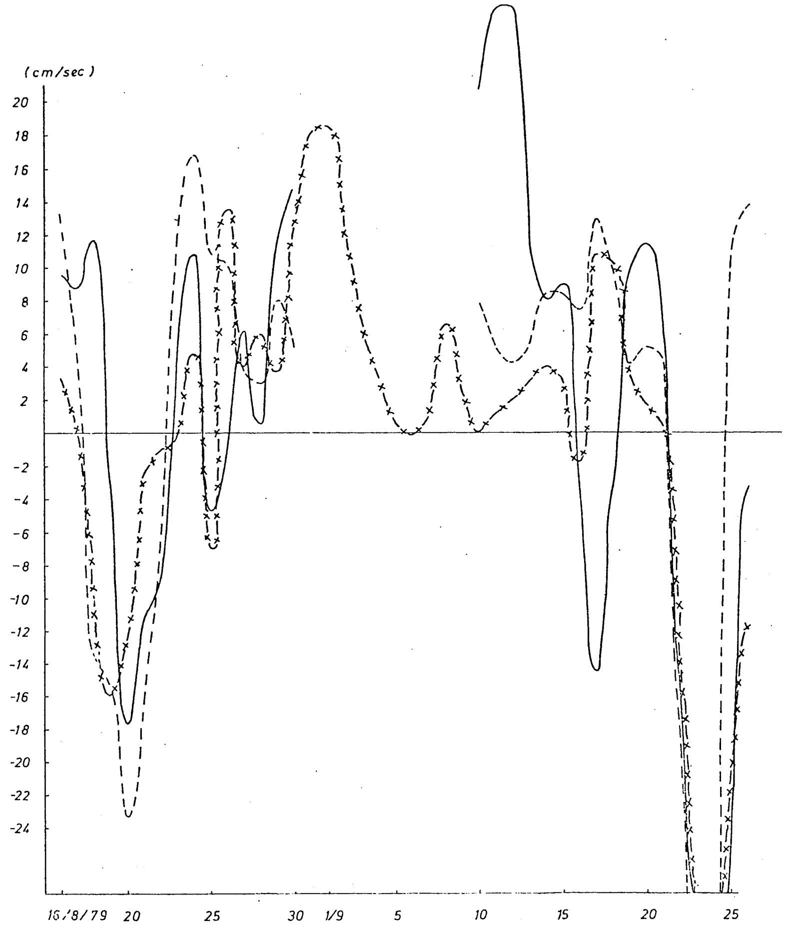

Fig. 3. — Time series of the alongshore velocity component (—— mooring B 10 m ; - - - mooring B 70 m ; - x - x - mooring A 70 m).

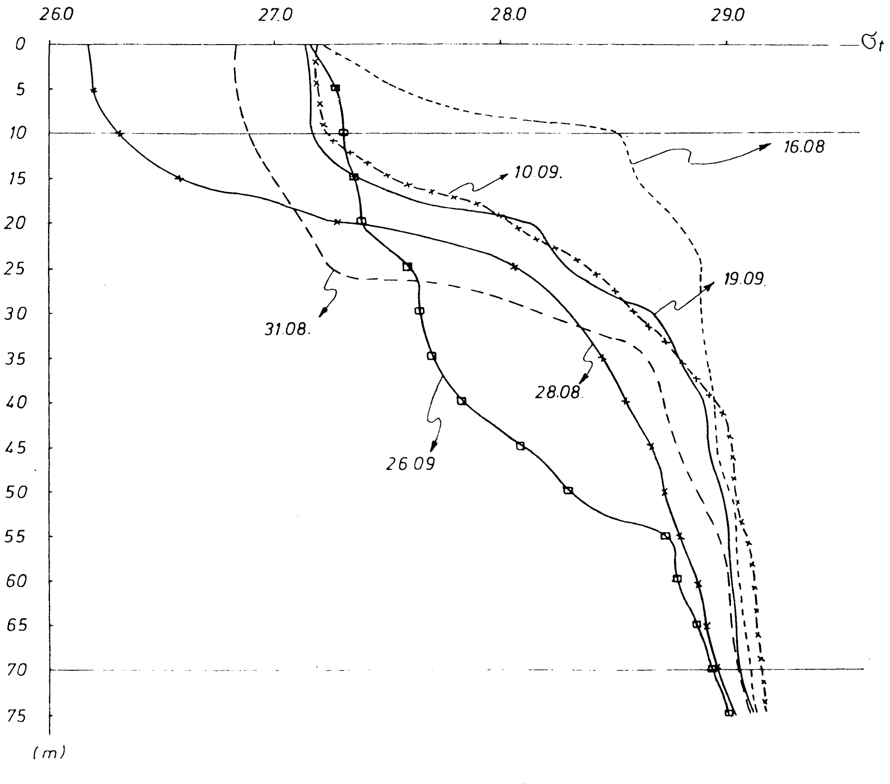

Fig. 4. — Vertical distribution of σ for the station O.

the depth of 10 and 70 m were in antiphase. The exception was only the alongshore velocity component during the strong wind event at about September 23 when at both depths appeared the strong windward current. During this wind event at the depth of 10 m there was a strong shoreward current while at the depth of 70 m there was a compensating current in an offshore direction. As the wind was generally parallel to the coast, the onshore current at the depth of 10 m could be attributed partly to the Ekman transport.

The possible explanation of the fact that both alongshore and onshore velocity components were inphase at both 10 and 70 m only in the first part of the record is in the vertical density distribution. At the Figure 4, vertical density distribution is presented for the station 0 for all the situations vertical STD profiles were done. It could be seen that only in Aug. 16 the thermocline was above 10 m while in all the other situations it was below. So only in the first couple of days both current meters were recording the current in the same layer i.e. below the thermocline while in the rest of the period of measurements one current meter was above and the other below it what could explain the fact that both velocity components were in antiphase, thermocline being the layer of the current reversal. More detailed vertical current structure could not be obtained as only two current meters were attached on each mooring. The fact that the thermocline is the layer of the current reversal suggests that the vertical shear in alongshore component is dictated by the cross shelf mass distribution. If the current oscillations were mostly baroclinic, good correlation between the

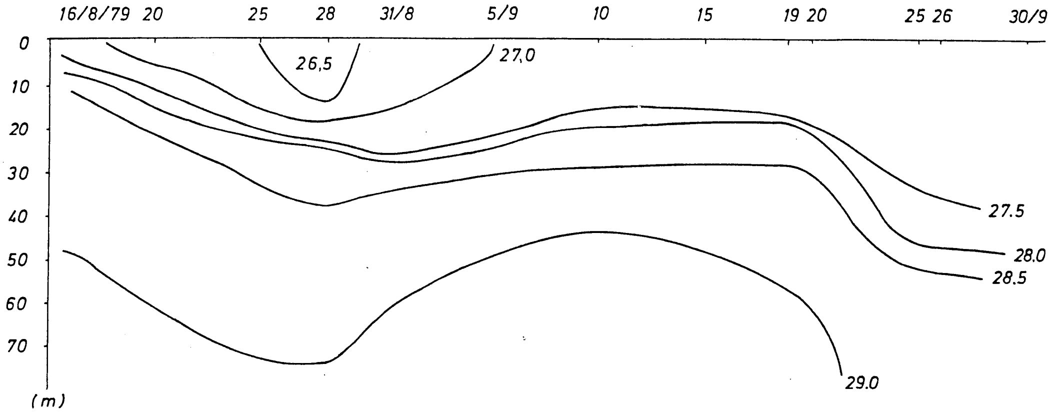

Fig. 5. — Time - depth diagram of σ for the station O.

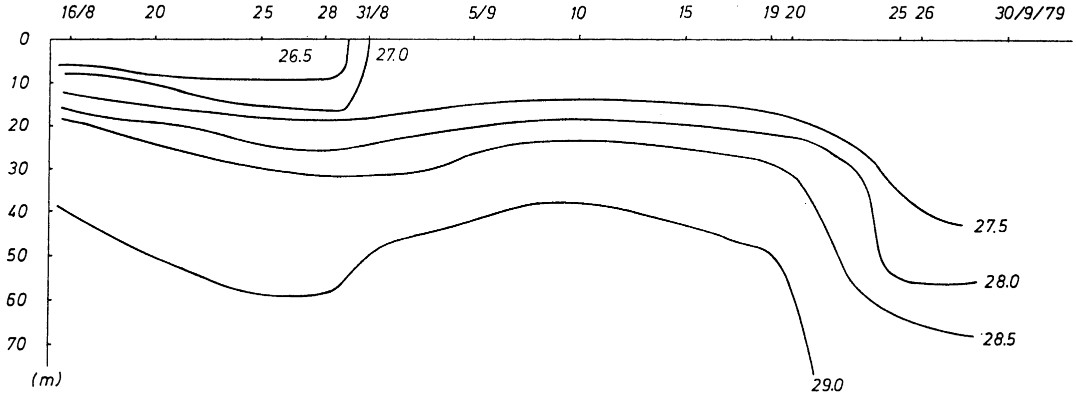

Fig. 6. — Time-depth diagram of σ for the station C.

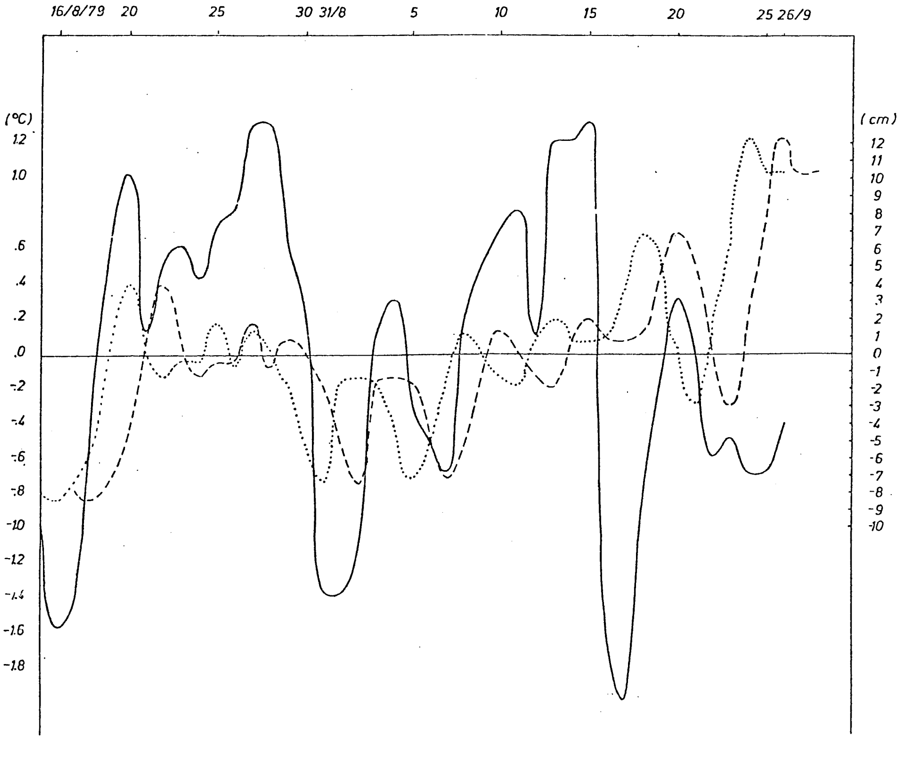

Fig. 7. — Time series of the SST (solid line), adjusted sea level (dotted line) and adjusted sea level with the phase lag of one day (dashed line).

SST and alongshore velocity component should exist, this being true only for the situations where the strong vertical mixing doesn't take place i.e. for the situations without strong local wind. To show this, we can start from the thermal wind relation for the alongshore velocity component in the right handed coordinate system with x-axis positive in the offshore direction:

$$f\frac{\partial v}{\partial z} = \frac{g\alpha}{\rho_0}\frac{\partial T}{\partial x} , \qquad 1$$

T being the temperature and α change of density per one degree centigrade, assuming also that the temperature is the only cause of density gradient.

If we integrate this equation from -z to $-z_0$, z being the depth of current meter and z_0 the level of no motion in baroclinic current, we obtain the following relation:

$$-f v_{-z} = g\frac{\alpha}{\rho_0}\left[\frac{\partial \bar{\bar{T}}}{\partial x}(z-z_0) - (\bar{\bar{T}} - T_{z_0})\frac{\partial z_0}{\partial x}\right] . \qquad 2$$

If we neglect the second term on the right hand side of the eqn. 2 and write it in finite difference form, it follows:

$$-f v_{-z} \doteq g\frac{\alpha}{\rho_0}\left[\frac{\bar{\bar{T}}_{os} - \bar{\bar{T}}_s}{\Delta x}(z-z_0)\right] , \qquad 3$$

$\bar{\bar{T}}_{os}$ and $\bar{\bar{T}}_s$ being mean temperature of the water column between z and z_0, offshore and at the shoreline respectively. Assuming that the distance Δx is just the internal radius of deformation, we can assume that $\bar{\bar{T}}_{os}$ is constant with time so by taking the time derivative of the eqn. 3, it follows:

$$f\frac{\partial v_{-z}}{\partial t} = \frac{g\alpha}{\rho_0 \Delta x}\left[\frac{\partial \bar{\bar{T}}_s}{\partial t}(z-z_0) - (\bar{\bar{T}}_{os} - \bar{\bar{T}}_s)\frac{\partial z_0}{\partial t}\right] . \qquad 4$$

Neglecting again the second term on the right hand side, what is relatively realistic assumption, we finally obtain:

$$f\frac{\partial v_{-z}}{\partial t} = \frac{g\alpha}{\rho_0 \Delta x}\frac{\partial \bar{\bar{T}}_s}{\partial t}(z-z_0) . \qquad 5$$

This relation gives the possibility to calculate the characteristic offshore length scale of the baroclinic part of current field, knowing the velocity at one level and mean temperature for water column between z_0 and z. We can also assume that the difference between time derivative of $\bar{T}_S$ and SST is constant:

$$\frac{\partial}{\partial t}\left(SST - \bar{T}_S\right) = K \qquad 6$$

so the relation 5 could be written in the form:

$$f\frac{\partial v_z}{\partial t} = \frac{g\alpha}{\rho_0 \Delta x}\frac{\partial (SST)}{\partial t}(z-z_0) - \frac{g\alpha K}{\rho_0 \Delta x}(z-z_0) \qquad 7$$

This way it was shown that, under all these assumptions, changes of the alongshore velocity could be proportional to the SST time changes. From the relation 7, it is also possible to estimate the horizontal offshore length scale knowing now the SST instead of $\bar{T}_S$ and v_z time series.

The relation 7 was used to calculate the horizontal offshore lengt scale in this experiment as we had time series of the mean daily SST for the period of current measurements. First the lagged correlation coefficient between daily mean vector at 70 m at station A and SST was calculated. Only interval without strong wind was taken into account and the correlation coefficient was maximum (r = .66 significant for 99% level) for the phase lag of 4 days, SST leading the v_{70}. The phase lag is probably due to the second term on the right hand side of the eqn. 7. Next step was to calculate the regression coefficient between SST and and from that, using the eqn. 7, the estimate of horizontal length scale was obtained as being 14.3 km, what is a realistic number. The usual way of calculating the internal radius of deformation is not very useful here due to the complicated shape of function $\rho = \rho(z)$ as shown in Fig. 4. This length scale estimate is more than two times larger than the length scale obtained in the same way for the basin of Virsko more (Gačić, 1980) what is to be wxpected as Virsko more is much shallower (the depth ratio between the two regions is about 3).

The decrease in amplitude of isotherm oscillations in an offshore direction could be seen comparing Figs. 5 and 6 showing the isotherm depth as a function of time for the stations O and C respectively. On the Figs. 5 and 6 also it could be seen the influence of the strong vertical mixing caused by a strong wind event at the end of the record.

At the Fig. 7, the SST and adjusted sea level were presented and it could be seen that almost perfect correlation exists between the two parameters with a phase lag of 1 day, suggesting that the adjusted sea level changes were of the baroclinic origin. The same was shown calculating the correlation coefficient between the vertical shear and adjusted sea level which is of magnitude of .52 being significant for 90% level.

In order to show that the current oscillations are polarized parallel to the orientation of isobaths, the coordinate system was rotated and each 20 degrees the variance of both components was calculated. The calculations were done for the whole interval and for the subinterval from Aug. 31 through Sept. 15 as an subinterval practically without wind. For the coordinate system with y-axis in the E-W direction and x-axis in the N-S direction, the variance of v-component for the whole interval is maximum and the variance of u-component is minimum, while for the subinterval from Aug. 31 through Sept. 15 the variance of v-component is maximum and of u-component minimum in coordinate system with y-axis positive toward 110° and x-axis toward 200°. In this coordinate system the y-axis is practically parallel to the wind direction and in it appears the largest difference between the variance of u-component for the whole interval and for the subinterval showing that only the wind could force the water to move upslope probaly through Ekman drift. It is evident that the orientation of y-axis of both coordinate systems is very close to the general orientation of isobaths.

The variance was also calculated for all the available oceanographic and meteorologic parameters and comparison was made between the whole interval and the subinterval from Aug. 31 through Sept. 15.

Table 1: The variance of different meteorologic and oceanographic parameters.

	250°		270°		290°		300°		sea Lev Dbk	sea Lev Far	adj sea Lev	atm press Dbk	SST	atm temp	[illegible]	[illegible]
	u	v	u	v	u	v	u	v								
Whole interval	36.8	122.3	22.0	167.4	33.4	122.2	65.8	82.3	54.8	54.3	21.5	22.1	.81	2.5	1.1	7.5
31/8-1/9	20.3	26.6	7.5	34.5	2.3	41.9	6.3	38.0	4.7	6.8	8.0	5.4	.80	.6	.4	3.2

On the table 1, the results of such calculations are presented. The variance of the unadjusted sea level for the whole interval is about 2.5 times larger than the variance of the atmospheric pressure, probably due to the influence of the wind. Even for the subinterval, the variance of the sea level is slightly higher than the variance of the atmospheric pressure. Comparing the two intervals the variance of both parameters for the subinterval is reduced with respect to the whole interval of measurements. The variance of sea level is reduced by the facor 8.2 and that of sea level by the factor 4. By comparison of the adjusted and the unadjusted sea level, it could be seen that for the whole interval the variance of the unadjusted sea level is 2.5 times larger than the variance of the adjusted sea level as a consequence of the wind influence. On the other hand, for the interval without wind, the variance of the adjusted sea level is 1.2 times larger than that of the unadjusted sea level, probably due to some wave-like motion in the shelf region. In order to show that the alongshore pressure gradient is much smaller than the onshore one, the comparison was made between the variance of sea level differences between Dubrovnik and Bar (along the coast) and Dubrovnik and Bari (across the Adriatic). The variance of the sea level differences across the Adriatic is about 7 times larger than the variance of the alongshore sea level differences.

It`s interesting that the variance of the air temperature is reduced by the factor 4 comparing the two intervals i.e. for the same factor as the atmospheric pressure. On the other hand the variance of the SST stays the same for both intervals showing that the air temperature is of a minor influence on it or, in another words, the SST changes are mostly the consequence of the isothermal slope oscillations and partly, the horizontal advection. This fact explai also the good correlation between the SST and v_{70} .

Conclusions

The results of current measurements in the South Adriatic shelf show the strong influence of the local wind causing the windward current from top to bottom. In the same time, the strong shoreward current appears at the surface with a compensating current in deeper layers. The onshore current reversal appears to happen in the thermocline. During the relatively calm weather, the current oscillations are of smaller amplitude, both onshore and alongshore current components in the surface layer being in antiphase with respect to the current in deeper layers. The vertical shear in the alongshore velocity component is the consequence of the cross shelf density gradient. The horizontal length scale of the baroclinic current oscillations is about 14 km as obtained from the relation between the SST and alongshore current at 70 m. It was shown also that such current oscillations are generally aligned with local isobaths and only in the situations with the strong local wind there is appreciable u slope current component.

References:

Gačić, M., 1980: Some characteristics of the response of the Adriatic Sea coastal region to the atmospheric forcing. Acta Adriatica, 22, in press.