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Divergence in the current field in the North Adriatic

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In an analysis of temperature, salinity and currents data, a divergence in the current field along with corresponding upwelling has been observed in the central part of the North Adriatic. This phenomenon appears in the heating period.

Key words: *divergence, North Adriatic*

INTRODUCTION

The North Adriatic's almost land-locked location plays a dominant role in its physical characteristics. This shallow (< 50 m) region of the Adriatic is the more heavily influenced by continental weather. In winter 1982, a frontal zone with a horizontal temperature gradient of about 0.25 °C km^{-1}, few kilometres wide, south of the Istra peninsula has been found. It appears that the position of this frontal zone depends on the strength of the dominant regional bora wind (from the northeast). The front separates coastal waters influenced by the major fresh water source, the Po River, from the saltier water of the southern origin. It has been also speculated that this frontal zone during winter period is the zone of convergence with downwelling (ZORE-ARMANDA *et al.*, 1983) and under some conditions a zone of formation of the dense North Adriatic Deep Water (NAdDW) (ZORE-ARMANDA *et al.*, 1999). However in the stratification period, with low frequency of bora wind, entirely different dynamic conditions are present.

In analysing different oceanographic data collected during field campaigns for the gas fields (IKA and IVANA) investigation close to the frontal zone of the North Adriatic 1978-1984, indications about the existence of divergence in the current field appeared, in the middle North Adriatic, accompanied with upwelling.

For this reason we have analysed all the available historical temperature and salinity data since 1911, as well as some SST satellite data from the period 1981-1991. The phenomenon was observed in the spring-summer season only, under stratified thermohaline conditions, from both, satellite and *in-situ* data. In this paper, evidences in favour of this hypothesis are presented.

MATERIALS

The *in-situ* data

All of the data used in this study from IVANA and IKA gas fields (Fig. 1.) databases are located at the Institute of Oceanography and Fisheries, Split and State Hydrographic Institute, Split as a part of the *MEDAS databank (DADIĆ, 1996). Hydrographic data collected in the MEDALPEX experiment from 1982

* MEDAS -Mediterranean Environmental Database of the Adriatic Sea

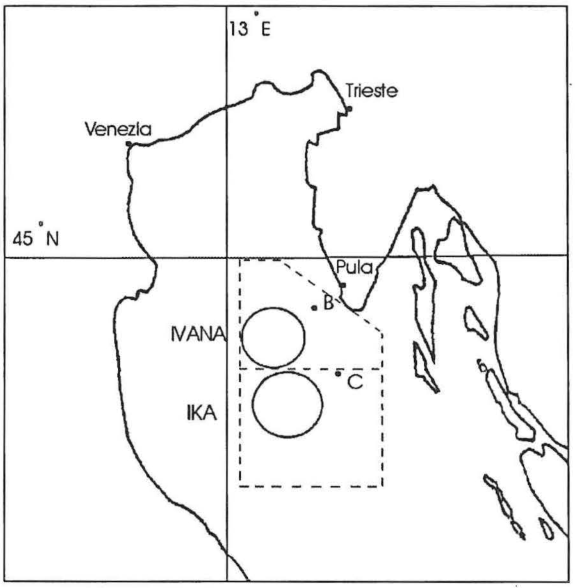

Fig. 1. Location of the gas fields IVANA and IKA; dashed lines mark the areas where from the oceanographic data from the MEDAS databank were used (DADIĆ, 1996); B and C are stations (after BRANA and KRAJCAR, 1995)

are also included. The periods of measurements and more detailed information about this data set can be found in ZORE-ARMANDA ed., 1996.

The historical hydrographical database used in this study included data beginning with the first NAJADE-CICLOPE expedition (1911-1914) and extends through 1986; the number of temperature and salinity measurements, by months, within the mentioned period, is given in the Fig. 2.

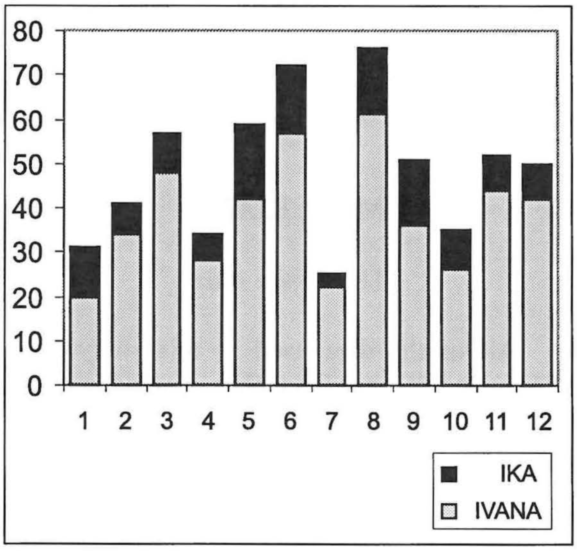

Fig. 2. Number of oceanographic data casts by months for the gas fields IVANA and IKA through 1911-1986

Sea temperatures collected by reversing thermometer data were analysed separately from bathythermograph (BT) data. The reversing thermometers sampled the water column with 0.02°C accuracy at depths of 0, 5, 10, 20, 30, 50 m etc. BT accuracy was 0.5°C, and samplings were continuous from surface to bottom, with 0.5 m accuracy. The most numerous temperature data were the BT data, which were mainly (90%) collected from the platforms.

Salinity was measured prior to 1979 using the classical MOHR-KNUDSEN titration method. From 1979 on, salinity was derived using inductive laboratory salinometers.

Both temperature and salinity data have shown the same phenomenon: upwelling of the water in the area, preferably in June and July, and eventually in August.

The research platforms current measurements used mechanical self-recording current meters ALEKSEEV, type BPV-2r, until 1984. These recorded current direction and speed at 15-minute intervals. From September 1984 to 1986, autonomous AANDERAA instruments were used. These recorded current direction and speed at 10-minute intervals. Before introducing the new current meters in 1982, both ALEKSEEV and AANDERAA instruments were hung in parallel for intercalibration. Later analysis showed the data were well correlated (VUČAK and SMIRČIĆ, 1983). The current meters were placed at three layers: surface (mean depth 5 m), intermediary (mean depth for IVANA 20 m, for IKA 30 m) and bottom (mean depth for IVANA 40 m, for IKA 50 m). The periods of measurements in particular years differ, so it is sometimes difficult to compare data between years. The total number of data, for all the layers in the two fields, is presented in the Table 1. In addition to the current meter data series from 1978-1986, the residual current measurements from 1989-1992, after BRANA and KRAJCAR (1995), were also included in analysis.

The satellite data

The satellite data are from the NOAA Advanced High Resolution Radiometer

Table. 1. Total number of current meter data records for the field IVANA for the measurement period, from 24 May 1978 through 24 March 1986 and for the field "IKA" for the period from 10 August 1979 through 13 May 1986

LAYER	Measurements period	TOTAL NUMBER OF DATA	
		IVANA φ:44° 35'-44° 47' λ:13° 07'-13°25'	IKA φ:44° 17'-44°32' λ:13° 13'-13°38'
SURFACE (5m)	Whole period	73248	102677
	Winter	27132	17425
	Spring	18941	19677
	Summer	11396	32458
	Autumn	15779	33177
INTERMEDIATE (20m)	Whole period	47145	84927
	Winter	17383	16685
	Spring	13882	12475
	Summer	7500	31346
	Autumn	8380	24421
BOTTOM (40m)	Whole period	53672	96966
	Winter	25234	19890
	Spring	8395	17416
	Summer	7445	26242
	Autumn	12598	33418

(AVHRR) (1981-1991) comprised both high and low-resolution data. Sea surface temperatures were derived using a two-channel atmospheric correction by Mc CLAIN *et al.* (1985) and their weekly mean and standard deviation produced.

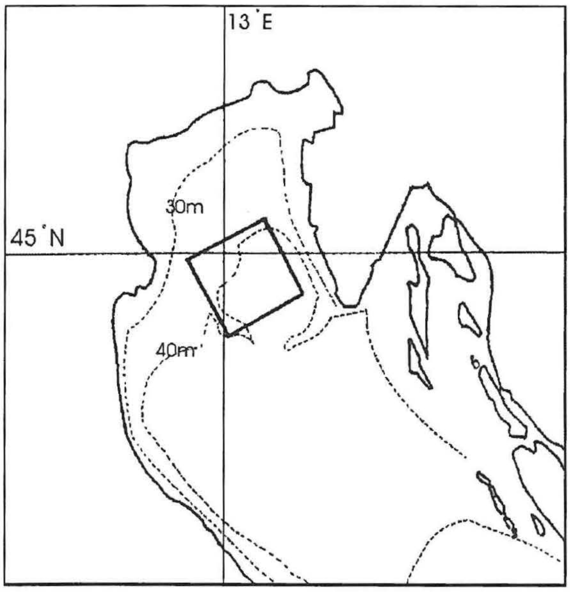

Fig. 3. Geographic location of the area (marked) in the North Adriatic, for the AVHRR satellite data sets

The main emphasis in the analyses will be low resolutions (18 - 20 km) data compiled into weekly (AVHRR) data sets that encompass a 60 by 60 km square in the centre of the study area (Fig.3). The imagery for the period of the double spikes was examined and the temperatures were not due to solar afternoon hot spots. We checked all of the data to ensure that such phenomena were not erroneously included in the analyses.

DISCUSSION

When the location of the coastal front was studied (ZORE-ARMANDA, 1983) in the North Adriatic, the influence of the Po River to the entire area was observed to occasionally reached the coast of Istra. There, the front appeared to separate the waters of the Istra coastal zone from that of the open North Adriatic. The goal of the MEDALPEX project was, among others, to determine the character and location of this frontal zone. It was performed at the polygon of stations shown in the Fig. 4. in March and May 1982. During both cruises the location of frontal zone was clearly indicated (ZORE-ARMANDA *et al.*, 1983). The frontal zone spreads few kilometres around indicated locations. It was evident that the frontal zone existed between the gas fields IKA and IVANA, or across the IKA field. It was later found that the location of the frontal zone in the cold period of year was under the strong influence of the bora wind (ZORE-ARMANDA and GAČIĆ, 1987). The impact of bora wind was understood as a double curl circulation (the northernmost cyclonic gyre and smaller southern anticyclonic gyre), which forced the current toward the frontal zone (Fig. 5 A). The southern branch of anticyclonic gyre pushes the water southward near the frontal zone area (convergence). The data showed different dynamical conditions in the frontal zone in the warm period of the year. Due to the lower frequency (or complete absence) of the bora wind, the influence of the southern water, hugging northward

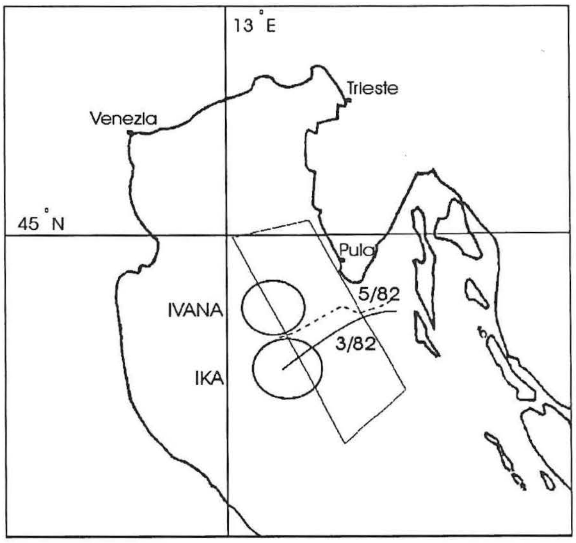

Fig. 4. Polygon delineates the MEDALPEX stations, the circles indicate the gas field positions, and lines show the frontal zone locations from March and May MEDALPEX cruises, which separated the northernmost Adriatic from the southern open waters

along the eastern coast, due to the general cyclonic circulation was dominant (Fig 5. B). The absence of anticyclonic gyre is characterised with upwelling in this shallow region.

Annual mean temperatures in the IVANA field (Fig. 6) show slow increase in temperature in June and a rather abrupt decrease of temperature in August. Annual temperature course,

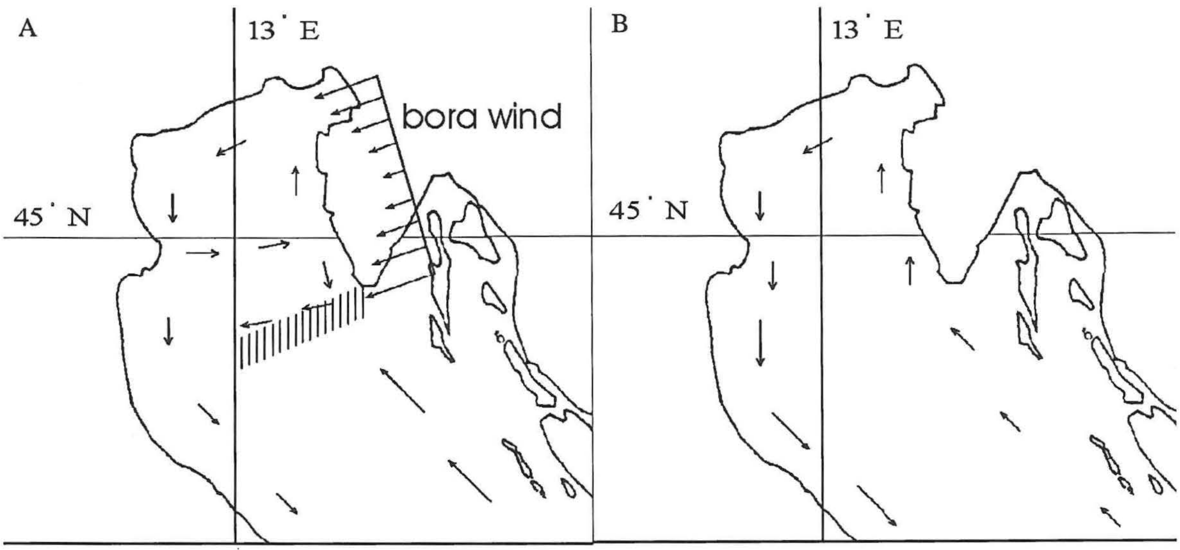

Fig. 5. A) Schematic representation of the bora wind stress and circulation in the North Adriatic during cold period of the year, frontal zone area is shaded (according to ZORE-ARMANDA and GAČIĆ, 1987); and B) surface circulation in the warm period of the year (according to ZORE-ARMANDA, 1967)

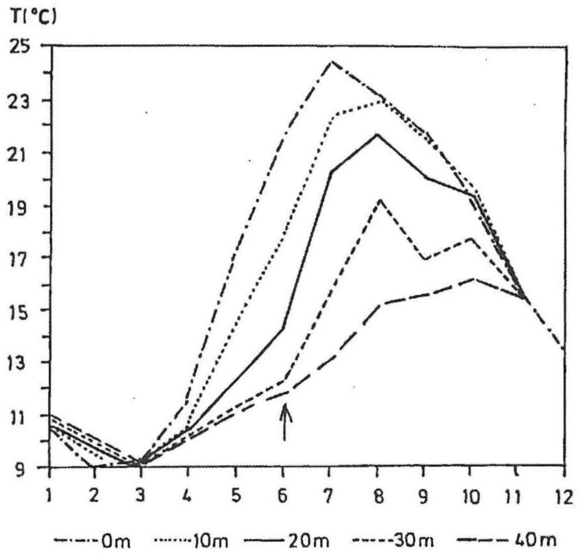

Fig. 6. Mean annual course of the sea surface temperature (dashed) and mean temperature for the whole water column (0-40 m) for the wider area of the IVANA gas field, according to the data from the MEDAS databank. The slower heating in June and the decrease of temperature in August can be observed

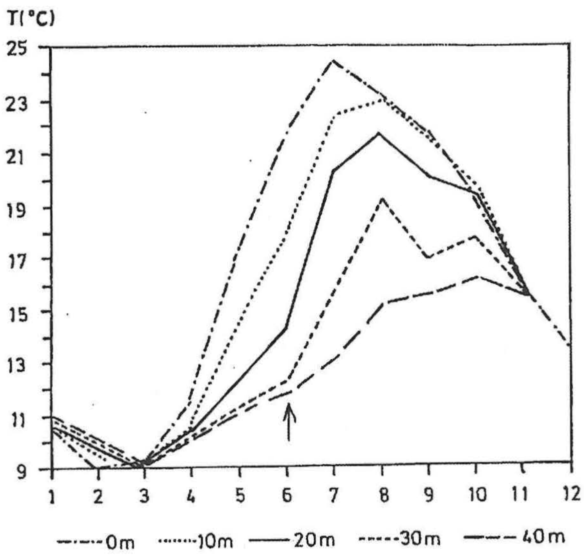

Fig. 7. Mean annual course of the sea surface temperature (dashed) and mean temperature for the whole water column (0-40 m) for the wider area of the IVANA gas field, from bathythermographic measurements (according to MOROVIĆ et al., 1996). The decrease of temperature is seen in deeper layers in summer, and again in September, later than in the other data

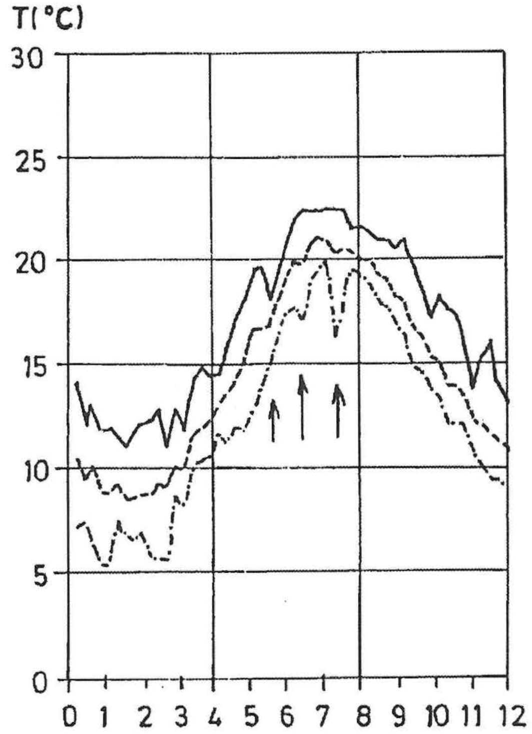

Fig. 8. Mean, maximal and minimal weekly sea surface temperature in the Northern Adriatic, according to the AVHRR satellite data (LA VIOLETTE, 1996), averaged for the region from the Fig. 3. Arrows indicate the decrease of temperature

according to batythermographic data shows slowing down of temperature increase in June (Fig. 7). This could be understood as an effect of the summer thermocline, however, satellite and salinity data from the surface layer clearly show the influence of upwelling. The decrease of temperature in September is probably due to autumn cooling.

Mean annual satellite data display the three strong temperature decreases during May, June and July (Fig. 8) respectively. Here, the data were averaged for the short time intervals (weeks), and therefore present a more realistic time scale. The satellite data also show that strong sea surface temperature fluctuations, including abrupt temperature decrease, appeared every year (between 1981-1990) in the warm period of year, but not always in the same month (Fig. 9).

Annual salinity in the both gas fields IVANA and IKA shows a marked increase in June and July in the upper layers (Figs 10 and 11). This cannot be connected to decreased Po River runoff, since in the warm period of year the water spreads in the surface, and the minimum period of runoff occurs in August.

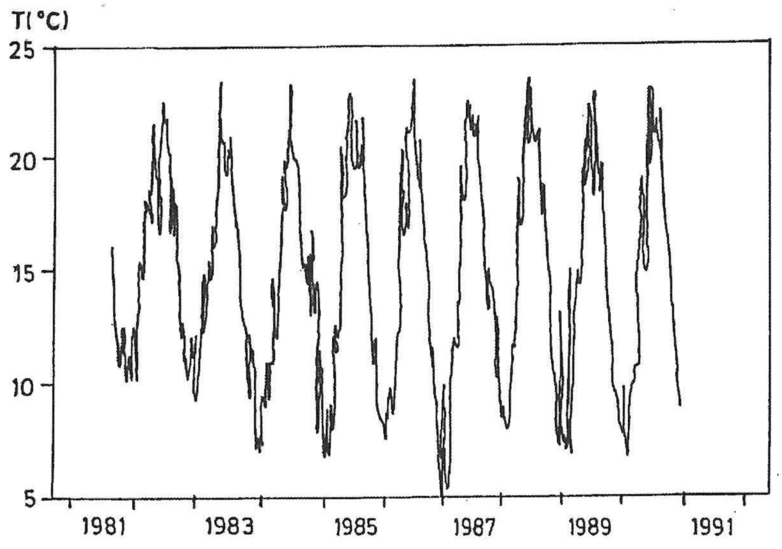

Fig. 9. Mean weekly sea surface temperature for the North Adriatic according to the AVHRR satellite data (LA VIOLETTE, 1996) averaged for the region from the Fig. 3

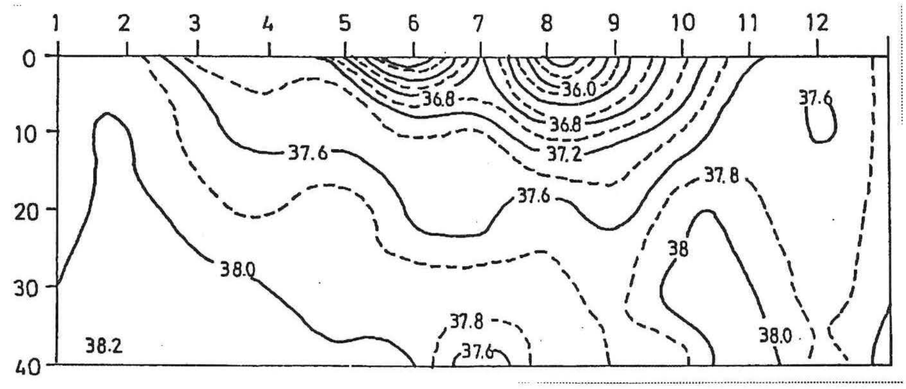

Fig. 10. Mean annual salinity course for the gas field IVANA (according to MOROVIĆ et al., 1996). The salinity increase can be observed at the surface in July

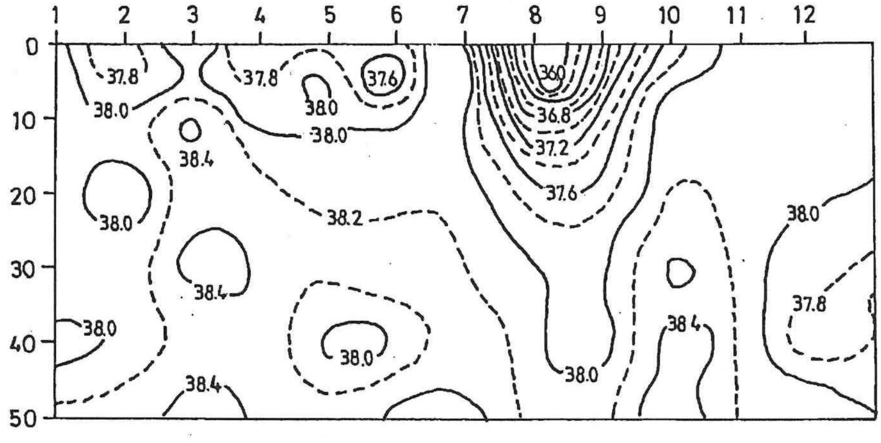

Fig. 11. Mean annual salinity course for the gas field IKA (according to MOROVIĆ et al., 1996). Marked salinity increase appears in June-July

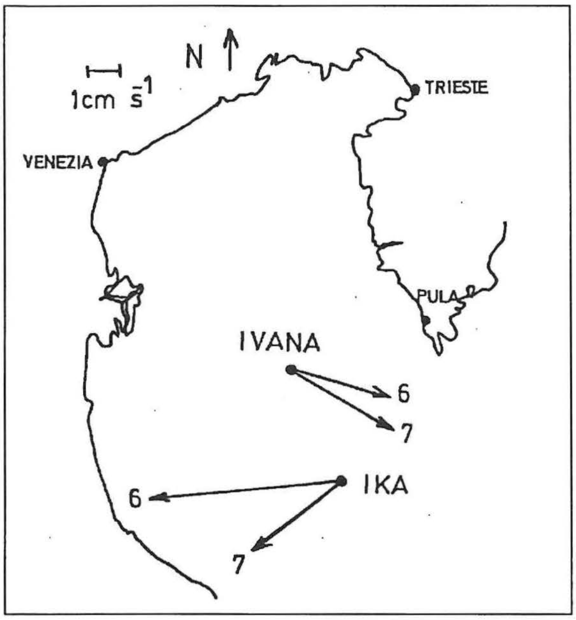

Fig. 12. Mean surface currents vector for June and July in the gas fields IVANA and IKA

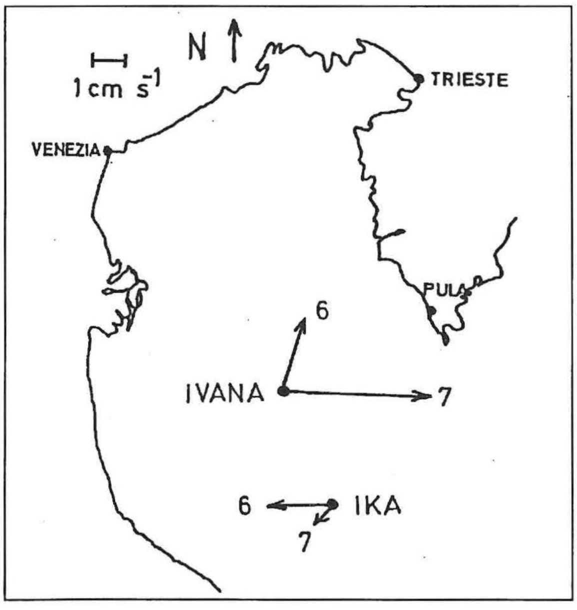

Fig. 13. Mean current vectors in the intermediate layer for June and July in the gas fields IVANA and IKA

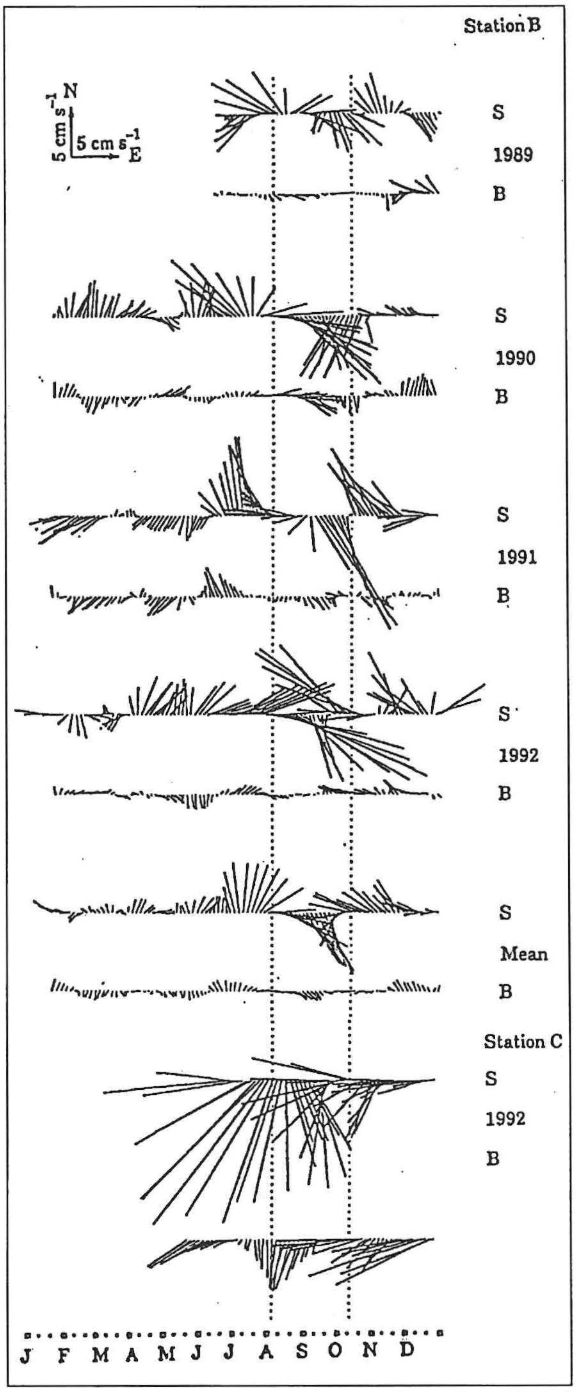

Fig. 14. The residual current vectors at the surface (S) and in the bottom layer (B), at the stations B and C(after BRANA and KRAJCAR, 1995)

Is there a rising up of water in June and July in the frontal zone area? It would seem that if upwelling does occur, it should be accompanied by a divergence of currents in the upper layer. Mean monthly vectors of currents for June and July for the surface and intermediate layer are shown in the Figs 12 and 13. It is possible to distinguish the divergence in the current field between the gas fields IVANA and IKA, especially in the intermediate layer. It is also interesting to observe the coincidence of the divergence of currents and in the surface layer, the decrease of temperature and increase of salinity. These appear to confirm an upwelling hypothesis. Aiding in this hypothesis is the fact that the gas field IKA area is under the influence of cyclonic circulation, which brings saltier water to the Northern Adriatic, along the eastern Adriatic coast. Also because of the bottom topography, this water is forced to rise up, in the shallow North Adriatic.

There are another evidences that sudden changes in the current field appear at the end of July. At the station B, close to IVANA field (see Fig. 1) during four years (1989 - 1992) current direction in June - July is different from the rest of the year (Fig. 14).

This is in accordance with the hypothesis that June - July are under specific dynamic regime in this region. Comparing the direction of the surface currents at the stations B and C in June - July 1992, these data also show divergence of currents between the IVANA and IKA region.

Therefore, the decreased temperature in annual course from June-July (eventually May to August) depending on the data series, increased salinity in June-July, divergence of currents in June-July all indicate the same phenomenon, the upwelling in the frontal zone. Due to the extremely variable circulation, which depends on the Po River inflow, winds, stratification, the location of the phenomenon may also be variable.

CONCLUDING REMARKS

The data were presented which indicate the divergence in the current field in an area of the North Adriatic that appears to occur as a consequence of the water upwelling in this area. Accompanying this phenomenon are the increase of salinity and the decrease of temperature, as a consequence of intrusion of saltier and colder waters from the deeper layers. It seems that it is possible to observe this phenomenon only in the warm period of the year, in some months between May and August, when the upwelled water is colder than the North Adriatic water.

Satellite data showed actual decrease of temperature in a short period (weeks), which happened every year, but in different months. Therefore, comparing with hydrographic data averaged over a much longer period cannot be strict, but both indicate the same phenomenon.

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Divergencija strujanja u sjevernom Jadranu

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SAŽETAK

Analizirani podaci temperature i slanosti mora te strujanja ukazuju na divergenciju u strujnom polju uz prateći upwelling u središnjem dijelu sjevernog Jadrana. Pojava se uočava samo u raslojenim termohalinim uvjetima, u razdoblju zatopljavanja. U ovom su radu predočeni dokazi u prilog ovoj pretpostavci.