WESTERN BLACK SEA CURRENTS BY THE SHIP AND SATELLITE DATA

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Abstract

In spring-time of 1993,94 both CTD, ADCP and satellite infrared measurements were carried out in the framework of CoMSBlack international program. Geostrophic flow field, ADCP current vectors and thermal structures at the sea surface displayed good agreement. Satellite data essentially assist in the interpretation of ADCP currents data and explain several peculiarities in vectors distribution as manifestations of meso-scale dynamic features. The results reflect the effect of the Black Sea flow field transformation from winter type to summer one. These seasonal changes are superimposed over the strong inter-annual variability of the water dynamics.

Key-words: Circulation, Hydrography, Mesoscale phenomena, Remote sensing

Introduction

In spring time of 1993,94, both CTD, ADCP and satellite infrared measurements were carried out in the framework of CoMSBlack and NATO TU-Black Sea international programs to study the water circulation and bio-chemical processes in the western Black Sea. The aim of this paper is to present some results concerning the integration of different kinds of information (satellite images, measured currents and geostrophic flow fields) for the description of water circulation within the upper 100m layer of the sea, including the mesoscale dynamical features. The same approach is often used for other regional studies (e.g., [1]), but there was no opportunity before to obtain more or less full set of quasi-synchronous high-quality data covering the most part of the Black Sea. General structure of the Black Sea surface water circulation has been recently described on the base of geostrophic currents calculations and qualitative analysis of satellite images [2]. The cyclonic meandering Rim Current (RC) follows along the continental slope around the sea. The flow field between the RC and shelf break consists of meso-scale anticyclonic eddies to the right of meandering jet. Some of them are quasipermanent and other mesoscale features are unstable and variable on a short-time scale (e.g., upwellings and cold jets, mushroom-like structures, RC instabilities) [3]. Seasonal (spring) changes in external forcing (wind weakening, surface layer heating and riverine runoff) lead to the current pattern transformation towards the less intensive and more meandering Rim Current. Sometimes the systems of mesoscale eddies are observed instead of continuous jet stream.

Data and methods

CTD data obtained during international experiments in the framework of CoMSBlack and TU-Black Sea programs (2-27 April, 1993 and 25 April - 14 May, 1994) were used for geostrophic circulation calculations. Observational stations grid had a spacing no more than 10 n.miles along meridian and 20 n.miles along parallel. Within the frontal and dynamically complex regions, stations have been sampled more frequently (steps were 2.5- 5 miles). Resulting grid covered deep-water, slope and shelf areas (in 1993, exception was the Bulgarian economic zone). The maps of geostrophic current vectors as well as the dynamical topography were produced. Dynamic heights were interpolated by means of Kriging procedure on the regular grid spaced by 0.20° in longitude and 0.12° in latitude, then geostrophic current components were revealed on the same grid from the horizontal gradients of dynamic heights. Also, CDT data were used to estimate the density of available potential energy (APE) distribution through the displacement of isopycnal surfaces regarding to their average levels for each survey.

ADCP current measurements were performed on board of R/V Bilim within the areas of CTD surveys, but without the Ukrainian economic zone in 1994. Data processing procedures were used for the ADCP information, such as: computing of absolute currents by means of the precise navigation data; error control and median filtration; statistical analysis for each level; producing of horizontal vector maps and vertical sections of currents. In present paper the vectors at 10 m level were analysed together with the satellite thermal images as the nearest to the sea surface valid ADCP data. Some statistical parameters for the 10 m depth are presented in Table 1. They give the first impression about general currents intensity and variability in the subsurface layer for the both surveys. Next steps of the data analysis were: (i) qualitative comparison of the vector current patterns with CTDderived dynamical topography and (ii) estimation of correlation between ADCP-measured and geostrophic velocities. The second procedure based on the data set for those points of dynamical topography regular grid where the ADCP measurements were made. Measured current components were obtained as the mean values for all ADCP-vectors within the half-step limits around the geostrophic vector nodes. Figure 1 presents the maps of dynamical topography calculated referring to the 500 m level, where the mean ADCP vectors used for the correlation calculations are shown as well. Finally, these current vectors were also used for the density of kinetic energy (KE) estimation. Table 2 presents the correlation coefficients derived for the different levels within the upper 100 m layer of the sea and Table 3 contains the results of basin-averaged APE and KE calculations for the same levels as well as the integrated values for 10-100 m layer. Satellite images obtained from NOAA AVHRR in HRPT mode on MHI

Satellite images obtained from NOAA AVHRR in HRPT mode on MHI receiving station are used in the present work. Software developed in MHI is used for the pre-processing, geographical positioning and geometrical transformation of images to the rectangular projection maps. Second stage of processing gives the digital radiation temperature maps for the infrared channel 4.





Their spatial resolution is 1' along meridian and 1.5' along parallel, and radiation temperature resolution is 0.1°C. Finally, shoreline, shelf boundary and ADCP measured current vectors were superimposed on the images.

Surface layerwater circulation and mesoscale features

Sea surface dynamical topography map for April 1993 demonstrates all of the main large and meso-scale peculiarities described earlier, such as, meandering jet of the RC, series of quasi stationary anticyclonic eddies to the right of it, cyclonic gyres in the central part (see Fig. 1a). Large-scale structures coinciding to the RC jet to the west of the Crimean peninsula and along the Turkish coast are well distinguished by the ADCP vectors having maximal velocities. Respectively weak flows on the north-west shelf (10-15cm/s), and in central regions of the sea (20-25cm/s) are observed. ADCP data reflect the complex meso-scale current picture. This makes them more preferable for the comparison with high resolution satellite thermal images, especially in higher spatial variability zones (RC's meanders and frontal regions of eddies). The comparison of current vector distributions at the 6 - 20 m levels allows to infer the vertical homogeneity of upper layer circulation and thus is a good base for the interpretation of sea surface satellite imagery.

Considering the distribution of ADCP current vectors and thermal patterns together, we can note a good agreement between the measured flows and thermal structures at the sea surface in April 19, 1993 for those areas where the ship tracks passed. The velocity maxima coincide with the temperature gradient locations of the RC and the vector directions correspond to the satellite



Figure 2.

derived flow configuration as well as with the stream function derived from hydrographic data. Moreover, presence of satellite data assists in the interpretation of ADCP current data in the way of explaining several peculiarities in vector distribution as the manifestations of mesoscale dynamic features. Fig. 2 contains image fragments with the some examples.

To the north of Bosphorus, at 42.0 - 42.2°N, vectors convergence is observed. The reason of this phenomenon was inferred from the satellite image as the confluence of flows. One of them comes from the north as a warm jet along 29.4°E, the other comes from shelf side as a cold water tongue directed to south-east (Fig. 2a). Northward directed vectors presence at the middle of the ship track between 31.3 and 32.3°E, about 42.4°N, and also south-westward currents in the northern part of next meridian track can be understood only by way of satellite data showing the cold-core anticyclonic eddy probably produced by RC jet instability (Fig. 2b). The main differences of the geostrophic cir-culation in May 1994 from the April 1993 one are less intensive flows in the RC and more pronounced meandering in its southern branch (see Fig. 1b). Anticyclonic eddies to the right of the main jet at the shelf break to the west of the Crimea are still presented, but they are more separated by the cyclonic meander. Another large quasi-stationary anticyclonic eddy in the western part of region (so-called, Bulgarian eddy) is described by the ship survey as well. ADCP vectors distribution almost fully reflects the details of circulation patterns in the measurement areas.

NOAA AVHRR thermal image received at 5 May, 1994 demonstrates the good agreement with the both geostrophic flows and ADCP vectors distributions in the cloud-free parts of the scene. Bulgarian anticyclonic eddy centred at 42.5°N, 29.0°E having about 80 km in diameter is fully described by all kinds of the observations (Fig. 2c). Large anticyclonic eddy-meander on the southern branch of the RC having ~160 km in height and about 140 km in wavelength was generated, most probably, by the RC jet instability caused by influence of strong north-western winds before the survey. The same meander evolution has been reported before [3]. Only top and foot of this meander is observed on the image while the central part is obscured by cloudiness (Fig. 2d). That not permits to describe it fully by satellite data but its top is looking like eddy rather than meander pattern, as it seems on the dynamical topography map. This eddy may be produced just in the surface layer, that is typic cal for the such unstable meanders.

Discussion and conclusions

The first conclusion which can be made is that the large- and meso-scale dynamic features are displayed in satellite derived thermal patterns. Good enough correspondence between measured current parameters and thermal circulation structures has obviously seasonal character since the conditions were preceding to seasonal thermocline development during the cruises. Significant reformation of temperature field took place as it has been seen from the latest satellite images. It remains uncertain whether these changes will reflect a close relation between meso-scale temperature and current fields peculiarities in summer season. This question requires further experimental investigations. But comparing the results obtained at present time, we can expect much worth agreement between the currents and temperature fields because of total weakening of the Rim Current jet flows and seasonal heating of the sea upper layer (that masks the influence of the water column dynamical processes on the sea surface). The April 1993 data were sampled just before the circulation transformation from the winter type to summer one. That is why the average and maximal current speed are about twice more than for the May 1994 observations (see Table 1). Probably, during the CoMSBlack-94 May survey, such reformation has been started. It proves by less intensive stream flows, more pronounced RC's meandering and eddies development. The comparison of correlation coefficients (see Table 2) gives an additional reason to conclude

Table 1. Statistics of the ADCP current measurements (cm/s) on the depth 10 m

	April 1993			May 1994		
Parameter	u	v	v	u	v	v
Average	8,3	0,8	29,2	3,1	- 2,3	14.3
Stan.Dev.	29,0	22,1	23,1	11,4	11,3	8,4
Minimum	-63,6	-70,3	1,7	-28,8	- 36,9	0,6
Maximum	95,9	74,8	103,9	56,0	30,0	65.6

Table 2. Correlation coefficients between the ADCP and geostrophic currents

Depth, m	April 1993		May 1994	
	u	v	u	v
10	0,81	0,72	0,65	0,46
30	0,84	0,73	0,61	0,55
60	0,80	0,67	0,62	0,54
100	0,73	0.56	0,52	0.41

that May 1994 data were sampled during the general circulation transformation. Geostrophic currents determined by total baroclinic layer stratification are more conservative (geostrophic adjustment period for the Black Sea is about 1 month), while ADCP measured currents are quasi-instant and reflect both time and spatial changes during the survey period. So, less correlation between them can be due to delay in the transformation of geostrophic circulation pattern from the real currents changes.

The discussion on the nature of differences between two obtained patterns of circulation can be continued in terms of their energetic parameters. Application of CTD data for the APE and ADCP data for the KE estimation gives the independent results for the both kinds of energy. In 1994 mean values of KE was about 6 times less than in 1993 but APE in 1994 was only 3 times less than in 1993 (see Table 3). Exception was the APE in 1994 on the 10 m level: it was about twice more than in 1993 and its value violates the general increasing of APE with depth. This fact is connected with the surface heating (buoyancy flux) and seasonal thermocline development during the May 1994. As it follows from the most recent analysis of climatic data and numerical modelling, strong seasonal changes of KE occur during the spring time: in upper 100 m layer KE falls down 2.5- 3 times regarding to its maximum in March [4]. The rest part of discrepancies between the surveys can be explained by strong inter-annual variability of the main pycnocline slopes which was reported for 1990-1995 years period [5]. These changes were found to be dependent on the degree of winter coling of water within the shallow N-W shelf of the Black Sea. The coldest year (1993) was also the year of most intense general circulation. In 1994 and further, the general slope of the pycnocline (difference in its depth between central cyclonic part and peripherial anticyclonic regions) receded to a level of 1991.

Thus, circulation patterns obtained by means of different data integration for 1993, 1994 reflect the situation of extremely high variability because of maximal seasonal and strong inter-annual changes combination.

Table 3. Basin-averaged ene	eroetic paramete	ers
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Depth,	, April 1993		May	1994
m	APE, J/m ³	KE, J/m^3	APE, J/m ³	KE, J/m ³
10	10,04	65,50	19,47	11,00
30	17,17	69,60	5,53	11,35
60	61,07	69,54	20,22	11,49
100	183.15	58,82	57,29	6,69
10-100	1841 J/m ²	3288 J/m ²	765 J/m ²	540 J/m ²

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