1996-02

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Shapiro, Georgy

<http://hdl.handle.net/10026.1/9740>

10.1016/0924-7963(95)00011-9

Journal of Marine Systems

Elsevier

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JOURNAL OF MARINE SYSTEMS

Journal of Marine Systems 7 (1996) 337–348

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G.I. Shapiro ^{*}, S.L. Meschanov

P.P. Shirshov Institute of Oceanology, 23 Krasikova Street, 117218 Moscow, Russia

Received 5 August 1994; accepted 14 December 1994

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Journal of Marine Systems 7 (1996) 337–348

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G.I. Shapiro^{*}, S.L. Meschanov

P.P. Shirshov Institute of Oceanology, 23 Krasikova Street, 117218 Moscow, Russia

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Abstract

The location, spreading pattern, mesoscale structure and the influence of bottom topography on the Mediterranean Water (MW) outflow were studied using historical hydrographic data from the Iberian Basin of the North Atlantic. It was shown on the basis of joint analysis of continuous and discrete component of the MW distribution, that after leaving the Gulf of Cadiz the MW outflow is broken into two main cores: Northwestern and Southwestern ones. The wide, intense Northwestern core spreads in a regular and continuous manner. West off the Tejo plateau it is split into three branches, the most intense of them keeps continuity up to 14° W. The less intense Southwestern core passes south of the Gettysburg bank and is split into two branches just after the Gulf of Cadiz. This core has a lenticular intermittent character starting with 11° W. West of 15° W all the branches of MW outflow spread in the form of isolated salty patches. In the Iberian Basin (32°–44° N, 8°–22° W) 30 MW lenses were found out, 12 of which were not mentioned in the literature before.

1. Introduction

The giant salt tongue of modified Mediterranean Water (MW) is an important feature of the hydrography of the Northeastern Atlantic. The MW is formed by mixing the high saline water of the lower current of the Strait of Gibraltar and North Atlantic Central Water (NACW) (Howe, 1982). The estimates of MW discharge vary from 2.6 Sv (Ambar and Howe, 1979) up to 6.5 Sv (Howe, 1984) in different places of the Gulf of Cadiz not only due to time variations but

also to entrainment and mixing with NACW. The MW spreads from the Gulf of Cadiz in the main thermocline at intermediate depths of 500–1500 m over many thousands of kilometers. The influence of the high salinity of the MW was detected even in the Indian and Pacific Oceans (Reid, 1978; Richardson et al., 1991).

According to the classical picture, the MW propagates uniformly in radial direction as a continuous water tongue and this process can be described in terms of large scale advective–diffusive balance (Defant, 1955). During the last two decades, field investigations have trustworthy shown that the MW spreads following a much more complex pattern. After leaving the Gulf of Cadiz, the major part of MW flow turns north along the Portugal coast. The result is that the

^{*} Corresponding author. P.P. Shirshov Institute of Oceanology, 23 Krasikova Street, 117218 Moscow, Russia. Tel: +7 (095) 124-7392, Fax: +7 (095) 124-5983, E-mail: pelevin@glas.apc.org.

climatic salinity maximum at the typical depths of MW spreading is shifted to the north of the latitude of Gibraltar (Richardson et al., 1991). In the eastern boundary layer of the Atlantic near the Portuguese coast the MW tongue is strongly influenced by the bottom relief (Zenk and Armi, 1990; Martins, 1992). According to Zenk and Armi (1990), the MW undercurrent forms two stacked outflow cores with different temperature–salinity characteristics and passes through a broad “gateway” between the Cape St. Vincent and the Gettysburg Bank entering the Iberian Basin. The upper core (depth 750 m) shows a strong tendency to follow the contours of the Portuguese continental slope. The lower core (depth 1250 m) primarily meanders west and northwestwards. The part of MW undercurrent goes southwestward directed to the Canary Basin (Zenk and Armi, 1990; Käse et al., 1986).

In addition to continuous tongue there are isolated layers, blobs and mesoscale lenses (MEDDIES) of high saline Mediterranean Water (Swallow, 1969; Armi and Zenk, 1984; Krauss and Käse, 1984). Hereafter such structure of the MW outflow will be referred to as a “lenticular” one (Emelianov and Fedorov, 1985). Mediterranean lenses are long-lived features keeping the initial values of temperature and salinity in the core over thousands of kilometers (Belkin et al., 1986; Belkin and Kostianoy, 1988; Richardson et al., 1989). The climatic paths of MEDDY propagation were estimated using spatial distribution of observed lenses (Belkin and Kostianoy, 1988; Richardson et al., 1991), direct measurements of individual lens trajectories over long time (Richardson et al., 1989) and theoretical calculations based on Lagrangean invariant method (Kostianoy and Shapiro, 1989). It was stated that the main lens trajectories are oriented southwestward to the Canary Basin. Nevertheless lenses were observed far to the northwest (Katz, 1970; Richardson et al., 1991) and west off the Strait of Gibraltar (Plakhin and Smirnov, 1982; Käse and Zenk, 1987).

In this paper we study the location, spreading pattern, mesoscale structure and the influence of bottom topography on the Mediterranean Water undercurrent in the Iberian Basin of the North

Atlantic. In contrast to Zenk and Armi (1990) who have restricted themselves to the analysis of data of some selected cruises we use the large data base of historical observations that covers period of several decades and includes individual stations in the deep ocean as well as in the coastal zone of the Iberian Basin. We pay a special attention to the evolution of the main (lower) core of MW while it spreads from the coastal region into the open ocean.

2. Materials and methods

The analysis presented in this paper is based on the concept issued by Emelianov and Fedorov (1985) on the lenticular structure of intermediate waters of Mediterranean origin. Developing this concept we use two independent approaches: the study of spatial distribution of (i) continuous tongues of MW and (ii) isolated blobs surrounded by the background mixed Mediterranean and North Atlantic Central Waters. The possibility of the investigation of main flow paths of the MW in the coastal zone of the Iberian Basin using the archived hydrographic data that were collected in different years and conditions is based on the hypothesis by Zenk and Armi (1990). They stated that the bottom topography (underwater canyons, seamounts, continental rise orientation) strongly influences the spatial distribution and structure of MW. Thus, one can expect that along with the stochastic component in the MW distribution caused by synoptic current activity, seasonal and annual variability there is a regular component that geographically correlates to the inhomogeneities of the bottom topography.

Our study is based on the materials of individual hydrographic stations taken in the Iberian Basin (32° – 44° N, 8° – 22° W). The data were obtained from National Oceanographic Data Center (NODC, Washington, 1906–1986), Russian National Oceanographic Data Center (WNI-IGMI-MCD, Obninsk, 1950–1986) and from several selected cruises listed below.

Only selected stations were retained that were as deep as at least 1250 m and had the sampling depth spacing less than 500 m. When necessary,

Nobs at 1100 m

Fig. 1. Distribution of available observations in the Iberian Basin at 1100 m depth.

the data were interpolated with a 100 m vertical step in the depth range 500–1300 m (Table 1). Distribution of hydrographic stations in $1^\circ \times 1^\circ$ bins at 1100 m used for the present analysis is shown in Fig. 1. Up to 62% of them were taken from NODC archive, 38% from other sources. In common the number of observations Nobs slightly diminishes with depth because some of old stations have gaps in data at deep levels.

To reveal the main paths of MW penetration we use two different statistical methods of data processing: (i) calculation of mean T , S fields in small spatial boxes and (ii) extreme statistics method. We also check visually the individual hydrographic stations with positive salinity anomalies relative to the background values at depths of MW propagation. Below we discuss the salinity field only.

The first method follows mainly the procedure used by Richardson et al. (1991). Mean salinity

S_{mean} was calculated in each $2^\circ \times 2^\circ$ box, individual observations with anomaly in salinity exceeding two standard deviations from the mean were eliminated, and the mean recalculated. Successive iterations were continued until consecutive values agreed to within 0.005 psu. The resulting grid of salinity values was slightly smoothed using inverse distance method, and maps of S_{mean} were drawn for levels 500, 600, 700, 800, 900, 1000, 1100, 1200 m. The mean salinity field reveals a continuous component of MW undercurrent only because it does not take into account rare anomalous stations corresponding to high salinity blobs and lenses.

According to the second method we split the study area into small boxes of different sizes in agreement with the density of observational grid and identify the extreme (in our case — maximal) values of salinity S_{max} in each box. This approach allows to identify not only areas where the positive anomalies typical for MW are observed repeatedly but also areas where anomalies are met infrequently. Maps of S_{max} were calculated at the same depth levels as S_{mean} using adaptive spatial grid. The largest boxes were $1^\circ \times 1^\circ$ in size. If the number of stations in a box was $30 < N_{\text{obs}} \leq 60$ the box was split into smaller $0.5^\circ \times 0.5^\circ$ boxes, if $N_{\text{obs}} > 60$ — into $0.33^\circ \times 0.33^\circ$ boxes. The usage of adaptive grid with variable step allows to reach the best spatial resolution near the Gulf of Cadiz and the Portuguese coast where the station grid is much denser than in the open ocean. The map of S_{max} allows to track both continuous and discrete components of MW outflow. If we used an ordinary averaging method the sporadic positive anomalies caused by irregular occurrence of meanders, isolated layers and lenses would be masked by large amount of background data.

Intensity of the discrete component of MW can be estimated using the deviation of maximal

Table 1
Number of observations in the Iberian Basin included in the data base

Depth, m	500	600	700	800	900	1000	1100	1200	1300
Nobs (total)	2643	2629	2612	2616	2613	2585	2573	2566	2547
NODC	1640	1636	1631	1625	1623	1600	1590	1586	1576
VNIIGMI-MCD	1003	993	981	991	990	985	983	980	971

salinity $S_{\max}$ from the background field S_{mean} . In the areas where MW spreads regularly the value of $S_{\text{delta}} = S_{\max} - S_{\text{mean}}$ is close to zero because both maximal and mean values of haline field are formed by the same water (MW). The parameter S_{delta} reaches its maximum in the areas where the spreading of MW occurs mainly in the form of isolated patches. Therefore, the analysis of spatial distribution of S_{delta} allows to pick out the regions of preferably continuous and discrete spreading of anomalous water and to locate the regions where the continuous tongue is split into isolated patches.

The independent analysis of discrete component of MW was made using method suggested by Richardson et al. (1991). We selected stations having positive anomalies compared to the local background. The “anomalous” stations were analyzed visually to find vertical profiles typical of MW. For each station with MW presence we found (where possible) the neighbouring stations taken in the same cruise and drew and analyzed vertical sections and/or horizontal salinity charts. The locations of isolated lenses both referred in the literature before and found by ourselves were used to reveal the paths of spreading of discrete component of MW.

3. Results

Fig. 2 shows the computed climatic field of S_{mean} at 1100 m level. The distribution of S_{mean} corresponds mainly to the results by Richardson et al. (1991). In the coastal zone the zonal axis of the climatic tongue of MW with the mean salinity up to 36.2° – 36.3° psu is located at 39° N, i.e. 3 degrees north of the latitude of Gibraltar. The isohaline 36.0 psu that represents the main core of MW tongue goes west as far as 15° W both at 1000 m and 1100 m levels.

Fig. 3 shows the chart of $S_{\max}$ computed at the same depth level using adaptive spatial grid. The mesoscale distribution of maximal salinity $S_{\max}$ looks strongly different from the mean field. Since the bottom topography is very important in discussion about $S_{\max}$, all the locations mentioned below are mapped in Fig. 8. The high saline MW

Fig. 2. Contours of the mean salinity field S_{mean} at 1100 m depth.

Fig. 3. Contours of the maximal salinity field $S_{\max}$ at 1100 m depth. Dots mark the nodes of adaptive grid. Isohaline $S_{\max} = 36.2$ psu is shown by a thick line.

Table 2

Number of stations with salinity anomalies in the Iberian Basin Richardson's et al. (1991) data are shown in brackets, the bin width is ± 0.5 psu

dS, psu	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Total	380	161 (16)	84 (17)	39	10	4	1
Lenses	1	8 (0)	7 (17)	6	4	3	1
Undefined	4	7	15	3	1	0	0
Not lenses	375	146	62	30	5	1	0

Table 3
Summary of MEDDIES in the North Atlantic

Lat., N	Lon., W	dS	S _{max}	Year	Month	Ship	Reference
20° 07'	38° 09'	0.9	35.90	85	06	<i>Ak.M.Keldysh</i>	KP
22° 00'	25° 00'	1.2	36.27	89	01–03	<i>Arnold Veimer</i>	LL
22° 00'	26° 04'	0.8	35.90	86	11	<i>Meteor</i>	ZKS; RWASP
22° 07'	22° 06'	0.6	35.82	86	10	<i>Endeavor</i> #	–
25° 24'	25° 59'	1.0	36.26	88	08	<i>Oceanus</i>	MCM
25° 40'	27° 49'	0.9	36.14	83	01	<i>Knorr</i> #	W86
26° 32'	29° 06'	0.7	36.05	80	03–04	<i>Oceanus</i> #	AS
26° 45'	25° 16'	0.6	35.96	88	08	<i>Oceanus</i>	RMCM
26° 55'	23° 37'	0.9	36.22	85	10	<i>Endeavor</i>	AHOPRR
28° 29'	22° 56'	0.4	36.27	85	06	<i>Hudson</i> #	AHOPRR
28° 30'	28° 20'	1.1	36.4	89	03	<i>Akademik S.Vavilov</i>	MSF
29° 29'	18° 14'	0.2	35.62	71	08	<i>Elisha Kent Kane</i> #	–
29° 30'	17° 00'	0.6	–	65	summer	–	P
29° 57'	27° 59'	0.5	36.05	71	01	<i>Elisha Kent Kane</i> # *	RMCM
30° 45'	28° 30'	0.6	36.1	90	08	<i>Akademik Kurchatov</i>	ZL
31° 00'	26° 42'	0.9	36.35	81	05	<i>Knorr</i>	AZ
31° 06'	22° 44'	0.8	36.28	81	06	<i>Knorr</i>	AZ
31° 29'	11° 37'	0.9	36.29	11	06	<i>Mowe</i> #	–
31° 30'	14° 27'	0.6	36.22	65	10	–	RMCM
31° 30'	22° 35'	0.2	35.8	82	03–04	<i>Poseidon</i>	KZ
31° 48'	27° 00'	0.9	36.2	89	11	<i>Akademik Ioffe</i>	DMNFS
31° 54'	27° 00'	0.9	36.35	90	06	<i>Vityaz</i>	–
31° 58'	21° 48'	0.8	36.30	84	10	<i>Oceanus</i>	AHOPRR
32° 13'	28° 59'	0.8	36.21	90	01	<i>Professor S. Dorofeev</i>	SME
32° 30'	11° 30'	0.6	–	65	summer	–	P
32° 30'	20° 30'	0.3	35.89	71	04	<i>Elisha Kent Kane</i> # *	AZ
32° 48'	12° 05'	0.8	36.58	87	03	<i>Professor S. Dorofeev</i>	VKOP
32° 50'	10° 50'	–	–	88	06–08	<i>Vityaz</i>	F
33° 00'	23° 10'	0.2	35.8	82	03–04	<i>Poseidon</i>	KZ
33° 08'	21° 33'	0.7	36.17	81	06	<i>Knorr</i>	AZ
33° 20'	21° 25'	0.7	36.26	93	10	<i>Professor Shtokman</i>	–
33° 28'	23° 20'	0.6	36.16	70	11	<i>Elisha Kent Kane</i> # *	AZ
33° 34'	10° 21'	0.4	36.00	70	11	<i>Elisha Kent Kane</i> # *	RMCM
33° 55'	24° 05'	1.1	36.56	85	11	<i>Endeavor</i>	RWASP
33° 56'	20° 19'	0.4	35.99	80	11	<i>Musson</i> #	–
34° 00'	13° 00'	0.5	36.33	66	06	–	RMCM
34° 00'	22° 38'	0.7	36.22	89	01–03	<i>Arnold Veimer</i>	LL
34° 01'	17° 01'	0.7	36.44	65	09	<i>Origny</i> # *	RMCM
34° 15'	11° 30'	–	–	88	06–08	<i>Vityaz</i>	F
34° 34'	11° 04'	0.6	36.57	71	09	<i>Elisha Kent Kane</i> *	RMCM
34° 35'	9° 00'	–	–	88	06–08	<i>Vityaz</i>	F
34° 38'	19° 42'	0.4	36.11	71	07	<i>Sands</i> # *	RMCM
34° 39'	24° 19'	0.6	36.20	83	06	<i>Discovery</i> #	–
34° 44'	23° 29'	–	36.53	92	03	<i>Charles Darwin</i>	PLC
34° 49'	21° 12'	0.7	35.95	90	03	<i>Akademik Ioffe</i>	BMRS
35° 00'	10° 00'	0.6	36.65	70	08	<i>Rockaway</i> # *	RMCM
35° 00'	26° 30'	0.5	35.90	67	07	<i>Gillis</i> # *	AZ
35° 09'	13° 22'	0.5	36.42	48	01	<i>Atlantis-I</i> # *	RMCM
35° 26'	10° 00'	–	–	88	09	<i>Oceanus</i>	KPS
35° 30'	9° 00'	0.8	36.74	82	09	<i>Ernst Krenkel</i> #	–
35° 30'	13° 00'	–	–	88	06–08	<i>Vityaz</i>	F
35° 30'	17° 00'	0.4	36.20	88	03	<i>Poseidon</i>	KBH; SHK

Table 3 (continued)

Lat., N	Lon., W	dS	S _{max}	Year	Month	Ship		Reference
35° 45'	8° 57'	0.3	36.55	58	11	<i>Discovery-II</i>	#	S
35° 52'	10° 36'	–	–	88	09	<i>Oceanus</i>		KPS
35° 52'	13° 33'	0.6	36.55	51	02	<i>San Pablo</i>	#	–
35° 58'	13° 59'	0.6	36.50	83	03	<i>Ernst Krenkel</i>	#	–
36° 00'	13° 30'	0.8	36.5	85	09	<i>Akademik Kurchatov</i>		ZO
36° 00'	17° 30'	0.5	36.45	83	01	<i>Viktor Bugaev</i>	#	–
36° 00'	20° 00'	0.4	36.19	84	03	<i>Ernst Krenkel</i>	#	–
36° 00'	20° 40'	0.4	36.1	82	03–04	<i>Poseidon</i>		KZ
36° 00'	22° 30'	0.5	36.21	79	09	<i>Musson</i>	#	–
36° 00'	22° 30'	0.8	36.51	83	08	<i>Ernst Krenkel</i>	#	–
36° 00'	24° 00'	0.7	36.30	83	04	<i>Viktor Bugaev</i>	#	–
36° 00'	24° 30'	0.4	35.91	67	03	–	*	RMCM
36° 00'	27° 31'	0.6	36.17	77	07	<i>Musson</i>	#	–
36° 00'	29° 58'	0.6	36.06	72	04	<i>Poryv</i>	#	–
36° 00'	30° 00'	0.7	36.18	76	04	<i>Ernst Krenkel</i>	#	–
36° 00'	30° 00'	0.6	36.42	76	06	<i>Ernst Krenkel</i>		PS82
36° 01'	17° 30'	0.7	36.63	81	04	<i>Ernst Krenkel</i>	#	–
36° 06'	9° 12'	–	–	88	09	<i>Oceanus</i>		KPS; PS92
36° 13'	8° 03'	0.8	36.6	71	03	<i>Discovery</i>		T
36° 14'	11° 53'	0.5	36.48	81	07	<i>Atlantis-II</i>	#	RW
36° 23'	10° 00'	0.4	36.34	71	01	<i>Elisha Kent Kane</i>	# *	RMCM
36° 25'	8° 35'	0.5	36.5	73	03	<i>Shackleton</i>		HAD
36° 30'	14° 45'	0.4	36.30	71	05	<i>Elisha Kent Kane</i>	# *	RMCM
36° 35'	12° 30'	0.7	36.48	92	03	<i>Charles Darwin</i>		PLC
36° 48'	10° 20'	0.4	36.51	56	06	<i>President T. Tissier</i>	# *	RMCM
36° 50'	12° 00'	0.6	36.55	88	03	<i>Poseidon</i>		KBH; SHK
37° 00'	19° 00'	0.8	–	85	02–03	<i>Arnold Veimer</i>		E
37° 00'	20° 01'	0.4	36.16	88	08	<i>Oceanus</i>		RMCM
37° 01'	10° 14'	0.5	36.45	58	04	–	*	RMCM
37° 04'	16° 42'	0.5	36.41	83	06	<i>Discovery</i>	#	–
37° 04'	18° 48'	0.4	36.15	31	06	<i>Dana</i>	# *	RMCM
37° 08'	10° 19'	0.5	36.51	57	10	<i>Crawford</i>	# *	RMCM
37° 28'	20° 28'	0.9	36.56	71	04	<i>Elisha Kent Kane</i>	# *	RMCM
37° 29'	21° 28'	0.4	36.08	71	07	<i>Sands</i>	# *	RMCM
37° 54'	9° 54'	–	–	91	11	<i>Sonne</i>		ZTB
38° 00'	12° 05'	0.4	36.52	70	05	<i>Gemma</i>	#	–
38° 00'	12° 48'	–	–	91	04–05	–		ST
38° 22'	13° 07'	0.4	36.49	30	08	<i>Albacora</i>	# *	RMCM
38° 30'	13° 20'	–	–	91	04–05	–		ST
38° 51'	18° 17'	0.3	36.15	71	06	<i>Sands</i>	#	–
39° 30'	15° 00'	0.6	36.27	88	03	<i>Poseidon</i>		KBH; SHK
39° 50'	14° 30'	0.4	36.27	89	06	<i>Poseidon</i>		HRKZ
40° 05'	12° 48'	0.6	36.45	89	06	<i>Poseidon</i>		HRKZ
40° 30'	12° 00'	0.7	36.30	88	03	<i>Poseidon</i>		KBH; SHK
40° 40'	26° 16'	0.6	36.02	49	10	–	*	RMCM
41° 13'	11° 30'	0.4	36.28	89	01	<i>Meteor</i>		ZMW
41° 14'	13° 08'	0.3	36.24	70	08	<i>Rockaway</i>	#	–
41° 30'	27° 40'	0.2	35.37	68	08–09	<i>Chain</i>		K
42° 00'	29° 15'	0.2	35.42	68	08–09	<i>Chain</i>		K
42° 53'	29° 20'	0.2	35.46	68	08–09	<i>Chain</i>		K
42° 34'	17° 30'	0.5	36.23	81	01	<i>Passat</i>	#	–
43° 10'	29° 15'	0.2	35.46	68	08–09	<i>Chain</i>		K
43° 32'	24° 45'	0.4	35.57	22	06	–	*	RMCM
44° 00'	17° 59'	0.6	36.06	71	09	<i>Elisha Kent Kane</i>	# *	RMCM

Table 3 (continued)

Lat., N	Lon., W	dS	$S_{\max}$	Year	Month	Ship		Reference
44° 02'	17° 59'	0.6	36.06	68	10	—	*	RMCM
45° 07'	15° 56'	0.4	35.99	58	09	—	*	RMCM
46° 00'	22° 00'	0.2	35.5	58	09	Discovery-II		H

* Found by Armi and Zenk (1984) and/or Richardson et al. (1991) using historical data.

Found in the present paper using historical data.

Abbreviations in Table 3: AS – Armi and Stommel (1983); AZ – Armi and Zenk (1984); AHOPRR – Armi et al. (1989); BMRS – Berezutsky et al. (1993); DMNFS – Dykhno et al. (1991); E – Elken (1987); F – Filyushkin (1989); HAD – Howe et al. (1974); H – Harvey (1982); HRKZ – Hinrichsen et al. (1993); K – Katz (1970); KZ – Käse and Zenk (1987); KP – Koshliakov and Panteleev (1988); KBH – Käse et al. (1989); KPS – Kenelly et al. (1989); LL – Laanemets and Lips (1991); MSF – Maltsev et al. (1990); P – Piip (1969); PLC – Pingree and Le Cann (1993); PS82 – Plakhin and Smirnov (1982); PS92 – Prater and Sanford (1992); RW – Roemmich and Wunsch (1985); RWASP – Richardson et al. (1989); RMCM – Richardson et al. (1991); S – Swallow (1969); SHK – Stammer et al. (1991); SME – Shapiro et al. (1992); ST – Shultz Tokos (1992); T – Thorpe (1976); VKOP – Vorobyov et al. (1988); W86 – Williams et al. (1986); ZMW – Zenk et al. (1989); ZKS – Zenk et al. (1991); ZTB – Zenk et al. (1992); ZL – Zhurbas and Lozovatsky (1991); ZO – Zubin and Ozmidov (1987).

outflow ($S_{\max} > 36.2$ psu) is broken up into two basic cores. The main core passes between the Cape St. Vincent and the Gettysburg bank north-westward in agreement with the results by Zenk and Armi (1990). One part of the core goes round the Tejo plateau, another one turns west, skirts the northern part of the Ashton seamount and splits into two branches. The first(northwest) branch crosses the Iberian abyssal plane and forms several patches of saline water at 41°–44° N after passing over small unnamed peaks shown

Fig. 4. Contours of the salinity anomaly field $S_{\delta} \geq 0.3$ psu at 1100 m depth.

in Fig. 8. The second (western) branch skirts the Josephine seamount and turns west-southwestward. It is split into isolated patches of more saline water in the latitude band of 36°–38° N.

The second of the two basic cores spreads from the Cape St. Vincent southwestward through the passage between the Gettysburg bank and the Ampere seamount. It skirts the southern peripheries of the Hirondele and Josephine seamounts. This core is not so wide as the main one. It

Fig. 5. Locations of MEDDIES in the Iberian Basin based on Table 3. OLD - MEDDIES reported in the literature before; NEW - MEDDIES found in this paper using the archival data set and not reported in the literature before.

Fig. 6. Salinity cross section through the lens observed by R/V *Viktor Bugaev*. The lens is centered at 36° N, 17° 30' W.

becomes intermittent earlier (approx. since 12° W). West of 16° W it becomes fully discrete and probably joins the main northwest core. Fig. 3 shows also a tendency for the southwest core to be split forming a more southern branch directed from the Cape St. Vincent to the Canary Basin.

Fig. 4. shows the distribution of S_{delta} at 1100 m. Small values of S_{delta} correspond to continuous, regular spreading of MW. The main northwest core is continuous east of 16° W where typical values of $S_{\text{delta}} < 0.3$ psu. The values of $S_{\text{delta}} \geq 0.3$ psu are typical for the lenticular structure of MW. They occur mainly inside the zonal band 34°–38° N west of 15°–16° W.

Fig. 7. Salinity cross section through the lens observed by R/V *Ernst Krenkel*. The lens is centered at 36° N, 22° 30' W.

The southward band of high S_{delta} values near the Cape St. Vincent shows that the south branch of the southwest core of MW outflow consists mainly of isolated patches and lenses.

The discrete component of MW outflow was studied in more detail by analyzing individual anomalous stations and the areas around. The number of stations having positive salinity anomalies $dS = (S - S_{\text{mean}})$ of 0.2–0.8 psu and thickness of an anomalous layer not less than 200 m is presented in Table 2. Based on vertical salinity sections we identify thirty lenses of Mediterranean Water (MEDDIES) in our data base. To our knowledge, twelve of them were not mentioned in the literature before. It was found that 619 anomalous stations were not taken in MEDDIES. We had not enough data to distinguish trustworthy the other thirty stations.

We carried out a similar search for the larger area of Eastern North Atlantic (20°–50° N, 8°–30° W). We found the total amount of 46 MEDDIES, 22 of which were not reported in the literature. The results of our search together with the lenses reported earlier are listed in Table 3.

Fig. 8. Composed pattern of main spreading paths of the Mediterranean Water in the Iberian Basin superimposed to the bottom topography. Isobaths 1000, 2000 and 3000 m are shown, areas shallower than 2000 m are shaded. List of locations: 1. Cape St. Vincent; 2. Tejo plateau; 3. Gettysburg bank; 4. Ashton seamount; 5. Hirondele seamount; 6. Ampere seamount; 7. Josephine seamount; 8. Madeira Islands.

Fig. 9. Salinity cross sections along 41° N off the Portuguese continental slope: (a) R/V *Elisha Kent Kane* (Nov. 1972); (b) archival data (1914–1982).

This Table is more complete than published before (Belkin et al., 1986; Belkin and Kostianoy, 1988; Richardson et al., 1991). The locations of the lenses in the Iberian Basin are shown in Fig. 5.

The number of lenses is less than the number of anomalous stations because of two reasons. First, normally there are several stations in the

same lens. Second, many stations with small values of dS were taken not in lenses but in the meanders of continuous large scale MW tongue.

Examples of individual lenses found in historical data are shown in Figs. 6, 7. Fig. 6 shows the lens revealed in hydrographic survey data gathered by R/V *Viktor Bugaev* (USSR) in January 1983. The lens belongs to the southwest core of

Fig. 10. Salinity cross sections along 42° N off the Portuguese continental slope: (a) R.R.S. *Discovery* (Jan. 1977); (b) Archival data (1914–1982).

the MW outflow. The maximal salinity is as large as 36.4 psu. One can see a “tail” of less saline water spreading east of the lens. Fig. 7 shows a lens found in data gathered by R/V *Ernst Krenkel* (USSR) in August, 1983. The lens is positioned at the same latitude but 5 degrees west and is a part of the same branch of MW. In the case of more distant lens the salty “tail” is ultimately divorced from the lens body.

The distribution of individual lenses shown in Fig. 5 allows to trace the main cores and branches of MW in the Iberian Basin. The discrete analysis confirms the main paths of MW spreading found above using statistical methods. Particularly the presence of the southward branch of the southwest core is supported by occurrence of at least 10 MW lenses. Additionally there are some indications that some lenses are transported across the Iberian abyssal plane far to the north (at 42° – 44° N) by the weak northwest branch of the main MW outflow.

4. Conclusions

The joint analysis of the distribution of continuous and discrete component allows us to reveal the qualitative pattern of the MW outflow in the Iberian Basin (Fig. 8). The most important result of our study is that in the coastal zone of the Iberian Basin the climatic pattern of the MW spreading constructed here using historical data coincides basically with the synoptic pattern suggested by Zenk and Armi (1990) on the basis of CTD-measurements in January 1989 (F/S *Meteor*) and June 1989 (F/S *Poseidon*). This coincidence is not a chance. It is supported by the analysis of salinity distributions at 41° N (Fig. 9) and 42° N (Fig. 10) off the Portuguese continental slope. The synoptic sections conducted by R/V *Elisha Kent Kane* in November 1972 (Fig. 9a) and R.R.S. *Discovery* in January 1977 (Fig. 10a) are practically similar to the corresponding climatic sections (Figs. 9b, 10b) based on historical data collected in 1914–1982. It confirms our initial assumption that the Mediterranean Water distribution has a regular component in the eastern boundary layer of the Atlantic and the flow

paths of MW are determined by local inhomogeneities of the bottom topography.

Acknowledgements

Funds were provided by the Russian Fund of Fundamental Research grants 94-05-17302a and 94-05-17400a and by the Russian Ministry of Science and Technology and by ISF Grant JG 7100.

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