Bollettino di Geofisica Teorica ed Applicata Vol. 44, n. 1, pp. 11-17; March 2003

Climatological analysis (1991-2002) of the thermohaline characteristics in the Marine Reserve of Miramare (Gulf of Trieste)

A. Bussani, M. Celio and C. Comici

Laboratorio di Biologia Marina, Trieste, Italy

(Received, January 23, 2003; accepted March 3, 2003)

Abstract - A climatological analysis has been performed on the seawater temperature, salinity and density excess data collected by the Laboratory of Marine Biology (LBM) in the Marine Reserve of Miramare (Gulf of Trieste) from January 1991 to July 2002. For each depth and parameter, descriptive statistics have been worked out and minumum, maximum and mean values at 0.5, 5, 10 and 15 meters are reported. A least squares trigonometric best-fit interpolation was then performed in order to compare LBM data with other data available in literature. The comparison has showed an increase of the seawater temperature of about 0.5 °C on the whole water column with respect to 1980-82 data and a phase difference of about one month in the salinity signal, while the mean annual salinity has not changed. The temperature increase is in accordance with the temperature data collected by the Istituto Sperimentale Talassografico – CNR of Trieste.

1. Introduction

The Marine Reserve of Miramare is a marine protected area situated in the Gulf of Trieste (Northern Adriatic Sea) in correspondence to the Miramare promontory (Fig. 1). The oceanographic characteristics of this area and, more generally, of the whole gulf, have been widely described in the literature (Stravisi 1983a, 1983b, 1988, 2000; Mosetti, 1988; Malacic, 1991; Cardin and Celio, 1997; Vinzi and Bussani, 2000; Celio et al., 2002) but few works (Stravisi, 2000; Celio et al., 2002) have faced the question of a climatological analysis of the thermohaline parameters, due to the lack of a long-time series for temperature and salinity data, with particular regard to the latter parameter.

Corresponding author: A. Bussani, Laboratorio di Biologia Marina, Via Auguste Piccard 54, 34010 Trieste, Phone: +39 040224400, Fax +39 040224437; e-mail: andrea.bussani@libero.it

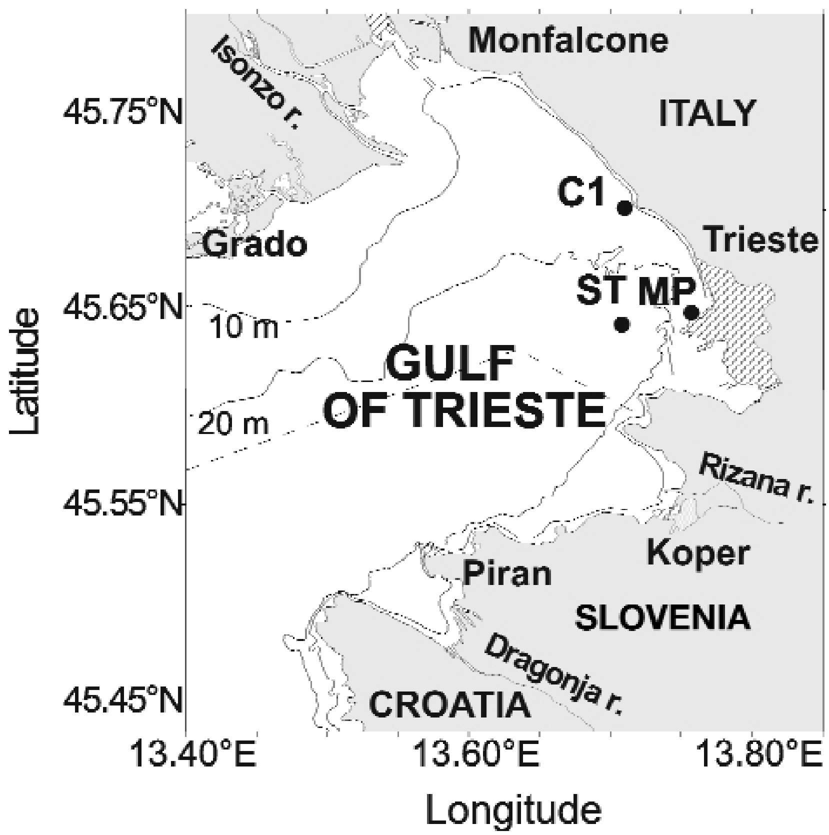

Fig. 1 - Gulf of Trieste and sampling stations.

The Laboratory of Marine Biology of Trieste (LBM) has been performing periodical samplings of the thermohaline parameters in the Marine Reserve of Miramare since 1986 and the use of multiparametric CTD probes started in 1991.

In this work, we analyse the CTD data collected in the Marine Reserve of Miramare by LBM from January 1991 to July 2002 and compare the results with other data available for the thermohaline parameters of the Gulf of Trieste (Stravisi, 1983b, 2000), adding new information to what was previously reported by Celio et al. (2002).

2. Materials and methods

The CTD vertical profiles were performed in a station (C1) situated in the Marine Reserve of Miramare (Fig. 1) at about 200 m from shore. The average depth of the station is 17 m. The measurements were collected from January 1991 to July 2002, with a circa-monthly sampling frequency (from one cruise per month up to two-three cruises per month), though a few months are missing (April 1992, April 1995, March and November 1997). CTD Idronaut 401 and 316 multiparametric probes, calibrated at time intervals of 6-12 months, were used with a pressure step of about 0.1-0.2 dbar. Soon after the acquisition of each profile, the CTD data underwent a visual check to prevent the collection of spurious values or spikes. Then data were averaged per meter (0.5 m, 1 m, 2 m, … up to 16 m). Salinity and density excess were obtained by applying algorithms for the computation of fundamental seawater properties (UNESCO, 1983). The total number of CTD profiles used in this work is 194.

The subsequent climatological analysis was performed on temperature, salinity and density excess data by means of both descriptive statistics and least-squares best-fit analysis. The first approach produced tables reporting minimum, maximum and mean values for temperature, salinity and density excess at different depths. In the second kind of analysis, data were interpolated for each depth and physical parameter, by means of a least squares trigonometric fitting procedure, according to the following formula (Stravisi, 1983b):

$$F(z, t) = A(z) + a(z) \cos (2\pi (t-\alpha (z))/T) + b(z) \cos (4\pi (t-\beta(z))/T), \quad (1)$$

where $T = 1$ year, z is the depth and t is the time. This fitting procedure is computed after Stravisi (1983b) in order to set up a best-fit data set that could be compared to what Stravisi (1983b) reported for the Gulf of Trieste for the years 1980-1982.

3. Results

3.1. Descriptive statistics of 1991-2002 data

The minimum, maximum, average and standard deviation values of temperature, salinity and density excess for each month and depth are represented in Fig. 2.

Temperature shows the well-known annual cycle: a thermally homogeneous water column characterizes autumn and winter, while a strong stratification is present in late spring and early summer. The thermocline disappears rather abruptly between September and October and the asymmetry in the temperature annual cycle is due to the different processes of heating and cooling of the water masses (Stravisi, 1983b).

The mean values of salinity, show an annual cycle characterized by the presence of two minima, in late spring (May and June) and autumn (mainly October), and two maxima, in winter (between December and March) and summer (August). In spring, the low salinity period is longer than in autumn, but the lowest salinity values are recorded in October. This is due to the different origin of the freshwater inputs: spring is characterized by snow melting and by the presence of a marked thermocline that prevents the mixing of freshwater with deeper layers. In October, river flows are dominated by rainfall and the fresh water inputs affect the subsurface seawater layer: a strong plume event can cause a drop of surface salinity to values lower than 20 (Naudin et al., 1996).

Density excess values are driven mainly by the temperature trend, but in October, the significant drop of density at the surface (1024 kg/m^3) is due to the low salinity values. The

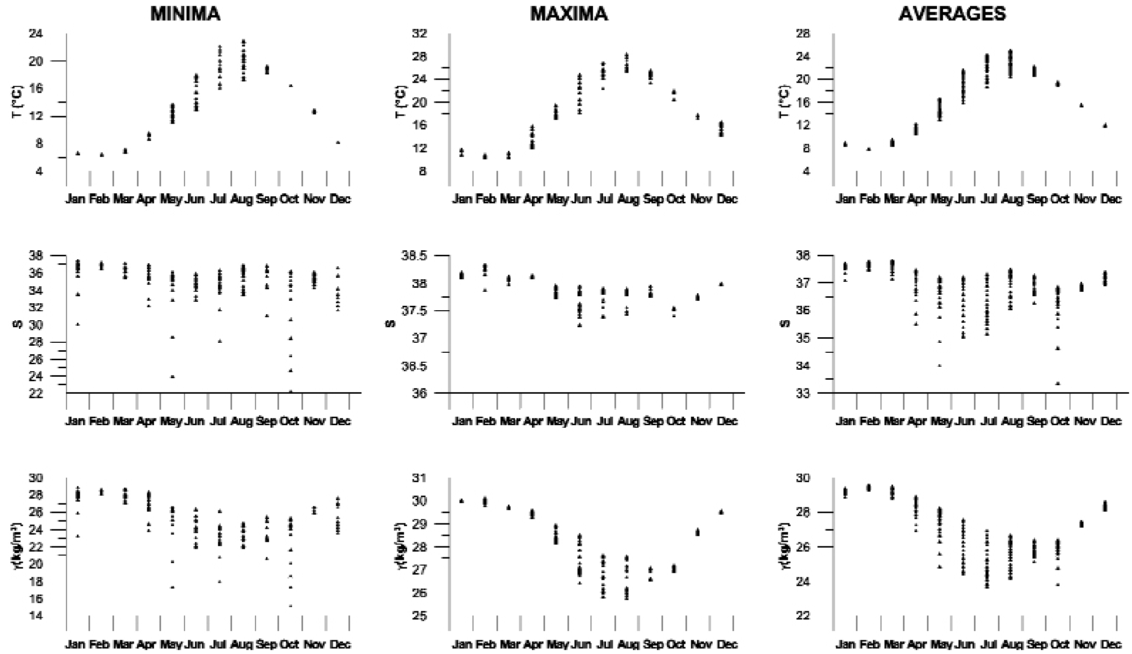

Fig. 2 - Minimum, maximum and mean values of seawater temperature, salinity and density excess for each month and depth at station C1 from January 1991 to July 2002.

formation of dense water (~ 1030 kg/m^3) can be seen in February. Such value is bigger than that used by Artegiani et al. (1997) to define the lower limit of Middle Adriatic Dense Water.

Table 1 shows the marked variability of the thermohaline parameters in the Gulf of Trieste very clearly: the differences between the maximum and minimum values over the whole water column are 21.99 °C, 16.12 and 14.99 kg/m^3 for temperature, salinity and density excess, respectively.

Table 1 - Minimum, maximum and mean values of temperature, salinity and density excess at four different depths (the dates represent the days in which the minimum and maximum values were recorded).

Depth (m)		Temperature (°C)		Salinity		Density excess (kg/m^3)	
0.5	Min	6.47	19/02/1991	22.21	01/10/1991	15.09	01/10/1991
	Max	28.39	04/08/1998	38.12	17/01/2000	29.93	21/01/2002
	Avg	16.12		35.89		26.25	
5	Min	6.43	19/02/1991	32.95	12/10/1998	22.47	01/07/1998
	Max	26.07	03/08/1992	38.29	03/02/2000	30.01	03/02/2000
	Avg	15.66		36.76		27.06	
10	Min	6.42	19/02/1991	34.57	24/06/1997	23.60	10/07/2001
	Max	25.50	23/08/1994	38.32	03/02/2000	30.05	03/02/2000
	Avg	15.11		37.10		27.48	
15	Min	6.40	19/02/1991	35.25	24/06/1997	24.25	04/07/2000
	Max	25.47	23/08/1994	38.33	03/02/2000	30.08	03/02/2000
	Avg	14.51		37.33		27.83	

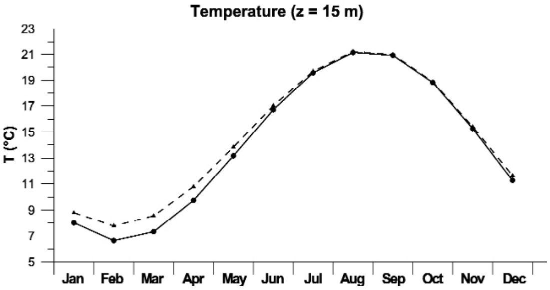

Fig. 3 - 2-harmonics best-fit plots for temperature at 15 m computed by Stravisi (1983b) (continuous line) and LBM (dashed line).

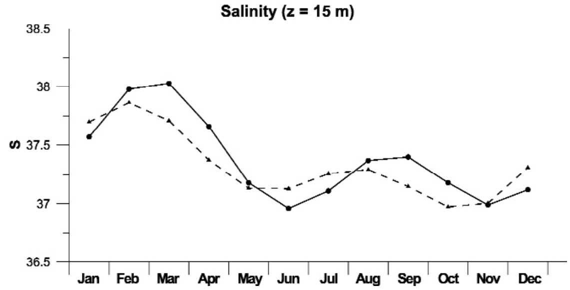

Fig. 4 - 2-harmonics best-fit curves for salinity at 15 m computed by Stravisi (1983b) (continuous line) and LBM (dashed line).

3.2. Comparison between 1980-1982 and 1991-2002 data

Between 1980 and 1982 Stravisi (1983b) performed CTD profiles in a sampling station situated 2 nautical miles west of Trieste Harbour (station ST, Fig. 1). Data were then interpolated with the function given in Eq. (1). The differences between the two best fit data sets, Stravisi 1980-1982 and LBM 1991-2002, show that the annual mean in temperature has increased by about 0.5 °C over the whole water column. At almost all depths, and in particular at the deepest (Fig. 3), the largest differences of temperature between the two sets can be found from January to May, with particular regard for March. Such increase can be explained considering the seawater temperatures of the Gulf of Trieste from 1946 to 1999 (Stravisi, 2000), collected at 2 m at station MP (Fig. 1): as showed in Fig. 5, the first Eighties were characterized by rather low values of the annual mean temperature. The temperature increase could be interpreted as a re-alignment of the temperature to the normal mean values, after the drop that occurred in those years.

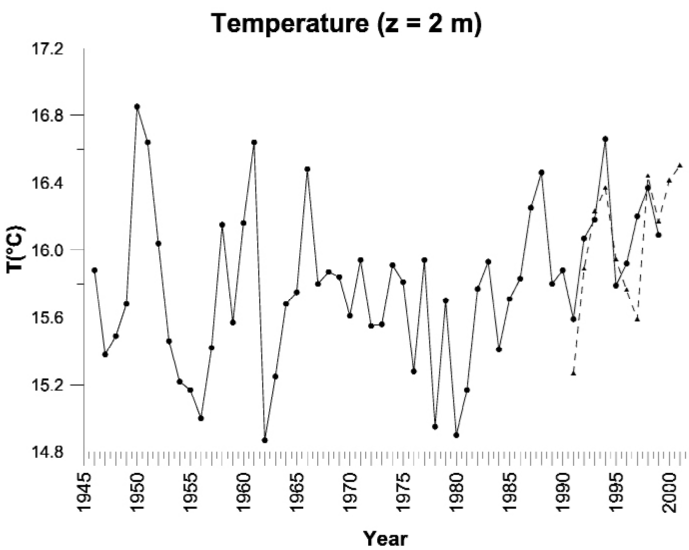

Fig. 5 - 2 m depth temperature data collected by Stravisi (2000) (continuous line) in station MP (Fig. 1) from 1946 to 1999 and by LBM (dashed line) in station C1 (Fig. 1) from 1991 to 2002.

From Fig. 4 another interesting consideration can be deduced: the salinity annual mean has not changed at any depth (Table 2) but a phase difference between the LBM and Stravisi salinity signal is detected. Data collected in 1991-2002 seem to be one month early with respect to what was recorded in the years 1980-1982. This might be due to a change in the circulation of the gulf and, more generally, of the northern Adriatic, maybe induced also by the variation of the density values, 0.5 kg/m^3 lower in March 1991-2002 with respect to March 1980-1982. However, a much more thorough and specific research work should be performed to get a deeper understanding of the underlying phenomena.

Table 2 - Annual mean values for temperature, salinity and density excess collected by Stravisi (1983b) and by LBM at four different depths. The last column represents the differences between Stravisi and LBM data.

Depth (m)	**T_S (°C)**	**T_{LBM} (°C)**	**ΔT (°C)**
0.5	15.72	16.17	0.45
5	15.12	15.71	0.59
10	14.62	15.15	0.53
15	14.05	14.55	0.50
Depth (m)	**S_S**	**S_{LBM}**	**ΔS**
0.5	35.87	35.91	0.04
5	36.78	36.75	-0.03
10	37.12	37.10	-0.02
15	37.38	37.32	-0.06
Depth (m)	**γ_s S(S,T,p) (kg/m^3)**	**γ_{LBM}(S,T,p) (kg/m^3)**	**Δγ (S,T,p) (kg/m^3)**
0.5	26.34	26.26	-0.08
5	27.19	27.04	-0.15
10	27.60	27.47	-0.13
15	27.95	27.82	-0.13

4. Conclusions

In this work, CTD data collected by LBM in the Marine Reserve of Miramare from January 1991 to July 2002 have been analysed from a climatological point of view and have been compared to other data found in literature relative to the years 1980-1982. The analysis confirmed the wide range of variability for the thermohaline parameters in the Gulf of Trieste, especially as regards surface salinity values, strongly affected by Isonzo river plumes.

The comparison between 1980-1982 and 1991-2002 data showed a marked increase in the temperature annual mean (~ 0.5 °C) on the whole water column and the difference is mainly due to the much higher (> 1 °C) values recorded in winter and early spring.

Salinity annual means have not changed, but the phase of the 2-harmonics salinity signal obtained by LBM is one month early with respect to the 1980-1982 signal.

Density excess annual means diminished by about 0.1 kg/m^3 and, in particular, by about 0.5 kg/m^3 in the monthly mean of March computed upon best fit data. Although during the winter period dense water formation is still present, this decrease could affect the northern Adriatic general circulation.

Acknowledgments. This work has been supported by Alpe Adria and Interreg Project and the Italian Environment Ministry Monitoring Programs. It was presented at the Workshop "Monitoring techniques applied to Marine Protected Areas Management – Trieste, 19-20 September 2002". The authors wish to thank Prof. Vlado Malacic and Prof. Serena Fonda Umani for their useful criticisms and comments and Dr. Fabio Voltolina for the data collection and elaboration.

References

Artegiani A., Bregant D., Paschini E., Pinardi N., Raicich F. and Russo A.; 1997: *The Adriatic Sea general circulation. Part II: baroclinic circulation structure*. J. of Phys. Oceanogr., **27**, 1515-1532.

Cardin V. and Celio M.; 1997: *Cluster Analysis as a statistical method for identification of the water bodies present in the Gulf of Trieste (Northern Adriatic Sea)*. Boll. Geof. Teor. Appl., **38**, 119-135.

Celio M., Comici C. and Bussani A.; 2002: *Thermohaline anomalies in the spring and early summer of 2000 in the Gulf of Trieste*. Mar. Ecol., **23**, supplement 1, 101-110.

Mosetti F.; 1988: *Condizioni idrologiche della costiera triestina*. Hydrores Information, **6**, 29-38.

Malacic V.; 1991: *Estimation of the vertical eddy diffusion coefficient of heat in the Gulf of Trieste (northern Adriatic)*. Oceanol. Acta, **14**, 23-32.

Naudin J.J., Malacic V. and Celio M.; 1996: *Hydrological characteristics of the Gulf of Trieste (northern Adriatic) during high fresh-water input in early summer.* In: Proc. of the workshop "Physical and biogeochemical processes in the Adriatic Sea", Portonovo (AN), Italy, 23-27 April 1996, pp. 71-81.

Stravisi F.; 1983a: *Some characteristics of the circulation in the Gulf of Trieste*. Thalassia Jugosl., **19**, 355-363.

Stravisi F.; 1983b: *The vertical structure annual cycle of the mass field parameters in the Gulf of Trieste*. Boll. Oceanol. Teor. Appl., **3**, 239-250.

Stravisi F.; 1988: *Caratteristiche oceanografiche del Golfo di Trieste, Parco Marino di Miramare*. Hydrores Information, **6**, 39-45.

Stravisi F.; 2000: *La temperatura del mare a Trieste: 1946-1999*. Hydrores Information, **20**, 7-16.

UNESCO; 1983: *Algorithms for computation of fundamental properties of seawater.* UNESCO Technical Papers in Marine Science, **44**, 1-53.

Vinzi E. and Bussani A.; 2000: *Risultati del monitoraggio delle caratteristiche termoaline in una stazione presso la Riserva Marina di Miramare (Trieste) nel periodo 1997-2000*. Hydrores Information, **20**, 85-102.