Digital Atlas and Evaluation of the Influence of Inter-Annual Variability on Climate Analyses

A.M. Suvorov[1], D. R. Palmer[2], A. Kh. Khaliulin[1], E.A. Godin[1], V.N. Belokopytov[1]
[1] Marine Hydrophysical Institute of the Ukrainian NAS
2 Kapitanskaya Street,
Sevastopol, 99011, Ukraine
suvorov@alpha.mhi.iuf.net
[2] NOAA/Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Cswy.,
Miami, FL, 33149, USA
david.r.palmer@noaa.gov

***Abstract-* The Black Sea is a well-investigated marine basin. Since 1980 more than 100,000 oceanographic stations have been established in it. However, their distribution in time and location is not uniform and the number of observations significantly decreases with depth. Comparisons of climate products obtained from temperature and salinity data at different periods of time are characterized by significant differences. This can be explained by the fact that many results were obtained from a limited and not always comprehensive information set and by the considerable dependence of the results upon the methods of calculation. As is known, until recently, the inter-annual variability of hydrological parameters was not taken into account when calculating climate products. The purpose of this work is to demonstrate a necessity of taking into account the inter-annual variability of hydrological parameters when calculating climatic products.**

I. DIGITAL ATLAS. CALCULATION METHODS.

Climatic fields were computed from the individual observations in the following manner:

- All quality controlled observations are averaged into the raw monthly values in each box of 20’x30’ for each month during appointed period on the depth intervals: 5 m to 100 m, 10 m to 300 m, 50 m to 1000 m, 100 m up to the bottom.
- The raw monthly fields objectively analyzed on a regular grid of 20’x30’ for each month in layer 0-200 m and yearly deeper than 200 m.

The vertical interpolation method was adopted from Reiniger, Ross (1968) which represents a combination of weighted parabolas and linear interpolation. The objective analysis scheme used is similar the scheme described by Levitus (1982) and Silva, Young, and Levitus (1994). This is an iterative difference-correction scheme (Cressman, 1959) with a weight function developed by Barnes (1954). That is

$$g_l(i,j) = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N} w_{l,m,n}[f(m,n) - g_{l-1}(m,n)]}{\sum_{m=1}^{M}\sum_{n=1}^{N} w_{l,m,n}} + g_{l-1}(i,j)$$

with the weight function

$$w_{l,m,n} = \exp(-r^2{}_{m,n} / 4K_l - t^2{}_{m,n} / 4V_l)$$

where
g = interpolated value
f = raw value
l = iteration number
t = time
r = distance
K = radius of influence
V = temporal radius

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE **01 SEP 2003**		2. REPORT TYPE **N/A**			3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Digital Atlas and Evaluation of the Influence of Inter-Annual Variability on Climate Analyses**					5a. CONTRACT NUMBER
					5b. GRANT NUMBER
					5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER
					5e. TASK NUMBER
					5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Marine Hydrophysical Institute of the Ukrainian NAS 2 Kapitanskaya Street, Sevastopol, 99011, Ukraine**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S)
					11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**					
13. SUPPLEMENTARY NOTES **See also ADM002146. Oceans 2003 MTS/IEEE Conference, held in San Diego, California on September 22-26, 2003. U.S. Government or Federal Purpose Rights License, The original document contains color images.**					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**6**	

A first guess was computed as

$$g_0(i,j)=\frac{\sum_{m=1}^{M}\sum_{n=1}^{N} w_{0,m,n} f(m,n)}{\sum_{m=1}^{M}\sum_{n=1}^{N} w_{0,m,n}}$$

To filter out spatial noise a 5-point nonlinear median filter (Beaton and Tukey, 1974) followed by two passes of a 5-point linear filter (Shapiro, 1970) was applied. The first guess was determined with a radius of influence of 128 NM. The objective analysis scheme repeated twice with radii of influence of 64 and 32 NM.

II. DIGITAL ATLAS. DESCRIPTION.

Digital atlas "Physical Oceanography of the Black Sea" was created on the base of the gridded climatic fields of temperature and salinity on 19 standard depths (0-2000 m) computed from data stored in the Black Sea data base. The gridded data have been calculated through objective analysis scheme [1-4], taking into account only the data which passed all the quality checks.

Horisontal grid resolution is 0.333 degree in latitude and 0.5 degree in longitude. Time resolution is monthly from the surface down to 300 m and annual below. Climatic fields of density, dynamic heights 0-300 db and heat storage 0-100 m were derived from climatic values of temperature and salinity. As a whole 444 WMF maps of mean values are presented on the CD-ROM atlas, see Tabl.1.

Climatic maps display all the oceanographic peculiarities of the basin. The Black Sea is a dilution basin due to substantial excess of river runoff, with surface salinity as two times less than in the Atlantic. It gains more saline deep waters from the adjacent Mediterranean. Winter convective overturning in the Black Sea never penetrates below the relatively shallow halocline and forms the prominent feature: Cold Intermediate Layer (CIL) which is confined within 40-100 m. CIL seasonal evolution consists of winter renewal mainly in western part of the basin and following advection by general circulation.

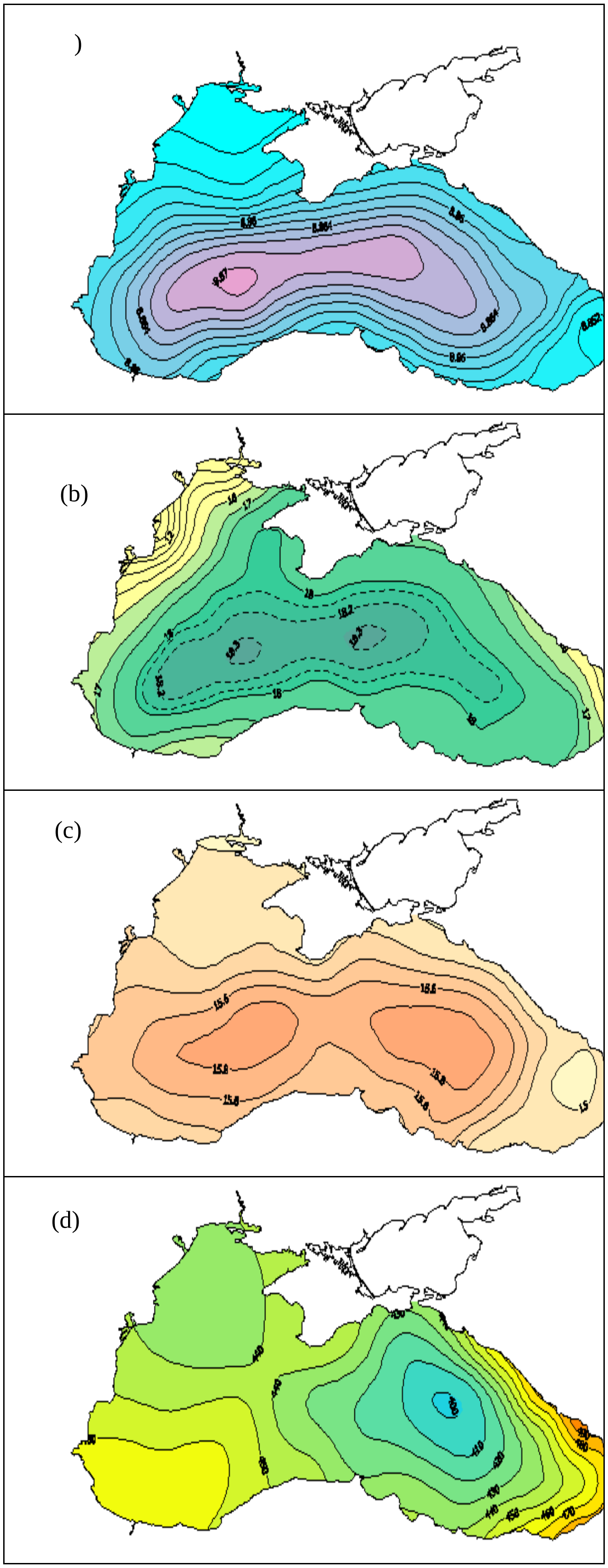
Table 1. List of maps presented in atlas "Physical Oceanography of the Black Sea"

Variable	Monthly	Annual
Temperature	0,10,20,30,50, 75,100,150, 200,250,300	400,500,600, 800,1000,1200, 1500,2000
Salinity	0,10,20,30,50, 75,100,150, 200,250,300	400,500,600, 800,1000,1200, 1500,2000
Density	0,10,20,30,50, 75,100,150,20 0,250,300	400,500,600, 800,1000,1200, 1500,2000
Heat storage	0-100	
Dynamic height	0-300	

Circulation pattern in the Black Sea such as general cyclonic rotation and existence of stationary gyres strongly depends on large-scale wind forcing. Positive wind curl reinforces in winter due to as cyclogenesis intensification on the Mediterranean branch of the Polar front. Decrease of wind curl is observed in summer owing to northeastward spreading of the Azor High and general weakening of atmospheric circulation. Dynamic topography has similar seasonal difference: strong single cyclonic gyre in winter; two weak cyclonic gyres and prominent anticyclone eddies in summer.

Ratio of different types of variability reveals that seasonal march prevails only for case of temperature in the layer from the surface down to 30 m. Long-term variability is very important : for CIL renewal as it depends on large year-to-year variations of winter cooling; for diluting of the sea as it depends on prominent long-term variability of rivers' runoff and for vertical displacements of main pycnocline which strongly depends on atmospheric circulation.

Examples of the climatic atlas maps are presented on the Figure 1.



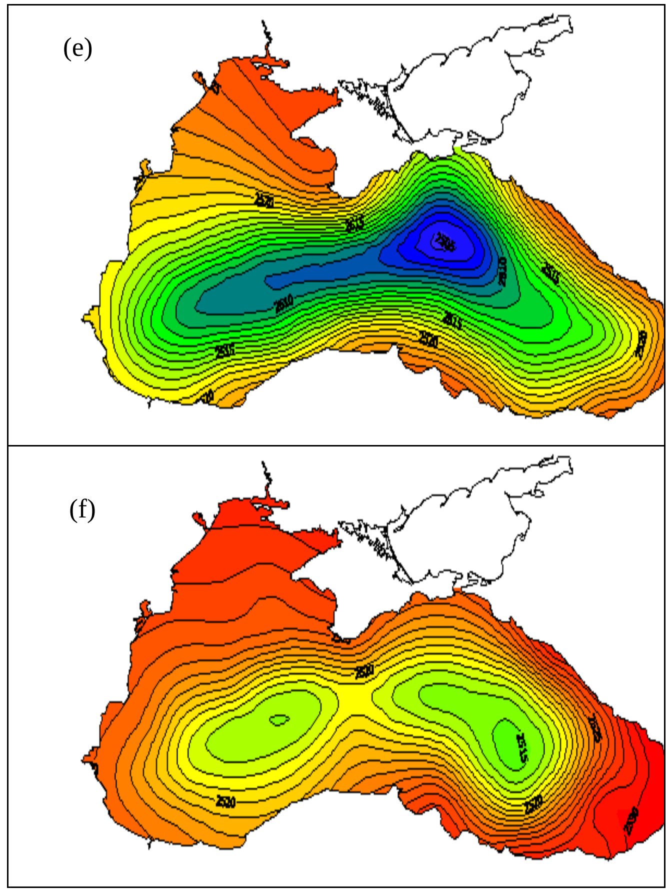


Fig.1 Climatic atlas map examples: (a) Temperature on 400 m; (b) Salinity on surface in May; (c) Density on 100 m in September; (d) Heat storage 0-100 m in September; (e) Dynamic height 0-300 db in February; (f) Dynamic height 0-300 db in August

III. EVALUATION OF THE INFLUENCE OF INTER-ANNUAL VARIABILITY

Most of the existing methods for calculating climate products from temperature and salinity data do not take into account inter-annual variability. As an illustration, most of the existing temperature and salinity data for the Black Sea were collected in the period from 1960 to 1995. In fact more than 50% of these data were collected in the 1970's and 1980's. Without taking into account inter-annual variability, climate products calculated from these data can only reflect conditions during this brief period.

We have estimated the behavior of temperature and salinity for the years when there were no correspondent observations in the Black Sea by establishing a connection between these parameters and environmental parameters reflecting global climatic variations and having a longer measurement period. These environmental parameters included the North Atlantic Oscillation index and sea level observation at locations in the Azov-Black Sea Basin. We using a new data base created as part of our project "Rescue of Black Sea Hydrological Data for Regional Classification and Studies of Seasonal and Inter-annual Variability." For five Black Sea ocean regions, picked because the existing data are plentiful, we have analyzed temperature and salinity data for depth levels below the cold intermediate layer where seasonal variability can be ignored.

For our study observed temperature and salinity data were picked for 4 levels (150, 300, 500 and 1000 m) and for 5 squares of the Black Sea. The size of each square is 40' by 60'. (This is approximately equivalent to an area 40 by 40 nm.) The squares are located in regions of the Black Sea having pronounced hydrological peculiarities and for which a large amount of observational data are available. (Fig.2 shows the locations of the squares and the number of stations that have been established within each square.) By selecting levels below the cold intermediate layer we are able to ignore seasonal variability. The size of the squares was picked so that we can safely ignore within each square the spatial variability of temperature and salinity.

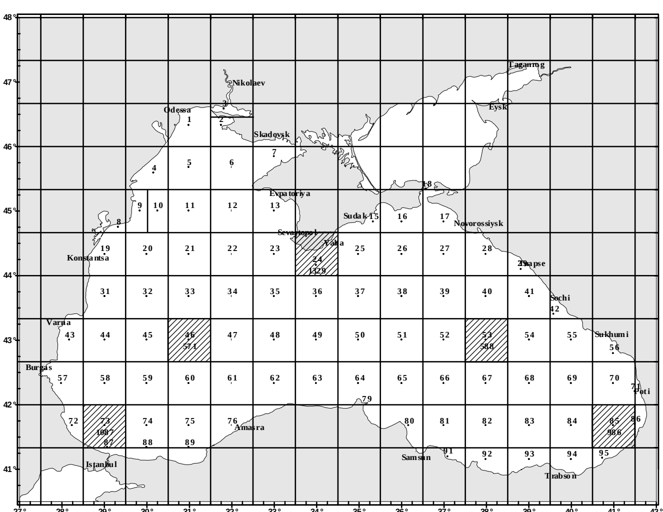


Fig. 2. Distribution of the squares (up – number of square, down – number of stations).

Most of the existing temperature and salinity data for the Black Sea were collected in the period from 1960 to 1995. In fact, more than 50% of these data were collected in the 1970's and 1980's. Without taking into account inter-annual variability, climate products calculated from these data can only reflect conditions during this brief observational period. Moreover, the number of observations significantly decreases with depth further reducing the reliability of climatic products (Table 2.).

Table 2. Number of stations for various depths.

DEPTH	SQUARES				
	24	46	53	73	85
150	1329	571	588	1087	986
200	1263	555	567	1042	950
250	958	507	498	987	631
300	869	487	461	935	543
350	617	441	334	847	299
400	597	438	331	825	295
500	537	418	319	708	264
800	283	298	198	362	101
1000	203	260	177	218	67
1500	42	104	86	22	25

Because in this study we are interested in long-period variability we have used a filter with a cut-off of 20 years to exclude those short-period components with periods of 15-20 years. The results we have obtained are shown in Fig. 3.

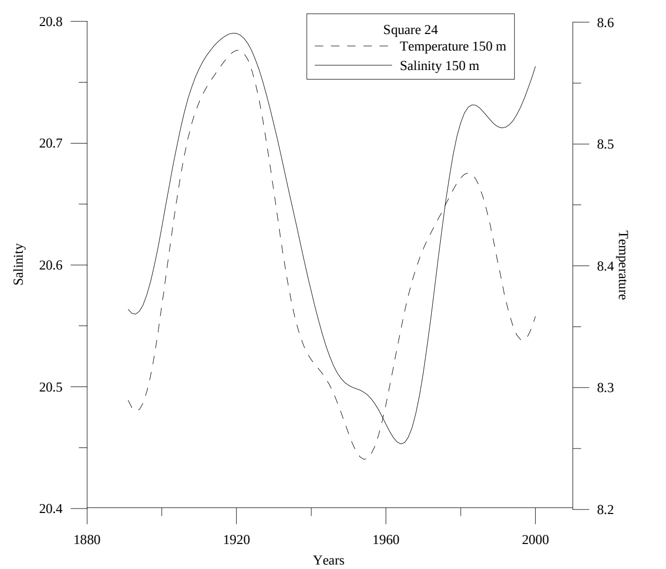


Fig. 3. Filtered Temperature and Salinity. Depth 150 m.

Analysis of these results show:

- the similarity of the temporal variation of the parameters in all the squares and at all the levels;
- the decrease in short-period oscillations with depth;
- the significant contribution at all levels of the long-period oscillations; and
- the contribution of the long-period component to dispersion increases with depth and its relative weight to dispersion becomes considerably greater.

possible dependence of inter-annual variability

Figure 4 shows the average multiannual variability of salinity on 150m and the filtered values of North Atlantic Oscillation index. One can assume that these curves describe some global climatic process, which has no constant trend. Apparently, the salinity oscillates in time, with cyclicity being approximately century-long. Comparing the curves, one can conclude that the diagrams showing the variability of the salinity and the NOAI agree well, which supports the corollary about the oscillatory nature of variability in the Black Sea.

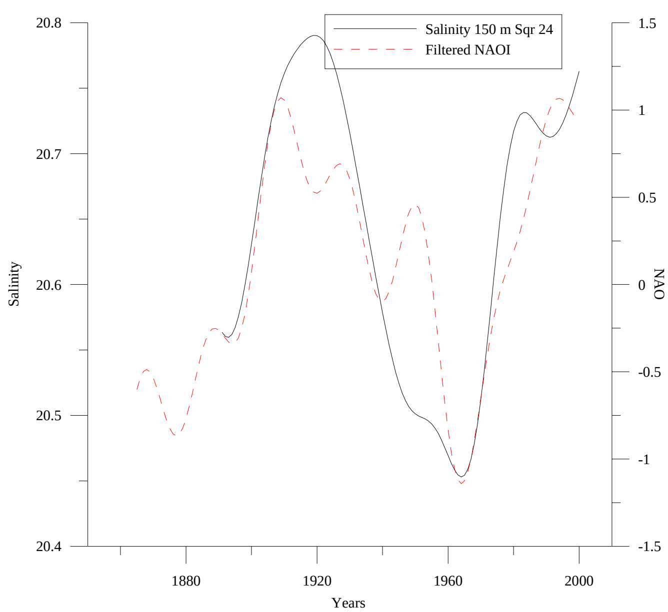


Fig. 3. The multiannual variability NAOI and Salinity on the depth 150 m.

This analysis shows the existence of pronounced inter-annual variability. Table 3a,b (1.Calculated value for the entire data set. 2.Calculated value for the mean annual values. 3.Smoothed value accounting the internal structure of observation set. - for filtered values) summarizes our results and illustrates the dependence of results on the method used to calculated climate products.

Table 3a. Square 24. Temperature.

Depth	TEMPERATURE			
	Standard Deviation	1	2	3
Square 24				
150 m	0.198	8.416	8.410	8.401
300 m	0.074	8.811	8.807	8.809
500 m	0.056	8.877	8.876	8.870
1000 m	0.042	8.952	8.953	8.948

Table 3a. Square 24. Salinity.

Depth	SALINITY			
	Standard Deviation	1	2	3
Square 24				
150 m	0.406	20.658	20.647	20.641
300 m	0.156	21.678	21.667	21.626
500 m	0.103	22.025	22.012	21.999
1000 m	0.080	22.284	22.281	22.273

IV. CONCLUSIONS

The investigation resulted in the following conclusions:

- Long-term variability with periods of 3-5 years, 11-12 years, 25-30 years, and, by reckoning, 90-100 years existed in all marine and atmospheric parameters studied.

- A significant connection exists between the variability in temperature and salinity and atmosphere circulation characteristics and sea-level changes.
- Phase shifts were found in the multi-annual time series of temperature and salinity in comparison to that of the parameters of atmospheric circulation and sea level observations.

The investigation resulted in a better understanding of the relevant processes and an increase in the accuracy and reliability of estimates of Black Sea climatic parameters and demonstrated the existence of a pronounced inter-annual variability. Further, it demonstrated the important result that the values obtained for climate products can depend on the method of calculation.

V. ACKNOWLEDGEMENTS

The authors thank both ESDIM which financial support made accomplishment of this work possible and Grant Assistant Programme of CRDF (Project UG0-1270) for their assistance

VI. REFERENCES

Levitus, S.: Climatological Atlas of the World Ocean, 1982: NOAA Prof. Paper No. 13 , U.S. Government Printing Office, Washington D.C., 173 pp.

Cressman, G.P., 1959: An operational objective analysis scheme: *Mon. Wea. Rev*., No 87, 329-340.

Barnes, S.L., 1964: A technique for maximizing details in numerical weather map analysis. *J. Appl. Meteor*., No 3, 396-409.

Beaton, A.E., and J.W.Tukey, 1974: The fitting of power series, meaning polynomials, illustrated on band-spectroscopic data. *Technometrics*, No 16, 147-185.

Shapiro, R., 1970: Smoothing, filtering and boundary effects. *Rev. of Geophys. and Space Phys.*, No 8, 359-387.

Silva, A.M., Young C. C. and S. Levitus, 1994: Atlas of surface marine data. NOAA Atlas NESDIS, Washington, D.C.

Eremeev V.N., Suvorov A.M., Khaliulin A.Kh., Godin E.A. Oceanographic Data Development for Anoxic Zone Boundary in the Black Sea. Proceedings of the NATO Advanced Research Workshop on Integrated Approach to Environmental Da-ta Management Systems, Bornova, Izmir, Turkey, September 16-20, Kluwer Academic Publishers Dordrecht /Boston/ London 1997

Eremeev V.N., Suvorov A.M., Khaliulin A.Kh., Godin E.A. The Black Sea Multidisciplinary digital atlas. In: Oceanography of the Eastern Mediterranean and Black Sea. Similarities and differences two interconnected basins. International Conference. Editors E.Th. Balopoulos, A.Iona, D. Sakellariou, 23-24 February 1999 Zappeion International Centre, Athens, Greece

Konovalov S.K., Eremeev V.N., Suvorov A.M., Khaliulin A.Kh., Godin E.A. Climatic and Anthropogenic Variations in the Sulfide Distribution in the Black Sea. Aquatic Geochemistry 5:13-27, 1999

Suvorov A.M., Khaliulin A.Kh., Godin E.A. Estimation of long-term variability of oceanographic parameters of the Black Sea. In: MEDAR /MEDATLAS -II Proiect, Final Workshop, Trieste, December 9-16, 2001. Abstracts, Institute Nationale di Oceanografia e di Geofisica Sperimentale-OGS, Trieste, Italy 2001 p. 65

Unesco 1993: Manual of quality control procedures for validation of oceanographic data, IOC UNESCO, pp.436.