**Ocean Science
Discussions**

Contribution of the Black Sea observing system to ECOOP

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Abstract

Regular observations in the Black Sea basin started in the past century, and quite good multidisciplinary observing system operated in the 70–80ies based on the ship observations. Modern oceanographic observing system in the basin is built according to the GOOS principles. It includes space remote sensing observations, data of free floating buoys and costal observational network. Integration of the observing system and its real-time operation were started within the framework of the FP5 ARENA project and later were improved during the FP6 ASCABOS project. The coastal observing system which includes time series from the coastal platforms and multidisciplinary surveys of the coastal areas fulfilled by the research vessels was set up during the ECOOP. Paper describes all components of the Black Sea observing system operated during the ECOOP project and its applications in the framework of the project.

1 Introduction

Regular observations in the Black Sea basin started in the 20ies of the past century. Quite good multidisciplinary observing system operated in the basin in the 70–80ies was based on observations from hydro-meteorological or research vessels. However, the traditional observing system was terminated at the beginning of 1990ies. The Black Sea GOOS project was established in May 1999 by the decision of representatives of the riparian countries under umbrella of IOC to implement a new oceanographic observing system based on the GOOS principles. The basic tasks of the Black Sea GOOS is to co-ordinate activities, develop coupling and interfaces, operationally and technically compatible routines, to optimise scientific design of a sampling system in terms of observing strategy and quality control, to improve components and harmonize products based on users' requirements and economic assessments. The approaches of the Black Sea observing system development were approved by the first and the second Black Sea GOOS workshops in Albena (Bulgaria, October, 2000) and Poti (Georgia, May, 2001).

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The Black Sea GOOS Member States adopted the Black Sea GOOS Strategic Action and Implementation plan, which was published by IOC in March 2003. Integration of the observing system and its real-time operation was carried out in the framework of the FP5 ARENA project and then improved under the FP6 ASCABOS project. The real-time basin-scale observing system implemented in the Black Sea is based mainly on the remote sensing and free floating buoys data according to the recommendations of the Black Sea GOOS Strategic Action and Implementation plan. The system was ready to the real-time operation at the beginning of the ECOOP project. The coastal observing system component was set up additionally during the ECOOP. It includes time series collected on the coastal platforms and multidisciplinary surveys of the coastal areas fulfilled by the research vessels. The goal of this paper is to present all components of the Black Sea observing system operated during ECOOP and to demonstrate its scientific significance.

2 Basin-scale observing system

The Black Sea basin-scale observing system is based on the remote sensing data and observations by free floating buoys. Remote sensing data allow monitor continuously mesoscale, seasonal and interannual variability of the basin. Observations by different modifications of the surface drifting buoys and data of profiling floats supplement remote sensing of the sea surface providing information about surface currents and vertical distribution of temperature and salinity. Basin-scale observations are used to obtain new information about physical processes in the basin in a broad range of temporal and spatial scales.

It is quite important that the basin-scale observing system provides the possibility to run the basin-scale circulation model in a data assimilation mode allowing interpolate and extrapolate heterogeneous information on a regular grid and to forecast short-term evolution of the basin. Some observations are used also for validation of the model outputs.

2.1 Remote sensing observations

The most important component of the Black Sea observing system is remote sensing data received from many space missions. Remote-sensing space data provide quasi-synoptic, basin- and sub-basin-scale knowledge of biological production and plant biomass (via sea colour scanners), sea-surface temperature (via infrared and microwave radiometers) and sea-surface height (via Topex/Poseidon, ERS, Jason and Envisat altimetry). The remote-sensing technology provides quasi-synoptic snapshots of a large area with fine spatial resolution, which is practically unattainable using drifters and other in situ techniques. It is important that remote sensing data are available for the Black Sea riparian countries in the real time or near-real time modes.

2.1.1 Space altimetry

The equalized along-track data of all available altimeter missions such as Topex/Poseidon, ERS, Jason1,2, GFO, ENVISAT provided by AVISO service as the sea level anomaly (SLA) product are used during the ECOOP project in the Black Sea. Relative variations of the sea level are measured with the error of about four centimetres. Such accuracy is sufficient for precise observations of mesoscale variability of the Black Sea basin. The along-track SLA data set is further processed at MHI NASU to exclude 30 km coastal zone known for the enhanced wave activity. Additional corrections are applied to exclude the influence of seasonal sea level changes due to river runoffs, evaporation, precipitation, atmospheric load effect and steric oscillation. The proposed correction is based on the assumption that the basin response to low frequency variability of the volume flux is almost uniform in space. Tidal correction was disregarded because of its negligible role in the Black Sea (Korotaev et al., 2001).

The output of the altimeter data processing is the dynamical topography of the Black Sea surface which describes surface geostrophic currents in the basin. Analysis of the dynamical topography maps made possible to explain typical seasonal cycle of the Rim current (Korotaev et al., 2001), study evolution of anticyclonic eddies situated onshore

of the Rim current jet and demonstrate the range of interannual variability (Korotaev et al., 2003). The example of the sea level map is presented on Fig. 1. Typical features of the Black Sea dynamics such as the Rim Current and its meandering, the eastern and western gyres, and anticyclonic eddies onshore from the current jet are well presented on the Fig. 1.

2.1.2 SST

The data of IR scanner AVHRR are available in the Black Sea region through their direct reception at HRPT receiving stations in Turkey and Ukraine. Up to four IR images of the Black Sea surface are collected daily. MHI NASU processes these data in the real time retrieving and mapping the Black Sea surface temperature. Standard NOAA algorithm is used for SST retrieving. SST retrieving from the IR remote sensing data is carried out in the cloud free regions. The Black Sea regional cloudiness filtration algorithm was developed by Plotnikov, (2009). The example of SST maps of the Black Sea is presented on Fig. 2.

Space SST data are assimilated by the basin-scale circulation model. The extended drifting buoys programme realized in the Black Sea last decade made it possible to evaluate accuracy of SST retrieving from IR radiometry. Assessment of the regional IR SST against the surface drifting buoy observations was carried out by (Ratner et al., 2004). Drifting buoy observations have covered all the seasons, therefore SST accuracy was estimated both for cloudy winters and sunny summers. Typical example of the SST time series measured by drifting buoys and by IR radiometer is presented on Fig. 3. The bias and route-mean-square error of IR SST are abount to 0.5°–$0.7\,^{\circ}$C.

2.1.3 Ocean colour

Modern multi-spectral sensors observing sea surface in the visible range, such as SeaWiFS, MODIS and MERIS (Franz et al., 2005; McClain et al., 2006; Lavender et al., 2008) are a basic source of information on the Black Sea ecology.

Space measurements are used for regular mapping the basin-scale distribution of the chlorophyll-*a* concentration and other parameters. However, the experience shows that the standard NASA products often have rather low accuracy for the Black Sea region.

Careful analysis of the sea color data was carried out to understand how to increase the reliability of the retrieved information. Ground truth data set of the chlorophyll-*a* concentration and light absorption properties of the Black Sea waters which were collected in 1998–2000 by Churilova et al. (2004) are used in the analysis. The data show significant impact of the coloured dissolved organic matter (CDOM) on the results of satellite data processing, and it constitutes the first significant source of errors. Thus, accuracy of chlorophyll determination can be increased by taking into account the impact of CDOM.

One more reason of distortions is related to the atmospheric correction procedure. Direct observations of the regional atmospheric aerosol properties by the CIMEL equipment as a part of the global AERONET program (Holben et al., 1998; Tolkachenko et al., 2006) on the Black Sea coast are used to clarify the problem. The analysis of the data obtained by CIMEL shows that optical properties of real aerosol in the Black Sea region sometimes differs significantly from the atmospheric models applied in the standard NASA atmospheric correction algorithm. The satellite observations are excluded from the following analysis in case of disagreement of the CIMEL data with the standard NASA model.

An archive of the refined SeaWiFS data was prepared in MHI NASU. Some examples of the maps from the archive are presented on Fig. 4. This archive, in particular, was used for testing of the sea colour data assimilation algorithm in the Black sea ecosystem model (Dorofeyev et al., 2008).

2.2 Free floating platforms

Free floating platforms are another important component of the Black Sea observing system. The International project 'Experimental monitoring of the Black Sea for operational meteorology and oceanography using surface drifting buoys' with participation

of Ukraine, Russia, USA, France and partial support of Turkey, Romania, Bulgaria and Georgia made it possible to launch 5–10 surface drifting buoys per year in the Black Sea in the beginning of this century (Eremeev et al., 2002). Further development of drifting buoys deployment in the basin was under the patronage of DBCP and Black Sea GOOS. In total about 70 surface drifting buoys of different modifications were launched in the Black Sea starting from 1999.

The first launch of the Black Sea profiling float was carried out within the framework of the project "Observing the Black Sea with Profiling Floats" funded by the NICOP program of Office Naval Research Europe. The project participants were IMS (Turkey), MHI (Ukraine) and School of Oceanography, University of Washington (USA). In total seven PALACE profiling floats operated in the Black Sea in 2002–2010. New initiative of EuroARGO and BulARGO projects started in December 2009 by the launch of two profiling float.

2.2.1 Surface drifting buoys

Drifting buoys deployed in the Black Sea are produced by MARLIN-YUG LTD following to common standards (Sybrandy et al., 2009). They have holey sock drogues on the depth 15m, and the system of buoys positioning by ARGOS-2 permits to determine velocity of surface currents. The sensors placed on drifting buoys measure atmospheric pressure and sea surface temperature. The data of drifting buoys are transmitted through GTS to the regional hydrometeorological centres and are available through the Internet.

A drifters with 60 m thermistor chain became a new efficient tool for the studying the Black Sea since 2004. It was elaborated by MHI NASU within the framework of the project Science and Technology Center in Ukraine "Remote Sensing of Marine Ecological System" (Tolstosheev et al., 2004). The set of such buoys was deployed in the Black Sea to study the upper mixed layer dynamics. Examples of the temperature sections measured by the drifter with a thermistor chain are presented on Fig. 5. The deepening of the mixed layer and formation of a new one are well presented on Fig. 5.

Data of drifters with thermistor chain were used to calibrate upper layer thermodynamics in the Black Sea circulation model.

Another modification of temperature-profiling drifter was used in the Black Sea in 2009. Three deployed buoys were updated to send the data via IRIDIUM satellite system and to define their locations via GPS receivers. These buoys permitted to define their locations with 30 min interval at any weather conditions. High frequency drifter positioning allows direct description of the inertial oscillations in the upper layer, which are presented on Fig. 6.

2.2.2 Profiling floats

Observations of the deep-see processes in real-time mode are provided by profiling floats (Davis et al., 2001). Such buoys freely propagate on the preset depth (parking depth) during the prescribed time interval on the expiry of which they rise to the surface. During their rising, the sensors installed on the buoy measure temperature and salinity profiles and/or other characteristics of marine environment. Having emerged on the surface, the buoys transmit the measurements to the receiving centre via a satellite, and, as well as the surface drifters, determine their co-ordinates. Then the buoys submerge again on the parking depth. Knowledge of the buoys' co-ordinates during their submersion and emersion permits to calculate mean flow velocity on the depth of the buoy's drift. The profiling floats substantially complement the possibilities of other instruments as they provide the information on deep-water variability of the oceanic fields.

A set of the profiling floats measurements was available before and during ECOOP. Since 2002, in total nine floats were launched within the framework of various research oceanographic programs in the Black Sea. Seven of them were deployed during and due to joint cruises of USA and Turkey, and two – by France (Peneva et al., 2010). All the profiling floats were deployed in the Western part of the basin on the depths between 100 m and 1600 m with the aim to monitor the surface and intermediate-depth characteristics of the flow fields and water mass structures. The temperature and

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salinity profiles via pressure and T-S relation together with float trajectories are presented in a near-real time mode on the web site. Additionally two floats procured by the French Institute IFREMER were deployed in 2009 by the research vessel "Akademik" as part of the Euro-Argo and BulArgo programs.

Profiling floats operated on the parking depth 1500 m provided first data about intensity of deep currents in the Black Sea. Traditionally dominant opinion was that currents in the Black Sea below the permanent pycnocline (i.e. below 300 m) are very weak. However observations by the profiling floats demonstrated that current speed on the depth 1500 m can achieve $0.07 \, \text{m s}^{-1}$. Moreover it was shown by Korotaev et al. (2006) that the trajectory of the float is controlled by the bottom topography.

3 Coastal observations

The Black Sea GOOS Strategic Action and Implementation plan recommended developing the coastal component of the observing system consisting of monthly measurements from small vessels along selected sections from the coastal zone to the continental shelf and slope, and measurements of standard hydrometeorological parameters from the coastal stations. Such an approach was partially realized during ECOOP. Two tide gauges for sea level measurements were additionally installed in Romania (Constanta) and Ukraine (Katsively) within the framework of the MedGLOSS initiative. Both stations operate in the real-time mode transmitting the data on the sea level, SST, pressure and air temperature to the web. Some measurements were carried out on two platforms near the Bulgarian and Ukrainian coasts.

3.1 Surveys by research vessels

The Bulgarian and Romanian coastal monitoring programmes consisted in a set of sections in the western shelf area. Sections were repeated on a seasonal basis. Sections of the Bulgarian monitoring programme are presented on Fig. 7.

The Bulgarian Black Sea Monitoring Programme (Palazov et al., 2007a) was approved to provide accurate description of a present state of the Western Black Sea. The major aim of the monitoring programme was to collect reliable data and to provide relevant information to the governmental agencies for taking decisions on protection and recovery activities for sustainable development of the coastal zone and the Bulgarian part of the Black Sea. Being an element of the Global Ocean Observing System, the Bulgarian Black Sea Monitoring Programme is a permanent system for observations, modeling and analysis of marine and ocean variables supporting operational ocean services.

During 2007–2009, in total 27 research cruises of the R/V *Akademik* were performed and more than 600 CTD profiles were collected. Based on these data the database was created to make the users' access to the data collected during implementation of the monitoring programme easier (Palazov et al., 2006). The database comprises both data and metadata, and provides the tools for searching, extracting and reporting. The data of monitoring are accessible through the friendly WEB interface.

The ecological status of the Romanian Black Sea transitional, coastal and marine waters is assessed based on physical, chemical, biological and hydromorphological indicators recommended by the Water Framework Directive and Marine Strategy Framework Directive: The set of physical and chemical parameters is measured in the Romanian coastal waters. It includes:

– annual and seasonal temperature regime, sea current velocities, wave parameters, turbidity;

– spatial and temporal distribution of salinity;

– spatial and temporal distribution of nutrients (P-PO4, N-NO2, N-NO3, N-NH4, N total, T total, Si-SiO4), dissolved oxygen and its saturability, BOD5, total organic carbon (TOC), chlorophyll-*a*, total suspended matter, pH;

– total petroleum hydrocarbons (TPH), heavy metals, organo-chlorinated pesticides, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs);

The set of biological and microbiological indicators are observed:

– phytoplankton (species, seasonal and geographical variability);

– macrozoobentos (species composition, biomass and annual/seasonal variability);

– zooplankton (species, seasonal and geographical variability);

– macro-algae (species composition, biomass and annual/seasonal variability);

– information on structure of fish populations, including the abundance, distribution and age/size structure of the populations.

– microbial pathogens;

NIMRD monitoring program is based on the analysis of water, sediment and biota samples collected from a network of 44 stations located between Sulina and Vama Veche (Fig. 8) by research vessel "Steaua de Mare 1" (6–$12\,t\,yr^{-1}$). The stations network consists of the survey of all water typologies included in Water Framework Directive and Marine Strategy Directive.

Less regular but rather intense surveys were carried out by Ukraine in the northern part of the Black Sea during 2007–2009. Information on all the cruises is presented on Fig. 9. The area under investigations ranges from the Danube mouth to the Kerch Strait in zonal direction and from the Dnieper–Boug estuary in the north to the central part of the sea ($44°$ N). Total amount of CTD stations is 338. Beside the hydrographic observations, the list of variables includes marine chemistry and some additional parameters, such as turbulence characteristics. Ships were also used as platforms for launching drifters.

In the North Eastern coastal zone of the Black Sea a regular hydrographical surveys are fulfilled by the ships of the Shirshov Institute of Oceanology, Russian Academy of Science. These surveys include a wide range of physical, biological and geochemical measurements.

3.2 Coastal platforms

Two oceanographic platforms are used to carry out regular oceanographic observations in the Black Sea. The Galata platform (Fig. 10a) is a fixed, earth gas production platform, owned and operated by a private gas company Melrose Resources Sarl. The platform is located in western part of the Black Sea on the Bulgarian shelf (34 m depth) 26 km east from the city of Varna (Fig. 10b). It is an unmanned fully automated platform whose operation is controlled by the shore control centre. The observing system (Palazov et al., 2007b) is designed to collect data with minimum components and to maximize application of the existing facilities. It consists of the measuring system located on the platform, the communication system, the onshore control centre and the operational centre. The measuring system placed on the platform consists of 24 sensors distributed in two main groups: meteorological sensors and oceanographic sensors. A part of oceanographic sensors is grouped in a wave and tide recording subset. Thirty one major oceanographic and meteorological parameters are measured including wind speed, wind gusts, wind direction, air temperature, relative humidity, air pressure, net radiation, visibility, dissolved oxygen, conductivity, turbidity, water temperature – three levels, chlorophyll, water temperature profile – 10 levels, surface current speed, surface current direction, sea level, significant wave height, maximum wave height and mean zero crossing period. Operational centre is a part of Bulgarian National Oceanographic Data Centre (BGODC). It receives the collected data from the measuring system via internet and stores it in a database. It also performs quality control/quality assurance of data to secure reliability of measurements. The operational centre provides access both to real-time and historical data stored in the database. The measuring system was installed at the platform in June, 2006. During the first four months all the components of the system were tested and the required software was developed. A regular data flow from the platform is available from November, 2006. The Galata platform real-time data is one of the most important sources of multi-parameter operational information in the Black Sea which provides monitoring, verification and improvement of modeling

results and forecasts, as well as collection of long- time series of data necessary for climatic research, marine physics, chemistry and biology. It also provides useful real time information for marine industry and safety.

Another oceanographic platform is situated near the Southern coast of the Crimea in the settlement Katsiveli where the Experimental Branch of Marine Hydrophysical Institute, National Academy of Sciences of Ukraine, is located. The platform is placed at a distance of about 600 m from the coast on the depth 36 m. A set of meteorological and marine parameters is measured at the platform. Meteorological measurements include air temperature, humidity, wind speed and direction. Marine observing component consists of measurements of sea surface temperature, temperature profile up to 30 m depth, surface waves, low frequency sea level oscillations and current velocity. Observations are carried out from the beginning of May until the end of October only.

3.3 Coastal hydrometeorological measurements

Wind, temperature, humidity, cloud cover, precipitation and evaporation are among the measurements routinely carried out at the Black Sea coastal meteorological stations. A tide-gauge network around the Black Sea is essential to calibrate satellite altimeter data. All these data are to be made available for the Black Sea GOOS on a real- or near-real-time basis. National meteorological/hydrometeorological services of the coastal countries maintain 46 coastal marine meteorological stations (Bulgaria – 6, Georgia – 8, Ukraine – 16, Romania – 4, Russian Federation – 5, Turkey – 7). In accordance with the WMO Technical Regulations the following parameters are measured: air and sea temperature; direction and speed of wind; height, period and direction of waves; atmospheric pressure; solar radiation; visibility; precipitation; three-hour humidity. A limited number of stations observe sea level, some chemical parameters, air pollution, etc. Some coastal marine meteorological stations have more than 50-year-long records of observations of certain parameters/elements. At all the stations observations are made manually.

Standard hydrometeorological observations collected by national networks of the Black Sea riparian countries are distributed via Global Telecommunication System (GTS). Regional real-time information system is built by the Russian Hydromeorological Centre. It is based on the data available from GTS. Atmospheric pressure, air temperature, wind speed and direction, water temperature sea level and surface wave characteristics are collected by the informational system of the above-mentioned Centre. The database of operational hydrometeorological data of the Black Sea and the Sea of Azov includes the following daily information:

– water and air temperature, wind speed (at 57 coastal stations of the Black Sea and the Sea of Azov (6 countries));

– ship observations of the sea surface temperature and wind speed and direction;

– information from drifters - sea surface temperature and sea level pressure;

– information from profiling floats (ARGO) – vertical distribution of temperature and salinity.

The information is available in the database the next day after measurements. The data is being collected since June, 2009. It is also possible to get there monthly average values and standard deviations, various kinds of graph products.

3.4 Coastal sea level measurements

Automatic stations of sea level measurements are installed in Constanta (Romania) and Katsiveli (Ukraine) within the framework of FP5 project ESEAS-RI under the leadership of IOLR (ISRAEL Oceanographic and Limnological Research Ltd, Haifa) as a part of the MedGLOSS network. The sea level measurements in Katsiveli are carried out near the shore where the depth exceeds four meters.

The observation data are transmitted every hour via Internet to the MedGLOSS ESEAS-RI centre at IOLR.

Observations include:

– three records of atmospheric pressure during two minutes;

– water temperature on 3 m level and water pressure every 30 s.

Atmospheric pressure, water temperature and sea level averaged during an hour are
finally simulated and stored. Similar observations are carried out by the station near
Constanta (Romania).

The Bulgarian Port Operational Marine Observing System (POMOS) (Palazov et al.,
2010) is a network of distributed sensors and a centralized data collecting, process-
ing and distributing unit. The system is designed to provide real-time assessment of
weather and marine conditions in the regions of large Bulgarian ports: Varna, Bour-
gas and Balchik. Real-time information is obtained due to various sensors placed at
thirteen points. All instruments are connected to communication system via intranet
that provides direct intranet access to the sensors. The measured data are trans-
mitted to the central collecting system where the information is processed and stored
in a database. The database is accessed through internet/intranet with the help of
browsers. Actual data can be displayed on the computer screens using a report server
that is a support to the Maritime administration, i.e. its efforts to provide safe naviga-
tion in bays, canals and ports. The system is developed within the framework of the
academy-government partnership.

4 Conclusions

The regional observing system is being developed by the Black Sea riparian countries
within the framework of a number of national and international projects under coordi-
nation of the IOC Black Sea GOOS project. This observing system was a base of the
basin-scale and coastal forecasts in the framework of the ECOOP project. Significant
part of observations during the ECOOP project was available in a real-time. Real-time

remote sensing data ensure operation of the Black Sea nowcasting and forecasting system which provides initial and boundary conditions for the ECOOP coastal forecasting. Real-time in-situ data provides the information necessary for validation of coastal forecasting products. Thus, in spite of its moderate capacity, the Black Sea observing system contributed to efficient participation of the Black Sea community in the ECOOP project.

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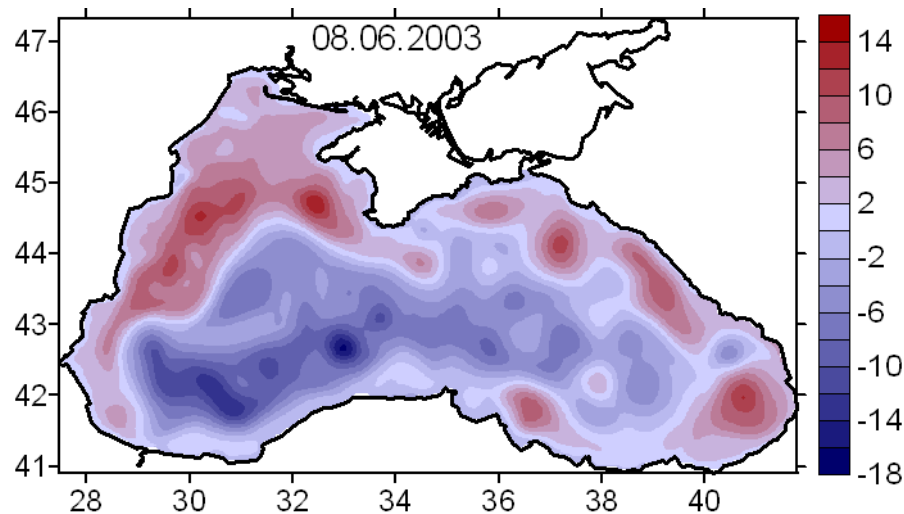
Fig. 1. The example of sea surface topography derived from space altimetry data.

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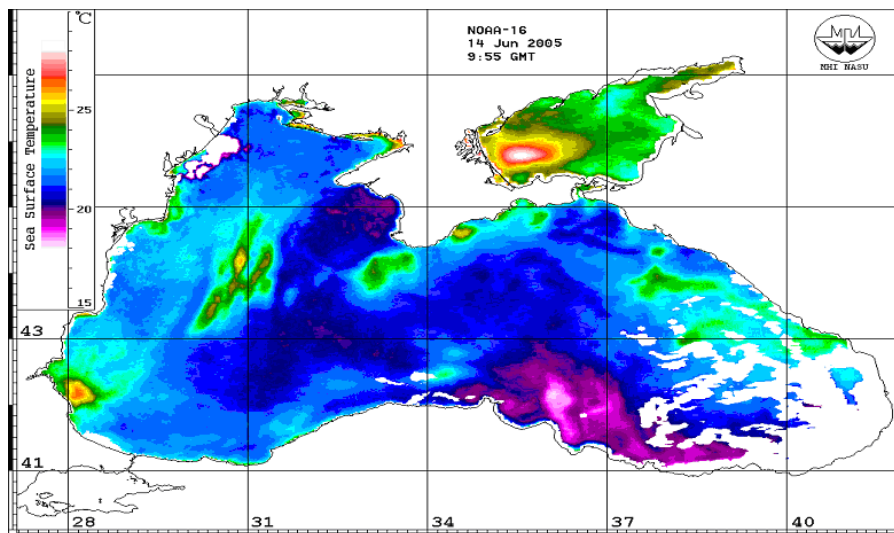
Fig. 2. The example of SST map of the Black Sea prepared in MHI.
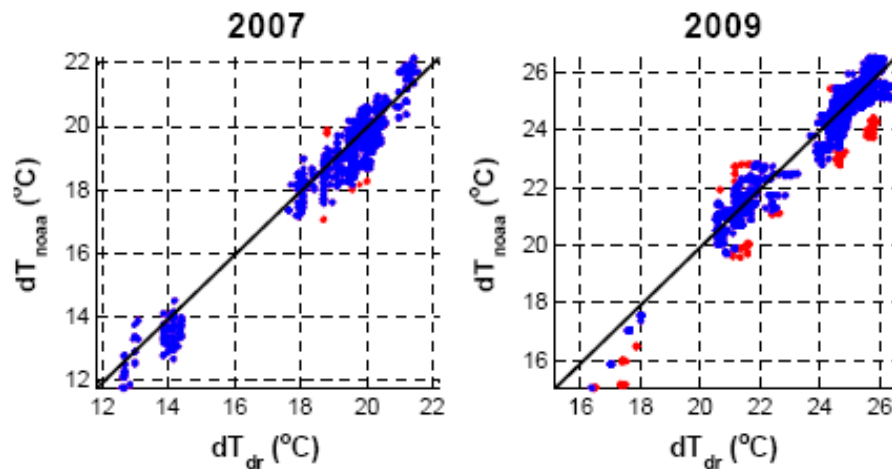
Fig. 3. Scattergram of SST measured by the drifters (x-axis) and the satellite (y-axis).
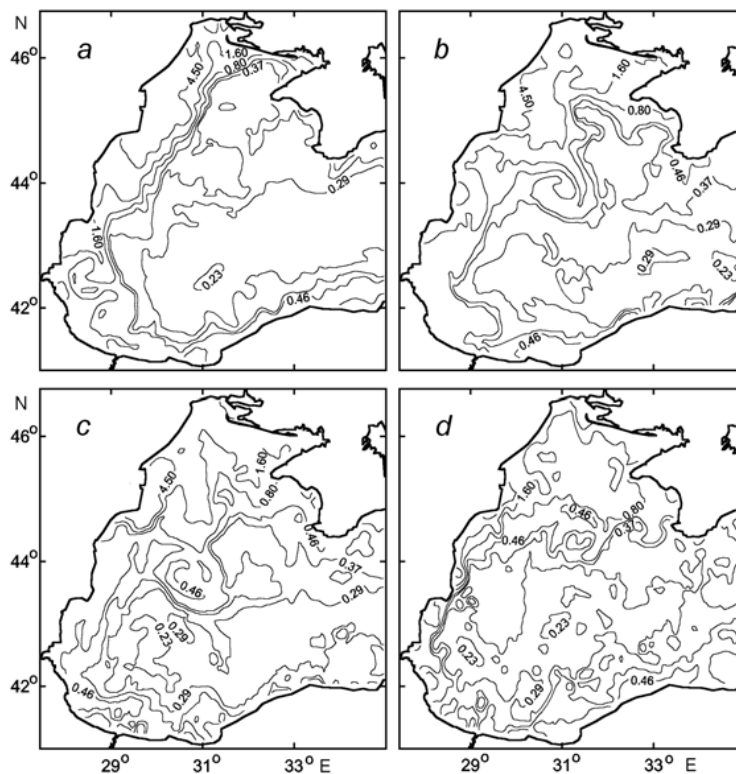
Fig. 4. Examples of spatial distribution of chlorophyll-*a* concentration (mg m^{-3}) in the western part of the Black Sea in summer 1998: **(a)** 16.06.98; **(b)** 13.07.98; **(c)** 19–20.07.98; **(d)** 19.08.98.
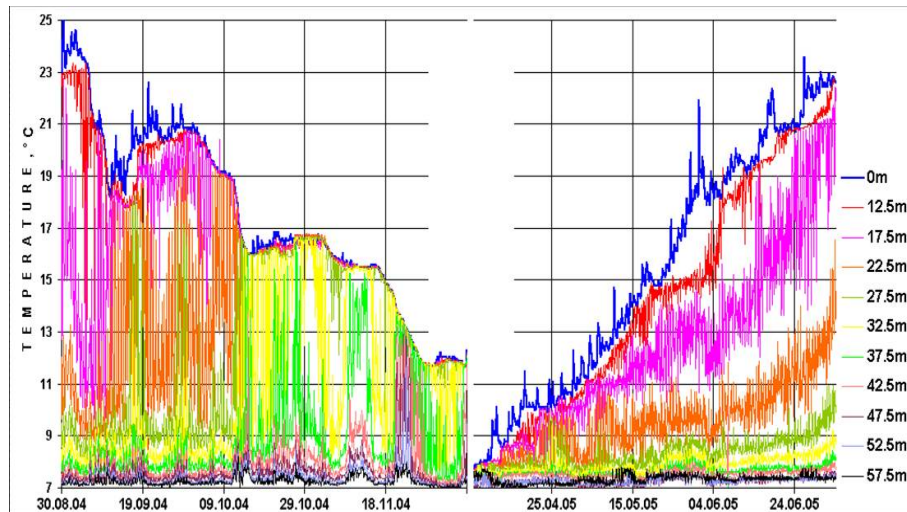
Fig. 5. Examples of temperature sections measured by a drifter with a thermistor chain.
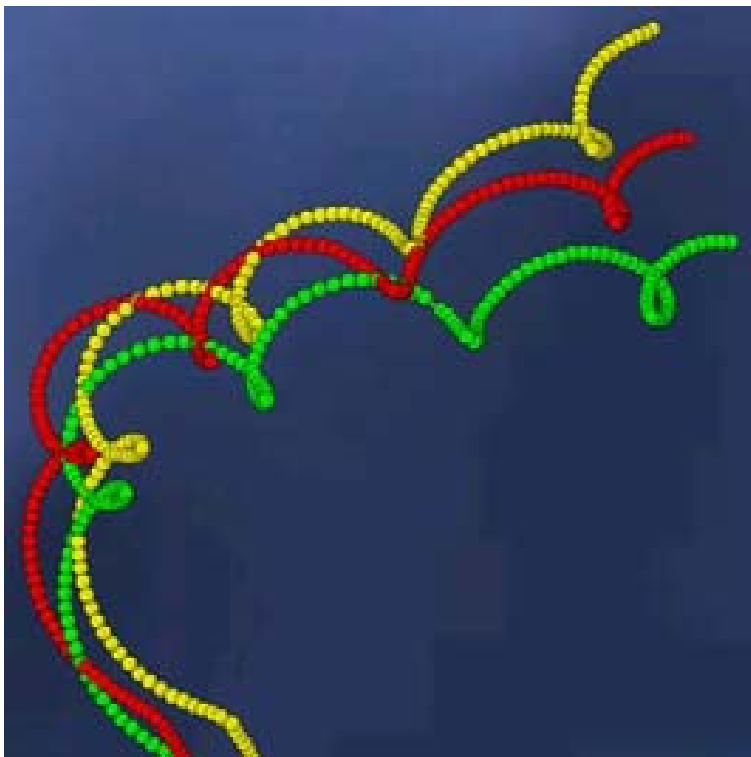
Fig. 6. Drifting buoy trajectories illustrating inertial oscillations in the upper layer.

Fig. 7. Bulgarian Black Sea monitoring scheme.
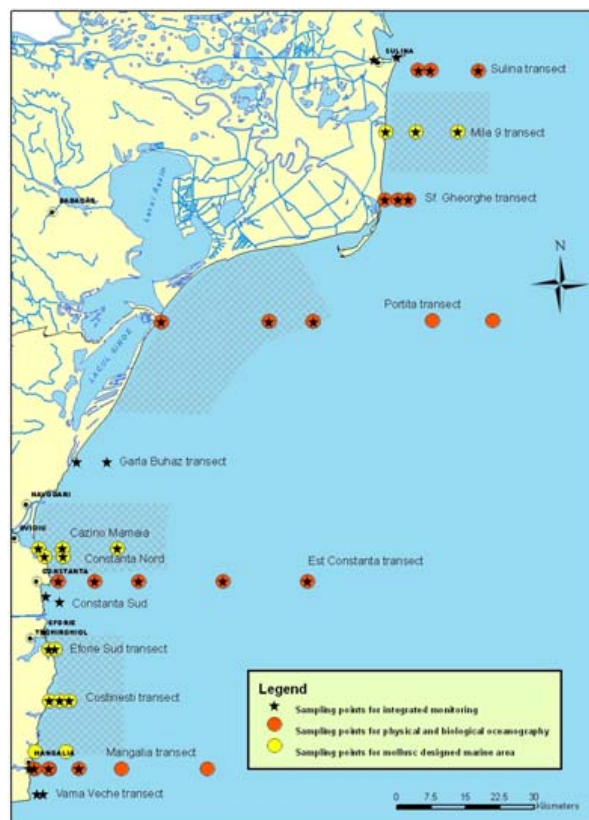
Marine Integrated Monitoring System

Fig. 8. Marine integrated monitoring system near the Romanian coast.
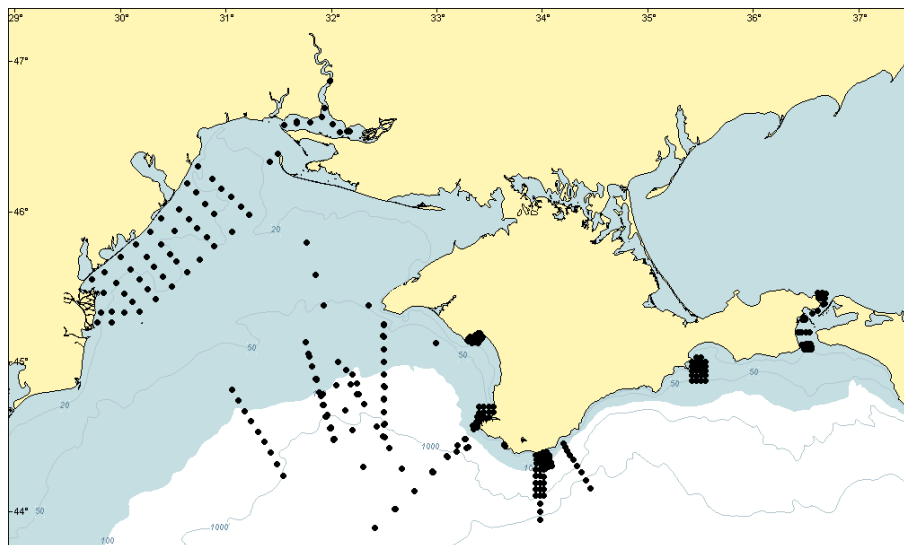
Fig. 9. Map of location of CTD stations performed during 8 oceanographic surveys in the northern part of the Black Sea in 2007–2009.

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Fig. 10. (a) The Galata platform. **(b)** The Galata platform location.