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Short-term hydrophysical and biological variability over the northeastern Black Sea continental slope as inferred from multiparametric tethered profiler surveys

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Abstract This presentation introduces a new ocean autonomous profiler for multiparametric surveys at fixed geographical locations. The profiler moves down and up along a mooring line, which is taut vertically between a subsurface flotation and an anchor. This observational platform carries such modern oceanographic equipment as the Nortek Aquadopp-3D current meter and the Teledyne RDI Citadel CTD-ES probe. The profiler was successfully tested in the northeastern Black Sea during 2007–2009. By using the profiler, new data on the layered organization of the marine environment in the waters over the upper part of the continental slope were obtained. The temporal variability of the fine-scale structure of the acoustic backscatter at 2 MHz was interpreted along with biooptical and chemical data. The patchy patterns of the acoustic backscatter were associated with physical and biological processes such as the advection, propagation of submesoscale eddy, thermocline displacement, and diel migration of zooplankton. Further applications of the multidisciplinary moored profiler technology are discussed.

Keywords Multiparametric observations · Tethered profiler · Marine environment · Layered structure · Physical processes · Zooplankton · The Black Sea

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1 Introduction

In the past few years, several international projects have started to enhance long-term monitoring (mostly in near real time) of ocean environmental change related to the interaction between ocean biogeochemical processes, marine ecosystems, ocean dynamics, and the climate. For example, EuroSITES Consortium (http://www.eurosites.info/) selected oceanographic platforms measuring variables from the sea surface to the bottom at 12 locations. EuroSITES, which integrates fixed point measurement systems, aims at observations in waters deeper than 1,000 m rather than in the transitional zones between the oceans and continents. The boundary zones where coastal waters interact with the open ocean still lack observational network. It should be noted that free-floating drifters like ARGO cannot be launched at the ocean boundary due to risk of the instrument entrapment at the sea floor. The moored buoys are more suitable for measurements of vertical distributions of multiple parameters over the continental slope and the outer continental shelf. Recently, a new tethered profiler Aqualog has been introduced for such studies in the northeastern Black Sea. This paper presents the first results of the acoustic and hydrographic surveys by means of the profiler Aqualog near Gelendzhik Bay of the Black Sea. It was the first moored profiler applications in the Black Sea.

It is worth to notice that the moored profilers were first introduced in the 1970s (Van Leer et al. 1974). Recently, there were developed several types of the tethered profilers including those transported by the bottom mounted winch or by the surface flotation mounted winch or by the propulsion system mounted on the profiler suite itself, e.g., by motor drive (Doherty et al. 1999). The Aqualog profiler belongs to the latter self-propelled devices. It is designed to carry on profiling up to near-surface layer of the ocean. There are magnetic switches on the profiler that determine locations of the special movement limiters at the mooring line thereby defining the profiling depth range automatically. The profiler can work in conditions of rather strong horizontal flow up to 0.8 m/s when the mooring line is inclined by 10–15° from the vertical axis. The profiler can be deployed from rather small ship. Also, it can be mounted on a pre-deployed mooring line by a diver and then it can be started by a magnetic key in the water.

The vertical profiling in contrast to the fixed depth measurements should be capable of resolving the ocean fine structure, thermohaline lenses and intrusions, plankton accumulations, and acoustic scattering layers with resolution better than 1 m. In the boundary zones between the oceans and continents, both biological events and physical processes are often transient in nature. For example, for diel migrations of zooplankton species in the Black Sea, the movement downwards usually takes 2 h and movement upwards lasts for 3 h (Svetlichny et al. 2000; Mutlu 2006) at dawn and dusk, respectively. Irregular physical processes such as upwelling or cascading of dense water have longer time scales, but they occur rather rarely in the Black Sea, several times in a season. Sufficiently long vertical profiling is necessary to observe the transient phenomena. Noticeably for the epipelagic zone, the measurements of vertical profiles of physical, chemical, and biological parameters should be carried out most frequently to avoid aliasing of periodic processes associated with daily cycles, tides, and inertial oscillations.

Hence, the measurements with vertical resolution of about 0.5 m at time intervals on order of 1 h during several weeks are needed to determine temporal variations in marine ecosystems and their relations to ocean dynamics. The development of the vertical profiling methodology for multidisciplinary measurements of thin layer structures in the specific environment of the Black Sea is in focus of the technological project, as it will be discussed below.

2 Instrument and methods

Aqualog is an observational platform that moves down and up along a mooring line, which is taut vertically between a subsurface flotation and an anchor (Ostrovskii et al. 2010). The profiler comprises a carrier with a load of oceanographic instruments (Fig. 1). The sensors include but are not limited to Teledyne RDI Citadel CTD-ES probe, Nortek Aquadopp-3D current meter, and AANDERAA fast Oxygen Optode 4330F. The acoustic Doppler current meter is a horizontal beam single-frequency 2-MHz instrument remotely sensing the water volume in the range of about 0.35–1.85 m from the profiler with a sampling frequency of 23 Hz. When the carrier is moving with the speed of 0.2 m/s, the vertical profiles are measured with a vertical resolution of 0.1 m for pressure, conductivity, and temperature; 0.8 m for acoustic backscatter signal and horizontal current speed; and 1.6 m for dissolved oxygen.

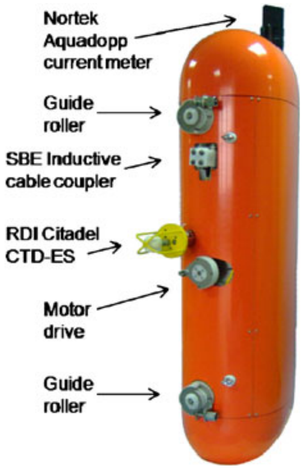


Fig. 1 Aqualog—a new tethered multisensor platform for autonomous vertical profiling in the ocean

Besides the cost optimization, the tethered multisensor profiler has other advantages. Unlike conventional mooring where the equipment is placed on fixed depths, Aqualog conducts continuous measurements of vertical profiles applicable for assessing both integral and differential characteristics of the ocean fine structure. By combining pressure, conductivity, temperature, and horizontal current velocity data, it is possible to evaluate vertical mixing. The joint analysis of dissolved oxygen data and the strength of the acoustic backscatter signal give a better understanding of the variability of the marine ecosystem vertical structure at multiple time scales.

There are slots in the profiler reserved to expand the set of sensors by installing additional probes such as the AQUAscat (by Aquatec Group Ltd.) for observations of the particulate matter and biota at multiple acoustic frequencies. We emphasize the importance of using acoustic sensors, which are better suited for long-term monitoring than optical sensors that can be sooner contaminated by biofouling. Here, it should be stressed that between the profiling cycles the profiler is parked in the aphotic zone to avoid extensive biofouling. Also, frequent profiling cleans the mooring line from foreign material hanging on the wire rope. Other popular sensors such as WET Labs's Fluorometer–Backscattering Meter FLbb-AP2 as well as an ocean acidity (pH) sensor can be installed on the profiler too.

The acoustic Doppler current observations by Aquadopp-3D mounted on the profiler have certain advantages over those done by a conventional acoustic Doppler current profiler (ADCP). Unlike the traditional ADCP approach where (1) a longer working range is achieved by the price of poorer vertical resolution (e.g., 700-m vertical profile is binned at 24-m cells by the longest range ever 38 kHz ADCP) and (2) the horizontal span of the beams widens proportionally to the distance from ADCP (e.g., about 508 m in horizontal at the distance of 700 m by 38 kHz ADCP), Aqualog obtains horizontal current profiles at the abovementioned fixed distance of 0.5–2 m in the horizontal direction from the profiler with an ocean thin-layer resolution throughout the full water column from the near-surface layer down into the abyss.

Since the paper written by Flagg and Smith (1989), ADCPs have been used to observe zooplankton. The current profile data by Aquadopp-3D mounted at Aqualog should have higher signal-to-noise ratio if compared to conventional long range ADCPs (38–150 kHz), the signals of which are more sensitive to certain larger scatterers; thus, the instruments may occasionally misestimate the swimming nekton species for current fluctuations. The Aquadopp-3D's 2-MHz acoustic remote sensing signal is most sensitive to scatterers of the equivalent spherical radius of about 0.05–2 mm including lithogenic particles suspended in the water, phytoplankton, and mesozooplankton. For zooplankton, the equivalent spherical radius, r, accounts for the systematic change in target strength as a function of animal length, for example, it is often assumed that $r=0.2$ mm corresponds to copepod's size of 1.13 mm.

The profiler oceanographic sensors are rigid, high precision, and stable, making an extended oceanographic profiling survey possible. The profiler technical data are brought into Appendix. So far, the typical depth range of Aqualog's profiling was 5–800 m. Vertical speed can be set within 0.1 and 0.3 m/s. The programmable hardware of the profiler allows the user to set an automatic operation algorithm (variable movement speed, time, and period of profiling depending on the depth range, etc.). The profiler mooring line is made of stainless steel wire rope or Kevlar™ fiber. The Aqualog has enough resources to profile a water column in the programming regime during several months. The total profiling distance is about 800 km in still waters for a profiler with a lithium battery pack.

The tethered profiler can be maintained rather easily. Even when the subsurface float is located at 15–20 m from the sea surface, it will be possible for an experienced diver to remove the profiler from the mooring line without recovering the entire mooring system. Then, the sensors can be maintained and can be cleaned aboard a boat. After that, the profiler can be secured by the diver back on the mooring line to continue the collection of data.

In October 2009, two Aqualogs were moored across the shelf break at the depths of 88 m and 270 m correspondingly at 44°29,75′N 37°59,13′E (site 1) and 44°29,36′N 37°58,44′E (site 2) west of Gelendzhik Bay (see Fig. 2). The first profiler performed descending/ascending cycles in the depth range of 10–82 m every 3 h during October 3–11. The second profiler made repeated round trips between 10 and 240 m every 2 h from the evening of October 4 throughout the noon of October 11. Simulta-

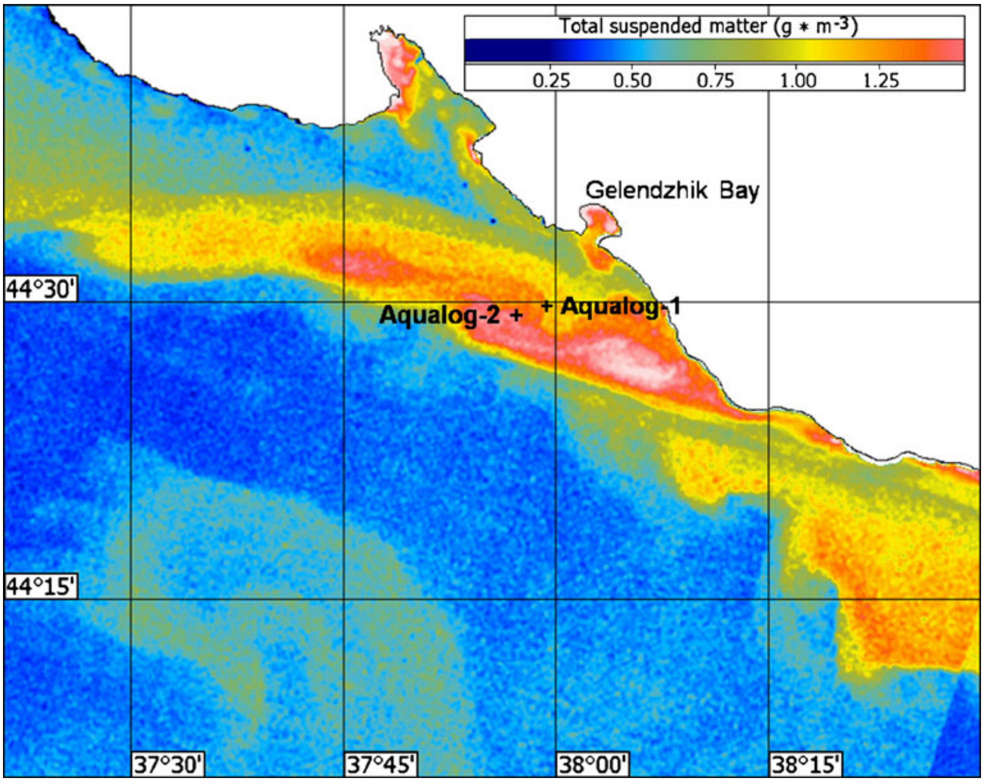


Fig. 2 The distribution of the total suspended matter in the near-surface layer of the north-eastern Black Sea observed by ENVISAT imaging spectrometer MERIS around 8:15 a.m. GMT on October 3, 2009. The Aqualog mooring sites are shown by *crosses*

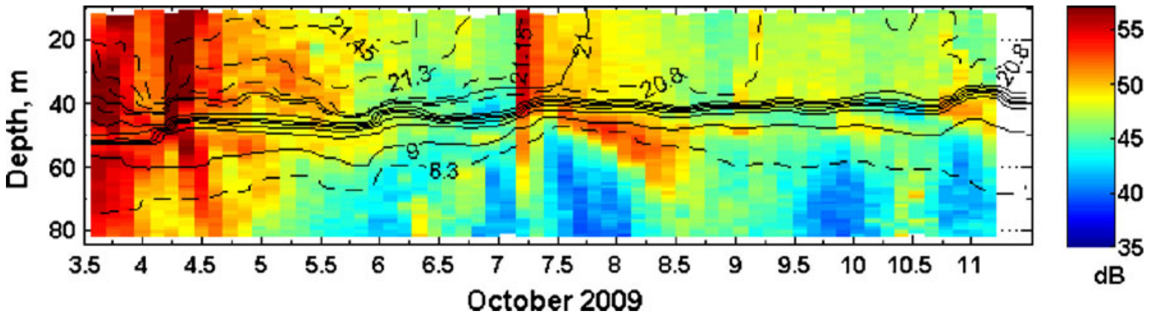


Fig. 3 Time–depth plot of the acoustic backscatter at the Aqualog mooring site 1 in the shelf waters of the northeastern Black Sea on October 3–11, 2009. Superimposed on the acoustic backscatter plot are the isotherms (degrees Celsius)

neous measurements of the vertical profiles of the acoustic backscattering, horizontal current velocity, temperature, and salinity allowed us to track individual processes that determine the variability of the marine environment. During the experiment, the current velocity sections were carried out by means of towed ADCP in the area around the Aqualog mooring sites. The T, S stations near the moorings were carried out by using Idronaut-316 CTD probe. The appropriate ENVISAT, AQUA, TERRA, METOP, and NOAA satellite data were also acquired and processed.

3 Results and discussion

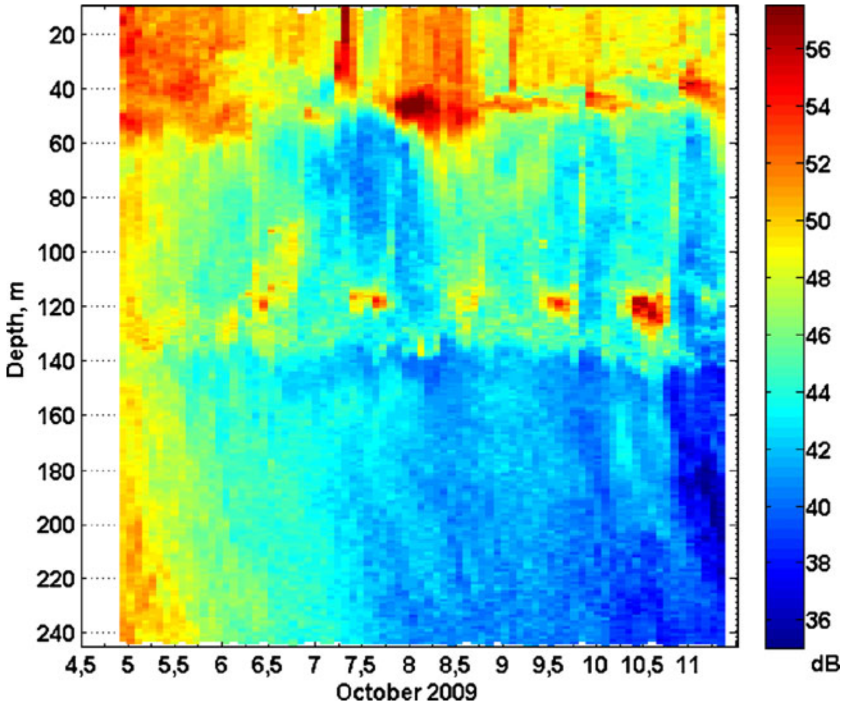
In October 2009, the most intriguing data were obtained by Aquadopp-3D. The observations revealed the acoustic scattering's time varying multilayer structure (see Figs. 3 and 4 below).

3.1 Euphotic zone

Between 10 m and the lower boundary of the upper mixed layer, ~40 m, the acoustic backscattering at 2 MHz by lithogenic and biogenic particles, phytoplankton, and mesozooplankton was rather uniform with depth.

It should be noted that at the beginning of the survey, the acoustic backscattering from suspended particles was higher throughout the water column because the suspended sediments were brought in by the northwestward jet from the near-shore zone (Figs. 5 and 6). The data indicated substantial decrease in the amplitude of the acoustic backscattering during the survey (Fig. 4).

Fig. 4 Time–depth plot of the acoustic backscatter at the Aqualog mooring site 2 in the waters off the shelf break in the northeastern Black Sea on October 4–11, 2009



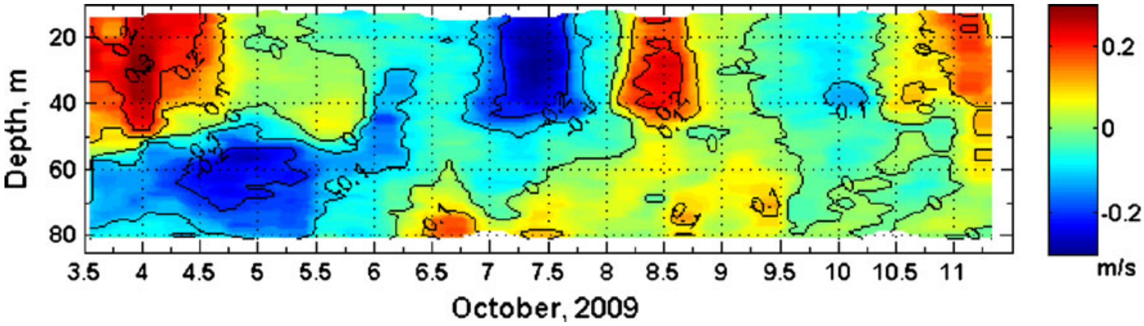


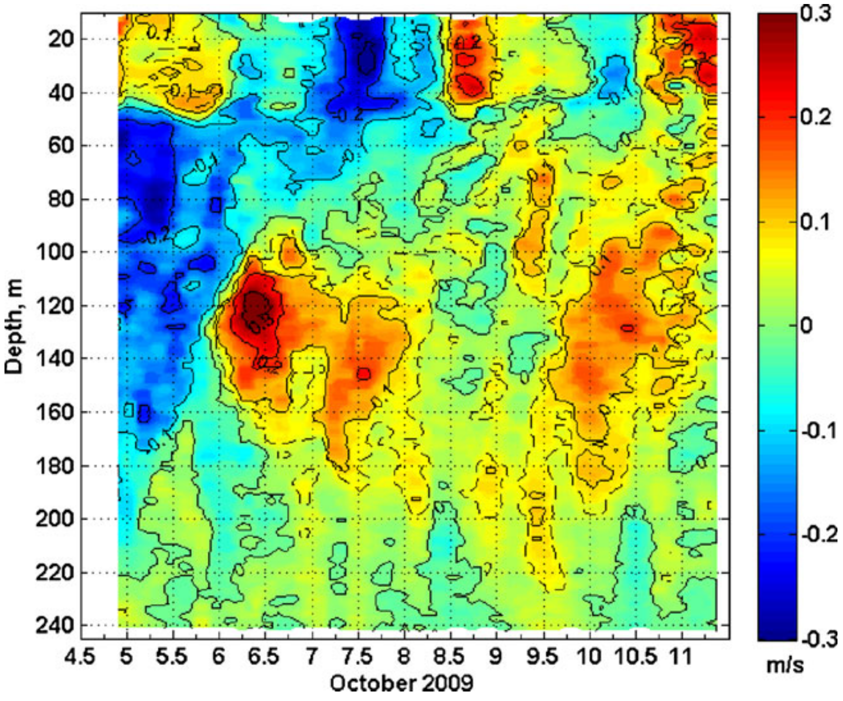
Fig. 5 Time–depth plot of the along-shelf current velocity (positive direction is northwestward) at site 1

The current profiles obtained at the Aqualog mooring site 1 indicated that the northward current velocity reached 0.3 m/s in the upper 50 m layer on October 3–4 (Fig. 5). At the site 2 (Fig. 6), in the deeper layer down to approximately 180 m, there was subsurface countercurrent up to 0.25 m/s strong.

Noticeably, the satellite remote sensing by ENVISAT imaging spectrometer MERIS showed much larger suspended matter concentration in the jet waters flowing towards the moorings from the southeastern shelf on October 3. There is simultaneous MERIS imagery of the chlorophyll-a concentration, which shows essentially similar pattern indicating much larger chlorophyll-a concentration in the jet near the mooring sites. The waters rich in suspended matter and chlorophyll-a were brought by the jet from the near-shore zone. The shear shelf eddies were associated with the jet. Largest of these submesoscale eddies were also observed by the NOAA-17 and METOP-2 infrared imagery on October 4.

On October 4–6, the northwest current moved offshore into the deep basin so that the horizontal transport of the suspended sediments near the moorings substantially decreased. The towed ADCP survey (Fig. 7) confirmed the change in the current field. The southeast current emerged in the upper 40–50 m layer over the continental shelf region limited by the isobaths of 70 and 200 m. The ADCP survey also indicated that a submesoscale cyclonic eddy was generated between the southeast current and the coast. This eddy moved off the coast and appeared near the first mooring around 10 p.m. on October 6. Figure 5 shows that the eddy occupied the upper layer above the thermocline. The cross-shelf current velocity data indicated that the eddy rotational speed was about 0.15 m/s. During the next few hours, the

Fig. 6 Time–depth plot of the along-shelf current velocity (positive direction is northwestward) at site 2



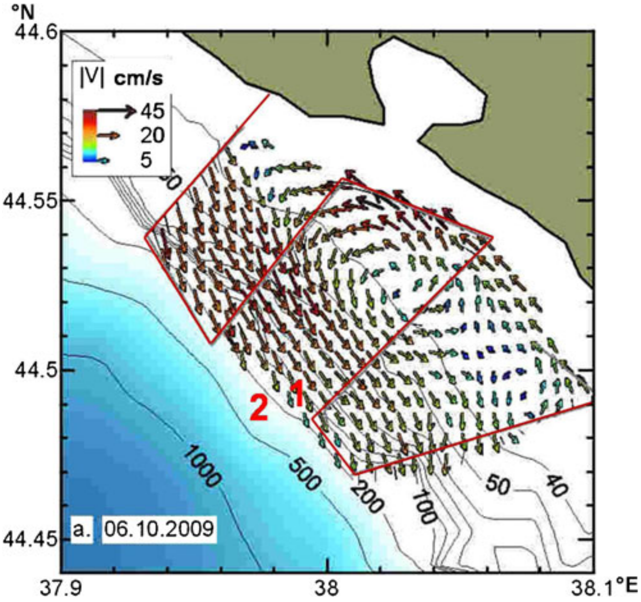


Fig. 7 The average currents in the upper ocean 45-m layer above the seasonal thermocline. The regularly gridded data were obtained by interpolation of the ship-towed ADCP data of October 6, 2009. The ship-towed ADCP track is shown by *red line*. The Aqualog mooring sites are shown by *numbers 1* and *2*

eddy's eastern front shifted further offshore towards the second mooring (see Fig. 6). The acoustic backscattering almost doubled in the upper 40 m layer between 3 and 6 a.m. on October 7. The sharp increase in the acoustic backscattering was associated with the approach of the submesoscale eddy front. The eddy core appeared right above the continental shelf break early in the morning of October 8. The eddy water carried more suspended particles than the surrounding waters. It seems that the turbid water propagated around the eddy in counterclockwise direction.

The changes in the current structure were associated with vertical displacements of the thermocline. The thermocline shallowing events were rapid: the isotherms moved upward by several meters in a few hours (Fig. 3). The most noticeable shifts occurred between 3 and 6 a.m. on October 4 and October 7. In the former case, the maximum vertical temperature gradient interface rose from 52 to 46 m. By the end of the survey on midday of October 11, the maximum vertical temperature gradient interface reached the depth of 40 m while the sea surface temperature gradually decreased from 21.5°C to 20.8°C.

The multilayer structure of the acoustic backscattering correlated with the vertical distributions of fluorescence, turbidity, and dissolved oxygen. The ship-borne castings of Idronaut-316 CTD equipped with fluorimeter, turbidimeter, and dissolved oxygen sensor are shown in Fig. 8.

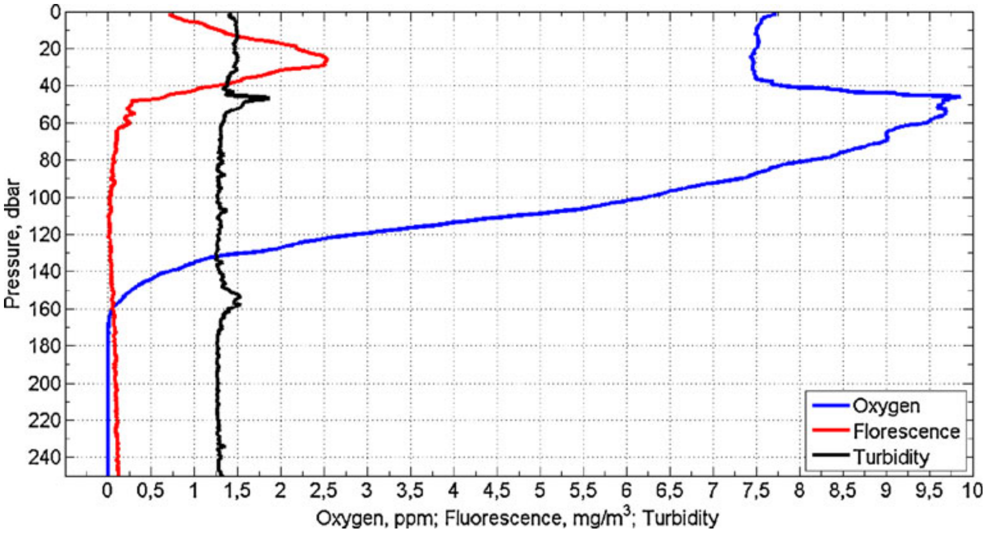
The CTD data indicated that the fluorescence of chlorophyll was at maximum value of 2.47 mg/m^3 at the depth of 26 m and it quickly decreased to 0.21 mg/m^3 downward throughout the lower portion of the upper mixed layer.

The amplitude of the echo signal substantially decreased in 5-m-thick core layer of the thermocline (see Fig. 3). Interestingly, the turbidity had a local maximum of almost 2 mg/m^3 in this layer (Fig. 8).

3.2 Oxycline and suboxic zone

The oxycline was located between 50 and 130 m whereas the upper boundary of the sulfide-containing zone slightly fluctuated near the depth of 160 m in the vicinity of the Aqualog mooring site 2 (Fig. 8).

Fig. 8 Vertical profiles of the dissolved oxygen, fluorescence, and turbidity observed near site 2 at about 5 p.m. on October 4



The local minimum 0.16 mg/m^3 of fluorescence was located at 52 m. A few meters below, there was a slight increase in the fluorescence to 0.25 mg/m^3. Downward, the fluorescence gradually decreased to 0.06 mg/m^3 at 63 m. Below this depth, the phytoplankton concentration almost ceased; thereby, it could not contribute substantially to the acoustic backscattering in the oxycline.

Strong variations of the sound scatterers were observed in the oxycline. During the daytime, in the layer of 110–130 m, the acoustic backscattering was high. This became evident from October 7 after the particulate matter, which had been brought in by the coastal jet, sank deeper than 150 m. Comparison of Figs. 4 and 6 showed that the backscattering at the depths of 110–130 m was stronger when the current direction in this layer was northwestward.

Earlier, Flint (1989) noted patchy assemblages of mass mesozooplankton species *Calanus helgolandicus*, *Sagitta setosa*, and *Pleurobrachia pileus* in the lower part of the oxic layer in autumn. These organisms, whose mature species grow up to 3.5, 8–22, and 5–20 mm correspondingly, along with the accumulations of the lithogenic particles and detritus of the size more than 0.05 mm can scatter the acoustic signal at 2 MHz in the oxycline.

The diel migrations of the mesozooplankton were observed at dawn and sunset. The migration events appear as nearly vertical strips in Fig. 4. The vertical migrations occur between the near-surface layer and the sigma-theta isopycnal surface of 15.7 g/m^3, i.e., almost reaching the hydrogen sulfide zone boundary. The vertical migrations took less than 2 h. During the survey, in the lower part of the oxycline, the maxima of the acoustic backscatter were found at 115–125 m below the sea surface where the dissolved oxygen content was 2.1–3.7 mg/l. Notice that the daily maxima of the echo energy varied depending on the current direction. These maxima were more extensive on October 6, 7, 9, and 10 when the subsurface current was directed northwestward and could bring nutrients from the coastal zone.

Just above the hydrogen sulfide zone, there was a few meters thick sound scattering layer. The higher sound scattering persisted at the depths between 130 and 140 m during the night time because some zooplankton animals rested and did not migrate upward at the sunset (see Vinogradov et al. 1985). In this layer, the dissolved oxygen did not exceed 1 mg/l.

3.3 Anoxic layer

In the anoxic layer, the short-term variations were dominated by irregular patchy sinks of the suspended matter. In the hydrogen sulfide layer, the sound scatter was caused by suspended sediments including the detritus (see Fig. 4). The lowest acoustic echo was observed at the depth of 140–145 m below the planktonic acoustic backscattering layers. An increase of the sound backscatter amplitude by 5% was found at 150–160 m depth where particle coagulation usually takes place. The pattern of the settling of the particulate matter was observed in the anoxic layer below 160 m. In the anoxic layer between 160 and 240 m, the depth-time patterns of the acoustic backscattering indicated that patches having higher concentration of the suspended sediments propagated downward with speed of about 0.002 m/s on October 4–6 and at 0.001 m/s at the end of the survey. Assuming that the horizontal current velocity was negligible below 200 m and the sinking particles are usually of alluvial and silicate fractions in the autumn season (e.g., Rusakov et al. 2003), one can approximately calculate that the sinking particles decreased in size from 0.07 to 0.05 mm during the survey. It should be noted that the alluvial fraction dominates in bottom sediments in the experiment area and the median size of the sediment particles is 0.03 mm (Pykhov 2003).

4 Discussion and conclusions

The tethered profiler Aqualog was successfully used to study the vertical structure of the Black Sea environment at the time scales from 1 h to several days in the northeastern Black Sea in autumn 2009. The side-looking acoustic Doppler current meter observations including data on echo energy were most valuable particularly when accompanied by ancillary environmental measurements. The single-frequency system Aquadopp-3D delivered qualitative data on temporal variations of the scatterer’s vertical distributions from near-bottom layer to near-surface layer as follows:

- In the anoxic zone below the depth of 140 m, the echo energy at a frequency of 2 MHz was due to suspended sediments (lithogenic and biogenic particles) only,
- In the oxycline and suboxic zone in the depth range between 50 and 140 m, the sound was scattered from both the suspended sediments and the zooplankton organisms,
- In the euphotic upper 50 m of the sea, the phytoplankton contributed to the assemblage of the scatterers along with zooplankton and lithogenic and biogenic particles.

The profiling survey revealed a multitude of dynamical and biological processes, which temporarily dominated the acoustic backscattering in the vertically stratified ecosystem over the continental slope. The data on the acoustic backscatter at 2 MHz appeared to be useful for studying the diel migrations of the zooplankton in the top 130 m of the Black Sea. The vertical velocity of the suspended matter sinking in the anoxic layer deeper than 150 m was also estimated to be 0.001–0.002 m/s. The joint analyses of vertical profiles of dissolved oxygen, fluorescence, turbidity, temperature, and current velocity provided insight for a better understanding of the processes determining the acoustic backscatter variability at short time scales. It is important that by frequent profiling of the entire water column, the moored observing system is capable of capturing the transient phenomena in the marine ecosystem due to irregular events, such as the movement of the submesoscale eddies.

The results of the sound scattering in the oxycline in October 2009 should be compared with similar data obtained at the same site in summer 2007 by using a prototype model of the Aqualog. Figure 9 shows the time–depth plot of the acoustic backscatter on July 11–13, 2007 near the mooring site 2. At that time, the profiling was carried out every 1 h and the diel migration pattern was better resolved. The thin layer where mesozooplankton diapaused had a vertical extent of a few meters, and it was located between isopycnals 15.8–15.9 g/m^3. Its depth fluctuated together with isopycnal surfaces with an amplitude of about 10 m. Such fluctuations could be partly caused by an internal semidiurnal tide, which should be checked in the future. Large zooplankton patches were observed from 8 a.m. to 6 p.m. between isopycnals 15.4 and 15.7 g/m^3. Late in the evening, the zooplankton migrated upward. At night, the patches of the higher acoustic backscattering were observed in the depth range of 20–30 m between isopycnals 13 and 13.8 g/m^3. The daily migration of zooplankton was observed in the upper 15-m layer too.

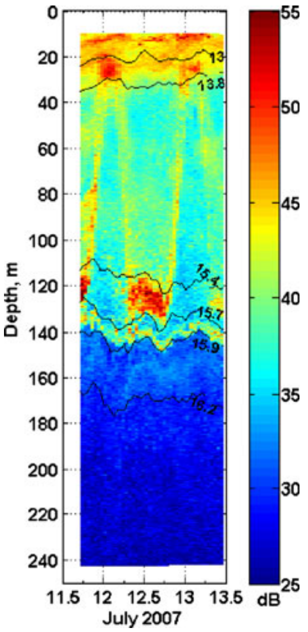


Fig. 9 Time–depth plot of the acoustic backscatter at the Aqualog mooring site 2 in the waters off the shelf break in the northeastern Black Sea on July 11–13, 2007. The *black lines* indicate sigma-theta isopycnals (grams per cubic meter)

It has been recognized that fine-scale, dense patches of organisms are ubiquitous features of the layered organization in the coastal ocean (Sullivan et al. 2010). Heterogeneity in physical conditions and motions result in complex vertical and horizontal structures in the ocean, which, in turn, contribute to a similarly patchy and complex distribution of nutrients and plankton. Osborne (1998) emphasized that turbulence affects organisms directly through their survival rates, reproduction rates, feeding rates, and predation rates. Among other thermodynamical processes, internal waves and the convection in the upper layer affect the light history and growth of phytoplankton by advecting them into and out of favorable environments. The sound-scattering thin layers often indicate the highly concentrated patches of plankton that have vertical extents on the order of centimeters to a few meters, yet can span horizontally for hundreds of meters and persist for hours to weeks. Indeed, when looking at the variability of thin layers, it is important to relate the dynamics of the organisms to the basic physical and hydrochemical parameters.

Overall, the moored profiler Aqualog is a useful tool for research on coupling of biological and physical processes in the sea on time scales from a few hours to several months. Autonomous profiling multiparametric observatories of the moored type have great potential for being the key technical means for marine environmental monitoring at the boundary zone between the deep ocean and the coastal waters.

5 Future work

Though the field experiment in October 2009 was just a pilot study, its results give way to more special experiments. One interesting subject for future experiments will be the temporal variability of the mesozooplankton diel migrations. The diel migrations have been long known in the Black Sea (e.g., Vinogradov et al. 1985; Drits and Utkina 1988). Recently, Mutlu (2003, 2006) examined swimming trajectories of copepods *Calanus euxinus* and chaetognaths *S. setosa* by using scientific echosounders at 120 and 200 kHz. The extended profiling survey supplemented by net tows will deliver information about the behavioral changes in the diel migrations due to changes in the environmental conditions during the mesozooplankton species life cycles.

Also, future research should focus on the environment where there is very low species diversity such as in the *Calanus*'s diapausing layer just above the hydrogen sulfide zone. This will simplify the interpretation of the acoustic backscattering data. In such conditions, the observations during a season or so may reveal zooplankton reaction upon variability of the physical processes, e.g., currents, upwelling, or convection, and changes in the other environmental conditions, e.g., dissolved oxygen distribution or vertical biogenic fluxes.

In the future, it will be worth to add transducers working at multiple frequencies in the range of 0.5–5 MHz to broaden the spectrum of the observing particles of particulate matter and planktonic organisms. The multi-frequency systems such as TAPS™ can provide quantitative information on the abundance, dynamics, and interactions of mesozooplankton (Holliday et al. 2003). Such a system should be integrated in the Aqualog profiler.

Based on the experience with the Aqualog profiler, we suggest that the next moored observational system should include both a meteorological buoy having conventional sensors and equipment, including solar batteries and a subsurface mooring profiler with underwater inductive modems at a safe depth nearby and connected by a bottom cable with the meteorological buoy. Such deployment compared to the old traditional buoy will have several general advantages: (1) minimization of the monitoring costs, (2) safe operation of the profiler due to the fact that the surface meteorological buoy will serve as an alarm for fish trawling, and (3) supply of energy from the surface solar batteries. The data from the mooring profiler will be transferred to the meteorological buoy for real-time operability to the user via a telecommunication system. Moreover, by this communication link, a user can also send commands to the profiler, for example, to change the frequency of the sampling, the data transmitting interval or the profiler's parking depth.

It is especially important for scientific research to deploy a network of profilers along the coastal slope so as to capture the essential spatial signals. The coastal systems worldwide have embarked on rapid and diverse changes, and are under anthropogenic stress. Hence, a comprehensive network of profilers is needed to interpret the trends on a local scale superimposed on the background of global climate change.

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Appendix

Table 1 Specification of the tethered profiler Aqualog

Profiling	
Speed	0.1–0.3 m/s
Depth range	5–800 m
Total profiling distance[a]	800 km
Maximum current velocity	0.8 m/s
Buoyancy	±5 N, (±1 N recommended)
Battery pack	
Lithium D-size batteries (option)	48 pcs
Alkaline D-size batteries	45 pcs
Voltage	9–13.5 V DC
Turning on/off	By magnetic switch or as preprogrammed
Indication of the status	LED on the cowling
Typical measurements	Pressure, salinity, temperature, dissolved oxygen, current velocity vector[b], inclination, heading, acoustic scattering strength
Vertical resolution[c]	
Pressure, salinity, temperature	0.05–0.15 m
Velocity	0.6–1.8 m
Dissolved oxygen	0.8–2.4 m
Measurement accuracy	
Pressure	0.04% of the range
Temperature	0.002°C
Salinity	0.002 psu
Velocity	1% of measured value±0.5 cm/s
Oxygen	<8 µM or 5%
Optional sensors	Turbidimeter, fluorimeter
Dimensions	1.43×0.35×0.64 m
Weight in air (without sensors)	68 kg

[a] With lithium battery pack, in still waters; depends on types of the sensors

[b] Measurement cell distance off sensor head ~0.35–1.85 m

[c] Depends on the profiling speed and types of the sensors

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