ISSN 1573-160X, *PHYSICAL OCEANOGRAPHY*, Vol. 31, Iss. 4, pp. 562-579 (2024)
Original Russian Text © E. V. Zhuk, N. V. Markova, 2024,
published in *Morskoy Gidrofizicheskiy Zhurnal*, 2024, Vol. 40, Iss. 4, pp. 611–630

Original article

Geoinformation System for *Argo* Floats Drift Assessment: The Black Sea Case

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Abstract
Purpose. The work is aimed at developing and implementing a geographic information system (GIS) that provides an opportunity for online work with the *Argo* floats data in the Black Sea and for its application to assess the float drift velocities in different sea layers.
Methods and Results. The geoinformation system is developed based on a client-server architecture using *PostgreSQL* DBMS to store the *Argo* float data, the *jQuery*, *Plotly* and *mapbox gl* libraries and, therefore, to implement a user interface and a cartographic service. The floats drift velocities are calculated and analyzed using the information provided by the *Argo* project in the public domain. The information is received from the autonomous drifting profiling floats and includes data on their satellite positioning, drift depths and profiling. The velocities at the float drift horizon are calculated using the data on its trajectory, meanwhile GIS assumes the possibility to recalculate velocities swiftly when new observation data are received, adjust calculation methodology, expand the range of statistical characteristics as well as to add a number of additional options. The *Argo* data array (early 2005 – mid 2022) was included in the system current version to calculate and analyze velocities. Application of GIS made it possible to estimate floats drift velocities in the Black Sea, specify mean velocity values as compared to the previous studies and show its seasonal variability in different layers of the sea.
Conclusions. The online services of the *Argo* project are complemented by the developed GIS that simplifies processing and scientific analysis of the Black Sea oceanographic data significantly with no need to use additional scripts, data downloads and external visualization systems. The examples of applying the system for the assessment of floats drift velocities at different depths and in certain parts of the sea are shown. In the future, GIS can be supplemented with new modules, such as automatic downloading of *Argo* data, operating with similar data arrays obtained, for example, from drifters or ADCP current profilers. Besides, it can be applied to any other regions.

Keywords: geoinformation system, GIS, *Argo* floats, drift velocity, currents, Black Sea, database, DB

Acknowledgements: the work on development and implementation of GIS was carried out within the framework of the themes of state assignment of FSBSI FRC MHI FNNN-2024-0012 and FNNN-2024-0014. The velocity field features were studied within the framework of theme of state assignment FNNN-2024-0001. The authors are grateful to DSc. (Geogr.) V.N. Belokopytov for useful consultations while developing and testing the system, as well as to the reviewers for their attention to the work and its appreciation.

For citation: Zhuk, E.V. and Markova, N.V., 2024. Geoinformation System for *Argo* Floats Drift Assessment: The Black Sea Case. *Physical Oceanography*, 31(4), pp. 562-579.

Introduction

Argo autonomous profiling floats [1] have become a source of regular data on the profiles of the main hydrological, hydrochemical and other characteristics of

[1] ARGO. *ARGO Data Management*. 2024. [online] Available at: http://www.ARGOdatamgt.org/ [Accessed: 18 March 2024].

the marine environment over the past two decades. Both data obtained by them and complete information about the main stages of the World Ocean observation system development using *Argo* floats including their design and operational features are publicly available. Profiling floats can be equipped with various sensors appropriate to the assigned tasks to carry out observations of marine environment parameters, while the basic observed parameters are temperature and salinity [1]. At the same time, they are unable to measure directly one of the most important oceanographic characteristics – current velocity. Calculation of velocity based on floats trajectories when the floats are used as Lagrangian tracers makes it possible to estimate direction and amplitudes of currents, structure and variability of the velocity field.

A fairly complete critical review of information obtained from *Argo* floats is presented in [2] which also refers to the methodology for calculating the velocity of floats movement under water based on their satellite positioning on the surface. At the same time, among the first works on calculating velocities in the ocean, study [2] is noteworthy, which provides the basics of methodology for calculating the velocities of *Argo* floats at their drift depths (parking levels) as well as assessing errors of such calculations due to vertical velocity shear. Calculations of average float velocities in the World Ocean were also carried out in a number of works, for example, in [3, 4] and in [5–8] when assessing currents in the Black Sea. Archives of calculated velocities obtained by various research groups are now freely available (Fig. 1), but a simple and convenient online system for scientific analysis of these data has not yet been created.

A procedure for calculating Lagrangian velocities for arbitrarily selected data and region is absent in the *Argo* project online services, although arrays with estimates of floats velocities based on their trajectories for the entire World Ocean are periodically added for public access, in particular in *Copernicus Marine Service* (Fig. 1). Although the data files are in the netCDF format, the lack of ability to select data (by float ID, region, date, parking level, etc.) makes these arrays not entirely convenient for analyzing dynamic processes.

At the same time, all other quality-controlled information received from *Argo* floats is currently available and is regularly updated. Therefore, taking into account continuous obtaining of new *Argo* observational data, it is necessary to create a flexible system for sampling, processing and primary analysis of float velocities in the selected basin, which is capable to produce the latest data processing results swiftly and visualize them. GIS implementation for calculating and processing Lagrangian velocities in the Black Sea basin at this stage is completely justified and useful as a rational addition to existing services. Its application will make it possible to obtain information on drift velocities for various samples (by layer, time, region) as well as determine quickly statistical characteristics and recalculate results in case of velocity calculation methodology improvement.

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[2] Lebedev, K.V., Yoshinari, H., Maximenko, N.A. and Hacker, P.W., 2007. *YoMaHa'07: Velocity Data Assessed from Trajectories of Argo Floats at Parking Level and at the Sea Surface*. Asia-Pacific Data-Research Center, 16 p. (IPRC Technical Note No. 4(2)). doi:10.13140/RG.2.2.12820.71041

Velocity products

ARGO DATA > ARGO DATA PRODUCTS > VELOCITY PRODUCTS

Global Velocity Products

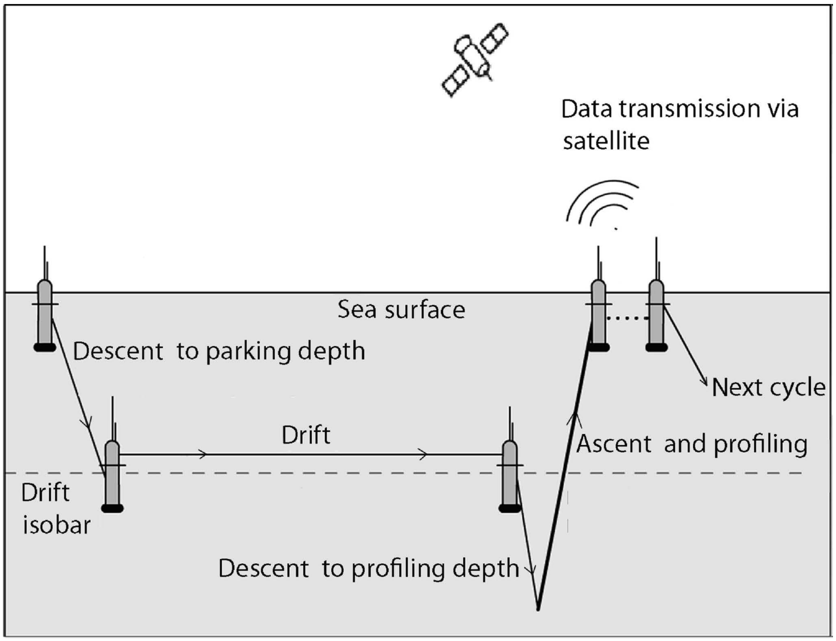
Institution	Documentation & Access	description	Temporal coverage	Update frequency
Univ. Brest, IFREMER, CNRS (SNO Argo France/LOPS)	10.1175/JTECH-D-12-00073.1data access	**ANDRO: a global Argo based deep displacement dataset**	2001 – 2020	yearly, but partially
Copernicus Marine Service	quality information pdf data access	**Global trajectory product based on v3.1 and higher trajectory files**	1997 – present	daily
CSIO	data access	**Global trajectory product based on v3.1 and higher trajectory files**	2001-2022	twice a year
IFREMER	pdf data access	**ANDRO in Argo Trajectory V3 NetCDF files**	2001 – 2009	rarely
IPRC	pdf data access	**YoMaHa'07: velocity data assessed from trajectories of Argo floats at parking level and at the sea surface**	1997 –	monthly
JAMSTEC	10.1007/s10872-010-0046-4 data access	**Global gridded ASCII and NetCDF of YoMaHa'07 QC'ed Argo drift trajectories**	Average since 2001-01-01	rarely
Scripps Institution of Oceanography	data access	**Scripps Argo trajectory-based velocity product**	2001 – 2022	twice a year
University of Washington	10.1175/JPO-D-12-0206.1data access	**Absolute Geostrophic Velocities from Argo (AGVA)**	2004 – 2010	rarely

F i g. 1. Data arrays on the floats drift velocities presented on the website https://argo.ucsd.edu/data/argo-data-products/velocity-products/

Thus, this work is purposed at developing and implementing a GIS that allows working online with *Argo* profiling floats data in the Black Sea and also, as an application example, to use it to assess the floats drift velocities in different sea layers for 2005–2022.

Data and methods

Observational data. The main data sources for calculating velocities are publicly available archives of *Argo* project[1] which contain information obtained by both active and already inactive profiling floats. It includes metadata for each float (with technical characteristics and settings) as well as observational oceanographic parameters and satellite positioning data. The drift depth of a profiling float is specified, but it is not necessarily a constant parameter for the entire operating time of the float. In addition, this depth may not be achieved in real conditions when the float moves (due to the characteristics of the bottom topography). The floats drift depths can be reconstructed from the built-in pressure sensor data, while at the same time their accuracy at certain moments of movement depends primarily on the specified discreteness of data recording. Thus, there are data arrays where pressure information was recorded only at the initial and final moments of the stages of float operating cycle (Fig. 2), which did not guarantee its drift at the same parking level (for example, in the presence of a bottom rise or access to shallow water). This point had to be taken into account when implementing the velocity calculation algorithm.



F i g. 2. *Argo* float cycle

In the Black Sea, the most typical float cycle has a period of 120 hours (5 days), the parking levels are between 200–1500 m, and profiling depths reach up to 2000 m. The presented study analyzes velocities calculated using *Argo* dataset including information for 2005–2022 from all profiling floats which exceeds in volume the data on the Black Sea applied in previous similar publications [5–8]. Most of the recently deployed floats are positioned by the *Iridium* satellite system, which makes it possible to improve the accuracy of determining float coordinates when surfacing compared to the previously more common *Argos* [3] communication system [2] and, accordingly, to calculate drift velocity more accurately.

Algorithm for drift velocity calculation. Mean drift velocities were calculated according to profiling float satellite positioning data as ratio of the distance of float covered underwater by the corresponding time interval between the float surfacing and its previous descent to the parking level: $\mathbf{v} = d\mathbf{r}/dt$, where $d\mathbf{r}$ is the distance between positioning points in cycles i and i-1; dt is time interval between float positioning in i and i-1 cycles.

As already noted, a similar technique for calculating the Lagrangian velocity for the Black Sea basin was first applied in [5] and later in [6–8]. It is clear that

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[3] Xeos Technologies Inc. *A Comparison of Iridium vs Argos Technology in Xeos Location Beacons*. 2019. [online] Available at: https://xeostech.com/comparison-iridium-vs-argos-technology-xeos-location-beacons [Accessed: 18 March 2024].

the previously mentioned formula assumes an error in determining velocity at any parking horizon, since the time interval includes not only periods of float drift at the parking level, but also periods of float drift on the sea surface (between the moments of its actual surfacing/descent and the closest positioning via satellite) and periods of float movement in vertical sections (during its ascent to the surface and its backward descent) (Fig. 2). Methods to eliminate errors were proposed for the World Ocean, for example, in works [2] and [3]. It is quite difficult to calculate accurately the float movement in the vertical sections of its trajectory in the Black Sea because the main assumptions for such correction are not only the constancy of ascent/descent velocity of the float (≈10 cm/s), but also the constancy of vertical velocity shear during the float cycle [2]. This condition is often violated due to strong density stratification of the Black Sea waters (presence of a permanent pycnocline) and spatiotemporal variability of currents in the basin [9, 10]. Therefore, a methodology similar to research [5–8] is used in this work, and the resulting refinement of velocity assessment is primarily due to an increase in the total amount of accumulated float data as well as faster positioning of most recently deployed floats by the *Iridium* system on the sea surface compared to previously used *Argos*. The database (DB) seeding with new float data implies further improvement of their velocity assessment.

This work uses data from 42 *Argo* floats drifting in the Black Sea at 200–1500 m depths from early 2005 to mid 2022. Velocity vectors were calculated with regard to all available data and monitoring whether the float reached the programmed depths. The drift depth metadata applied for each profiling float cycle are more accurate than in [8] when the parking level specified in the metadata for the entire float trajectory was considered. In addition, their percentage increases with the deployment of new floats positioned by the *Iridium* satellite system using GPS [2, p. 5]. *Iridium* telecommunications system provides faster and more accurate determination of float coordinates and the ascent/descent surface timing. When processing the *Argo* [1] data, it was discovered that although they were quality-controlled before being made available for users to download, they still contained errors in positioning of some stations. As a result, these stations were rejected and data quality flags were stored in the GIS database.

Geographic information system. Drift velocities of *Argo* floats were assessed by an analysis of the calculation of their mean velocity using GIS available at: **http://www.bod-mhi.ru/ff/** [4]. The data sources for GIS were *Argo* float data files in netCDF and csv formats containing information about the float ID, its location, profile time, measured parameters as well as separate metadata files that provide information about the drift depth before the start of profiling. Actual drift depth during the cycle is known for all floats except ID 7900465, 7900466, 4900540, 4900541, 4900542, 4900489. For these floats, the same check method as in [8] was used. In this case, the data from the float description section (profiling cycles, measurement depth and drift depth) on the website [1] was applied; the indicated drift

[4] MHI of RAS. *Oceanographic Data Bank of the Marine Hydrophysical Institute of RAS*. [online] Available at: http://www.bod-mhi.ru/ff/ [Accessed: 27 March 2024].

depth was checked for compliance with actual observations (profiling start depth and site depth must be no less than declared drift depth). Similar checks were carried out in [3, p. 769].

Based on the analysis of floats data structure, the authors developed the structure of a relational database as well as software modules for source data parsing and inputting information to the database tables. *PostgreSQL* is used as a DBMS [5]. The database consists of a table containing metadata (*argo_trajectories*) and measurement data table (*argo_profiles*) corresponded to each other by key fields. The database initial structure was presented in [11]. In this work, *argo_trajectories* table was supplemented with drift velocity values; the updated structure of the tables is given below (Tables 1 and 2). The tables were filled in automatically using a developed software module in Python.

T a b l e 1

Metadata (*argo_trajectories*)

Field name	Data type	Description
id	serial	Index
argo_platform_id	int	*Argo* identifier
cycle	int	Profiling cycle number
date_time	timestamp	Date and time of profiling
latitude	float	Latitude
longitude	float	Longitude
drift_depth	float	Drift depth
velocity	float	Drift velocity absolute
direction	int	Drift direction
qc	int	Quality flag

T a b l e 2

Profiling data (*argo_profiles*)

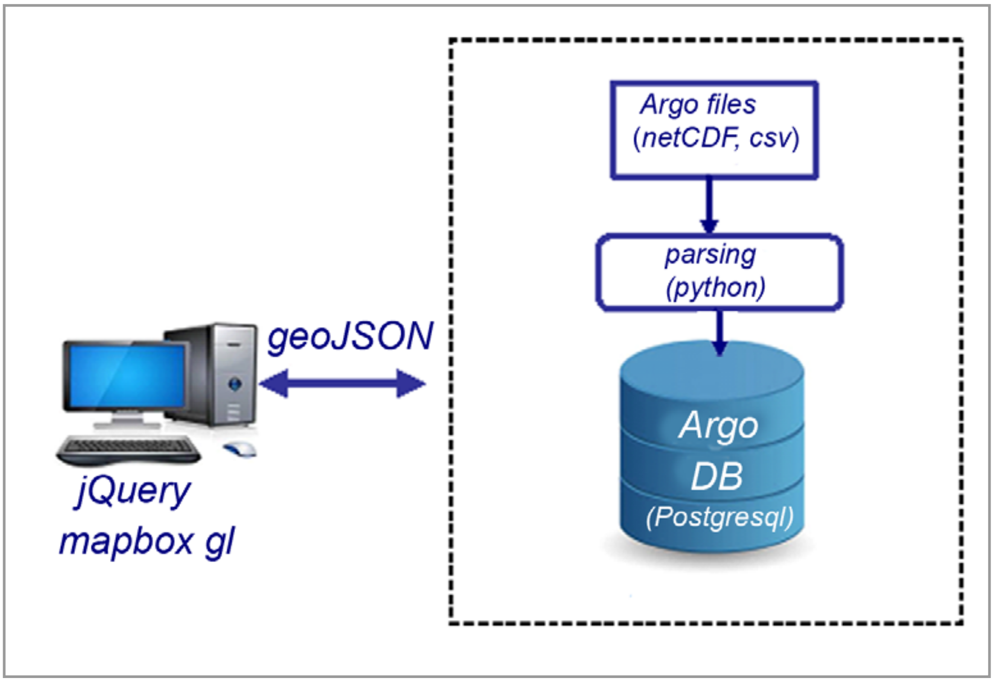
Field name	Data type	Description
id	serial	Index
argo_platform_id	int	*Argo* identifier
cycle	int	Profiling cycle number
pressure	float	Pressure
temperature	float	Temperature
salinity	float	Salinity
doxy	float	Oxygen concentration
chlorophyll	float	Chlorophyll concentration

N o t e: Key fields in the tables are highlighted in bold.

A user web interface that provides all the necessary functionality was developed for convenience in database access, carrying out statistical calculations, selecting and visualization of profiling and drift data. The structure of data storage and retrieval system is shown in Fig. 3.

[5] *PostgreSQL: The World's Most Advanced Open Source Relational Database*. 2024. [online] Available at: https://www.postgresql.org/ [Accessed: 27 March 2024].

The developed GIS provides the ability to work in two main modes:
– with **one** profiling float selected by identifier,
– with **all** the floats.

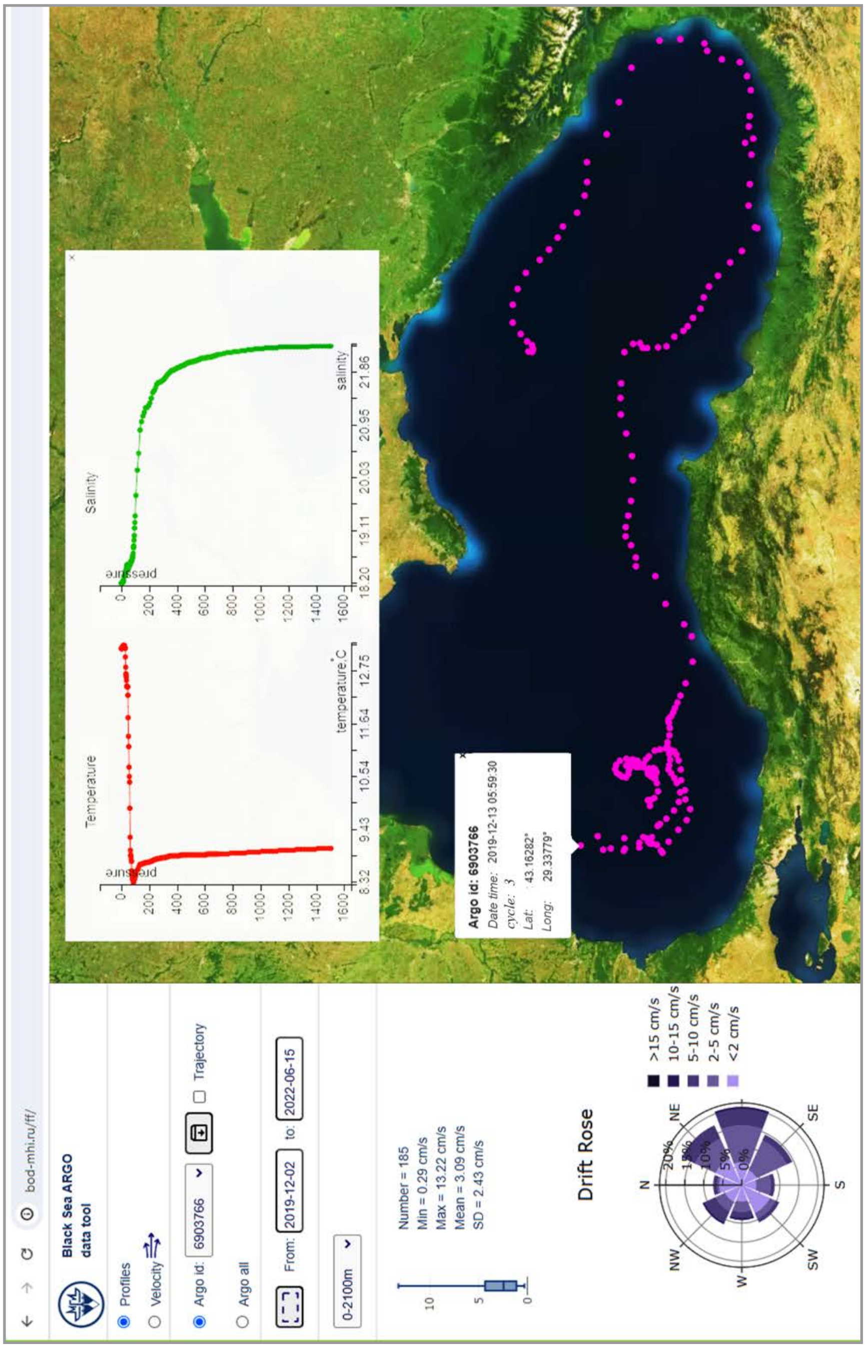


F i g. 3. Structure scheme of the *Argo* data access system for the Black Sea

Switching between the modes occurs with a special user interface option. In each of the modes, it is possible to display the float (floats) position as points (if Profiles option is selected) or as drift velocity vectors (if Velocities option is selected). When a User clicks on the displayed point or vector, a pop-up window appears with information about the float ID, coordinates, station; profiles of parameters measured during this sounding are constructed (if Profiles option is selected) or information about the float drift velocity and direction is displayed (if Velocity option is selected). For both modes, it is possible to retrieve data over a rectangular area specified on the map and over a specified time interval.

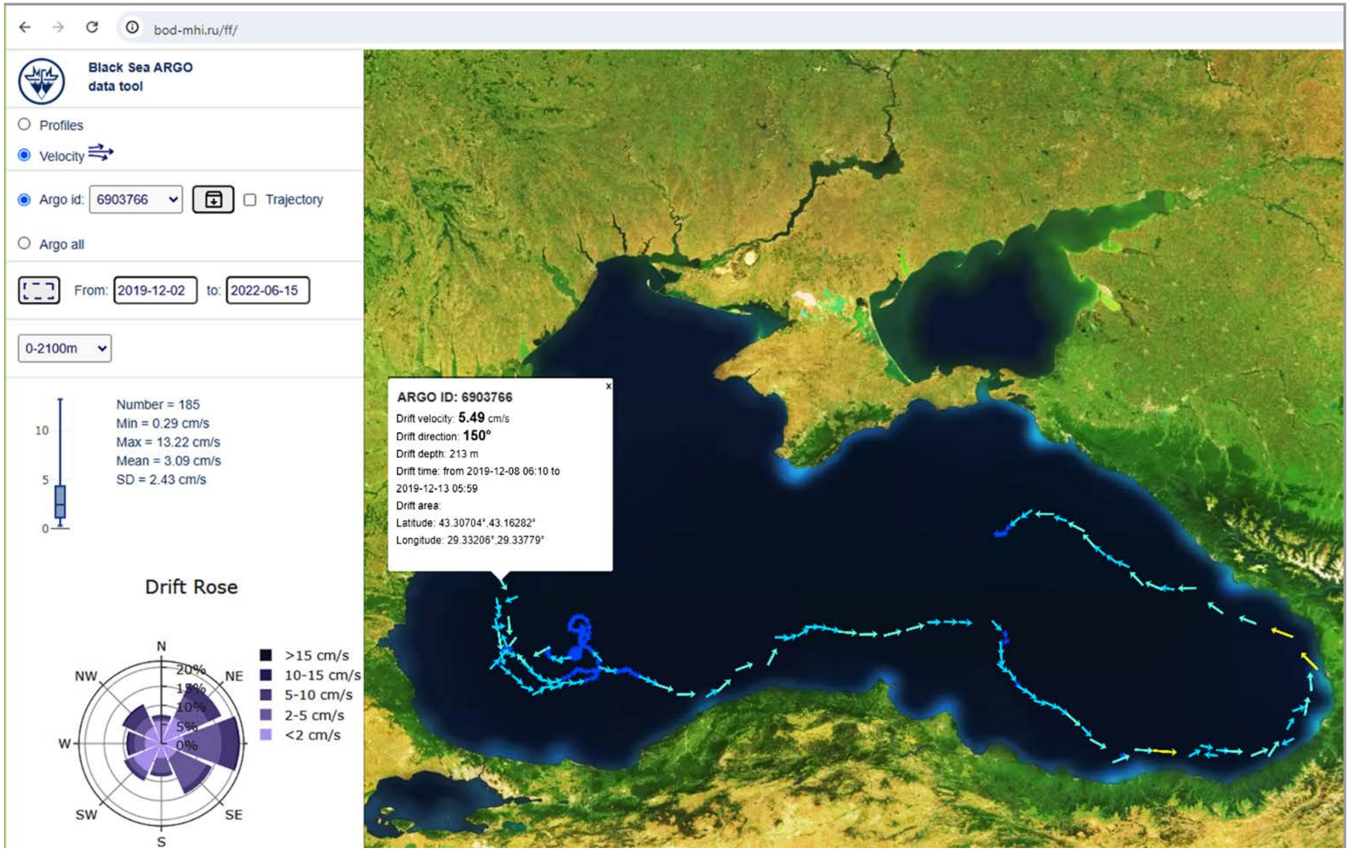
Selection by layers corresponding to the floats drift depths is also available in the mode when all floats are selected (All option). For each new selected dataset, the main statistical characteristics of drift velocities are calculated (minimum and maximum velocities, mean value, standard deviation), a current rose and a box and whisker diagram are constructed.

Data downloading by float ID in netCDF format is available. Figs. 4–6 demonstrate examples of data selecting and visualization. In the figures next to the maps, there are diagrams (roses) of currents demonstrating direction and value of calculated velocities in the selected area.



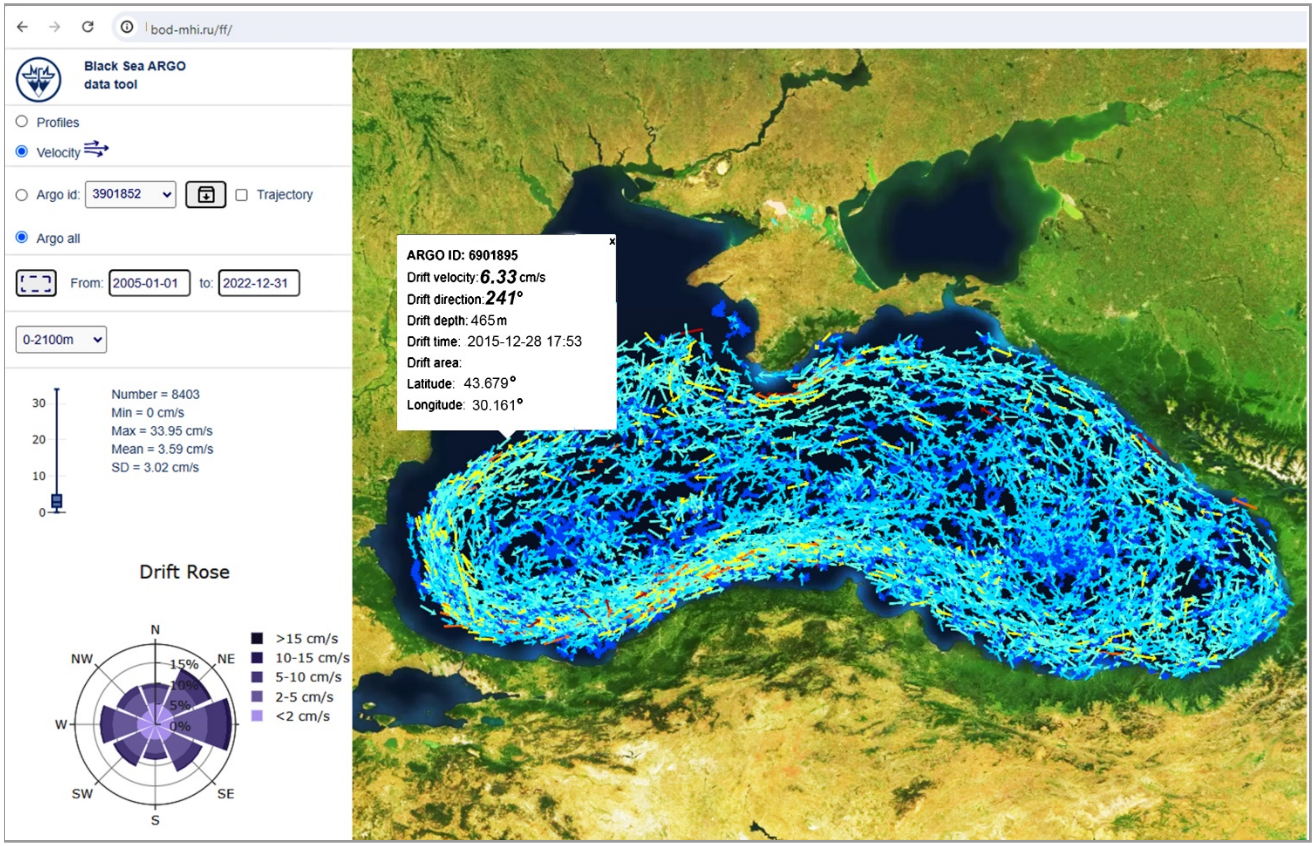
bod-mhi.ru/ff/
Black Sea ARGO data tool
Profiles
Velocity
Argo id:
6903766
Trajectory
Argo all
From:
2019-12-02
to:
2022-06-15
0-2100m
Number = 185
Min = 0.29 cm/s
Max = 13.22 cm/s
Mean = 3.09 cm/s
SD = 2.43 cm/s
Drift Rose
>15 cm/s
10-15 cm/s
5-10 cm/s
2-5 cm/s
<2 cm/s
Temperature
temperature,°C
Salinity
salinity
pressure
Argo id: 6903766
Date time: 2019-12-13 05:59:30
cycle: 3
Lat: 43.16282°
Long: 29.33779°

a

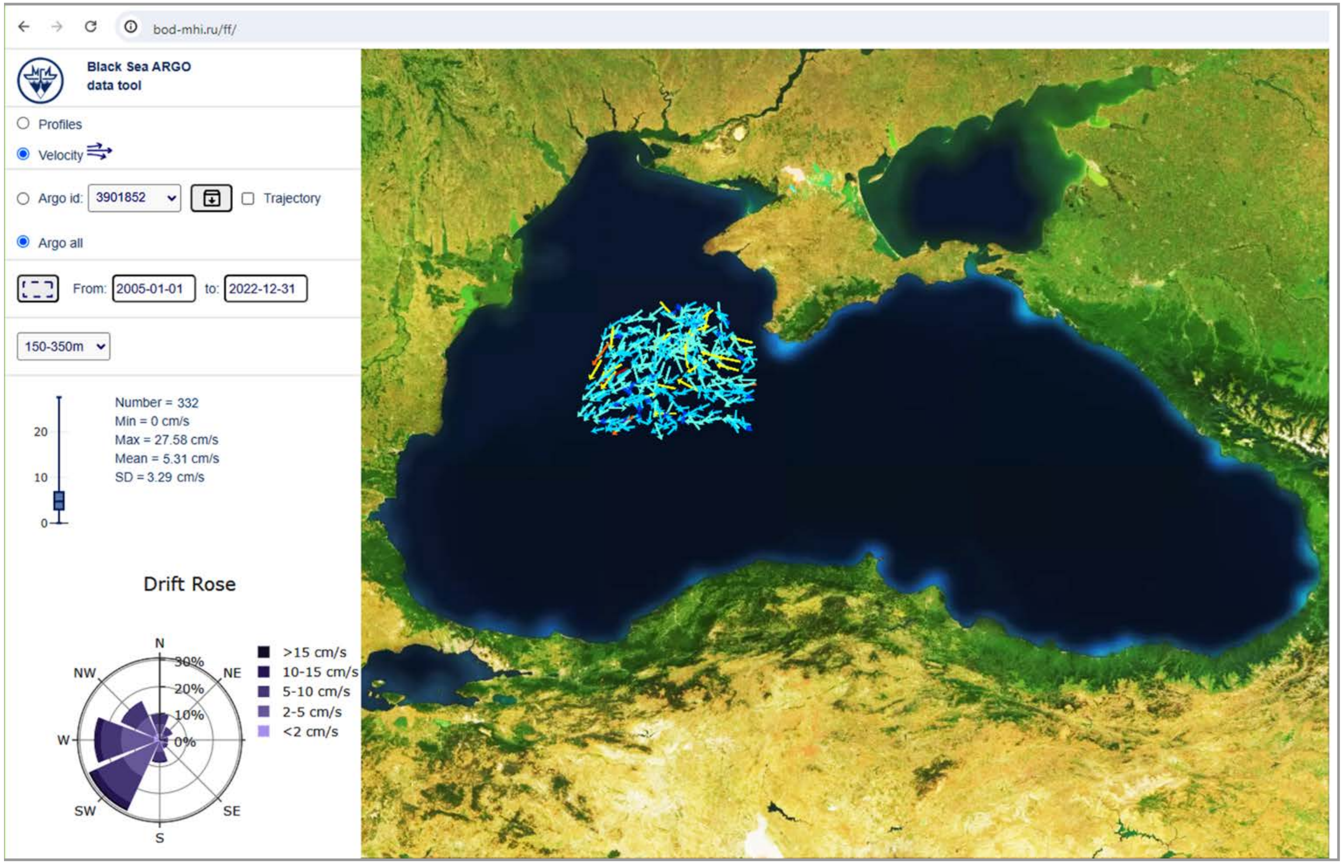


b

F i g. 4. An example of using the web interface to display: a – trajectory of the *Argo* float ID 6903766 and vertical profiles of temperature and salinity, and *b* – float drift velocities



F i g. 5. An example of using the web interface to display velocities of all the *Argo* floats drifting in the 150–350 m layer



F i g. 6. An example of using the web interface to display velocities of all the *Argo* floats drifting in the 150–350 m layer within the selected rectangular area

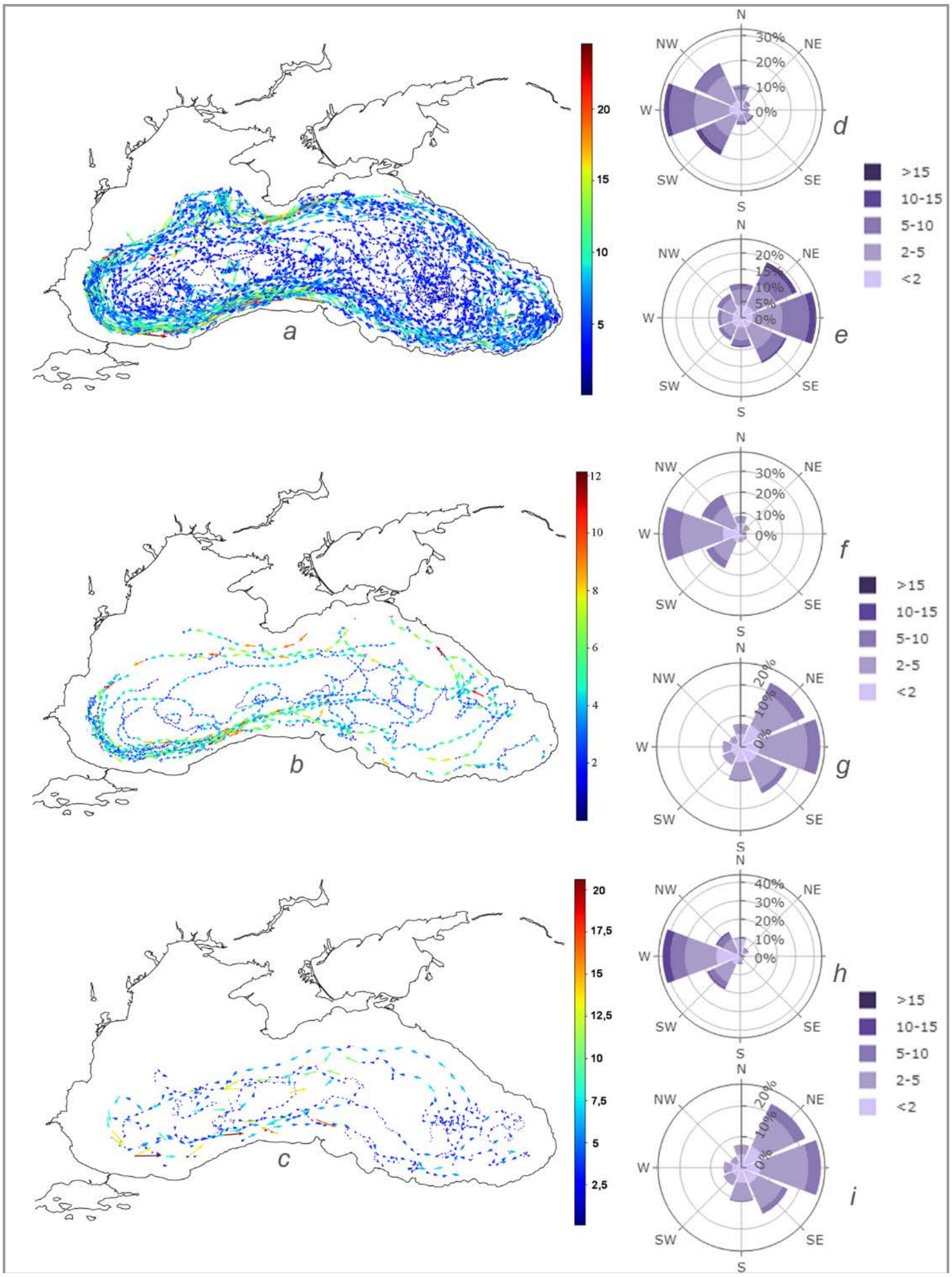
Results analysis

Using the developed GIS, the Back Sea velocities calculated from *Argo* floats data were analyzed in comparison with the most comprehensive published results on this topic. In [5], data from only three profiling floats were considered: mean velocity of the float at 200 m horizon was estimated at 7 cm/s, at 750 m horizon – at ~ 4 cm/s, at 1550 m horizon – within the range of 1–5 cm/s. In [6], based on the data from 7 floats that operated in 2002–2009, it is shown that their mean velocities at 750–1550 m depths were 2.2–2.7 cm/s, at 500 m horizon – 4 cm/s. In [7], after examining the data from floats with parking levels of 200–1000 m for the period 2005–2010, it was shown that current velocities decrease with depth, and in summer they are weaker than in other seasons. The calculated velocities at 750 m depth were up to 10 cm/s and at 1000 m depth they were within the range of 1–5 cm/s. In [8], a 10-year array of *Argo* measurements (2005–2015) was applied to estimate the velocities, which made it possible to examine the dynamics of the Black Sea deepwater currents in more detail, but the velocities in the upper layer were not assessed. In this case, the authors determined the following velocity values: 3.6 ± 0.4 cm/s at 350–600 m depths, 4.0 ± 0.2 cm/s in 600–800 m layer, 5.7 ± 0.6 cm/s in 800–1200 m layer and 3.5 ± 0.2 cm/s in 1200–1600 m layer (the lower of the considered ones) [8, p. 32]. Compared to this work, the number of deep-water *Argo* observations by mid 2022 increased significantly: at least 1.3 times in the layer below 1200 m and more than 5 times in 800–1200 m layer. For 200 m horizon, the number of observations increased by more than three times compared to the number used in the work with the most relevant data [7]: from approximately 1500 stations in 2015 to 4774 ones in 2022. Table 3 shows the calculation results of *Argo* floats drift velocities in different layers of the Black Sea. The number of calculated velocity vectors turned out to be less than the number of performed stations because in some cases the condition for the float to be located in the same layer between neighboring stations was not met. This situation is possible, in particular, when a float enters a zone with depths less than its parking level during one cycle and then the resulting velocity vector cannot be attributed to any of the layers.

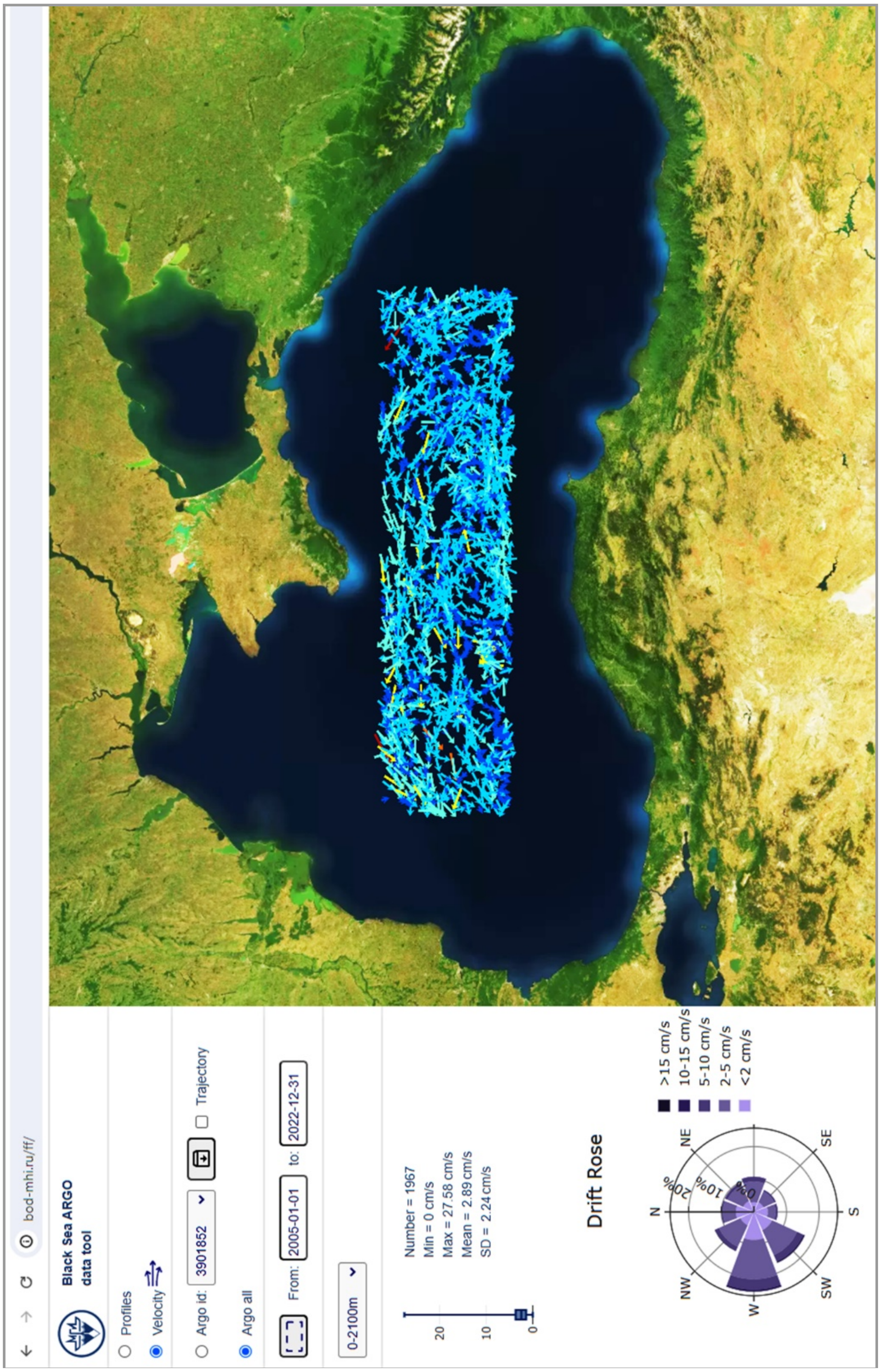
Table 3

Statistics of calculated velocity vectors by layers

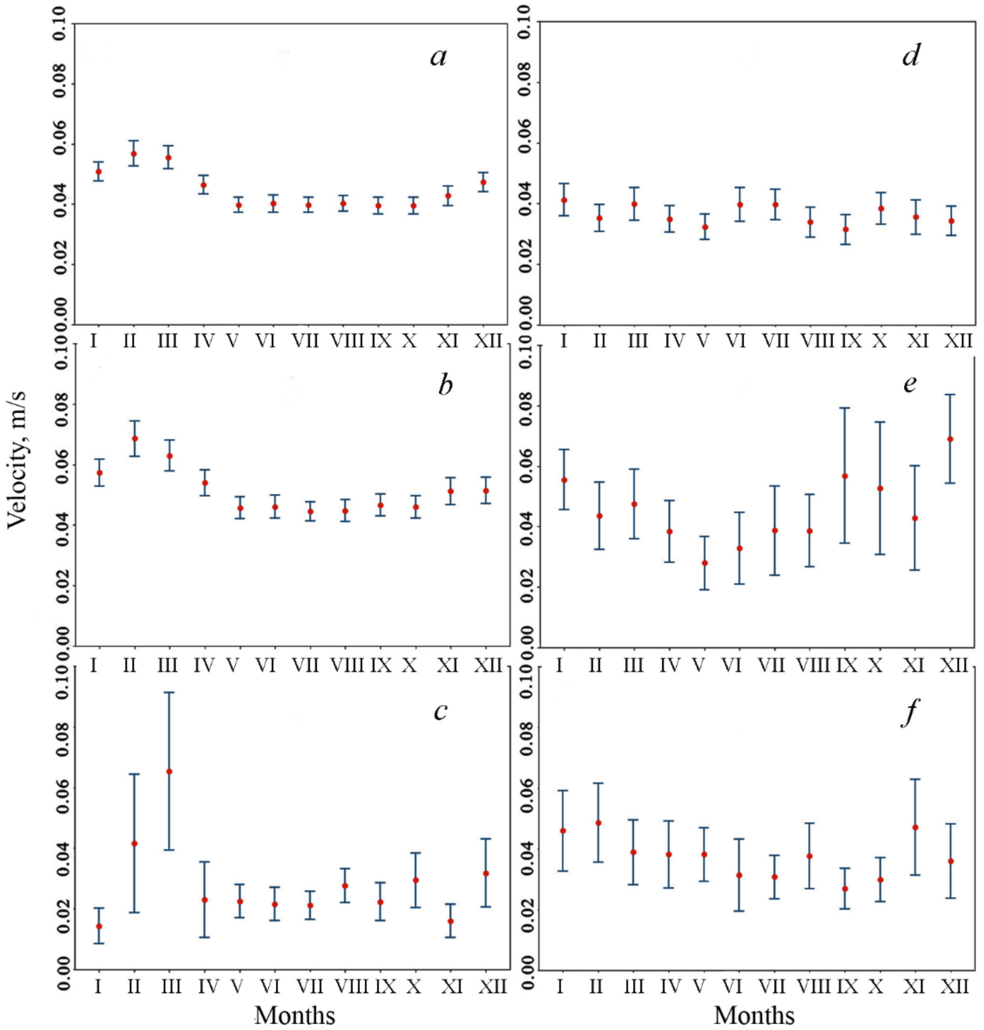
Layers by depth, m	Number of stations	Number of vectors	Mean velocity, cm/s	95% confidence interval, cm/s
150–250	4774	4695	4.2	±0.1
350–600	409	345	2.3	±0.2
600–850	1419	1348	2.9	±0.1
850–1200	820	772	3.4	±0.3
1200–1600	636	614	2.9	±0.2



F i g. 7. Calculated vectors of the *Argo* floats velocities (cm/s) and corresponding current roses in the 150–250 m (*a*), 600–850 m (*b*) and 1200–1600 m (*c*) layers in the northern (*d*, *f*, *h*) and southern (*e*, *g*, *i*) parts of the sea



F i g. 8. Calculated vectors of the *Argo* floats velocities in all the layers of the sea central part and corresponding current rose



F i g. 9. Seasonal variation of the *Argo* floats drift velocities in the Black Sea (red dots) with the corresponding confidence intervals (vertical segments): a – in the whole volume of the basin; *b* – in the 150–250 m layer; *c* – in the 350–600 m layer; *d* – in the 600–850 m layer; *e* – in the 850–1200 m layer and *f* – in the 1200–1600 m layer

It can be seen from Table 3 that the largest number of drift velocity vectors was calculated for 200 ± 50 m layer, the mean value with a 95% probability falls in the range of 4.2 ± 0.1 cm/s. In the next layer of 350–600 m, the number of calculated vectors is an order of magnitude smaller and mean velocity was 2.3 cm/s which is lower than the value of 4 cm/s indicated in [5, 6] and the values 3.6 ± 0.2 cm/s from [8]. In three deeper layers, mean velocities were slightly higher (2.9, 3.4 and 2.9 cm/s, respectively). Thus, in 850–1200 m layer, we reveal a slight increase in the mean velocity previously obtained in [8] and confirmed in this work using a significantly larger dataset. Moreover, taking into account the confidence interval, the mean velocity values in deep-water layers are quite close and amount to ~3 cm/s.

Fig. 7 shows the maps of calculated drift velocities of *Argo* profiling floats in some sea layers. According to the constructed diagrams, the prevailing direction of currents is western in the northern part of the sea in all layers, and in the southern part – eastern which is consistent with the concept of general cyclonic circulation in the basin. In addition to the main direction, the western, northwestern and southwestern directions of drift velocities are also clearly defined in the lowest layer. Velocity values in this layer are predominantly 2–4 cm/s, but they can reach 10–12 cm/s. In the central part of the basin, westerly drift predominates (Fig. 8) with 5–10 cm/s velocities and a maximum of 15 cm/s in 150–250 m layer (based on data on 1091 calculated velocity vectors), with 2–5 cm/s velocities in 350–600 m layer (93 calculated vectors) and 2–5 cm/s in 600–800 m layer (354 velocity vectors). In general, calculated characteristics of floats drift indicate a complicated structure of the current field in all layers, in particular, the presence of vortex formations of different scales and vorticity sign.

Figure 9 is plotted using monthly mean velocity found for the entire period under consideration; it shows that float drift velocities are higher in winter at almost all horizons than in summer. This is the result of a seasonal increase in winds over the sea in winter [9, p. 26]. Indicative in this regard are the diagrams for two upper layers (Fig. 9, *b*, *c*) which make the greatest contribution to the overall increase in velocity (Fig. 9, *a*). At the same time, the maximum of mean velocities in the upper layer is observed in February (7 cm/s), in the second layer (at 350–600 m depths) – in March (6.5 cm/s). In summer, velocities decrease to 2.5–4 cm/s in two upper layers. In 600–850 m layer (Fig. 9, *d*), seasonal variation in the mean velocities is not distinguished and mean velocities over the entire period are about 2.9 cm/s. In the deeper layers, at > 850 m depths, summer velocities (3–4 cm/s) are less than in other seasons (up to 6 cm/s).

Conclusion

Using the developed geographic information system, the drift velocity of *Argo* profiling floats which obtained oceanographic data in the Black Sea in 2005–2022 was assessed. Velocity analysis was performed on a more complete *Argo* dataset compared to previously published works. Mean velocity was clarified and drift features in some sea layers were shown. It is found that the winter increase in float velocities in the Black Sea associated with a seasonal increase in wind occurs not only in the upper, but also in the deeper sea layers. It is determined that in winter, at depths of more than 850 m, mean velocities increase up to 1.5–2 times relative to summer ones, and mean velocities in 350–600 m layer can increase up to 2–2.5 times with a clearly defined maximum in February–March. The dominant western direction of floats movement in the northern part of the sea at all horizons and dominant eastern one in the southern part indicate the cyclonic circulation pattern in the basin. The predominance of westerly directed drift velocities is determined in the central deep-water part of the sea. Analysis of vectors of other directions indicates the velocity field inhomogeneity, non-stationariness of currents and presence of vortex formations of different scales in all the layers under consideration.

GIS application for analyzing *Argo* data simplifies the work with oceanographic data for the Black Sea region and their scientific analysis greatly. At the same time, GIS implies the possibility of quick velocities recalculation when new observational data occur, to include a number of additional options into the system as well as to improve a methodology for calculating velocities at a parking level with regard to various estimates of float movement during its ascent/descent cycle phase.

Further system development implies adding functionality to visualize data from drifters and ADCP current profilers for the Black Sea, and enabling an automatic seeding of the database with new observational data from *Argo* floats. It is also possible to adapt the developed GIS for other areas of the World Ocean.

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Submitted 02.04.2023; approved after review 02.05.2024;
accepted for publication 16.05.2024.

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The authors have read and approved the final manuscript.
The authors declare that they have no conflict of interest.