

FEATURES OF THE HYDROLOGICAL STRUCTURE
OF VARNA LAKES AND THE ATMOSPHERIC IMPACT
ON THE WATER AREA IN THE PERIOD 2022–2023

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Abstract

The results of continuous direct measurements of the water temperature and salinity in the surface layer in two points for the period June 2022–August 2023, as well as from 102 vertical profiles obtained during seven polygon quasi-synchronous seasonal surveys of the water area of Varna Lakes, are shown. The intra-annual cycle of variability of both hydrological characteristics is reconstructed experimentally, and characteristic peculiarities of their vertical distribution during the different seasons are deduced. Based on data registered from a coastal meteorological station on the bank of the channel between the lakes, as well as from other two regional ones, the character of atmospheric influences on the studied water area for the indicated period is summarized. The salinity in Beloslav Lake is significantly affected by the inflow of the Provadiyska river and the precipitation in the area.

Key words: Varna Lake, Beloslav Lake, temperature, salinity, atmospheric impact

Introduction. The target of this study are the two deepest Bulgarian coastal lakes – Varna and Beloslav (s. c. Varna Lakes). They are located west of Varna Bay and represent a submerged river valley. Varna and Beloslav Lakes are, respectively,

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15 and 8 km long, the width varies from 1.3 to 3.8 km and from 0.5 to 3.5 km, their area is, respectively, 19 and 10 km², the maximal depth is 19 and 14 m (21–23 m for navigable canals). The banks of the lakes are low, covered by marsh vegetation. Provadiyska river and several small rivers are discharging their water masses into the lakes.

During the last century several periods of significant changes in the aquatic environment of the lakes have been observed caused by continued anthropogenic impact, transforming the lakes from freshwater estuaries into saltwater basins. For the character of changes in the first period (1909–1954) of connecting the lakes with each other and with Varna Bay with navigable canals, these changes have been summarized in the complex study [1]. The second period, when the lakes were under strong anthropogenic pressure from the extensive development of chemical industry in the western part of Beloslav Lake, naval transport and port activities, urbanization, agriculture, began in 1954 and lasted until the early 1990s. The Provadiyska river is also a significant source of polluted water, as large quantities of fresh water from it and from the Devnya springs are used for industrial purposes before being discharged into the lakes; additional three power plants were thermal sources of water pollution. In 1976 began the construction of a second deeper navigation canal from Varna Bay across the lakes with extensive and subsequent maintenance dredging causing increase of sea influence and of anthropogenic impact on lake water, as well as of sediments, and biodiversity. In some cases, under the influence of dynamic conditions, the coastal water from Varna Bay can also favour pollution. In general, the anthropogenic impact leads to the formation of persistent hypereutrophic conditions and the enormous plankton blooms cause mortality of fish, and benthos flora and fauna [2–5].

In the late 1990s, following an economic and industrial collapse, the closure of some chemical plants, the reduction in the use of chemical fertilizers, and the introduction of stronger legal restrictions on pollution processes, the ecological status of the lakes gradually improved from poor to moderate [6]. However, this favourable trend was not sustainable, and the ecological state of Varna lakes remained unstable and risky, and often – out of control. During this period there were periodic extensive and unregulated anthropogenic interventions: in the period August 2019–September 2020, significant and long-term emergency spill of fecal water from the city collector into Varna Lake was observed; capital and maintenance dredging works in the navigation canals and in new port areas are still being carried out unchecked, with dredged material being discharged into the lake water areas.

Organization of the research. Changes in the lake environment have been consistently monitored over the years. The results of the observations provide insight into the nature of these changes, but due to the strong spatial and temporal irregularity of the measurements – especially in the period after 1990 – they are not sufficient for precise quantitative estimates. In order not only to qualitatively

determine the trends in the oceanographic state of the lakes, which is formed against the background of dynamically ongoing climate change and not estimated anthropogenic impact, it is necessary to assess more accurately the current state of the lakes, i.e. there is a need for more detailed complex experimental observations. Such a task was set in the framework of the European DOORS Project [7] when a system for long-term continuous observations of the aquatic environment and the adjacent atmosphere was established in the lakes. The system includes the following basic components:

a) Direct continuous measurements with duration greater than one year from two automated monitoring buoys with installed at a depth of 1.5 m from the lake surface an YSI EXO2 multi-parameter sonde. The mooring location coordinates are [43.19288°N; 027.85687°E] and [43.19520°N; 027.68670°E] and the bottom depth is 16.5 m and 11 m in Varna and Beloslav Lakes, respectively (Fig. 1). The following water characteristics were measured from the beginning of June 2022 until the beginning of August 2023 with time resolution of 20 min: temperature T , salinity S , oxygen (dissolved and saturated), pH, turbidity, chlorophyll- a , blue-green algae. All results were Internet accessible in real time.

b) Long-term (03.08.2021–05.03.2024) and continuous standard meteorological observations with time step 10 min of temperature, pressure, humidity, wind (average velocity, gust, direction), rainfall, solar radiation, snowfall, using one new automatic station installed on the shore of the Varna-Beloslav Lake channel



Fig. 1. A Google map with location of: Varna (B1) and Beloslav (B2) buoys, and Beloslav (M1), Karantinata (M2) and Naval Academy (M3) meteostations. Numbers indicate the location of the oceanographic stations during one of quasi-synchronous surveys

[43.19436°N, 027.71196°E] and two other existing ones (see Fig. 1). The presence of meteorological information is particularly important, as it makes it possible to compensate for the lack of knowledge about the nature of water circulation in the lakes and of water exchange between neighbouring basins. Wind, turbulence, winter convection play an important role in the dynamics of mixing processes in the upper active layer and in the redistribution of the different characteristics of the lakes environment.

c) Periodical boat based observations – profiling of the water column from the lake-surface to the lake-bottom, during 7 polygon surveys from May 2022 until May 2024, and 5 control measurements in the buoys' location (Fig. 1). As a final result, a total of 103 profiles with data for vertical distribution of T , S , oxygen (saturated and dissolved), turbidity, pH, and chlorophyll- a at different points of the lakes and different seasons were obtained. The basic instrument for measurement was an YSI EXO2 multi-parameter sonde with water pressure meter. Planning of this type of activities, the location of the oceanographic stations was chosen to cover the water area of the two lakes mainly in their deeper part, where the dynamics of the processes is greater. During the measurements, a quasi-synchrony condition was imposed – the duration of each survey conducted was one day. Other methodological requirements for the actual measurements and subsequent data processing were also adopted. Given the technical characteristics of the CTD-sonde and its low recording frequency (1 Hz), the lowering of the device was relatively slow to ensure a sufficient number of records for each meter of the water column. When performing the quality and quantity control procedures, only the data measured by lowering of the instrument towards the bottom were used, while those collected during the lifting to the lake surface were of a control character and were considered for expert decisions only. After removing questionable data and obvious errors, the remaining data measured within a meter, (usually about 10 in number) were averaged and assigned to the corresponding horizon – finally the vertical spatial resolution of the data thus obtained is ~ 1 m or less.

Due to considerable reduction of the project budget, important components were excluded from the original initial program: additional, long-term measurements for the Varna Buoy of the selected parameters in the bottom layer and profiling of the current velocity vector, study of the nature of the water exchange with Varna Bay under different hydro-meteorological situations, etc. However, the experimental system constructed for in situ observation makes it possible to follow in detail the intra-annual hydrological variability in the surface layer, as well as to obtain specific pictures for the seasonal vertical distribution of the described parameters.

Peculiarities of the hydrological intra-annual variability. The analysis of experimentally obtained hydrological data includes the results of measurements from both buoys in the surface water layer from the beginning of July 2022 to the

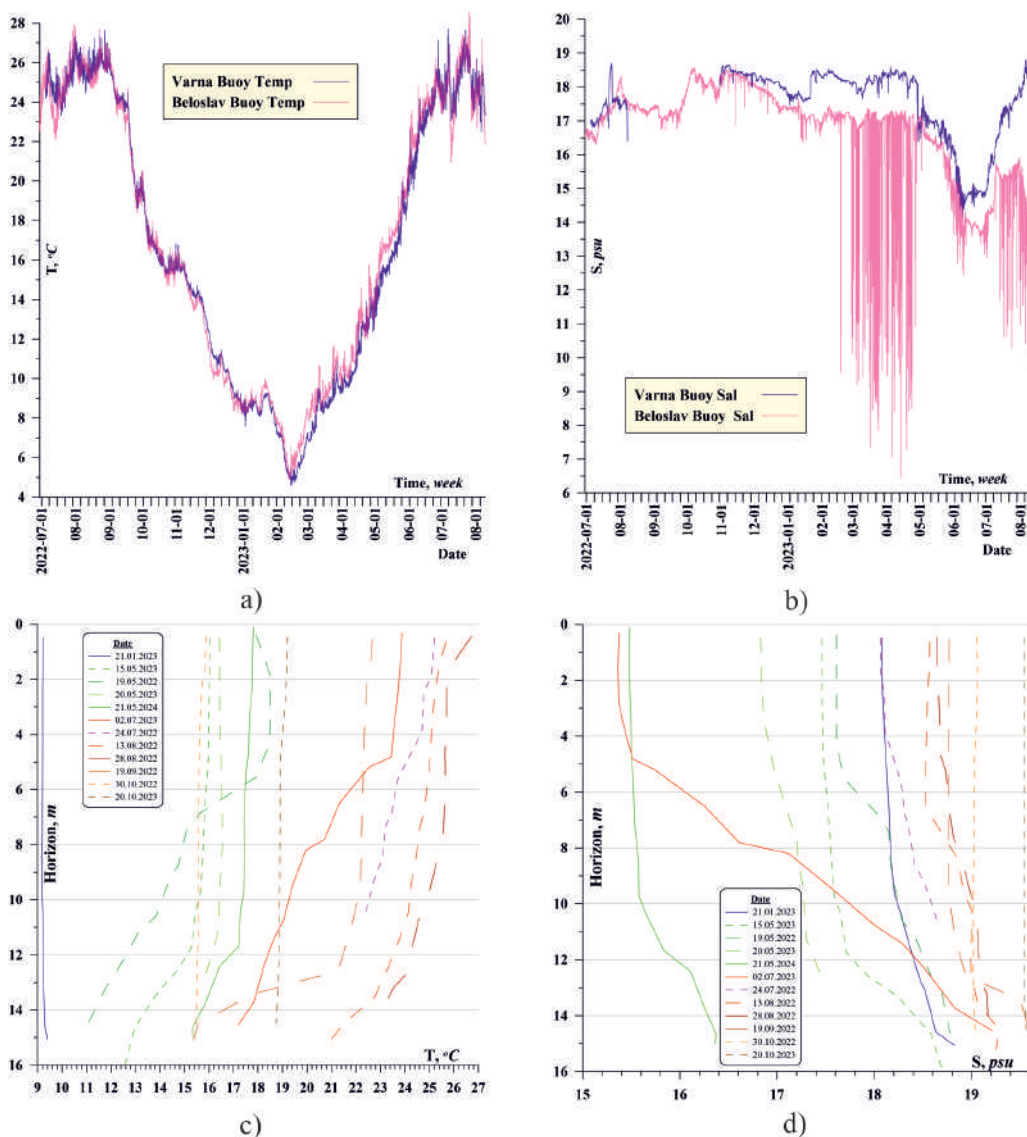


Fig. 2. Intra-annual variability of the T (a) and S (b) in the surface water layer at the buoy's locations and vertical distribution of T (c) and S (d) for Varna Lake Buoy on different dates

end of July 2023. The course of variations in time of T (Fig. 2a) and S (Fig. 2b) is shown synchronously for both buoys; Table 1 presents their main statistical characteristics during the separate months of the period. As should be expected (due to the nearness of the two basins and their shallow depth) the temperature changes were qualitatively the same, and quantitatively similar. The temperature maximum was reached in July-August: $27.31\text{--}27.62^{\circ}\text{C}$ and $27.95\text{--}27.71^{\circ}\text{C}$, for Varna and Beloslav Lakes, respectively; absolute minima were recorded in Febru-

ary and were again close in value (4.59°C and 4.88°C). The synoptical variability of the temperature field is well pronounced on the background of its seasonal course. Comparison of temperature data in the lakes and in Varna Bay [8] generally shows qualitative and quantitative similarity. The exceptions were three cases of pronounced upwelling during the warm half-year (September 2022 and August 2023), when T decrease in the bay exceeds 10°C , while there was no change in the lakes. Clearly, the presence of the “sea-lake” canal and its specific geometry contribute to blocking the process.

The long-term tendency of increasing the salinity of the lake water [4, 9] is preserved (Fig. 2b). In Beloslav Lake, it remains lower than in Varna Lake, but cases are possible when it almost levels off (October 2022). According to [10] and the data from Beloslav weather station (Fig. 3), in the spring and summer of 2023, the higher amounts of rainfall and of runoff from the Provadiyska river lead to a significant and rapid decrease in salinity, especially in Beloslav Lake when S dropped below 12–10 psu and a minimum (6.46 psu) was recorded (Fig. 2b). The relative increase in salinity during the summer months of 2022 cannot be directly linked to increased evaporation alone, as there is also parallel weakening of river inflow and rainfall. Moreover, the nature of the water exchange between Varna Lake and Varna Bay remains completely unresolved. Due to the immediate water exchange with the bay, the remoteness of the Provadiyska river and the presence of the navigable “lake-lake” canal, the amplitude of changes in Varna Lake is not so great. The presence of abrupt moment fluctuations of S in Beloslav Lake against

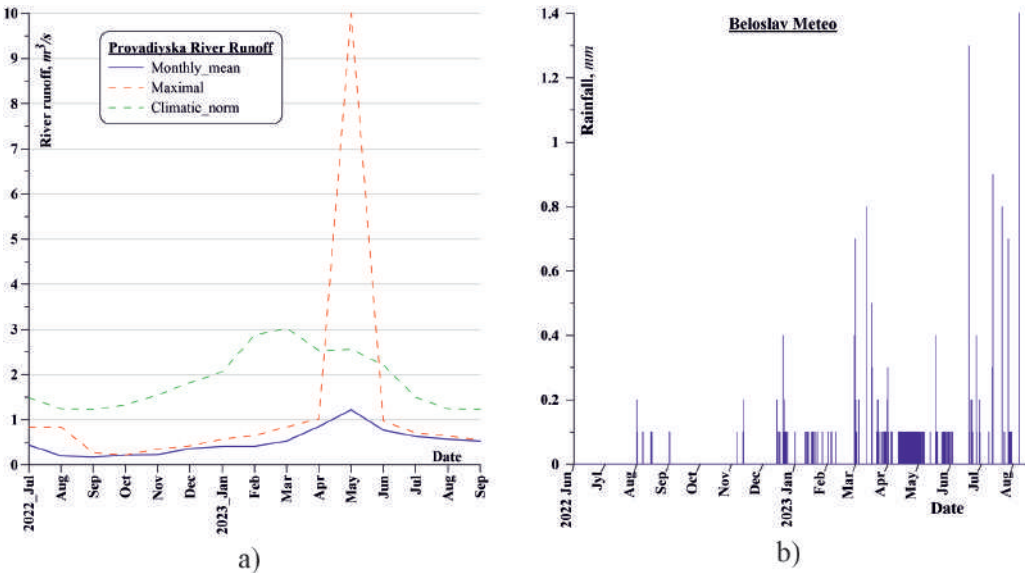


Fig. 3. Elements of the freshwater balance: (a) intra-annual variability of the Provadiyska river runoff [m^3/s]; (b) time evolution of measured rainfall [mm] at Beloslav meteorostation

the background of a qualitatively similar general course trend in both lakes can be considered an evidence of the spotty nature of salinity in the surface layer. Such rapid and abrupt deviations from the mean level lead to qualitative changes in the living environment, can play a significant role in the redistribution of different water characteristics in the lake and, in the case of pollution entering from the river or through rainfall, can have an additional negative impact on the living conditions in the aquatic environment and on the ecological status of the lake.

Peculiarities of the vertical distribution and its seasonal variability.

Describing the temporal variability of T and S in the buoy's locations does not provide any insight into their vertical structure and seasonal variability. The lack of this type of information from the direct continuous measurements is overcome by periodic profiling of the water column from the surface to the bottom. For the present analysis, 12 profiles at the Varna buoy mooring location are chosen (Fig. 2c, d). The point chosen to visualize this kind of results is one of the deepest compared to the other stations and is in relatively open water, and therefore allows the presence of a variety of structures to be tracked in more detail. On the one hand, these results can be compared with those shown above for the surface layer; on the other hand, they are also an indicator of the nature of seasonal variations of T and S . They make it possible to establish the presence of characteristic surface, intermediate, and near-bottom layers, of a weak inversion in the surface water layer (21.05.2024) or, respectively, of a quasi-uniform distribution in depth from the surface to the bottom (e.g. on 30.10.2020 and 20.10.2023 for T and S , on 21.01.2023 only for T). The presence of such a layered (or conversely, of a quasi-homogeneous) structure, has a significant influence on the vertical distribution of the other measured characteristics not subject to the present analysis. As a rule, the vertical distributions of both observed hydrological parameters and their seasonal variability have a logical explanation. In general, the seasonal signal in vertical T profiles is strongly influenced by the specific synoptic situation. For S , the characteristic minimum in spring and early summer is well traced out, and it is most pronounced in the results from 21.05.2024.

Peculiarities of the intra-annual variability of the observed atmospheric influence. Air temperature is the most important meteorological parameter for determining the state of the climate system under conditions of its instability. Analyzing the temperature regime at Beloslav station (Table 1), a comparative analysis was carried out with data from meteorological observations at the outlet of Varna Lake in Varna Bay (Karantinata station), near the shore of the bay in its central part (Naval Academy) – see Fig. 1, and summarized data of the National Institute of Meteorology and Hydrology [10]. It is natural to match all qualitatively with minor quantitative distinctions. The minimal temperatures at all stations reach $\sim -8^{\circ}\text{C}$ in January and February each year. The difference is in the number of measurements with values below 0°C : at Beloslav and Naval Academy stations, more cases compared to Karantinata station. The

T a b l e 1

Intra-annual variability of the monthly extremums, mean and standard deviation (SD) of the surface T and S from both buoys and of air temperature (T_a) from Beloslav meteorostation

Year		2022								2023						
Month		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul		
T	Min	23.33	24.45	18.60	15.26	12.23	8.23	7.20	4.59	6.78	9.25	13.10	19.49	23.05		
	Max	27.31	27.62	26.49	20.01	16.74	12.22	9.29	7.31	10.87	14.61	20.82	27.12	27.71		
	Mean	24.90	25.81	22.61	16.44	14.44	10.20	8.52	5.90	8.63	11.45	16.47	23.00	25.10		
	SD	0.77	0.46	2.22	1.05	0.97	1.00	0.44	0.82	0.90	1.45	1.65	1.56	1.03		
S	Min	16.77	16.40		18.00	17.98	17.71	17.46	18.02	17.64	16.38	15.88	14.16	14.97		
	Max	18.71	17.66		18.45	18.64	18.42	18.53	18.53	18.49	18.60	17.73	16.16	18.03		
	Mean	17.38	17.49		18.24	18.45	18.13	17.92	18.28	18.13	18.20	16.80	14.95	16.87		
	SD	0.44	0.16		0.10	0.10	0.14	0.32	0.12	0.18	0.40	0.34	0.36	0.80		
T	Min	22.09	24.67	18.36	14.64	11.37	8.22	7.61	4.88	7.84	9.58	13.69	19.94	20.95		
	Max	27.95	27.71	26.70	20.48	16.67	11.42	9.99	8.52	11.67	15.78	21.23	26.21	28.58		
	Mean	24.71	25.71	22.46	16.48	14.15	9.75	8.82	6.59	9.45	12.10	17.34	23.39	24.88		
	SD	1.19	0.47	2.26	1.13	1.22	0.83	0.49	0.92	0.86	1.45	1.49	1.20	1.47		
S	Min	16.30	17.09	16.72	17.52	16.87	17.20	16.36	9.57	7.34	6.46	13.64	12.43	10.28		
	Max	18.24	18.32	17.96	18.58	18.67	18.11	17.63	17.44	17.39	17.31	17.16	15.22	15.92		
	Mean	17.10	17.46	17.27	18.16	18.29	17.70	17.14	17.01	15.82	15.99	16.18	13.98	15.09		
	SD	0.49	0.21	0.24	0.21	0.14	0.25	0.21	0.92	2.30	2.17	0.56	0.40	0.70		
T _a	Min	13.45	16.18	5.42	1.66	2.21	-4.41	0.17	-7.63	-3.01	2.55	3.74	9.14	14.49		
	Max	34.33	35.36	35.39	28.43	27.59	20.88	20.73	20.73	21.61	22.98	27.08	31.92	39.33		
	Mean	23.78	25.07	19.02	14.24	10.73	6.09	5.93	4.70	7.97	11.27	16.34	21.07	24.89		
	SD	4.79	4.31	5.53	4.94	4.51	4.72	4.69	6.53	4.52	3.94	4.47	4.96	5.00		

maximal values are about 34 °C at Karantinata and Naval Academy, while at Beloslav station – about 40 °C (39.33 °C in July 2023). Thus, the annual amplitudes at Karantinata and Naval Academy stations are about 42 °C, while at Beloslav station they are about 48 °C. The periods with temperatures 30–35 °C are measured in July, August and September at Beloslav station, while at Karantinata and Naval Academy stations the periods of 30–33 °C air temperature are observed in July and August. The local climate at Beloslav is less pronounced as maritime compared to Karantinata station. We have data for a longer period than the considered here: August 2021–November 2024 for Beloslav, and from August 2020 – for Karantinata and Naval Academy stations. Annual cycles are well-defined and similar from year to year, with no specific deviations noted during these observation periods. Four hot summers have been recorded in Beloslav with the highest peaks in 2022 and longer hot periods in 2023.

Due to the shallow depth and small horizontal dimensions of the lakes, the response of water temperature to changes in the atmospheric temperature regime is apparently sufficiently rapid, and therefore there is no delay of about 20 days in the hydrological seasons from those for the weather characteristic of the Black Sea basin.

It is possible, having data from three regional weather stations, to determine not only the general wind regime in the lake's area, but also to establish the presence of local peculiarities in its spatial distribution. Data on the wind regime in Beloslav station for the period August 2021–November 2024, and for Karantinata and Naval Academy stations for the period August 2020–November 2024 are presented in Fig. 4. The prevailing wind direction throughout the period at all stations is from the west (WNW, SW, and NW), when the higher wind speeds are also present. The summer daytime sea breeze is from ENE at the Black Sea shore and from E at Beloslav. Due to urban structure influence, the direction is SE for the Naval Academy. The estimation of influence of the local conditions from the wind data shows again that the marine climate is less pronounced at Beloslav compared to Karantinata station.

The breeze circulation plays an essential role in the formation of the wind field and the ventilation of the surface atmosphere. For the Varna Bay area it has been studied in various climate studies [11,12], which show that it penetrates up to 40–50 km from the coast. Therefore, the two lakes – and Beloslav station in particular, fall under its influence. The geometry of the coastal line and the specific orography define quite different regime at all three locations. At the coast (Karantinata station), NW and SE directions are prevailing.

Conclusions. The prototype system for complex oceanographic and meteorological observations, built in the water area of the two lakes, has operated effectively for a long period. As a result, a hitherto unknown amount of information on the current state of the lake environment and the adjacent atmosphere has been accumulated, which will be used to make various objective assessments,

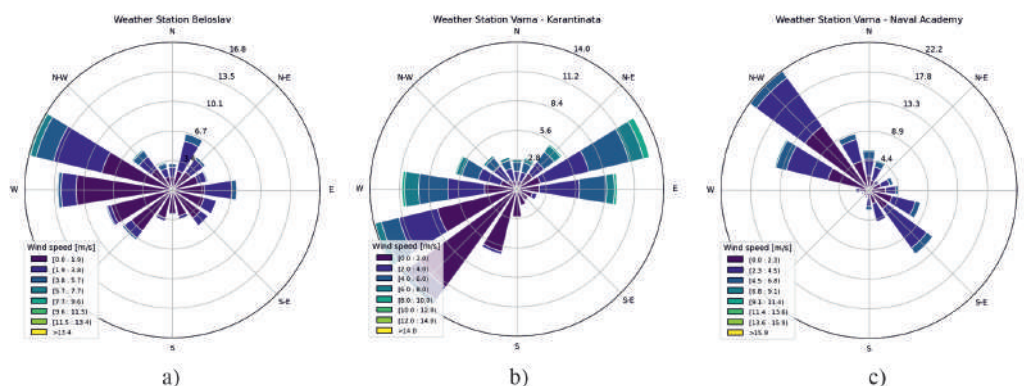


Fig. 4. The wind regime in stations: Beloslav (a) for the period August 2021–November 2024, Karantinata (b) and Naval Academy (c) for the period August 2020–November 2024

establish cause-effect relationships, and to build mathematical models. An annual cycle of temperature and salinity in the surface layer, as well as the local characteristics of the adjacent atmosphere, was traced. The various measurements of vertical hydrological structure are dominated by quasi-homogeneous distributions of T and S , but layered ones are also observed, possibly forming surface, intermediate or bottom layers. Increasing inflow from the Provadiyska river and increasing precipitation may lead to a decrease in salinity of more than 10 psu at the eastern end of Lake Beloslav and to the periodic formation of a mottled structure with short-term abrupt fluctuations in S .

REFERENCES

- [1] VALKANOV A. (1941) Hydrographische Untersuchungen an den Varna-Seen, Arbeiten aus den biologischen Meeresstation am Schwarzen Meer in Varna, **10–11**, 1–55.
- [2] ROZHDESTVENSKY A. (1967) Changes in hydrochemistry and hydrology of some important lakes along Bulgarian Black Sea coast, Proceedings of Research Institute for Fishery and Oceanography, **8**, 93–12, (in Bulgarian).
- [3] ROZHDESTVENSKY A. (1977) Changes in chemistry, pollution and hydrology of Beloslav Lake, Oceanology **2**, 5–17, (in Bulgarian).
- [4] ROZHDESTVENSKY A. (1992) The impact of anthropogenic factors on the hydrology and on the hydrochemistry of the Varna lake, Proceeding of the Institute of Oceanology, Varna, **1**, 48–57, (in Russian).
- [5] ROZHDESTVENSKY A. (1996) Hydro-chemical monitoring of Beloslav Lake during the period from 1975 until 1984, Proceedings of Inst. of Fisheries, **24**, 183–191, (in Bulgarian).
- [6] SHTEREVA G., B. DZHUROVA (2007) Varna Lake – recent state and impacts, J. of Balkan Ecology, **10**(1), 35–40.
- [7] DOORS Black Sea, <https://www.doorsblacksea.eu>.

- [8] String Meteo, https://www.stringmeteo.com/synop/sea_water.php.
- [9] SHTEREVA G., O. HRISTOVA, T. NIKOLOVA et al. (2001) On the state of the Beloslav Lake during 1990–1999 period, Proceeding of the Institute of Oceanology, Varna, **3**, 23–28, (in Bulgarian).
- [10] Monthly Hydrometeorological Bulletin (6–12 2022, 1–8 2023), National Institute of Meteorology and Hydrology of Bulgaria, ISSN 1314-894X, (in Bulgarian).
- [11] BATCHVAROVA E., S. GRYNING (1998) Wind climatology, atmospheric turbulence and internal boundary-layer development in Athens during the MEDCAPHOT-TRACE experiment, Atmos. Environ., **32**(12), 2055–2069.
- [12] BATCHVAROVA E., X. CAI, S. GRYNING, D. STEYN (1999) Modeling internal boundary-layer development in a region with a complex coastline, Boundary Layer Meteorology, **90**(1), 1–20.

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