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ПАССИВНОЕ ОПТИЧЕСКОЕ ЗОНДИРОВАНИЕ РЕЧНЫХ ПЛЮМОВ С БОРТА СУДНА С ПОМОЩЬЮ ГИРОСТАБИЛИЗИРОВАННОГО КОМПЛЕКСА ЭММА

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Наибольшая изменчивость экологического состояния прибрежных вод наблюдается в районах впадения рек. Плюмы рек могут отличаться от окружающей морской воды как по составу примесей, так и по их концентрации. При этом размеры и положение плюмов характеризуются сильной изменчивостью. Для мониторинга таких акваторий требуется проведение измерений с хорошим пространственным и временным разрешением. Продемонстрирована возможность оперативной оценки распределения естественных компонент морской воды в районе речного плюма у Кавказского побережья Черного моря методом пассивного оптического зондирования с борта судна. Для этого использовался портативный трехканальный гиперспектральный комплекс ЭММА — экологический мониторинг морских акваторий, установленный на гиростабилизированной платформе. Данные комплекса ЭММА были обработаны специальным алгоритмом, позволяющим получить спектры поглощения света морской водой и оценить концентрации природных компонент в ее составе. Обсуждается эффективность работы гиростабилизированного комплекса по сравнению с измерениями без стабилизации. Показана возможность получения оценок концентрации основных естественных составляющих морской воды гиростабилизированным комплексом ЭММА в условиях неравномерного освещения при низком положении солнца, что существенно расширяет временные рамки проведения измерений. Представленный комплекс может быть полезен при проведении подспутниковых измерений в прибрежных районах океана и внутренних морях, включающих речные плюмы.

Ключевые слова: пассивное оптическое дистанционное зондирование, коэффициент спектральной яркости моря, поглощение света морской водой, концентрация взвеси и окрашенного органического вещества в морской воде, речной плюм.

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PASSIVE OPTICAL SENSING OF RIVER PLUMES FROM BOARD OF A VESSEL USING GYRO-STABILIZED COMPLEX EMMA

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The greatest variability of the ecological state of coastal waters is observed in the areas of river mouths. River plumes can differ from the surrounding sea water both in the composition of impurities and in their concentration. Moreover, the size and position of plumes are characterized by strong variability. Monitoring of such water areas requires measurements with high spatial and temporal resolution. The possibility of operative estimation of natural sea water components distribution at a river plume by the method of passive optical sensing from board a vessel was demonstrated at the Caucasian coast of the Black Sea. Portable three-channel hyperspectral complex EMMA (Ecological Monitoring of Marine Areas) installed on a gyro-stabilized platform was used for this purpose. The data of the EMMA complex were processed by a special algorithm, which allowed obtaining light absorption spectra of sea water and estimating concentrations of its natural components. The efficiency of the gyro-stabilized complex is discussed in comparison with measurements without stabilization. It has been shown that it is possible to obtain estimates of the concentration of the main natural seawater constituents with a gyro-stabilized complex EMMA under conditions of uneven illumination at low sun position, which significantly expands the time frame for measurements. The presented complex may be useful for ground truth measurements in coastal areas of the ocean or inland seas with river plumes.

Key words: passive optical remote sensing, sea radiance coefficient spectrum, sea water absorption, concentration of seawater suspended matter and coloured organic matter, river plume.

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1. Introduction

Sea areas at river mouths are often the most changeable places at the sea coast, so for their ecological monitoring one needs some measuring tools with high spatial as well as high temporal resolution. Satellite facilities are not sometimes capable to meet these demands due to inappropriate revisiting time, cloudiness and some limitations of working at the water-land interface [1]. Moreover, the complex relationship between physical processes and biological and chemical content of different coastal and inland waters leads to great variety of their optical properties and demands diversity of algorithms for their processing [2–4]. It is essential especially in the coastal water areas with river plumes, as it is shown during some investigations of numerous lakes which waters are influenced by inflowing rivers [5]. To solve this problem a representative base of optical water types of inland and coastal waters in a wide geographical set was created [6]. Optical classification approaches allowed chlorophyll-*a* determination in some cases [7, 8], however, on the whole the thorough *in situ* estimation of the water constituents concentration is necessary to provide regional retrieval algorithms for every water body [9, 10]. Thus, it is desirable to provide three types of data for the water area investigation: in situ measurements on the water samples, satellite based optical instruments data and above-water remote optical measurements that can be used for satellite data calibration or instead of them in case of no satellite data.

The information of water content from water samples analysis getting by standard methods is quite reliable [11], there are also some methods of direct measuring of water absorption spectra using an integrating sphere [12]. The limited temporal frequency and spatial coverage of in situ sampling can be overcome by remote sensing data [13]. Satellite data themselves need thorough ground truth verification due to the signal distortions made by the atmosphere in the coastal areas. In slow changing case of rather small water basins (lakes, sea bays) a fixed position of a spectrometer system may be sufficient for this purpose [14]. However, as river plumes often change their location and intensity due to weather conditions (direction and strength of the wind, sea currents, the intensity of the river drain, etc.), remote sensing of the coastal water areas from board of a moving vessel with passive optical devices, that are rather cheap and need not high energy supply, is in great demand. It must be taken into account that the upward radiation from the sea consists of two parts — the light reflected by the water bulk itself and the one reflected by the water surface. Its total intensity corresponds to the water surface illumination. Thus, at least three values should be measured. The first works in this field were started at the end of the last century (see, for example, [15, 16]). Nowadays three-channel spectrometers are already produced and used for assessing of coastal waters [9, 17–20]. However, it is quite a problem to retrieve information about natural water components concentration from the obtained spectra of water reflectance as the latter are strongly affected by the weather conditions.

To solve this problem, we constructed a portable three-channel hyperspectral complex EMMA (Ecological Monitoring of Marine Areas) operating in semiautomatic regime [21]. It contains a new data processing algorithm allowing to calibrate measured spectra and to get estimates of light absorption in water bulk [22]. To eliminate some inaccuracy in primary data associated with the vessel heeling during movement, as well as with sea waves, it was proposed to install the EMMA complex on board a vessel on a gyro-stabilized platform. The paper presents the results of using the gyroscopically stabilized EMMA complex for studying the plume of the Psezuapse River in the area near Lazarevskoe settlement on the Caucasian Black Sea coast of Russia.

2. Measuring complex and primary data processing

The EMMA complex consists of a three-channel hyperspectrometer, which provides measurements at a frequency of 1 Hz in semi-automatic regime in the spectral range of 350–800 nm with a resolution of 3 nm, and equipment for controlling, recording, and further processing of information using original algorithms. The three channels of the hyperspectrometer are designed for simultaneous measurement of upward radiation from the sea (B_{sea}) with sighting at an angle of −45° to the horizontal, the radiation of the sky area that mostly contributes to the radiation reflected from the sea surface (B_{sky}) with sighting at an angle of +45° and the total irradiation of the sea surface with zenith sight, which after appropriate calibration is converted into the radiation of the horizontal white screen (B_{ws}). Based on these three spectra the spectrum of the coefficient of spectral radiance (CSR) [15, 23], which characterizes the water bulk itself, is calculated:

$$\text{CSR} = (B_{sea} - r \cdot B_{sky}) / B_{ws},$$

here r is Fresnel reflection coefficient. CSR is equal to the often used water reflectance [16] multiplied by π.

All measurements are carried out in a semi-automatic regime. It requires, firstly, the preliminary setting of the sensitivity of each channel by determining the signal recording time. Secondly, in the case of a vessel turning, it is necessary to turn the device manually so that its field of view does not fall into the area of sun glint or into the shadow area from the side of the vessel, in other words, to satisfy the requirements for the azimuthal angle. The measurement results and coordinates from GPS/GLONASS are saved in the data base for further processing. The EMMA complex is installed on board a vessel on a gyroscopically stabilized platform (fig. 1). The total weight of EMMA on the platform does not exceed 2 kg.

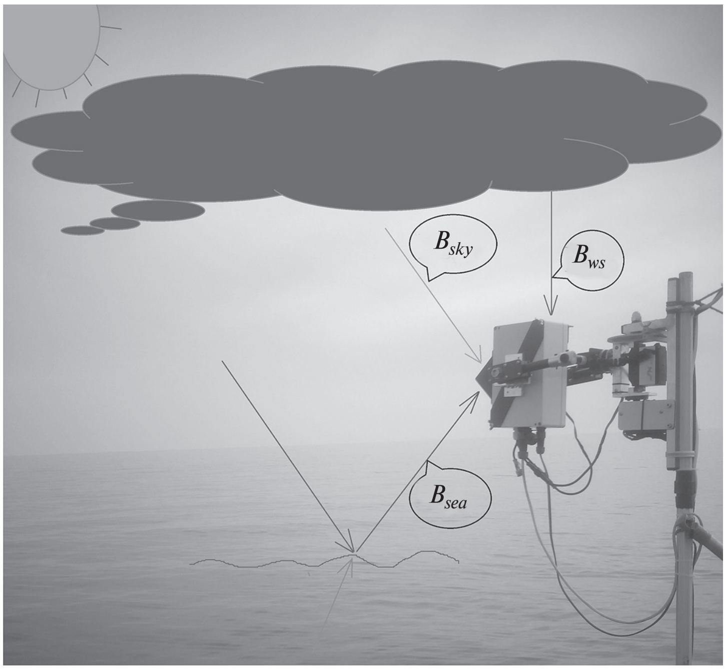

Fig. 1. General view of the EMMA complex for remote passive optical sensing on a gyroscopically stabilized platform.

3. Comparison of EMMA data with and without stabilization

The installation of the EMMA complex on a gyro-stabilized platform significantly improves the quality of the obtained spectra. Fig. 2 shows the characteristics of the signals received from the three channels in the presence of stabilization (Lazarevskoe) and without it (Feodosia). In both cases the vessel moved at a speed of 6 knots making stops for sampling water. The weather conditions were approximately the same: the sunny day with rare clouds, the sea state being slight.

It is seen that stabilization of EMMA is especially useful for the total irradiation measuring. In fact, at Feodosia the vessel heeling on move led to this signal deviation of 5—7 %, while the deviation at Lazarevskoe was about 0.5 %. Moreover, at Feodosia the vessel stops (11:30—11:33, 11:45—11:57 and 12:12—12:20) led to a change in the vessel orientation (the vessel bow was not raised as while moving and the field of view of B_{ws} channel includes more bright areas of the sky) that gave a significant increase of the average white screen signal. At Lazarevskoe the B_{ws} average signal decreased smoothly with the setting sun despite the stops or changes of the vessel movement direction. The signals of the other two channels also became smoother with stabilization.

It should be noted that at Lazarevskoe the measurements were taken in May an hour before sunset (the height of the Sun at 6 p. m. is about 18°). On the contrary, the measurements at Feodosia were carried out in September at a high position of the Sun (local time from 11 a. m. till 1 p. m., the height of the Sun is about 50°) when the illumination of the sky is much brighter and more uniform than before sunset. In this case the mean standard deviation was no less than 5 units (fig. 2). At sunset without stabilization it would cause 50—100 % relative measurement error that would make further estimating process too vague. However, at Lazarevskoe, despite the significant deterioration of the illumination level, the gyro-stabilization of the complex made it possible to obtain reasonable estimates of the water components concentration from the CSR spectra. For the vessel moving at a speed of 6 knots, this means getting estimates every 3 meters.

4. Results and their discussion

In May 2018 at Lazarevskoe the measurements with the EMMA complex were carried out from board a moving vessel continuously within an hour — more than 2.5 thousand spectra of the CSR were calculated. For their further processing the original algorithm [9] was implemented, which used as a regularizing factor the peculiarities of the light absorption spectrum of pure sea water, manifested in all CSR spectra. This algorithm makes it possible to obtain light absorption coefficient spectra of seawater (fig. 3).

It is seen that the values of CSR spectra do not differ much from each other and only taking into account the difference in their form one can get their absorption spectra which are dramatically diverse.

After subtracting the light absorption spectra of pure sea water from the latter, we got the total absorption index spectra of all natural water components: phytoplankton pigments, coloured organic matter and suspended matter. Taking into account the specific absorption spectra of these natural components [24] their concentrations that gave the best approximation to the total absorption index spectrum at each point of the route were calculated (fig. 4).

The received concentrations are given in the units of light absorption: for phytoplankton pigments it is an absorption index in the "blue maximum" at 440 nm, for coloured organic matter it is an absorption index at 500 nm and for the suspended matter it is nonselective absorption plus backscattering index in 400–600 nm range.

Sharp increases in the sky radiance detected on the route (fig. 2) are associated with the sharp changes of the vessel movement direction (see its route in fig. 5) and the time of measurements — in low sun, the brightness of the sky above the horizon depends greatly on the azimuth. It can be seen that the water radiance increased due to the reflected part and for calculating the SRC spectra these radiance fluctuations did not affect their value. This is clear when comparing fig. 2, *a* and fig. 4: the maximum brightness of water does not coincide with the maximum content of suspended matter and other water constituents.

It should be mentioned that the error in determining the concentrations caused by both the noise of the device and the change in the light detection conditions in the three channels is not more than 30 % (50 % for a concentration of less than 0.005 m^{-1}). This is due to the stabilization of EMMA, especially due to the fact, that the contribution of the irradiation channel to the entire error becomes negligibly small.

Using these results, the distribution of the main natural components in sea-water in the region of the river plume obtained from operative remote sensing measurements are shown (fig. 5; see Insert). The results were interpolated using Natural Neighbor method. It is seen that despite the measuring time practically at the sunset and quite complicated route of the vessel including several 180° turns the estimated distributions are rather smooth. The forms

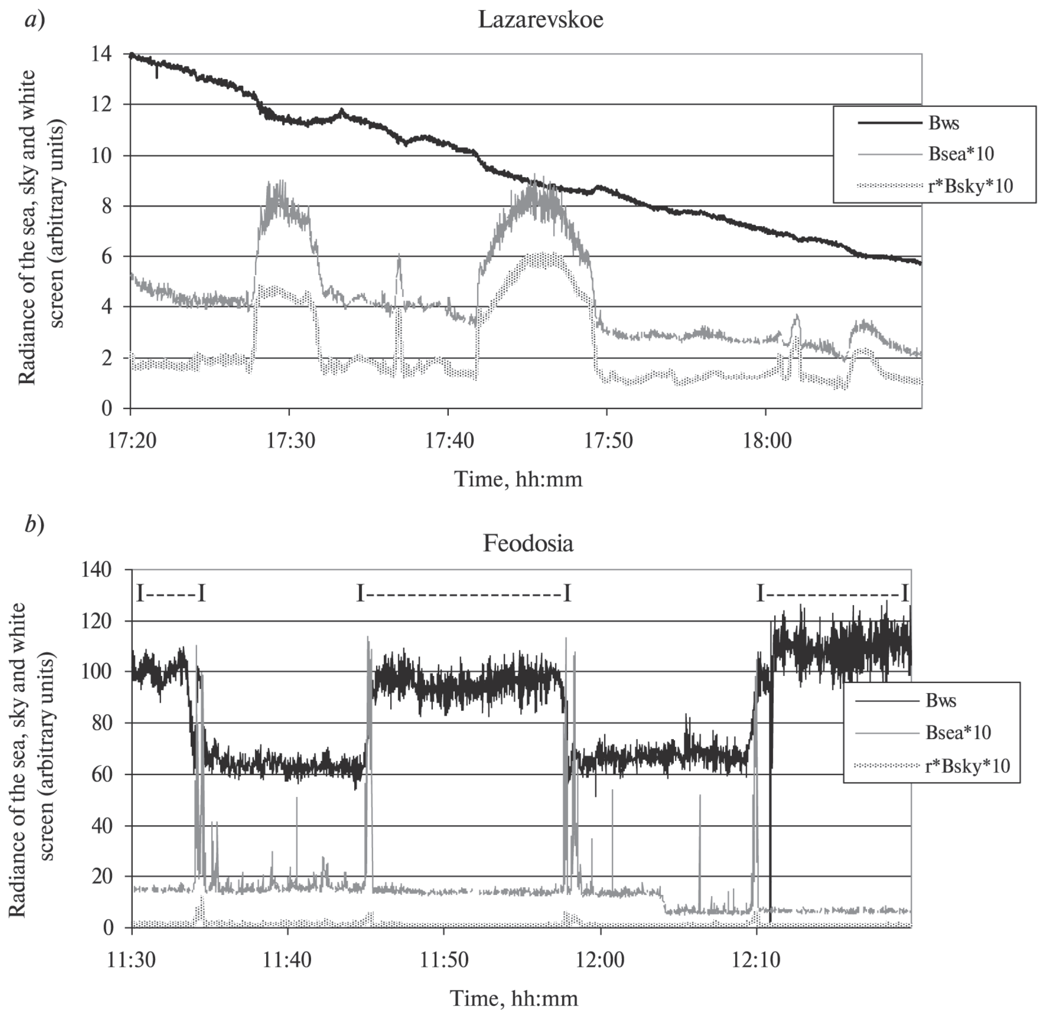

Fig. 2. Comparison of the data obtained by the EMMA complex with stabilization on the gyro-platform (*a* — Lazarevskoe) and without gyro-stabilization (*b* — Feodosia), (I——I — stations).

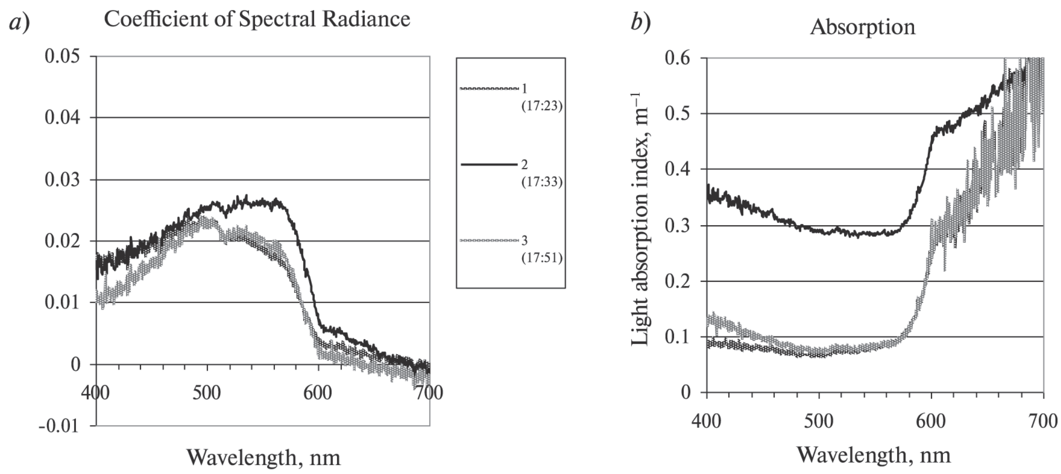

Fig. 3. Three CSR (coefficient of spectral radiance) spectra (*a*), obtained far from the river mouth at the beginning of the measurements — 1 (17:23), near the river mouth in the plume — 2 (17:33) and at some distance from the plume — 3 (17:51). Three appropriate light absorption spectra calculated using an original algorithm (*b*).

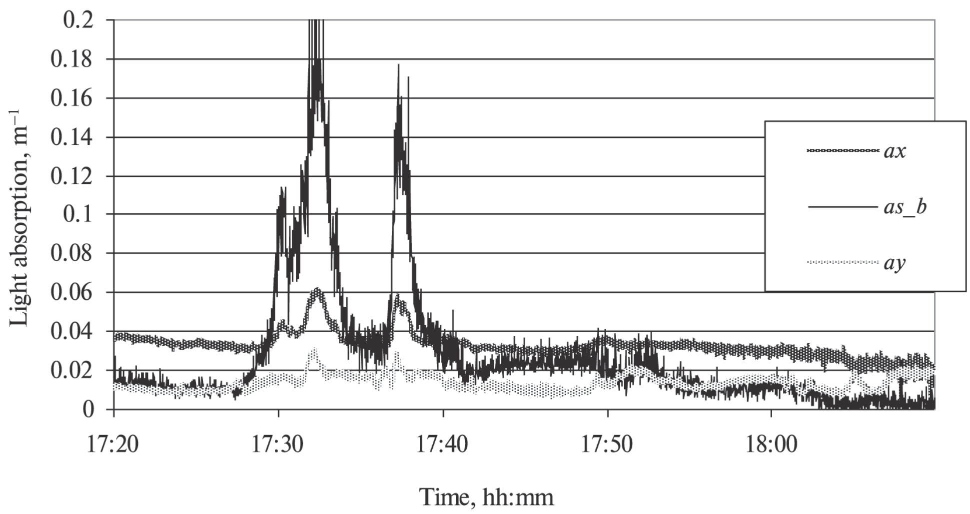

Fig. 4. Concentrations of the main natural components in seawater estimated on base of remote measurements from board a moving vessel by the EMMA complex on the gyro-stabilized platform: — absorption index of phytoplankton pigments at 440 nm (*ax*); — non-selective absorption index of suspended matter (*as_b*); — absorption index of coloured organic matter at 500 nm (*ay*).

of different components distribution correspond to the river plume and resemble each other. However, while for phytoplankton pigments and coloured organic matter the values of concentration demonstrate two times difference, for the suspended matter such difference is equal to ten. Significant predominance of the suspended matter over the other components is observed exclusively at the river mouth area and can be used as a plume boundary. In the figure, it corresponds to values of suspended matter concentration of the order of 0.03 m^{-1} (white to green transition).

5. Conclusion

Thus, measurements on the Caucasian coast of the Black Sea by the EMMA complex on a gyro-stabilized platform showed a significant improvement in the quality of primary data compared to measurements without gyro-stabilization. This modernization made it possible to assess the concentration of the main natural components of sea water under a significant deterioration in measurement conditions (decrease in the level of illumination of the sea, some turns of the vessel leading to falling into the region of sun glint or into the region of bright sky near the horizon). The distributions of the natural components of sea water in the area of the river mouth were obtained and it was revealed how the ratio of these components in the plume and outside it changed in this case. According to these data, the shape and size of river plumes can be estimated, which is important when monitoring the ecological state of the coastal waters, as well as when assessing the discharge of various types of pollution by river runoff. As water colour measurements from space nowadays are the expanding source of data of ecological state of seas and lakes, the EMMA complex could be a reliable instrument for necessary ground truth experiments.

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Литература

1. *Mouw C.B.*, *Greb S.*, *Aurin D.*, *DiGiacomo P.M.*, *Lee Z-P.*, *Twardowski M.*, *Binding C.*, *Hu C.*, *Ma R.*, *Moore T.*, *Moses W.*, *Craig S. E.* Aquatic color radiometry remote sensing of coastal and inland waters: Challenges and recommendations for future satellite missions // Remote Sens. Environ. 2015. V. 160. P. 15–30.
2. *Schaeffer B.A.*, *Schaeffer K.G.*, *Keith D.*, *Lunetta R.S.*, *Conmy R.*, *Gould R.W.* Barriers to adopting satellite remote sensing for water quality management // Int. J. Remote Sens. 2013. V. 34. P. 7534–7544.
3. *Tyler A.N.*, *Hunter P.D.*, *Spyrakos E.*, *Groom S.*, *Constantinescu A.M.*, *Kitchen J.* Developments in Earth observation for the assessment and monitoring of inland, transitional, coastal and shelf-sea waters // Sci. Total Environ. 2016. V. 572. P. 1307–1321.
4. *Hestir E.L.*, *Brando V.E.*, *Bresciani M.*, *Giardino C.*, *Matta E.*, *Villa P.*, *Dekker A.G.* Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission // Remote Sens. Environ. 2015. V. 167. P. 181–195.
5. *Palmer S.C.J.*, *Kutser T.*, *Hunter P.D.* Remote sensing of inland waters: Challenges, progress and future directions // Remote Sens. Environ. 2015. V. 157. P. 1–8.
6. *Spyrakos E.*, *O'Donnell R.*, *Hunter P.D.*, *Miller C.*, *Scott M.*, *Simis S.G.H.*, *Neil C.*, *Barbosa C.C.F.*, *Binding C.E.*, *Bradt S.* et al. Optical types of inland and coastal waters // Limnol. Oceanogr. 2018. V. 63. P. 846–870.
7. *Le C.*, *Li Y.*, *Zha Y.*, *Sun D.*, *Huang C.*, *Zhang H.* Remote estimation of chlorophyll a in optically complex waters based on optical classification // Remote Sens. Environ. 2011. V. 115. P. 725–737.
8. *Huang C.C.*, *Li Y.M.*, *Yang H.*, *Li J.S.*, *Chen X.*, *Sun D.Y.*, *Le C.F.*, *Zou J.*, *Xu L.J.* Assessment of water constituents in highly turbid productive water by optimization bio-optical retrieval model after optical classification // J. Hydrol. 2014. V. 519. P. 1572–1583.
9. *Alikas K.*, *Ansko I.*, *Vabson V.*, *Ansper A.*, *Kangro K.*, *Uudeberg K.*, *Ligi M.* Consistency of Radiometric Satellite Data over Lakes and Coastal Waters with Local Field Measurements // Remote Sens. 2020. V. 12. 616. doi:10.3390/rs12040616
10. *Yushmanova A.*, *Kopelevich O.*, *Vazyulya S.*, *Sahling I.* Inter-Annual Variability of the Seawater Light Absorption in Surface Layer of the Northeastern Black Sea in Connection with Hydrometeorological Factors // J. Mar. Sci. Eng. 2019. V. 7. 326. doi:10.3390/jmse7090326
11. *Коновалов Б.В.*, *Кравчишина М.Д.*, *Беляев Н.А.*, *Новигатский А.Н.* Определение концентрации минеральной взвеси и взвешенного органического вещества по их спектральному поглощению // Океанология. 2014. Т. 54, № 5. С. 704–711.
12. *Глуховец Д.И.*, *Шеберстов С.В.*, *Копелевич О.В.*, *Зайцева А.Ф.*, *Погосян С.И.* Измерение коэффициента поглощения морской воды с использованием интегрирующей сферы // Светотехника. 2017. № 5. С. 39–43.
13. *Dörnhöfer K.*, *Klinger P.*, *Heege T.*, *Oppelt N.* Multi-sensor satellite and in situ monitoring of phytoplankton development in a eutrophic-mesotrophic lake // Sci. Total Environ. 2018. V. 612. P. 1200–1214.
14. *Bresciani M.*, *Pinardi M.*, *Free G.* et al. The Use of Multisource Optical Sensors to Study Phytoplankton Spatio-Temporal Variation in a Shallow Turbid Lake // Water. 2020. V. 12. 284. doi:10.3390/w12010284
15. *Матюшенко В.А.*, *Пелевин В.Н.*, *Ростовцева В.В.* Измерение коэффициента яркости моря трехканальным спектрофотометром с борта НИС // Оптика атмосферы и океана. 1996. Т. 9, № 5. С. 664–669.
16. *Mobley C.D.* Estimation of the remote sensing reflectance from above–water methods // Appl. Optics. 1999. V. 38, P. 7442–7455.
17. *Hommersom A.*, *Kratzer S.*, *Laanen M.*, *Ansko I.*, *Ligi M.*, *Bresciani M.*, *Giardino C.*, *Beltrán-Abaunza J.M.*, *Moore G.*, *Wernand M.*, *Peters S.* Intercomparison in the field between the new WISP-3 and other radiometers (TriOS Ramses, ASD FieldSpec, and TACCS) // J. Appl. Rem. Sens. 2012. V. 6, N1. P. 1–21.
18. *Simis S. G.H.*, *Olsson J.* Unattended processing of shipborne hyperspectral reflectance measurements // Remote Sens. Environ. 2013. V. 135. P. 202–212.
19. *Peters S.*, *Laanen M.*, *Groetsch P.*, *Ghezehegn S.*, *Poser K.*, *Hommersom A.*, *De Reus E.*, *Spaias L.* WISPstation: A new autonomous above water radiometer system // Proc. Ocean Optics XXIV Conf., Dubrovnik, Croatia, 2018.
20. *Ruddick K.*, *De Cauwer V.*, *Park Y.*, *Moore G.* Seaborne measurements of near infrared water-leaving reflectance: The similarity spectrum for turbid waters // Limnol. Oceanogr. 2006. V. 51. P. 1167–1179.
21. *Гончаренко И.В.*, *Ростовцева В.В.*, *Коновалов Б.В.* Использование нового судового комплекса пассивного оптического зондирования для получения распределения естественных примесей в прибрежных водах // Фундаментальная и прикладная гидрофизика. 2018. Т. 11, № 3, С. 97–101.

22. *Ростовцева В.В.* Метод получения спектров поглощения морской воды по данным пассивного дистанционного зондирования с борта судна с использованием свойств чистой воды // Оптика атмосферы и океана. 2015. Т. 28, № 11. С. 1003–1011.
23. *Ростовцева В.В., Коновалов Б.В., Гончаренко И.В., Хлебников Д.В.* Способ оценки содержания примесей в морских водах с помощью оперативной спектрофотометрии // Океанология. 2017. Т. 57, № 4. С. 560–574.
24. *Wozniak B., Dera J.* Light Absorption in Sea Water. New York: Springer Science+Business Media, LLC. 2007.

References

1. *Mouw C.B., Greb S., Aurin D., DiGiacomo P.M., Lee Z-P., Twardowski M., Binding C., Hu C., Ma R., Moore T., Moses W., Craig S. E.* Aquatic color radiometry remote sensing of coastal and inland waters: Challenges and recommendations for future satellite missions. *Remote Sens. Environ*. 2015, 160, 15–30.
2. *Schaeffer B.A., Schaeffer K.G., Keith D., Lunetta R.S., Conmy R., Gould R.W.* Barriers to adopting satellite remote sensing for water quality management. *Int. J. Remote Sens*. 2013, 34, 7534–7544.
3. *Tyler A.N., Hunter P.D., Spyrakos E., Groom S., Constantinescu A.M., Kitchen J.* Developments in Earth observation for the assessment and monitoring of inland, transitional, coastal and shelf-sea waters. *Sci. Total Environ*. 2016, 572, 1307–1321.
4. *Hestir E.L., Brando V.E., Bresciani M., Giardino C., Matta E., Villa P., Dekker A.G.* Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission. *Remote Sens. Environ*. 2015, 167, 181–195.
5. *Palmer S.C.J., Kutser T., Hunter P.D.* Remote sensing of inland waters: Challenges, progress and future directions. *Remote Sens. Environ*. 2015, 157, 1–8.
6. *Spyrakos E., O'Donnell R., Hunter P.D., Miller C., Scott M., Simis S.G.H., Neil C., Barbosa C.C.F., Binding C.E., Bradt S.* et al. Optical types of inland and coastal waters. *Limnol. Oceanogr*. 2018, 63, 846–870.
7. *Le C., Li Y., Zha Y., Sun D., Huang C., Zhang H.* Remote estimation of chlorophyll a in optically complex waters based on optical classification. *Remote Sens. Environ*. 2011, 115, 725–737.
8. *Huang C.C., Li Y.M., Yang H., Li J.S., Chen X., Sun D.Y., Le C.F., Zou J., Xu L.J.* Assessment of water constituents in highly turbid productive water by optimization bio-optical retrieval model after optical classification. *J. Hydrol*. 2014, 519, 1572–1583.
9. *Alikas K., Ansko I., Vabson V., Ansper A., Kangro K., Uudeberg K., Ligi M.* Consistency of Radiometric Satellite Data over Lakes and Coastal Waters with Local Field Measurements. *Remote Sens*. 2020, 12, 616. doi:10.3390/rs12040616
10. *Yushmanova A., Kopelevich O., Vazyulya S., Sahling I.* Inter-Annual Variability of the Seawater Light Absorption in Surface Layer of the Northeastern Black Sea in Connection with Hydrometeorological Factors. *J. Mar. Sci. Eng*. 2019, 7, 326. doi:10.3390/jmse7090326
11. *Konovalov B.V., Kravchishina M.D., Belyaev N.A., Novigatsky A.N.* Determination of the concentration of mineral particles and suspended organic substance based on their spectral absorption. *Oceanology*. 2014, 54(5), 660–667.
12. *Glukhovets D.I., Sheberstov S.V., Kopelevich O.V., Zaytseva A.F., Pogosyan S.I.* Measuring the sea water absorption factor using integrating sphere. *Light & Engineering*. 2018, 26, 1, 120–126.
13. *Dörnhöfer K., Klinger P., Heege T., Oppelt N.* Multi-sensor satellite and in situ monitoring of phytoplankton development in a eutrophic-mesotrophic lake. *Sci. Total Environ*. 2018, 612, 1200–1214.
14. *Bresciani M., Pinardi M., Free G.* et al. The Use of Multisource Optical Sensors to Study Phytoplankton Spatio-Temporal Variation in a Shallow Turbid Lake. *Water*. 2020, 12, 284. doi:10.3390/w12010284
15. *Matyushenko V.A., Pelevin V.N., Rostovtseva V.V.* Measurement of the Sea Radiance Coefficient with Three-Channel Spectrophotometer from board a Research Ship. *Atmospheric and Oceanic Optics*. 1996, 9, 5, 421–424.
16. *Mobley C.D.* Estimation of the remote sensing reflectance from above–water methods. *Appl. Optics*. 1999, 38, 7442–7455.
17. *Hommersom A., Kratzer S., Laanen M., Ansko I., Ligi M., Bresciani M., Giardino C., Beltrán-Abaunza J.M., Moore G., Wernand M., Peters S.* Intercomparison in the field between the new WISP-3 and other radiometers (TriOS Ramses, ASD FieldSpec, and TACCS). *J. Appl. Rem. Sens*. 2012, 6, 1, 1–21.
18. *Simis S.G.H., Olsson J.* Unattended processing of shipborne hyperspectral reflectance measurements. *Remote Sens. Environ*. 2013, 135, 202–212.
19. *Peters S., Laanen M., Groetsch P., Ghezehegn S., Poser K., Hommersom A., De Reus E., Spaias L.* WISPstation: A new autonomous above water radiometer system. *Proc. Ocean Optics XXIV Conf., Dubrovnik, Croatia*, 2018.
20. *Ruddick K., De Cauwer V., Park Y., Moore G.* Seaborne measurements of near infrared water-leaving reflectance: The similarity spectrum for turbid waters. *Limnol. Oceanogr*. 2006, 51, 1167–1179.
21. *Goncharenko I.V., Rostovtseva V.V., Konovalov B.V.* Using of new shipborne complex for passive optical remote sensing for obtaining distribution of natural admixtures in coastal waters. *Fundamentalnaya i Prikladnaya Gidrofizika*. 2018, 11, 3, 97–101 (in Russian).
22. *Rostovtseva V.V.* Method for sea water absorption spectra estimation on the basis of shipboard passive remote sensing data and pure sea water properties. *Atmospheric and Oceanic Optics*. 2016, 29, 2, 162–170.
23. *Rostovtseva V.V., Konovalov B.V., Goncharenko I.V., Khlebnikov D.V.* Method for estimating admixture content in seawater using operative spectrophotometry. *Oceanology*. 2017, 57, 4, 505–519.
24. *Wozniak B., Dera J.* Light Absorption in Sea Water. *New York, Springer Science+Business Media, LLC*. 2007.

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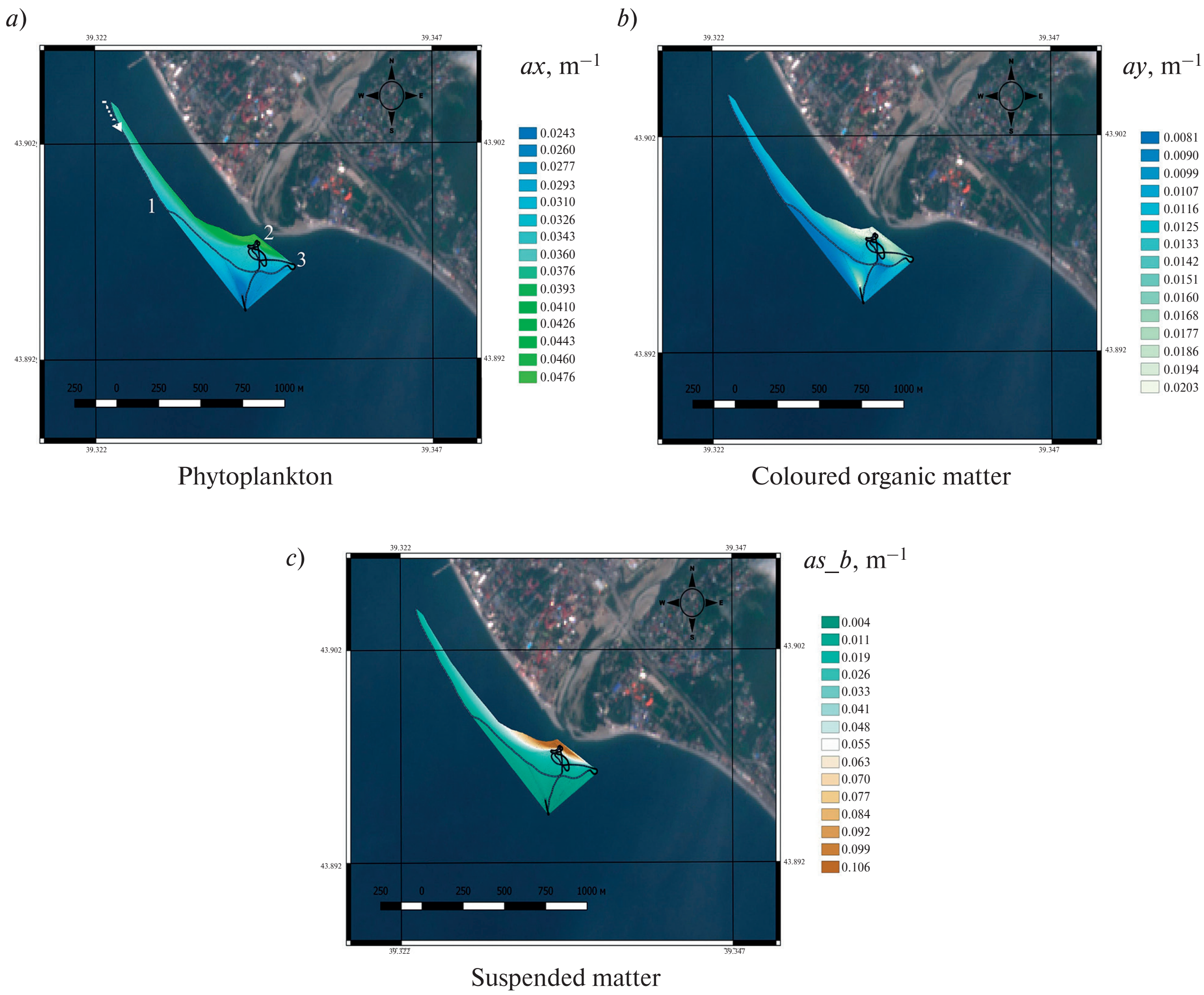

Fig. 5. Distribution of the phytoplankton pigments (light absorption by pigments at 440 nm) (*a*), coloured organic matter (light absorption at 500 nm) (*b*) and suspended matter (*c*) in sea water at the estuary of the Psezuapse River at Lazarevskoe, obtained remotely from board a vessel with the EMMA passive optical complex on a gyro-stabilized platform.