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К ОЦЕНКЕ РАСПРОСТРАНЕНИЯ МИКРОПЛАСТИКА В ВОСТОЧНОЙ ЧАСТИ ФИНСКОГО ЗАЛИВА

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Для изучения характеристик распространения частиц микропластика, поступающих с водами Невы, в Невской губе и в восточной части Финского залива используется трехмерная численная гидродинамическая модель, основанная на Принстонской модели океана POM. Модель реализована на равномерной квазиортогональной горизонтальной сетке с шагом 100 м, в вертикальном направлении используются 7 равномерно распределенных сигма-уровней. Морские начальные условия и условия на западной границе для уровня воды, температуры и солености были взяты из оперативной модели Балтийского моря HIROMB-BOOS Датского метеорологического института с дискретностью 1 час. На восточной границе в устье Невы были заданы среднемесячные климатические значения расхода и температуры Невы. Атмосферное воздействие было взято из результатов реанализа ERA-Interim с 6-часовым временным разрешением и пространственным разрешением 0.125 × 0.125°. Были рассмотрены два типа суспензии, которые моделировали распространение частиц микропластика в воде: примесь нейтральной плавучести и оседающая взвесь со скоростью опускания 0.2 м/сут. Оба типа взвеси поступают из Невы с постоянной объемной концентрацией 10^{-6}. Для расчета толщины слоя осаждающейся фракции на дне используется упрощенное уравнение Экснера. Расчеты проводились за период май—август 2018 года, когда был выполнен мониторинг пластикового мусора на пляжах Невской губы и восточной части Финского залива.

Согласно результатам расчетов, пространственное распределение опускающихся частиц в целом повторяет распределение примеси нейтральной плавучести, с той лишь разницей, что чем дальше от источника частиц на запад, тем ниже концентрация опускающихся частиц. Существенной особенностью распределения является то, что большая часть рассматриваемого периода концентрации в северной части модельного домена выше, чем в его южной части. Изменение толщины донного слоя частиц осаждающейся фракции в конце периода счета 31 августа 2018 г., т.е. накопление частиц микропластика в донных отложениях за рассматриваемый период, характеризуется той же особенностью, что и распределение взвеси обоих типов в воде: накопление микропластика в донных отложениях в северной части модельной области за пределами Невской Губы было заметно больше, чем в южной части, особенно в прибрежной зоне.

Данные по мониторингу загрязнения пляжей побережья пластиковым мусором косвенно подтверждают полученные результаты: на южном побережье восточной части Финского залива за пределами Невской Губы практически не было пластикового мусора в период с июня по август 2018 года, хотя он был обнаружен в значительных количествах на северном побережье. Таким образом, модельные оценки распространения частиц микропластика в воде и их накопления в донных отложениях могут быть использованы для выбора районов для будущей работы по мониторингу загрязнения пластиковым мусором побережья Финского залива.

Ключевые слова: морской мусор, микропластик, гидродинамическое моделирование, мониторинг, Финский залив, Невская губа.

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ON THE ASSESSMENT OF MICROPLASTIC DISTRIBUTION IN THE EASTERN PART OF THE GULF OF FINLAND

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To study the propagation characteristics of microplastic particles coming with the Neva river waters, in the Neva Bay and in the eastern part of the Gulf of Finland, a three-dimensional numerical hydrodynamic model based on the Princeton Ocean Model is used. The model is implemented on a uniform quasi-orthogonal horizontal grid with a step of 100 m, in the vertical direction 7 uniformly distributed sigma levels are used. The marine initial conditions and conditions at the western boundary for water level, temperature and salinity were taken from the Baltic Sea operational model HIROMB-BOOS of the Danish Meteorological Institute with discreteness of 1 hour. On the eastern boundary at the mouth of the Neva the average monthly climatic river discharge and temperature of the Neva were set. Atmospheric forcing was taken from the results of the ECMWF ERA-Interim reanalysis with 6-hour temporal resolution and with a spatial resolution of 0.125 × 0.125°. Two types of suspension were considered that simulated the propagation of microplastic particles in the water: admixture of neutral buoyancy and a sinking suspension with a sinking velocity of 0.2 m/day. Both types of suspension come from the Neva River with a constant volume concentration of 10^{-6}. To calculate the thickness of the layer of the settling fraction at the bottom the simplified Exner equation is used. The calculations were performed for the period May—August 2018 when the quantity and composition of plastic litter was monitored on the coast of the Neva Bay and the eastern part of the Gulf of Finland.

According to model results, the spatial distribution of the sinking particles, in general, repeats the distribution of the admixture of neutral buoyancy, with the only difference being that the farther from the particle source to the west, the lower the concentration of the sinking particles. An essential feature of the distribution is that during most time of the considered period the concentrations of both suspensions in the northern part of the model domain is higher than those found in its southern part. The change in the thickness of the bottom layer of the particles of the settling fraction at the end of the period on August 31, 2018, i.e. the accumulation of microplastic particles in bottom sediments for the period under consideration, is characterized by the same feature as the space distribution of the admixture of neutral buoyancy in water: the accumulation of microplastic in bottom sediments in the northern part of the model area outside the Neva Bay was noticeably greater than in the southern part, especially in the coastal zone.

The data on monitoring the coastal pollution by plastic litter indirectly confirm the model results: there was practically no plastic litter on the southern coast of the eastern Gulf of Finland outside the Neva Bay between June and August 2018, while it was found on the northern coast in significant quantities. Thus, model estimates of the distribution of microplastic particles in water and its accumulation in bottom sediments can be used to select areas for future work on monitoring plastic litter pollution on the coast of the Gulf of Finland.

Keywords: marine litter, microplastics, hydrodynamic modeling, monitoring, Gulf of Finland, Neva Bay.

1. Introduction

Microplastic consists of plastic particles and fibers with a size of 5 mm or less [1, 2]. The size range of microplastic may include several orders of magnitude. Microplastic particles, depending on their buoyancy, can be concentrated in the water column, in the surface layer and in the layer of bottom sediments. Particles in the near-surface layer of the atmosphere and in the ocean upper layer can be transported by wind, surface ocean currents and also by sea ice. Still, the distribution of microplastics cannot be driven solely by physical processes. It is also necessary to take into account biological processes in the ocean [3]. However, a detailed description of such interaction for further use in ocean numerical models has not been developed yet. According to the estimates [4], more than 70% of plastics in the ocean surface layer are made up of particles larger than 200 mm. However, at the moment, the largest amount of field data on the content of plastics in water has been collected for particles less than 200 mm in size.

A large number of recent studies related to the problem of the inflow and distribution of microplastics in the ocean have been published. The transport, spatial distribution and accumulation of microplastics were studied using several approaches: numerical simulation [5], drifters [6], direct field observations [4, 7]. In [8] a comprehensive review of microplastic distribution in the ocean was given and its interaction with biological processes was discussed. Such biological interaction includes, first of all, the entry of micro- and nanoplastics (<300 μm) into the food web of marine organisms, which can explain the relatively low concentration of floating microplastics compared with the total microplastic emissions into the oceans. In [6] authors used the drifter data obtained within the framework of the Surface Velocity Program (SVP), which later became the Global Drifter Program (GDP). The data cover the period from 1979 to 2007. Based on these data, a statistical probabilistic model was constructed which made it possible to identify the five main zones in the oceans in which drifters accumulated. These results were used to explain the distribution of floating debris in the ocean. The lack of reliable data on the location of the plastic litter sources was compensated by the fact that the model was integrated for a rather long period (10 years). It should be noted that microplastic particles could be "washed out" to the shore in that model when a particle entered a model's cell adjacent to the coastline. The formation of floating debris accumulation zones was explained to be associated with the convergence of Ekman currents with horizontal scales of the order of the variability of the wind field, which significantly exceeds the ocean mesoscale. However, on scales less than 100 km the distribution of floating plastic debris can be controlled by ocean eddies and frontal zones – a process that has yet to be studied. A similar modeling approach to study the microplastic distribution was used in [9, 10], however "washing out" process was not implemented – the particles remained afloat forever.

Distribution of floating debris on a global scale was also studied in [5], but a different modeling complex was used: HYCOM/NCODA global ocean circulation model [11] was coupled with the Lagrangian model of floating particles Pol3DD. The results obtained are similar to those presented in [6]. In addition, the work also considered not only the input of plastic particles into the ocean from land but also from off-shore sources (ships, fishing nets, etc.). A new method for specifying the entry of plastic litter into the ocean was proposed. But "washing out" of floating particles was again not taken into account.

It is important to note that none of the models described above considered the losses of plastics from the ocean upper layer due to its gravitational sinking and/or biological processes because of the lack of observational data needed for parameterizing of these processes. The process of refinement of suspended plastic particles was not considered as well.

There is a number of works focused on modeling the propagation of microplastics in freshwater basins, e.g. in rivers, which are considered to be one of the main sources of microplastics for the ocean due to the flow of microplastic-polluted waters from land to the ocean. An example of one of such works is [12] where the NanoDUFLOW model [13] was used and specifically configured to reproduce the transfer of microplastic particles (nano-, micro-, and millimeter-size ranges) in a river system. The model took into account such processes as aggregation, sedimentation, degradation, dissociation, resuspension and burial. Particles were considered to be spheres with 25 different diameters ranging from 100 nm to 10 mm. The particle density was set equal to 1040 kg/m^3 and further varied in a number of experiments from 1000 to 1500 kg/m^3 which included both floating and settling plastics. In general, the work can be classified as theoretical but it also included simulations for a real object – the Dommel River located in the Netherlands.

Microplastic content in Arctic ice samples obtained during the expeditions of 2005 and 2010 was estimated in [14]. It was found that Arctic ice even far from industrial centers contained high concentrations of microplastics. Those concentrations were several orders of magnitude greater than the concentrations found in the areas of floating microplastics in the ocean gyres such as the Pacific Gyre. Thus, polar sea ice represents a huge historical storage of particles of anthropogenic origin that were previously suspended in the water. In [15] the problem of suspended microplastics in the Arctic Ocean was discussed and various methods for collecting samples in water, sediments and ice were considered.

According to the findings of various researchers based on observational data and modeling, the percentage of small plastic particles increases with depth due to wind-wave mixing. In addition, the distribution of microplastics is influenced by biological processes and the possibility of their resuspension with bottom sediments.

In [16] the processes of plastic entry into the ocean, its quantity and main sources were considered, with a list of some numerical models and datasets used to reproduce the propagation of microplastic in the ocean.

For the Baltic Sea region, the inflow and distribution of microplastics was discussed in, e.g. [17—22]. Still, no researches of potential sources and routes of microplastic transfer by means of a high-resolution numerical modeling combined with coastal monitoring have yet been carried out for the Neva Bay region and the eastern part of the Gulf of Finland.

The aim of this work was to study the propagation of microplastic particles in the Neva Bay and in the eastern part of the Gulf of Finland, presumably coming from the Neva runoff, under conditions of real hydrodynamic and meteorological forcing. A high-resolution numerical model and the monitoring data of coastal pollution by plastic debris were used. Numerical experiments were focused at determining the influence of river runoff and water circulation on the formation of areas of increased microplastic concentration in the coastal zone and its accumulation in the sediment layer of lagoon-type basins which include the Neva Bay and the adjacent part of the Gulf of Finland.

2. Methods and data

2.1. Numerical model

To study the distribution of microplastics potentially arriving from the Neva River throughout the Neva Bay and the eastern part of the Gulf of Finland we used a three-dimensional numerical hydrodynamic model based on the Princeton Ocean Model [23]. Previously, this model was successfully used to reproduce ice conditions [24], storm surges [25], and sediment resuspension [26—29] in the Neva Bay, as well as to assess the erosion intensity of the western coast of Kotlin Island [30]. In the horizontal plane a quasi-orthogonal computational grid with a 100-m step was used; in the vertical direction 7 uniformly distributed sigma levels were implemented. The model domain is shown in fig. 1 (see Inset). The number of grid nodes from west to east is 600, from south to north – 400. The maximum depth within the domain is 34.4 m, and the minimum is 0.2 m.

The initial and boundary (for the western boundary) conditions for sea level, temperature and salinity were taken from the Baltic Sea operational HIROMB-BOOS Model (HBM) of the Danish Meteorological Institute (DMI) [31], which are available online with the 1 hour resolution. At the eastern boundary at the mouth of the Neva the average monthly climate river runoff and water temperature were set. The salinity of the river waters was set equal to zero.

Meteorological forcing included wind velocity components, air temperature and humidity, total cloudiness and atmospheric pressure at the sea level. These data were taken from the results of the ECMWF ERA-Interim reanalysis [32] with 6-hour temporal resolution and with the maximum available spatial resolution of 0.125 × 0.125°.

Two types of suspensions were considered within the model, that simulated the distribution of various suspended microplastic particles in water: suspension with neutral buoyancy (C1) and a settling suspension (C2). Both types of suspension come from the Neva River with a constant volume concentration of 10^{-6} which is equivalent to the content of 1 cm^3 of microplastic particles in 1 m^3 of water. This concentration does not relate to any actual plastic particles concentration in water, which is currently unknown, and is used simply to specify an external source of suspended microplastic particles in the model. At the open western boundary the radiation condition for outflow and zero concentration for inflow were specified for both suspensions. A zero flux was set at the upper and lower boundaries for C1. In a similar manner, a zero flux was set at the upper boundary for C2, whereas a flux of gravitational sinking of C2 was specified at the lower boundary thus simulating the falling of C2 particles out of the water column.

The thickness of the bottom layer consisting of falling particles is calculated using the Exner equation [33, 34] which describes the precipitation of particles from the system with the formation of a layer of sedimentary deposits through the accumulation of particles at the bottom. This sedimentation model was successfully applied to assess the sedimentation rates in the coastal zone in the Bothnian Bay of the Baltic Sea [35]. In the current study, due to a lack of field data on the intensity of microplastic particles resuspension from the bottom and their transport in the bottom layer, the Exner equation is used in a simplified form that does not contain divergence of the bed-load transport and resuspension:

$$\frac{\partial h}{\partial t} = -\left(W_{bl} - W_s\right)C_b, \quad (1)$$

where h – thickness of the bottom layer consisting of falling particles, m; t – time, s; C_b – volume concentration of suspended particles of C2 fraction in the lowest model layer near the bottom, m^3/m^3; W_{bl} – vertical fluid velocity in this near-bottom layer, m/s; W_s – vertically-constant C2 particle fall velocity, m/s. The spatial discretization adopted in POM treats C_b to be located at the center of a near-bottom cell in the lowest model sigma layer. Model's vertical velocity W_{bl} was interpolated between W values at the cell's upper and lower facets to be exactly at the cell's center where C_b is calculated. The model also prevents the 'lift' of bottom layer's particles when the value in parentheses in formula (1) is positive.

The modeled spatial distribution of C1 was used as a reference estimate of the suspended particles' transport, as well as to analyze the general circulation pattern for the period considered.

It should be noted that the current study does not take into account any hypotheses concerning the biological cycle of microplastic particles [6] or their interaction with ice [17].

A time period of May—August 2018 was chosen for the model simulations since it covers the period of field observations in the study area when the quantity and composition of plastic litter was monitored along the coasts of the Neva Bay and the eastern part of the Gulf of Finland. Numerical experiments for a longer period were too complicated due to long calculation time. The high model spatial resolution (100 m) and the dynamical features of circulation in the domain (high flow velocities in the Neva Bay during storm surges and strong winds) required the use of very small time steps to ensure the computational stability of the model. Thus, in this work, the time step was set equal to 0.2 seconds.

2.2. Monitoring of plastic litter accumulation on sandy beaches

Field data on the plastic litter distribution on the beaches of the Neva Bay and the eastern part of the Gulf of Finland were collected in 2018 [36] as a result of monitoring studies using various international methods of sediment sampling [37]. Two methods of sand sampling on beaches were used in the June—July 2018:

1. "Frame" method, which is applied to lagoon coasts, enclosed bays, and river estuaries, and necessarily includes a wave-wreck zone (i.e., the zone of wave impact and material accumulation). The method was the main one when surveying the sandy coasts of the Neva Bay.

2. "Rake" method, when the entire width of the beach is sampled from the waterline to the vegetation line and is applied for large areas of the beaches regularly cleaned by the city services from macro-litter. This method was chosen to survey the sandy beaches of the outer part of the estuary (Kurortny District, beaches of Kronstadt and the southern coast near the Flood Protection Barrier (FPB)).

During the summer of 2018, seven lagoon-type beaches (Neva Bay) and eight beaches outside the FPB on the northern and southern coasts of the eastern Gulf of Finland were surveyed. The amount and distribution of anthropogenic litter along the coasts varied considerably depending on the location of the beaches, weather conditions, hydrological and morphometric characteristics of the coasts [36].

The studies revealed a significant difference in the composition and quantity of marine litter in general on the northern and southern coasts of the Neva Bay. The largest pollution of the wreck zone was found on the southern beaches (Lomonosov, Alexandria and the beach near the Zhemchuzhny District). The main types of litter here were plastic pellets, broken glass, cigarette butts, rusty metal and pieces of construction plaster (stucco) (fig. 2, *a* – see Insert). At the same time, the share of plastic in the composition of the sampled litter on the beaches of the southern coast of the Neva Bay on average was not more than 10—12%. On the northern coast, the amount of litter was smaller, but the bulk of it was plastic – 50—60% of the total amount of litter of all factions. In the outer part of the estuary, the predominant type of beach pollution is microplastics, the average amount of which is 0.8 pcs/m^2 when using the Frame method of data collection in the wreck zone and 0.5 pcs/m^2 when using the Rake method (fig. 2, *b* – see Insert). It should be noted that concentrations of microparticles in general, and plastic in particular, on the northern coast in the Kurortny District, as well as on the north beach of Kotlin Island were 5—6 times higher than on the southern coast of the Gulf of Finland (Bolshaya Izhora and Lebyazhye) [38]. Thus, the accumulation of microplastics on local beaches occurs mainly in the outer estuary – the eastern part of the Gulf of Finland, while in the inner estuary microplastics is found in small quantities.

At the same time with measuring concentrations of microplastics on sandy beaches the first studies of microplastic pollution in the aquatic near-shore environment of the Gulf of Finland were carried out. Water sampling in some areas of the Gulf showed that the concentrations of microplastics in the water are highly dependent on weather conditions and the resuspension of microplastic particles from the bottom in the coastal shallow zone. In order to detect trends in microplastic particle accumulation in coastal waters, more frequent and regular measurements are needed, but in general, monitoring results showed the presence of microplastic particles (microfibres and microplastic fragments) in all samples collected in 2018 (0.2 to 1.8 particles/l) [39].

2.3. Average velocity of microplastic gravitational settling

One of the key parameters controlling the distribution of microplastic particles in the water column after they exit the source (the mouth of the Neva) is the gravitational sinking velocity. Unfortunately, there are no data of measured settling velocity of microplastic particles detected during field monitoring in 2018.

It is known that the sinking velocity of suspended particles depends on the density of particles, their size, shape and concentration. Microplastic particles and fibers are often aggregated with mineral and organic suspensions. Therefore, even knowing the gravitational sinking velocity of particles of a certain density, size and shape (see [40]) and the distribution of microplastics by composition and sizes in the marine environment, which is currently unknown, it is hardly possible to determine the average gravitational settling velocity of microplastics. Thus, taking into account the fact that significant amounts of marine microplastics were found along the coast closest to the western boundary of the model region, the gravitational sinking velocity of suspended particles in the model was set so that the microplastic particles coming from the Neva waters could reach this boundary in appreciable quantities. According to the results of numerical experiments, setting the sinking velocity equal to or greater than 0.5 m/day leads to the significant decrease of C2 concentration compared to the concentration of C1. It does not allow the sinking suspension C2 to propagate in appreciable quantities into the areas located to the west of the Kotlin Island since the particles almost completely fall to the bottom in the immediate vicinity of the mouth of the Neva River. After a series of calibration experiments a settling velocity equal to 0.2 m/day was chosen for the sinking suspension C2. It provides noticeable concentration of C2 in regions located to the west of the Kotlin Island up to the western boundary of the model domain.

3. Results and discussion

The first month of the calculation was used to spin-up the model: adapting the velocity field to external influence and generating the initial distribution of the suspensions. According to calculations, this time is enough to establish the concentration distribution in the model domain, although the distribution to the west of the dam is a subject to significant variability due to fluctuations in external forcing.

Figures 3—4 (see Insert) show the spatial distribution of the modeled volume concentration of suspended particles of both types in the surface layer.

The surface spatial distribution of the settling particles, on the whole, repeats the distribution of the particles with neutral buoyancy, with the only difference being that the farther from the source to the west, the lower is the concentration of settling particles. Of course, the instantaneous distribution of the surface concentration fields does not give a general picture of the suspension propagation. The averaged over the analyzed period (June—August 2018) fields of the volume concentration of the sinking particles in the upper (fig. 5, *a*) and bottom (fig. 5, *b*) layers shown in fig. 5 (see Insert) practically do not differ from each other, which allows us to conclude that the fluid within the studied region is well mixed, so that even the vertical profile of sinking particles' concentration is almost uniform from the surface to the bottom. An essential feature of the distribution of sinking particles is that most of the time the concentrations in the northern part of the region are higher than those found in its southern part (see fig. 4—5).

The accumulation of particles at the bottom at the end of the model run is shown in fig. 6. The maximum values for the bottom layer thickness are observed near the mouth of the Neva River and monotonously decrease westwards. An important feature is the larger thickness of the bottom layer in the northern part of the model domain, both within the Neva Bay and beyond the dam. All these features of the bottom layer thickness distribution are due to the general pattern of the cyclonic circulation in this estuary. As for the increased values of the bottom layer thickness in the shipping channel, they are most likely artifacts caused by errors in the calculation of the pressure gradient or fluid vertical velocity in the sigma model due to the sharp changes in depth. Note that in a region of a sharp change in depth, the sigma-model vertical velocity of the fluid cannot be interpreted as strictly vertical, since it is actually only perpendicular to the sigma surfaces. Thus, some errors are possible during the calculation of the flux of settling particles in regions with sharp sloping topography. Still, absolutely most of the model domain has relatively small horizontal depth gradients and it is fair to expect that the results of calculation are generally correct, but this is unlikely to occur at the borders of the shipping channel.

The monitoring data of coastal pollution by microplastics (fig. 2 and Section 2.2) to a certain extent and indirectly confirm the results obtained by the model if we assume that the concentration of plastic litter that has landed on the shore is higher at locations where the accumulation of plastic in the bottom layer is greater. Indeed, there was practically no plastic litter in the period from June to August 2018 on the southern coast of the studied eastern part of the Gulf of Finland outside the dam, although it was found on the northern coast of the Gulf in significant quantities. The distribution of microplastics on the coast of the Neva Bay (fig. 2) is not consistent with the modeled distribution of microplastic accumulation at the bottom (fig. 6), which may be due to the input of microplastic particles to the Neva Bay from other sources, e.g. domestic wastewater.

It should be noted that the resuspension of microplastic particles from the bottom was not taken into account in the current study. Nevertheless, in reality the stirring of particles from the bottom by currents and waves usually takes place, especially in shallow coastal areas. Therefore, the next step in this work will be to determine the influence of this mechanism on the total distribution of microplastics in the coastal zone of the study area.

The simplifications of the Exner equation mentioned in Section 2.1 for equation (1) were made because there were no field data on the intensity of microplastic particles resuspension and their transport in the bottom layer (bed-load transport). Still, making any assumptions about the equivalence of these processes to processes for, e.g. sand, for which they are relatively known, would introduce many unknown variables into the model that would unreasonably complicate the interpretation of the results.

4. Conclusion

The presented study implements the calculation of bottom layer thickness with the aim of obtaining some time-integrated pattern of the spatial distribution of the zones in which the settling particles are deposited at a given rate of its gravitational sinking. The resulting assessment can be used to justify the selection of areas for future field works focused on the microplastic pollution monitoring of the coastal zone and the coasts of the eastern part of the Gulf of Finland.

It should be noted that we considered only one of the possible sources of microplastics in the Gulf of Finland – the Neva River. Among the other possible sources that will be investigated in the future we can emphasize urban municipal wastewaters, as well as the transport of microplastic from city landfills to the water surface by storm winds.

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К статье *Мартьянов С.Д., Рябченко В.А., Ершова А.А., Ерёмина Т.Р., Мартин Г.* К оценке распространения микропластика в восточной части Финского Залива

Martyanov S.D., Ryabchenko V.A., Ershova A.A., Eremina T.R., Martin G. On the assessment of microplastic distribution in the eastern part of the Gulf of Finland

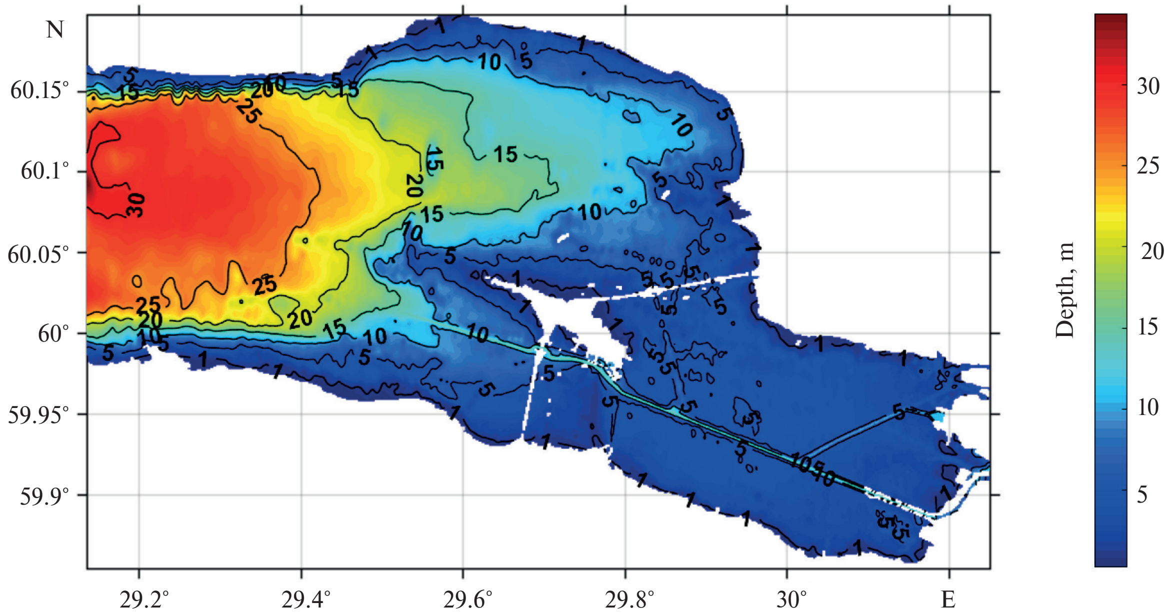


Рис. 1. Модельная область и поле глубин.

Fig. 1. Model domain and bathymetry.

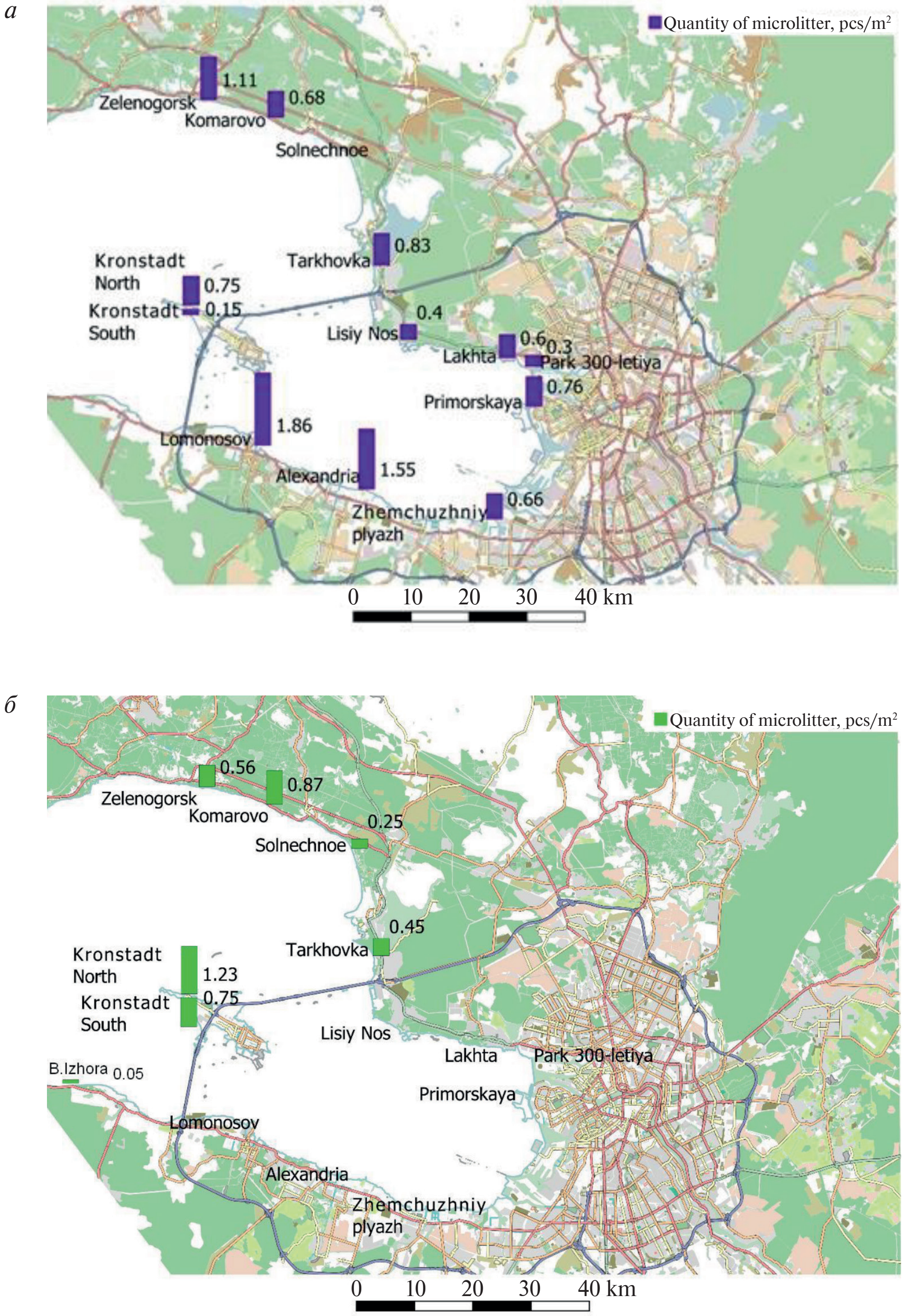


Рис. 2. Концентрация морского микромусора (шт/м^2): *а* – в зоне заплеска на побережьях Невской губы и внешней части эстуария (фрейм-метод); *б* – на пляжах восточной части Финского залива (рейк-метод).

Fig. 2. Concentration of marine microlitter (pcs/m^2): *a* – in the wreck-zone on the coasts of the Neva Bay and the outer part of the estuary (Frame method); *b* – on the beaches of the Eastern part of the Gulf of Finland (Rake method).

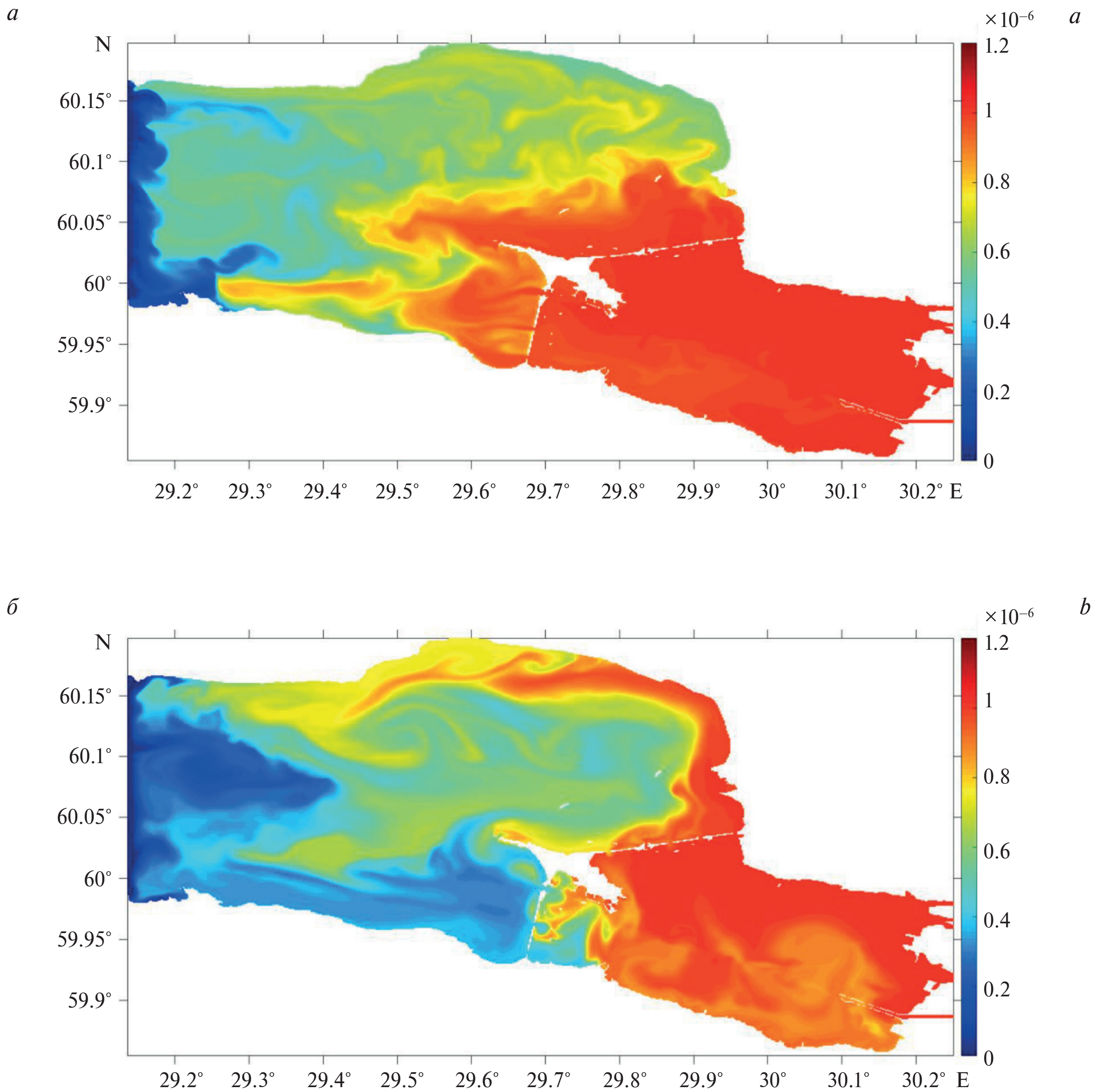


Рис. 3. Модельное распределение объемной концентрации примеси нейтральной плавучести в верхнем слое на 10.07.2018 (*а*) и 10.08.2018 (*б*).

Fig. 3. The modeled distribution of the volume concentration of neutral buoyancy particles in the upper layer on July 10, 2018 (*a*) and August 10, 2018 (*b*).

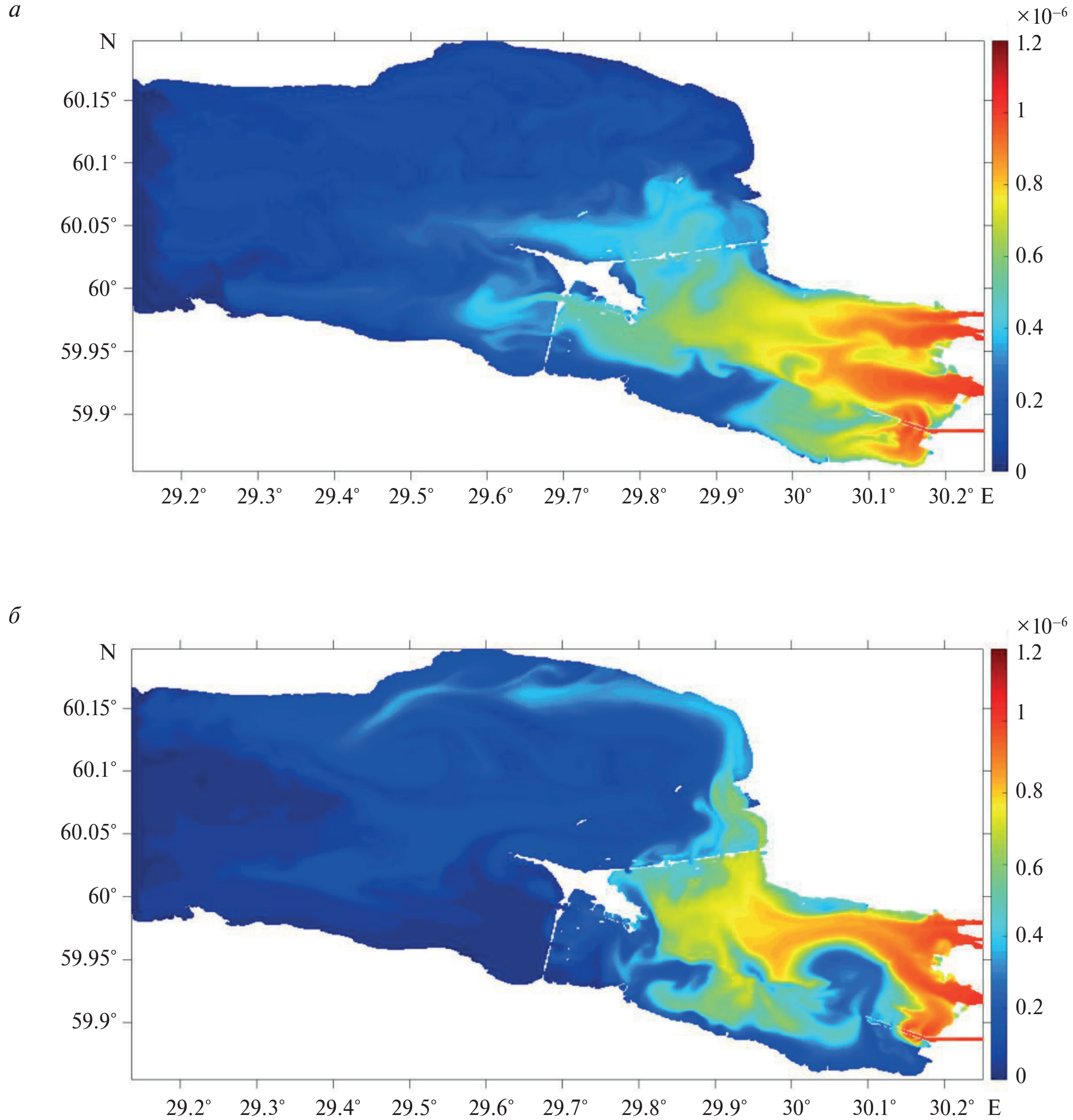
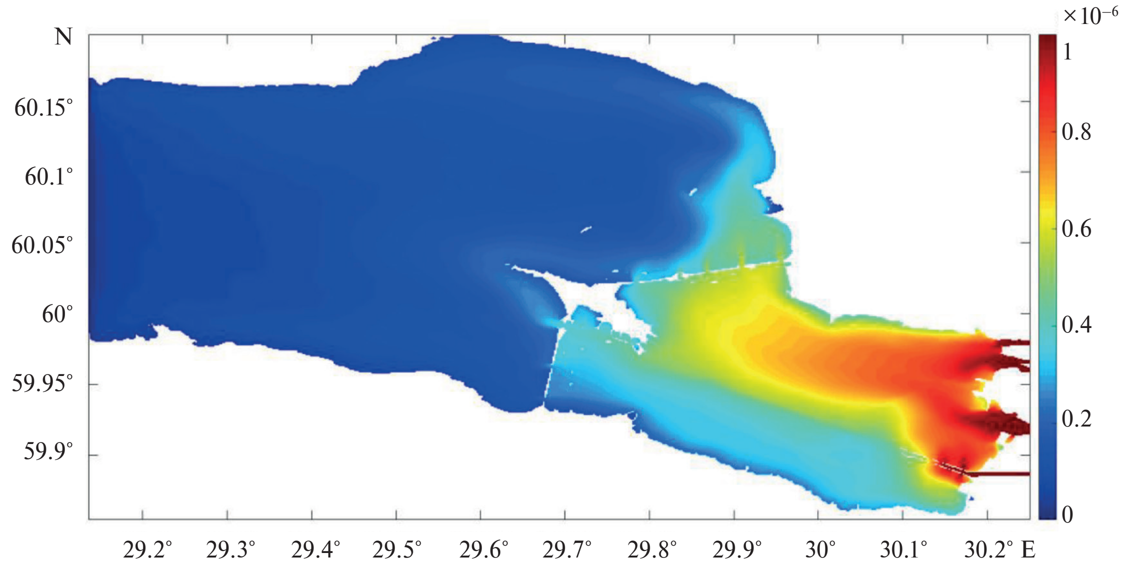


Рис. 4. Модельное распределение объемной концентрации оседающих частиц в верхнем слое на 10.07.2018 (*а*) и 10.08.2018 (*б*).

Fig. 4. The modeled distribution of the volume concentration of sinking particles in the upper layer on July 10, 2018 (*a*) and August 10, 2018 (*b*).

а



б

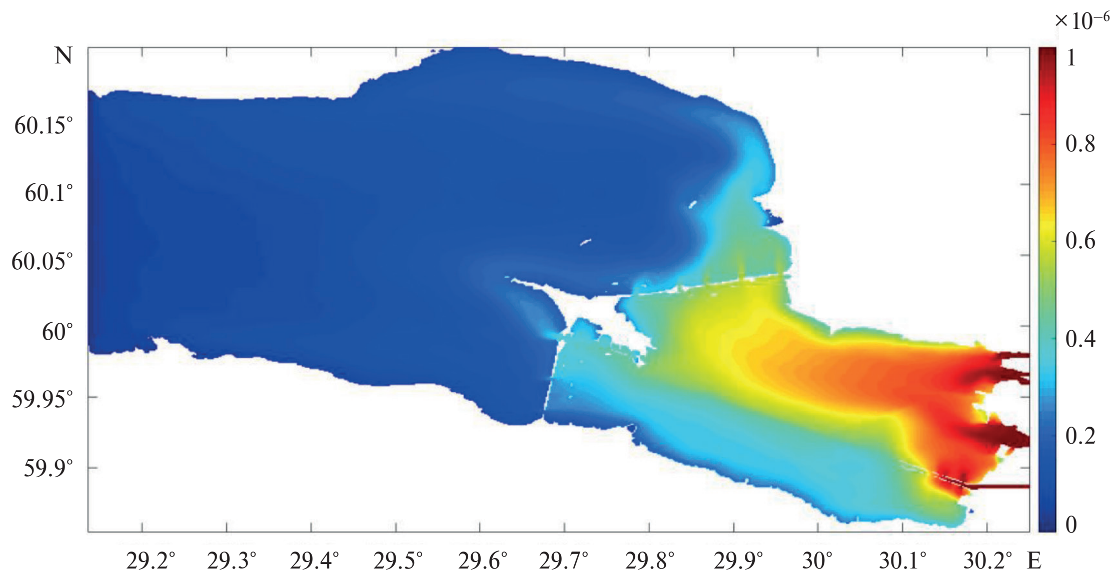


Рис. 5. Среднее за анализируемый период (июнь–август 2018 г) модельное распределение объемной концентрации оседающих частиц в верхнем (*а*) и придонном слоях (*б*).

Fig. 5. The averaged (for the analyzed period, June–August 2018) modeled distribution of the volume concentration of sinking particles in the upper (*a*) and bottom layers (*b*).

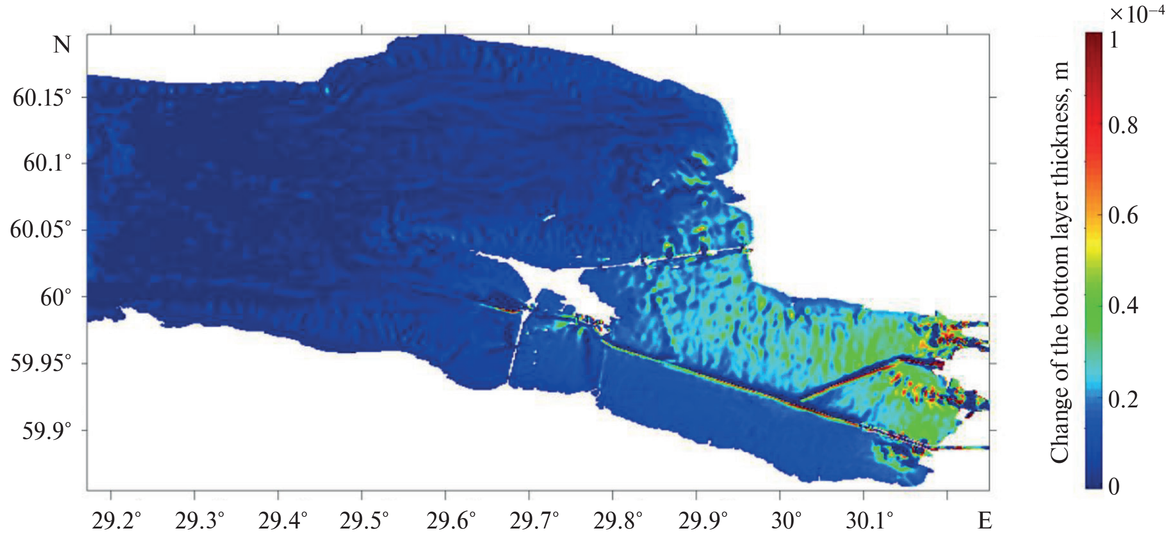


Рис. 6. Изменение толщины донного слоя частиц оседающей фракции (м) на конец счета 31 августа 2018 г.

Fig. 6. Change of the bottom layer thickness of the settling particles at the end of the model run on August 31, 2018.