Vietnam Academy of Science and Technology

Vietnam Journal of Marine Science and Technology

journal homepage: vjs.ac.vn/index.php/jmst

Hydrodynamic modelling of microplastics transport in Bach Dang estuary

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Received: 31 December 2021; Accepted: 30 September 2022

ABSTRACT

In this study, the three-dimensional Delft3D-PART model was applied to study micro-plastics transport in the Bach Dang estuary. Micro-plastics as data input for the model in this study were assessed by taking water samples by 80 μm mesh size plankton net, and sediment samples by Petersen grab. The determination of input parameters for the micro-plastic transport model through averaging the particle characteristics of micro-plastics has been applied. Microplastics results appear in 10 water samples and 10 sediment samples surveyed. The results of micro-plastics in the water body of Bach Dang estuary presented that the regional tidal regime was closely related to the number of micro-plastics according to the season. In the wet season, the number of micro-plastics was around 2–3 nr/m^3, spreading stronger than in the dry season.

Keywords: Micro-plastics Transport, Delft3D-PART model, Bach Dang estuary.

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https://doi.org/10.15625/1859-3097/16490
ISSN 1859-3097; e-ISSN 2815-5904/

INTRODUCTION

Microplastics are tiny plastic particles smaller than 5 mm in size that pollute the environment. The small microplastics makes them readily available for ingestion by a wide range of organisms in the marine environment. Bivalves, zooplankton, mussels, fishes, shrimps, oysters, copepods, lugworms, and whales have been reported to ingest microplastics [1, 2]. Studies have reported that microplastics have been detected globally in growing numbers in rivers and lakes and at very high levels. Microplastics are mainly composed of polyvinyl chloride (PVC), polyethylene (PE), and polyethylene terephthalate (PET) [3], such sources of secondary micro-plastics include water and soda bottles, fishing nets, and plastic bags.

The Bach Dang estuary is located in the northeastern part of the Red river delta and receives water from the Lach Tray river as well as the Cam and Bach Dang rivers, whose confluence is located 10 km from the mouth of the estuary (Figure 1). In recent years, water quality degradation has been associated with the rapid socioeconomic development in the Bach Dang estuary area. Almost microplastic predominately originates from the land; studying microplastic behaviors in the river estuary and coastal waters is critical. However, there is considerable uncertainty regarding what factors are influencing the trajectories, distribution and deposition sites of micro-plastics. Along with complex physical processes and scarcity of empirical data, there is currently little knowledge and understanding of the transport and fate of microplastics in coastal and estuary areas.

It is well known that it is crucial to study and assess the environmental factors that cause accidents as well as the many factors related to river discharge that cause ecological pollution of sea water from land waste. The study aims to obtain more insight into behaviors of microplastic to examine the most important processes and quantify the effects of parameter uncertainty on modeling the transport and fate of microplastic in the Bach Dang estuary. Furthermore, numerical model is a tool to help us understand the micro-plastics transport in the water cycles, and a three-dimensional model was applied to studying the transport of microplastics through the impacts of hydrodynamics and meteorological processes (tides, river discharge, winds, wave, etc.) in the Bach Dang estuary.

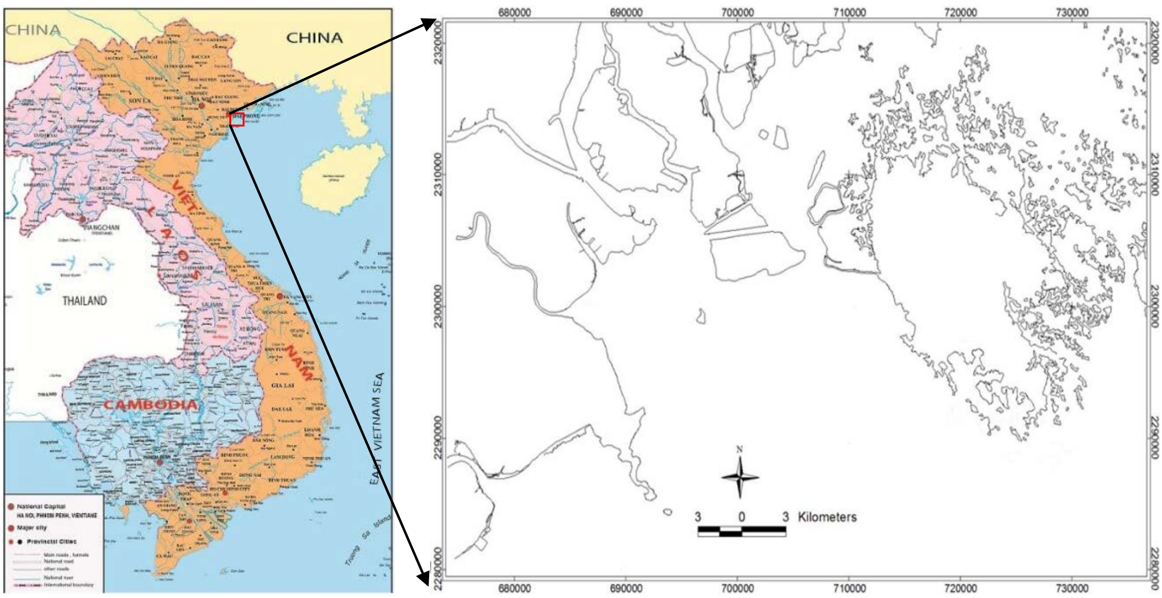


Figure 1. Study area

DATA AND METHODS

Materials

Bathymetry and coastline in the Bach Dang estuary area were digitized from topography maps, which were published by the Department of Survey and Mapping, now belonging to the Ministry of Natural Resources and Environment of Vietnam. The harmonic constants of 13 main tidal constituents will be imposed at open sea boundaries in the refined grid. The tidal harmonics constants imposed offshore were extracted from TPOX 8.0 Global [4] Wind data recorded at the Hon Dau station during the dry and wet seasons. The averaged river discharges, temperature and salinity provided by a previous project, KC09.17/11–15; 2013–2015, were used to set up the river boundary conditions in these rivers. The micro-plastic as input data for the model was the VAST project coded KHCBBI.01/18–20 and one coded VAST06.02/19–20 by Institute of Marine Environment and Resources (IMER).

Methods

One needs to solve the equations governing particle motion to simulate plastic transport. In many transport models, the movement and spreading of a particle are described by the advection-diffusion equation and the velocity fluctuations due to turbulent mixing, which can be approximated by introducing the concept of "eddy diffusivity", where it is assumed that turbulent fluxes in flow velocities can be described by analogy with molecular diffusion [5], formulated in an Eulerian or Lagrangian form. The Lagrangian method, known as "particle tracking", simulates particle transport by considering single particle motions. The individual particles are tracked in time and space, and it is based on a moving frame of reference in which the change of momentum of a particle and its behaviour towards the environment is observed. In a Lagrangian particle tracking model, the trajectories of a set of discrete particles are simulated. The cloud of individual particles then represents the concentration. The displacement of each Lagrangian particle is given by a sum of a deterministic and stochastic component. The deterministic component represents the displacement due to advection, while the stochastic component represents the chaotic nature of the flow field [6].

Delft3D-PART is a random walk particle tracking model, which is based on the principle that the movement of dissolved (or particulate) substances in water can be described by a limited (large) number of discrete particles that are subject to advection due to the currents and by horizontal and vertical dispersion. The movement of the particles consists, therefore, of two elements. For each time-step, the first step is the advection step due to the shear stresses from currents (bottom) and wind (surface). The second step is the random walk step, in which the size and direction of the movement is a random process but are related to the horizontal and vertical dispersion. This study simulated the hydrodynamics condition in the Delft3D model by the hydrodynamics module. The NESTING method created sea boundary conditions for the inner grid (refined) within a coarse model (using the overall grid); a modeling system that could efficiently simulate hydrodynamics (Delft3D-FLOW), wave (Deflft3D-WAVE), and Delft3D-PART model [7–9]. The Delft3D-PART (Particle Tracking) was applied to simulate the micro-plastics transport in the Bach Dang estuary (Figure 2).

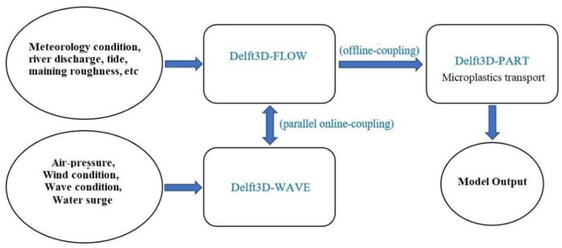


Figure 2. Overview of the micro-plastic transport model framework

The spatial and temporal transport patterns of micro-plastics are modeled using the Delft3D-PART stochastic module. The PART module of Delft3D simulates the micro-plastics transport using a particle tracking method. The particle tracking method is based on random-walk since the simulated behavior is stochastic [10]. The tracks are followed in three dimensions over time, whereby a dynamic concentration distribution is obtained by calculating the mass of particles in the model grid cells. The processes are assumed to be deterministic except for a random particle displacement at each time step.

Model configuration

This study uses the coupled model to simulate the hydrodynamics and microplastic transport (online coupling with hydrodynamics and offline coupling on microplastic transport model). The sparse model grid consists of 267 × 168 grid cells which is limited from 106.70°E to 108.12°E and from 19.86°N to 21.49°N, with a resolution of approximately 250–300 m for coastal areas and 1,000 m for offshore areas. The high-resolution model grid (inner grid) is nested inside the outer model domain (Fig. 3).

The inner model grid consists of 289 × 189 grid cells, which have a high resolution of approximately 150 m grid size in the coastal and river basin areas. The offshore site has a resolution of roughly 500 m of grid cells. The microplastic transport model uses the same computational domain and computational grid (inner grid) applied for the hydrodynamics model.

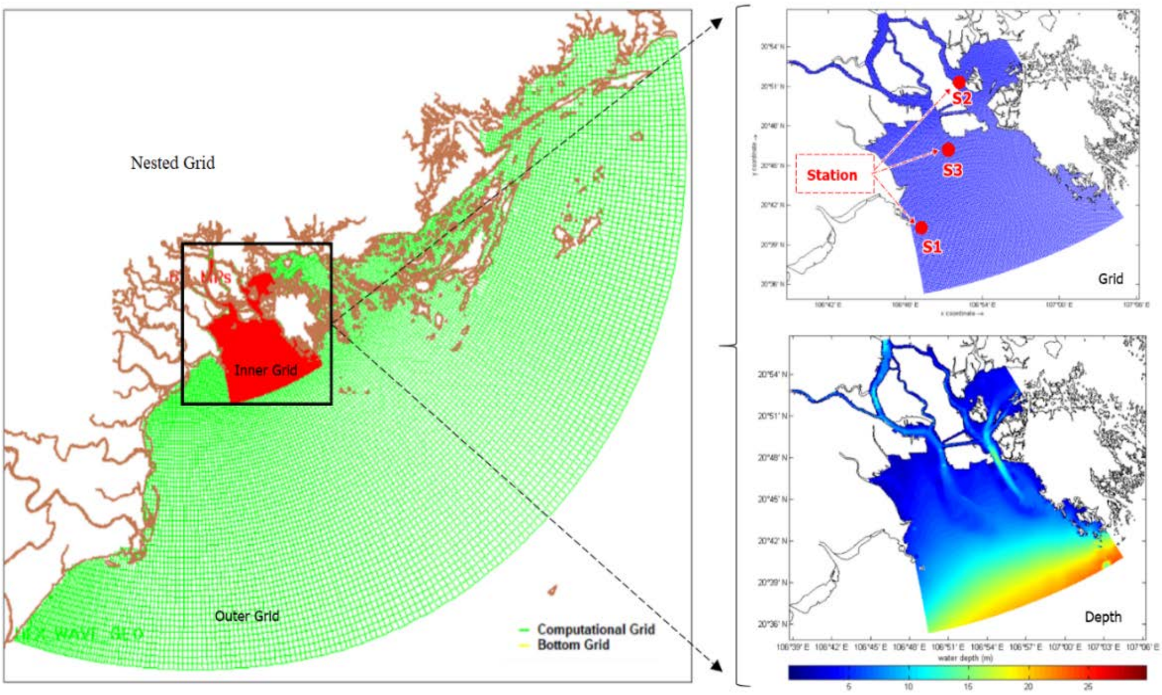


Figure 3. Model grids and bathymetry

The initial conditions of the surface water elevation and current velocities at the beginning of the simulation are set to be zero uniforms. The harmonic constants of 13 tidal constituents (*M*2, *S*2, *K*2, *N*2, *O*1, *K*1, *P*1, *Q*1, *MF*, *MM*, *M*4, *MS*4, *MN*4) are considered to be the open sea boundary of input data for the sparse model. The appropriate river discharge boundaries are adjusted based on monthly-averaged discharge data recorded. Wave boundary conditions with wave height, direction, and period were applied to the sparse model (nested and online coupled).

In this study, the simulated microplastic type is polyethylene (PE), with an average size of 4 mm. The parameters of micro-plastics used for the reference particle transport model from empirical formulas include micro-plastic density, settling velocity, roughness, wind drag, decay rates, etc. The amount of micro-plastics in the water at the liquid boundary in the river is referenced from the sample collection results of the VAST project coded KHCBBI.01/18–20 by the Institute of Marine Environment and Resources (IMER). The main parameters of the hydrodynamics and micro-plastics transport model are shown in Table 1.

Table 1. The main parameters of the hydrodynamics and micro-plastics transport model

The hydrodynamics model		The micro-plastics transport model	
Parameters	Unit	Parameters	Unit
Grid cell (*M*, *N*)	289, 189	Micro-plastic type	PE
Grid size (Δx, Δy)	150–500 m	Grit size	4 mm
Time step	60 second	Source type	Continuous release
Threshold depth	0.1 m	Micro-plastic density	926 kg/m^3 [10]
Time in a simulation	75 days	Settling velocity A_0	-0.00045 m/s [11]
Horizontal Eddy Viscosity	1.0 m^2/s	Roughness	0.5 [12]
Vertical Eddy Viscosity	1.0×10^{-6} m^2/s	Decay rates	0 (1/day)
Horizontal Eddy Diffusivity	1.0 m^2/s	Wind drag	1
Vertical Eddy Diffusivity	1.0×10^{-6} m^2/s	Coefficient a	1
Sigma-coordinate	On	Coefficient b	0.05
Model for 3D turbulence	*k*-epsilon	Particle tracks	3D tracks

Models Calibration and Evaluation

Calibration of the numerical model is standard practice and it involves estimating parameters based upon observed data. It is generally carried out manually by adjusting the parameters of the model by using practical observations.

We use the root mean square error (RMSE) to evaluate the model results for calibration and verification. The RMSE and is calculated for the data set as follows [13]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(X_{obs,i} - X_{model,i}\right)^2}{n}}$$

where: $X_{obs,i}$ is observed values and $X_{model,I}$ is modeled values at time/place *i*.

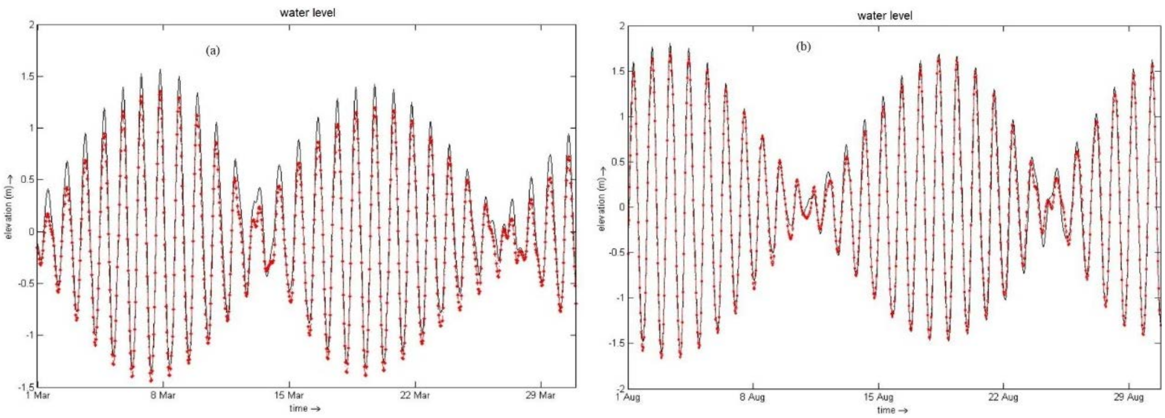


Figure 4. The comparison of modeled water level with observation data at Hon Dau during the dry season (a) and wet season (b)

To realize validation and model calibration for hydrodynamic models in Bach Dang estuary, we used simulated water levels to compare with observed data at Hon Dau station during the dry and wet seasons. Modeling results and water level data at Hon Dau station (*S*1 station, Figure 3) have a relative agreement on both amplitude and phase (Figure 4). Graphical comparisons indicate that the model reproduced general trends at Hon Dau station. In general, the agreement between observed and simulated data is good.

A time series of observed current velocities were set for 48 hours with 1 hourly interval during the wet seasons at Chanh River estuary station (*S*2 station, Figure 3). The comparison results of velocity showed the RMSE is a difference of 0.094 m/s (Figure 5). Though simulated results show deviations from the observed data, the speed reasonably agrees with the measurements.

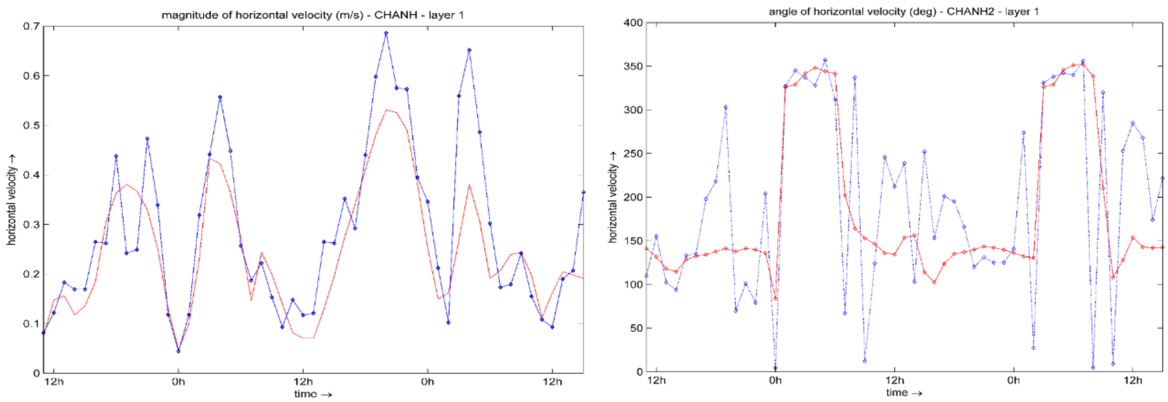


Figure 5. Comparison of measured and modeled velocity at S2 station (Chanh river mouth)

RESULTS AND DISCUSSION

The amount of microplastics in the water is related to the source of micro-plastic waste; it is also strongly influenced by the water exchange capacity of the water body. As we know, microplastics exist in the aquatic environment for a long time, and most plastics don't biodegrade, which means they're destined to break down into smaller and smaller pieces called microplastics, which might rotate in the sea eternally. Therefore, the hydrodynamic processes of microplastics have different properties than other suspended properties in water body. However, they are also influenced by regional hydrodynamic processes during transport in the water body, and the dependence on tide conditions is weaker during the season. Figure 6 shows the changes in the number of microplastics in the surface water layer during the dry and wet seasons. Thereby, it is evident that the difference in the number of microplastics in the water mass is closely related to the regional tidal regime.

Model results show that amount of microplastics ranged from 2 to 3 items in ebbs and flood tides during the wet season. During the dry season, the average amount of microplastics in the water environment is about 3.5 nr/m^3. In the rainy season, the average amount of microplastics (PE) in the water environment is about 3.0 nr/m^3 (Figure 6). Maybe the number of plastics (PE) in the water body was mixed between the surface with the bottom layer, due to the river and sea interaction in these estuary bays.

The model results showed that, during the dry season, there are relevant differences amongst micro-plastic items along the delta: amount of micro-plastics is higher in Southwestern estuaries than in Northeastern estuaries. In the flood stages, amount of micro-plastics varies between 3 nr/m^3 to 4 nr/m^3, with higher values in the Southwestern estuaries and river mouth area as well. During dry season, Northeastern winds are dominant, micro-plastics tend to move towards the Cam Cap dykes, and Southeastern of Dinh Vu coastal area (Figure 7).

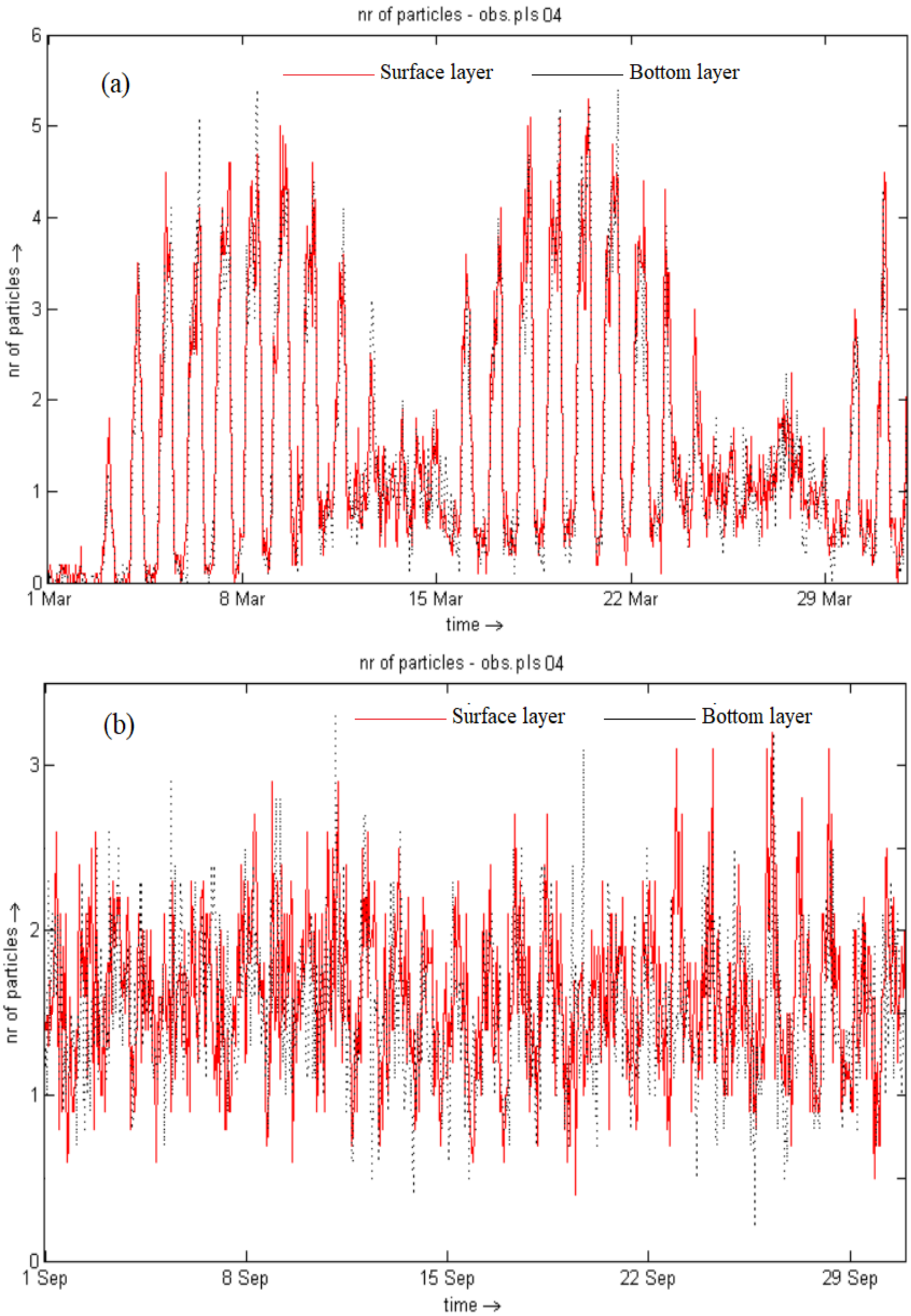


Figure 6. The modeled of the micro-plastics at *S*3 station (20°46’9.64”N; 106°51’13.46”E) during dry season - March (a) and wet season - September (b)

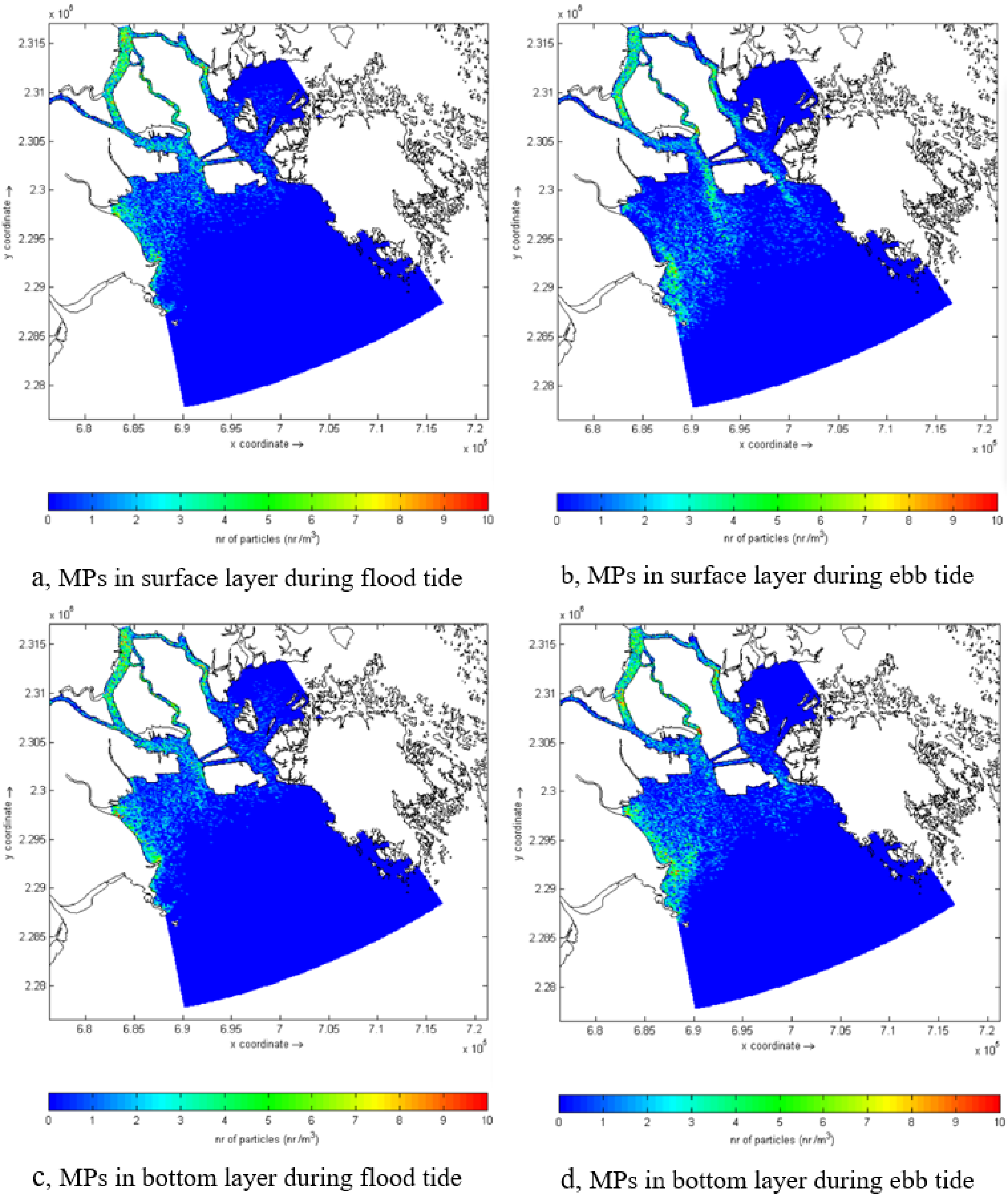
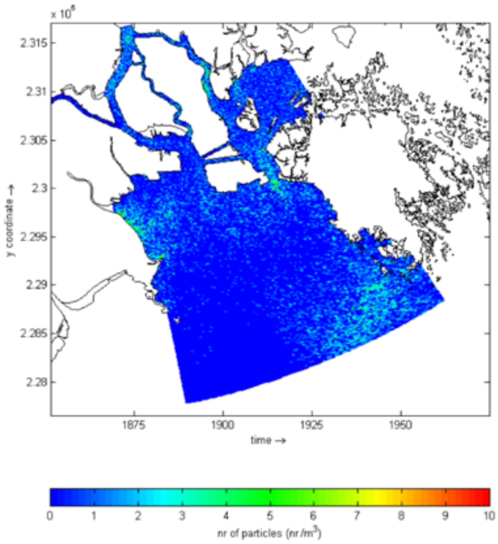
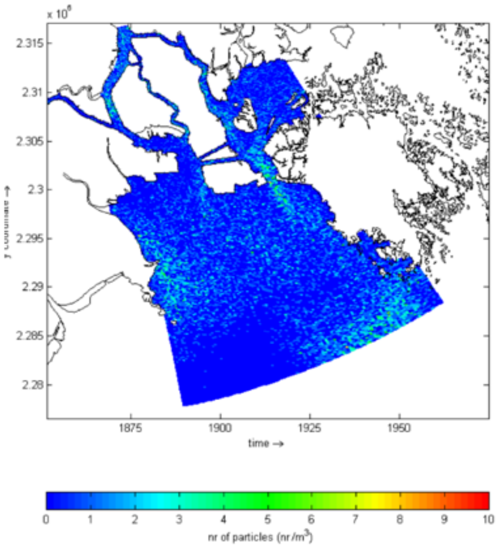


Figure 7. Modeled transport of micro-plastic in Bach Dang estuary during dry season

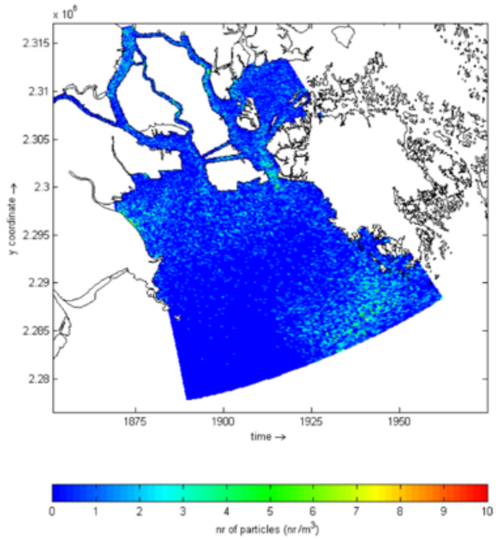
The amount of microplastics depends on the source of microplastics from the rivers to the sea and depending on the ability to exchange water (the difference in tidal amplitudes between the dry season and the rainy season). During the wet season, number of microplastic varies between 2 to 3 nr/m^3 during flood stages, with higher values in the river mouth. During the wet season, the dominant wind direction is Southeastern, which causes more micro-plastic transport to the Cat Ba and Ha Long Bay than in the dry season. Microplastic dispersion in the wet season is stronger than in the dry season (Figure 8).



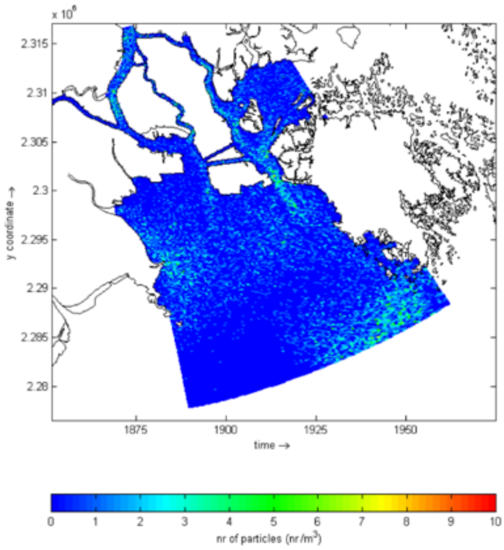
a, MPs in surface layer during flood tide



b, MPs in surface layer during ebb tide



c, MPs in bottom layer during flood tide



d, MPs in bottom layer during ebb tide

Figure 8. Modeled transport of micro-plastics in Bach Dang estuary during wet season

CONCLUSIONS

In this research, we initially applied the particle tracking module (Delft3D-PART) to simulate the distribution and transport of the microplastics in the water environment in the Bach Dang estuary. This approach will provide knowledge to understanding the transport of microplastics through position tracking of the particles evolved in time from their release until the end of the simulation. The parameterization of the input parameters of the microplastic for the digital model has been done through references from published studies; the main parameters include resin type, density, decay, velocity settling, diffusion coefficient, roughness coefficient, sink rate, dispersion rate, etc. The present study is the first on the application of numerical models to simulate the transport of micro-plastics in Vietnam. It aims to improve the knowledge of transportation, distribution, and possible accumulation of microplastic litter in the coastal area. However, it is necessary to establish more numerical simulations scenario in various types and sizes of microplastics.

Acknowledgements: This section devotes to acknowledge the supports by Project code TNMT. 2018.05.16 of Vietnam Ministry of Natural Resources and Environment (MONRE); and VAST project coded KHCBBI.01/18–20 and one coded VAST06.02/19–20 by Institute of Marine Environment and Resources (IMER); and VAST project coded CSCL 10.01/22–22 by Institute of Geography (IG).

CRediT authorship contribution statement: Le Duc Cuong, Dao Dinh Cham, Nguyen Ba Thuy, Nguyen Quoc Trinh: Methodology, Numerical modeling of micro-plastic transport; Duong Thanh Nghi, Duong Thi Lim: Investigation, Funding acquisition; Nguyen Van Thao, Du Van Toan: Formal analysis, Supervision.

Declaration of competing interest: The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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