Defect and Diffusion Forum
ISSN: 1662-9507, Vol. 396, pp 42-49
doi:10.4028/www.scientific.net/DDF.396.42

Submitted: 2019-03-19
Accepted: 2019-05-29
Online: 2019-08-16

Lagrangian Trajectory Simulation of Floating Objects in the State of São Paulo Coastal Region

Jader Lugon Junior[1,a*], Francine de Almeida Kalas[2,b],
Pedro Paulo Gomes Watts Rodrigues[2,c], José Luiz Jeveaux[3,d],
Hugo Gallo Neto[3,e], Maria Manuela Juliano[4,f],
and Antônio José da Silva Neto[2,g]

[1]Instituto Federal Fluminense, Macaé/RJ, Brazil

[2]Instituto Politécnico, Universidade do Estado do Rio de Janeiro, Nova Friburgo/RJ, Brazil

[3]Instituto Argonauta para Conservação Costeira e Marinha, Ubatuba/SP, Brazil

[4]University of Azores, Ponta Delgada, São Miguel, Azores, Portugal

[a]jljunior@iff.edu.br, [b]frankalas@iprj.uerj.br, [c]jjeveaus@gmail.com,
[d]hugo@aquariodeubatuba.com.br, [e]manuela.juliano@gmail.com, [f]ajsneto@iprj.uerj.br

*corresponding author

Keywords: Floating objects. Cetacean. MOHID. Hydrodynamics. Downscaling.

Abstract. In this work a computational model is presented in order to simulate the trajectory of objects near the Ilhabela island region, in São Paulo coastline, Brazil. The MOHID platform (MOdelagem HIDrodinâmica - Hydrodynamics Modelling) was used with the downscalling technique used to obtain local hydrodynamic currents at local scale. Two different applications are tested, the first is the hypothetical trajectory of a dead cetacean specimen drifting that could have happened in fact if it was not arrested to a more adequate spot near Ilhabela island in November, 2017, and the second is the simulation for the drift of floating objects that resulted from an accidental release of containers at the Port of Santos in August, 2017. The use of these technologies has great potential for researchers interested to simulate different drift occurrences near the Brazilian costal region.

Introduction

There are many academic and practical studies that requires the simulation of the pathways, and also the transformation of many different kinds of objects using Lagrangean trajectory models. In 2018, a literature review listed 32 different software that are available to simulate oceanic trajectory of drifting objects, each one with specific characteristics depending on the developer interests [1].

The MOHID (MOdelagem HIDrodinâmica - Hydrodynamic Modelling) Platform is one of such software, and can be downloaded from the website www.mohid.com. In this work, a MOHID based computer model is described that calculates the hydrodynamics that is needed to perform the Lagrangian Trajectory simulation, for two specific applications:

1) estimative a hypothetical trajectory of a dead cetacean specimen found near Ilhabela island in November, 2017.

2) the simulate the trajectory resulting from an accidental droppage of containers, which resulted in many floating objects, at the Porto of Santos in August, 2017.

Model Description

The MOHID Platform three-dimensional hydrodynamic model is used in the solution of Navier-Stokes equations (Eqs. 1 - 4), with the Boussinesq and hydrostatic approach [2].

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_1}{\partial t} + \frac{\partial (u_j u_1)}{\partial x_j} = f u_1 - g\frac{\rho_\eta}{\rho_0}\frac{\partial \eta}{\partial x_1} - \frac{1}{\rho_0}\frac{\partial p_s}{\partial x_1} - \frac{g}{\rho_0}\int_s^\eta \frac{\partial \rho'}{\partial x_1}\partial x_3 + \frac{\partial}{\partial x_j}\left(v_h \frac{\partial u_1}{\partial x_j}\right) \tag{2}$$

$$\frac{\partial u_2}{\partial t} + \frac{\partial (u_j u_2)}{\partial x_j} = f u_2 - g\frac{\rho_\eta}{\rho_0}\frac{\partial \eta}{\partial x_2} - \frac{1}{\rho_0}\frac{\partial p_s}{\partial x_2} - \frac{g}{\rho_0}\int_s^\eta \frac{\partial \rho'}{\partial x_2}\partial x_3 + \frac{\partial}{\partial x_j}\left(v_h \frac{\partial u_2}{\partial x_j}\right) \tag{3}$$

$$\frac{\partial p}{\partial x_3} = -\rho g \tag{4}$$

where u_i are the velocity components in the Cartesian directions $x_i, i = 1,2,3$; η is the elevation of free surface; f is the Coriolis parameter; v_h is the turbulent viscosity; p_s the atmospheric pressure; ρ is the density; ρ_0 is the reference density, ρ' is a deviation from the reference density and ρ_η is the density at the free surface.

Using an integration of the equation of continuity in the water column, the following equation is obtained for the free surface elevation:

$$\frac{\partial \eta}{\partial t} = \frac{-\partial}{\partial x_1}\int_{-z}^{\eta} u_1 dz - \frac{-\partial}{\partial x_2}\int_{-z}^{\eta} u_2 dz \tag{5}$$

where u_1 and u_2 are, respectively, the vertical integrated velocities in the Cartesian directions x and y; η is the free surface elevation and $-z$ is the bottom depth.

Different properties of interest (θ), such as salinity and temperature, are modeled using the transport model

$$\frac{\partial \theta}{\partial t} + \frac{\partial (u_i \theta)}{\partial x_1} = \frac{\partial}{\partial x_1}\left(K\frac{\partial \theta}{\partial x_i}\right) + F_\theta \tag{6}$$

where K represent the diffusivities of θ, and F are the possible sinks or sources.

The model discretization in the MOHID platform is performed using a Finite Volume approach to allow the simultaneous implementation of different coordinates systems – Sigma on the top and Cartesian on the bottom – in the Geometry module. A sigma coordinate system is usually applied at the first barotropic level model, whereas for the other levels (downscaled baroclinic model) a combination of these two coordinates systems is adopted. This approach is often applied to simulate oceanic hydrodynamics, where the flow is influenced by density variations.

The viscosity and diffusivity coefficients are calculated using the GOTM (*General Ocean Turbulence Model*) with the k-ε model for the turbulent kinetic energy.

The Open Boundary Conditions (OBC) in the nested downscaling model are set according to the model domain. In the first level, a 2D barotropic model is forced with tidal data and computes values that are imposed in the subsequent levels, which consists of 3D baroclinic models [3,4].

The Lagrangian module in MOHID's Water Platform is used to calculate the movement of the tracers affected by the velocity field of the hydrodynamic module. The average velocity affects the displacement of the tracer, given by

$$\frac{\partial x_i}{\partial t} = u_i(x_i, t) \tag{7}$$

where u_i is the mean velocity, and x_i is the position in the domain.

Each particle position is calculated with the MOHID Lagragian module using

$$x_i^{t+\Delta t} = x_i^t + \Delta t. u_i^t \tag{8}$$

The circulation pattern and the velocity fields are simulated in the hydrodynamic module, with the calculation of level, velocity and water flow.

The interaction of Hydrodynamic and Lagrangian modules is represented in Figure 1.

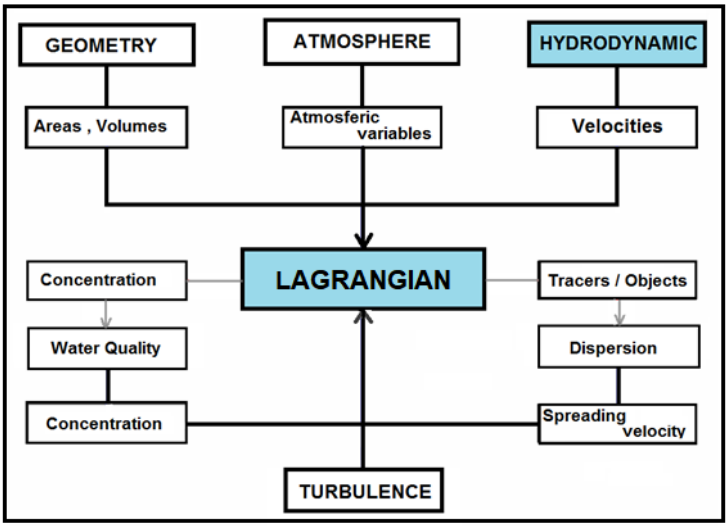


Figure 1: Hydrodynamic and Lagrangian modules interaction process, Adapted from [5].

The dispersion and trajectory of particles and fluids simulated in the Lagrangian module allow the modelling of different processes, such as dispersion of objects, oil, larvae, sediments, among others. This module uses the concept of tracer, whose main properties are the position $(x_1, x_2, x_3)= (x, y, z)$, the volume and the concentration of the property of interest [5, 6].

Model implementation

A hydrodynamic model was implemented using a downscaling technique, with 4 domain levels covering all South America region (Table 1, Figure 2). The first level of the model considered a barotropic model and has a 2D hydrodynamic formulation, whereas the other levels use a baroclinic model implementation with a 3D hydrodynamic formulation.

Table 1: Domain discretization resolution

Domain		**Vertical resolution**		**Maximum Depth**	**Vertical Discretization**
Level	Name	Degrees	Meters	Meters	
1	South America	0.120	12,000	8050	1 Sigma
2	Brazil	0.120	12,000	5300	7 Sigma 43 Cartesian
3	Santos	0.024	2,400	2580	
4	Ilhabela island	0.008	800	280	

The first domain level (South America) adopted a single vertical sigma layer and was forced at the open lateral boundary by the tidal harmonic components of the model FES2012 (Finite Element Solution) [7]. All other 3D model domains (Brazil, Santos, and Ilhabela island) were forced by MyOcean model data (temperature, salinity and water level) [8] as well as GFS meteorological data [9]. In Figure 2 the area covered in the father domain (level 1) is shown, as well as each nested domain (level 2 – 4), with the corresponding bathymetry.

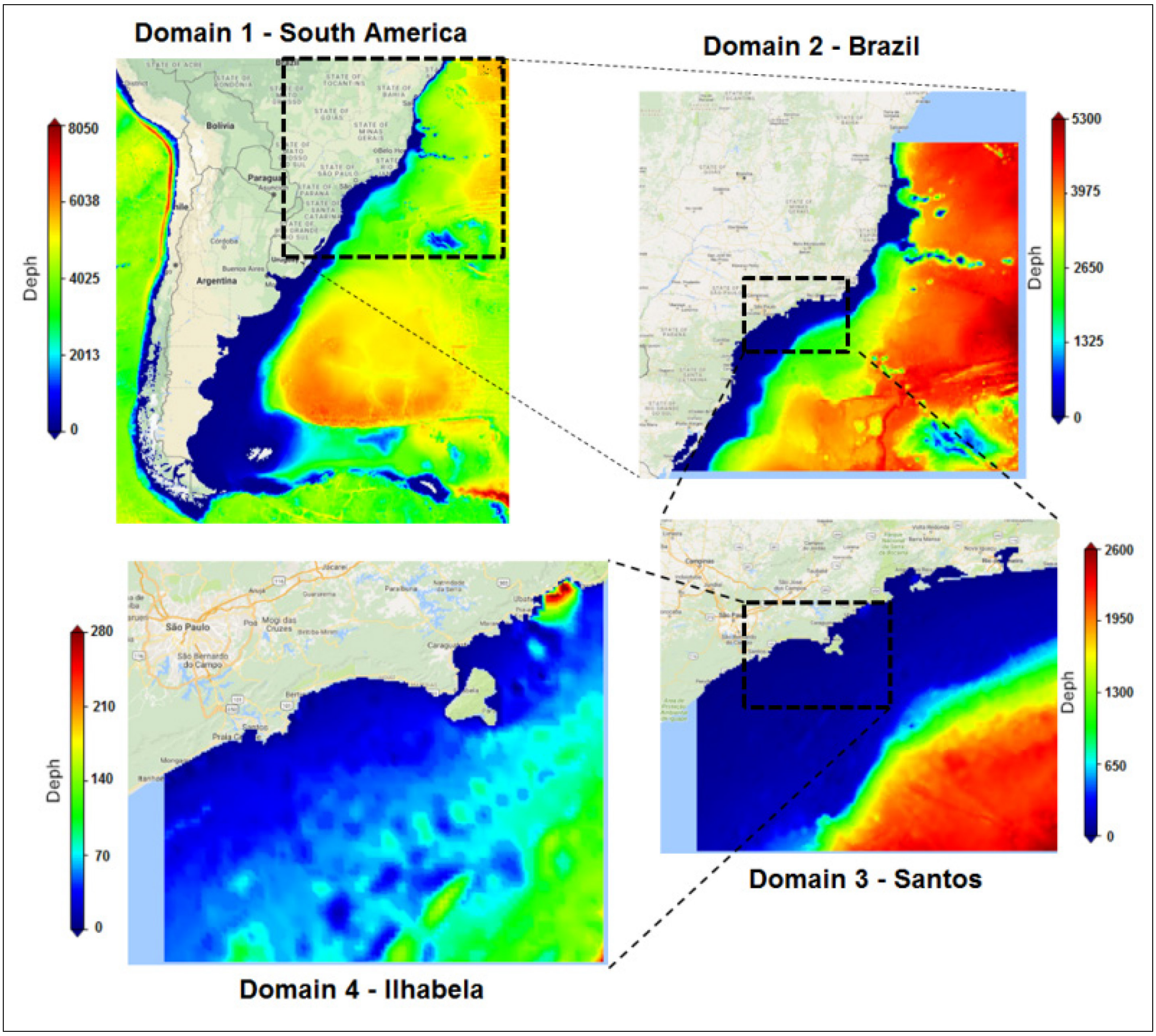


Figure 2: Area covered by the model in the four different levels, with the corresponding bathymetry in meters.

Case studies description

The simulation results for the Lagrangian trajectories in the applications considered in this work are described in this section. The validation of both case study simulations was performed with the comparison of sea surface temperature data, water temperature and water salinity profiles provided by GFS and Argo, in the Brazilian domain, showing a satisfactory statistical results.

Drift of stranding cetaceans near Ilhabela island. Since 2010 the Argonauta Institute [10] has been activated with information about strandings and sightings of cetaceans on the north coast of São Paulo (São Sebastiao, Ilhabela island, Caraguatatuba and Ubatuba municipalities).

On November 11th, 2017, a skeleton of a Bryde (*Balaenoptera brydei*) whale was sighted in the vicinity of Curral beach, in Ilhabela island. The displacement of this specimen was carried out, by the technical team of Argonauta Institute, to an uninhabited region, known as São Sebastião beach.

Figure 3 shows the region in which the sighting occurred and lashing of the beached whale.

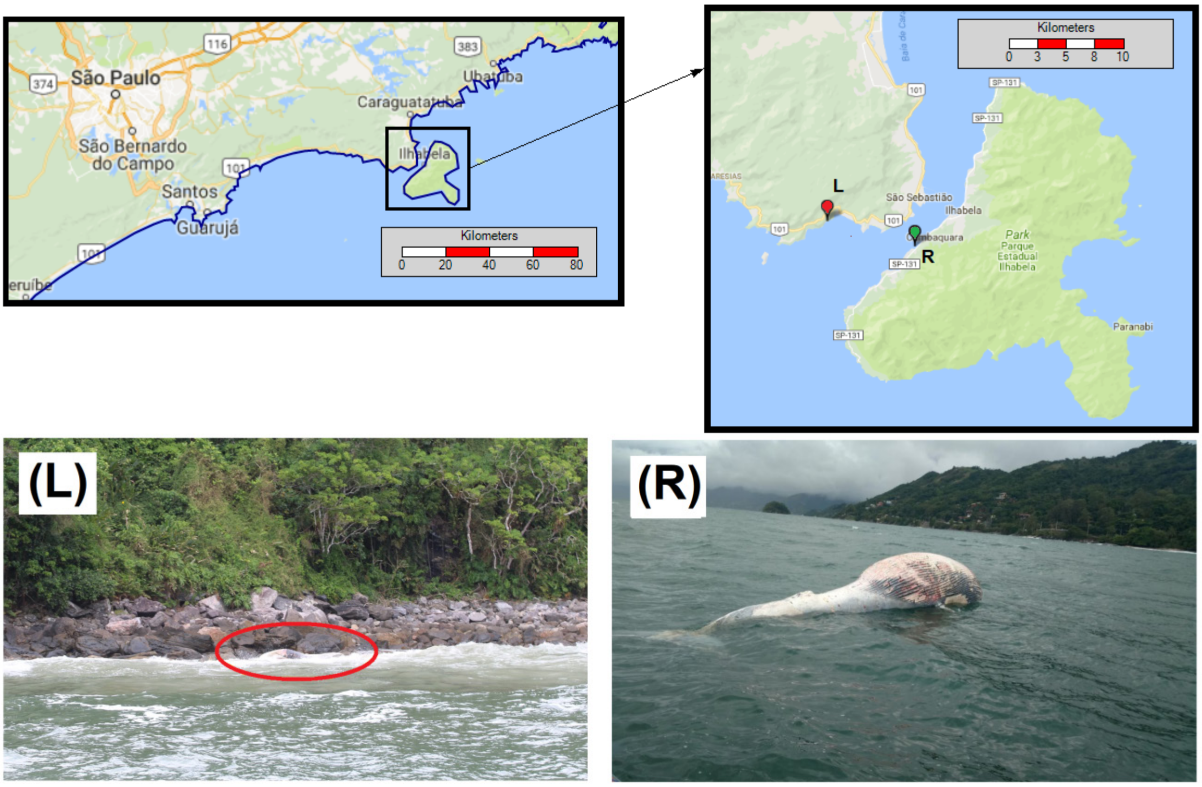
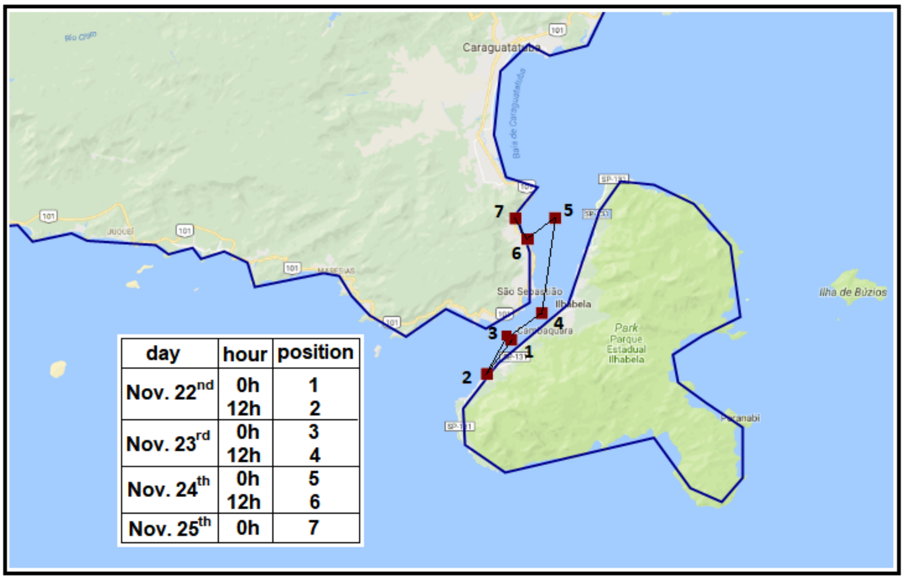


Figure 3: Area in which the sighting occurred (green balloon – R) and lashing (red balloon – L) of beached whale in São Paulo State coastline.

This work uses a lagrangian module of the MOHID Water Platform to simulate a hypothetical trajectory of the whale carcass considering that there was no human interference, i.e. only under the action of winds, waves and currents. The results are presented in Figure 4.



day	hour	position
Nov. 22nd	0h	1
	12h	2
Nov. 23rd	0h	3
	12h	4
Nov. 24th	0h	5
	12h	6
Nov. 25th	0h	7

Figure 4: Simulation of the trajectory of the Bryde's carcass according MOHID implementation

The results from the model show that the specimen would reach the Arrastão and São Franscisco beaches (points 6 and 7 in the map, respectively, Figure 4), a touristic and portuary region. The presence of a whale's carcass and its decomposition, especially in urbanized and more densely populated regions, can generate a serious public health problem, with a generation of gases that can exude a foul odor and even may attract sharks to coastal waters.

Drift of objects released in an accident with containers at the Port of Santos. In the Brazilian press it was published that the ship Log-in Pantanal had part of its cargo (46 units) accidentally dropped, at a distance of approximately 3.2 kilometers from the coast at dawn (between 1:30 a.m. and 3:00 am) of August 11th, 2017 [11]. From the 46 units, 38 of them sank, and only 8 containers were recovered at the coastal region. Those containers that were damaged in the fall from the ship released material in the ocean, which was drifted by currents and winds [12].

The smaller floating objects were collected few days later after the accident, along the north coast of the São Paulo State, by the team of the Argonauta Institute for Coastal and Marine Conservation [10].

In this work, in order to simulate the trajectories, it was adopted a single point of release for fully immersed floating objects. The trajectory of the objects was then simulated considering the time period August 15th – 21st, 2017, for a single object backwards (from the point where it was found aiming at determining the point of release) with the backtracking algorithm. This technique is usually employed to detect illegal discharges and pollutant sources [13, 14].

Figure 5 shows the results for the trajectory simulation using the Lagrangian module of the MOHID Water Platform.

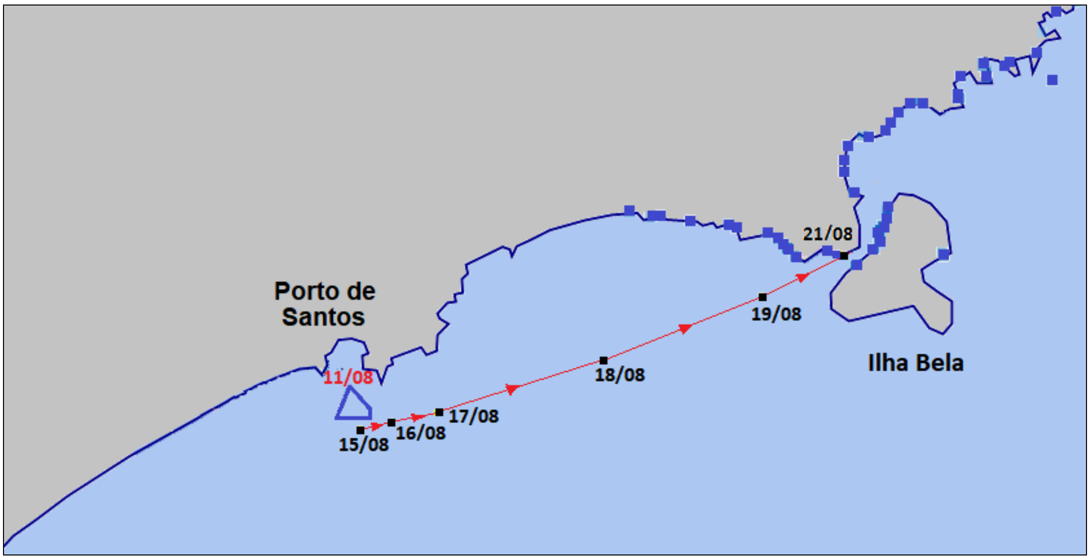


Figure 5: Trajectory simulations for floating objects using MOHID's Lagrangian module.

The blue polygon indicates the point where in fact the containers droppage took place (Port of Santos anchorage area number 3) and the blue dots are the locations where they were found by the Argonauta Institute. The backtracking model was able to find the origin of the objects with reasonable accuracy as can be observed in Figure 5, although in many cases objects are retained in any circulation pattern, such as a vortex, and their origin are not found.

Conclusions

In spite of the great complexity of coastal systems, hydrodynamic models coupled to transport models are able to reproduce and even predict the dispersion of solid waste, and also reproduce and predict the drift of cetacean skeletons in such environments.

The backtracking technique is useful to find the origin of accidental release, but difficulties may arise when particles are retained near the coast or in any circulation pattern, such as a vortex.

This study was restricted to the simulation of the transport of floating objects and one dead specimen whale, therefore immiscible in water, such as oil and solid residues. However, much of the results obtained here can be extended to the transport of soluble substances, which testifies to the broad application of these models as environmental management tools.

Acknowledgements

The authors acknowledge the financial support provided by ***InovUerj***, *Departamento de Inovação da Uerj,* ***FAPERJ****, Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro*, ***CNPq****, Conselho Nacional de Desenvolvimento Científico e Tecnológico*, and ***CAPES****, Fundação Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*.

References

[1] DAGESTAD, K.; RÖHRS, J.; BREIVIK, Ø.; ÅDLANDSVIK, B. (2018) *OpenDrift v1.0: a generic framework for trajectory modelling*. Geosci. Model Dev., vol. 11, pp. 1405–1420. https://doi.org/10.5194/gmd-11-1405-2018.

[2] MARETEC (2012) *MOHID description* [in Portuguese]. Campos dos Goytacazes (RJ): Essentia Editora. 132 pp. ISBN: 978-85-99968-20-8.

[3] CAMPUZANO, F.J.; JULIANO; M.; FERNANDES, R.; PINTO, L. (2013) *Downscalling from the deep ocean to the estuarine intertidal areas: an operacional framework for the portuguese exclusive economic zone*. In Actas de 6th SCACR International Short Course/Conference on Applied Coastal Research. pp. 1-9.

[4] FRANZ, G.A.S.; LEITÃO, P.; SANTOS, A.; JULIANO, M.; NEVES, R. (2016). *From regional to local scale modelling on the south-eastern Brazilian shelf: case study of Paranaguá estuarine system*. *Brazilian Journal of Oceanography*, 2016, vol. 64, núm. 3, pp. 277-294.

[5] BARRETO, I.; EZZATTI, P.; FOSSATI, M. (2009). *Estudio inicial del modelo Mohid.* [in Spanish]. Reporte Técnico RT 09-10. Instituto de Computation. Faculdad de Ingeniería. Universidad de la República. Montevideo, Uruguay. 39 p.

[6] PAIVA, P.M.; LUGON JR., J.; BARRETO, A.N.; SILVA, J.A.F.; SILVA NETO, A.J., (2017). Comparing 3D and 2D computational modeling of an oil well blowout using MOHID platform – A case study in the Campos Basin. *Science of the Total Environment*, <http://dx.doi.org/10.1016/j.scitotenv.2017.04.007>

[7] CARRÈRE, L.; LYARD, F.; CANCET, M.; GUILLOT, A.; ROBLOUT, L. (2012). *FES2012: A new global tidal model taking advantage of nearly 20 years of altimetry*. In Proceedings of the meeting 20 Years of Altimetry, Venice.

[8] COPERNICUS (2017) *Marine Environment Monitoring Service*. [ref. November 20th, 2017]. Accessed in Web: http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw\&task=results.

[9] GFS - Global Forecast System (2017). *GFS Analysis*. [ref. November 20th, 2017]. Accessed in Web: https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs.

[10] ARGONAUTA (2018). [ref. March 19th, 2018]. Accessed in Web: http://institutoargonauta.org.

[11] VENTURA, L.A.S (2018). *45 containers drop ship in Santos bay – Economy – State* [in Portuguese]. [ref. January 20th, 2018]. Accessed in Web: http://economia.estadao.com.br/noticias/geral,45-conteineres-caem-de-navio-na-baia-de-santos, 70001932779

[12] PIMENTEL, J.C. & ROSSI, M. (2018). *Containers break in the sea and clothing and electronics are spread between two cities* [in Portuguese]. [ref. January 20th, 2018]. Accessed in Web: https://g1.globo.com/sp/santos-regiao/porto-mar/noticia/conteineres-se-rompem-no-mar-e-produtos-eletronicos-e-de-vestuario-se-espalham-entre-duas-cidades.ghtml.

[13] Al-SALEM, K.; ALOSAIRI, Y.; Al-RASHED, A. (2017) *Development of a backtracking numerical model for offshore oil spills*. *Journal of Eng. Research*, vol. 5, núm. 1, pp 1-22.

[14] FERNANDES, R.; GALVÃO, P.; LOURENÇO, F.; VIEGAS, C.; NEVES, R. (2011). *Modeling of pollutant spills: Development and integration in the new generation of decision support tools* [in Portuguese]. In Anais do 11º Congresso da Água, Porto.