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USE OF COMPUTATIONAL MODELING TO SIMULATE DRIFT OF STRANDING CETACEANS IN COASTAL REGIONS - A CASE STUDY IN THE PAULISTA COASTLINE.

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Abstract. *In this work it is simulated the trajectory of a beached whale sighted near Ilhabela region, in São Paulo coastline, Brazil, in November 2017. The computational implementation was performed on the MOHID platform (HIDrodynamics MOdel), using the Water module. The downscalling technique was used to obtain local hydrodynamic currents at local scale. The validity of the model was considered satisfactory after statistical analysis comparing the results to satellite measurements of the sea surface temperature and also temperature and salinity profiles measured by ARGO buoys, attesting the purpose to use the model to simulate the trajectory of the cetacean specimen. The use of these technologies has great potential for researchers, since it allows the accompaniment of these organisms and avoids the stranding in tourist or densely populated regions, like Paulista region.*

Keywords: *Mohid platform, Hydrodynamic model, Lagrangian trajectory, Beached whale*

1. INTRODUCTION

Cetaceans represents a taxonomic group that includes whales and dolphins. On the coast of the State of São Paulo, about 620 km long, specimens of cetaceans have been reported since the 17th century, and information has been grouped and organized since 1993, with sightings and strandings of 29 species along the Paulista coastline (Santos *et al*, 2010).

Bryde's whale, focus of this study, has often been found stranded on Brazilian coast (Moura & Siciliano, 2012). According to Siciliano *et al* (2004), these species remain in warm waters along the year, frequentely appearing in coastal waters of the south-eastearn region, and do not migrate extensively in latitudinal movements. Although there is few information on their seasonal occurrence and biology , some authors suggest that they are opportunistic feeding on some pelagic fishes such as sardines and herrings (Gallardo *et al*, 1983).

In addition to accidental catches of anthropic nature, local oceanographic and topographical conditions, as water temperature, direction and speed of the wind and marine currents, are among the main factors cited in the literature for the occurrence of strandings in coastal regions (Parente *et al*., 2017).

In this study, the MOHID computational tool was used with an algorithm to evaluate the trajectory of a beached whale in the case considering there is no human interference in its towing and sowing. This study intends to evaluate the importance of the management Argonauta Institute action in the destination of cetacean skeleton, stranding near north coast of Sao Paulo.

2. HYDRODYNAMIC SIMULATION

The three-dimensional hydrodynamic model MOHID Water is applied to surface water bodies (oceans, estuaries and reservoirs) solving the equations of continuity and momentum (Eqs.1-4) for incompressible fluids from the Boussinesq and hydrostatic approximations (Rodrigues *et al*, 2012). The turbulence is calculated according to the coefficients of diffusivity and viscosity k-ε of the global ocean turbulence model (GOTM).

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

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

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

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

where u_i are the velocity components in the Cartesian directions x_i ; η is the elevation of free surface; f is the Coriolis parameter; ϑ is the turbulent viscosity; p_s to pressure atmospheric; and ρ is the reference density, ρ' is the specific mass anomaly and ρ_η is the density at the free surface.

Spatial discretization obeys a finite volume methodology and temporal discretization is obtained with application of semi-implicit algorithms (ADI). Spatial discretization in MOHID Water is implemented in the "Geometry" module and allows the simultaneous selection of different types of coordinates (Figure 1). Sigma-type coordinates, generally applied to barotropic models, are defined at the top of the domain and fit with bathymetry and water column variations. The Cartesian type coordinates, applied to baroclinic embedded models, are defined at the bottom of the domain, in layers from the hydrographic zero (ZH) or fixed depth (h).

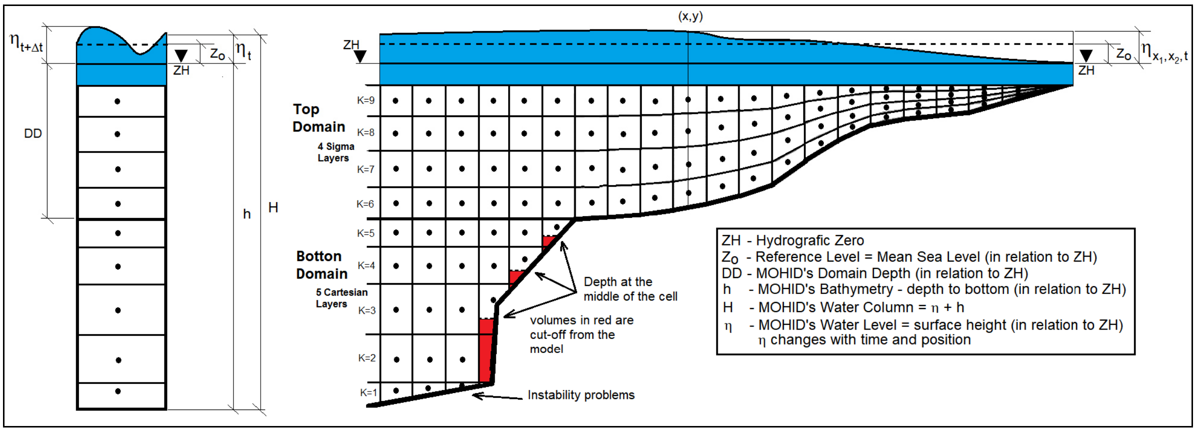

Figure 1 – Spatial discretization in Mohid Water

The particle trajectory is calculated in the lagrangian module, according to the field of currents coming from the hydrodynamic module, at each calculation instant. The displacement of the particles is affected by the mean flow velocity (Eq. 5), with the velocity of wind drift being included through a space-time constant.

$$\frac{\partial x_i}{\partial t} = u_i(x_i, t) \tag{5}$$

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

The MOHID platform presents an object-oriented language which allows the use of several simultaneously nested models, in which the boundary conditions are provided to the sub-models from a general model. The forcing data used by the downscalling technique were: the tidal harmonic components from FES2012 (Càrrere *et al*, 2012), daily salinity, temperature and mean water level obtained from MyOcean (Copernicus, 2017) and meteorological information obtained from GFS (GFS, 2017).

3. METHODOLOGY

3.1 Study area

The Argonauta Institute, located in Ubatuba city, has been activated since 2010 with information about strandings and sightings of cetaceans on the north coast of São Paulo (São Sebastiao, Ilhabela, Caraguatatuba and Ubatuba municipalities), carrying out procedures to tow skeleton drift and seizure in uninhabited regions (Figure 2).

Figure 2 – Management action of a beached whale by Argonauta Institute team (A) and the whale anchoring in rocky region (B).

On 11/22/2017, a skeleton of a Bryde (*Balaenoptera brydei*) whale was sighted in the vicinity of Curral beach, in Ilhabela. The displacement of this specimen was carried out, by the technical team of Argonauta Institute, to an uninhabited region, known as Sao Sebastiao beach. Figure 3 shows the region that occurred the sighting and lashing of the beached whale.

Figure 3 – Area that occurred the sighting (red balloon – A) and lashing (green balloon – B) of beached whale in Paulista coastline.

The choice of the final site of anchoring of the cetacean skeleton by Argonauta team is usually takes into account the absence of inhabitants, to avoid the contact with numerous parasites, as a source of diseases, and also the attraction of opportunistic predators such as sharks.

3.2 Model implementation

The implementation of the hydrodynamic model in this work was performed according to the technique of downscaling. A 2D hydrodynamic formulation was implemented for the general bartotropical model, South America (domain 1) and a 3D baroclinic formulation for the Brazil (domain 2), São Paulo (domain 3) and Ilha Bela (domain 4). Figure 4 below shows the area covered and the bathymetry of each modeled domain. The batimetric data was obtained from GEBCO Grid Database (GEBCO, 2017). The MOHID espatial discretization at each domain is present in the follow table (Table 1).

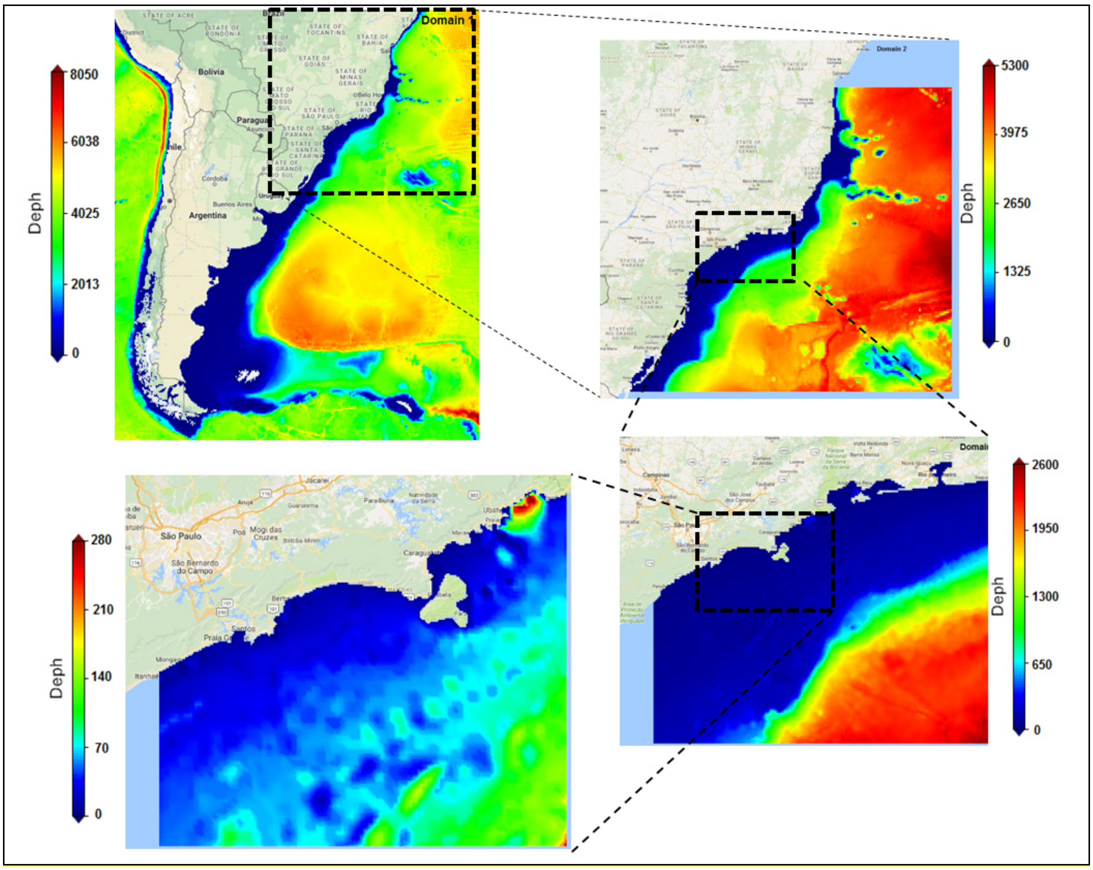

Figure 4 – Area covered by the model in diferent scales: A – South America (domain 1); B – Brazil (domain 2); C – Santos (domain 3); D – Ilha Bela (domain 4)

Table 1 – Mohid spatial discretization

Level	Domain	Horizontal resolution		Maxime Deph
1	South America	0.120°	12,000 m	8050 m
2	Brazil	0.120°	12,000 m	5300 m
3	Santos	0.024°	2,400 m	2580 m
4	Ilhabela	0.008°	800 m	280 m

Open boundary conditions (OBC) differs in the present model from Level 1 to Level 4 nested downscaling. The first level, number 1, is forced with tide alone (there is no wind in “Atmosphere” module and “InterfaceWaterAir” module). From the second level to the last one, number 2 to 4, the models are nested 3D domains (e.g., including the density gradient effects) and the OBC are resolved by imposing a Flow Relaxation Scheme (FRS) that is similar to the one presented by (Marchesiello et al, 2001). The FRS was applied to temperature (T), salinity (S) and velocities (U, V) (Martinsen & Engedahl, 1987) being combined with a radiation scheme from Flather (1976) for the barotropic mode.

4. RESULTS AND DISCUSSION

4.1 Model validation

The validation of the hydrodynamic model, performed in the Brazil domain, was performed through of the statistical comparison with 135,000 sea surface temperature (SST) data to satellite images of the GFS project (GFS, 2017). In the case of the validation in depth profiles, it was used 134,000 data of temperature and salinity obtained from 30 buoys of ARGO project (ARGO, 2017) available in Brazilian coast domain. The statistical evaluation os modeling results presented an excellent agreement with observed data, with R analyses values of 0,91 for SST, 0,99 for temperature profile and 0,95 for salinity profile.

4.2 Simulation of the whale's carcass trajectory

After domain definition, initial and boundary conditions includes, and hydrodynamic validation, the characteristics of the whale was adjusted in the "Lagrangian" module. The spatial evolution is computed integrating the velocities in the Cartesian directions x and y, according the water column continuity equation.

The simulation of trajectory was based in the Argonauta whale report in 22/11/2017, near São Paulo coastline, in front of Ilhabela region. Figure 5 shows the trajectory of the whale carcass simulated by MOHID if there was no human interference, only under the action of winds, waves and currents. According to the model estimative, the specime would have been carried out to the Arrastão and São Franscisco beaches (points 6 and 7 in the map, respectively, Fig. 5), a touristic and portuary region.

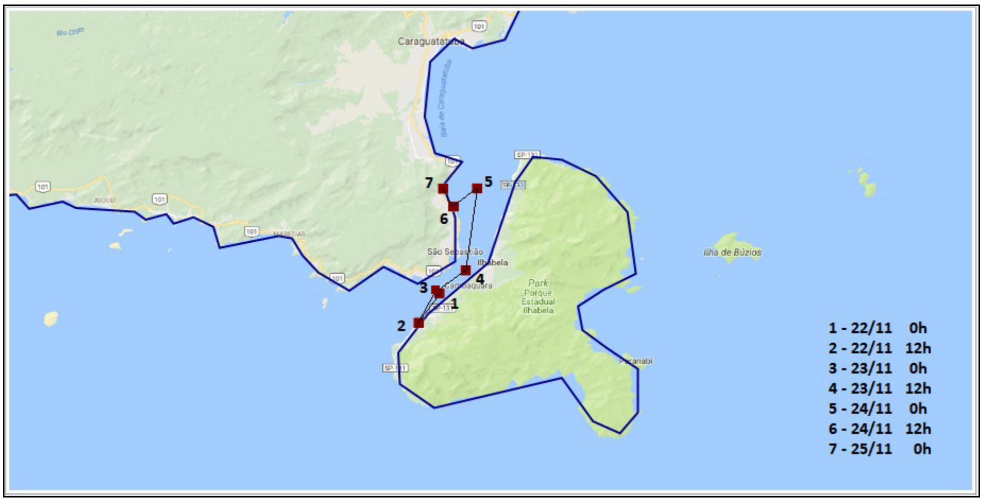

Figure 5 – Simulation of the trajectory of the Bryde's carcass according MOHID implementation

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. The decomposition of its skeleton generates some gases that can exude a foul odor, causing great economic losses in tourist areas and urban beaches. The removal can be laborious and costly, or even impossible, both for society and for the Public Authorities.

5. CONCLUSIONS

In spite of the great complexity of coastal systems, hydrodynamic models coupled to transport models can be able to reproduce and even predict the drift of cetaceans skeletons in such environments. This study was restricted to the simulation of the trajectory of one dead specimen whale sighted on November 2017 in coastline of Sao Paulo, Brazil. The results show that this tool can be used by researchers in order to follow the drift of these animals as well as to avoid stranding in tourist areas.

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