

Implementation of the Tagus Estuary Hydrodynamic Model



Date

March 2014

Authors

Guilherme Franz

Ligia Pinto

Isabella Ascione

Rodrigo Fernandes

Contents

Summary	1
1. Introduction	2
2. Software.....	2
2.1. Mohid water modelling system	2
2.2. Mohid Studio	3
2.3. Automatic Running Tool	4
3. Model Implementation.....	4
3.1. Model domains	4
3.2. Vertical grid.....	5
3.3. Tide.....	6
3.4. Open boundary conditions	6
3.5. Atmospheric forcing	6
3.1. Freshwater discharges	7
4. Preliminary Results.....	8
5. Future Developments.....	10
5.1. Model Validation.....	10
5.2. Very high resolution model for the Lisbon Region	10
Bibliography.....	10

Summary

This report describes the implementation of MOHID Water modelling system at Tagus estuary, Portugal, in fulfillment of the requirements of the Project ISDAMP (Grant Agreement No. 638516/2012/ECHO/A5/SUB). The model was implemented by using Mohid Water modelling system. The report describes data used to implement the model. The hydrodynamic model was implemented by using downscaling technique. Examples of model results are described as well. The hydrodynamic model will provide hydrodynamic forecasts which will be used to assess the best location of oil booms in the occurrence of oil spill.

1. Introduction

This report describes the implementation of MOHID Hydrodynamic model at Tagus estuary, Portugal. The hydrodynamic model will provide hydrodynamic forecasts which will be used to assess the best location of oil booms in the occurrence of oil spill. The model was implemented by using downscaling. The idea of downscaling consists of simulating hydrodynamics on a local scale, based on information provided by larger-scale models. The geographic area covered by a model is named as domain. A domain included inside the domain of another model is named as nested domain, or subdomain. A domain can have one or more subdomains. The boundary conditions are then provided from a domain to its subdomains. Models with larger domains are called “father” models, and provide boundary conditions to their nested models, named as “son” models. Son models are used to represent estuaries, harbors, and lagoons at a spatial resolution higher than this of the father model. Downscaling techniques are used to transfer information from regional to local models, enabling a comprehensive description of hydrodynamics and water quality processes. Furthermore, these techniques enable to extend the operational forecasts to the local scale as well. In the last years, downscaling techniques have been successfully applied in the field of coastal oceanography to simulate hydrodynamics and water quality, and to solve common management questions on the local scale (Leitão *et al.*, 2005; Ascione Kenov *et al.*, 2012; Mateus *et al.*, 2012).

2. Software

2.1. Mohid water modelling system

MOHID is a three-dimensional water modelling system, developed at the Marine and Environmental Technology Research Centre (MARETEC) at Instituto Superior Técnico (IST) which belongs to Technical University of Lisbon in Portugal. The model has been applied in Portugal and worldwide such as to the Sado Estuary (Cancino and Neves, 1998; Martins *et al.*, 2001), to the Aveiro lagoon in Portugal (Vaz *et al.*, 2007), to the Ria de Vigo in Spain (Taboada *et al.*, 1998), to the Western European Margin (Coelho *et al.*, 1999), and to Brazilian reservoirs (Deus *et al.*, 2013) among others.

The Hydrodynamic Module is the core of the MOHID Water modelling system. This is a three-dimensional hydrodynamic model which solves the Navier-Stokes equations, considering the Boussinesq and hydrostatic approximations. The equations are numerically solved by using the finite volumes approximation concept with a generic vertical discretization, which allows for the simultaneous implementation of various types of vertical coordinates. The equations solved in the model are:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad \text{eq. 1}$$

$$\frac{\partial u}{\partial t} + \frac{u\partial u}{\partial x} + \frac{v\partial u}{\partial y} + \frac{w\partial u}{\partial z} - fv = -\frac{1}{\rho_r} \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left(A_h \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left(A_h \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z} \left(A_v \frac{\partial u}{\partial z} \right) \quad \text{eq. 2}$$

$$\frac{\partial v}{\partial t} + \frac{u\partial v}{\partial x} + \frac{v\partial v}{\partial y} + \frac{w\partial v}{\partial z} + fu = -\frac{1}{\rho_r} \frac{\partial p}{\partial y} + \frac{\partial}{\partial x} \left(A_h \frac{\partial v}{\partial x} \right) + \frac{\partial}{\partial y} \left(A_h \frac{\partial v}{\partial y} \right) + \frac{\partial}{\partial z} \left(A_v \frac{\partial v}{\partial z} \right) \quad \text{eq. 3}$$

$$\frac{\partial p}{\partial z} + \rho g = 0 \quad \text{eq. 4}$$

u , v and w are the components of the velocity in the x , y and z directions respectively, f is the Coriolis parameter, A_h is the coefficient of turbulent viscosity along the horizontal direction and A_v is the coefficient of turbulent viscosity along the vertical direction, p is the pressure, ρ_r is the reference density and ρ is the water density calculated on the basis of the UNESCO equation of state as a function of the temperature and salinity.

2.2. Mohid Studio

MOHID Studio is a graphical user interface for the MOHID Water Modelling System. MOHID Studio enables to edit data files, create and launch simulations and analyze model results. Map data can be displayed through an integrated GIS system and time series data can be displayed in an integrated graph visualization engine. A set of tools enables the user to create and preprocess MOHID data files. MOHID Studio also offers the possibility to convert data among a set of common formats and MOHID internal formats. All features of MOHID Studio are described along the user guide (Braunschweig *et al.*, 2012).

2.3. Automatic Running Tool

The Automatic Running Tool (ART) developed at MARETEC allows running the hydrodynamic model in operational mode. This software has been designed to enable automatic simulations of MOHID water modelling applications. ART can be used to run historic periods or in nowcast/forecast mode.

This software system is responsible for:

- a) preparation and configuration of model inputs, including downloading, extraction, glueing and interpolation of boundary and initial conditions;
- b) running model simulations;
- c) backup & storage of output results
- d) generation of maps and timeseries based numerical results obtained
- e) sending emails controlling the evolution of the system.

3. Model Implementation

3.1. Model domains

The model used at Tagus estuary includes 2 domains. The horizontal resolution in Domain 1 ranges from 2 km in the open ocean to 300 m around the estuary mouth. The Domain 2 is a refined version of the Domain 1 to the inner part of the estuary with a constant horizontal resolution of 200 m. The bathymetry of the first domain was generated from the ETOPO 2' and Portuguese Hydrographic Institute databases. The bathymetry of the second domain was generated from the last update of the Portuguese Hydrographic Institute database for the Tagus estuary. The bathymetries for both domains are presented in Figure 1. The geographic extent and number of cells of the grids used to represent each domain are described in Table 1.

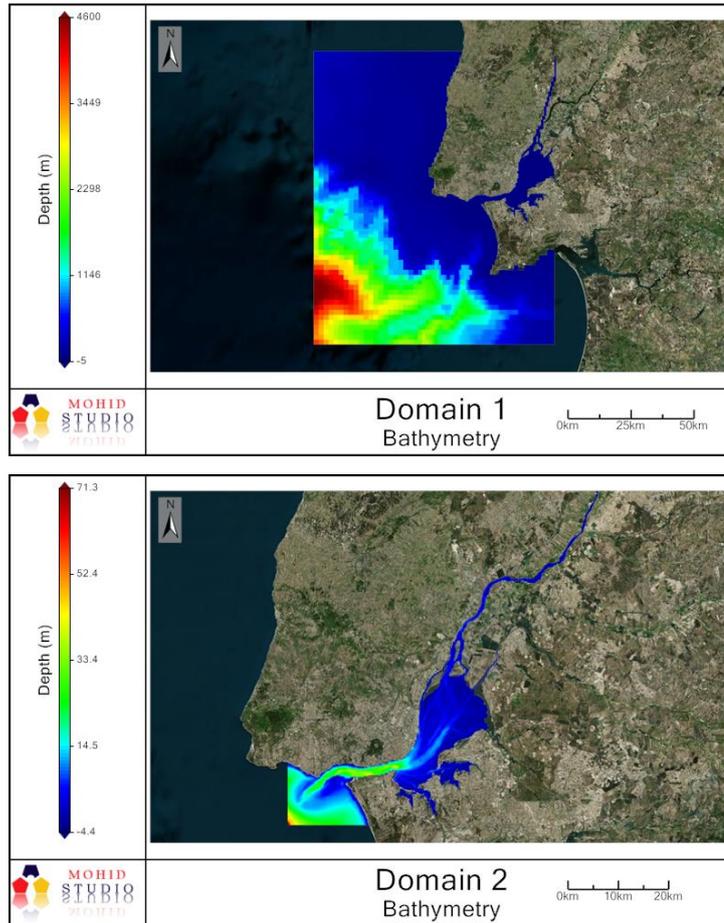


Figure 1 – Tagus estuary model bathymetries.

Table 1 – Tagus estuary model grid

Name	Cells	Min Depth	Max Depth	Min Lon	Max Lon	min Lat	max Lat
Domain 1	120x145	-5 m	4600 m	-10.02°	-9.08°	38.16°	39.21°
Domain 2	351x405	-4.4 m	71 m	-9.39°	-8.66°	38.59°	39.22°

3.2. Vertical grid

The vertical discretisation of Domain 1 consists in 43 Cartesian layers overlapped by 7 Sigma layers. The vertical resolution is about 1 m near the water surface. In Domain 2, the vertical discretisation is the same, but with only 14 Cartesian layers due to the shallower area covered by this domain.

3.3. Tide

Tidal boundary conditions were obtained from the Portuguese Coast Operational Model System (PCOMS) (see more on Mateus et al., 2012). The PCOMS is forced by the FES 2004 (Finite Element Solution) tide model (Lyard *et al.*, 2006), based on a hydrodynamic model which assimilates tide gauges and altimeter data (Topex/ Poseidon and ERS-2). The FES 2004 model comprises global coverage of tidal components at resolution of $1/8^\circ$. The tide is propagated from PCOMS to the Tagus estuary model domains with the Flather (1976) radiation scheme, which enables to radiate external gravitational waves over the perturbation produced by other mechanisms, as the wind and the Coriolis force.

3.4. Open boundary conditions

The ocean conditions for the Tagus estuary model are given from the PCOMS. Open boundary conditions to PCOMS were considered from Mercator-Ocean GLOBAL_ANALYSIS_FORECAST_PHYS_001_002 (available at MYOCEAN website) for North Atlantic region at a spatial resolution of 18×13 km. The vertical resolution of the database includes 43 vertical layers between 0-6000m. The database contains the average daily distribution of the following parameters:

- Temperature
- Salinity
- Velocity
- Water level

3.5. Atmospheric forcing

The atmospheric boundary conditions were provided by the WRF model (Weather Research and Forecasting), implemented by the IST Meteorological team with nested grids of 9 km for Portugal and a 3 km in a square domain with approximately 200×200 km in an area centred in Lisbon (Trancoso, 2012). Initial and boundary conditions to WRF were provided by the Global Forecast System (GFS) with 0.5°

resolution. The results from WRF with 3 km resolution were interpolated to the Tagus estuary model domains, including the following parameters:

- Atmospheric pressure
- Wind velocity
- Solar radiation
- Air temperature
- Relative humidity
- Downward long wave radiation
- Cloud cover

The wind plays a secondary role in the Tagus estuary hydrodynamic, but can be important to the transport of contaminants presents in the water surface. Figure 2 shows an example of WRF results interpolated to the Domain 2 of Tagus estuary model.

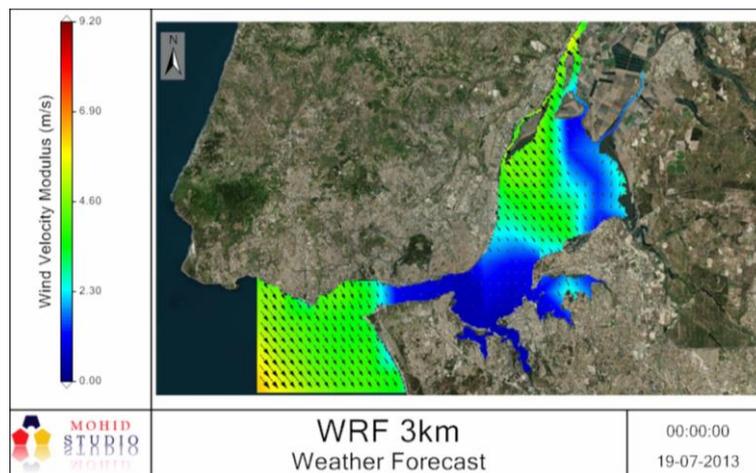


Figure 2 – Wind velocity modulus from WRF interpolated to the Domain 2 of Tagus estuary model

3.1. Freshwater discharges

The Tagus river is the main freshwater input to the estuary with an annual average flow of about $300 \text{ m}^3 \text{ s}^{-1}$. The Tagus river flow is provided to the model by data from Almourol hydrometric station (<http://snirh.apambiente.pt>). The freshwater input of the other two most important rivers, Sorraia and Trancão, were defined by monthly average values. Water properties concentrations for the rivers inputs come from climatological analysis. The rivers location is presented in Figure 3.

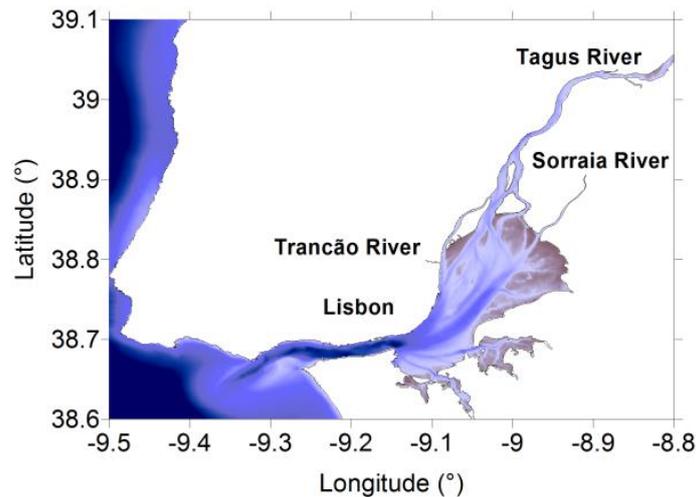


Figure 3 – Location of the three most important rivers of Tagus estuary

4. Preliminary Results

The Tagus estuary model has been implemented with the software ART and is currently running in operational mode, with daily forecasts results (<http://www.maretec.org/#!products>). Previously, the day before is run with the best ocean and atmospheric conditions, and hourly flow measurements from the automatic hydrometric station of Almourol. In the forecasts days, the last measured flow data is defined as input in the Tagus river. This methodology allows considering the Tagus river flow variations and, consequently, the effects in the Tagus estuary hydrodynamic.

The tide is the main mechanism forcing the flow in the estuary, determining the direction of the currents and the water level variations. The maximum velocities are reported in the estuary mouth, where in the ebb of spring tides values in the order of 2 m s^{-1} are reached. In the intermediate estuary and main channels, the maximum velocities are approximately 1 m s^{-1} , decreasing in the shallower upper estuary. As a consequence of the high velocities, the distance travelled by a particle during a flood or ebb tide is about 15 km. An example of velocity intensities observed in the Tagus estuary model results during one tidal cycle is presented in Figure 4.

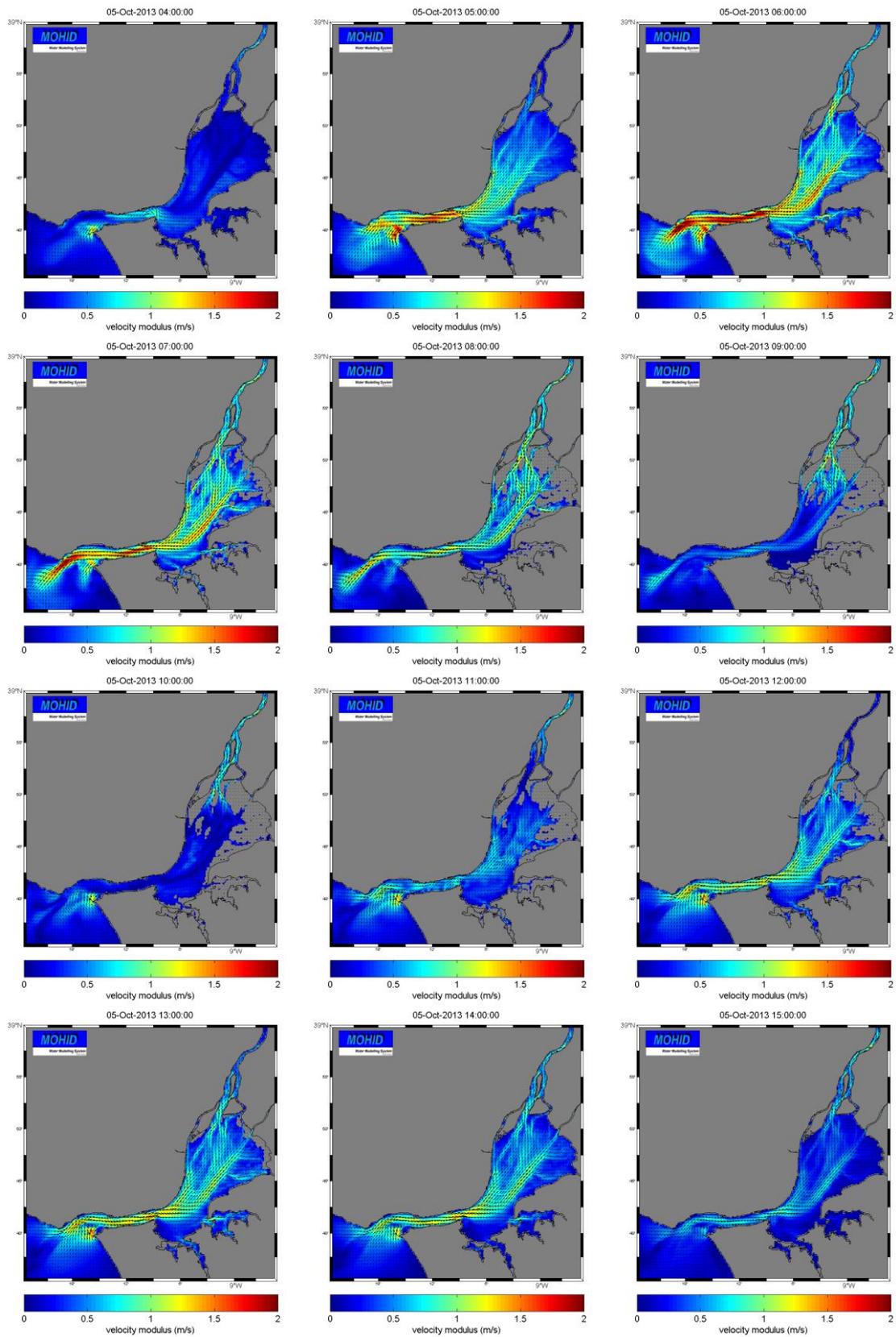


Figure 4 – Velocity intensities in the Tagus estuary during one tidal cycle

5. Future Developments

5.1. Model Validation

Water level was validated by harmonic analysis. Current velocities were validated with ADCP data. In terms of temperature and salinity, in-situ data are also available through buoys in different estuary points. They were also compared with model. Validation results will be edited and presented in an additional validation report.

5.2. Very high resolution model for the Lisbon Region

The implementation of a 100-m spatial resolution model is being studied for the area of interest in Lisbon. The purpose is to investigate if a model like this will increase substantially results already achieved with the 200-m resolution. In that case, this model will be considered for the ISDAMP exercises.

Bibliography

Ascione Kenov, I., Garcia, A. C. and Neves, R. (2012). Residence time of water in the Mondego estuary (Portugal). *Estuarine, Coastal and Shelf Science* **106**: 13-22.

Braunschweig, F., Fernandes, L. and Lourenço, F. (2012). *MOHID Studio User Guide*. Lisbon.

Cancino, L. and Neves, R. (1998). Hydrodynamic and sediment suspension modelling in estuarine systems. Part I: description of the numerical models. *Journal of Marine Systems* **22**: 105-116.

Coelho, H. S., Neves, R., Leitão, P. C., Martins, H. and Santos, A. (1999). The slope current along the Western European Margin: a numerical investigation. *Oceanography of the Iberian Continental Margin. Boletín del Instituto Español de Oceanografía* **15**: 61-72.

Deus, R., Brito, D., Ascione, K. I., Lima, M., Costa, V., Medeiros, A., Neves, R. and Alves, C. N. (2013). Three-dimensional model for analysis of spatial and temporal patterns of phytoplankton in Tucuruí reservoir, Pará, Brazil. *Ecological Modelling* **253**: 28-43.

Leitão, P., Coelho, H., Santos, A. and Neves, R. (2005). Modelling the main features of the Algarve coastal circulation during July 2004: A downscaling approach. *Journal of Atmospheric & Ocean Science* **10**(4): 421-462.

Lyard, F., Lefevre, F., Letellier, T. and Francis, O. (2006). Modelling the global ocean tides: modern insights from FES2004. *Ocean Dynamics* **56**(5-6): 394-415.

Martins, F., Leitão, P. C., Silva, A. and Neves, R. (2001). 3D modelling in the Sado estuary using a new generic vertical discretization approach. *Oceanologica Acta* **24**(Supplement 1): 551-562.

Mateus, M., Riflet, G., Chambel, P., Fernandes, L., Fernandes, R., Juliano, M., Campuzano, F., de Pablo, H. and Neves, R. (2012). An operational model for the West Iberian coast: products and services. *Ocean Science* **8**(4): 713-732.

Taboada, J. J., Prego, R., Ruiz-Villarreal, M., Montero, P., Gómez-Gesteira, M., Santos, A. P. and Pérez-Villar, V. (1998). Evaluation of the seasonal variations in the residual patterns in the Ria de Vigo (NW Spain) by means of a 3D baroclinic model. *Estuarine, Coastal and Shelf Science* **47**: 661-670.

Trancoso, A.R., 2012. Operational Modelling as a Tool in Wind Power Forecasts and Meteorological Warnings. PhD thesis. Technical University of Lisbon, 120 pp.

Vaz, N., Dias, J. M., Leitão, P. C. and Nolasco, R. (2007). Application of the MOHID-2D model to a mesotidal temperate coastal lagoon. *Computers & Geosciences* **33**: 1204-1209.

